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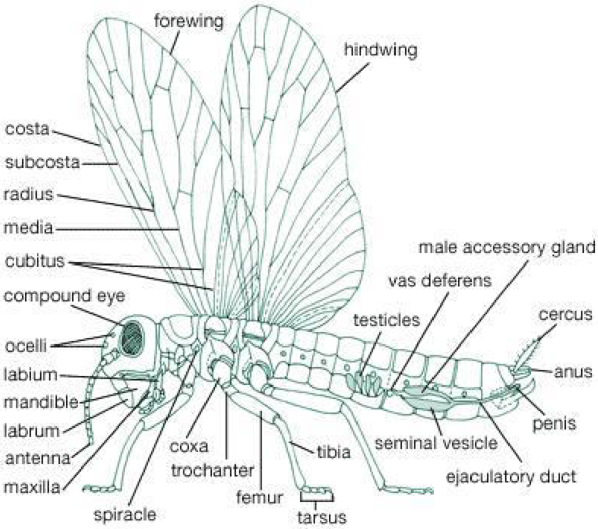

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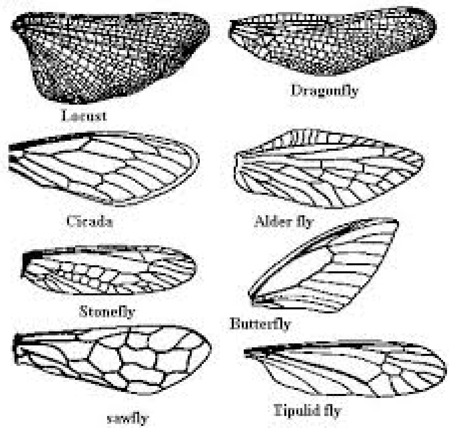

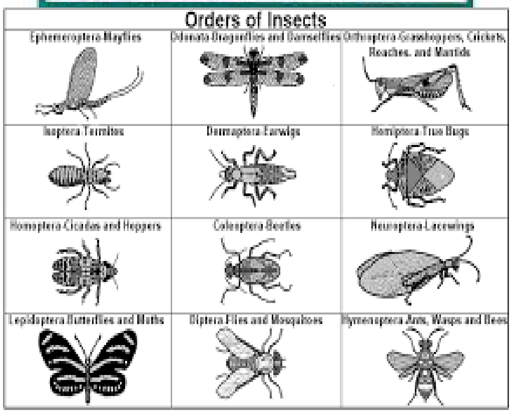

Entomology I

MZO-08

Vardhman Mahaveer Open University, Kota

Entomology I

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Preface

The present book entitled "**Entomology I**" has been designed so as to cover the unit-wise syllabus of MZO-08 course for M.Sc. Zoology (Final) students of Vardhman Mahaveer Open University, Kota. The basic principles and theory have been explained in simple, concise and lucid manner. Adequate examples, diagrammes, photographs and self-learning exercises have also been included to enable the students to grasp the subject easily. List of books suggested for further study will be a great help the students. The unit writers have consulted various standard books and internet as their reference on the subject and they are thankful to the authors of these reference books. Suggestions for the further improvement of the book will be thankfully acknowledged and incorporated in further editions.

Unit-I

Insect Morphology – I

Structure of the unit

1.1 Objective

After going through this unit you will be able to understand

- Why insects are more successful.
- Origin of insect world.
- How insect segmentation started and their integuments modifies.
- How insect grow if they are have such a tough, impermeable, non flexible integument.
- To learn , recognize and identity insect external morphology.

1.2 Introduction

Term morphology is the Greek word means *morphé*: shape or form and *lógos*: word. It is the study of form and structure of an organism. This includes how the insect looks like with their modifications. Morphology is closely related to physiology which is study of function. The external morphology is important for identification of insect and for its classification. There is large variation in the form and structure of the insect groups. This modification allows the insect to secure different ecological niche, food habitats and life cycles. The size of the insect may be as small as 0.3mm in mymarid wasp and as large as 30 cm in case of American owlet moth with its wing span.

1.3 Fundamentals of segmentation of an insect body

1.3.1 Why insects are successful arthropods

Insects are most successful invertebrates as they have tremendous diversity and numbers. The important reasons are probably their body architecture; they have jointed appendages, high reproductive capacity, wonderful adaptations and occupy all habitats in air like butterfies, moths, mosquitoes, housefly, in water like water bugs, water beetles, larva of many insects and on land like cockroaches, silverfish, most bugs. They may be parasitic like head louse, scavenging like flesh flies etc. They have light and strong integument covered by outermost layer of wax that does not allow water loss from evaporation. Insects are variable in sizes from small in size, microscopic (smallest insect is *Dicomorpha echmepteryg* fairy flies 0.13 mm, order Hymenoptera: family Mymaridae) to larger in size upto 10-12 inches. (stick insect, Oder Phasmida).

Flying is the most important characteristic feature that helps them from escaping predators and dispersal of species for speciation. The insects have short generation period and pass many generations a year so that they can compete with unfavorable conditions.

1.3.2 Origin of Insect

In modern time the age of trilobites is called the age of the insect in Paleozoic era.

Insect evolution is due to rapid adaptation because of their high fecundity. There is symbiotic relationship between flowering plants and insect as they are closely associated with pollination. Insects also gain importance as they are vectors of many pathogens. Archaeognatha and Thysanura still have rudimentary appendages on their abdomen called styli is one of the facts that insect evolve from an annelid ancestors

Earliest arthropods like scorpions, centipedes, and millipedes walk on land like annelids. They occur in Carboniferous period. Manton (1964) concluded that insects are not the direct descendants of myriapods but they share common ancestory. First major step in insect origin is the segmentation. The most primitive living insects, such as wingless silverfish, have lead biologists to believe that insects may have evolved from a creature similar to the *Annelida*. The insect started their life by ancestors having segmented (each segment is called somite), worm-like body having anterior prostomium and posterior periproct like a member of the phylum Annelida. Afterwards Simple eye, antenna and pair of appendages occur on each segment like Onychophorans. Onchophoran group leads to trilobites having three major lobes with compound eyes and jointed legs. Then first six segments of such an animal combine to form the head, the next three the thorax, and the remainder ten constitute the abdomen. This lead to the insectan level via myripod level where mandibulated mouth parts developed (FIG.1.1).

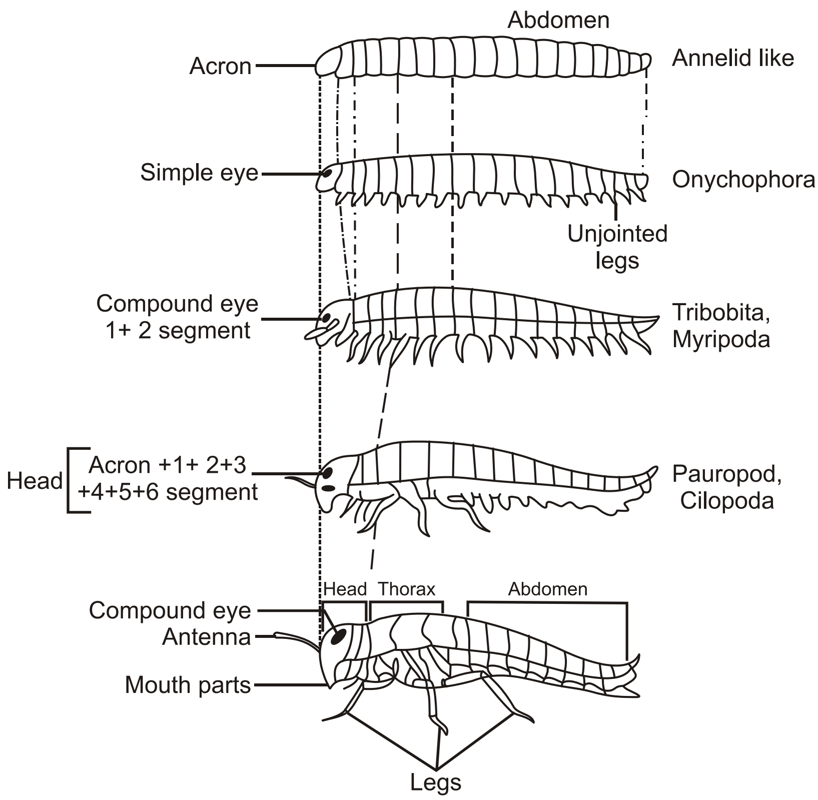


FIG.1.1: Trends of evolution in insects. The most commonly accepted theory of the origin of the insects is here illustrated.

The next evolutionary step was the development of wings. Carpenter (1977) recognised four major stages in the evolution of insecta:

1. Evolution of wingless insects, apterygotes in Devonian period
2. Origin of wing flexing mechanism lacking, paleopterous exopterygotes with simple metamorphosis.
3. Wing flexing mechanism present, neopterous exopterygotes with simple metamorphosis.
4. Wing flexing mechanism present, neopterous endoopterygotes with complete metamorphosis.

1.4 Insect body wall strfuctures; Cuticle and cuticular outgrowths

Body wall is called the integument in insects. It is composed of many layers as follows:

1. **Cuticle**: it is the outermost layer of insect integument/ wall which is differentiated into outer **epicuticle** and inner **procuticle**. Epicuticle is 0.03-4 µm thick and made up of cement layer, wax (lipid), polyphenol, sulphur and **cuticulin** (lipoprotein). Cuticulin is a thin layer rich in polyphenol resistant to acids and organic solvents. It is due to this cuticulin that allows expansion of cuticle during moulting. In epicuticle chitin (FIG.1.2) is absent and have wax canal that contains wax filaments. Procuticle is 200µm thick further distinguished into outer **exocuticle** and inner **endocuticle.** Procuticle is made of chitin and a mixture of protein. Exocuticle is a highly stabilized layer which is pigmented and consists of sclerotin protein. There are found some vertical canals traversing through both exo and endocuticle called **pore canals**. Wax molecules are transferred to epicuticle via pore canals.

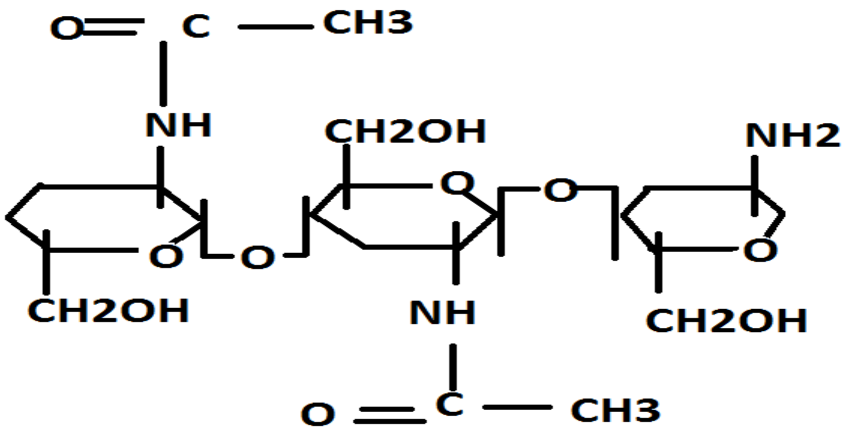


FIG 1.2: Structure of chitin

2. **Epidermis/ hypodermis**: It is a layer of living cells resting on basement membrane. It consists of cells like tormogen cells, trichogen cells, nerve cells, sensory cells, oenocytes and dermal glands. It is meant for the secretion of cuticle and moulting fluid that dissolves older cuticle layer and forms new cuticle. The process of shedding of cuticle is known as ecdysis/ moulting. Pore canal is 1 µm diameter tube arises from epidermal layer.

3. **Basement membrane**: It is the innermost layer of integument 0.5µm thick and contains neutral mucopolysaccharides. It is secreted by aggregation of haemocytes (FIG.1.3).

- Epicuticle- cuticulin present, chitin absent, permeable.
- Exocuticle- highly stabilized, hard, inert and strong, chitin and protein present.
- Endocuticle- thickest, chitin and protein present.

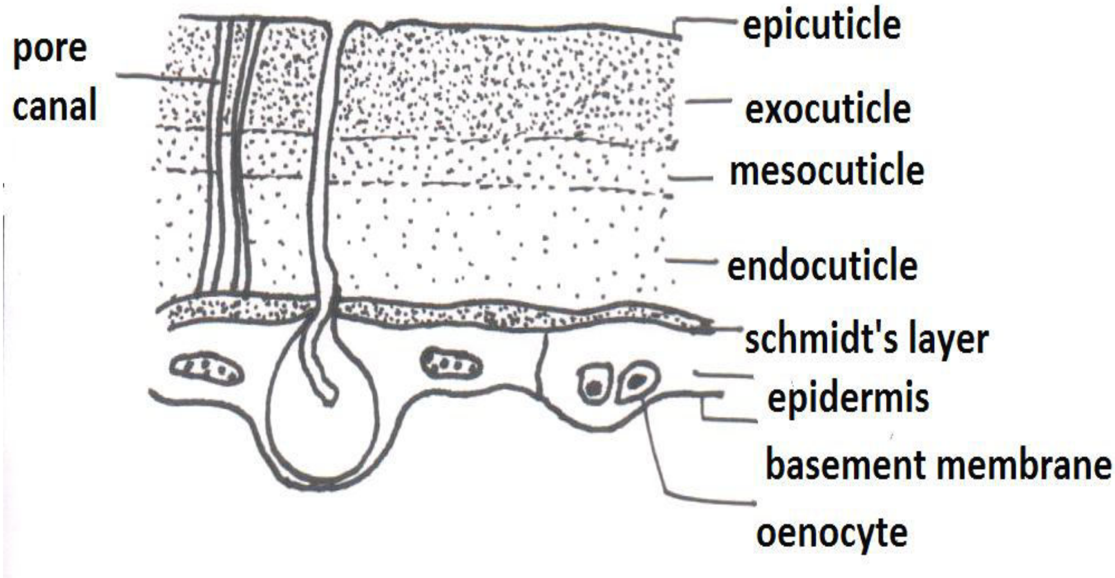


FIG 1.3: Structure of integument

Cuticle gives cuticular outgrowths like setae, hairs, acanthae or microtrichia to provide movement above hard surface. Males of *Dolichopu*s fly anal appendages bears setae to hold the female while reproduction**.**

Function of integument:

1. **Protection:** Exoskeleton works as our skin and bones do. It completely covers the body and serves as a supportive skeleton.
2. **Barrier:** It provides a barrier as it is waterproof so it does not allow water to escape from body. It also acts as a barrier to stop pathogens, parasites and harmful chemicals to enter inside. In aphids, caterpillars the state of wax is softer as compared to egg and pupae having hard wax.
3. **Structure and form:** It maintains a definite shape, structure and form.
4. **Movement:** As muscles are attached to the exoskeleton apodem of the body, this enables the insect to move, run, fly, dig and jump.
5. **Hard:** the integument is hard due to three proteins as sclerotin, resilin rubber like and anthropodin as soluble protein.
6. It also helps in respiration and food manipulation.
7. The cuticular outgrowth like campaniform sensilla, trichoid sensilla and chordonotal organs acts as sensors to environmental changes.

8. Some insects deposits excretory products below cuticle so acts as an accessory excretory organ.Whenever moulting takes place these products are removed with older cuticle.
9. The scales, hairs and color are some of the external features which help in behavior modulation during mating.
10. The colour of the integument is useful in mimicry, frightening and warning predators. Usually the chromophores are conjugated with the chromoproteins.
11. The change in color called iridescence are common in Coleoptera and Lepidoptera.

1.5 Coloration and special integumentary structures

1.5.1 Process of tanning

Polyhydric phenols and quinones play important role in sclerotisation and melanisation. From the haemolymph tyrosine oxidize to form dopa which further decarboxylate to form dopamine. N-acetyladopamine is formed from dopamine by the process of acetylation in endocuticle. N-acetyladopamine with the help of enzyme diphenol oxidase converted into quinine in epicuticle. Polyhydric phenols, quinines and protein are responsible for tanning in procuticle (FIG.1.4).

Tyrosine → Dopa → Dopamine → N-acetyldopamine → quinine →tanning

In *Rhodnius* bug (assasian bug) placiticising factor is secreted that changes pH of cuticle and allows expansion of cuticle while taking blood meal.

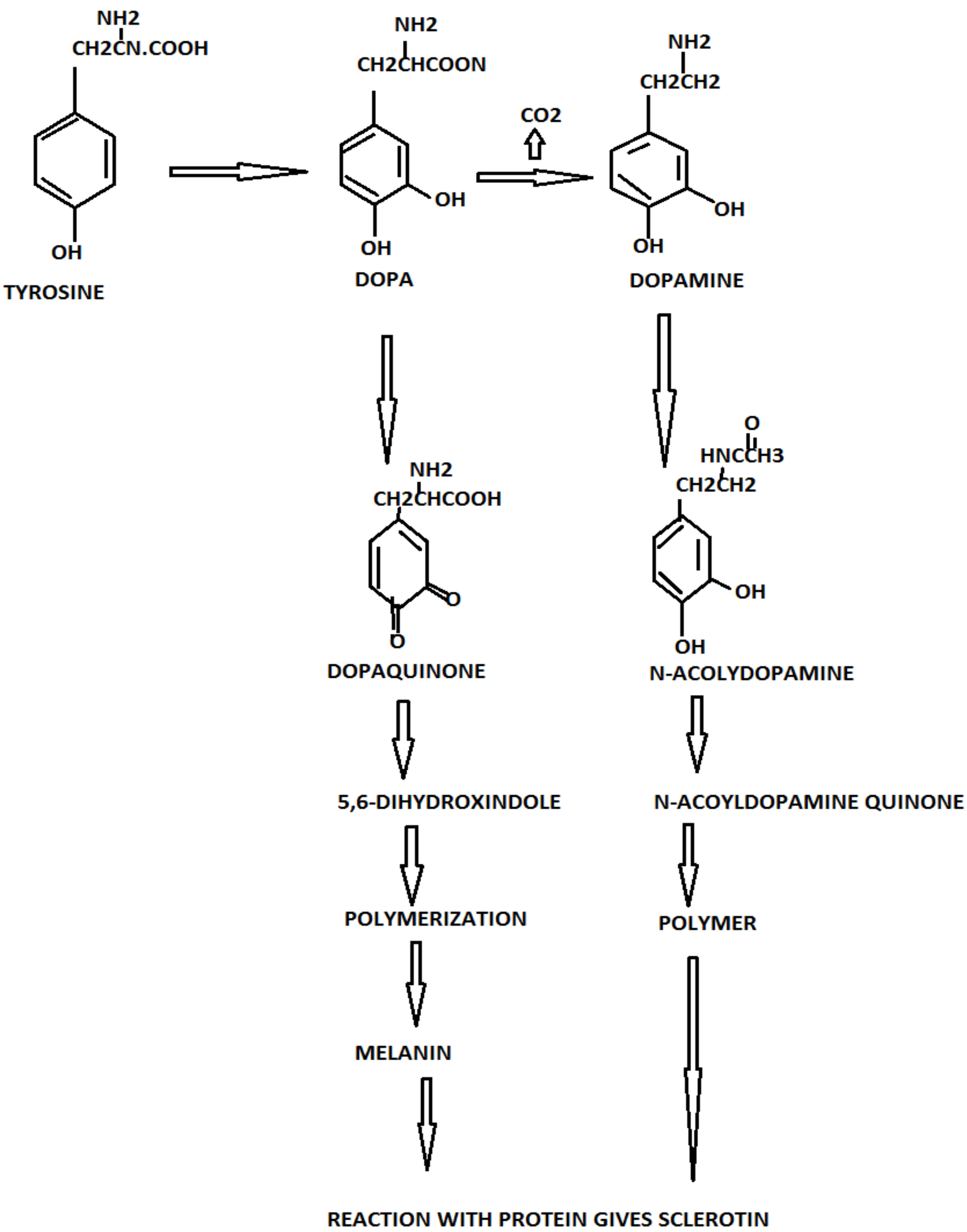


FIG 1.4: Process of tanning

1.5.2 Common pigments: are there whose deposition in cuticle is responsible for integumental coloration.

- Melanin- for yellow, brown or black
- Carotenoid- for red or yellow phytophagous insect
- Ommochromes- for red, brown or yellow pigment in eyes

- Anthroquinones- for red, yellow or orange and confined to aphids, carmine (red) in lac insect
- Pterins- red, yellow or white in wings
- Flavin- green or yellow
- Anthoxanthins- white or yellow
- Metallic color is not due to the pigment but because of interference of light rays that penetrate thin layer of exocuticle.
- Red color of Chironomous larva is due to presence of haemoglobin in haemolymph.

1.5.3 Special structures of integument

Integuments shows some of the processes that may be external or internal. Internal processes are restricted to apodemes but external processes may be cellular or non-cellular. Unicellular outgrowths are like hairs, bristles, setae and scales. In all of these membraneous articulation is absent (FIG.1.5). Hairs/ sensilla trichoidea occurs on all parts of body but more confined to antenna, legs and mouthparts. Hairs may also called microchaetes, microtrichae and microsetae. They are less than within a micron in diameter. Hairs in aquatic insects may serve as plastron which functions in respiration. It may be long and delicate respond to slight force and thick, short spine requires considerable force. Setae proper are the outgrowth of entire integument lined by layer of epidermal cells. They may be of different shapes and consist of membraneous articulation. Setae is fixed in a socket and develop from trichogen cell and supported by tormogen cell (FIG.1.6). Setae function to cover the body like hair. Sensory setae found on appendages are associated with nervous system and sensory in function. Multicellular outgrowths include spurs and spines. Spurs are present on the legs of many insects. Among non-cellular outgrowths microtricha are present in Mecoptera and Diptera. Papilla is a conical protrusion secreted around microvilli.

Scales are present in insects mainly on butterfly wing and all over the body.

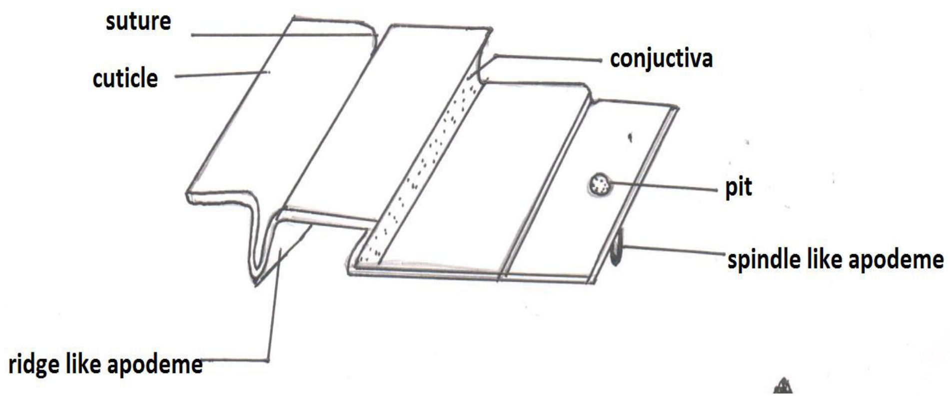


FIG 1.5: Special structure of integument

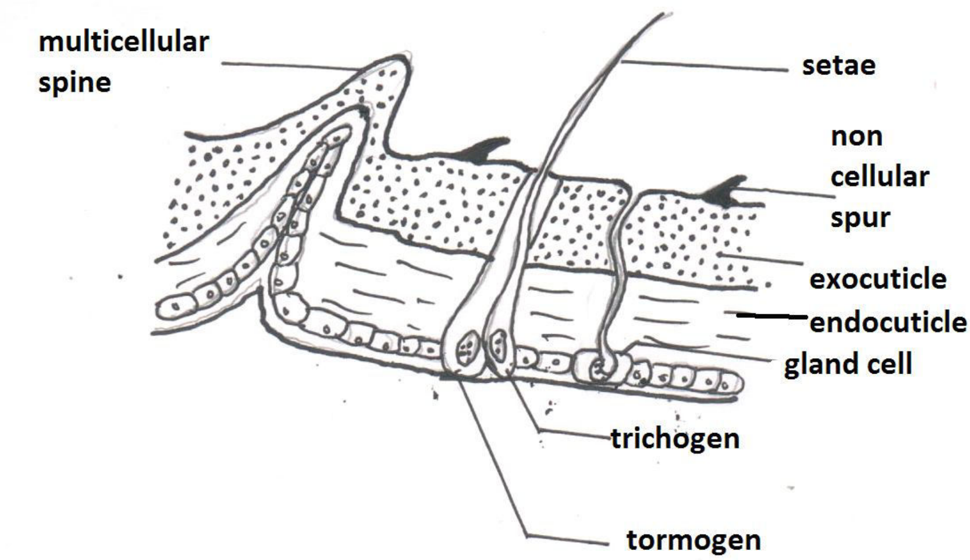


FIG 1.6: Integument with tormogen, trichogen spur,setae, spine

1.6 Body Tagmata

Insect's body is divided into segments as they develop from wormlike ancestors. Some authors believe that they are made of twenty segments existed in their ancestors. Insects of new world show a reduction in this number. Certain segments fused together and differentiated into three body regions named head, thorax, and abdomen. The insect word is derived from word "**insectum**" which means to cut into. The division of body into functional regions is known as t**agmosis**. Tagmata is a plural word, singular is tagma. Head is important as it bears eyes, antenna, mouthparts, brain and sensory centers. Thorax is important as it function commonly in flying and locomotion. Finally the role of abdomen is to bear genital openings and external genital apparatus that it has function of reproduction. So each tagmata has a specific function. Number of tagmata are different groups are different like;

Troilobites- three tagmata or lobes

Insects- three tagmata- head, thorax, abdomen (FIG.1.7)

Spiders, mites, ticks- two tagmata- cephalothorax, abdomen (FIG.1.8)

Difference between metameric segmentation and tagmata:

In the case of Annelida it is divided into segmented body called metameric segmentation. Here each segment performs all functions and are copy of each other. But on the other hand tagmata are a group of segments which is specialized to perform a proper function.

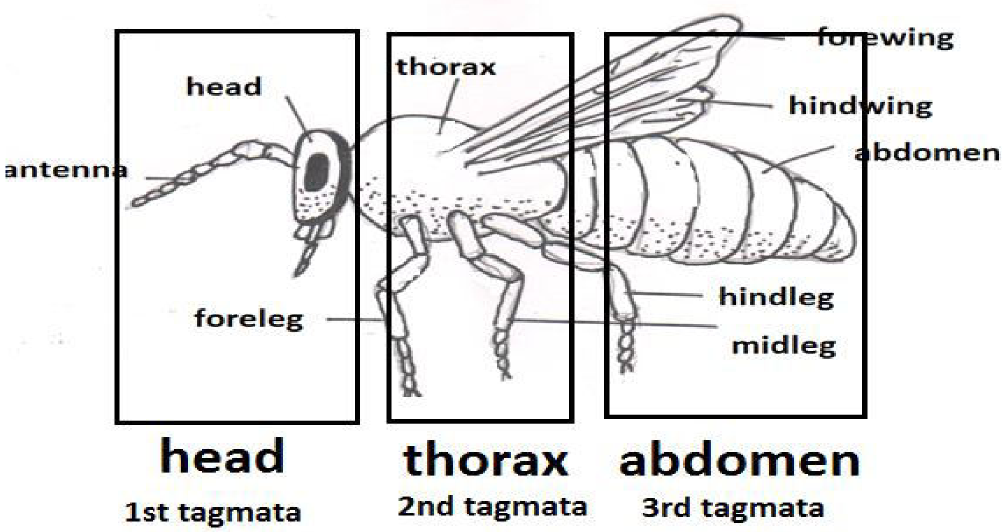


FIG 1.7: Diagram showing three tagmata in insects

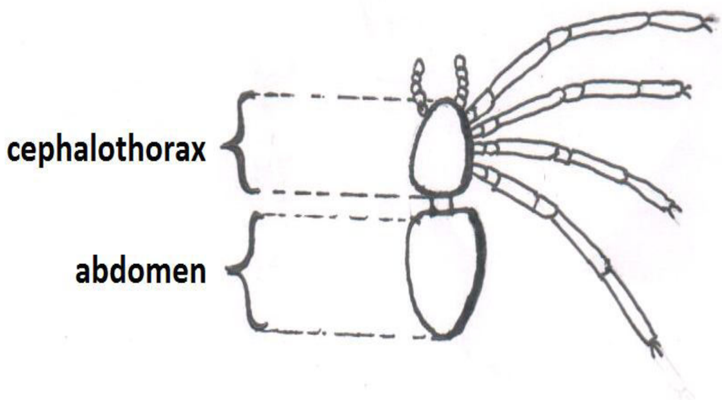


FIG 1.8: Diagram showing two tagmata in spiders

1.7 Sclerites and their segmental arrangements

A scerite is a Greek word "*scleros means hard"*. Sclerites is equivalent to sting of cone cell, radula in Mollusca, valves of *Chiton.* In Arthropods the hardening of sclerites is obtained by the proess of sclerotization. Body of insect covered with hard and tanned exocuticle but in areas of joints exocuticle is missing therefore it is membranous, flexible and folded. These areas provide movements between sclerites i.e hard adjacent plates. Joints may be monocondylic if articulated by one angle like antenna joints or dicondylic if articulated by more than one angle like most leg joints. Articulation may be internal if points lie within the membrane or external if articular surface lies outside. There are plates at dorsal side called tergum, at ventral surface called sternum and at lateral side called pleuron (FIG.1.9). The subdivisions of terga, sterna and pleura are tergites, sternites and pleurites. With this the terga of thorax region are also differentiated as prothorax is pronotum, mesothorax is mesonotum and metathorax is metanotum (FIG.1.11). The abdominal segments are connected through a less sclerotized and soft membrane called intersegmental membrane (FIG.1.10) to provide a little flexibility needed for movement. Segmentation may be primary or secondary.

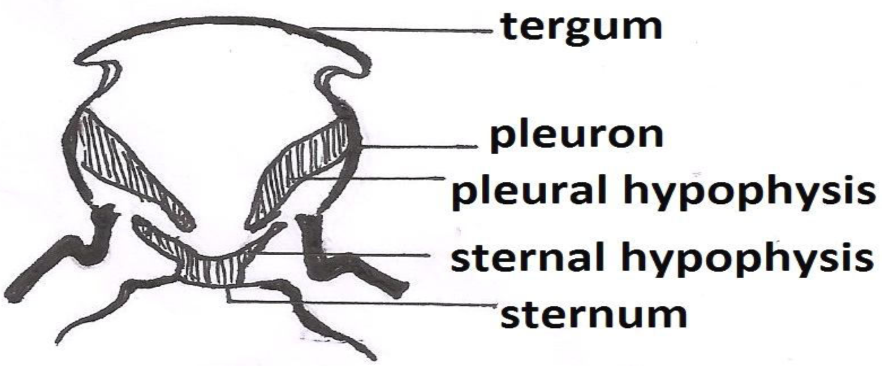


FIG 1.9: Endoskeleton and sclerites

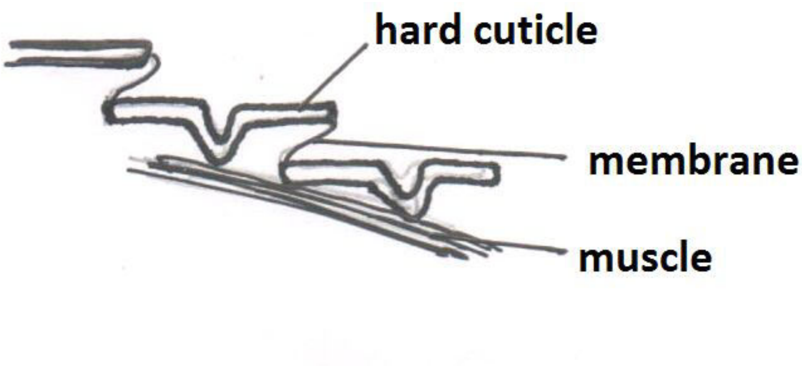


FIG 1.10: Diagram showing membrane between segments(in laterlo-section view)

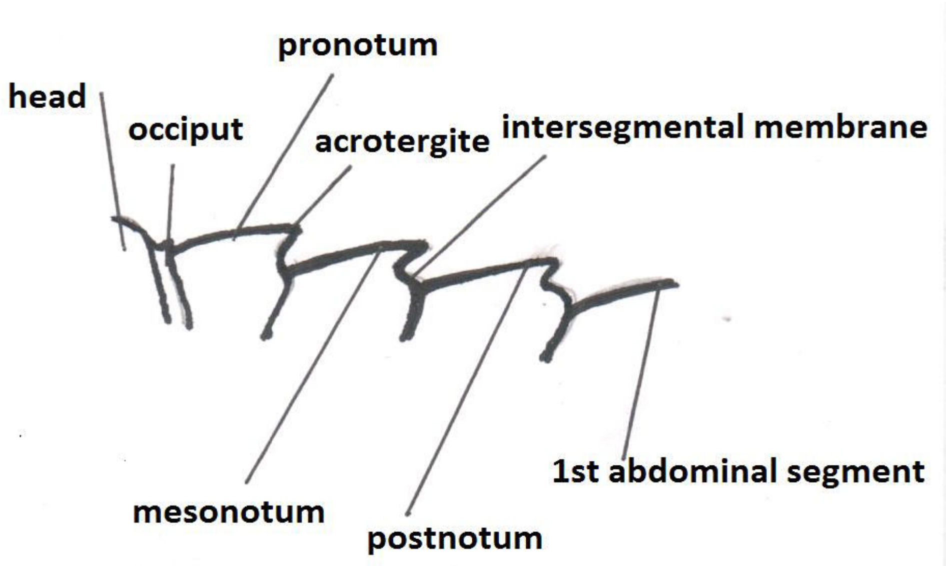


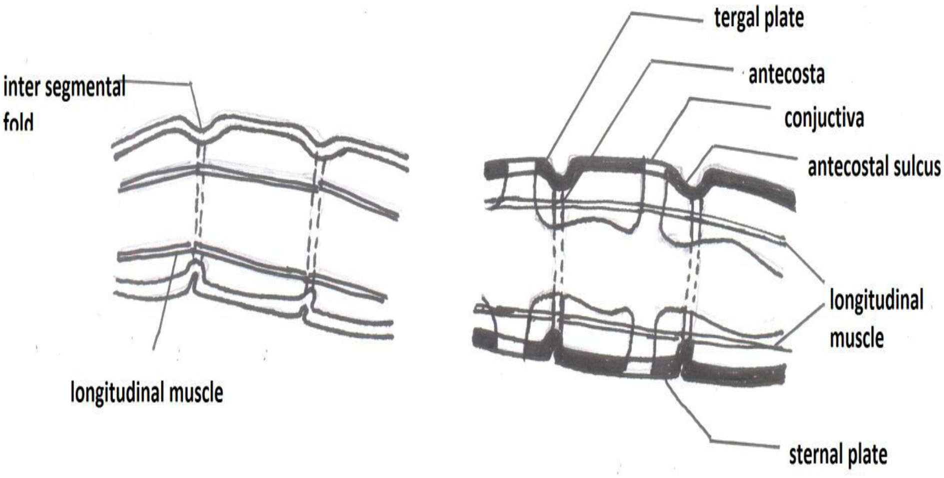
FIG 1.11: Insect thorax with pro, meso and metathorax

1.7.1-Primary segmentation

Entire cuticle is thin and flexible and integument invaginates, intersegmental folds in between segments so that longitudinal muscles easily attaches to it, example in larva. It provide larva to move freely (FIG.1.12 A).

1.7.2-Secondary segmentation

In adults due to heavy sclerotisation the scerites are divided into dorsal terga, ventral sterna and lateral pleura. The primitive intersegmental fold becomes as internal ridge of cuticle called antecosta seen externally as antecostal sulcus (FIG.1.12 B).



A) B)

FIG 1.12: Types of body segmentation A) primary B) secondary

These segments majorily divide insect into three tagamata head, thorax and abdomen but inspite of them some lines mark the segments into sulcus/suture. Although sulcus and suture is considered to be same but there is small difference between , a suture is a line separating two sclerites and sulcus is merly a fold or ridge in the same plate. There are some of the internal processes called apodemes that strengthen and gives point of attachment for the muscles like tentorium. There is another likely term phragma/phragmata in plura means partitions are there for the attachment of indirect longitudinal flight muscles in mesothorax and metathorax.

1.8 Biochemistry of cuticle and process of moulting

Chitin is a nitrogenous polysaccharide N-acetyl-D-glucosamine in 9:1 ratio linked by β-1,4 configuration. Chitin is equal to cellulose but two carbon atom of OH group replaced by acetamide group. D-glucosamine made up 25-60% of dry weight of exocuticle and endocuticle. Chemical formula is (C8H13 O6N)n and is insoluble in water, alcohol and organic solvents. Chitin is a component that does not exist in pure form.

Protein constitutes 25-37% of dry weight and made up of non chitinised substances.

- Arthropodin: is a non chitinised soluble protein.
- Resilin: As the insect is unable to move if sclerotin is found everywhere so, in certain places near wings, legs rubber like flexible protein is needed called resilin.

- Sclerotin: Exocuticle is hard not because of chitin but due to insoluble, hard, horny and tanned protein sclerotin. It is water insoluble but alkali soluble component.

1.8.1- Process of moulting/ Ecdysis

In the case of insect during growth it needs to replace the rigid exoskeleton regularly with a new one, the phenomenon is known as moulting/ ecdysis. Term ecdysis is an ancient Greek word which means to take "off/ strip off". It is common in animal groups like arthropods, nematods, velvet worms, tradigrades and cephalorrhyncha. It is a complex process controlled by hormones, including the cuticle of the body wall, the cuticular lining of the tracheae, foregut, hindgut and endoskeletal structures.

The three major stages of moulting:

1. **Apolysis**—Ecdysone hormones are released into the haemolymph and the old cuticle separates from the underlying epidermal cells.
2. **Ecdysis**—It is a process of splitting of the old cuticle, commonly starting in the midline of the thorax's dorsal side.
3. **Sclerotisation**—When the insect emerges from the old cuticle, the new cuticle is soft and after an hour the exocuticle hardens and darkens.

Mechanism:

1. Firstly epidermal cells becomes active, increases in size and number.
2. Moulting fluid is then secreted by epidermis which digests 80-90% of endocuticle before immature insect moults. Moulting fluid is made up of chitinase and protinase.
3. Digested materials are then absorbed.
4. Due to this digestion an **Excuvial membrane** appears between epidermis and old cuticle. It is transparent, thin and homogenous. **Excuviae** is the empty, dead and remains of exoskeleton left after moulting.
5. Exo and epicuticle is resistant to moulting fluid as it is insoluble in organic solvents (FIG.1.13).
6. Due to the space formed i.e excuvial membrane new cuticle starts depositing as follows cuticulin, protein, exocuticle, endocuticle and lastly cement layer.

7. The space traps air, water or as hydrostatic pressure of blood that splits the old cuticle. The separation of old exoskeleton is called **apolysis**. The insect after apolysis is called **pharate** (FIG.1.14).
8. When new cuticle formation ends then old cuticle sheds except tracheals and gland ducts.
9. After ecdysis light, pale and soft freshly laid cuticle turns into dark, solid, brown or black. As the new cuticle is soft there are greater chances of insects to be trapped by predators. So, it can cause death up to 70-80% of insects. The maturation and time taken to get rigid exoskeleton may take from days to weeks in longer life span insects.
10. Cement layer is the last to secrete in this process.
11. Color of the tanned integument depends upon the amount of o-quinone as in low amount the insect is paler ad in high amount the skin is much tanned.

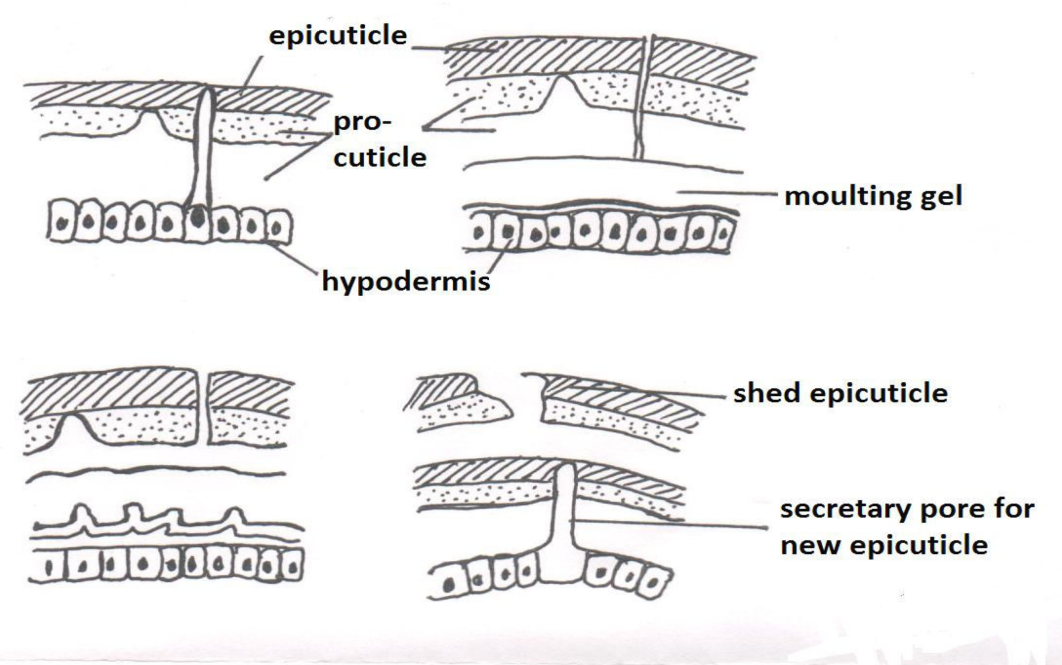


FIG 1.13: Process of moulting

The number and time of moulting depends upon the type of insect. Moulting is initiated due to the moulting hormone secreted by ecdysial gland in insects. The stage of development between moults in endopterygotes is called **stadium/instar**. There can be 4-5 instars in a insect life cycle. The stage of development between moults in exopterygotes is called **nymph**. There can be 15 or more nymphal stages in insects.

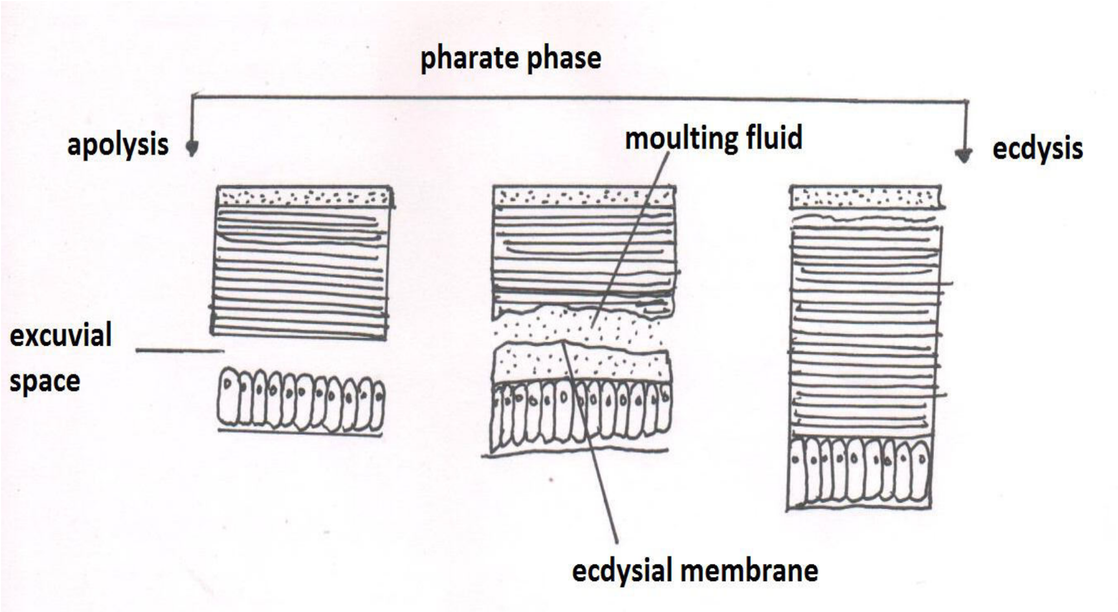


FIG 1.14: Showing pharate phase during ecdysis

Significance of moulting

- As the cuticle is hard and does not expand therefore it has to be shed time to time so that growth can take place.
- The waste products are deposited under cuticle so; when the cuticle sheds these excretory products are also eliminated from the body.

1.8.2 Hormonal control during moulting:

Ecdysone/ moulting hormone is released by a pair of prothoracic glands located in thorax region of the insect. It is a steroid that being influence by the secretion of Prothoracotrophic hormone (PTTH). Juvenile hormone (JH) secreted by another pair of corpora allata gland also has a role in growth. All these hormones are closely related to each other. PTTH and ecdysone is necessary for larva to larva and pupa to adult convertions (FIG.1.15). As there is enough JH, ecdysone metamorphoses larva to larva but as its amount gets lowered down it results in larva to pupa conversion. The growth disc with the amount of hormones shows three phases as inhibited phase where JH is high and ecdysone is low, proliferating phase in which both hormones increases and differentiating phase in which they shows a peak in secretion. If the JH is completely absent formation of adult takes place soon. If corpora allata is surgically removed from the insect the larval moulting does not takes place and the larva directly forms cocoon to become adult (FIG.1.16).

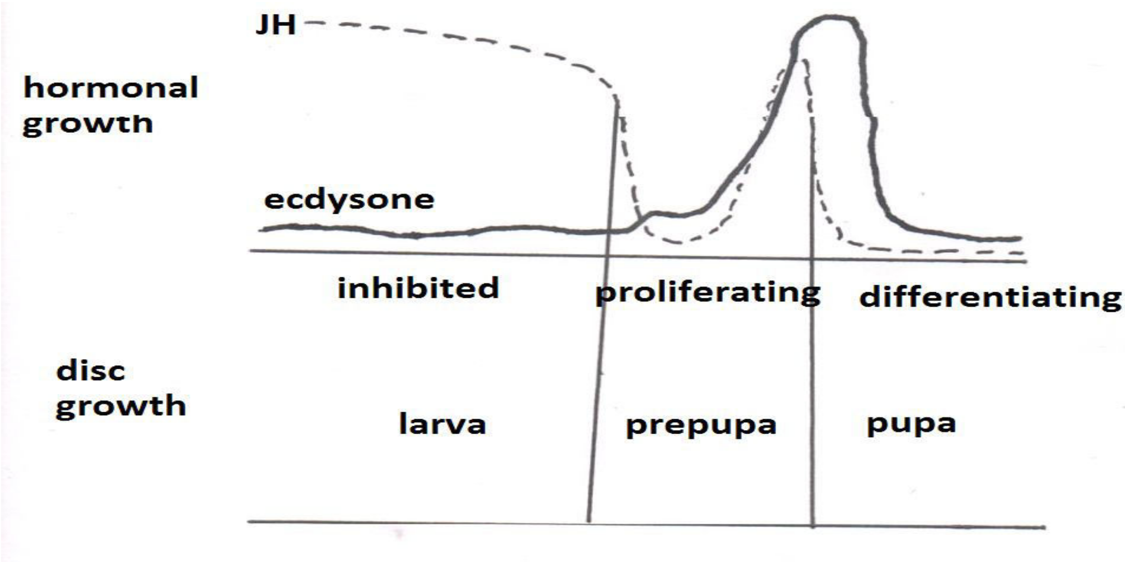


FIG 1.15: Graph showing the role of hormone

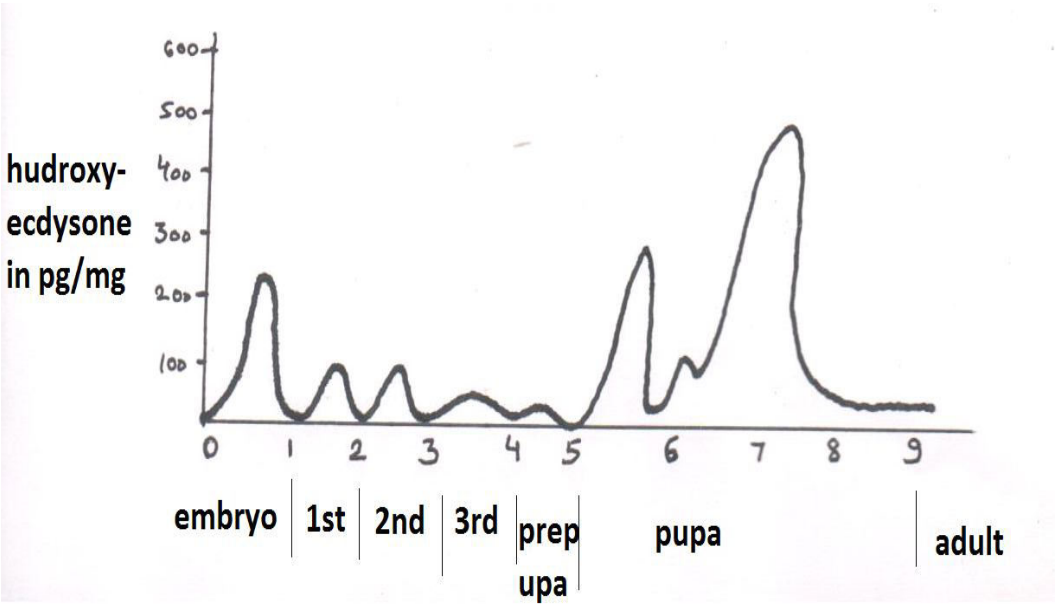


FIG 1.16: Graph showing the variation in amount of 20-hydroxyecdysone from embryo to adult

1.9 Summary

All the representatives of insect world have characteristic morphological feature that makes the insects so different as compared with other invertebrate groups. Different types of mechanism like moulting, body segmentation or pigmentation acclimatize them to survive in air, water or land. That is why insects are most successful and diverse group of all organisms. Insects are considered to have originated from annelid like animals, having distinct exoskeleton called integument containing cuticle. Integument of insect is made up of many layers including exocuticle, endocouticle and epicuticle, all of which are secreted by epidermis layer below which basement membrane is present. Integument has multifunctions like protection, giving shape, form, waterproof, acts as barrier, helps in secretion, reproduction, feeding and many more. Insect is a group of diverse animals that shows two types of segmentation primary and secondary. The process of moulting is triggered due to moulting hormone. This process includes three major steps apolysis, ecdysis and sclerotisation. Moulting is one of the important ways to grow in size as cuticle is hard and not expandable so it has to shed. The integument of some insects is brightly colored due to the color pigments. It is a simple process which is also dependent upon many physical factors that affect the life cycle directly or indirectly.

1.10 Glossary

- **Apolysis**:The separation of old exoskeleton is called apolysis.
- **Cuticle**: It is the outermost layer of insect integument/ wall.
- **Endocuticle:** inner layer of procuticle.
- **Epicuticle:** outer layer of cuticle.
- **Excuviae:** It is the empty, dead and remains of exoskeleton left after moulting.
- **Exocuticle:** outer layer of procuticle.
- **Nymph**: The stage of development between moults in exopterygotes is called **nymph**.
- **Pharate**:The insect after apolysis is called **pharate**.
- **Procuticle:** inner layer of cuticle.
- **Stadium/instar**: The stage of development between moults in endopterygotes is called **stadium/instar**.
- **Tagmata:** The division of body into functional regions.
- **Intersegmental membrane:** It is a flexible, soft and comparatively less scelerotized membrane between two segments to provide flexibility and movement.
- **Terga:** upper flat plate like sclerite on dorsal side of segment.

- **Sterna:** lower sclerite on ventral side of segment.
- **Pleura:** It is paired lateral plates of segment.

1.11 Self learning Exercise

Section -A (Very Short Answer Type):

1. Name the smallest insect?
2. Name the orders having abdominal appendages?
3. What made cuticulin?
4. Which layer of integument is living?
5. Which component is responsible for sclerotisation and melanisation?
6. Which pigment is present in lac insect?
7. Name the hormones responsible for moulting?
8. Ecdysone is released from which endocrine gland?
9. JH is released from which endocrine gland?
10. Name the sclerite which is present in between two segments?
11. Name the smallest insect?
12. Name the largest insect?
13. What is the insect skeleton called?

Section -B (Short Answer Type)

1. Differentiate between suture and sulcus?
2. What is the difference between primary and secondary segmentation?
3. Define sclerite and excuvial membrane?
4. Name the flexible and hardening protein?
5. Explain how integument is multifunctional in nature?
6. Describe the hormonal control of moulting during metamorphosis?
7. What is the difference between ecdysis, apolysis and pharate?

Section -C (Long Answer Type)

1. Explain the process of moulting and its significance?
2. Write the biochemistry of cuticle?
3. Name the different pigments of insects?
4. What are the special integumental structures of integument?
5. Write down about the basics of insect origin?
6. Why the body is divided into segments and how metamorphosis is significant?

Answer Key of Section-A

1. *Dicomorpha echmepteryg* fairy fly 0.13 mm
2. Archaeognatha and Thysanura
3. lipoprotein
4. Epidermis or hypodermis
5. Polyhydric phenols and quinines
6. Anthroquinones
7. JH and ecdysone
8. Prothoracic gland
9. Corpora allata
10. Intersegmental membrane
11. Mymarid wasp (order Hymenoptera: family mymaridae) it is a parasite of other insect egg
12. American owlet moth (order Lepidoptera: family noctuidae)
13. exoskeleton

1.12 References

- Cedric Gillot: Entomolgy
- Kachhwaha N.: Principles of Entomology- Basic and Applied

Unit - 2

Insect Morphology – II

Structure of the unit

2.1 Objective

After going through this unit you will be able to understand

- What are the divisions of insect body?
- What are the specialization of insect head, thorax and abdomen?

- How these are modified to adapt their environment?
- These tiny creatures have external genitalia to mate.
- Various types of legs, antenna and wings are the basis on which these insect looks different.

2.2 Introduction

The success of organisms in its environment is based on their particular structural features with their internal body organization. Some modification in insect morphology offers the insect to acclimatize more easily. Their morphology helps them to overcome during favorable and unfavorable conditions. Some of the important adaptations are derived from specialized structures that function and compete with their external environment. General morphological characteristics of all insects include:

1. They have segmented bodies divided into head, thorax and abdomen.
2. In insects the body is covered with cuticle that act as exoskeleton.
3. They have jointed appendages -
4. Insects are bilaterally symmetrical.
5. The head bear sense organs like mouth parts, compound eyes, antenna
6. The thorax has three pair of legs and two pairs of wings.
7. The abdomen contains external genital organs for purpose of copulation and fertilization.

2.3 Head

Head is the first and the foremost division of insect body having sense organs, mouth parts and large compound eyes. Insect head has certain modifications of antenna and mouth parts which forms the basis of classification of insect order, family, species and subspecies.

2.3.1 Theories of segmentation

There are many theories regarding head segmentation and it is difficult to say which one is true or which one is false. As we compare the insect head in egg, larva, pupa and adult it is difficult to say that which segments are fused together and where are the lines of separation. Embryo consist of two layered germ bands protocephalic (forms primary head region) and protocormic (forms primary trunk region). Protocephalic region contains preantennary, antennary and intercalary segments. First, second and third segments unite to form head appendages except preantennary. In embryo the head is usually large and bilobed at anterior end followed by long body. The mouth is placed at stomodeum and then segment starts. In the next stage on the head there is a pair of lobes laterally for antenna and big lobe on upper surface for labrum (upper lip). Afterwards three pairs differentiate in future called maxilla, mandible and labium. Behind these structures there are series of appendages. The early insects develop from Trilobites in which body is divided into three lobes (FIG 2.1)**.**

If we see the head of crustacean there are two antennae first and second, and second one is more modified to catch prey. In present insects some head segments combined in embryonic head to give present modern insect head. In young caterpillar there are pairs of lobes for antenna, mandibles, first and second maxilla followed by leg lobes. So, we are able to understand that there are four postoral segments that form a definitive head. The head of Orthopteriod insect mandibles, antenna, maxilla and labium all are well defined and fully developed. An adult head shows many inter-segmental lines which are simply the grooves that form internal ridges. This strengthens the skeleton of head and gives a base for attachment of muscles. These are called **sutures** and have no relation with primitive segments of head. Suture is a Latin word means "a seam". It is much convenient to called it by another Latin word **sulcus** means grooves/ furrow. There is epicranial suture on head anterior region, line where the skin splits and insect came out of its old skin. It's also called ecdysial line. In head lobes there are two pairs of little cavities in the mesoderm known as coelomic sacs. Pre-antennal and antennal coleomic sacs are these two cavities.

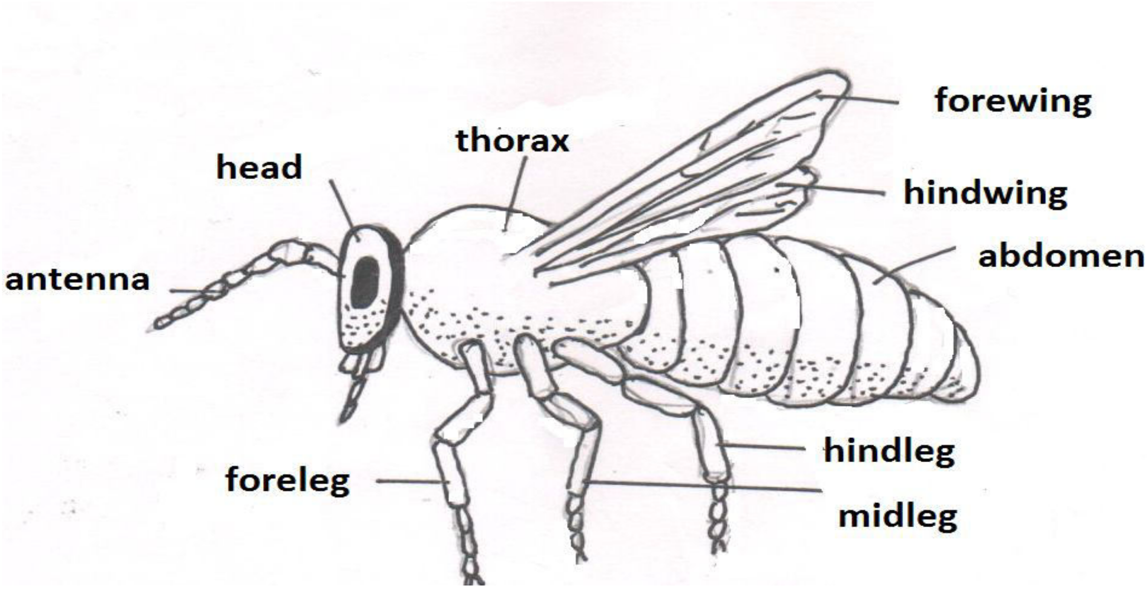


FIG 2.1 : Generalized insect body showing tagmosis

2.3.2 Structure of head

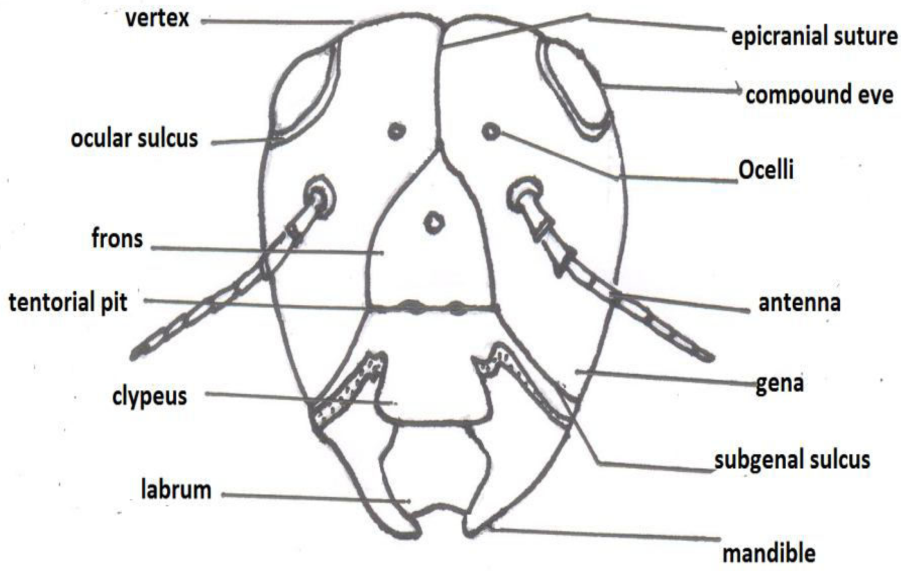
The head is heavily sclerotized and hard capsule called epicranium with exception of some holometabolous insects where head capsule is not fully sclerotized.. The head of insects is specialized for feeding. It is differentiated into cranium**,** antennae, mouth parts and eyes. Six segments of head in embryo and five segments in adult modify to form compound eyes, simple eyes (ocelli), mouthparts like mandible, maxilla, labrum, and antennae. The head of an insect is composed of many rigid sclerites (sclerotized segments) and sutures. Sclerites are strongly scleritized plates with narrow lines where they are attached called sutures/sulcus (FIG 2.2, A, B, C). Different sclerites are:

- **Frons:** it is large unpaired and frontal plate. It bears antenna and ocelli.
- **Clypeus**: It is found below frons and attach to upper lip/ labrum.
- **Labrum**: It is like upper lip and is movable.
- **Vertex**: Upper part lies between compound eyes; their lateral plate is called **parietal** and extends back to occipital sclerite.
- **Occiput**: It is a narrow sclerite lying behind the vertex and extends on each side to form post gena. It bears the neck membrane that attach to head and a foramen named **foramen magnum.**
- **Gena:** parital/ gena are found laterally followed by post gena towards occiput. Gena can be compared with cheek in human.
- **Ocular sclerite**: compound eyes are surrounded by narrow sclerite.
- **Antennal ridge:** antenna is embedded in a sclerite in front.

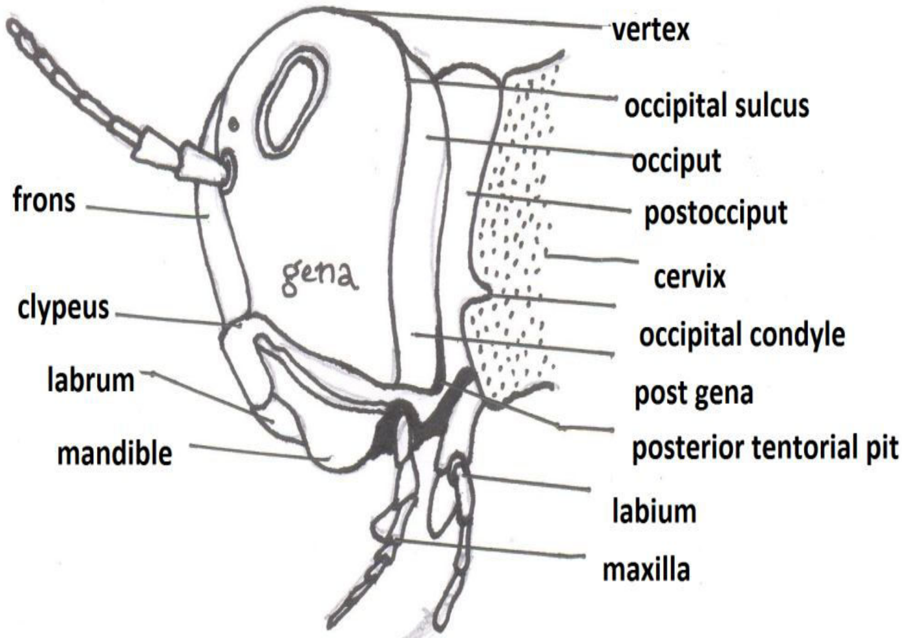
2.3.3 Endoskeleton of head/ Tentorium

Internally, the cranium is supported by two pairs of invaginations of the body wall that unite to form the tentorium**.** First pair of cuticular invagination is called anterior tentorium arm and second one is posterior tentorium arm. The point of origin is the anterior tentorium pits and posterior tentorium pits. The posterior arms unite to form a transverse rod called tentorium bridge. It lies on ventral nerve cord and also supports foregut which passes above it. Its function also includes providing a base for attachment of muscles of maxilla, mandibles, labium and hypopharynx. In Orthoptera central part of tentorium broaden to form corporotentorium. In some orders it may reduced but rarely absent (FIG

2.2,

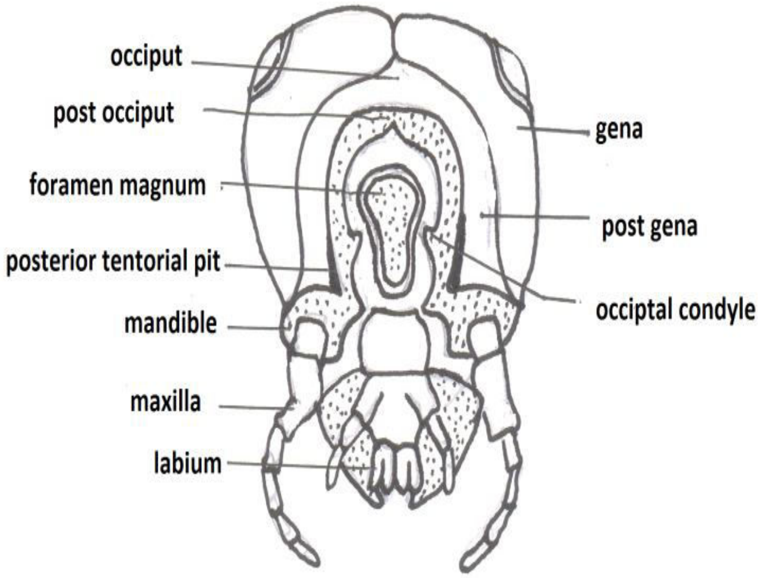

vertex
epicranial suture
compound eye
ocular sulcus
Ocelli
frons
tentorial pit
antenna
clypeus
gena
subgenal sulcus
labrum
mandible

D).

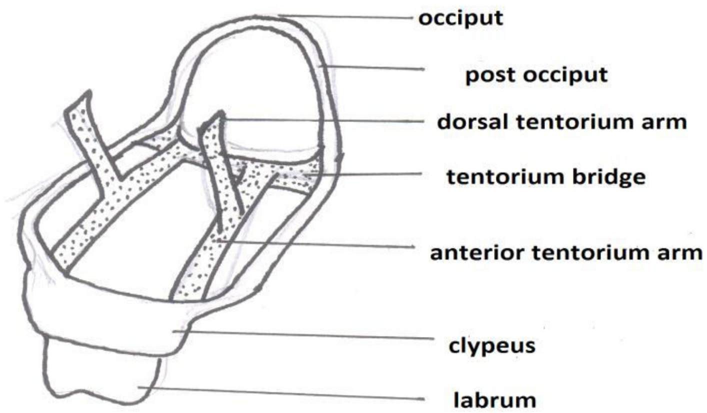

vertex
occipital sulcus
occiput
frons
postocciput
gena
cervix
clypeus
occipital condyle
labrum
post gena
mandible
posterior tentorial pit
labium
maxilla

A)

B)

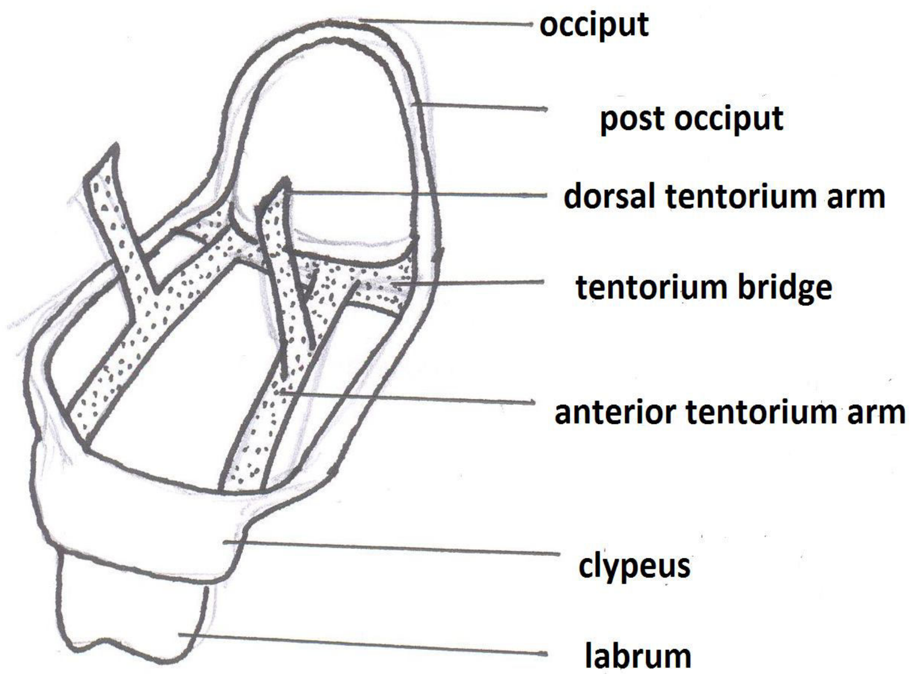


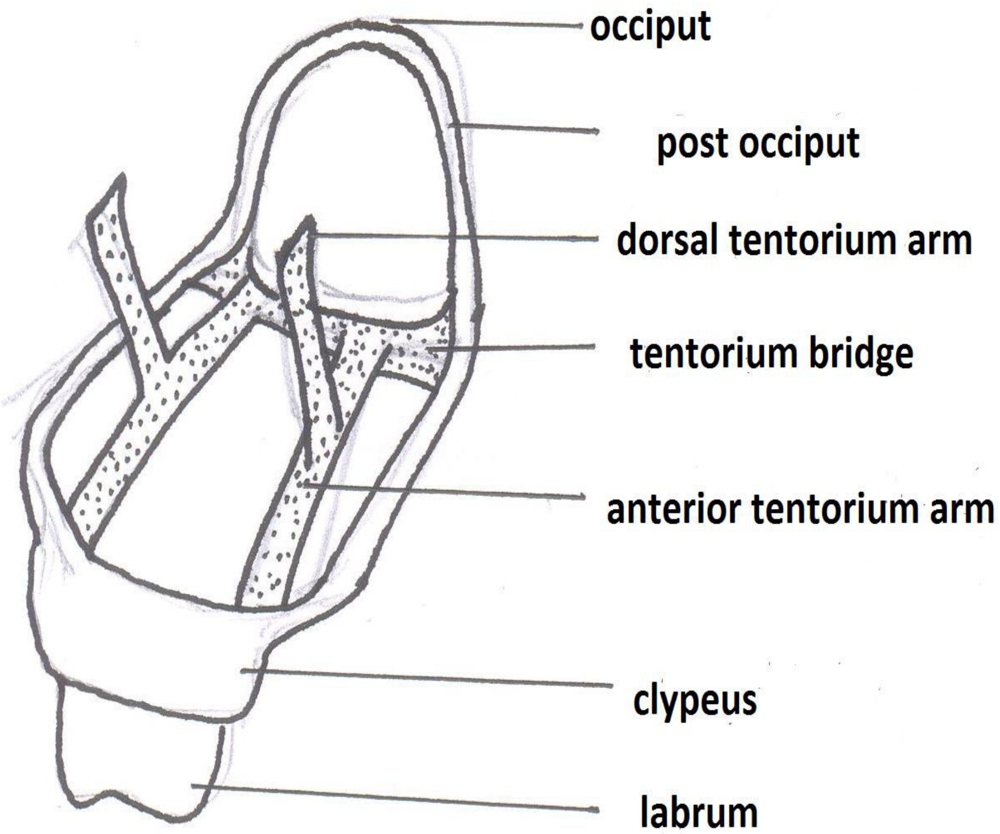
C)



D)

FIG. 2.2: Illustration of a typical insect head. (A) frontal view (B) lateral view (C) posterior view D) tentorium





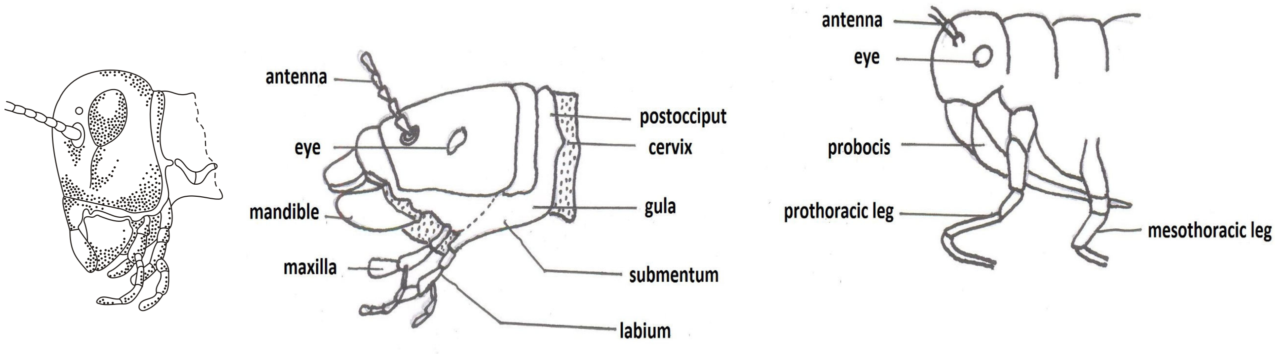
Neck sclerite: Head and thorax are connected with a flexible neck or cervicum. Neck is strengthen by thin chitinous plate call neck/ cervical sclerite, occurs in pair on each side of the neck. Neck contains both labial and prothoracic components. It consist of intersegmental line and muscles are attached to the antecosta of prothoracic segment and arises from postoccipital ridge. It allows movement of neck.

Compound eyes and ocelli: Two types of eyes are present in insects compound eye and ocelli. In most insects there is one pair of large, prominent compound eyes composed of basic units called ommatidia. Number of ommatidia in each eye varies like worker ant, *Ponera* contains only one ommatidium, cockroach 2000 ommatidia, housefly 4000 ommatidia and dragon fly may contain upto 10,000-28000 ommatidia. Insects have binocular vision and sensitive to UV and blue-green region of electromagnetic spectrum. They are red color blind except butterflies. Their function is to form images and photoreception; it gives acute perception of movement. Stemmata/ lateral ocelli present on frontal plate between two compound eyes. In holometabolous larvae it is responsible for detecting colour, form and distance perception. It receives nerve supply from the brain.

2.5.4 Variation in structure

The insect cranium or brain box is a hardened capsule. It leads to thorax by a small opening. It is attached to the thorax by short neck/cervix. Different insect has different type of arrangement of cranium. So, on the basis of orientation of head as compared to body:

- **Prognathous:** mouth parts are directed forward to head eg. Coleoptera
- **Hypognathous:** cranium corresponds to the body but mouth directed downwards i.e perpendicular eg. Orthoptera.
- **Opisthognathous:** deflection of facial region giving mouthparts a posterio-ventral position eg. Hemiptera (FIG 2.3).
- **Entognathous:** eyes are absent and mouthparts can be retracted within head eg. Diplura, Collembola, Protura.



Grasshopper (Hypognathous) Beetle (Prognathous) Cicada (Ophisthognathous)

FIG. 2.3: Types of head

2.3.5- Mouthparts

The structure and position of mouthparts depends upon type of feeding habits.

In primitive form like grasshoppers and beetles the mouthparts include:

1. **Labrum (upper lip):** The labrum is a simple fused sclerite, often called as upper lip, and moves longitudinally. It is hinged to the clypeus. The interior, fleshy surface of the labrum, endowed with numerous sensory structures, is referred to as the **labrum-epipharynx.**
2. **Mandibles (jaws):** These are a pair for chewing. They are highly sclerotized paired structures that move at right angles to the body. They are used for biting, chewing and severing food (FIG 2.5, A).
3. **Maxillae (second jaws):** The maxillae are paired structures that can move at right angles to the body and possess segmented palps (FIG 2.5,B).
4. **Labium** (lower lip): It is a fused structure that moves longitudinally and possesses a pair of segmented palps (FIG 2.5,C).
5. **Hypopharynx:** It is unsegmented outgrowth of the body wall and lies in the preoral cavity like a tongue and salivary duct opens into it.
   Cibarium: the portion between preoral cavity and labrum.
   Salivarium: the portion between preoral cavity and labium (FIG 2.4).

Epipharynx: It is attached to the labrum, present at the roof of the mouth and basically is an organ of taste, present only in grasshoppers and crickets.

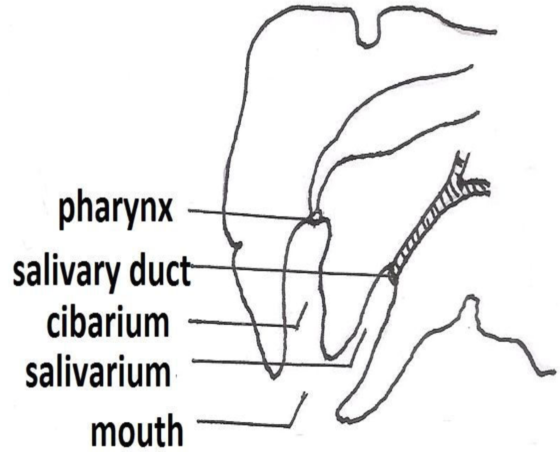


FIG 2.4: Diagram showing cibarium and salivarium

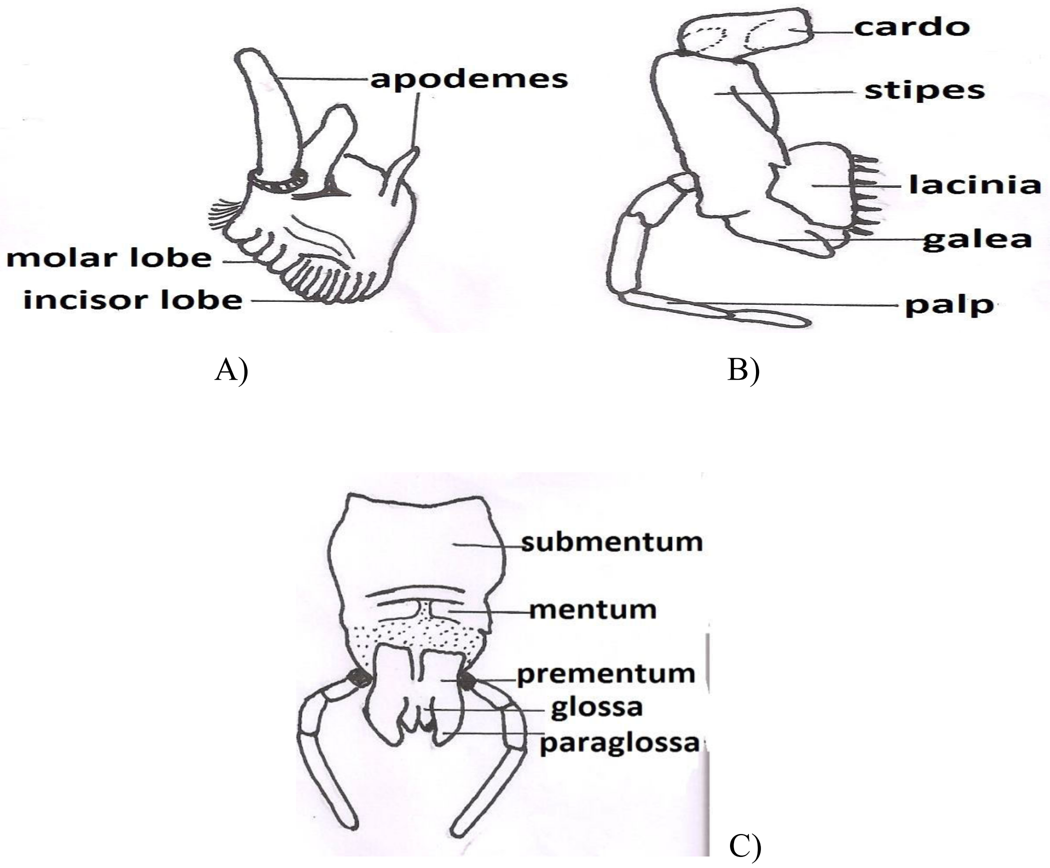


FIG 2.5: A) mandible B) Maxilla C) labium

2.3.6Types of mouthparts

Several types of mouthparts occur in insects groups with modifications that are evolved from the basic chewing type. In addition to chewing, insects have types that include piercing-sucking (FIG 2.7), rasping-sucking, siphoning (FIG 2.8,B), sponging (FIG 2.6), cutting-sponging, and chewing-lapping (FIG 2.8, A).

	Piercing and sucking type	**Biting and chewing type**	**Rasping and sucking type**	**Siphoning type**	**Sponging type**	**Chewing and rasping type**
Modified structure	Mandibles and maxilla needle like to peirce and epipharynx for sucking	Mandibl-es strong for cutting, maxilla for retaining in libarium	Rostrum formed from labrum, and labium, inside beak hypopharyx and both maxillary lacinia and mandibles are present as stylets .	Maxilla hollow tube like, coiled and two galea of maxilla fuse to form probosci-s	Fleshy, retractie probosc-is, labium divided into 3 parts rostrum, haustell-um, labellum, proboscis is modified from labrum, labium, hypophary-nx	Labrum, mandibles chewing type, maxilla, labium as lapping tongue
Reduced structure	2 maxilla with no maxillary palps	Most primitive generaliz-ed type so all mouthpa-rts develope	Structure between chewing and piercing type, mandible reduced to stylets	Maxillay palp, labrum reduced, mandibl-es absent	mandibles absent, maxilla only palps present	Maxillary palps and labial palps small or reduced

		d				
Types of food	Liquid	solid	Liquid	liquid	Liquid with some solid particles	nector
Example	Hemiptera, Diptera- mosquitoes , aphids, bedbugs	Orthoptera, Coleoptera- grasshoppers, lice beetles	Thysanoptera- Thrips	Lepidoptera- moths and butterflies	Diptera- housefly, fleshfly	Hymenoptera- honeybees, wasp

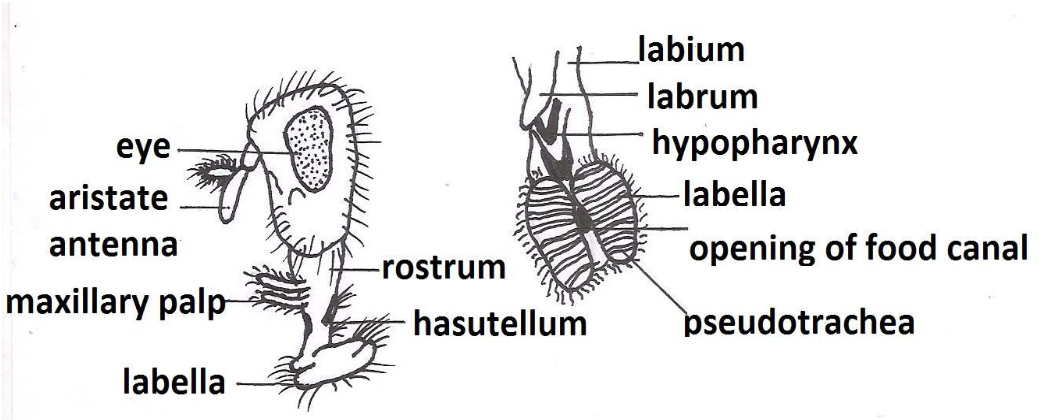


FIG 2.6: Mouth parts of house fly Sponging type and its proboscis enlarged

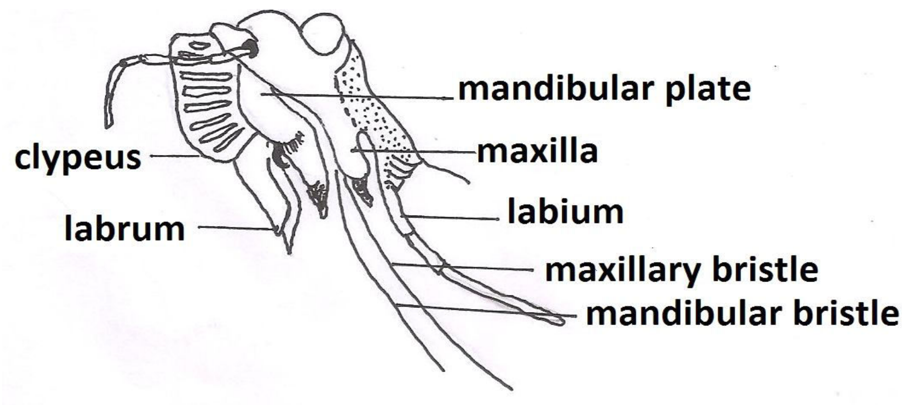
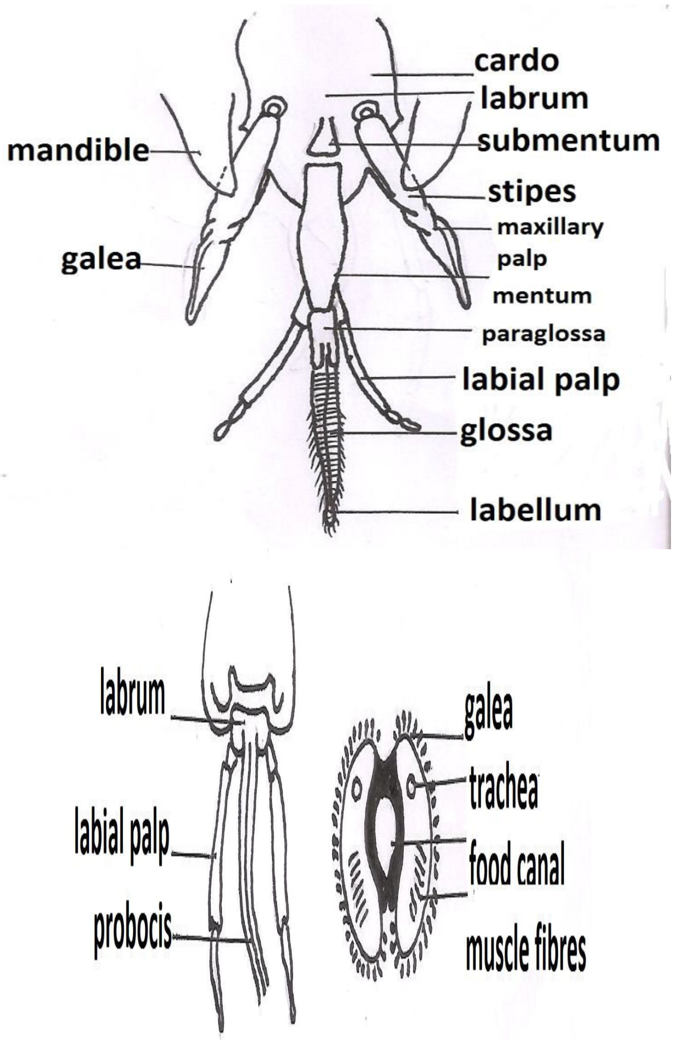


FIG 2.7: Mouthparts of Hemiptera piercing and sucking type



A) B)

FIG 2.8: Mouthparts of honeybee (chewing and lapping), Lepidoptera (sponging type)

2.3.7 Antenna and types

Antennae are the sensory organs perform variety of functions to detect motion and orientation, odor, sound, humidity, and a variety of chemical**.** Antennae vary according to order and sometimes character of family, it follows a basic plan in which

- first segments call **scape**,
- second segment is **pedicel** and

- last remaining antennal segments/ flagellomeres are jointly called the **flagellum** (FIG 2.9).

Antennae are a pair of appendages present on anterior region of head between the compound eyes. These are movable and contain sensory structures and perceive reception of external stimulus. They are different in different order or family, often between sexes of the same species i.e. they clearly exhibhit sexual dimorphism.

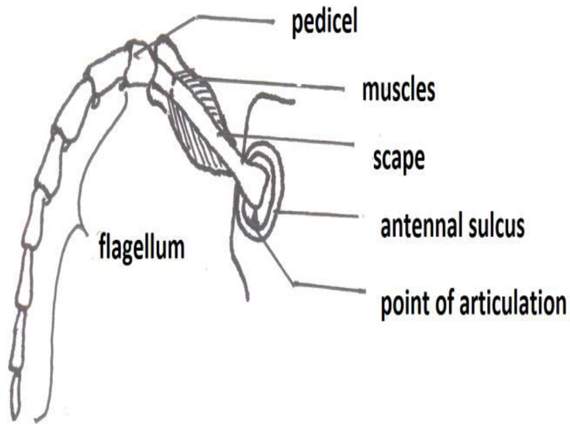


FIG 2.9: Structure of antenna

Types of Antennae in insect

In insects various types of antenna are present where their structure forms differentiation. The differences forms the basis to classify insect species (FIG 2.10).

1. **Aristate** antennae are pouch-like with a lateral bristle and last segment is aristate type, housefly and shore flies (order Diptera).
2. **Capitate** antennae are clubbed at last segments, Butterflies (order Lepidoptera).
3. **Clavate** antennae are gradually clubbed at the end, Carrion beetles (order Coleoptera), butterflies, Mallophaga, Siphonoptera.
4. **Filiform** antennae have a thread-like shape, ground beetles and longhorned beetles (order Coleoptera), cockroaches (order Blattaria).
5. **Geniculate** antennae having three parts club, funicle, ring segments, Formicidae, Cucurlionidae, Lucanidae.

6. **Lamellate** antennae end in nested plates, Scarab beetles (order Coleoptera).
7. **Monoliform** have a bead like or globose shaped segments, Termites (order Isoptera).
8. **Pectinate** antennae have a comb-like in appearance. It can be one side monopectinate or both side bipectinate, Fire-colored beetles and fireflies (order Coleoptera), unipectinate - moths, bipectinate- Saturniidae family.
9. **Plumose** antennae have bristles or hairs at each segment, male mosquito.
   Pilose (less hairy), Female mosquitoes.
10. **Serrate** antennae have a saw-toothed shape structures, Click beetles, elatridae family (order Coleoptera).
11. **Setaceous** antennae have a bristle-like shape, Dragonflies and damselflies (order Odonata).
12. **Flabellate** antenna, Strepsiptera male.

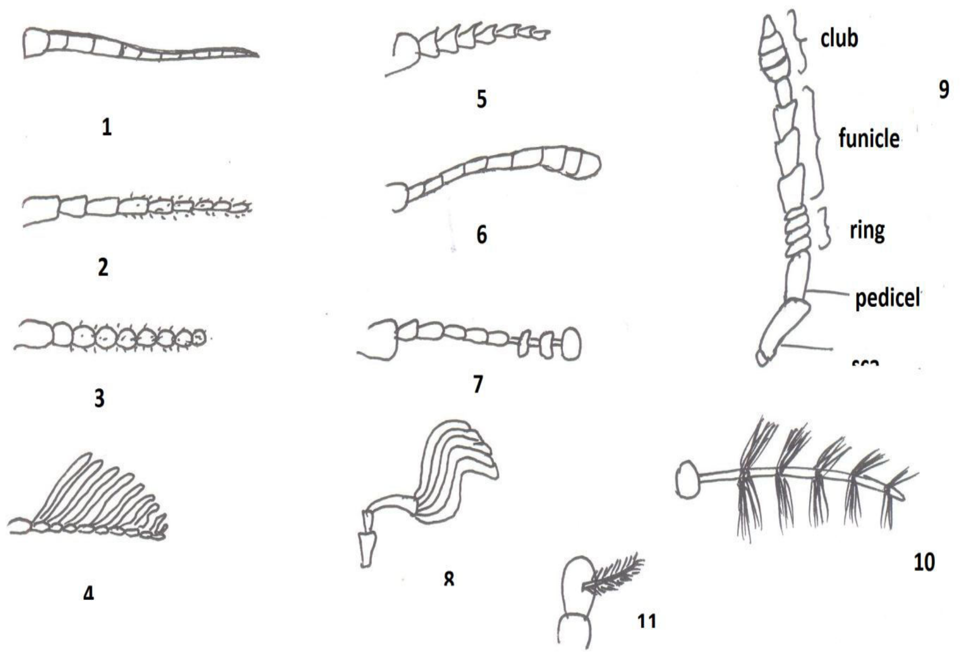


FIG 2.10: 1. Setaceous 2. Filiform 3. Monoliform 4. Pectinate 5. Serrate 6. Clavate 7. capitate 8. Lamellate 9. Geniculate 10. Plumose 11. aristate

2.4 Thorax

2.3 Thorax: Structure of terga, sterna and pleura

Thorax of insect is divided into three segments, the prothorax (*pro*: first), mesothorax (meso: middle), and metathorax (*meta*: last). Prothorax expanded and overlaps mesothorax in locust and grasshoppers. Each segment consists of hard plates/sclerites (FIG 2.11). The sclerites placed dorsally are called tergum (singular: terga), laterally placed sclerites are called pleura (singular: pleuron) and ventrally placed sclerites are sterna (singular: sternum). The tergum of thorax is called notum and notum of first segment/prothorax is known as pronotum, mesothorax is mesonotum and metathorax is metanotum. Meso and metanotum is divided into three sclerites prescutum, scutum and scutellum. Bugs have developed prominent triangular scutellum (FIG 2.12). Pleural segment is same in all the three sements of thorax. In the pleura the anterior region is episternum and posterior region is epimeron. The articular membrane between episternum and coxa is called trochantin. Episternum and epimeron subdivided into smaller sclerites at wing base called epipleurites. Likewise the sternum is divided into presternum in prothrorax, basisternum in mesothorax and sternellum in metathorax.

Pterothorax: Mesothorax and metathorax are often commonly called pterothorax as it bears wings. All the three thoracic segments consist of one pair of legs. Legs are also segmented therefore insects comes in Phylum-Arthropoda (segmented appendages). Wings are of two type; forewing present on mesothorax and hindwing present on metathoracic segments.

The pronotum is highly modified in orders like Hemiptera, Blattaria, and Coleoptera. **Membracidae,** cow bug (order Hemiptera) have very large pronotum extended to head.

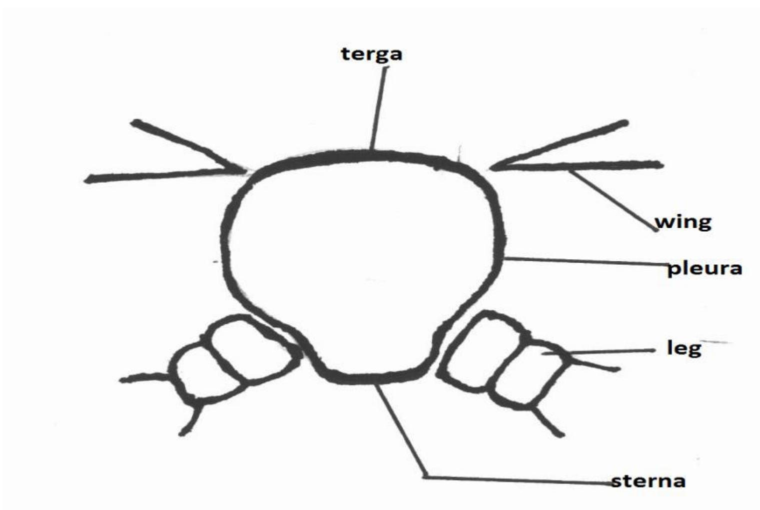


FIG 2.11: T.S of insect body showing sclerites

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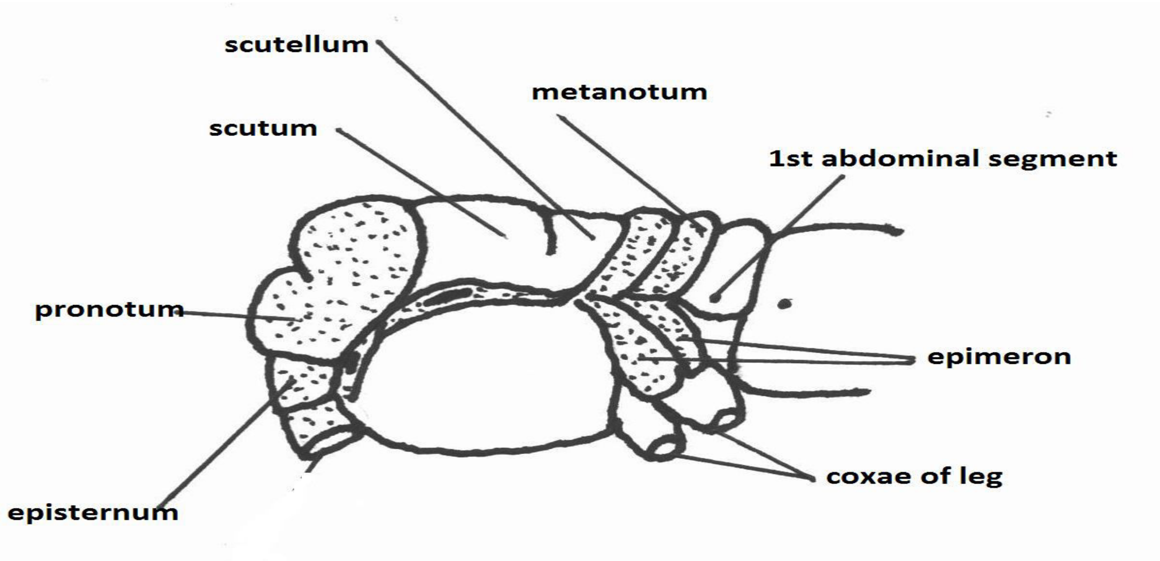

FIG 2.12: Thorax of wood wasp

2.4.1 Structure of leg

Legs are also differentiated on the basis of which part of thorax it is present.

- Prothoracic legs attached on prothorax.
- Mesothoracic legs attached on mesothorax.
- Metathoracic legs attached on metathorax.

Insect legs are segmented appendages consisting of five segments. From the part nearest to body towards farthest, these segments are the coxa, trochanter, femur, tibia, and tarsus.

- **Coxa** is a base of leg attached to thorax. It is placed in a cuplike depression of the body, which allows multidirectional movement like ball and socket joint in mammals.
- The **trochanter** is the smallest part of the leg that connects the coxa to the femur. It is triangular in shape in most insects that bends legs towards forward.
- **Femur** is the largest and strongest segment of the leg.
- Next segment is **tibia** which is longest of all segments. It is long, slender structure with downwardly pointed spines that help in climbing.
- Last segment tarsus is further sub-segmented called **tarsomeres.** It consists of segments varying in number from 1to 5 segments. In Collembola order tarsus fuses with tibia to form **tibiotarsus** as it is a primitive order**.** Last tarsal segment is called pretarsus consist of a pair

of claws with a pad called the **arolium/pulvillus/empodium** meant for adhesion (FIG 2.13).

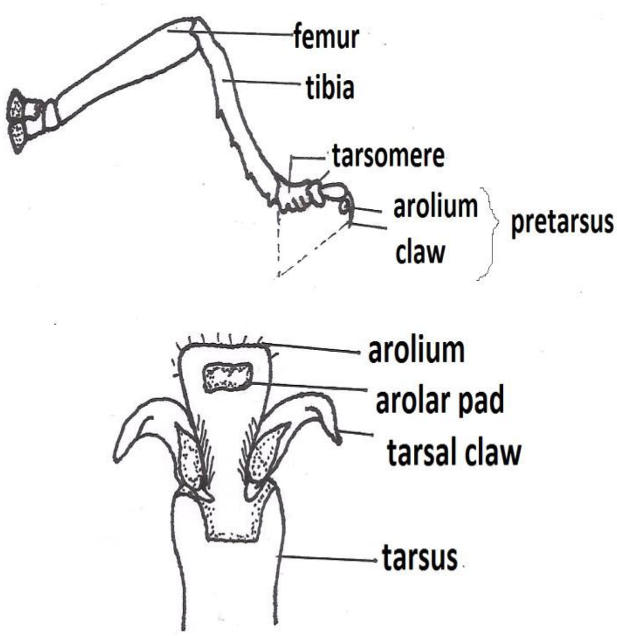

FIG. 2.13: Morphology of insect's leg and arolium with claws magnified

2.4.2 Modification of leg

In legs femur and tibia are the usual segments showing modification. The tarsus may sometimes divided into subsegments /pseudosegments called **tarsomeres**.

Depending upon the environment in which insect adapt and acclimatize legs are modified to capture prey, offense, defense, mimicry, behavior etc.

1. **Cursorial legs**- They are simple structures meant for running. It consists of long, thin leg segments. Examples: Cockroaches (order Blattaria), ground beetles and tiger beetles (order Coleoptera).
2. **Fossorial forelegs**- They are modified forelegs for digging. Tibia consists of triangular tarsomeres. Examples: mole crickets (order Orthoptera, FIG 2.16, B) and cicada nymphs (order Hemiptera).
3. **Natatorial legs**- They are modified for swimming. Here tibia and tarsi have bears swimming hairs. Examples: water beetes (order Coleoptera) and water bugs (order Hemiptera) hindleg of *Gyrinus* (FIG 2.15, A).

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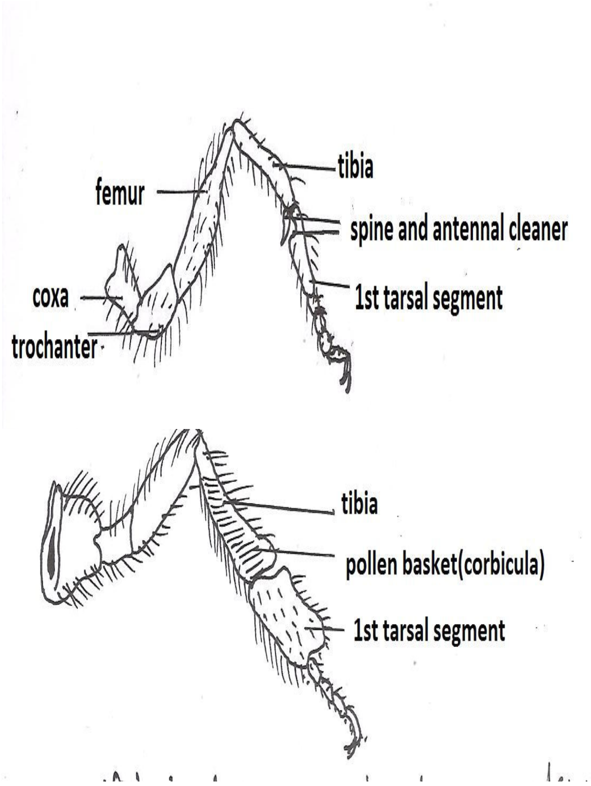
4. **Raptorial forelegs**- They are modified forelegs for grasping (catching prey). Here coxa is movable with tibia spinose and femur is swollen and spiny. Examples: Mantids (order Mantoidea, FIG 2.15,B), water scorpions (order Hemiptera).
5. **Saltatorial hindlegs**- They are modified for jumping or hopping. These have an elongated femur and tibia. Examples: Grasshoppers, crickets, katydids (order Orthoptera).
6. **Stridulatory legs**- They are the one part which stridulate with wing and constitute the sound producing organs, example grasshoppers.
7. **Scansorial legs**- tarsi one segmented with a sharp, curved and pointed claw meant for clinging, example head louse (FIG 2.16,A).
8. Forelegs of *Dyticus* is meant for holding female as tarsomere consist of suctorial pads.
9. In honey bees hind leg parts such as metatarsi are modified to have a brush like called as pollen basket / corbicula to collect pollen grains. (FIG 2.14).



A B

FIG 2.14: A) foreleg of honey bee showing antenna cleaner B) hindleg of honey bee showing pollen basket

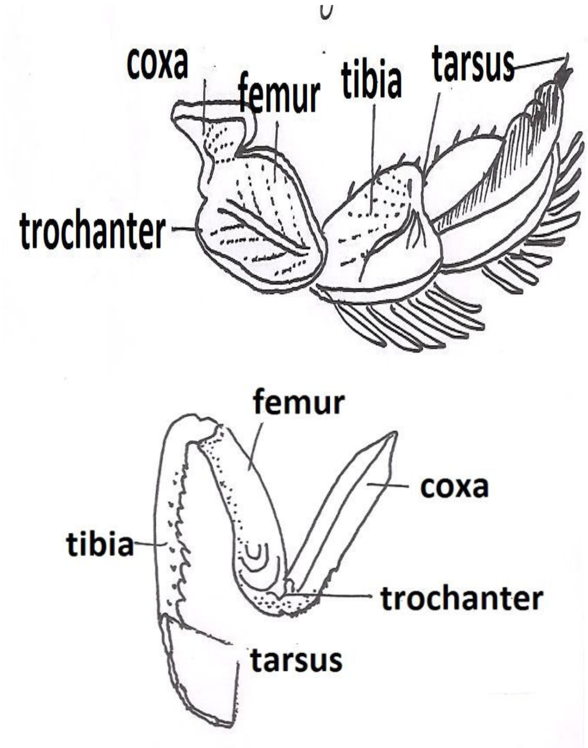


FIG 2.15: A) Hind leg of *Gyrinus* (swimming type) B) Foreleg of *Mantis* (raptorial type)

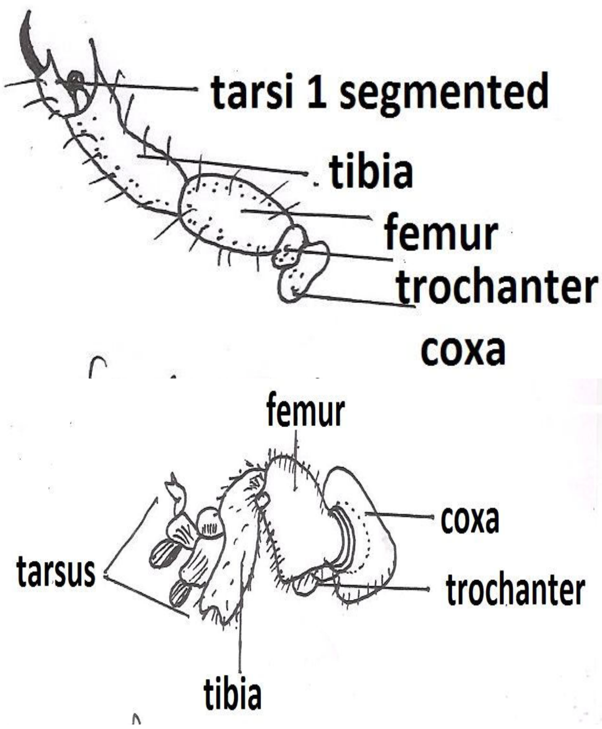


FIG 2.16: A) Foreleg of louse (clinging) B) Foreleg of mole cricket (digging)

2.4.3 Wings

Wings are found on the second and third thoracic segments the mesothorax and metathorax. Like legs differentiation wings are named accordingly if present on mesothorax it is called as forewing and on metathorax it is known as hindwing. They are found in adults only. They are membranous, thin, transparent and sometimes pigmented . They have thickened lines like leaves of plants called wing venation. These veins strengthen the wings. Wings of butterflies and moths are covered with small dust like colorful scales. Usually there are two pairs of wings but in flies and mosquitoes they have one pair of wings, ant and termite are wingless and in beetles front pair of wings are hard or leather-like covering.

2.4.4- Wing origin

There are two most acceptable theories regarding wing origin.

1. Tracheal gill theory: Given by Graber and Woodworth, according to them wing arises from thoracic tracheal gills.
2. Paranotal theory: Given by Miller, according to them wing arises from lateral extension of thoracic terga that enables insect to fly.

10. In **hemimetabolous insects /Exopterygota** wings are developed externally as flattened double layered extension of body wall. In the lumen it bears nerves, trachea and body fluids. In **hemimetabolous insects/ Exopterygota** wings develop internally by the body wall invagination where wings are formed within the pouches. Here imaginal disc invaginates and form wings beneath the cuticle. In later development wing rudiment, peripodial cavity lined by peripodial membrane forms wing bud which is everted during larval-pupal moult. Hypodermal cells elongates and basement membrane of body wall fuses leaving some channels at certain points to left open (FIG 2.17).

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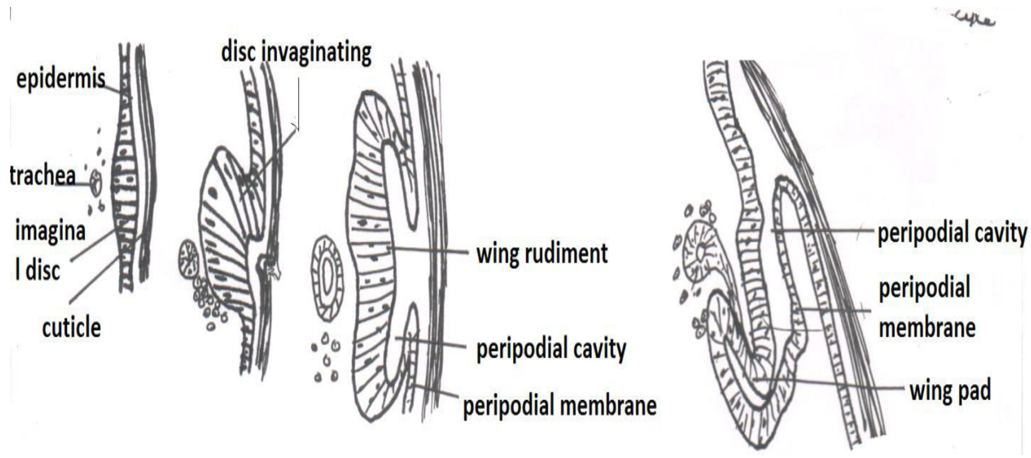

Fig 2.17: Development of wing bud of *Pieris* (Lepidoptera)

Functional wings are present only in the adult stage, except in the order Ephemeroptera, where subimago possesses well developed and functional wings, which are shed at the final moult. According to wings presence and absence, or whether it is developed externally or internally insects are classified into subclasses:

1. Subclass Apterygota being wingless and primitive.
2. Subclass Pterygota, wings are present except some pterygote such as the fleas and lice.
   a) Infraclass exoterygota wings develop externally
   b) Infraclass endoterygota wings develop internally

In new insects there are sclerites tegula, axillary cords, axillary sclerites and skeletal plates that articulate with various parts of the wing. Tegula confined to forewings of Hymenoptera, Diptera and Lepidoptera. Axillary cords are lobe like structure lying near anal margin and axillary sclerites at the base of wing, first at base of subcostal vein, second at base of radius vein and third lying between anal veins and sometimes forth is present occasionally in Orthoptera and Hymenoptera. Two plates also present to support wings named medial and humeral plates. Medial plate occurs in pairs associated with media, cubitus and first anal vein. Humeral plate is well developed in dragonflies

Primitive insects of the Paleoptera are unable to fold their wings and carry their wings vertically or horizontally to their bodies. Most modern insects of the Neoptera are able to fold their wings over their abdomen.

2.4.5 Wing modification

1. **Halters wings-** Halteres are found in Order Diptera (true flies), in which the hind wings are reduced and used for balance and revolve the direction during flight.

2. **Elytra (singular elytron)-** These are the hard and heavily sclerotized forewings of beetles (Order Coleoptera). They don't vibrate but function to protect the hind wings when at rest (FIG 2.18).

3. **Hemielytra**- This is the type of elytra where forewings of Hemipterans are said to be hemielytrous because they are hardened only at the proximal two-thirds, while the distal portion is membranous. They function as flight wings. In hemielytra cells are specifically named as embolium, corium, cuneus, membrane and clavus. Examples: Bugs (order Hemiptera FIG 2.19, 20).
4. **Tegmina (singular tegmen**)- They are the leathery and thickened forewings of some insects. The tegmina are used to protect the more vulnerable and longer hind wings. The tegmina offer little or no power during flight. Examples: orders Orthoptera, Blattaria, and Mantodea.
5. **Pterostigma**- It is an opaque spot on wings found in forewing of Plecoptera, Neuroptera and in both wings in Odonata (FIG 2.22).
6. **Hairs-** Wings are covered with many long hairs or bristles often at margin as fringe e.g. Thrips (FIG 2.23).

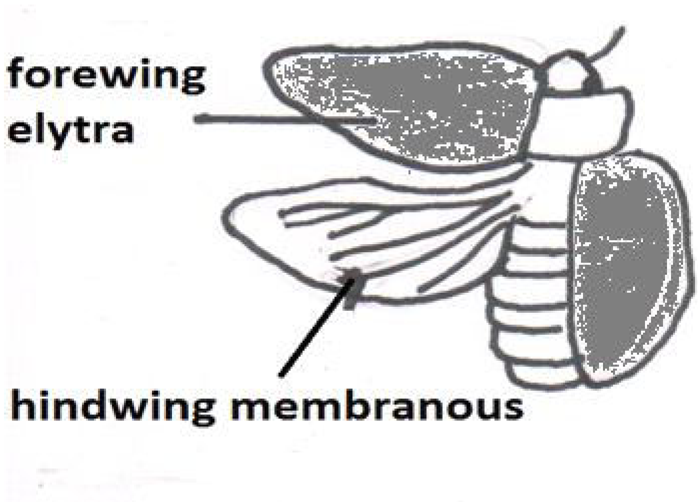

FIG 2.18: Coleopteran showing elytra

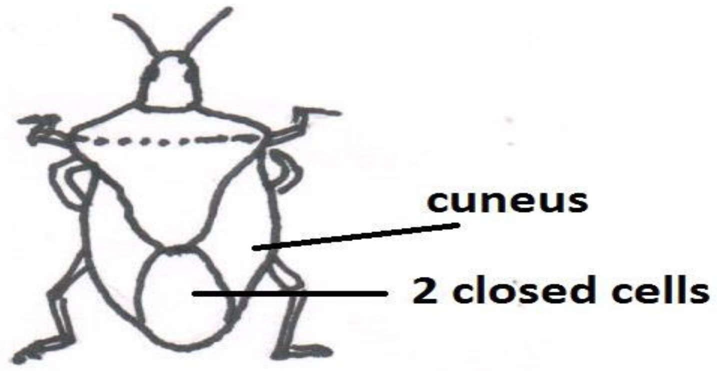

FIG 2.19: Hetropteran showing their hemielytra folded at rest

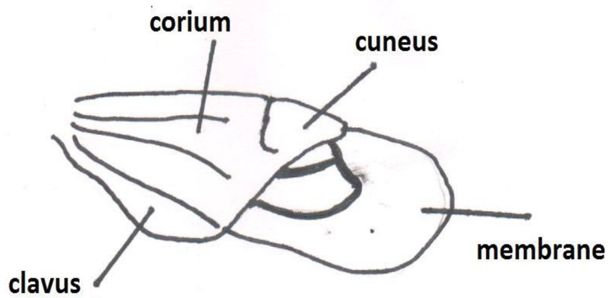

FIG 2.20: A single hemielytra showing its various parts

2.4.6 Wing venation

Veins in wing shows nomenclature known as wing venation given by Comstock and Needham. It is used as identification of insect of particular order or family. It consists of longitudinal veins (FIG 2.21)

- precosta (PC),
- costa (C) a convex vein,
- subcosta (SC) a concave vein divided into SC1 and SC2,
- radial (R) divided into five branches R1 (convex), R2,R3,R4 and R5 (rest all concave),
- medial branched into anterior MA1,MA2 (convex) and posterior MP1, MP2, MP3, MP4 (concave)
- cubitus Cu1 (Cu1a, Cu1b) and Cu2 all convex
- anal A1,A2, A3 all convex and

- sometimes jugal J1, J2 may be present.

Along with these straight veins some cross veins are also found

- humeral (h) connect costa and subcosta
- sectional (s) between R2+R3 and R4+R5
- radiomedial (rm) between radius and medial
- median between M2 and M3
- Mediocubitus between medial and cubitus

  The transverse section shows that the vein consist of trachea, nerve, blood space (FIG 2.24).

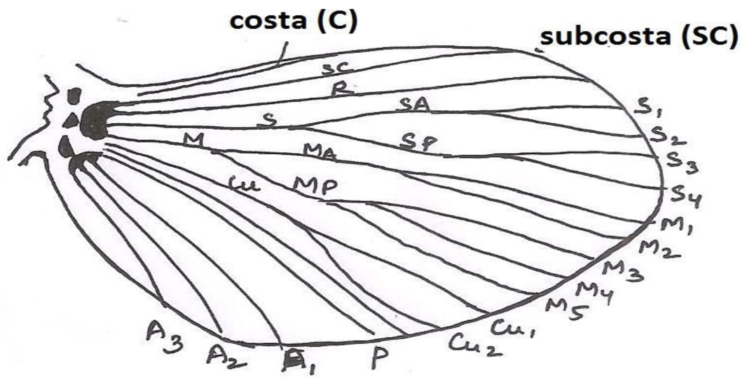

FIG 2.21: Hypothetical structure of wing showing venation

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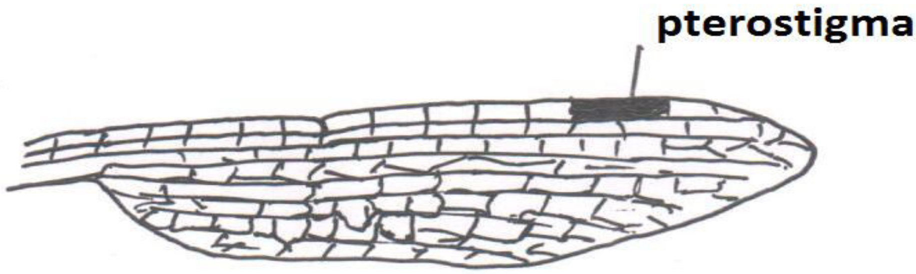


FIG 2.22: A dragonfly wing showing pterostigmata

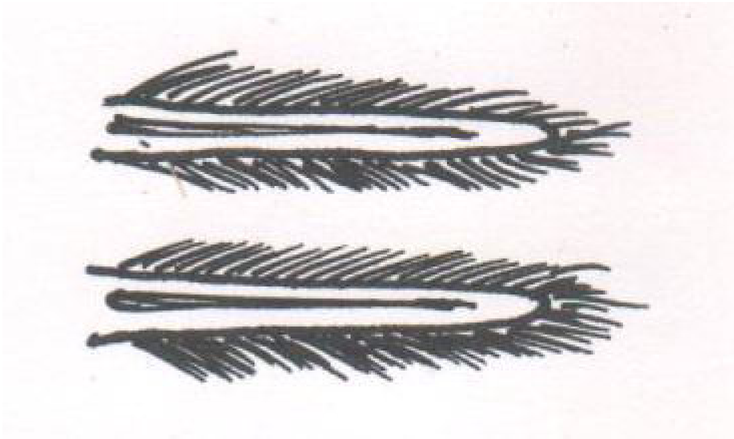


FIG 2.23: Thrips wing

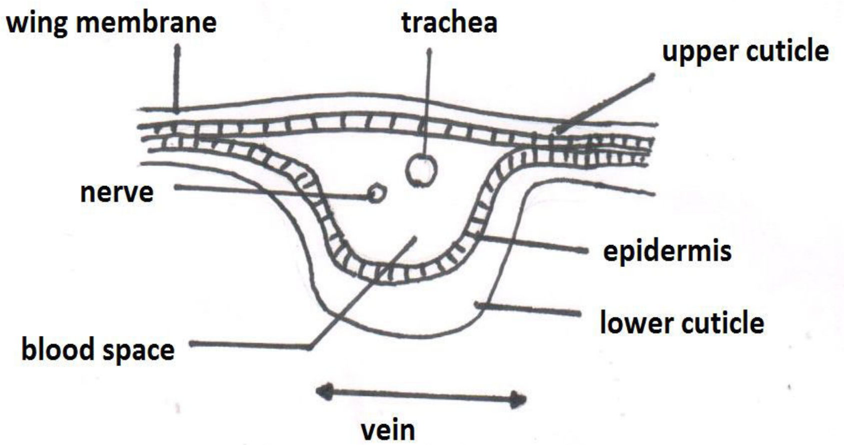


FIG 2.24: Wing in T.S. through vein

2.4.7 Wing margins and angles

There are three margins and three angles found in a generalized wing. On outer side apical margin, anterior costal margin and inner anal margin is present. Humeral angle at the base of costal margin, apical angle between costal and apical margin and anal angle between apical and anal margin (FIG 2.25).

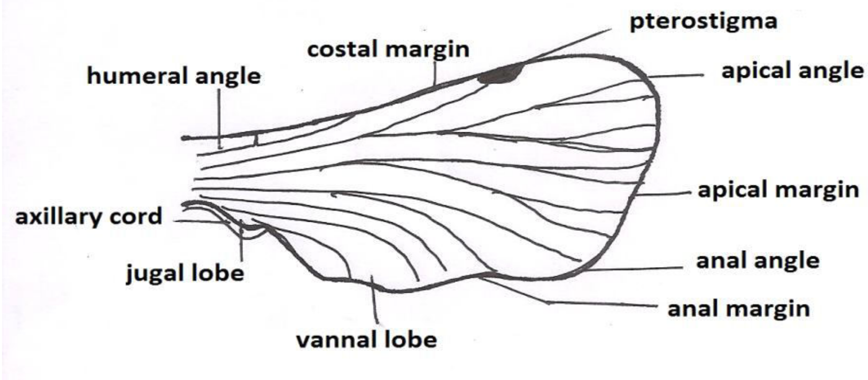
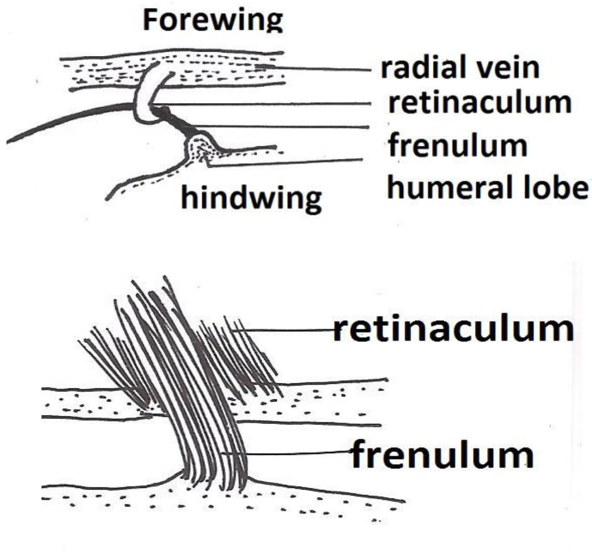


Fig 2.25: diagram showing wing margins and wing angles



A **B**

FIG 2.26: Frenate wing coupling in Lepidoptera male and female *Hippotian scrota*

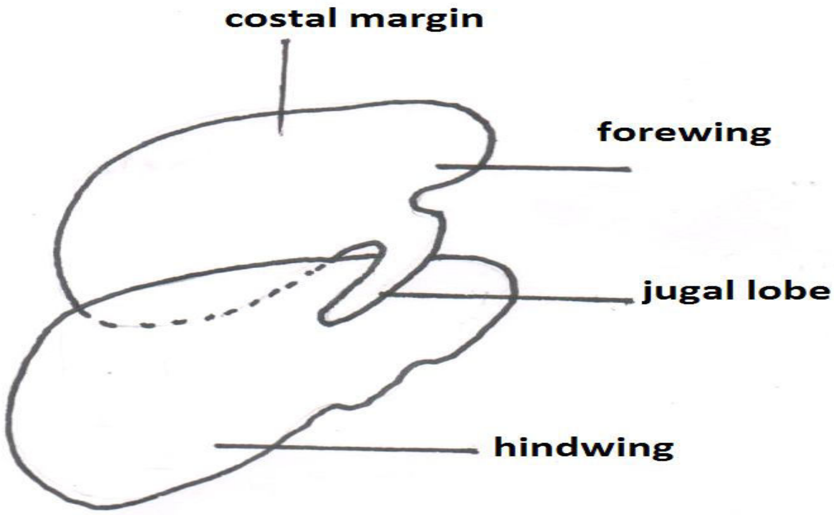


FIG 2.27: Jugal coupling

2.4.8 Wing movement and coupling

Wing movement or flight is due to the contraction of tergosternal muscles. As the muscle contracts it raises the wing upward and longitudinal muscles when contract wings gets lowered down. Both the pairs of wing forewings and hindwings move together like a single unit with some of the modified units and the phenomenon is called wing coupling apparatus.

1. **Jugate wing coupling**- Strong jugal lobe beneath the costal margin of forewing and humeral lobe of hindwing forms Jugate wing coupling. Example, order Trichoptera, Mecoptera (FIG 2.27).
2. **Jugo-frenate coupling**- Jugal lobe of forewing and frenular bristles of hindwing forms Jugo-frenate coupling. Example, family Micropterygidae (FIG 2.28, B).
3. **Fenate coupling-** retinaculum of forewing and and frenulum (2-20 bristles fuse to form single stout spine) of hindwing responsible for frenate coupling. Example, Order Lepidoptera (FIG 2.26).
4. **Hamuli**- In Hymenoptera there are rows of hook called hamuli along the costal margin of hindwing which catch into the fold of forewing (FIG 2.28, A).

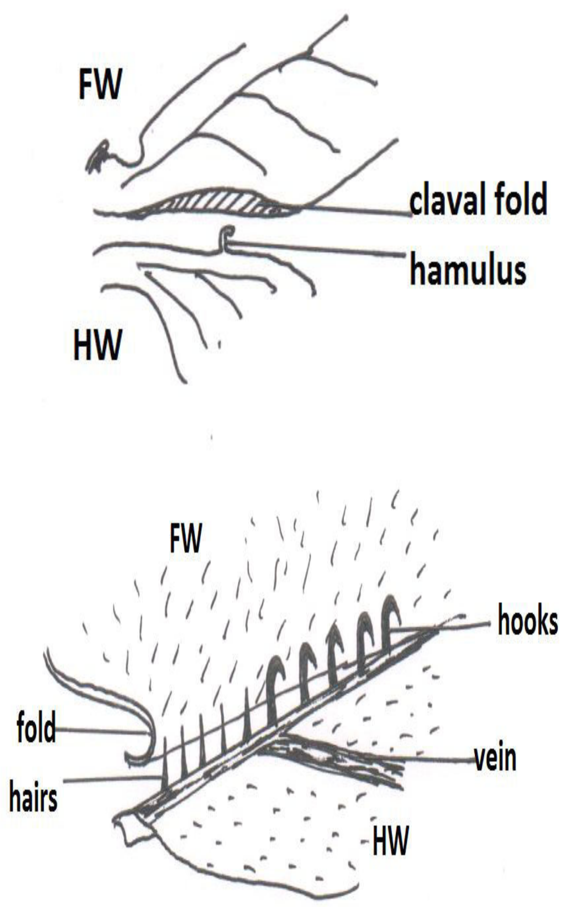


FIG 2.28: A) Hamuli in Hymenopteran B) Hooks and hairs coupling in wings

2.5 Abdomen

The third major division of insect body is abdomen. It is 12 segmented in primitive insect where 12th segment is telson persist in order Protura. In generalized insect abdomen is 11 segmented. It may be reduced to 5-6 segmented where reduction of segments occurs at posterior end of the body. In Acrididae family first abdominal segment laterally have in large tympanic membranes one each on either side. In hymenopterans first abdominal segement is stalk like between thorax and abdomen called petiole. Insects have three plates on 11th segment. It is paraproct two in number on either side of the anus and one epiproct dorsal side or above the anus.

2.5.1 Segmentation and segmental appendages

Like other Arthropods, insects possess no legs on the abdomen in the adult form, except Protura which have rudimentary leg like appendages on the first three abdominal segments. Many larval insects particularly the Lepidoptera and the Symphyta (Sawflies) have appendages called pseudo/ prolegs on their posterior abdominal segments as well as thoracic legs that allow them to grip onto the surface. Terminal segment may bear a pair of appendages called cerci in silverfishes. Non genital abdominal appendages are styli present in Thysanura, Protura and male cockroaches.

In the Collembola (Springtails) the abdomen has only six segments. It has springing apparatus consisting of three structures collophore, organ of adhesion located on first segment, tentaculum on 3^{rd} and furcula on 4^{th} abdominal segment. When the furcula is released from collophore it strikes the surface and as a result the insect jumps. In the Hymenoptera there is a constriction where the 1^{st} and 2^{nd} abdominal segments meet, this is called the pedicel (constricted first abdominal segment meets metathorax), and the remaining portion of the abdomen is called the gaster. Cerci is forcep/clasper like in earwigs, feeler like in crickets, reduced in cockroaches and absent in bugs and endopterygotes.

In female 8^{th} and 9^{th} abdominal segments and in males 9^{th} are modified to form reproductive appendages.

Paired reproductive structures arises from the 8^{th} and 9^{th} abdominal segments, form an egg laying apparatus known as the ovipositor, in most females. Most males have an external copulatory organ called as aedeagus, developed from a pair of appendages of the 9^{th} segment and sometimes parts of the 10^{th} segment. Female gonopore is located on 8^{th} or 9^{th} segment and male gonopore on 9^{th} abdominal segment.

The abdomen contains the reproductive organs, alimentary canal, nerve cord, and the majority of the organ systems. Spiracles are the openings of respiratory system found in between the terga and sterna of abdominal segments 1-8 their number varies from order to order.

2.5.2 Female external genitalia and modifications

The ovipositor is the egg laying apparatus previously defined in female insects developed from 8^{th} and 9^{th} abdominal segments. In some insects, the ovipositor is highly modified, visible and sometimes inconspicuous. Ovipositor functions to dig or bore eggs in soil or wood. The apparatus may be pointed needle like in Crickets or blunt blade-like in katydids. In all apterygote ovipositor has 3 pair of valvulae which originates from small pleural slerite as follows;

- First pair of valvulae borne from first valvifer on 8^{th} segment.
- Second and third pair of valvulae born from common basal sclerite, second valvifer on 9^{th} segment

In Hymenoptera ovipositor is modified into sting (FIG 2.29,B) and accessory /collateral gland into poison gland. In sawfly ovipositor is long and slender shaft where 1st and 2nd valvulae is short and broad ensheathed between 3rd pair of valvulae. In bees 1st gonapophysisis converted into lancelet and 2nd gonapophysis developed into stylet. In housefly ovipositor is absent and posterior abdominal segments becomes telescopic, projected and egg layed from gonopore. In Coleoptera, Diptera and Lepidoptera valves are absent or reduced so apical abdominal segments functions as ovipositor (FIG 2.31).

- In apterygotes as in order Thysanura in addition to stylet an additional slender process gonopod/gonapophysis/valvulae born on basal coxopodite/gonocoxae. Here styli and gonapophysis combined to form ovipositor (FIG 2.29, A). Second gonapophysis unites and forms a tube through which egg passes. Gonangulum is the base of ovipositor which is a small sclerite derived from anterior part of exopodite and articulate with second gonocoxae and tergum of 9th segment (FIG 2.30,A,B). Parasitic wasps (order Hymenoptera) use their ovipositors to insert eggs or small larvae into or onto a host.

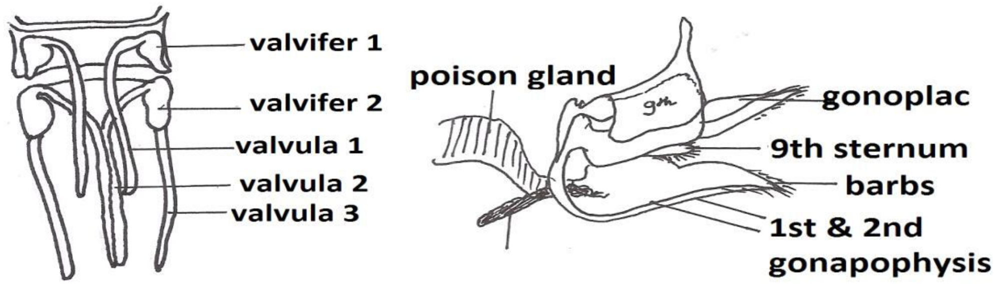
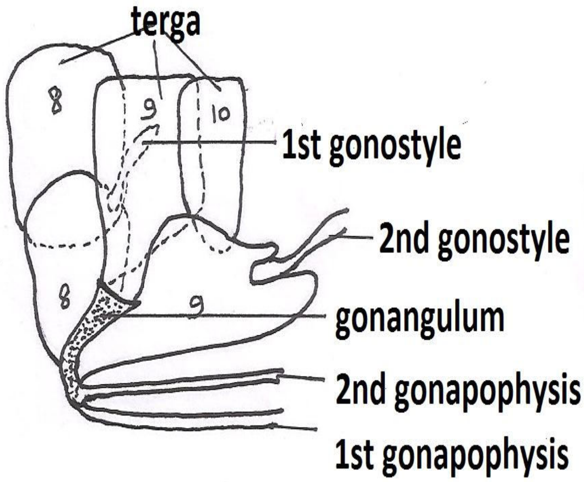
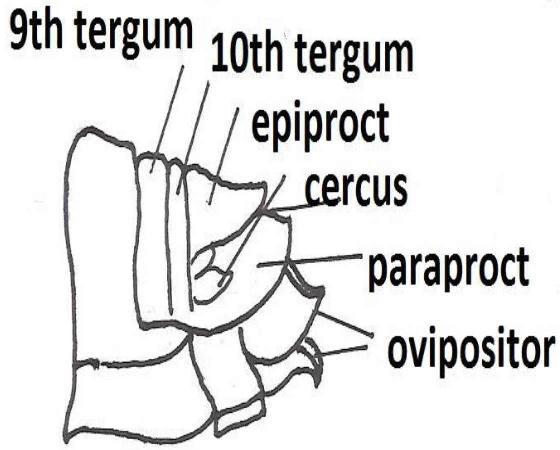


FIG 2.29: A) abdomen of female ovipositor B) sting of honey bee





A B

FIG 2.30: A) Structure of ovipositor (*Lepisma*) B) postgenital segments of female grasshopper

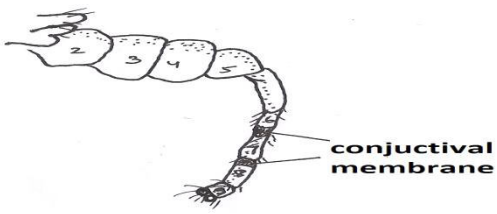


FIG 2.31: Abdomen of a female housefly note the extension of posterior segments egg laying its eggs.

2.5.3 Male external genitalia and modifications

In advanced pterygotes a pair of movable appendage/ plate at 9th segment called clasper/subgenital plate/ phallomere/ phallic lobe/ phallus/ gonapophysis. Phallic lobe has inner mesomere and outer paramere. Inner mesomere unite to form aedaegus, inner wall of aedaegus is in continuation with ejaculatory duct and inner passage called endophallus. The opening of endophallus is called phallotreme. Parameres develop into claspers i.e coxites and styles of 9th segment and sometimes made up of only styles. Paramere and mesomere mounted on basal plate phallobase. Endophallus and phallotreme combine to form penis. Penis lies in aedegus and contains male gonopore at apex. A pair of paramere and the pair of claspers help to grasp the female while mating (FIG 2.32,A,B,C).

In Thysanura male genitalia is simple phallus is having proximal phallobase and distal aedaegus. Coxite on 9th sternum prolonged into slender and fingerlike clasper. In primitive orders Ephemeroptera and earwigs the opening of each genital duct opens independently by two gonopores on paired penis.

In Orthoptera and Dictyoptera phallmere don't form aedaegus and both pairs are asymmetrical. Left parameres having titilator, pseudopenis and accutolobus while right paramere is having paired plates.

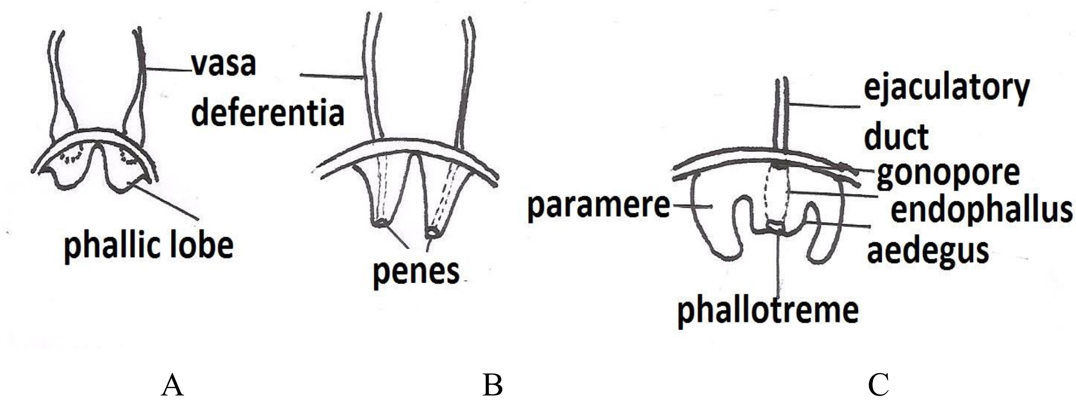


FIG 2.32: A) primary phallic lobes B) paired penes in Ephemeroptera C) formation of aedegus

2.6 Summary

All segments are closely seated to each another. Insects have three major tagmata as head, thorax and abdomen. Each division of insect body head, thorax and abdomen has definite sclerites, associated appendages and their modification. Head is made up of six fused segments with compound eyes, antenna, mouthparts and ocelli. Specific type of antenna (pilose, plumose, geniculate, clavate, clubbed, serrate, capitates, filiform, monoliform etc.) and mouth parts (biting and chewing, sponging, siphoning, piercing and sucking, rasping) in head region gives specific identification to insect. These segmentation forms basis of classification. Thorax bears two pairs of wings forewing and hindwing and three pairs of legs foreleg, midleg and hindleg in a generalized insect. A pair of legs which are also different in different insect to adapt their environment and functions as jumping, digging, swimming, clinging, reptorial and running. Generally the meso and metathorax have paired wings. Wings have wing venation like that of leaf and their modification appears in many insect. Abdomen largely meant for carrying vital organs and genitalia for reproduction. Abdomen of male and female is different showing ovipositor in females and aedeagus in male both parts may be visible externally in male and female respectively.

2.7 Glossary

- **Cibarium:** the portion between preoral cavity and labrum.
- **Ecdysial line**: There is an epicranial suture on head at anterior region. It is a line from where the integument splits and the grown and large sized insect comes out of its old body moult.
- **Entognathous:** eyes are absent and mouthparts can be retracted within head.
- **Hypognathous**: mouth parts directed downwards i.e perpendicular.
- **Opisthognathous**: deflection of facial region giving mouthparts a posterio-ventral position.
- **Pedicel**: second segment of antenna is pedicel**.**
- **Prognathous:** mouth parts are directed forward to head.
- **Salivarium**: the portion between preoral cavity and labium.
- **Sulcus/suture**: An adult head shows many inter-segmental lines which are simply the grooves that form internal ridges.
- T**agmosis**: The division of body into functional regions is known as tagmosis.
- **Tentorium**: The cranium is supported by two pairs of invaginations of the body wall that often unite to form the endoskeleton of head called as the tentorium.

2.8 Self learning Exercise

Section -A (Very Short Answer Type)

1. Last segmented part of antenna...............
2. Flabellate type of antenna is found in which group?
3. Name the insect having clinging type of legs?
4. Humeral vein connects which of the two veins?
5. Rasping- sucking mouthparts present in Thrips T/F?
6. Name the mouth parts of a housefly?
7. Name the longest part of leg?
8. Name the most primitive and generalized mouthparts in insects?

Section -B (Short Answer Type)

1. Define ovipositor and aedeagus?
2. Which of the segment of leg shows more modification?
3. Draw structure of a generalized leg?
4. Draw and define piercing and sucking type of mouth parts?
5. Explain two widely accepted theory of wing development?
6. Name different veins of a generalized wing?
7. What are the structures in a male and female genitalia?
8. How wing moves up and down?
9. What is elytra and hemielytra?

Section -C (Long Answer Type)

1. Explain different types of legs?
2. What is wing coupling and explain its types?
3. What are different types of mouth parts?
4. Draw and explain structure of the head and its sclerites?
5. Explain generalized structure of female external genitalia?
6. Write in brief different types of antenna?

Answer Key of Section-A

1. Flagellum
2. Strepsiptera male
3. Head louce, *Pediculus* spp.
4. Costa and subcosta
5. True

6. Sponging type of mouthparts
7. Tibia
8. Biting and chewing type

2.9 References

- Cedric Gillot: Entomolgy
- Kachhwaha N.: Principles of Entomology- Basic and Applied

Unit 3

Insect Anatomy and Physiology – I

Structure of the unit

3.1 Objectives

After reading this unit student will be able to:

- Describe the Scope and importance of insect anatomy and physiology.
- Describe muscular systems in insects.
- Describe the structure and function of digestive system.
- Know, describe and understand physiology of digestion.
- Understand the role of vitamins, proteins, amino acids, carbohydrates, lipids, minerals and other food constituents in insect nutrition.
- Describe extra and intra cellular micro organisms and their role in physiology

3.2 Introduction

All the muscles of insects are built on a similar plan with elongate cells housing the contractile elements and in many cases inserted into the integument at either end. The internal arrangement of the muscle cells however varies in different muscles and wing muscles often have characteristic forms. Shortening of the muscles involves the filaments of which they are composed sliding between each other. The muscles are stimulated to contract by the arrival of nerve impulses which cause local changes within the cell. Usually one nerve impulse causes one contraction but in specialised muscles which can oscillate at high frequency the muscles may contract several times as a result of a single nervous impulse. The speed with which these muscles oscillate depends on their mechanical properties and on the structures to which they are attached. The output of power by flight muscles may be very high and the associated metabolic rate is higher than in any other tissue. In order to maintain such a high level of metabolism the supply of oxygen and fuel must be adequate anatomically, physiologically and biochemically to ensure that this is the case.

An insect uses its digestive system to extract nutrients and other substances from the food it consumes. Most of this food is ingested in the form of macromolecules and other complex substances (such as proteins, polysaccharides, fats, and nucleic acids) which must be broken down by catabolic reactions into smaller molecules (i.e. amino acids, simple sugars, etc.) before being used by cells of the body for energy, growth, or reproduction. This break-down process is known as digestion.

Digestive system composed of alimentary canal and various glands related with it either directly (salivary glands, gastric caeca) or indirectly (malpighian tubules).

3.3 Scope and importance of insect anatomy and physiology

Entomology is a branch of zoology, which deals with the study of insect. The word entomology has two parts viz., Entomon = Insects and logos = study. Agril. Entomology deals with the study of insects in relation to agriculture.

Study of entomology aims at understanding insect body organization and function, their habitats, behaviours, relation to one another and to the surrounding in which they live, their classification, development distribution, post history and their economic importance.

Use of insects and insect products as items of medicinal value (oil beetles, use of lac, use of red ants in suturing wounds) have found a place in certain indigenous systems of treatments. Honey is used more as medicine than as a food. Parts of insects have been used as cheap jewellery by certain tribes.

As far as study of insect is concerned in agriculture it is of worth importance. Related to agriculture, insects are both useful and harmful. As a harmful role they damage our crops, lay waste vast areas of cultivated land, despoil on feed; they bring about different diseases and some of the examples are Malaria, plague, typhus, sleeping sickness etc. The serious disease malaria was earlier thought to be beyond the reach of mankind. A lot of money was just wasted in Malaria management but was of no use. When the entomologist studied the morphology and taxonomy of mosquitoes, they get interesting information on malaria transmitting mosquito, theAnopheles and the problem was solved just like anything. Another example is that of body louse spreading typhus fever in 1944 in Italy amongst the civilians living in crowded conditions. In 1939 Dr. Paul Muller discovered the insecticidal properties of DDT, which was then used in control of body louse. DDT become famous overnight as an insecticide and Muller saved thousands of soldiers from the deadly disease, typhus and not surprising, therefore that P. Muller was awarded the Nobel prize for Medicine in 1948. These are some insects, which are of international importance as a pest e.g. Locust. To show their devasting features some statistics related to them sufficient. A swarm of locust is estimated to contain more than 1500 million individuals. They fly with a speed of 150km/day. Even sunlight can not pass on earth when they are flying. They just eat everything which is green on earth. Army worms behaves like an army and destroy the crop within an overnight. This is about the harmful role played by insect.

Entomology as applied science has its own importance both in plant protection and getting benefit for mankind from the useful role played by insects. Scientific entomology is over a century old in India and a firm foundation of economic entomology has been laid by scientists like Lefroy, Fletcher, Ramkrishnan Ayyar and Ramchandra Rao in India. Till absent 1930, the subject was morphological all over the world. This study yielded considerable information on Taxonomy, insect pests and control. Towards the later period, applied entomology developed and a fundamental basis for pest study and methods of pest control including biological and legal control formed the major activity in this branch of science. Recognizing the usefulness of insect as an experimental animal Wigglesworth showed that physiology of insect is a fascinating field of study, and he established insect physiology as a separate discipline in 1930-38; in later period the same was extended into field of insect control also. In 1950-60 entomology emerged as a biological science encompassing morphology, ecology, physiology, phenology, pestology, biochemistry and ethiology (behaviour).

Scope: In their attempt to secure food insect inflict considerable damage to almost every part of the plant. The origin of insect dates back to about 350 million years ago. Of the estimated 1.35 million living species of animals more than 9,00,000 are insects. Their capacity for multiplication and wonderful adaptations has made them a serious threat to human being and his existence. They compete man for three basic needs i.e. Food, clothing and shelter. Among these food is common to both of them. Looking towards increasing population this vital item is now a days becoming scare and to secure this food man has to always think about insect as his first enemy. Due to this, entomology has its scope first in the area of plant protection. Research is continuously going on and newer insecticides are evolved as a result.

Still the problem is not solved. And hence man is taping new feeds in plant protection. As result of this new generation pesticides were born some of them are use of harmones, antihormone coupounds, chemosterilents, antifeedant, repellants, pheromones etc. which now a days replacing use of hazardous pesticides.

We are not yet able to identify most of the insects on earth where there may be chance of identifying a new pest. There is a scope for entomologist to identify more no of insects. Similarly scope is there for designing newer and cheaper methods of pest control because all the pesticides are toxic to human being causing several deaths every years. Also they are producing resistance in insect, where to control such a resistant progeny is a great challenge. To solve this problem upto certain extent a new technique adopted is IPM. (i.e. Integrated pest management) but still IPM for all the crops is not available here also a vast scope is there. New field called genetic engineering is coming up where one can develop pest resistant (immune) crop variety which will solve all further problems arising as a by product of pesticide use. Such work is in progress all over the world. (e.g Bt rice, transgenic cotton etc.)

On the other hand we haven't yet able to exploit the fullest utilization of useful role of insect in agriculture. As seen earlier insect benefit to us in several ways one of it is their valuable products. Still in India the silk industry is not growing as it is growing in other countries like Japan and France this is because of lack of knowledge, excluding Karnataka other states should come up in production of silk which has a great potential in earning foreign exchange. Similarly bee keeping it yields honey and wax which are very important commodities, other then that pollution by bees is an additional advantage and farmers should take help of these pollinators to uplift their yields.

Entomology can generate employment up to certain extent e.g. production of parasites/ predators, diseases causing agents. This job one can do by taking short training and can earn money as well as can help the farmer in adoption cheap and non polluted plant protection.

For increasing population we will be in short of food material and to secure it we have to do a lot of labour in this field . Where still a lot of scope is there.

The **morphology** of **insects** is the study and description of the form and structure of insects. Terminology is related to that of the morphology of other arthropods. There is a large variation in the modifications that have been made by various taxa to the basic insect body structure. This is a result of the high rate of speciation, short generations, and long lineages of the class of insects. These modifications allow insects to occupy almost every ecological niche, use a staggering variety of food sources, and possess diverse lifestyles. This article describes the basic insect body and some of the major variations that it can take; in the process it defines many of the technical terms used to describe insect bodies.

Insect physiology includes the physiology and biochemistry of insect organ systems.[1]

Although diverse, insects are quite indifferent in overall design, internally and externally. The insect is made up of three main body regions (tagmata), the head, thorax and abdomen. The head comprises six fused segments with compound eyes, ocelli, antennae and mouthparts, which differ according to the insect's particular diet, e.g. grinding, sucking, lapping and chewing. The thorax is made up of three segments: the pro, meso and meta thorax, each supporting a pair of legs which may also differ, depending on function, e.g. jumping, digging, swimming and running. Usually the middle and the last segment of the thorax have paired wings. The abdomen generally comprises eleven segments and contains the digestive and reproductive organs.[2] A general overview of the internal structure and physiology of the insect is presented, including digestive, circulatory, respiratory, muscular, endocrine and nervous systems, as well as sensory organs, temperature control, flight and molting.

3.4 Muscular system

Basic muscle structure

Each muscle is made up of a number of fibres, which are long, usually multinucleate, cells running the whole length of the muscle. Each fibre is bounded by the sarcolemma, which comprises the plasma membrane of the cell plus the basement membrane. The cytoplasm of the fibre is called sarcoplasm and the endoplasmic reticulum which is not connected to the plasma membrane is known as the sarcoplasmic reticulum. The plasma membrane is deeply invaginated into the fibre, often as regular canals between the Z and the H bands, this system of invagination is called the transverse tubular or T system. It is associated with vesicles of the sarcoplasmic reticulum. When the two systems are very close the space between their membranes is occupied by electron dense material and the arrangement is called a dyad. In Philosamia (Lepidoptera) the T system is extensive and about 70% of the muscles plasma membrane is within the system. This may be a common phenomenon. The nuclei occur in different positions in the cell in different types of muscle.

The characteristic feature of muscle cells is the presence of myofibrils embedded in the sarcoplasm and extending continuously from one end of the fibre to the other. The arrangement of the fibrils varies but they are always in close contact with the mitochondria which are sometimes known as sarcosomes.

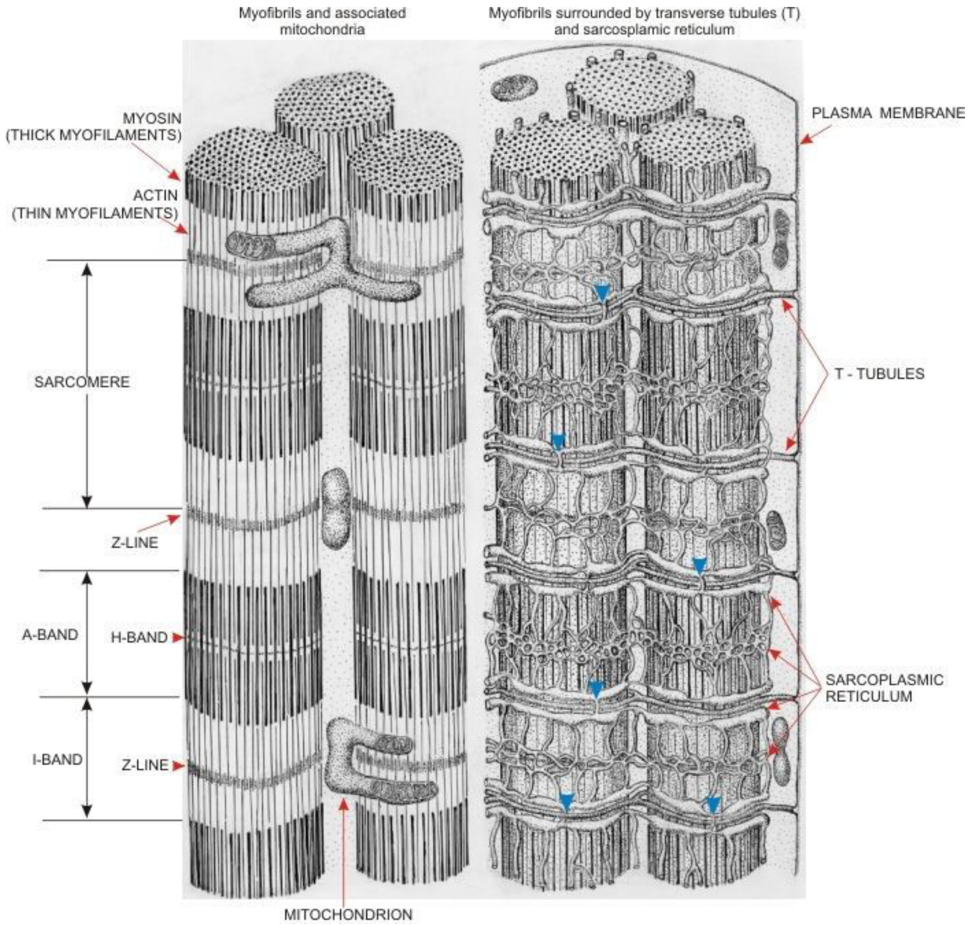


Fig. Diagram of a lateral view of part of a muscle fibre showing the arrangement of the major constituents.

The fibrils in their turn are composed of molecular filaments consisting mainly of two proteins: myosin and actin. The myosin filaments are stouter and are made up of numerous myosin molecules. These are elongate structures with two globular heads at one end and in each sarcomere all the molecules in one half are aligned in one direction while all those in the opposite half are aligned in the opposite direction. The myosin molecules are probably arranged round a core of another protein, paramyosin, with their heads arranged in a helix. The thick filaments are each surrounded by a number of thin actin filaments which consist of two chains of actin molecules twisted round each other. The actin filaments are orientated in opposite directions on the two sides of a Z line. At this line actin filaments are joined together overlapping each other and held by an amorphous material. All the filaments in a fibre are aligned with each other so that the joints between the ends of the actin filaments form a distinct line known as the Z line running across the whole fibre. The unit of the muscle between two Z lines is called a sarcomere. On either side of each Z line actin filaments extend towards but do not reach the centre of the sarcomere. The myosin filaments do not normally reach the Z lines although there is some controversy concerning the presence of a connection with the Z lines in fibrillar muscle. Hence each sarcomere has a lightly staining band at each end and a darkly staining band in the middle known respectively as the isotropic (I) and anisotropic (A) bands. In the centre of the A band where actin filament are absent is the rather paler H zone. Other bands may also be present and changes occur when the muscle contracts.

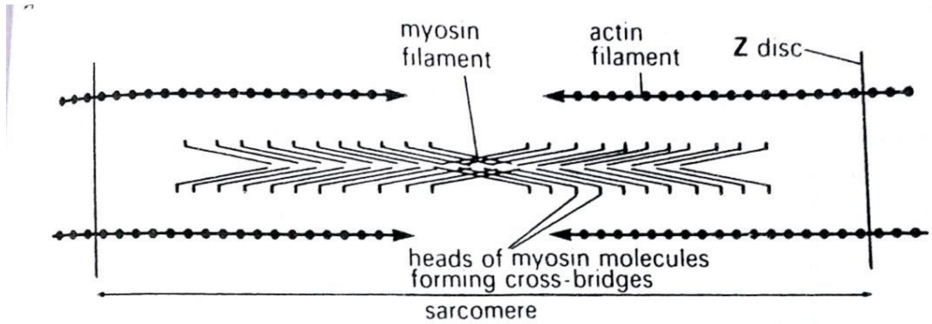


Fig. Diagrammatic representation of the orientations of the actin and myosin molecules and filaments in a muscle.

The actin and myosin filaments are linked at intervals by cross bridges formed from the heads of the myosin molecules which carry an ATPase. These cross bridges provide structural and mechanical continuity along the whole length of the muscle fibre. Further proteins, tropomyosin and troponin A and B are also present in small quantities in the contractile elements. Troponin A acts as a receptor for Ca^{++} ions.

The muscle fibres are collected into units of 10-20 fibres separated from neighbouring units by a tracheolated membrane. Each muscle consists of one or a few such units and for instance there are five in the dorsal longitudinal flight muscles of Schistocerca. Each muscle unit may have its own nerve supply independent of all the others and in this case it is the basic contracting unit of the muscle but in other cases several muscle units may have a common innervations and so function together as the motor unit.

Innervations

The nervous supply to a muscle consists of a small number of large axons. Basically each unit is innervated by a fast axon and a slow axon and sometimes also by an inhibitory axon. Such multiple innervations is called polyneuronal. Within the unit each muscle fibre receives endings from the fast axon and some may also be innervated by the slow axon. In the jumping muscle of the locust about 40% of the fibres receive branches from both axons but in the flight muscles of Odonata, Orthoptera, Diptera and Hymenoptera only fast axon are present.

Characteristically in insects there are many nerve endings spaced at intervals of 30- 80 μm along each other. Where a fibres has a double innervations it is probable that both axons have endings in the same terminals.

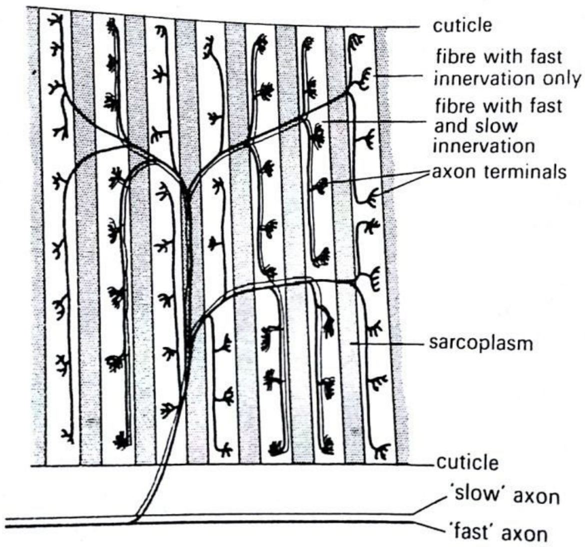


Fig. Diagram illustrating the innervations of a typical muscle unit. All the fibres receive branches of the fast axon, while some also have endings from the slow axon.

Oxygen supply

Since muscular contraction requires metabolic energy the muscles have a good tracheal supply and this is particularly true of the flight muscles, where often the respiratory system is specialised to maintain the supply of oxygen to the muscles during flight. In most muscles the tracheoles are in close contact with the outside of the muscle fibre. This provides an adequate supply of oxygen to relatively small muscles or those whose oxygen demands are not high, but in the flight muscles of many insects the tracheoles indent the muscle membrane becoming functionally, but not anatomically, intracellular within the muscle fibre.

Muscle insertion

Skeletal muscles are fixed at either end to the integument, spanning a joint in the skeleton so that concentration of the muscle moves one part of the skeleton relative to the other. Typically such muscles are said to have an origin in a fixed or more proximal part of the skeleton and an insertion into a distal, movable part, but these terms become purely relative in the case of muscles with a dual function. In many cases muscles are attached to invaginations of the cuticle called apodemes.

At the point of attachment of the muscle fibre to the epidermis the plasma membranes interdigitate and are held together by desmosomes. Within the epidermal cell, microtubules run from the desmosomes to hemidesmosomes on the outer plasma membrane and from each hemidesmosome a dense attachment fibre passes to the epicuticle through a pore canal. In earlier studies the microtubules and attachment fibres were not separated and were called tonofibrillae. Only actin filaments reach the terminal plasma membrane of the muscle fibre inserting into the dense material of desmosomes or hemidesmosomes.

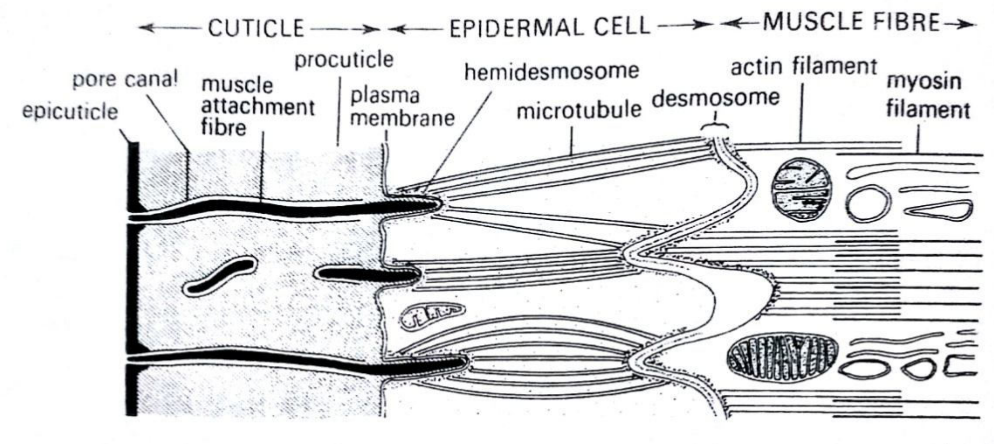


Fig. Diagrammatic representation of the attachment of a muscle fibre to the integument

The muscle attachment fibres are not digested by moulting fluid and so during moulting they retain their attachment to the old cuticle across the exuvial space between the new and old cuticles. As a result, the insect is able to continue its activities after apolysis during the development of the new cuticle. The connections to the old cuticle are broken at about the time of ecdysis.

Muscle attachment fibres which extend to the epicuticle can only be produced at a moult and most muscles appear to form their attachments at this time. Muscle attachment can occur later on however if cuticle production continues in the postecdysial period but in this case the attachment fibres are only connected to the newly formed procuticle and do not reach the epicuticle.

Variations in structure

The structure of muscles varies in different parts of the body. Two broad categories can be distinguished:

Skeletal muscles, which are attached at either end to the cuticle and move one part of the skeleton relative to another. It can be differentiated functionally into synchronous and asynchronous or fibrillar muscles. Fibrillar muscle fibres only occur in the flight muscles of Thysanoptera, Psocoptera, Homoptera, Heteroptera, Hymenoptera, Coleoptera and Diptera and in the tymbal muscles of Cicadidae. All other muscles are synchronous muscles that is they exhibit a direct relationship between contraction and motorneurone activity.

Visceral muscles, which move the viscera and have only one or more commonly, no attachment to the body wall.

Control of muscular contraction

Excitation of the muscle

With the exception of some visceral muscles, muscles are stimulated to contract by the arrival of a nerve impulse at the nerve/ muscle junctions. Where the junction involves excitation of a skeletal muscle it is almost certain the L-glutamate is the chemical transmitter across the synaptic gap and this may also be true with visceral muscle (Miller, 1975). Some spontaneous discharge of transmitter substance into the synaptic gap normally occurs, but the rate of release of the vesicle is greatly enhanced by the arrival of the nerve impulse (Usherwood, 1974).

As in a nerve, there is a difference in electrical potential across the muscle membrane so that it has a resting potential of 30-70 mV, the inside being negative with respect to the outside. Since the magnitude of the potential is not always what would be expected from the ionic concentrations in the muscle and the surrounding haemolymph, it is possible that the fluid in the tubules of the T-system, rather than the haemolymph in general, determines the size of the potential and that its composition differs from that of the haemolymph. The arrival of the excitatory transmitter substance at the postsynaptic membrane on the muscle surface causes a change in permeability leading to an influx of sodium ions and a rise (that is a depolarisation) in the muscle membrane potential. Subsequently an increase in the permeability to potassium ions leads to their movement out from the muscle and so the potential falls to its original level. The short lived increase in potential produced by these changes in the relative permeability to sodium and potassium detrermine its size. The postsynaptic potential spreads from the synapse but decreases rapidly, its effect is therefore localised and in order to stimulate the whole fibre a large number of nerve endings are necessary.

It is probable that the invaginations of the T- system convey the changes in potential deep into the muscle and close to the fibrils. This is important since activation of the fibrils involves chemical transmission within the fibres and the diffusion of a chemical from the surface membrane to the central fibrils would involve a considerable delay in contraction. The T- system greatly reduces this delay by bringing the plasma membrane to within a few microns of each fibrils.

Activation of the muscle fibre

Activation of the contractile mechanism involves the release of calcium from the sarcoplasmic reticulum and it is presumed that this occurs where the T-system and sarcoplasmic reticulum form dyads. The calcium binds to both the actin and the myosin filaments and its effect is to activate an ATPase in the myofilaments. In the resting muscle this activity is inhibited by a protein, called troponin B, in the actin filament, but in the presence of Ca++ ions the inhibition is removed, other proteins, troponin A and tropomyosin, are also involved in this process.

The effect of the ATPase is to break down ATP to ADP with the release of energy which is used in muscle contraction. It is believed that the actin and myosin filaments first become linked together by the cross bridges and that movement of these links with subsequent breaking and recombination causes the actin filaments to slide further between the myosin filaments so that the sarcomere and hence the muscle, shortens. Relaxation of the muscle possibly involves the sequestration of calcium ions so that ATPase activity is suppressed. Each cycle of contraction and relaxation of the muscle is associated with calcium release and sequestration.

In fibrillar muscle the picture is rather different. The muscles start to contract in response to a burst of motor nerve impulse, which presumably results in the release of Ca++ ions from the sarcoplasmic reticulum. However, subsequent muscle oscillations are not related directly to nervous stimulation and occur at a constant concentration of calcium within the fibre. After the initial activation, the muscle is maintained in an active state by rapid changes in length and tension which result from the mechanical properties of the muscle itself and the resonant characteristics of the thorax.

Changes in muscles banding during shortening

As a result of the sliding of the filaments during muscle contraction the I bands shorten and may disappear as the myosin approaches the Z- lines. Hence the length of the I band in relaxed muscle is roughly proportional to the degree of shortening which the sarcomere can undergo. Some muscles may shorten by as much as 50% of their length, while flight muscles may shorten by as little as 1%.

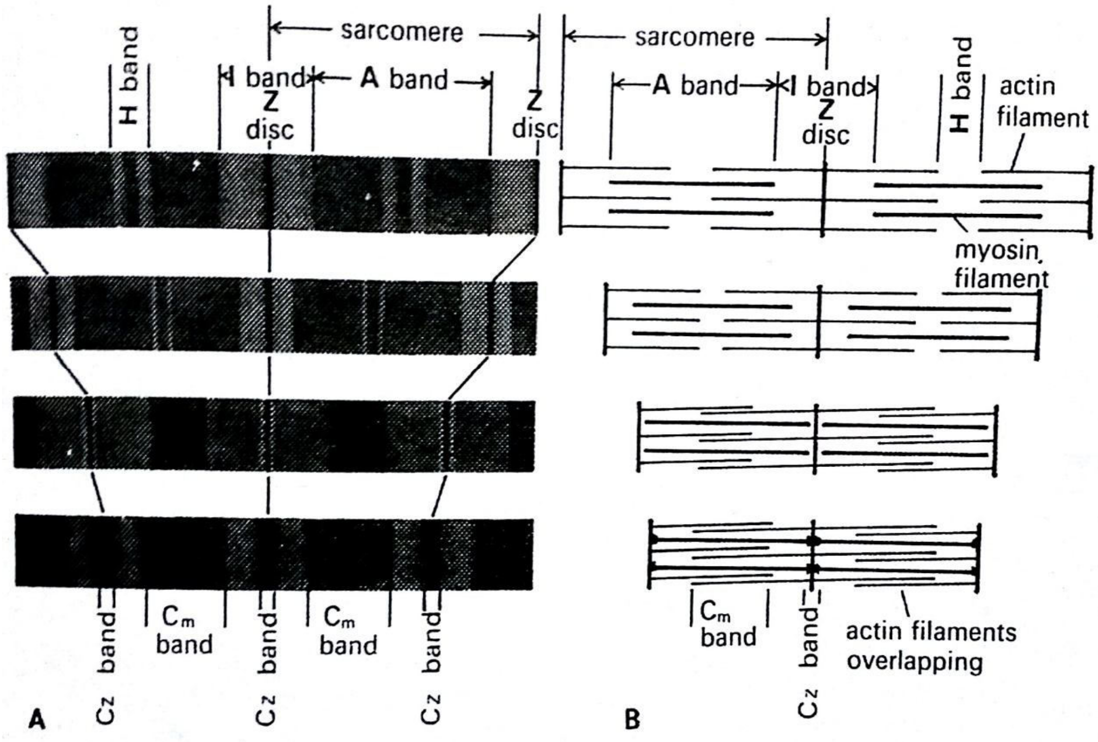


Fig. (A) The appearance of a muscle fibre in various states of contraction. (B) Diagrams showing the presumed arrangement of the muscle filaments in positions corresponding to (A)

As the I band is obliterated by the myosin filaments the H band also disappears as the ends of the actin filaments approach each other. Ultimately the actin filaments from the two ends of a sarcomere may come to overlap each other so that another dark band, C_m forms. Extreme contractions may cause crumpling of the myosin filaments at the Z- line so that a dark band, C_z is formed.

Some visceral muscles have the capacity of supercontraction the sarcomeres shortening by more than half their length. In these muscle the myosin filaments pass through pores in the Z- line so that they project into the adjacent sarcomeres. This may be made possible by the cross bridges on a myosin filament linking with the actin filaments of the next sarcomere as it passes through the Z- line pores.

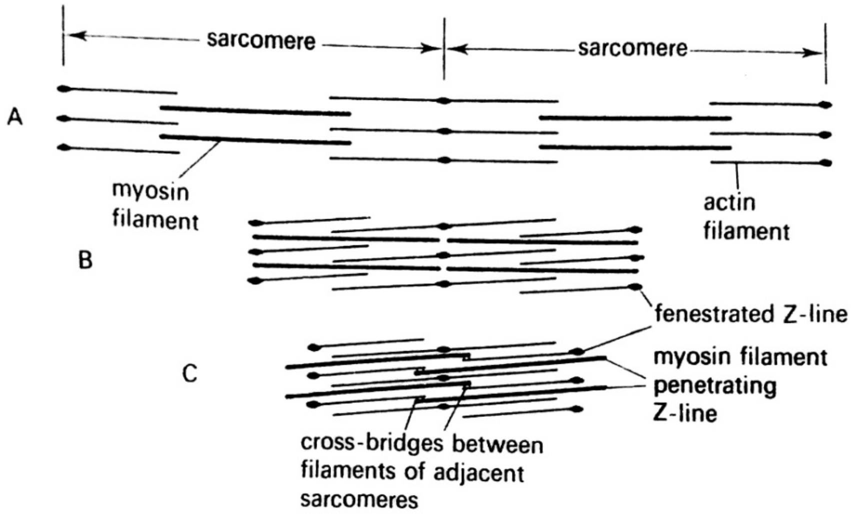


Fig. Diagrammatic representation of the probable mechanism of supercontraction in a visceral muscle. (A) Fully relaxed muscle, (B) Partially contracted, (C) Supercontracted.

Inhibition of muscle contraction

In addition to the normal excitatory innervations, some fibres of some muscles have an inhibitory nerve supply. Inhibitory axons are known to run to some leg muscles in locusts and cockroach.

At an inhibitory nerve/ muscle junction a neural transmitter, probably γ- amino butyric acid (GABA) is released and causes a change in permeability at the postsynaptic membrane but unlike the process occurring at an excitatory synapse, this results in an influx of chloride ions. As a result the membrane potential becomes even more negative the membrane is hyperpolarised and the tension exerted by the fibre decreases.

Control of visceral muscles

In visceral muscles which are innervated the principles of muscle control are the same as in skeletal muscle. L- glutamate may be involved as a neurotransmitter, but it is conceivable that different transmitters are involved in different muscles. Axons containing neurosecretory material are known to be associated with various visceral muscles in a number of insects and it is possible that these muscles are controlled via the neurosecretory system.

There is no clear picture of how the activity of muscles which have no innervations is controlled.

3.5 Digestive system: Alimentary canal and modification

One of the major reasons for the biological success of insects is their ability to eat, digest and utilise an enormous diversity of foods. This ability allows the extreme diversity observed in the modification and specialisations of the alimentary system of insects. The structural and biochemical modifications of the alimentary system of a particular species depend upon the type of food eaten. There are structural and functional differences in the way foods are obtained, stored, processed and absorbed between the sexes, e.g. caterpillars chew up plant material, whereas adults suck up only floral nectar and female mosquitoes suck up a vertebrate blood, whereas males suck up plant sap.

Alimentary canal

The insect's digestive system is a closed system, with one long enclosed coiled tube called the alimentary canal which runs lengthwise through the body. The alimentary canal only allows food to enter the mouth, and then gets processed as it travels toward the anus. The insects alimentary canal has specific sections for grinding and food storage,enzyme production and nutrient absorption. Sphincters control the food and fluid movement between three regions. The three regions include the foregut (stomatodeum), the midgut (mesenteron), and the hindgut (proctodeum).

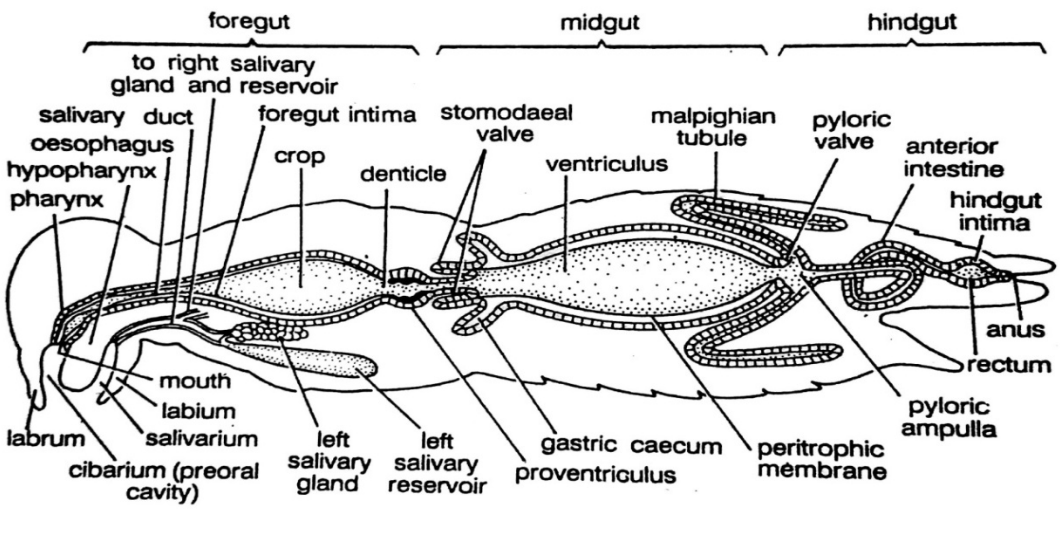


Fig. Alimentary canal of a generalized insect

In addition to the alimentary canal, insects also have paired salivary glands and salivary reservoirs. These structures usually reside in the thorax (adjacent to the fore-gut). The salivary glands produce saliva, the salivary ducts lead from the glands to the reservoirs and then forward through the head to an opening called the salivarium behind the hypopharynx; which movements of the mouthparts help mix saliva with food in the buccal cavity. Saliva mixes with food which travels through salivary tubes into the mouth, beginning the process of breaking it down.

The stomatedeum and proctodeum are invaginations of the ectoderm and are lined with chitinous intima, which is continuous with the cuticle of the integument and therefore at the moult both foregut and hindgut and their contents are shed. The mesenteron is derived from endoderm and not lined with cuticle but with rapidly dividing and therefore constantly replaced, epithelial cells. The cuticle sheds with every moult along with the exoskeleton. Food is moved down the gut by muscular contractions called peristalsis.

Foregut or stomodeum

An insect's mouth, located centrally at the base of the mouthparts, is a muscular valve (sphincter) that marks the "front" of the foregut. Food in the buccal cavity is sucked through the mouth opening and into the pharynx by contractile action of cibarial muscles. These muscles, located between the head capsule and the anterior wall of the pharynx, create suction by enlarging the volume of the pharynx (like opening a bellows). This "suction pump" mechanism is called the cibarial pump. It is especially well developed in insects with piercing/sucking mouthparts.

From the pharynx, food passes into the oesophagus by means of peristalsis (rhythmic muscular contractions of the gut wall). The oesophagus is just a simple tube that connects the pharynx to the crop, a food storage organ. Food remains in the crop until it can be processed through the remaining sections of the alimentary canal. While in the crop, some digestion may occur as a result of salivary enzymes that were added in the buccal cavity and/or other enzymes regurgitated from the midgut.

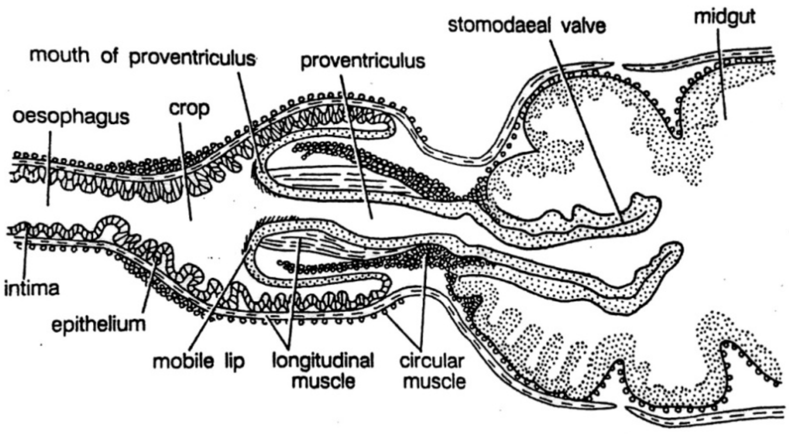


Fig. Longitudinal section of the proventriculus of honey bee

In some insects, the crop opens posteriorly into a muscular proventriculus or gizzard. It is absent in fluid feeder but is well developed in orthopteroid insects (e.g. cockroach). This organ contains tooth like denticles that grind and pulverize food particles. The proventriculus, regulates the flow of food from the stomodeum to the mesenteron. The hard denticles inside the proventriculus are made from the intima.

Midgut or mesentron or ventriculus

The midgut begins just past the stomodeal valve. Near its anterior end, finger-like projections (usually from 2 to 10) diverge from the walls of the midgut. These structures, the gastric caecae, provide extra surface area for secretion of enzymes or absorption of water (and other substances) from the alimentary canal. The rest of the midgut is called the ventriculus -- it is the primary site for enzymatic digestion of food and absorption of nutrients. Digestive cells lining the walls of the ventriculus have microscopic projections (microvilli) that increase surface area for nutrient absorption.

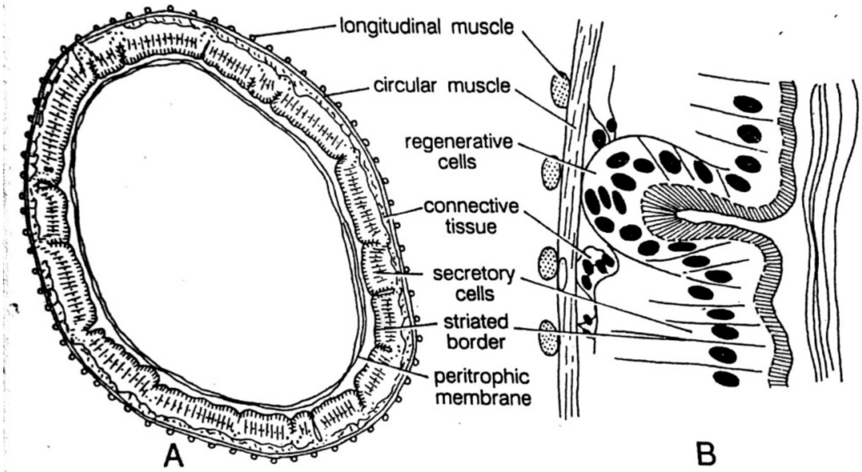


Fig. (A) Transverse section of midgut. (B) A section of midgut highly magnified.

The midgut epithelium of most insects is composed of three basic cell types: columnar digestive cells with microvilli forming a striated border regenerative cells and endocrine cells. The basal plasma membrane of digestive cells is characteristically infolded, and mitochondria are associated with these folds. These cells are involved in the synthesis of digestive enzymes and absorption of digestive food. At the bases of the midgut epithelial cells are small regenerative cells or replacement cells. These cells replace the actively functioning gut cells that die or that degenerate as a result of holocrine secretion.

The midgut is derived from embryonic endoderm so it is not protected by an intima. Instead, the midgut is lined with a semippermeable membrane secreted by a cluster of cells (the cardial epithelium) that lie just behind the stomodeal valve. This peritrophic membrane consists of chitin fibrils embedded in a protein carbohydrate matrix. It protects the delicate digestive cells without inhibiting absorption of nutrient molecules. The bugs, which are fluid feeders lack a peritrophic membrane.

The posterior end of the midgut is marked by another sphincter muscle, the puloric valve. It regulates the flow of material from the mesenteron to the proctodeum.

The plant bugs in order to obtain adequate quantity of nutrients ingest large amount of sap. In them, the gut is modified to provide the rapid elimination of the excess of water taken in to avoid excessive dilution of the haemolymph and to concentrate the food to facilitate enzyme activity. In leaf hoppers and aphids, the rapid removal of water to the rectum is achieved by the anterior midgut forming a large thin walled bladder which is closely bound to anterior hindgut and malphighian tubules by its own basement membrane. The chamber formed within this fold is called the filter chamber. Water passes directly from the hindgut along an osmotic gradient and there may be no significant flow of fluid through the lumen of the gut.

Hindgut or proctodeum

The hindgut is composed of cuboidal epithelial cells and is lined by a layer of cuticle which is thinner and more permeable than that of the foregut. The pyloric valve serves as a point of origin for dozens to hundreds of malpighian tubules. These long, spaghetti like structures extend throughout most of the abdominal cavity where they serve as excretory organs, removing nitrogenous wastes (principally ammonium ions, NH_4^+) from the haemolymph. The toxic NH_4^+ is quickly converted to urea and then to uric acid by a series of chemical reactions within the malpighian tubules. The uric acid, a semi solid accumulates inside each tubule and is eventually emptied into the hindgut for elimination as part of the faecal pellet.

The hindgut is divided into three sections; the anterior is the ileum, the middle portion, the colon, and the wider, posterior section is the rectum. This extends from the pyloric valve which is located between the mid and the hindgut to the anus. The rectum usually contains a number of pads or papillae (usually six) that project into the lumen. These structures receive an extensive supply of tracheae and are metabolically very active. They play an especially important role in the excretory system.

Functions of the hindgut include the following:

i. Water absorption from urine and faeces,
ii. Ion absorption from urine and faeces,
iii. Cryptonephridial system for water conservation,
iv. Modifications in structure for housing symbiotic microorganisms (e.g., termites).

Salivary glands

Although there may be glands associated with the mandibles (e.g.silver fishes, queen honey bee), maxillae (e.g. proturans, spring tails), and hypopharynx (e.g. worker honey bee), salivary glands are typically associated with the labial segment. The salivary glands or labial glands are paired structure lie ventral to the foregut in the head and thorax and occasionally extend posteriorly into the abdomen. Depending on the type of food eaten and the insect species involved salivary glands vary in size, shape and the type of secretion produced.

Two basic types of salivary glands exist:

a) Acinar (e.g. Orthoptera and Dictyoptera)

b) Tubular (e.g. Diptera, Lepidoptera and Hymenoptera)

In the acinar type each acinus bears a tiny duct that communicates with other similar ducts, eventually forming a lateral salivary duct. Lateral salivary ducts run anteriorly and merge as the common salivary duct, which empties between the base of the hypopharynx and the base of the labium. This region is called the salivarium and in some sucking insects forms a salivary syringe that injects saliva into whatever is being pierced. The lateral salivary ducts may communicate with salivary reservoirs, as in the cockroaches.

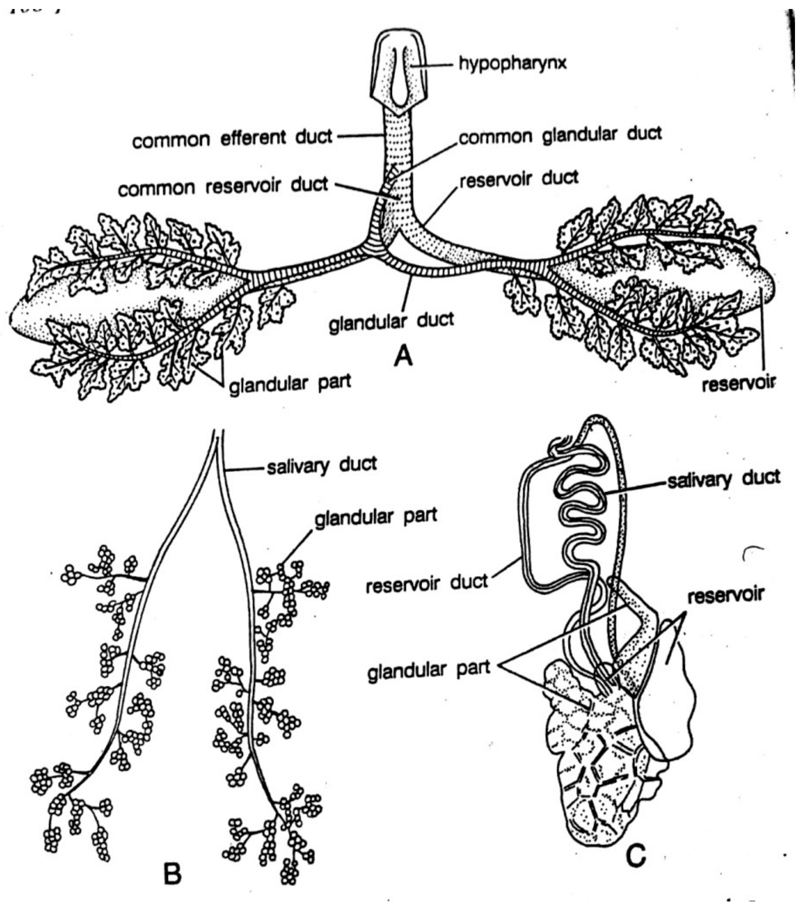


Fig. (A) Salivary glands of cockroach, (B) grasshopper and (C) red cotton bug.

Functions of salivary gland:

The secretory products of the salivary glands are generally clear fluids that serve a variety of functions in different insects:

1. They moisten the mouthparts and serve as a lubricant
2. They act as a food solvent
3. They serve as a medium for digestive enzymes and various anticoagulins and agglutinins
4. They secrete silk in larval Lepidoptera (caterpillars) and Hymenoptera (bees, wasps and relatives)
5. They are used to flue puparial cases to the substrate in certain flies
6. They serve for the production of toxins and
7. They secret antimicrobial factors (e.g. in certain blow fly larvae).

Amylase and invertase are the most common enzymes found in saliva of insects however the saliva may also contain lipase and protease. Aphids secrete a pectinase that aids their mouthparts in the penetration of plant tissues. The spreading factor hyaluronidase which attacks a constituent of the intercellular matrix of many animals has been found in the assassin bug.

Blood sucking (haematophagous) insects contain various antihaemostatic agents.

Production and secretion of saliva in the dragonflies, grasshoppers and cockroaches are regulated by nervous innervations from both the stomatogastric nervous system and the subesophageal ganglion whereas in the Diptera (e.g. the adult blow fly) these glands are controlled by an unidentified neurohormone. Salivation has been shown to be controlled by phagostimulation of external chemoreceptors on the mouthparts. This same stimulus probably also activates the salivary pump.

3.6 Physiology of digestion, including special foods

In fluid feeders, digestion may begin before the food is ingested through the injection or regurgitation of enzymes on to the food, or in foregut but in general most digestion occurs in the midgut where most of the enzymes are produced. In insects having biting and chewing type of mouthparts, food is masticated not only in the buccal cavity but also in the proventriculus. This not only facilitates passage through the alimentary canal but increases the surface area for enzymatic action. Digestion takes place by a series of progressive enzymatically catalysed steps, each producing a simpler substance until molecules of absorbable size or nature are produced.

Extra intestinal digestion

Digestion of the food taking place outside the alimentary canal before the food is ingested is known as extra intestinal digestion. It happens with fluid feeders where salivary enzymes are injected onto the food (e.g., house fly) or into the host in predatory or parasitic insects for example, assassin bugs inject saliva into the prey which histolyses the contents before ingestion.

Intestinal digestion

In general most of the digestion occurs in the midgut where enzymes are secreted however, some digestion also takes place in foregut, particularly in crop, where midgut enzymes are regurgitated into it. In locust, the major proportions of digestion takes place in crop.

The enzymes synthesized in the midgut depend upon the diet. For example, insects feeding protein diet proteases are important, whereas a nectar feeding butterflies they are absent. Aphids feeding on phloem sap having no polysaccharides or proteins lack enzymes and proteinase but have invertase.

Digestion of carbohydrates

Carbohydrates are generally absorbed as monosaccharides so that, before they are absorbed, disaccharides and polysaccharides must be hydrolysed to their component monosaccharides.

Polysaccharides: Starch, glycogen, chitin and cellulose are the major polysaccharide food to be digested by different insects. Starch (amylose) is hydrolysed to maltose, and glycogen to glucose by the action of amylase, which specifically catalyses the hydrolysis of 1,4-α-glucosidic linkage in polysaccharides. The major portion of the food of phytophagous and xylophagous insects contains cellulose, only few insects (Ctenolepisma, Schistocerca and some psocids) are able to secrete cellulase. The insects unable to secrete cellulose, either cellulose is excreted as such or they harbour micro-organisms (bacteria, flagellates) to secrete cellulase.

Other polysaccharides, viz., chitihn, lignocelluloses and hemicelluloses are digested by chitinase, lignocellulase and hemicellulase, respectively.

Disaccharides: The common disaccharides in the food are maltose, trehalose, sucrose, cellobiose, melibiose and lactose that contain a glucose residue which is linked to a second sugar residue by either α-linkage and β-linkage. In the hydrolysis water molecule is the typical acceptor for the sugar residues as follows :

$$\text{Maltose} + H_2O \xrightarrow{\text{maltase}} \text{Glucose} + \text{Glucose}$$

Trehalose + H_2O $\xrightarrow{\text{trehalose}}$ Glucos e + Glucose

Sucrose + H_2O $\xrightarrow{\text{sucrase}}$ Glucose + Fructose

Cellobiose + H_2O $\xrightarrow{\text{cellobiase}}$ Glucose + Glucose

Melibiose + H_2O $\xrightarrow{\text{melobiase}}$ Galactose + Glucose

Lactose + H_2O $\xrightarrow{\text{lactase}}$ Glactose + Glucose

Digestion of proteins: Insects possess a series of proteases. A trypsin like proteinase is secreted in the midgut which hydrolyses protein to peptones and polypeptides. The products are then broken down by peptidases. The carboxypolypeptidase attacks peptide chain from the –COOH end and aminopolypeptidase attacks the chain from the $-NH_2$ end. Some of these occur in the gut lumen, but most of them are found in the intestinal epithelium. It indicates that most of the polypeptides are absorbed before being further digested to amino acids. Certain insects are able to digest ordinarily stable proteins. For example, chewing lice and a few other insects are able to break down keratin a protein that occurs in hair and feathers.

Digestion of lipids: Many insects secrete lipases which hydrolyse fats to fatty acids and glycerol. Wax moth (*Galleria*) is able to digest beeswax (a mixture of esters, fatty acids and hydrocarbons). The insect is known to produce not only the lipase, but also lecithinase and cholinesterase with the help of bacteria.

Midgut pH (typically pH 6-8) buffering capacity, oxidation reduction potential and temperature are important factors in the digestive process. These factors vary from species to species and may also vary from one region of the another within the same insect.

Absorption of the digested food

The midgut is the major site of absorption. In hindgut only reabsorption of urine components occur while in foregut no absorption takes place. All the substances are absorbed in solution and no phagocytosis of food particles occurs. There are three major factors that affect the absorption of digested food materials:

I. The presence of microvilli, which increase the surface area for absorption,
II. The functional differences in membrane permeability of various regions of the digestive tract and
III. The presence of a counter current.

Absorption may be active or passive. Passive absorption takes place from the higher concentration inside the lumen of the gut to lower one (inside the gut epithelium). Active absorption depends on some metabolic process for movement of a substance against a concentration or electrical gradient.

Carbohydrate: Carbohydrates are mainly absorbed as monosaccharides that diffuse concentration gradients between the midgut lumen and haemolymph. The diffusion of simple sugars like glucose and fructose is enhanced by the rapid conversion of these sugars to trehalose in the fat body a process called facilitated diffusion that maintains a concentration gradient across the gut epithelium. Some insects are able to absorb disaccharides as such.

Proteins: Proteins are absorbed as amino acids after hydrolysis mainly in the midgut and caeca. Some amino acids in urine are also reabsorbed in hindgut. Insects are unique in that they maintain rather high levels of free amino acids stores in the haemolumph, thus many amino acids have to be actively absorbed against a concentration gradient. Some insects are able to absorb peptide fragments or even the protein as such e.g., midgut cells of a haemolymph bug *Rhodnius* absorb haemoglobin as such. Active absorption of amino acids varies among insect species and depends on the composition of the diet and the haemolymph.

Lipids: Like some disaccharides and proteins, lipids are also sometimes absorbed unchanged. The products of wax are absorbed in a phosphorylated form while cholesterol is esterised before absorption. The midgut caeca appear to be particularly active in lipid absorption, but in few insects like adult Hymenoptera, lipid is absorbed in hindgut.

Water: Water is absorbed mainly in midgut and also in hindgut either by diffusion or active transport depending upon the need of the insect as insects regulate the salt water balance very precisely. As the amount of food is very poor in the contents of phloem and xylem, insects feeding on them, e.g., plant bugs, in order to obtain sufficient amount of amino acids and other nutrients, they possess various mechanisms for concentrating the necessary nutrients from a dilute food source by eliminating water. The filter chamber, present in the Cicadoidea and Cercopidae (order Homoptera) is a modification of the anterior midgut, which in combination with the malpighian tubules facilitates water removal and concentration of the desired nutrients prior to absorption.

Inorganic ions: Inorganic ions are absorbed in the midgut and reabsorbed in the fluid in the rectum. Even in the midgut there are specified cells that absorb particular ions, e.g., Fe^{++} and Cu^{++} . All the three ions Na^+, K^+ and Cl^- are absorbed actively as their concentrations is very high in haemolymph than the gut lumen.

The active transport of Na^+ may play a key role in the diffusion of other molecules. When Na^+ molecules are pumped from the midgut cells into the haemocoel, they are replaced by Na^+ diffusing into the midgut cells from the lumen. The movement of Na^+ across the cells tends to produce a water gradient between the lumen and the cells concentrating water in the lumen. Hence, water would diffuse into the cells which, in turn, tend to concentrate other molecules that would then diffuse down gradients into the cells. It implies that the work necessary to produce the gradients for diffusion (a passive process) of water and other absorbable molecules would be the active transport of Na^+.

Regulation of the alimentary system/ metabolism

Regulation of the alimentary system in insects involves control of food movement, control of enzyme secretion, and control of absorption. The alimentary canal is regulated in part through the action of the stomatogastric nervous system. Food is ingested by the actions of the mouthparts, cibarium and pharynx and is typically stored in the crop. It is then released gradually, via the stomodeal valve, into the midgut where digestion and absorption occur. In most insects that have been studied stretch receptors associated with the crop provide information to the brain (via the frontal ganglion) regarding crop distension and help prevent overfilling of this organ. In some insects, stretch receptors in the abdominal wall have a similar role.

Control of passage of food from the crop to the midgut (rate of crop emptying) has been studied mainly in the cockroach, Periplaneta americana. Passage of food from the cockroach crop is inversely related to the osmotic pressure of the food, i.e., the higher the concentration of food, slower the passage. Osmotic receptors have been identified in the wall of the cockroach pharynx.

Two mechanisms for the control of enzymes secretion in the insect gut have been suggested: Secretogogue (a substance in the ingested material may stimulate enzyme secretion) and hormonal. The secretogogue control is an immediate response to food, whereas hormonal control is more related to developmental and environmental effects. Nervous control is highly unlikely because the midgut is sparsely innervated or not at all.

Absorption appears to be controlled by the availability of absorbable molecules, release of food material from the crop being so regulated that digestion and subsequent absorption occur at an optimal rate for a given circumstance.

Many insects ingest foods with a very high water content. Some of these insects (e.g., butterflies and many true flies) store the dilute food in the impermeable crop and pass it gradually to the midgut. In others (e.g., many blood feeding insects) food may go to the midgut where excess water is rapidly absorbed in the haemolymph and then excreted via the malpighian tubules. Both mechanisms probably prevent extensive dilution of the haemolymph and removal of water concentrates solid food increasing the efficiency of digestion.

Movements of the alimentary canal (mainly foregut and hindgut) that complement the action of the digestive enzymes and help absorption are under neural or neurosecretory control in some insects. In others, having no neural connections, gut movements are assumed to be myogenic. Hormonal stimuli may also have a great deal to do with the rate of gut movement.

3.7 Insect nutrition

Like other animals, insects also require a balance diet having appropriate amount of proteins, amino acids, 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 (by the insect itself or through associated micro-organisms). 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 synthesise nucleic acids, however only some insects are able to synthesise vitamins, non essential amino acids.

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 they are capable of synthesizing. Although some 20 amino acids are needed for protein production only ten are essential in the diet, the others can be synthesised from these ten. The ten essential amino acids are arginine, lysine, leucine, isoleucine, tryptophan, histidine, phenylalanine, methionine, valine and threonine. In addition to essential amino acids, few insects need glycine (e.g., flies) or alanine (e.g., Blatella) or proline (e.g., Phorima), however in these cases methionine is not essential.

In general the absence of any one of these essential acids prevents growth. Although other amino acids are not essential, they are necessary for optimal growth to occur because their synthesis from the essential acids is energy consuming and necessitates the disposal of surplus fragments (Dadd,1973). Consequently glutamic acid and aspartic acid are necessary in addition to the essential amino acids for good growth of Bombyx larvae and further improvement is obtained if alanine, glycine or serine are also present. Good growth of Mysus persicae depends on the presence of cysteine with glutamic acid, alanine or serine.

Carbohydrate: Carbohydrate are not considered to be essential nutritive substance for most insects, but they are probably the most common source of chemical energy utilised by insects. However, many insects (e.g., many moths) do, in fact, need them if growth and development are to occur normally. Schistocerca for instance needs at least 20% sugar in an artificial diet for good growth. Tenebrio fails to develop unless carbohydrate constitutes at least 40% of the diet and growth is optimal with 70% carbohydrate. The carbohydrate may be converted to fats for storage or to amino acids. In the diet of Galleria carbohydrate can be entirely replaced by wax and this is also true in many Diptera, such as Musca. Larval Phorima which normally live in necrotic tissues containing little carbohydrate are adversely affected by any carbohydrate in the diet.

There may be differences in the ability of larvae and adults to utilise carbohydrates. For instance, the larva of Aedes can use starch and glycogen while the adult cannot.

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 hormones. Most insects are able to synthesise lipids from carbohydrates and protein sources. However, some insect species do require certain fatty acids and other lipids in their diets. For example, certain Lepisoptera require linoleic acid for normal larval development. All insects need a dietary source of sterol (cholesterol, phytosterols or ergosterol) for growth and development. Carotenoids are necessary in the diets of all insects as the visual pigment retinene is derived from the food.

Vitamins: Vitamins are unrelated organic substances that are needed in very small amounts in the diet for the normal functioning of insects as they cannot be synthesised. They provide structural components of coenzymes. Vitamin A (fat soluble) 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.

Minerals: Like vitamins several minerals are required in traces by insects for normal growth and development, e.g., potassium, phosphorous, 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.

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.

Water: Like all animals, insects require water. Insects fulfil their water requirements from body, 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. Some, like the rice weevil *(Sitophilus oryzae)* can survive and reproduce on essentially dry food. Others, for example honey bees and house flies, require large amounts of water for survival. The excrement of the rice weevil is hard and dry with almost all the water absorbed by the insect, while the excrement of bees and house flies contains large amounts of water.

Microbiota and nutrition

Types of micro-organism

The most commonly occurring micro-organisms in insects are bacteria or bacterium like forms which are found in Blattoidea, Isoptera, Homoptera, Heteroptera, Anoplura, Coleoptera, Hymenoptera and Diptera. In addition flagellates are found in wood eating cockroaches and termites, yeasts in Homoptera and Coleoptera and an actinomycete in Rhodnius. In many cases the precise nature of the micro-organisms is not known.

Location in the insect body

In some insects the symbionts are free in the gut lumen. This is the case with the flagellates which live in the hindguts of wood eating cockroaches and termites and with the bacteria living in the caeca of the last segment of the midgut in plant sucking Heteroptera. In Rhodnius, Actinomyces lives in crypts between the cells of the anterior midgut.

Most micro organisms are intracellular in various parts of the body. The cells housing the symbionts are known as mycetocytes and these may be aggregated together to form organs known as mycetomes.

Mycetocytes are large, polyploid cells occurring in many different tissues. Normally the micro organisms are incorporated into them when the cells are first differentiated in the embryo, but sometimes the cells develop for a time before they are invaded. Most commonly the mycetocytes are scattered through the fat body, as they are in cockroaches and coccids, but in *Haematopinus* (Siphunculata) they are scattered cells in the midgut epithelium and in other insects they may be in the ovarioles or free in the haemolymph.

The presence of microbes in the gonads ensures the infection of any egg produced thus transferring the microbes in next generation.

The wood eating cockroaches have two sets of symbionts : intestinal flagellates and intracellular bacteroids in the fat body. This situation also occurs in the termites *Mastotermes darwiniensis* but the remainder of the wood eating termites only retain the intestinal fauna.

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 hindgut 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.

The roles of micro organisms in the insect

It is known that the intestinal flagellates of cockroaches and termites are concerned with the digestion of wood and that they release products which can be utilised by the insect. The yeast of Stegobium (Coleoptera) provides vitamins and sterols, which may be secreted into the gut or released by the digestion of the micro organisms. There is some evidence that the micro organisms particularly those in Homoptera and Heteroptera are concerned with nitrogen metabolism (Toth, 1952).

In the coccid *Stictococcus sjoestedti* the bacterium like micro organism may be concerned with sex determination. In the mature insect mycetocytes invade the ovary but only infect those oocytes to which they are adjacent. Consequently two types of eggs are developed : those with and those without micro organisms. The eggs develop parthenogenetically and the uninfected eggs develop into males, while the infected ones give rise to females (Richards and Brooks, 1958).

3.8 Summary

- Each muscle is made up of a number of fibres, which are long, usually multinucleate, cells running the whole length of the muscle. Each fibre is bounded by the sarcolemma, which comprises the plasma membrane of the cell plus the basement membrane. The cytoplasm of the fibre is called sarcoplasm and the endoplasmic reticulum which is not connected to the plasma membrane is known as the sarcoplasmic reticulum.
- The unit of the muscle between two Z lines is called a sarcomere.
- Digestive system composed of alimentary canal and various glands related with it either directly (salivary glands, gastric caeca) or indirectly (malpighian tubules).
- The salivary glands or labial glands are paired structure lie ventral to the foregut in the head and thorax and occasionally extend posteriorly into the abdomen.
- The most commonly occurring micro-organisms in insects are bacteria or bacterium like forms which are found in Blattodea, Isoptera, Homoptera, Heteroptera, Anoplura, Coleoptera, Hymenoptera and Diptera. In addition flagellates are found in wood eating cockroaches and termites, yeasts in Homoptera and Coleoptera and an actinomycete in Rhodnius.

3.9 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Define sarcomere.
2. What is mycetocytes?
3. Define apodemes.

Section -B (Short Answer Type)

1. Describe structure of muscles with suitable diagram.
2. Write short essay on insect nutrition.

3. Write short notes on :
    a) Function of salivary glands
    b) Activation of muscle fibres

Section -C (Long Answer Type)

1. Describe the muscular system of insects?
2. Write short notes on:
    a) Control of muscular contraction
    b) Salivary gland
3. What do you mean by digestion? How does it take place in insects? Describe.
4. Write short notes on :
    a) Microbiota and nutrition of insects
    b) Absorption of digested food
5. Describe the physiology of digestion in insects.

3.10 References

- **Elements of Entomology by Rajendra singh**
- http://bugs.bio.usyd.edu.au/learning/resources/Entomology/importance/importance.html
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Unit - 4

Insect Anatomy and Physiology – II

Structure of the unit

4.1 Objective

After going through this unit you will be able to explain that

- Different organs associated with circulatory and respiratory system.
- Function of hemolymph.
- Various adaptation of different insects living under different habitat.
- How parasitic forms cope up with environment?
- What is the importance of hemolymph?
- How the circulatory system is called open and closed?

4.2 Introduction

Generally the circulatory system concern with transport of nutrients, gases, hormones, blood cells towards and away from cells in the body to protect, stabilize body temperature and pH to maintain internal body environment i.e homeostasis. This system includes cardiovascular system which distributes blood and the lymphatic system which distributes lymph. It includes dorsal vessel, heart, ostia, pusatile organs and hemolymph. The flow is unidirectional from posterior to anterior region and having open spaces or cavities called heamocoel as the insects consists of open circulatory system.

The respiratory system is a way to distribute oxygen to all cells of the body and for excrete waste product carbon dioxide (CO2) in cellular respiration. The respiratory system of insect is separate from the circulatory system as it is a complex network of tubes called a tracheal system that delivers oxygen-containing air to every cell of the body in case of aerial respiratory system. The air enters through openings called spiracles and transport to the body parts through many longitudinal and transverse channels. Other larval forms, parasitic forms adapt and modify themselves according to the environment. All insects are aerobic organisms. They must obtain oxygen (O2) from their environment in order to survive. They use the same metabolic reactions as other animals (glycolysis, Kreb's cycle, and the electron transport system) to convert nutrients (e.g. sugars) into the chemical bond energy of ATP. During the final step of this process, oxygen atoms react with hydrogen ions to produce water, releasing energy which is captured in a phosphate bond of ATP.

4.3 Circulatory organs in insects

Insects are deficient of veins or arteries but they do have separate system to circulate fluids. As blood moves in large spaces instead of vessels, the organism is known to possess an open type of circulatory system. It differs from closed circulatory system found in vertebrates and higher invertebrates both in structure and function. In an open circulatory system, blood/ hemolymph lies in large and opened body cavities called haemocoel and thus blood makes direct contact with all internal tissues and organs. The thoraco abdominal body cavity is divided into three major compartments with the help of two partitions. These partitions are called dorsal diaphragm placed dorsally and ventral diaphragm placed ventrally. Due to these diaphragm the insect body cavity is divided into three cavities pericardial cavity that surrounds the dorsal aorta, perivisceral cavity that surrounds the alimentary canal and perineural cavity that surrounds the nerve cord.

Difference between open and closed circulatory system:

During the evolution of animals the lower animal phyla like porifera, colenterata and platyhelminthes do not have definite circulatory system. As the complexity started from lower to higher animal phyla the arthropods and mollusca are having efficient circulatory system with open type as the blood flowing in vessels opens into open spaces called sinus or body cavities called hemocoel. All the organs and tissues are bathed in blood and remain in direct contact with the blood. Due to the open channels low blood pressure is maintained in insects. As far as closed type of circulatory system is concerned blood flows in arteries divide and redivide into capillaries reach to the organ and come back to heart via veins as in annelid and vertebrates (FIG 4.1).

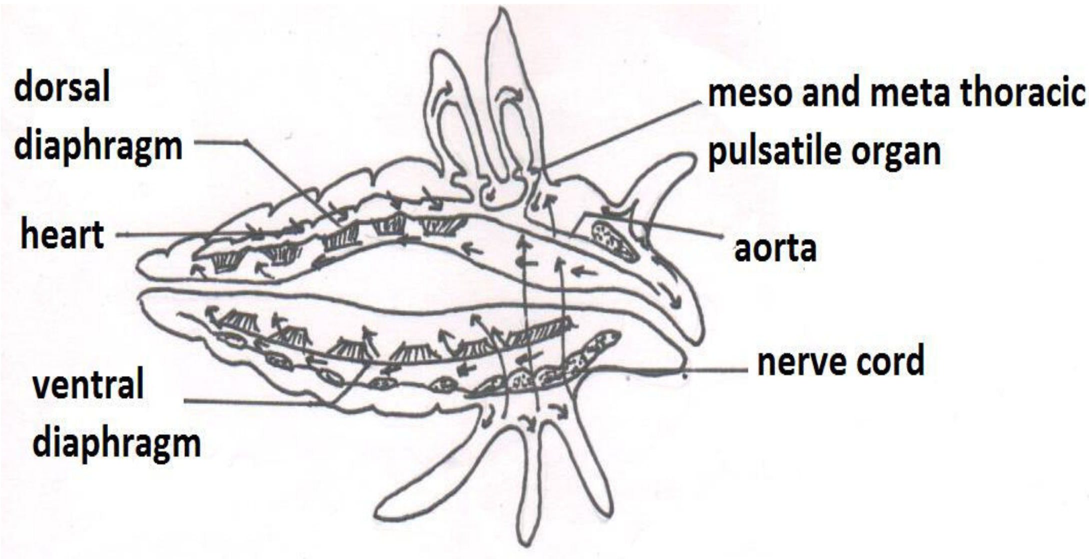


FIG 4.1: Direction of circulation in L.S. of insect.

4.3.1 Circulatory organs

1. Dorsal Vessel/ dorsal aorta/heart

Dorsal aorta as the name suggests lie in the dorsal region of the body below the body wall. It is a longitudinal tube runs from thorax and abdomen and constitute major structural component of an insect's circulatory system. It is further divided and often constricted into 5 to 6 heart chambers separated by valves (ostia) to ensure unidirectional flow of hemolymph. In *Nymphalid* butterfly only larva has both forward and backward peristaltic movements exceptionally. It is a fragile simple tube without ostia and sometimes connected with vertical diverticulum associated with pulsatile organs. In most insects, hemolymph flows in a direction from posterior to anterior end of the body that is from abdomen to the head. It consists of aortic valve near heart and divides into 2-3 cephalic arteries which again further divides into smaller vessels.

2. Ostia

In heart incurrent and excurrent both types of ostia are present. Incurrent ostia consist of 9 pairs in abdomen and 3 pairs in thorax. The ostia are valvular in generalized insects like cockroach. Numbers of incurrent ostia are variable like in wasp 5 pairs and in housefly 3 pairs are present. Excurrent ostia are non valvular, in grasshoppers, silverfishes 2 thoracic and 5 abdominal pairs are present. In cockroaches where excurrent ostia are absent certain lateral segmental vessels are associated with heart. During each diastolic phase/relaxation, the ostia open to allow inflow of hemolymph from the body cavity and during contraction of heart these ostia closes and the hemolymph move forward.

3. Alary/ Aliform muscles

Many pairs of alary muscles are attached laterally to the walls of each chamber of heart so as to keep them in position. Alary muscles are 2 thoracic and 10 abdominal in grasshoppers and 4-7 pairs in bugs. It is due to these muscles, peristaltic contractions occur which force the hemolymph forward from one chamber to another.

4. Accessory pulsatile organs

These organs are there in mesothorax or sometimes in metathorax which are concerned with circulation of hemolymph into legs/ wings/ antenna. In some insects, pulsatile organs are located on the base of the wings, appendages or antenna in grasshoppers and cocokroaches. Pulsatile organs do not usually contract on a regular basis, but they force hemolymph out into the extremities.

There are two diaphragm dorsal and ventral which separates the haemocoel into three compartments or sinuses perineural, perivisceral and pericardial (FIG 4.2).

4.3.2 Heart beat

The rate of pulse is 30-200 beats/minutes. As the temperature falls or rises the heart beat vary. In larva of stag beetle heart beat is 14 beats/minutes and in flies it is 150 beats/minutes. Heart beat of larva is slower as compared to adult, and in older pupa no heart beat is found. Younger larva sometimes stops beating.

4.3.3 Control of heart

Insect's heart is myogenic and it lacks pacemaker. In cockroach neurogenic nerves supplied from corpora cardiac and motor fibres of segmental ganglia controls heart. Cardioaccelerator neuropeptide proctolin acts as myotropins and regulate heart. Indolalkylamine in insects is equivalent to adrenaline of higher organisms that accelerate the heart beat.

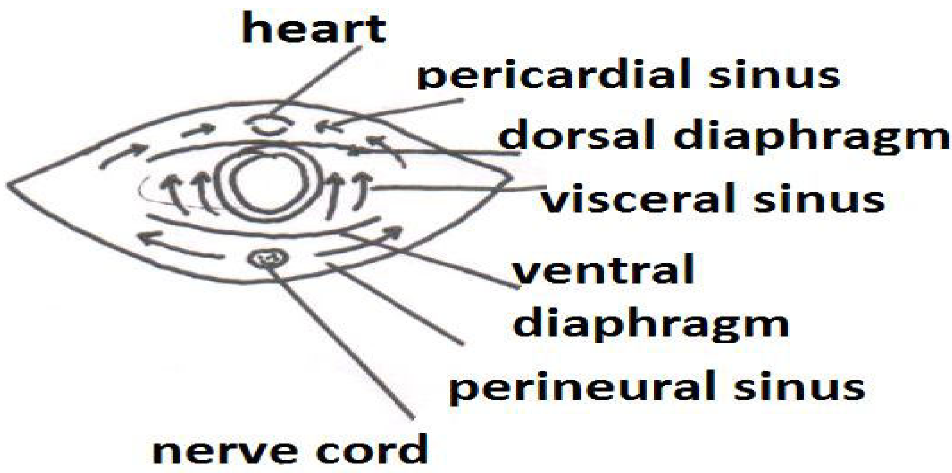


FIG 4.2: Direction of circulation in T.S.

4.4 Composition and function of hemolymph

Hemolymph or blood flows in aorta, small vessels in open channels in insects. The body cavity/ blood sinus is divided into three compartments pericardial surrounding heart, perivisceral surrounding alimentary canal and perineural sinus around nervous system by two thin sheets of muscles or membrane known as the dorsal and ventral diaphragms. The dorsal diaphragm is formed by alary muscles of the heart and related structures separating the pericardial sinus from the perivisceral sinus. The ventral diaphragm separates the perivisceral sinus from the perineural sinus in the same way. Hemolymph is composed of plasma and haemocytes. In insects 170µl of hemolymph contains 7-20 millions of circulating cells.

4.4.1 Plasma

Major portion about 90% of insect hemolymph is plasma and carries 5-40% of total body weight. It is a watery fluid containing 85% water, usually clear colorless fluid, but sometimes green, yellow or brown in color. It is slightly acidic in pH and consist of almost all amino acids. In comparison to vertebrate blood, insects have high concentrations of amino acids, proteins, sugars (glucose in honeybees), uric acid, pigments and inorganic ions. Haemolyph is a dynamic fluid that changes with diet, environmental factors or life stages. For example; In carnivores they have high concentration of Mg+ and K+, In herbivores high Na+,in terrestrial insects high protein, amino acids and uric acids.In aquatic insects high allantion, allantoic acid, NH3, urea are there. Trehalose is a major blood sugar in most insects which is a non reducing dimer of glucose. In certain insects blood sugar may be glucose, fructose or ribose depending upon their food sources . Hemolymph also contains sorbitol or glycerol which is a cryoprotectants or antifreezing agents in the plasma to prevent it from freezing during the winters and fight against cold stress. Lipophorin is a lipoprotein that functions to transport fatty acids, cholestrol, carotenoids, xenobiotics and hydrocarbons. Tyrosin plays important role in sclerotization of cuticle previously explained and proline acts as a flight energy source.

4.4.2 Haemocytes

Left 10% of hemolymph volume is made up of various cell collectively known as hemocytes. All types of cells occurs in haemopioetic organs present in developing stages and adults in exopterygotes and these organs are absent in endoterygotes adult. Different types of cells are as follows;

1. Prohaemocytes are like archaeocytes of sponges that give rise to all other cells. They are spherical in shape having large nucleus and quite RNA rich.
2. Plasmatocytes are of variable shapes with vacuolated cytoplasm. It is most abundant of all and phagocytic in nature.
3. Granulocytes are the largest and phagocytic in nature like plasmatocytes. They have granulated and acidophilic cytoplasm.
4. Oenocytoids are special cells present in some Coleopterans, Dipterans, Lepidopterans and Hemipterans having large and rounded nucleus eccentric in position, but they are not derived from prohaemocytes.
5. Coagulocytes/ cystocytes having scattered granules and helps in coagulation.
6. Spherules may be spherical, oval or spindle shaped with spherules present in cytoplasm. They are present in only Diptera and Lepidoptera.

Porhaemocytes, plasmatocytes and granulocytes are present in all types of insects. Total number of cells varies and depends upon species, developmental stage and physiological state of insect (FIG 4.3). Number of haemocytes increases with instars development, decreases first in early pupal stage and increases in later pupal stage, then decreased in adult stage.

The hydraulic (liquid) properties of blood are important. The hydrostatic pressure generated internally by muscle contraction is used to facilitate hatching, moulting, expansion of body and wings after moulting, physical movements (especially in soft-bodied larvae), reproduction (e.g. insemination and oviposition), and evagination of certain types of exocrine glands. In some insects, the blood aids in thermoregulation: it can help cool the body by conducting excess heat away from active flight muscles or it can warm the body by collecting and circulating heat absorbed while basking in the sun.

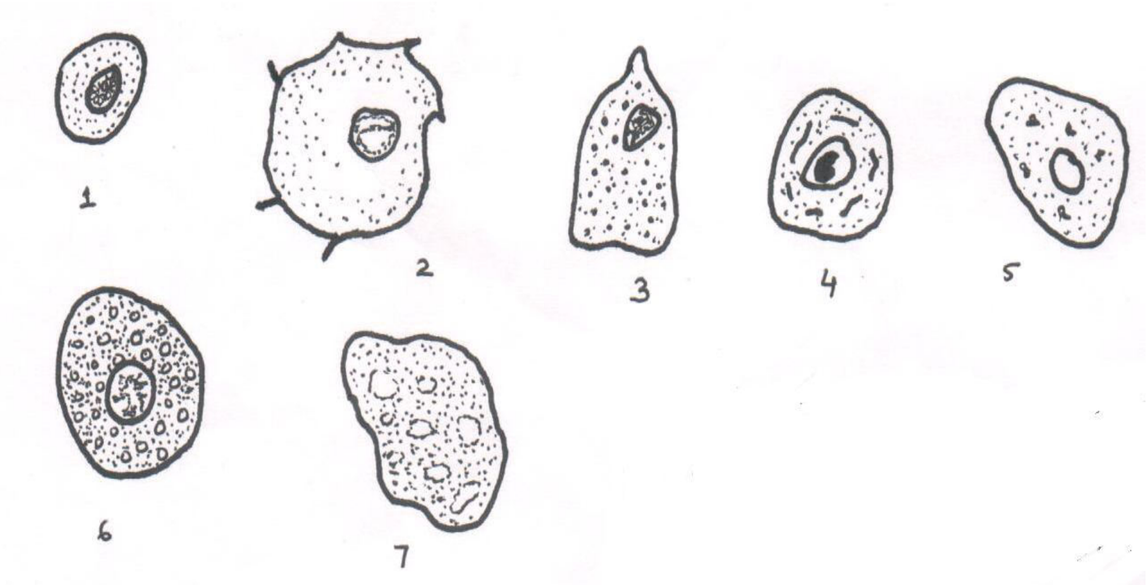


FIG 4.3: Different types of haemocytes 1. Prohaemocytes 2. Plasmatocyte 3. Granular haemocyte 4. Oenocyte 5. Cytocyte 6. Spherule 7. adipocyte

4.4.3 Function of hemolymph

1. Haemolymph creates hydrostatic pressure generated due to muscle contraction that helps the insect to circulate many things.
2. It also facilitates hatching, moulting and expansion of body.
3. Physical movements especially in soft-bodied larvae.
4. It also helps in reproduction like insemination and oviposition.
5. In some insects, the haemolymph aids in thermoregulation, it cool the body by conducting excess heat away from active flight muscles or it can warm the body by collecting and circulating heat absorbed while basking in the sun.

6. It seals off wounds through a clotting reaction.
7. The main function of hemolymph, is to transports hormones, nutrients and waste products.
8. It is important for osmoregulation, temperature control, immunity and storage.
9. It also plays an essential part in predatory defence by having chemicals that deter predators.

4.5 Insect immunity against pathogens

Immunity can be innate/ natural and acquired/ induced. Innate comprises mainly of cell mediated phenomenon like phagocytosis and encapsulation which is performed by the haemocytes. Acquired comes in function when any antigen enters the host. They are different from vertebrate immunity as the antigen antibody reaction is non specific, does not have memory cells and immunogens are not proteins. Two types of humeral immunity are found non inducible and inducible. Non inducible is one which does not require synthesis of RNA and protein like lectins (haemoagglutinin), phenyloxidases. Other is inducible immunity which requires synthesis of RNA and protein like lyzozymes, cercopins, attacins etc. It encapsulates and destroys internal parasites and produces distasteful compounds that provide a degree of protection against predators. Example; hairy caterpillar contains poison in hemolymph.

4.6 Respiratory organs in insects

All insects consume oxygen so they are aerobic. The simple channel for respiration is named as tracheal system which is a complicated system carries many channels.

4.6.1 Types of tracheal system

a) On the basis of connectives and commissure

1. **Simple type**: It is simple and opens through spiracles but it does not connect one trachea to another. Example, springtails.
2. **Complex type**: It consists of dorsal, ventral and lateral trachea connected with commissure and connectives. With this spiracles and air sacs are also present.

b) On the basis of spiracles

1. **Open tracheal system**: Spiracles present. Example, most insects.

2. **Closed tracheal system**: Spiracles absent and gaseous exchange takes place through integument. Example, *Chironomus* larva, mayfly nymph.

They carry oxygen from their environment and use the same metabolic reactions as other animals do like glycolysis, Kreb's cycle, electron transport chain to convert nutrients into ATP. At the last step of this process, oxygen atoms combine with hydrogen ions to produce water, releasing energy that is stored in the form of ATP.

Insects inspire oxygen and exhale carbon dioxide, as a waste product of cellular respiration. Oxygen is transported to the cells directly through respiration, and not carried by blood as in vertebrates. Carbon dioxide diffuses 35 times faster than oxygen.

4.6.2 Respiratory organs

1. Spiracles

The sides of the thorax and abdomen consist of a row of small openings called spiracles. These allow the intake of oxygen from the air into the tracheal system (FIG 4.5, B). The number and types of spiracles varies according to the species.

Types of spiracles

- **Simple spiracles:** It is simply a hole with no provision of regulating the size of aperture. Example, Apterygote, Plecoptera.
- **Typical spiracles**: This type of spiracle has a sclerotic plate called peritreme which surrounds the opening at atrial orifice. The atrial opening leads to the sac called atrium which further leads another opening .Tracheal orifice leads to trachea. It is found in most insects.
- **Biforous spiracles:** Here two orifices are present primary and secondary. Primary orifice is functional only in moulting and secondary orifice is functional. Example, larva of certain Coleopterans.
- **Lid type:** They are spiracles with external closing apparatus. The opening and closing of aperture is controlled by outer lips of atrium. Example, most insects.

- **Valvular type**: They are the spiracles bearing internal closing apparatus called filter apparatus with bristles and a valve that regulate the aperture. Example, abdominal spiracles (FIG 4.6).

In flies, beetles and moths spiracles are covered with sieve plate having large number of pores.

On the basis of number of spiracles: The insects are also called polypneustic having many pairs of spiracles, oligopneustic having few and apneustic having no spiracles. In the case of polypneustic the insects may carry 10, 9 or 8 functional spiracles and named as holopneustic (in cocroaches), peripneustic (in some fly larva) and hemipneustic. Oligopneustic type consist of one mesothoracic and one abdominal spiracles functional while all rest are non functional in amphineustic (second maggot stage of mosqutio), only last abdominal functional in metapneustic (first maggot stage of mosqutio) and only mesothoracic in propneustic type (in most of the dipteran larva). The older orders Collembola, Protura and Chironomid larva consist of absolutely no spiracles (FIG 4.4).

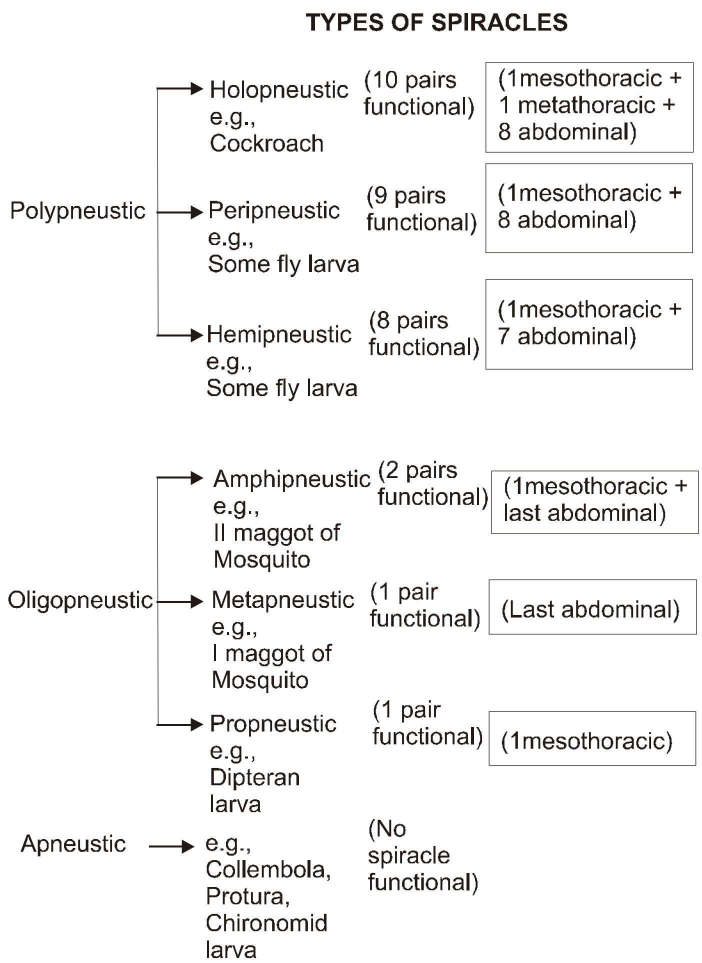


FIG 4.4: Types of insects on the basis of number of spiracles functional

2. **Trachea**

The spiracles leads to the longitudinal tube called trachea lined with intima propria. Cuticulin layer of epicuticle covers entire integumental surface including trachea and tracheoles. The intima of of trachea sheds in each moult. Trachea develops from the invagination of ectoderm during embryonic development (FIG 4.5, A). Trachea is absent in Collembolla, Protura and endoparasitic forms. The intima of the tracheal tube is folded and forms spiral ridges called taenidia that protect the insect from collapsing. Trachea is classified according to the place they are situated as dorsal, ventral, lateral, dorso-lateral and ventro-lateral.

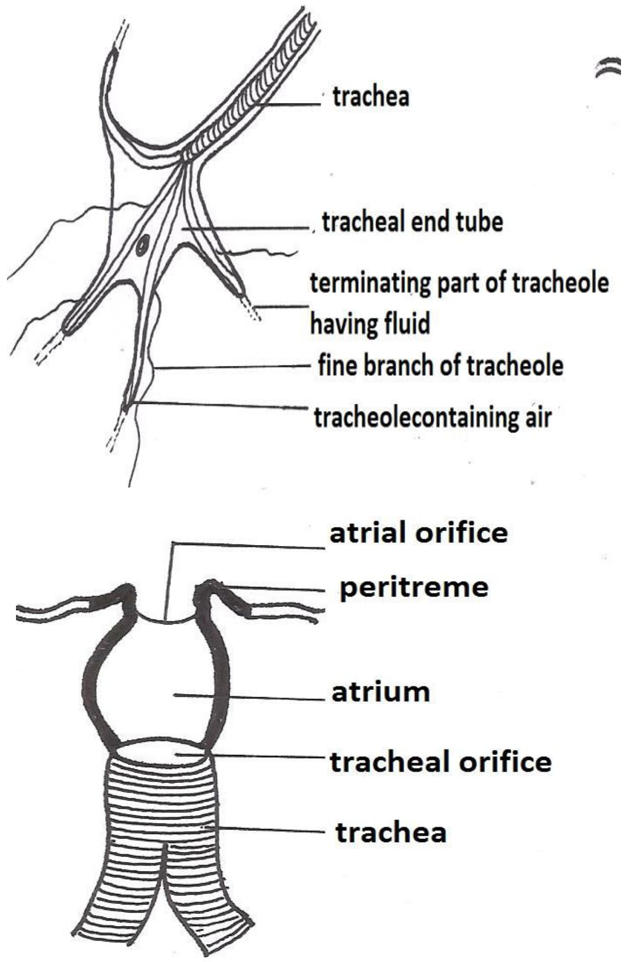


FIG 4.5: A) Tracheole B) Spiracle

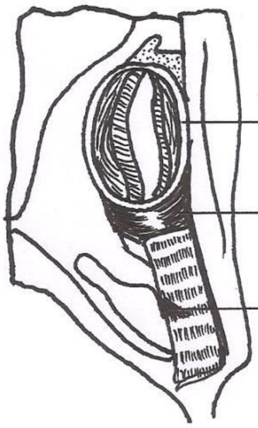


FIG 4.6: Outer and inner view of 2nd thoracic spiracle of grasshopper

3. Tracheoles

The longitudinal tracheal trunk gives a complex, branching network of tracheal tubes that subdivides into smaller and smaller diameters and reaches every part of the body called tracheoles. Tracheoles are enclosed in a very thin layer of cytoplasm from the tracheal end cell (tracheoblast). It is 0.2μ- 1μ in diameter and is associated with the organs having more oxygen demand like flight muscles, ovaries, fat body, malphigian tubules, rectal papilla and gut epithelium. Large tracheoles consist of cuticle and epidermis but in small tracheoles only epicuticle is present. In fifth instar of silkworm , 1.5 million tracholes are present (FIG 4.7).

4. Air sacs

In some areas, however, there are no taenidia, and the tube swell like a balloon to form air sac capable of storing/reserve air. Air sacs are mostly the characteristic feature of flying insect as taenidia absent. It increases the volume of air which performs various functions prevent collapsing, heat conservation, forms tympanic cavity aid in hearing organ in *Cicada* moth.

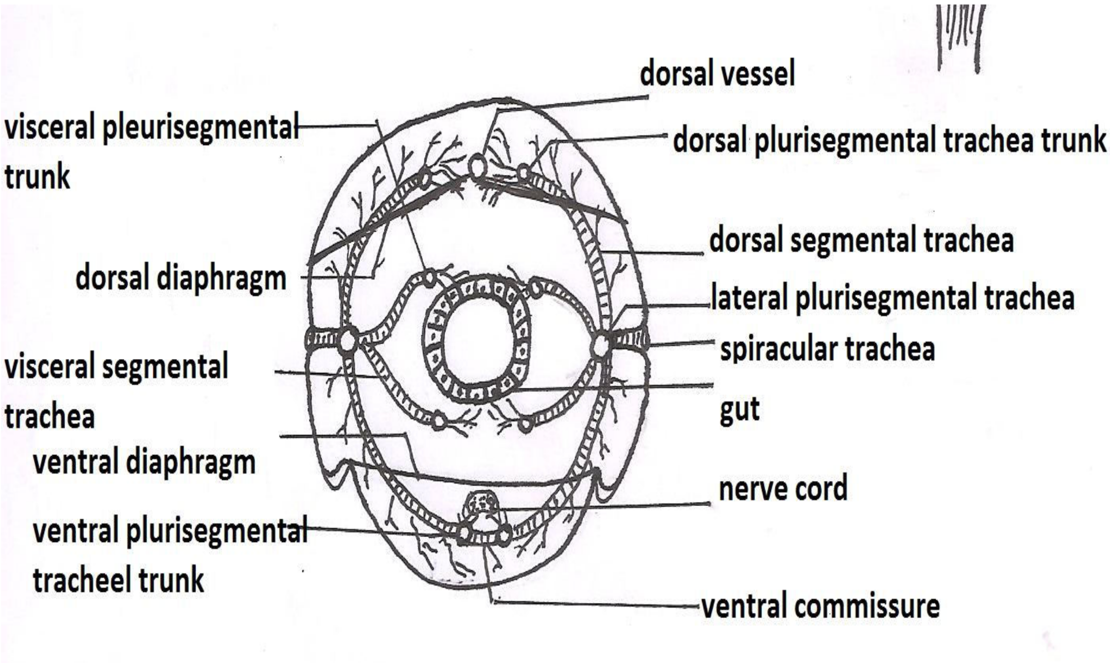


FIG 4.7: T.S. of generalized insect through abdomen showing main tracheal trunks

In terrestrial insects during high evaporative stress, air sacs conserve water by closing its spiracles. In aquatic insects stored air in sacs provide buoyancy in water. It also helps in moulting by air sacs enlargement that breaks old exoskeleton and expands a new one.

4.6.3 Mechanism of respiration

Gaseous exchange takes place between tissues and wall of tracheoles by the process of diffusion, active ventilation and passive ventilation.

1. Diffusion is based on tracheal length, its diameter and permeability. Oxygen in the tracheal tube first dissolves in the liquid of the tracheole and then diffuses into the cytoplasm of an adjacent cell. At the same time, carbon dioxide, produced as a waste product of cellular respiration, diffuses out of the cell and, eventually, out of the body through the tracheal system.
2. **Passive ventilation** facilitates respiration in larval stages and pupal ventilation occurs through suction. This uses high solubility of carbon dioxide in water and spiracular valve kept closed. When CO2 is produced it is stored partly in haemolyph in the form of bicarbonates and partly in tracheal system.
3. **Active ventilation** occurs through alternatively decreasing and increasing the volume of tracheal system. This is due to the contraction

of abdominal dorso-ventral muscles that increases the hemolymph pressure.

Autoventilation may occur in orders Odonata, Orthoptera, Hemiptera, Isoptera, Lepidoptera and Hymenoptera.

4.7 Respiration in endoparasitic forms

Mostly endoparasitic insects fulfill their requirement through cutaneous respiration. In larva of *Blastothrix* (FIG 4.8, A), (Order Hymenoptera) attaches remains of egg posteriorly and maintains contact with atmosphere. In larva of *Thrixion* (FIG 4.8, B). order Diptera forms respiratory funnel formed by ingrowth of host integument. In first instar larva of endoparsitic Hymenoptera and Diptera tracheal system is filled with liquid. In *Cotesia* larva hindgut has an everted structure called caudal vesicle.

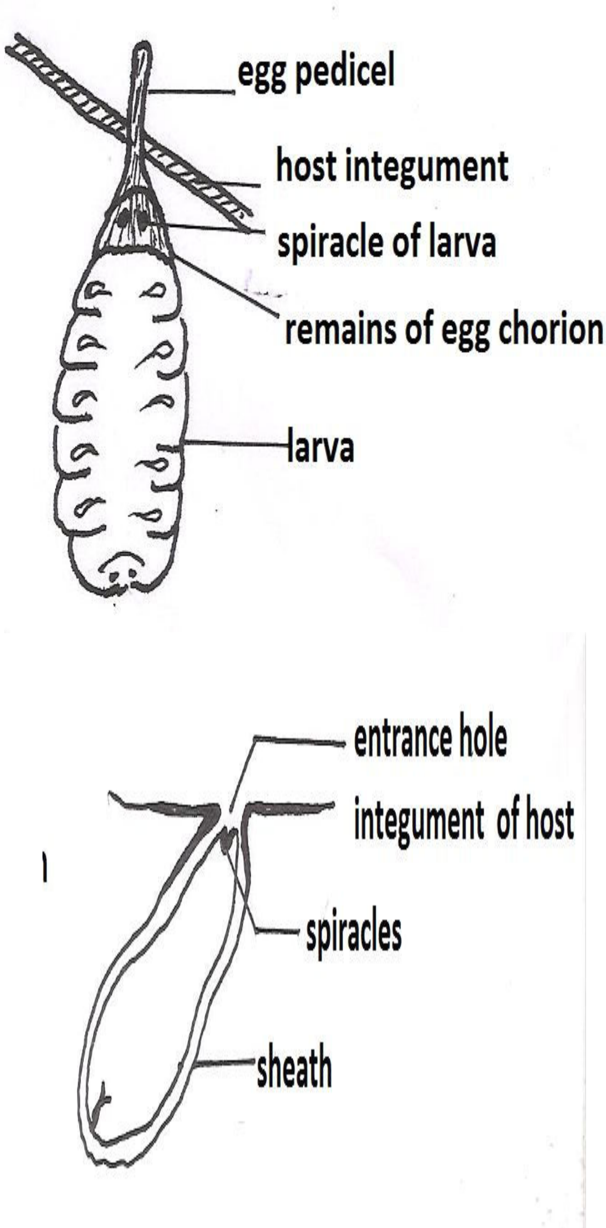


FIG 4.8: A) larva of Blastothrix (Hymenoptera) B) larva of Thrixion (Diptera)

4.8 Adaptations in aquatic insects and immature stages

Aquatic insects also respire through intake of oxygen but air has to be stored in air sacs so that they can breathe under water. The insects having open tracheal system come to the water surface to store air in tracheal system often at regular intervals. The insects with closed tracheal system the air may be directly taken by body wall. They are equipped with a variety of adaptations as follows:

1. **Tracheal gills**: They are the outgrowth of body wall of hindgut, example, Mayflies and Damselflies larva. The outgrowth may be of

caudal region called caudal lamella in Zygoptera, lateral abdominal gills in Ephemeroptera, Plecoptera, Coleoptera and rectal gills in Anisoptera.

2. **Hydrofuge hairs:** In some aquatic insects spiracles are surrounded by water repellent hairs on the base lies special oil secreting cells, dipteran larvae, *Notonecta* (FIG 4.9, A).
3. **Cuticular Respiration:** Many aquatic species can exchange gases through thin and permeable integument, black fly pupa.
4. **Spiracular gills:** They are the outgrowth of body wall near spiracles, pupa of *Psephenoides gahani* (Coleoptera) and pupa of certain Diptera.
5. **Plastrons:** These are special hydrophobic hairs which are bending on tip and thickened at base so as to create air space next to the body. Air is trapped within a plastron when insect comes regularly to exchange gases. Examples, *Elmis* (Coleoptera) and *Aphelocherirus* (Hemiptera, FIG 4.10).
6. **Biological Gills:** These are organs which can allow dissolved oxygen from the water to pass into an organism's body by the process of diffusion. In insects gills are usually outgrowths of the tracheal system. They are covered by a thin layer of cuticle that is permeable to both oxygen and carbon dioxide. Example, *Dytiscus, Notonecta*.
7. **Breathing Tubes/ siphons**: Many aquatic insects living under water and come to surface to get air from hollow breathing tubes, in mosquito larvae, the siphon tube is an extension of the posterior spiracles in abdomen. The opening of the tube is surrounded by a waterproof layer of hairs. When the insect goes down in water the hairs comes close to each other and closes the opening.
8. **Air Bubbles:** Some aquatic insects carry a bubble of air with them whenever they dive beneath the water surface, such as in diving beetles. This bubble may be held under the elytra, specialized hairs or around one or more spiracles. An air bubble provides insect with a short-term supply of oxygen.
9. **Integument/ cuticular respiration:** Many aquatic insects have comparatively thin integument for the diffusion of gases oxygen and carbon dioxide. These are present in insects living in cold and fast moving streams where there is enough dissolved oxygen. Sometimes integument acts as respiratory organ, example, *Chironomus* larva.

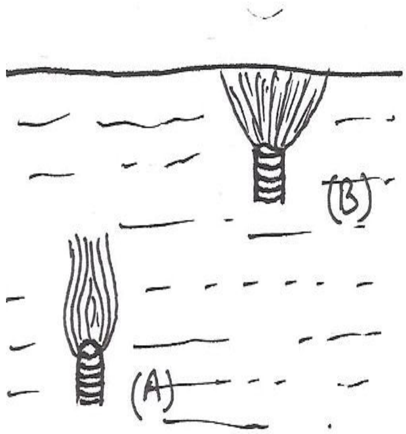


FIG 4.9: A) Hydrofuge hair around spiracle in submerged stage B) on water surface

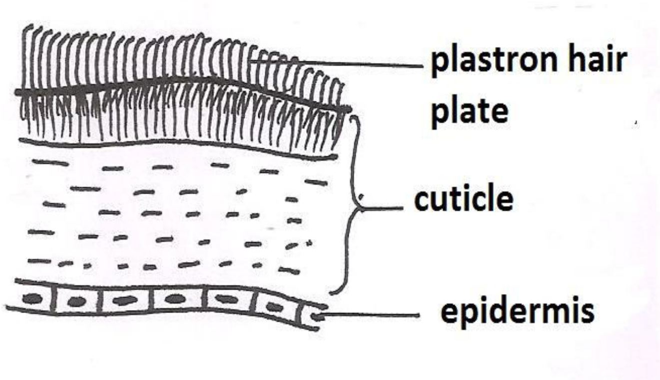


FIG 4.10: Diagram showing plastron hair for respiration

Respiratory pigments in insects

Respiratory pigments are the molecules that can carry oxygen and other gases present in blood. Crustaceans and arachnids contains haemocyanin respiratory pigment.Most insects does not have these pigments but Chironomus larva (midges/ commonly known as bloodworms), backswimmers, horse bot fly (*Gasterophilus*) are red in color due to haemoglobin in plasma. Kat haemoglobin in *Rhodnius*, carotene, flavin, xanthophil in herbivore insects and protapin in aphids are present in plasma. Riboflavin, flurocyanine, insectoverdin are found in locust.

4.9 Summary

The circulatory system includes contractile dorsal aorta, heart, ostia, sinuses and hemolymph. The blood or haemolymph is made of plasma and cells performing different functions and make up less than 25% of an insect's body weight. The main function of hemolymph, is to transports hormones, nutrients and wastes and is important for osmoregulation, temperature control, immunity and storage. It also plays an essential part in the moulting process, predatory defence by chemicals that deter predators.

Body fluids enter through unidirectional way through valved ostia which are openings situated on the aorta. Flow of the hemolymph occurs by peristaltic contraction, originating at the posterior end which pumps the hemolymph forwards into the dorsal vessel. The hemolymph is circulated to the appendages with the help of accessory pulsatile organs found at the base of the antennae or wings or legs.

Respiratory system is meant for gaseous exchange and oxygen is more readily diffuses than carbon dioxide. This exchange is possible through tracheal system in insects which is a system developed from invagination of the integument. Two diaphragm divides whole thoraco-abdominal cavity into three compartments pericardial, perivisceral and perineural cavities. Insect respiration is specialized system without lungs by a complicated system of internal tubes and sacs through which gases either diffuse in and out of the body. Oxygen is directly transported to the tissues that need oxygen and eliminate carbon dioxide via their cells as RBC are not present in the haemolyph. Air is taken in through spiracles, situated laterally in the pleural wall, usually a pair on the anterior margin of the meso and meta thorax, and pairs on each of the eight or less abdominal segments. Numbers of spiracles vary from 1 to 10 pairs on which basis the insect is said to be holopneustic, oligopneustic, apneustic. The oxygen passes from the tracheae to the tracheoles and lastly to the end cell.

The major tracheae are thickened spirally by taenidia that prevent it from collapsing and often swell into air sacs. Spiracles are closed and opened by means of valves and are of different types. The closures of spiracles are essential from losing moisture from the body. There are some aquatic insects have a closed tracheal system, for example, in Odonata, Tricoptera, Ephemeroptera, which have tracheal gills for respiration and having no functional spiracles. The tracheal system may be open or close and number of spiracles may vary from species to species. Aquatic and endoparasitic insects have modification to adapt their environment.

4.10 Glossary

- **Alary muscles:** Muscles which are attached laterally to the walls of each heart chamber to keep them in position.
- **Apneustic:** No functional spiracle.
- **Haemocoel:** These are the open body cavities with blood/ haemolyph.
- **Oligopneustic:** Having one or two functional spiracles.
- **Pericardial sinus:** It is the cavity surrounding heart.
- **Perineural sinus:** It is the cavity around nervous system.
- **Perivisceral sinus:** It is the cavity surrounding alimentary canal.
- **Polypneustic:** Having three or more functional spiracles.
- **Spiracles:** Small openings on the sides of thorax and abdomen.
- **Respiratory pigments:** They are the molecules that can carry oxygen and other gases present in blood.

4.11 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Which cell functions as archeocyte of sponges?
2. What are the percentages of plasma and heamocytes in hemolymph?
3. Name the major blood sugar in insect?
4. Name the abundant type of cell in insect hemolymph?
5. Name the cells which are phagocytic in nature?
6. What is the component in insects that regulate heart beat like that of adrenaline in vertebrates?
7. How many pairs of alary muscle are there in grasshoppers?
8. Which insect has the most primitive and generalized mouthparts in insects?
9. Name the cryoprotectant in insect?
10. Name the amino acid responsible for flight and sclerotization of cuticle?

Section -B (Short Answer Type)

1. Define hemolymph and haemocyte?
2. Differentiate between open and closed tracheal system?
3. Draw labeled diagram of tracheal system?
4. What makes insect to respire in water?
5. Explain the immunity in insects?
6. What are the types of haemocytes?

7. Write the types of spiracles on the basis of their number?
8. Write a short note on respiratory pigments?
9. Write differences between open and closed circulatory system?

Section -C (Long Answer Type)

1. Explain different organs of respiration?
2. What are the different organs associated with circulation?
3. Write down in brief adaptation of endoparasitic and aquatic insect?
4. What is the mechanism of respiration?
5. Write the composition and function of hemolymph?
6. How insects protect themselves against diseases and antigen?

Answer Key of Section-A

1. Prohaemocytes
2. 90% and 10%
3. Trehalose
4. Plasmatocyte
5. Plasmatocyte and granulocyte
6. Indol alkylamine
7. thoracic and 10 abdominal
8. Grasshoppers and cockroaches
9. Sorbitol and glycerol
10. Proline and tyrosine

4.12 References

- Cedric Gillot: Entomolgy
- Kachhwaha N.: Principles of Entomology- Basic and Applied

Unit - 5

Insect Anatomy and Physiology – III

Structure of the Unit

5.1 Objectives

After reading this unit student will be able to:

- Describe the excretory system in insects.
- Describe excretory organs and their modification, including cryptonephridial arrangement in insects.
- Describe the Physiology and regulation of excretion in insects.
- Know, describe and understand nervous system and its basic component.
- Understand the role of brain in nervous system and transmission of nerve impulse in insects.

5.2 Introduction

The function of the excretory system is to maintain a constant internal environment (homeostasis) which is largely determined by the haemolymph as it surrounds the visceral organs of the insects. Thus the excretory system maintains the uniformity of the haemolymph which is achieved by the elimination of nitrogenous metabolic wastes and the regulation of salt and water. The malpighian tubules are concerned in the excretion whereas the rectum is involved in reabsorption of salts and water. Both excretory substances and salts and water pass into the rectum. Nitrogen is usually excreted as uric acid with minimum of water and thus conserves water. Nitrogenous wastes are eliminated either as: 1) Ammonia – as in aquatic insects, meat eating maggots and aphids, 2) Urea- as in clothes moths (and humans), 3) Uric acid – as in most insects. The choice of nitrogenous excretory product is dependent upon the need to conserve water.

An insect's nervous system is a network of specialized cells (called neurons) that serve as an "information highway" within the body. These cells generate electrical impulses (action potentials) that travel as waves of depolarization along the cells membrane. Every neuron has a nerve cell body (where the nucleus is found) and filament like processes (dendrites, axons or collaterals) that propagate the action potential. Signal transmission is always unidirectional-moving toward the nerve cell body along a dendrite or collateral and away from the nerve cell body along an axon.

5.3 Excretory organs and their modification, including cryptonephridial arrangement

Excretory organs

A. Malpighian tubules

The Malpighian tubule system is a type of excretory and osmoregulatory system found in some insects, myriapods, arachnids, and tardigrades. The system consists of branching tubules extending from the alimentary canal that absorbs solutes, water, and wastes from the surrounding hemolymph. The wastes then are released from the organism in the form of solid nitrogenous compounds. The system is named after **Marcello Malpighi**, a seventeenth-century anatomist. It is unclear as to whether the Malpighian tubules of arachnids and those of the Uniramia are homologous or the result of convergent evolution.

Structure

Malpighian tubules lie in the haemocoel and are attached to the gut at the junction between the midgut and hindgut. Each tubule is usually long slender blind tube and may open directly into the midgut or hindgut or more commonly into a dilated ampullar structure. These tubules are commonly convoluted and are usually free in the body cavity. Their number varies depending on species, from 2 (in scale insects) to 250 or more (in Orthopterans) with large surface area. In *Periplaneta*, with 60 tubules, their total surface area is about 1320 cm^2. Certain insects lack malpighian tubules, e.g., springtails and aphids. They contain actin for structural support and microvilli for propulsion of substances along the tubules. Malpighian tubules in most insects also contain accessory musculature associated with the tubules which may function to mix the contents of the tubules or expose the tubules to more hemolymph. The insect orders,Thysanura, Dermaptera and Thysanoptera do not possess these muscles.

Association of the Malpighian tubules with the gut: at least two types of arrangement of Malpighian tubules and posterior part of the gut are observed : gymnonephridial (free kidney) and cryptonephridial (hidden kidney) arrangement.

a) **Gymnonephridial arrangement:** The distal ends of the Malpighian tubules are lying freely in the body cavity. This type of Malpighian tubules are of two types:

    i. **Orthopteran type:** Histologically the malpighian tubules are alike throughout its length and are only secretory in nature.

    ii. **Hemipteran type:** Histologically the basal absorptive region of the Malpighian tubules differs from the distal secretory region.

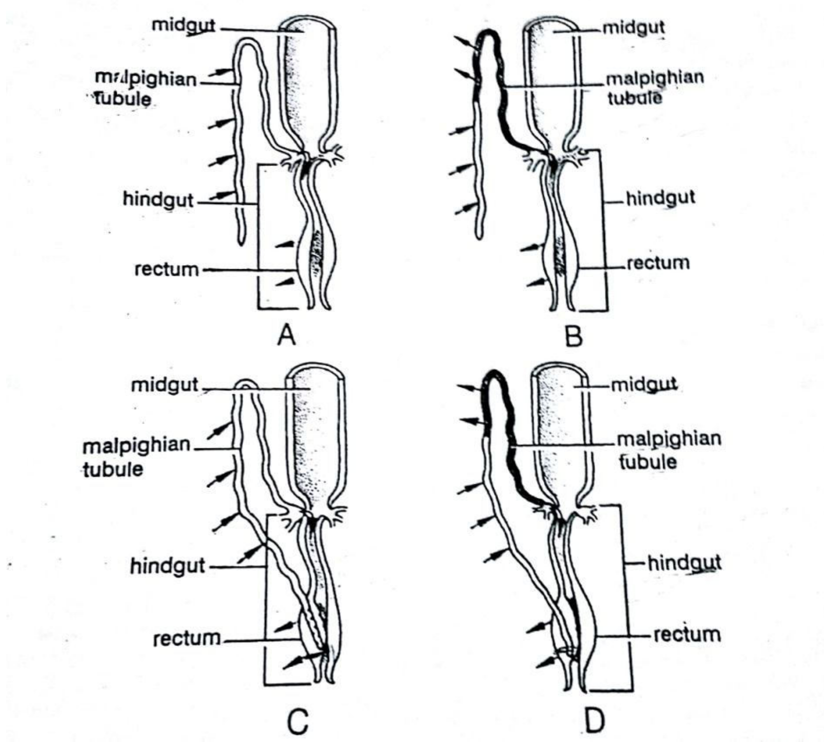


Fig. Major types of Malpighian tubule- hindgut system. (A) orthopteran type, (B) hemipteran type, (C) coleropteran type, (D) lepidopteran type. Arrows indicate the direction of movement of substances in and out of the tubule lumen.

b) **Cryptonephridial arrangement:** The distal ends of the tubules are embedded in the tissues surrounding the rectum. Such an arrangement is concerned with improving the uptake of water from the rectum. This type of Malpighian tubules are also of two types:

   i. **Coleopteran type:** similar to orthopteran type the Malpighian tubules are alike throughout its length and are only secretory in nature.

   ii. **Lepidopteran type:** similar to hemipteran type the basal absorptive region of the Malpighian tubules differs from the distal secretory region.

Histology of Malpighian tubules

Except silver fishes, earwigs and thrips, muscles are associated with the tubules which produce serpentine movement in the Malpighian tubules that helps in propelling the contents of the lumen toward the opening into the alimentary canal, mixing of the luminal contents and exposure of the tubules to more haemolymph. The tubules are usually well tracheolated and are one cell thick with one or a few cells encircling the lumen. These cells rest on a tough basement membrane.

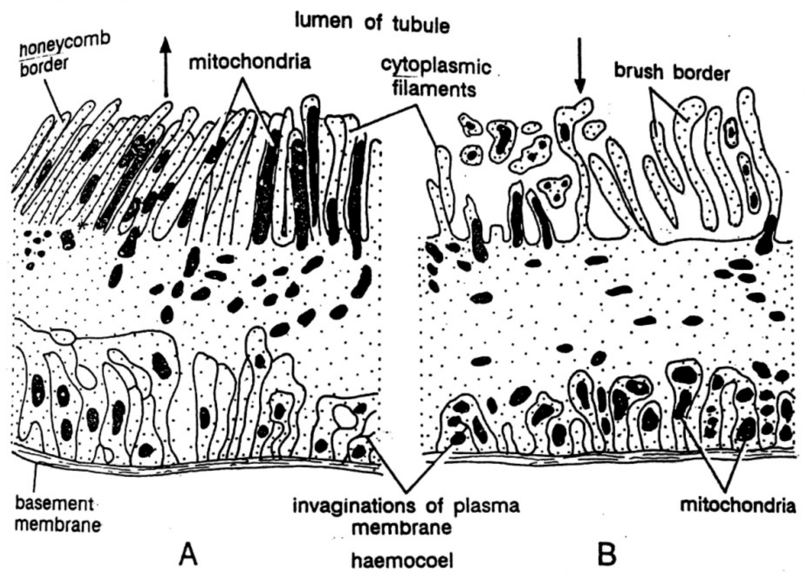


Fig. Transverse section of a cell from (A) the distal end of a Malpighian tubule showing the regular cytoplasmic filaments of the honeycomb border, (B) the proximal region showing the irregular filaments of the brush border. Arrows indicate the direction of secretion.

The cytoplasm of these cells varies in appearance and is usually colourless. It is generally filled with various refractile or pigmented inclusions and sometimes contains needle like crystals but may be nearly clear. In some insects the free margins of the cells of more distal parts of the tubules are produced into cytoplasmic filaments and packed very close together, forming the so called honey comb border and is secretory in nature. The more proximal cells have a typical brush border. This too, is formed of cytoplasmic filaments, but these are separated from each other by their own width and are concerned with absorption through active transport. The tubular cells contain a very large number of mitochondria.

B. Nephrocytes

Nephrocytes occur singly or in groups in several parts of the body. Their size varies with insect species. They are large in dipterous larvae whereas are small and may be multinucleated in others. They are closely associated with pericardium and hence are also known as pericardial cells. In dragonfly the nephrocytes are scattered throughout the fat body. The nephrocytes transform the original waste materials into a form that enter routine metabolic pathway later on. It is supposed that nephrocytes also take part in protein metabolism and regulation of heartbeat.

C. Excretion by rectum

The Malpighian tubules of *Periplaneta* do not contain uric acid but the granules of it are found in the wall of the rectum and in the faeces suggesting that the hindgut may have an excretory function. There are typically six rectal pads in *Periplaneta* each is a longitudinal folding of cuticle containing thickened patches of epithelium and many tracheal branches. In ammoniotelic insects. Ammonia passes directly into the gut without involving Malpighian tubules. In certain aquatic insects ammonia is secreted directly into the rectum.

D. Other excretory organs

Springtails that have no Malpighian tubules and larvae of wasps and bees and oriental cockroaches in which Malpighian tubules do not excrete uric acid, uric acid is eliminated through other organs given below :

1. **Labial glands:** In springtails, labial glands are supposed to be involved in excretion which consist of an upper saccule followed by a coiled labyrinth and have a gland opening into the outlet duct.

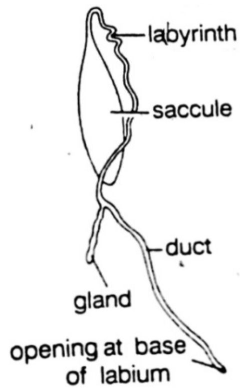


Fig. Labial gland of a springtail.

2. **Utricular glands:** In cockroaches (*Blatta, Blatella*), uric acid is stored temporarily in the utricular glands (male accessory glands) and then is poured out over the spermatophore during copulation. Recent studies demonstrated that it provides an alternate source of nitrogen to the embryo. Also, the female's own uric acid stores could be passed onto her embryos. Thus, it is suggested that both sexes can make a parental investment in the offspring. Uric acid in embryo is hydrolysed by the enzyme uricase produced by micro organisms (in mycetocytes of fat body) and serves as a nutritional nitrogen source.
3. **Fat body:** In the oriental cockroaches, uric acid is also stored in the urate cells of fat body. It is possible that the uric acid in urate cells provide a store of nitrogen (storage excretion) for use in the production of new tissue or that after reduction it supplies adenine for nucleoprotein synthesis. Uric acid stored in the fat body of larvae may be the end product of metabolism of the individual cells and is subsequently, in pupa, it is transferred to the Malpighian tubules and excreted with meconium.
4. **Other tissues:** Epidermis of *Rhodnius* also accumulates uric acid and during each moulting it is removed. Uric acid produced during pupal stage may also be stored in scales of wings in butterflies.

Nitrogenous excretion

Excretory products

Nitrogenous products of various types are usually accumulated in the haemolymph as a result of protein, amino acid and nucleic acid metabolism. These materials are usually of no use to an insect and may be toxic and it must either be excreted or stored in an inert state until they can be used for another function or be excreted. Insects excrete nitrogenous wastes in the form of ammonia, urea, uric acid, allantoin, allantoic acid, amino acids and even protein.

The habitat of the insects usually determines the type of excretory end products. Like other animals most terrestrial insects are uricotelic (excrete uric acid), whereas most aquatic insects are ammoniotelic (excrete ammonia). The aquatic larvae produce ammonia as its major excretory product while the terrestrial adults produce uric acid. Uric acid, however is the major waste product and excreted making up to 80% or more of the nitrogenous end products observed in the urine of most terrestrial insects as it does not need a large amount of water for its elimination being less soluble in water. Excreting uric acid the insects also conserve water. On the other hand, ammonia is the major nitrogenous waste produced by aquatic insects as ammonia is highly soluble in water. The red cotton bug (*Dysdercus*) excretes a large amount of allantoin but no uric acid, although the latter is present in the haemolymph. The meconium of moths and butterflies contains allantoic acid. Urea is commonly present in the urine of insects in very small quantity. In tse tse fly (*Glossina*) two amino acids arginine and histidine from the blood of the host are excreted unchanged after absorption. The allantoin, allantoic acid and urea are produced from the breakdown of uric acid.

5.4 Physiology of excretion and regulation of excretion

Materials in excess in the haemolymph are basically filtered through the Malpighian tubules which are highly permeable to small molecules. They enter the lumen of a tubule either by simple diffusion (e.g., sugars, amino acids, urea, certain ions) or linked with active transport of potassium ions, which generates fluid flow (e.g., uric acid). Figure shows the movement of ions, water and other molecules between the haemolymph and Malpighian tubules and the hindgut and the haemolymph in a generalised insect. In some insects e.g., *Rhodnius*, instead of uric acid, potassium urate is secreted. Either the whole of the tubules or more distal parts of the tubules are secretory. The substances that are needed by the insects are reabsorbed into the haemolymph either in the proximal portion of the tubules (hemipteran and lepidopteran types of Malpighian tubules) or in the rectum. These reabsorption processes may also be active transport or simple diffusion. A continuous flow of water down the tubules to the rectum carries the uric acid with it so that ultimately the nitrogenous waste is excreted with the faeces through the anus. The rate of movement of K^+ and hence of water is proportional to the concentration of K^+ in the haemolymph as the movement of water is linked with the movement of K^+. The K^+ movement is also correlated with the rate of secretion.

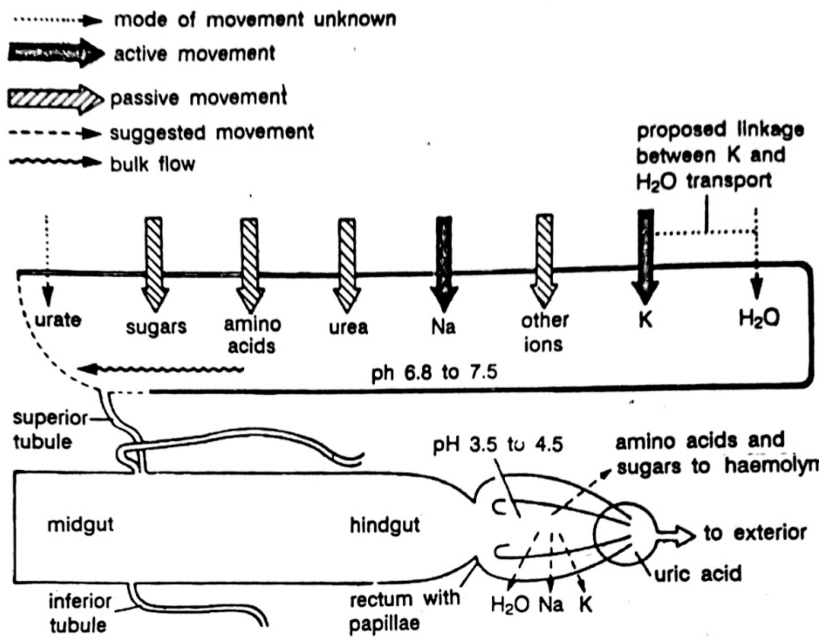


Fig. Diagrammatic representation of the movement of ions, water and organic molecules between the haemolymph and Malpighian tubules and the hindgut and the haemolymph in a generalised insect.

Salt and water balance (osmoregulation)

Different environmental conditions pose different salts and water problems for insects. Terrestrial forms are constantly faced with the tendency to lose water through evaporation and are generally dependent on ingested food for needed water and salt. Depending on the water content of their diet, the faecal material may be quite watery (e.g., plant sap feeding insects that take in an excess of water), or a dry powdery pellet (e.g., insects that feed on materials of very low water content such as cereals). Similarly, freshwater insects in which a large amounts of water is absorbed through the integument and by the gut along with ingested food must excrete water and at the same time must conserve the inorganic ions. Marine insects similar to terrestrial insects must constantly conserve water or utilise metabolic water. They also take high amount of salt with the food and the excess is eliminated in the urine after regulated resorption from the rectum.

Active transport is probably not always involved in rectal absorption. For example, in *Dysdercus,* absorption is entirely passive and occurs only when the rectal fluid is hypotonic relative to the haemolymph.

Certain other factors, e.g., spiracular control, integument permeability, food selection and habitat selection are also involved with the regulation of salt and water in insects. In certain aquatic insects (e.g., mosquito larvae), chloride ions are taken into the haemolymph by way of papillae surrounding the anus. This is an active process, occurring against very high concentration gradient. In addition, these papillae are also responsible for Na^+, K^+ and water uptake.

Some insects are able to absorb water from a drop on the cuticle. The cuticle of *Periplaneta* is asymmetrical with regard to the passage of water since water passes in more quickly than it passes out.

Dietary problems and excretion

Insect diets considerably affect the excretory system to enable the insect to encounter the problems created by the type of food ingested. Insects feeding on vertebrate blood must actively conserve sodium by reabsorption of Na^+ from a food source low in that particular ion, whereas herbivore insects face a different problem (i.e., the food is high in both K^+ and Ca++). Thus, they must excrete the excessive amounts of both ions to maintain homeostasis of the haemolymph.

In addition to the problems associated with differences in ionic concentrations between the food sources and the haemolymph, herbivore insects face in additional problem, i.e., the toxic phytochemicals. Though such insects have ability to detoxify these chemicals, but if absorbed into the haemolymph, the detoxified chemicals and the toxic chemicals themselves must be excreted. In such a situation following ingestion of plants containing the toxicant, the transport mechanism of the Malpighian tubules is induced, thus facilitating rapid excretion of the toxin from the insect's haemolymph. However, some insects retain and sequester these toxicants to their benefit rather than to excrete them, e.g., *Zonocerus* (a grasshopper).

Control of diuresis and gut motility

Diuresis, or the production of urine in insects is controlled by diuretic or antidiuretic hormones. These substances have been isolated from the pars intercerebralis of the brain, the corpus cardiacum and various ventral chain ganglia, including the sub oesophageal ganglia. A diuretic peptide (DP) from *Locusta* and an antidiuretic hormone (ADH) effecting the Malpighian tubules of the house cricket, *Acheta domesticus*, have been isolated. Similarly a chloride transport stimulating hormone (CTSH) has been isolated, which has shown to regulate both ions and water balance in the rectum of the locust. Proctolin, a neuropeptide that was isolated from the hindgut of *Periplaneta americana* is widely distributed in the insect nervous system and functions as an excitatory neurotransmitter. It produces a myotropic effect on the visceral muscles of the hindgut.

5.5 Nervous system: Basic component and functional anatomy, Brain

Insects have a complex nervous system which incorporates a variety of internal physiological information as well as external sensory information. Like other animals the nervous system in insects serves to coordinate the activities of its various systems. The units of this system are elongated cells or neurons which carry information in the form of electrical impulses from external and internal sensilla (sensory cells) to appropriate effectors (e.g., glands, muscles) and special cells called glial cells which protect, support and provide nutrition for the neurons.

Structure of the nervous system

Neurons

The basic functional unit of the nervous system is the nerve cells or neuron. Typically a neuron consists of a cell body (perikaryon or soma) and one or more long, very thin fibres or axons that end in terminal arborisation. Frequently the axon has collateral branch. Associated with the perikaryon or near it there are tiny branching processers, the dendrites.

The neurons may be unipolar (monopolar), bipolar or multipolar. Unipolar neurons possess single stalk from the cell body and are more frequent in insects. Peripheral neurons are bipolar the cell body bears an axon and a single, branched or unbranched dendrite. In hypocerebral and frontal ganglia the neurons have an axon and several branched dendrites hence they are multipolar.

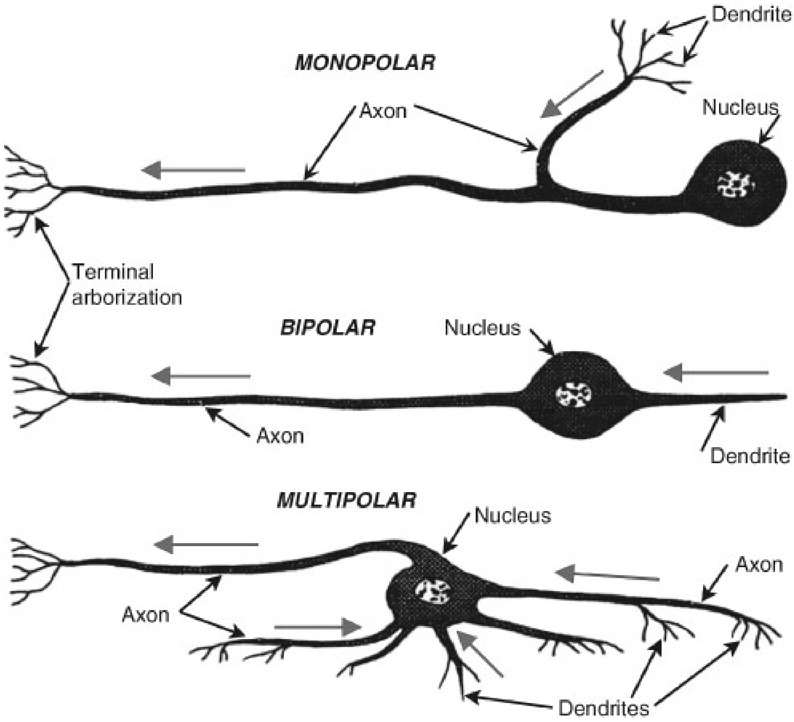


Fig. Show various types of neuron.

The terminal arborisations of an axon come into extremely close association with the dendrites or axon of another neuron or they may end near a muscle (i.e., a neuromuscular junction). The association between terminal arborisations and dendrites is called a synapse and the space between the arborisations and dendrites is called the synaptic cleft. The perikarya lie within the ganglia.

Several histological components of a ganglion have been identified. The entire nervous system is enveloped in a connective tissue called the neural sheath or neural lamella. It provides a mechanical support for the central nervous system, holding the cells and axons together. Beneath the neural sheath there is a thin layer of cells rich in mitochondria called as perineurium which probably secretes the neural lamella. Below this regions containing the perikarya with associated glial cells are found. Indeed glial cells invest the neurons and serve as protective sheet and insulation. The glial cells also provide nutrition to the neurons. There is a central region consisting of intermingling, synapsing axons encapsulated by processes of glial cells, the neuropile. Between the glial cells are extracellular spaces with fluid. The fluid in these spaces contains higher concentrations of sodium and potassium ions and a lower concentration of chloride ions than the haemolymph. Maintenance of the proper ionic concentration of this fluid is critical to neural function. The neural lamella, perineurium and glial cells are involved in maintaining the composition of this fluid as well as transporting and storing nutrients used by neurons.

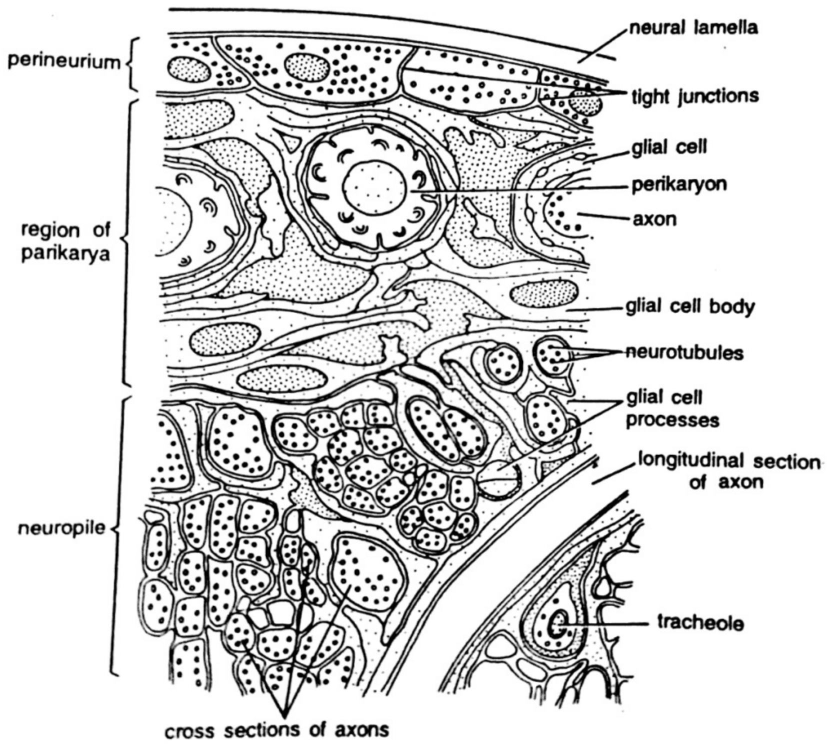


Fig. Cross section of part of the caudal ganglion of the cockroach. Darkly shaded areas indicate extracellular spaces.

Nerves are bundles of axons invested in the neural lamella and the underlying glial cells that form the perineurium. The nerves provide connection among ganglia and between ganglia and other parts of the nervous system.

Neurons are usually classified in ways that relate to function e.g., sensory or afferent that receive stimulus from the environment and motor or efferent that carry the information to glands or muscles; excitatory or inhibitory; and cholinergic (acetylecholine as neurotransmitter); glutaminergic (glutamic acid as neurotransmitter) etc.

Sensory neurons are usually bipolar with peripherally located cell bodies. The dendrite is associated with a sensory structure of some type; the proximal process usually directly associated with a motor neuron or more with one or more interneurons. Their distal processes usually frofusely branched over the inner surface of the integument or over the alimentary canal, while their axons enter the ganglia of the central nervous system.

Motor neurons are unipolar with perikarya lacking dendrites are located in the periphery of a ganglion. The bundles of axons from the cell bodies form the motor nerves that activates muscles.

Cell bodies of interneurons and association neurons are also located in the periphery of a ganglion and may synapse with one or more other interneurons, sensory neurons or motor neurons. Some interneurons being quite large (giant axons) having very large diameters (45µ) may run the entire length of the ventral nerve cord (e.g., in *Periplaneta americana*). These axons serve as a rapid conduction system for alarm reactions.

Based on anatomy the insect nervous system is divided into three major parts :

1) The central nervous system
2) The visceral (sympathetic or stomatogastric) nervous system and
3) The peripheral nervous system.

Central nervous system

The basic units of the central nervous system (CNS) are essentially the brain and a double chain of ventral nerve cord having segmental ganglia joined by lateral and longitudinal connectives.

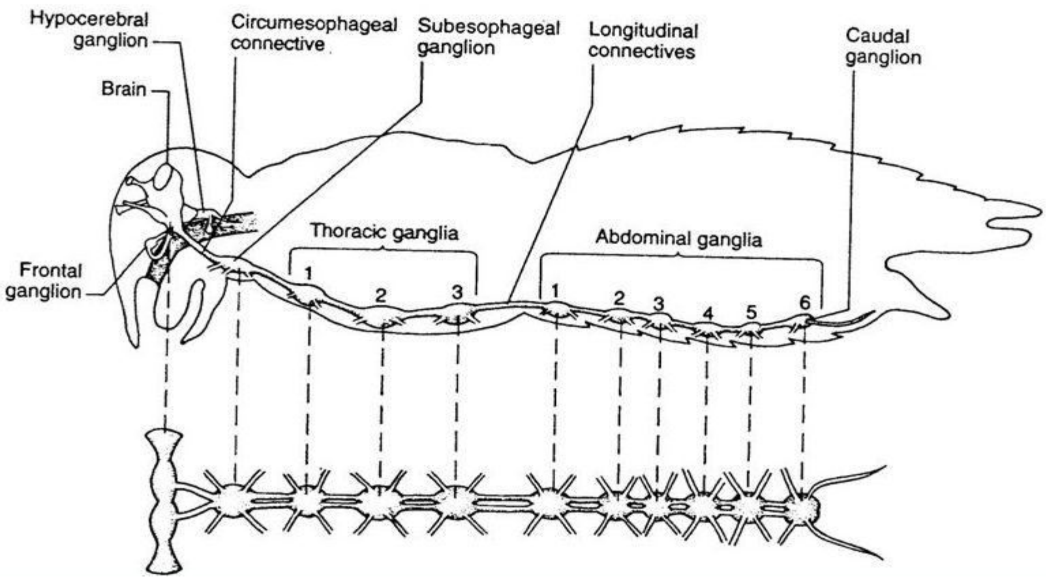


Fig. Central nervous system of a generalised insect.

1. **Brain:** The brain is very complex and is located in the head dorsal to the oesophagus. The brain is connected behind to the suboesophageal ganglion by circumoesophageal connectives ventral to the oesophagus. The insect brain is a very complex structure formed by the fusion of three anterior most paired segmental ganglia during development and thus three distinct lobes from dorsal to ventral are observed: protocerebrum, deutocerebrum and tritocerebrum.

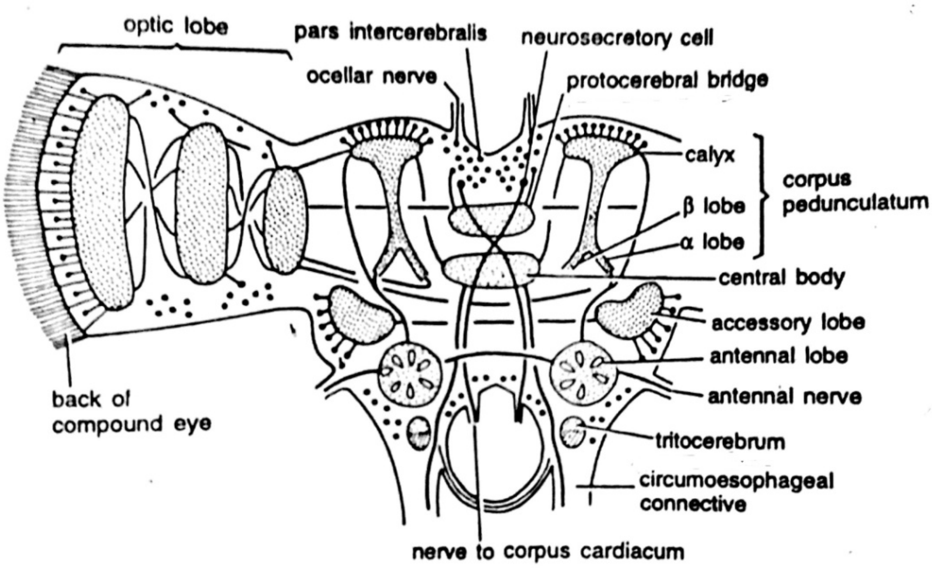


Fig. Diagram showing major neuropile region (shaded) of the brain and some connections between these regions. Black dots indicate location of perikarya.

a. **Protocerebrum:** The protocerebrum is the largest and most complex part of the brain having following distinct cell masses and regions of neuropile : optic lobes, ocellar centers, central body, protocerebral bridge, pars intercerebralis and corpora pedunculata.

   i. **Optic lobes:** The optic lobes are lateral extensions of the protocerebrum and receive sensory input from the compound eyes. Each optic lobe is composed of three neuropiles viz., lamina ganglionaris, medulla externa and associated perikarya and connectives (chiasma). The axons of retinular cells of the compound eyes pass into the lamina ganglionaris where they synapse with monopolar neurons.

   ii. **Ocellar centres:** The ocellar centers are associated with the bases of the nerves from the ocelli.

   iii. **Central body:** Centrally located central body is a neuropile and connects the right and left lobes of the protocerebrum. It receives axons from various parts of the brain and may be the source of premotor outflow from the brain.

iv. **Protocerebral bridge:** The protocerebral bridge or pons cerebralis is a mass of neuropile located medially dorsal to central body. It is connected with axons from many parts of the brain except the corpora pedunculata.

v. **Pars intercerebralis:** The pars intercerebralis is located in the dorsal median region above the protocerebral bridge. It contains two groups of neurosecretory cells that transport neurosecretory material (neurohormone) to the corpus cardiacum.

vi. **Corpora pedunculata:** The corpora pedunculata (mushroom bodies) are located at the sided of the pars intercerebralis. It is composed of a central stalk that splits ventrally into α and β lobes and capped dorsally by the calyx. The calyx is a mass of neuropile and associated perikarya. The corpora pedunculata contain interneurons which do not extend outside of these bodies and terminal portions of axons that enter from perikarya located in other parts of the brain. The connections to the calyx and α lobe are mainly sensory; those connecting with the β lobe are premotor axons which in turn synapse with motor fibres.

The protocerebrum is considered to be the location of the higher centers in the central nervous system, which control the most complex insect behaviour. The fact that the corpora pedunculata are comparatively large in the social Hymenoptera (ants, bees and wasps) and small in less behaviourally sophisticated insects (true bugs, flies etc.) strengthens this concept.

b. **Deutocerebrum:** The deutocerebrum contains the antennal or olfactory lobes. Each lobe is divided into dorsal sensory and ventral motor neuropiles. The antennal lobes is divided into dorsal sensory and motor axons from the antennae. The two neuropiles are connested with each other by a commissure. Tracts of olfactory fibres connect the antennal lobes and corpora pedunculata of the protocerebrum. The antennal lobes are important as they are the centres for receiving and processing several kind of information related with host selection, mate location, food finding, locating oviposition sites etc.

c. **Tritocerebrum:** The tritocerebrum is a smallest part of the brain and consists of a pair of lobes beneath the deutocerebrum. It connects the brain to the stomatogastric nervous system via the frontal ganglion and to the ventral chain of ganglia via the circumoesophageal connectives. The tritocerebrum also receives nerves from the labrum. The connecting nerves contain both sensory and motor elements.

2. **Ventral nerve cord:** In the thorax and abdomen there is typically a nerve ganglion in the ventral portion of each segment. The ganglia of adjoining segments are joined by paired connectives.

   a. **Suboesophageal ganglion:** The first ganglion in the ventral chain is the suboesophageal which is composed of three fused ganglia representing the mandibular, maxillary and labial segments. It innervates sense organs and muscles associated with the mouthparts, excitatory or inhibitory effect on the motor activity of the whole insect.

   b. **Thoracic ganglia:** There are typically three segmental thoracic ganglia behind the suboesophageal ganglion, each having the sensory and motor centre for its respective segment. Two pairs of major nerves arise from each ganglion supplying the legs and the musculature of each segment. In winged insects the mesothoracic and metathoracic ganglia each give rise to a third pair of nerves supplying the wing musculature. There is a tendency of fusion of thoracic ganglia in some insects belonging to Hymenoptera, Diptera and some Coleoptera.

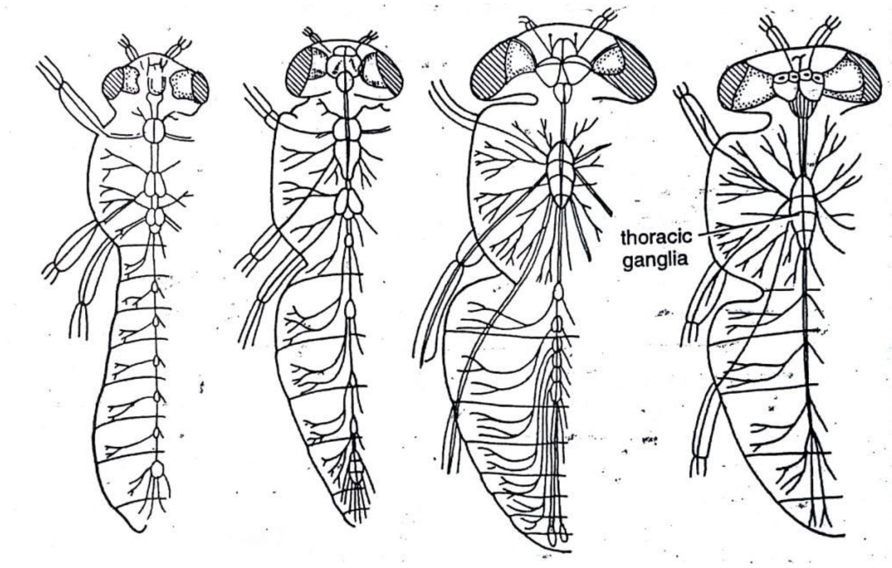


Fig. Variation in the concentration of the thoracic and abdominal ganglia of four species of Diptera.

c. **Abdominal ganglia:** The largest number of a abdominal ganglia occurring in larval or adult insects is 8 in the first 8 abdominal segments in apterygote insects and many larval forms. The last abdominal ganglion is formed by the fusion of last 4 abdominal ganglia (of segment 8-11). However, there has been a tendency toward reduction in the number of abdominal ganglia e.g., 7 in dragonfly, 5 or 6 in grasshoppers and their relatives and even 1 in several adult flies which is partially fused with the large single thoracic ganglion. The last abdominal ganglion furnishes the sensory and motor nerves for the genitalia and is therefore involved in the control of copulation and oviposition. The other abdominal ganglia typically give rise to a pair of nerves to the segmental muscles. Although ganglia are associated with specific body segments the muscles of one segment may receive nerves from a ganglion associated with a different segment.

3. **Visceral nervous system :** Insects possess a so called visceral or sympathetic nervous system that controls some of the involuntary motions of the anterior portion of the gut and dorsal blood vessel. It is made up of three separate subsystems : stomatogastric (stomodeal), ventral visceral and caudal visceral nervous systems.

I. Stomatogastric nervous system: The stonatogastric nervous system consists of a number of small ganglia and their associated nerves.

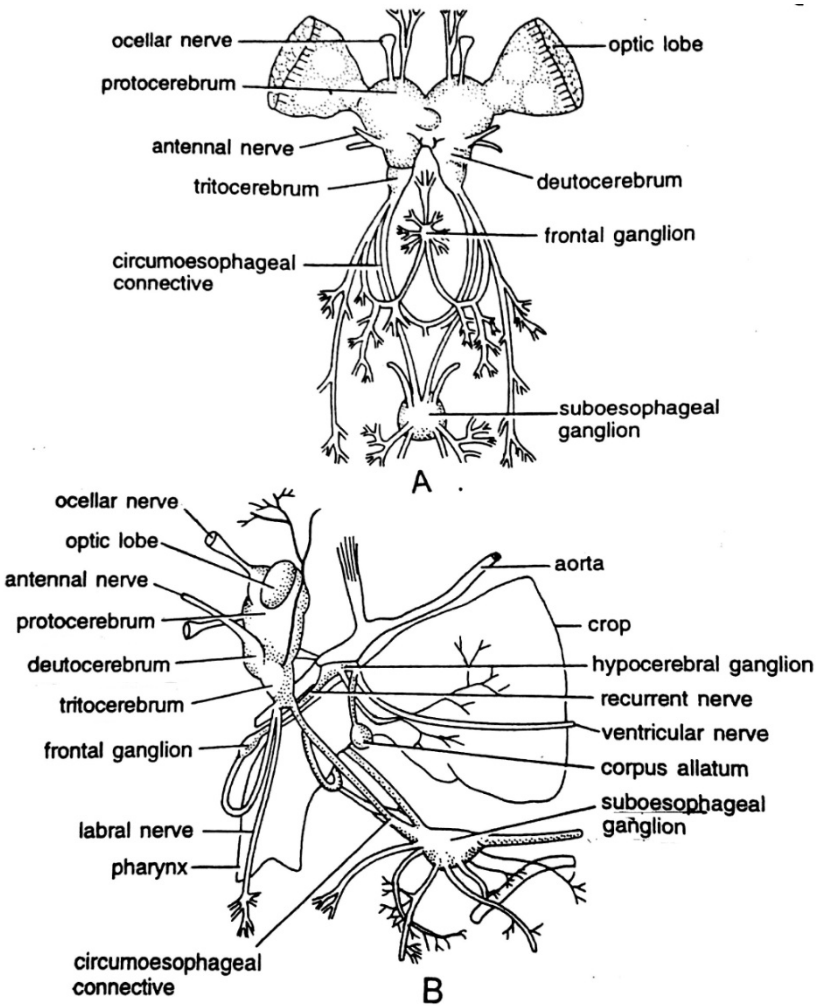


Fig. Brain and stomatogastric nervous system of the grasshopper. (A) Anterior view and (B) Lateral view.

It includes a frontal ganglion which lies on the dorsal midline of the oesophagus in front of the brain. The frontal ganglion connects with the tritocerebrum of brain by nerves on either side. The recurrent nerve srises medially from the frontal ganglion and extends beneath and posterior to the brain.

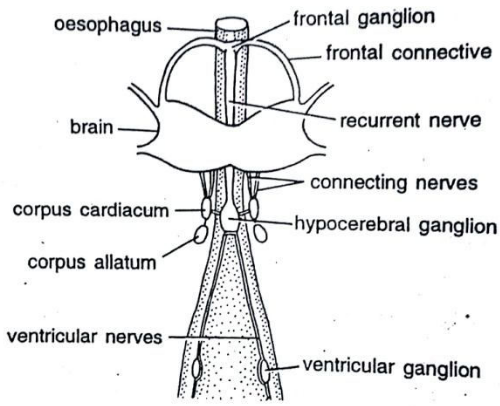


Fig. Relationship between stomatogastric nervous system and endocrine glands.

The recurrent nerve ends posteriorly in a hypocerebral ganglion which may give rise to one or two gastric nerves or ventricular nerves which continue posteriorly and terminate with a ventricular ganglion. Two endocrine glands corpora cardiac and corpora allata are connected with nerves to the hypocerebral ganglion. Sometimes suboesophageal ganglion is also connected with hypocerebral ganglion by nerve.

The stomatogastric system regulates the swallowing movements and possibly the labral muscles, mandibular muscles and the salivary glands. In *Locusta* the frontal ganglion also control the release of the secretion by the corpora cardiaca.

II. **Ventral visceral nervous system:** Ventral visceral nervous system is associated with the ventral nerve cord and its ganglia. From each segmental ganglion a single median nerve arises and divides into two lateral nerves. These nerves innervate the muscles and regulate the closing and the opening of the segmental spiracles. These nerves may be absent in some insects.

III. **Caudal visceral nervous system:** The caudal visceral nervous system is associated with the posterior segments of the abdomen. The nerves of this system arise from the caudal ganglion of the ventral chain and supply the posterior portions of the hindgut and the internal reproductive organs.

4. **Peripheral nervous system :** All the nerves emerging from the ganglia of the central and visceral nervous systems comprise the peripheral nervous system. The dendrites of sensory neurons within these nerves are associated

with sensilla, whereas the axons usually synapse with neurons within a ganglion of the central nervous system. Nerves contain motor fibres. The perikarya of these nerves are located in the ganglia of the central nervous system and the axons terminate in the muscles, glands and other effector organs. The peripheral nervous system continuously inform the insect about its surroundings by receiving stimuli through sensory organs. These sensory structures are located all over the body but are generally concentrated on the antennae, tarsi, palps, labellum, ovipositor and cerci. Sense organs such as the eyes and tympana also provide information. The information about the external and internal environment is continuously carried from the sensilla to the central nervous system where it is integrated in a way that appropriate behavioural and regulatory changes are made.

5.6 Transmission of nerve impulse in insects

Axonal transmission

In the resting condition (polarized state) due to the presence of abundant sodium ions ($Na^{+)}$ outside, the outer membrane is charged positively and the inner membrane is charged negatively. This is due to the movement of sodium ions from axoplasm to the outside of the axons. The outward flow of the sodium ions is known as sodium pump. On the other hand the potassium ions are more abundant in the axoplasm.

Upon stimulation by an external stimulus the permeability of the membrane is charged and the flow of sodium ions stops. This causes the movement of sodium ions inside the axons and depolarization of the membrane takes place. Further more on account of flow of sodium ions inside is very fast causing inner membrane positively charged and the outer part of membrane is charged negatively. Thus propagating a short electro chemical current or impulse along the axon. This is known as action potential.

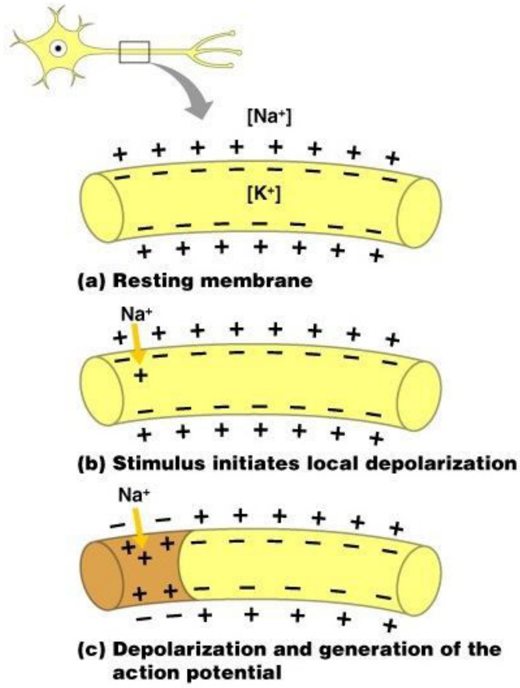


Fig. Axonal transmission in nerves.

The period of permeability to sodium ions is short lived and is followed by a period of increased permeability to potassium ions. As a result of which the potassium ions flow outside the axon , negatively charges the inner membrane. This is called as falling phase of the action potential. In this way nerve impulse are propagated in the axons. As the impulse passes in the forward direction, the permeability of the membrane assumes original state i.e. polarized condition due to decreased flow of potassium ions outside the axons as a result of which repolarization takes place.

Synaptic transmission

The axon terminals of the neurons are not continuous but are contiguous with that of other terminals having a short gap. This gap is known as synaptic gap. When an impulse has passed along an axon it must cross the synapses in order to stimulate another neuron. Transmission across the synaptic gap takes place with the help of a neurotransmitter stored in the synaptic vesicles. This is acetylcholine (ACH). As soon as the impulse reaches the terminal end of the axon, the synaptic vesicle fuse with the membrane of axon, the intermediate wall dissolve and the neurotransmitter is released into the synaptic gap.

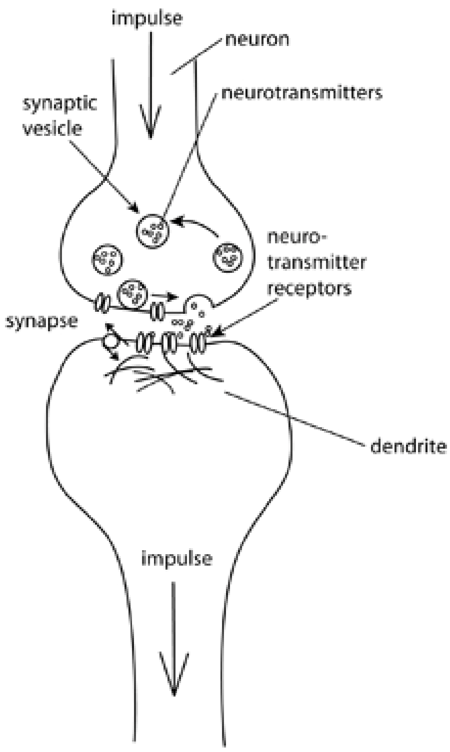


Fig. Shows synaptic transmission.

The ACH comes in contact with post synaptic terminal of the next neuron having ACH receptors. Now ACH molecules bind with ACH receptors present on post synaptic terminal. It changes the permeability of the membrane causing depolarization and this initiates propogation of nerve impulse. In this way the impulses caused by external stimuli reach from one neuron to next neuron via axon through synapses.

After the synaptic transmission the ACH is hydrolized into acetic acid and choline by the action of an enzyme acetyl cholinesterase (ACHE). In this way the ACH receptors become unoccupied in order to receive the second message. Thus in the synaptic transmission the neurotransmitter (ACH) acts as stimulus to the receptor axons.

5.7 Summary

- The function of the excretory system is to maintain a constant internal environment (homeostasis) which is largely determined by the haemolymph as it surrounds the visceral organs of the insects.
- The Malpighian tubule system is a type of excretory and osmoregulatory system found in some insects, myriapods, arachnids, and tardigrades. The system consists of branching tubules extending from the alimentary canal that absorbs solutes,

water, and wastes from the surrounding hemolymph. The system is named after **Marcello Malpighi**, a seventeenth-century anatomist.

- Diuresis, or the production of urine in insects is controlled by diuretic or antidiuretic hormones.
- The basic functional unit of the nervous system is the nerve cells or neuron.
- Based on anatomy the insect nervous system is divided into three major parts :
  The central nervous system, The visceral (sympathetic or stomatogastric) nervous system and The peripheral nervous system.
- In the resting condition (polarized state) due to the presence of abundant sodium ions ($Na^{+)}$ outside, the outer membrane is charged positively and the inner membrane is charged negatively.
- The axon terminals of the neurons are not continuous but are contiguous with that of other terminals having a short gap. This gap is known as synaptic gap. Transmission across the synaptic gap takes place with the help of a neurotransmitter stored in the synaptic vesicles. This is acetylcholine (ACH).

5.8 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Who discover malpighian tubules?
2. Define diuresis.
3. Give any four names of excretory organs in insects.
4. How many types of neuron present in insects and write their names?
5. What is the basic functional unit of nervous system?
6. Define unipolar and multipolar neurons.

Section -B (Short Answer Type)

1. Describe mechanism of excretion.
2. Write short notes on:
   a) Axial transmission
   b) Osmoregulation in insects
3. Describe structure of neurons with suitable diagram.
4. Write short notes on:
   a) Protocerebrum
   b) Utricular gland and Nephrocytes

Section -C (Long Answer Type)

1. Give an account of excretory organs of insects.
2. Describe the excretory physiology of insects.
3. Write brief notes on :
   a) Malpighian tubules
   b) Excretory products
   c) Visceral nervous system
4. Describe various parts of insects nervous system.

5.9 References

- Entomology by Rajendra singh
- Introduction to general and applied entomology by V.B. Awasthi
- https://en.wikipedia.org/wiki/Malpighian_tubule_system

Unit - 6

Insect Anatomy and Physiology – IV

Structure of the unit

6.1 Objective

After going through this unit you will be able to understand

- The role of brain and hormones in insects.
- Different types of hormones and pheromones.
- Different types of sense organs which receives external messages and pass on to the CNS.
- Male and female reproductive organ and their associated glands.
- Role of pheromone in reproduction, mating, oviposition etc.
- Role of hormones in polymorphism, caste regulation, phases of locust etc.

6.2 Introduction

This unit comprises of many system which coordinates in a manner to show a particular behavior or character. As nervous excitation is caused when external stimuli is perceived by sense organs like photoreceptors, audio-receptors, visual receptors, mechano- receptors, chemo- receptors. These receptors pass message to the CNS and from their endocrine glands are triggered to secrete hormones or pheromones. Endocrine glands are important for mating, growth, development, metamorphosis, polymorphosis, moulting and many more. Reproductive system consists of separate male and female insects with only a few insects that show hermaphroditism. Female reproductive system has a pair of ovaries, lateral oviduct, median oviduct and a genital pore. Male reproductive system has a pair of testis, lateral vasa deferens, median ejaculatory duct with an aedegus as opening aperture and a device for transfer of sperms. Reproductive system and glands associated with the process of fertilization, production of gametes eggs/ sperms and oviposition.

6.3 Neuro-endocrine system

This system comprises of neurosecretory cells and hormones produced by endocrine glands. In neuro-endocrine system the neurosecretory system translate neural information received by external stimuli into hormonal messages secreted by triggering endocrine glands (FIG 6.1).

6.3.1 Endocrine organs

1. **Neurosecretory cells-** Neurosecretory cells of the brain and ganglions (pars intercerebralis of protocerebum) secrete hormone called brain hormone peptide in nature and are stored in neuro-haemal organs and bind to the protein molecules (carrier) named neurophysin.

2. **Prothoracic glands**- Two prothoracic glands/ecdysial glands are ectodermal in origin and are located in the ventro-lateral areas of prothorax. It is also associated with lateral longitudinal tracheal trunks and absent in apterygotes (wingless insects). If these glands are cut out in a full grown larva, pupation does not takes place. And if these glands are transplanted somewhere else in the larval body, larva metamorphose into pupa.

3. **Corpora allata**- Two small glandular bodies named corpora allata present on either side of corpora cardiacam on sides of the oesophagus. These are mostly paired but they are single in Dermeptera and Heteroptera .
4. **Copora cardiaca-** It acts as a neurohaemal organ lying behind the brain on dorsal part of foregut associated with cephalic aorta. It is absent in Collembola.

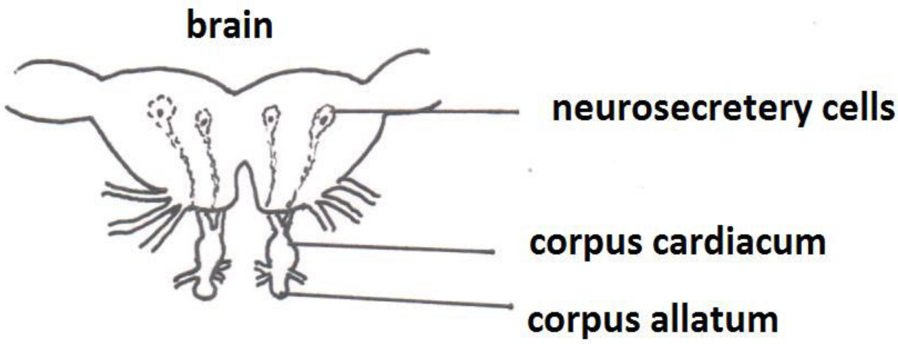


FIG 6.1: Position of endocrine glands

6.3.2 Hormones and pheromones

Hormones and pheromones are the chemicals which are responsible for a specific function and behavior. Hormones are secreted by endocrine glands and deals with the maintenance of the internal body environment. Pheromones are secreted by body parts which communicate between the same species or opposite sex for mating.

Hormones

The word hormone was given by C. M. Williams and it is also called third generation pesticide/ Insect Growth Regulators (IGR). These are the chemicals which are secreted by endocrine glands and its function is to regulate internal environment of body.

1. **Brain hormone**- Neuro-haemal organs on stimulation releases neurohormone which diffuses into the blood, and activate other endocrine gland. Brain hormones directly or indirectly control all the life processes of insect. Brain hormone stimulates feeding in blood sucking bug *Rhodnius* and stretch receptor in pharyngeal wall in grasshopper and locust.
2. **Prothoracicotropic Hormone (PTTH)/ Ecdysone-** Moulting a process when the cuticle is shed and larva metamorphose into next larval stage and pupation a process when last larval stage prepares itself for next

stage pupa. Both the moulting and pupation require it, PTTH, secreted by a prothoracic gland that is bilobed. Under the influence of PTTH, they secrete the steroid hormone ecdysone also known as moulting hormone. Moulting hormones are of two types' α-ecdysone and β-ecdysone. PTTH triggers every moult, larva to larva as well as pupa to adult. It maintains the changes during metamorphosis. PTTH is a homo-dimer of two polypeptides of 109 amino acids originated from protocerebrum targeted to ecdysial gland for ecdysone production. PTTH does not drive pupation directly but, as its name suggests, acts on the prothoracic glands. Ecdysone secreted by ecdysial gland target to epidermis for shedding the cuticle. Insects have rigid exoskeleton and can grow only by periodically shedding their exoskeleton called moulting. Moulting occurs repeatedly during larval development.

3. **Juvenile hormone-** Juvenile hormone is secreted by corpora allata and it is a non sterolic compound generally terpenoid. JH target fat body, accessory reproductive glands and follicle cells. Its function is to control metamorphosis or maintains larval stages. It is responsible for yolk deposition in eggs, egg maturation, vitellogenin production and tanning of the cuticle. They are also involved in green brown polymorphism in locust. And sometimes it is noted that mating behavior in social insects are due to neotenin. As long as there is much amount of JH, ecdysone promotes larva to larva moults. As the amounts lowers, ecdysone promotes pupation. Complete absence of JH results in formation of the adult. Therefore, if the corpora allata are removed from an immature silkworm, it immediately spins a cocoon and becomes a small pupa. A miniature adult eventually emerges. On the contrary, if the corpora allata of a young silkworm are placed in the body of a fully mature larva, metamorphosis does not takes place. The next moult produces an extra large caterpillar (FIG 6.2).

4. The hormone secreted by corpora cardiaca is not specific but it is found to regulate the heart beat, oxygen consumption and affects respiratory metabolism. In male cockroach copulation movement depends upon this gland and its secretion.

In the protocerebrum the neurosecretary cells releases the brain hormone. It triggers the prothoracic glands to secrete moulting hormone and corpora allata secretes juvenile hormone. Both the hormones are involved in moulting and metamorphosis during the life cycle of an insect.

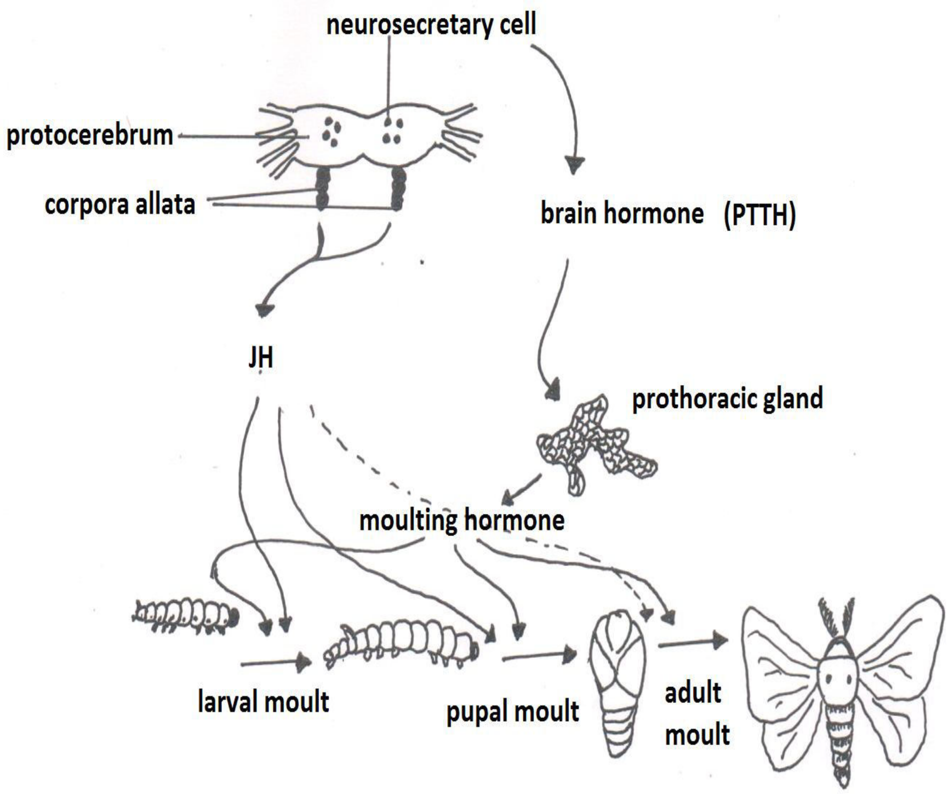


FIG 6.2: Role of hormones during metamorphosis

Pheromones

The term *pheromone* was introduced by Peter Karlson and Martin Lüscher (1959) and is based on the Greek word *pherein* (to transport or to carry) and *hormon* (to stimulate or to excite) is a chemical that triggers a natural behavioral response in another member of the same species. Among the insect orders it is observed in Orthoptera, Heteroptera, Diptera, Isoptera, Neuroptera, Siphonoptera, Coleoptera, Hymenoptera and Lepidoptera.

They are called ectohormones as they are secreted by exocrine glands. It may be volatile or non volatile in nature. They are species specific, sex specific and can be artificially synthesized.

Types of Pheromones

There are alarm pheromones, food trail pheromones, sex pheromones, and many others that affect behavior or physiology. They can be classified:

a) Based on sense organ influenced it can be
   i. Olfactory acting pheromones
   ii. Orally acting pheromones
b) According to the response it can be categorized into
   i. Releaser substances: Those chemicals that produces an immediate change in the behavior of the recipient.
   ii. Primer substances: Those chemicals which trigger off a chain of physiological changes in recipient without any immediate change in behavior.
c) On the basis of biological functions: Sex Pheromones (Aphrodisiaces), queen mandibular pheromones, spacing pheromones, trail pheromones, alarm pheromones, aggregation and trail making pheromones.

i. **Trail Pheromones** are common in social insects. For example, ants mark their paths with these pheromones to communicate their members for food finding which basically non volatile hydrocarbons. *Dolichoderine* ants synthesize pheromones in their pavan's gland, *Solenopsis* fireants in dufour's gland and Myrmicinae ants in poison glands. In termites trail pheromone is secreted by sternal gland located on 5^{th} abdominal segment. Example, *Zootermopsis* secretes caproic acid.

ii. **Alarm/Alerting Pheromones** are released if attacked by a predator and trigger flight (in aphids) or aggression (in bees) in members of the same species. This behavior is commonly seen in Hymenoptera and Isoptera and appears to be chemical releasers for social behavior. Honeybees also have an alarm pheromone e.g. *Melipona* stingless bees and *Trigona* bees secrete citral pheromone and formicine ants secrete undecane. The workers of *Coromyrma pyramica* produces alarm pheromone 2-heptanone. Honey bee's leaves traces of isoamyl acetate at sting region to induce other bees to sting on it.

iii. **Aggregation Pheromones** are secreted by con-specific insects of both sexes to secure themselves from predators, maximum utilization of food source, and attraction of social insects and to mate. They are produced by one or the other sex, these pheromones attract individuals of both sexes. Examples, bark beetles and *Ambrosia* beetle (Scotylinae).

iv. **Territorial Pheromones** (Area Making Pheromone) are laid down in the environment and mark the boundaries of an organism's territory. In dogs, these hormones are present in the urine, which they deposit on landmarks serving to mark the perimeter of the claimed territory. Example, male bumble bee secretes 2, 3-dihydro-6-trans farnesol by its mandibular gland to mark their territory sites.

v. **Caste regulating pheromone** differentiates caste in social insects and regulated by corpora allata/ Juvenile hormone that acts as pheromones in termites.

6.3.3-Endocrine control of Polymorphism in insects

Polymorphism means many forms of an organism in the same life stage. This phenomenon is found in some insects of order Orthoptera, Lepidoptera, Isoptera, Hymenoptera. The well known examples are phases of locust, caste system in social insects, alary polymorphism in crickets and color polymorphism in butterflies. Polymorphism is controlled genetically, influence by external factors or endocrine system. If the interior environment of the body is changed by the change in hormones concentration it leads to polymorphism. If JH is more than the amount required the adult will retain juvenile characters like lack of wings on the contrary if JH is low, the larva shows early maturation by developing reproductive system.

In aphids there are sometimes eight distinct forms are found. In spring and summer when food is abundant it reproduce parthenogenetically or paedogenetically to give rise large number of wingless individuals. In other season when food is in shortage it reproduce sexually to form winged individuals called alate forms. The alate forms develop when factors like photoperiod, temperature, water content and population density changes which ultimately brings changes in endocrine activity.

Termites and aphids shows **discontinuous polymorphism** as the forms are totally different to each other but locust shows **continuous polymorphism** as the forms are slightly different. In locust if population density is low, abundant food is available solitary phases occurs which lays more eggs, short winged, enlarge body accumulates less fat. Conversely if population density is high and food availability is low gregarious forms come into role that exhibits character like small body, large wings, accumulate more fat and lays less eggs as compared to solitary phase. All these factors affect endocrine gland specially corpora allata. It is experimentally proved that if JH is applied to solitary forms they develop into gregarious larvae.

In termites number of primary reproductive caste (king and queen), supplementary reproductive caste, workers and soldiers have a fixed proportion in a colony by means of inhibitory pheromones which is modified by corpora allata of endocrine system.

6.4 Sense organs

The internal and external environment is always changing so insect has to maintain itself to sense these changes. There are specialized structures which receive this information to the central nervous system. Chemical senses includes chemoreceptor's, related to taste and smell, affect mating, selection of habitat, feeding sites, breeding sites and parasite-host relationships. Taste receptors are present on the mouthparts and antenna sometimes. Insects are able to smell due to the presence of olfactory sensilla found in the antennae.

Mechanical sensilla provide the insect with to make directed orientation, general movement, fight from enemies, reproduction and feeding. They are sensitive to mechanical stimuli such as pressure, touch and vibration. Hearing structures are located on different body parts wings, abdomen, legs and antennae. They are responsive to various frequencies between 100 to 240 kHz depending upon insect species. Pressure on the body wall is detected by the campiniform sensilla and internally distributed stretch receptors that senses muscle distension and stretching.

The insects see the objects with the help of compound eyes and ocelli. More the number of ommatidia greater will be the visual acuity. The ocelli are not to form focused images but are sensitive to different light intensities. Many insects have temperature and humidity sensors and due to their small size, they cool more quickly than larger animals. Insects are cold-blooded or ectothermic as their body temperature rising and falling with the environment. In flying insects their body temperature raises through the action of flight, above environmental temperatures. The body temperature of butterflies and grasshoppers in flight may be increased by 5 °C or 10 °C above environmental temperature. In the recent research, the discoveries of new receptor nocioreceptors which are sensitive to pain found in the larvae of fruit flies.

6.4.1 Mechanoreceptors

These are the receptors which sense mechanical stimuli as they are sensitive to physical touch to solid surfaces, air movements, sound waves and gravitational forces. Even they can detect their position in air and water while flying and swimming (FIG 6.3,A).

- **Sensory hairs/ sensilla trichodea-** They are the simplest type of mechanoreceptors. They are distributed to all parts of the body but they are more on those parts of insect body which are in continuous contact to the medium like antenna, mouthparts and tarsal segments. Hair is placed in a socket and four associated cells. These associated cells are inner cell called trichogen cell which generate the hair cell, outer cell called tormogen cell which produces membrane of the cell, neurilemma cell which cover cell body and axon of sensory neuron and the sensory neuron. The hairs may be long which are sensitive to slight touch or short thick hair which stimulated to considerable force.
- **Proprioreceptor-** They are sensitive to pressure and detect change in length, tensions, compression, and body posture and body position. Different types of proprioreceptors hair plate, campaniform sensilla (FIG 6.3, B), chordonotal organs, stretch receptors and nerve nets. Campaniform sensilla are homologous to tactile hair except hair shaft replaced by dome shaped plate. Chordonotal organs consist of chordonotal sensilla (FIG 6.3, C) which lacks exocuticular component and associated with body wall, skeletal structure and trachea. Stretch receptors attach to connective tissue and other end connected with body wall/ intersegmental membrane/ muscle and associated with multipolar neurons. It gives message to the CNS about breathing, gut peristalsis and locomotion. Nerve plexus/net consists of many bipolar and multipolar neurons placed below body wall. It detects movement and stress on body.

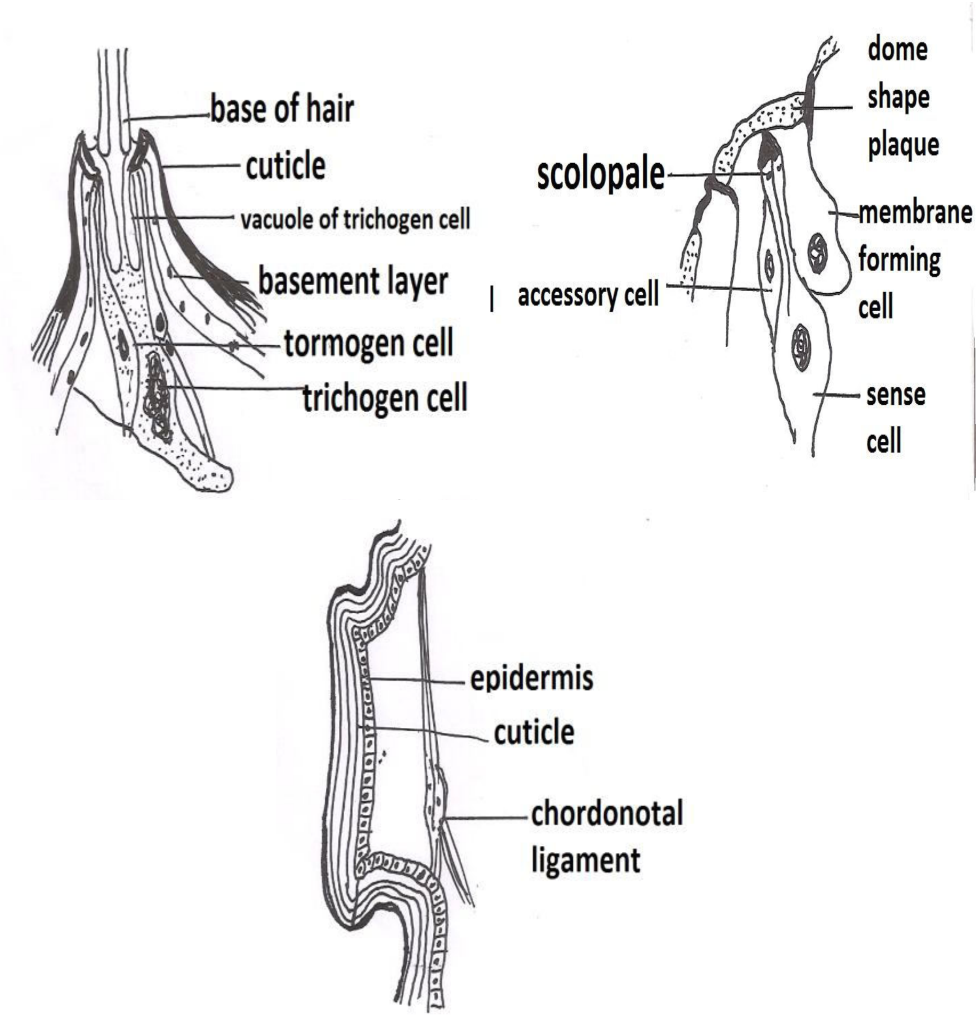


FIG 6.3: A) Mechanoreceptor B) Campaniform sensilla C) Chordonotal organ

6.4.2 Chemoreceptors

These receptors deal with taste (gustatory) and smell (olfactory) of food, oviposition sites, locating host, mate finding, detect attractants and repellents. Sometimes the same sensilla function of both smell and taste as they are identical structures. Chemosensilla are of two types:

1. One is uniporous chemosensilla which are thick walled, terminate in a single pore and innervated by many neurons. Example, food canal of aphids, hypopharynx of cockroach, labellum of flies. They resemble with the tactile sensilla.
2. The other type is multiporous which are thin walled, consist of many to several thousand pores and connected to multineural innervations. Example, antenna of many orders.

In general they are present on mouthparts specially palps, body surface, antenna in Hymenoptera, ovipositor in parasitic Hymenoptera, Diptera and tarsi of many Lepidoptera.

6.4.3- Sound and light producing organs

Sound is produced either by rubbing one part of body to another part or one part by other external object.

- Sound can be produced simply by beating of wings which are audible in flies and bees. They can be calculated by counting beats/ cycle per second like bees beats at the rate of 250 c/sec, *Culex* mosquito 280-340 c/sec and grasshoppers 60-6400 c/sec.
- Termites produce by striking the head/jaws by hard surface.
- Hind femur and elytra rubbed against each other producing sound in Acridiae family (Orthoptera).
- Posterior femora with 2 or 3 abdominal segments producing sound waves in Gryllidae (Orthoptera).
- Elytral stridulation in crickets, Coleopteran and larval psyllids.
- Tip of rostrum against sterna file.
- In *Acherontia* (deaths head hawk moth) moth a whistling sound is produced by sucking air through proboscis which enlarges pharynx and this vibrates epipharynx 280 c/sec.
- In cicada tymbal is covered with thin sheet called tymbal cover which are associated with air sacs and tymbal muscles. By the contraction of tymbal muscles the tymbal gets pulled producing a click and when it relaxes another click is produced when tymbal takes back its position.

Light is produced by light producing bioluminescent organs. There are some insects which consist of photogenic cells called **photocytes** which contain membrane bound vesicles called **luminelle**. In these luminelle there are many tiny vesicles called **lumisomes** (FIG 6.5).

Mechanism:

It is a mechanism where reactions occur in a cascade fashion. A nerve impulse stimulates acetylcholine which on hydrolysis gives acetic acid and choline. In presence of ATP and CoA it is converted into acetyl CoA, pyrophosphate and adenylic acid. Now luciferin comes in action and in the presence of enzyme luciferase and magnesium or manganese salts produces adenyl-luciferin and pyrophosphates. This on oxidation gives oxyluciferin and adenylic acids emitting light (FIG 6.4).

$$Luc + D\text{-}LH2 + ATP \xrightarrow{Mg^{2}+} Luc.LH2\text{-}AMP + PPi \ldots\ldots\ldots\ldots(i)$$

$$Luc.LH2\text{-}AMP + O2 \longrightarrow Luc.oxyluciferin^{*} + AMP + CO2 \ldots\ldots\ldots\ldots(ii)$$

$$Luc.oxyluciferin^{*} \longrightarrow Luc.oxyluciferin + light \ldots\ldots\ldots\ldots(iii)$$

$$Luc + L + ATP \xrightarrow{Mg^{2}+} Luc.L\text{-}AMP + PPI \ldots\ldots\ldots\ldots(iv)$$

FIG 6.4: Mechanism of bioluminescence

It is noted in various representatives of orders:

- Collembola- spring tails, *Achrorutes muscorum* whole body produces light.
- Homoptera- lantern flies, *Fulgora lanternaria* by head region.
- Coleoptera– *Lampyris noctiluca, Photinus* (fire flies), *Lucicola* light emitted by ventral side of abdomen, *Photuris* by 6-7 abdominal segment in males and 7 segment in females, *Pyrophorus* by either side of thorax.
- Diptera - glow worms *Platyura fultoni* by caudal region, *Arachnocampa luminosa* by end of malphigian tubules.

The nature of light also differs like *Lampyris noctiluca and Photinus* emits yellow green light, lantern flies white light, larva and adult of *Phrixothrix* green light. The flow of light can be uniform as in female of *Lampyris,* intermittent glow in *Photinus* pulsation glow in *Lucicola*.

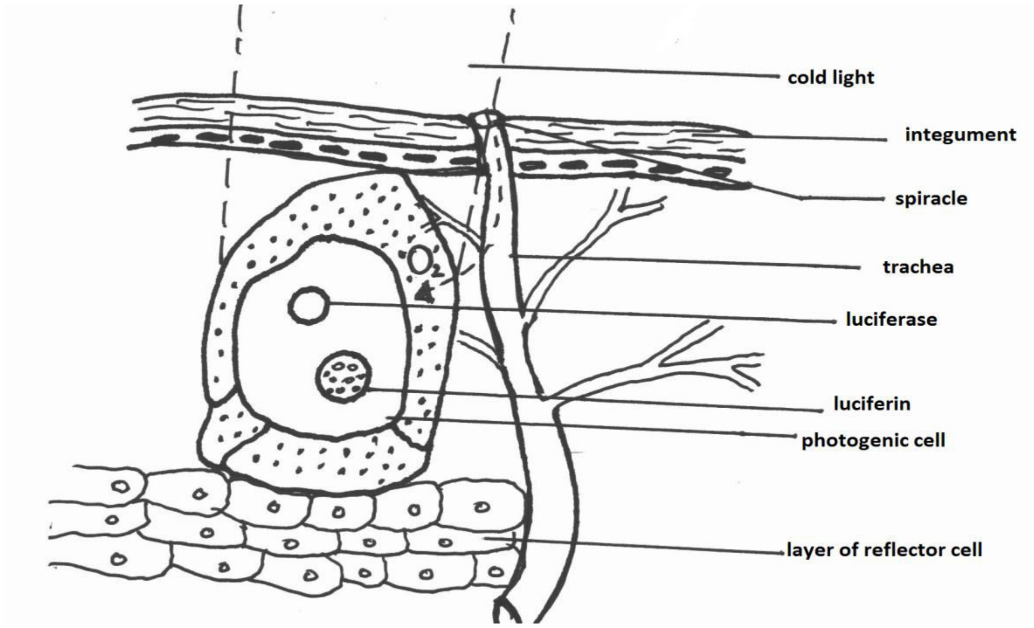


FIG 6.5: Bioluminescence in glow worm

Function:

- It is important for mutual attraction of sexes.
- It is of taxonomic value as it is species specific. Example, male firefly flies above 50 cm from ground.
- It attracts others members for locating food, e.g *Balitophilia***.**

6.4.4 Audioreceptors

Sound are the waves which are air borne or water borne as the particles in the medium vibrate and these vibrations are received by organ of hearing. They are present on antenna and cerci and named as sensilla trichodea. There are some organs associated with audioreceptors Johnston's organs of in antenna and tympanal organ which respond to air borne vibrations, subgenual organ respond to solid vibrations.

- **Johnston's organ**- It is located on the pedicel of the antenna in all adults and some of the larval forms. It is important organ for deciding position of head, direction and orientation of body. In male mosquito and chironomids these locate female while flying to mate. For this reason male bears bushier antenna with long hair which vibrate and give information to the organ. The Johnston's organ consists of two rings of scolopidia inner ring parallel to flagellum and outer ring perpendicular to flagellum. Inner scolopidia are more sensitive.

- **Tympanal organ**- They are located on foretibia of Tettigonidae, Gryllidae (Orthoptera), abdomen in cicada (Hemiptera) and metathorax in Noctuidae (Lepidoptera). They consist of many chordonotal sensilla (FIG 6.6).
- **Subgenual organ**- They are present on tibia (10-40 sensilla) in Coleoptera, Diptera and Thysanura.

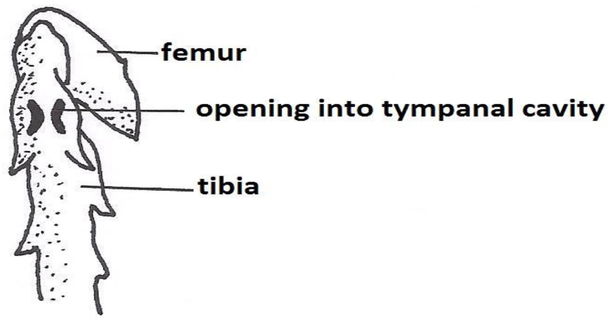


FIG 6.6: Tibial Tympanal organ of *Decticus*

6.3.5- Photoreceptors and Visual organ

All insect can detect light energy due to photo sensory structures like compound eyes, ocelli or stemmata**.** They are still wanting in cave dwelling and nocturnal insects where they can sensitize through general body surface. Fruit fly oviposition is stopped if light source ceases, on the contrary codling moth lays eggs in darkness. In aphids the non sexual to sexual reproduction occurs in short day length.

- **Compound eyes:** A pair of compound eyes is present on the dorsal side of the head and is well developed in most of the insects. It may be reduced or absent in parasitic forms like lice, fleas, female scale insect etc. **Holoptic condition** is found in some insects like dragon flies, horseflies, male tabanids in which eyes are large and meet posterior at mid dorsal line. Number of small units called ommatidia each forms a part of image and join to each other therefore called compound eyes. Each ommatidium (FIG 6.7,A) consists of cornea, cornegean cells, cone cells, crystalline cone, retinal cells, rhabdom, primary and secondary iris pigment. The ommatidium consists of light gathering component made of corneal lens and crystalline cone. The retinular cells are the primary sense cells which collect and transduce light energy. Crystalline cone is secretes by four cone cells/ Semper's cell. There are actually eight retinal cells but one degenerate and left seven eccentrically arranged with centrally placed a receptive area called rhabdom. It contains visual pigment which are conjugated proteins called rhodopsin resembling the pigment of vertebrate eye. The photosensitive chromophores consist of aldehyde of vitamin A *i.e* retinaldehyde. Secondary pigment cells consisting of ommochromes which contain granules of brown, red and yellow pigments.

Types of compound eyes:

1. **Eucone**- in this type of compound eye cone cells secrete hard refractive crystalline cone. Example Orthoptera, Lepidoptera, Odonata,Coleopetra.
2. **Pseudocone**- Cone is filled with gelatinous fluid since crystalline cone is absent. Example : Diptera.
3. **Acone-** Cone is totally absent. Example, Hemiptera, Dermaptera.
4. **Exocone**- The inner surface of cornea extends inside replacing the crystalline cone. Example: some of the Coleopterans.

- **Ocelli:** They are simple eyes located at dorso-frontal region of head and contain 500-1000 photosensitive cells below the common lens. At the distal part each of them forms rhabdom which together form rhabdom (FIG 6.7,**B**). They are more sensitive and respond more rapidly than compound eyes. They are able to form image below rhabdom that is why no physiological significance. They can measure light intensity and are essential to maintain diurnal rhythms. Ocelli are found in many adult insects and young ones of many exopterygotes .
- **Stemmata/ lateral ocelli:** They are another type of simple eye found in larva of many endopterygotes behaving as the only photosensitive structure in body. They lie lateral in position so also called lateral ocelli (FIG 6.7,C). In saw fly and beetle larva one pair of stemmata on either side is present consist of single lens with many photosensitive cells lying beneath ending in a single rhabdom. Several stemmata are present in larvae of Neuroptera, Trichoptera and Lepidoptera but with above components they also bear corneal and retinal cells. Sometimes, from outside there is no sign of stemmata but pocket of photosensitive cells are present below cuticle in larvae of Diptera (cyclorrhaph). They are responsible for color discrimination.

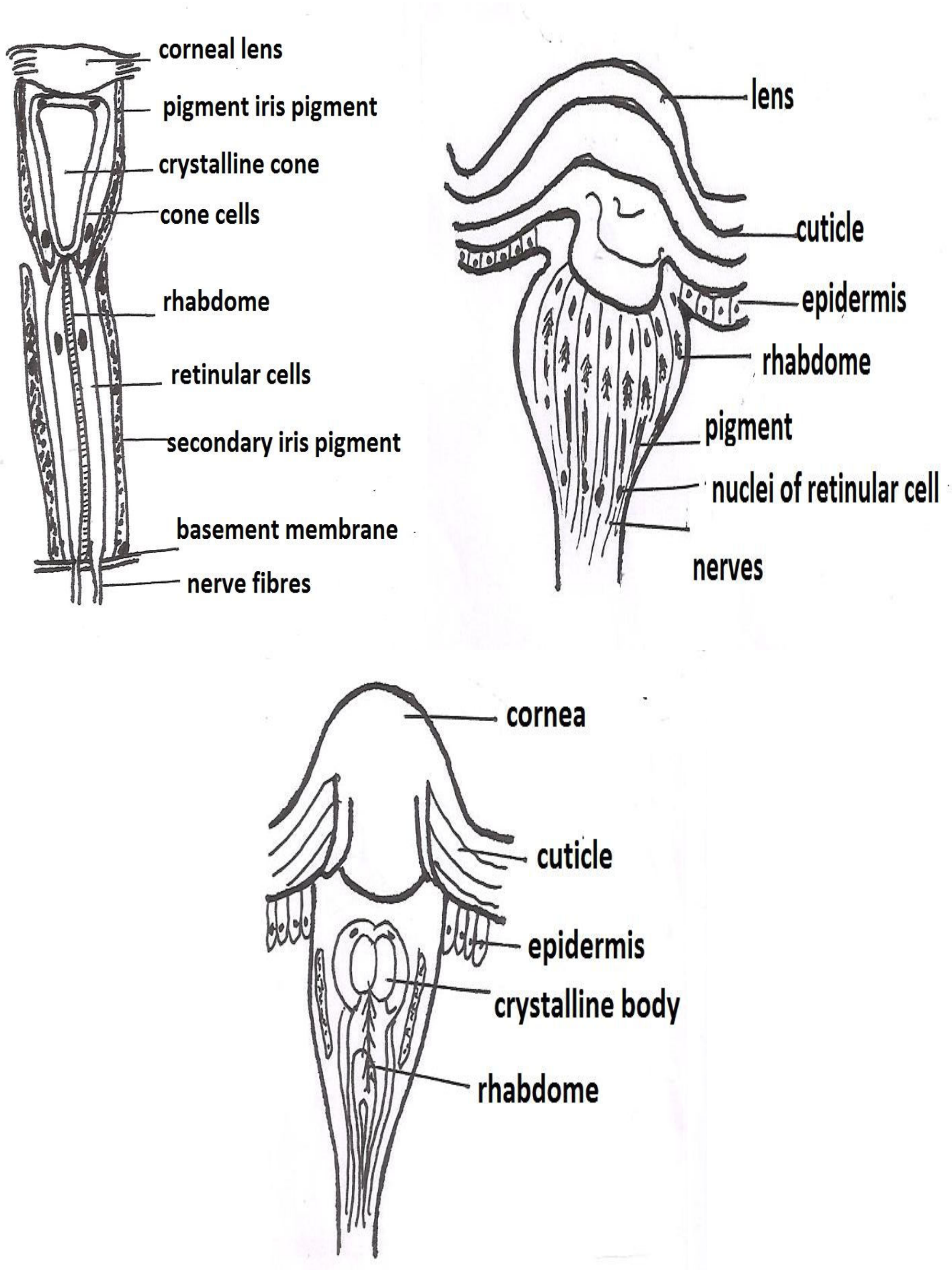


FIG 6.7: A) Ommatidium B) Ocellus (Hemiptera) C) Stemmata (Lepidoptera)

6.4.6 Physiology of vision

Insects have binocular vision and sensitive to UV and blue green light of electromagnetic spectrum. Bees are attracted towards yellow flower as flower reflects UV rays. They are also red color blind except butterflies which can recognize red flower. Two types of images are formed (apposition and superposition) and on this basis ommatidium is also differentiated into two types (photopic and scotopic).

1. **Apposition image/ photopic ommatidium**- In these pigment cells get extended and isolates ommatidium so that light rays can pass through the central axis. The other light rays get absorbed. This type of image is formed in diurnal insects (FIG 6.8).
2. **Superposition image/ scotopic ommatidium-** Pigment cells are in contracted state so that each rhabdom receives various light rays from many lenses. This type of image is formed in nocturnal insects (FIG 6.9).

The sharpness of image depends upon the number of ommatidia per unit surface area of the eye. Since the surface of the eye is curved, insect can detect the distance to their prey or predator from them.

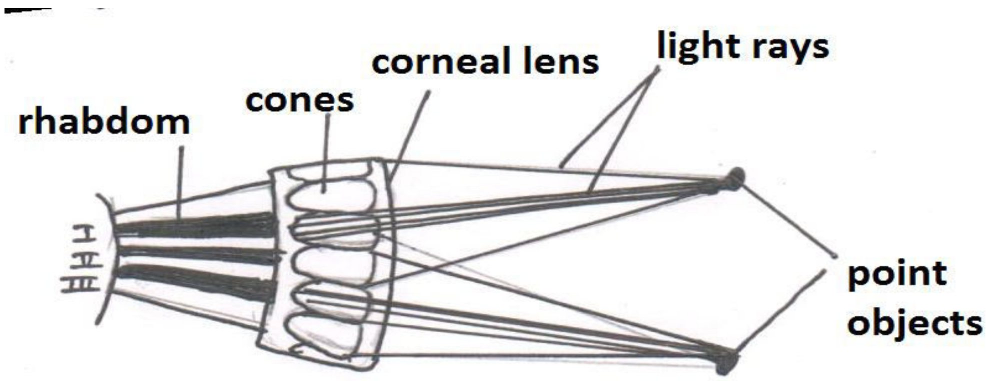


FIG 6.8: Apposition image

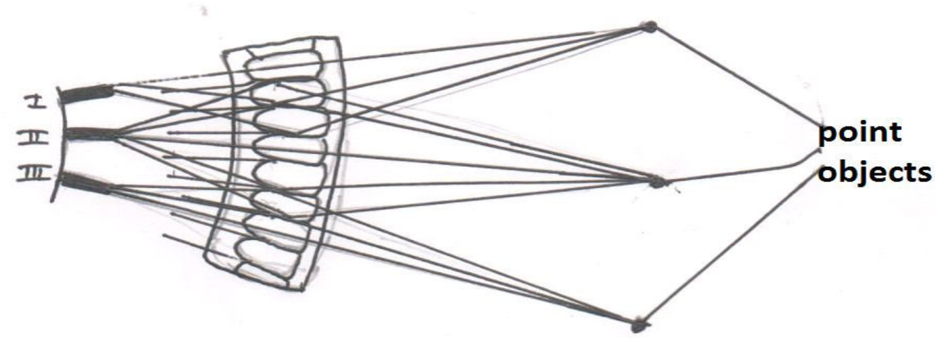


FIG 6.9: Superposition image

6.5 Reproductive systems

Insects have a high rate of reproductive rate and a short generation time, so that they evolve faster and can adapt to environmental changes much faster than other slower breeding animals. There remains a basic design and function for each reproductive part as all the animals have like gonads, accessory gland and external genitalia.

Reproductive system is meant for mating and reproduces young ones. Although sexual reproduction is common to insects but there are many insects which have special type of development like parthenogenesis, polyembryony or paedogenesis. The two individual male and female shows sexual dimorphism in many insects but in some by examining the external features one is not able to differentiate between them. In some insects male and female reproductive organs are found in same individual, phenomenon called **hermaphroditism** as in case of *Drosophila* and scale insect. Reproductive organ produces ova and sperms like that of vertebrates with common character as they are unicellular, haploid, ova larger than sperm.

6.5.1 Structure and Physiology

Female Reproductive System

A pair of ovaries present on either side of the abdomen. Each ovary is divided into many functional units named ovarioles. Ovariole lies parallel to each other and are the site of production of ova. Ovarioles in Diptera and young ones of many insects covered with layer of peritoneum called peritoneum sheath. This sheath disappear with growth and are absent in adults. The number of ovarioles may vary from one insect to another for example, 1 in tse-tse fly, dung beetle and beetles to 2,000 in termite queen. Ovariole is divided into three parts terminal filaments, egg tube and pedicel. Terminal filament is the topmost part of ovariole with egg tube in middle and pedicel at the end (FIG 6.10). Egg tube further divided into germarium containing germ cells and vitellarium where egg grows in size. Germarium produces two types of cells cystocytes give rise to follicle cell and trophocyte giving nurse cells. During active oogenesis, new oocytes are produced within each ovariole and migrate toward the basal end of the ovariole. Each oocyte undergoes meiosis yielding one egg and three polar bodies which may disintegrate. As the developing egg grow in size by absorbing yolk (produced by nurse cells) move down the ovariole. Each ovariole contains a linear series of eggs in progressive stages of maturation. By the time an egg reaches the base of ovariole pedicel it becomes fully mature and up to 100,000 times larger than the original oocyte. A mass of follicle cells plugs the pedicle and get dissolved when egg is laid.

Function: The female insect's main reproductive function

- is the production of eggs,
- to protect egg by covering them with egg's protective coating,
- to store the male gametes until egg is ready for fertilization

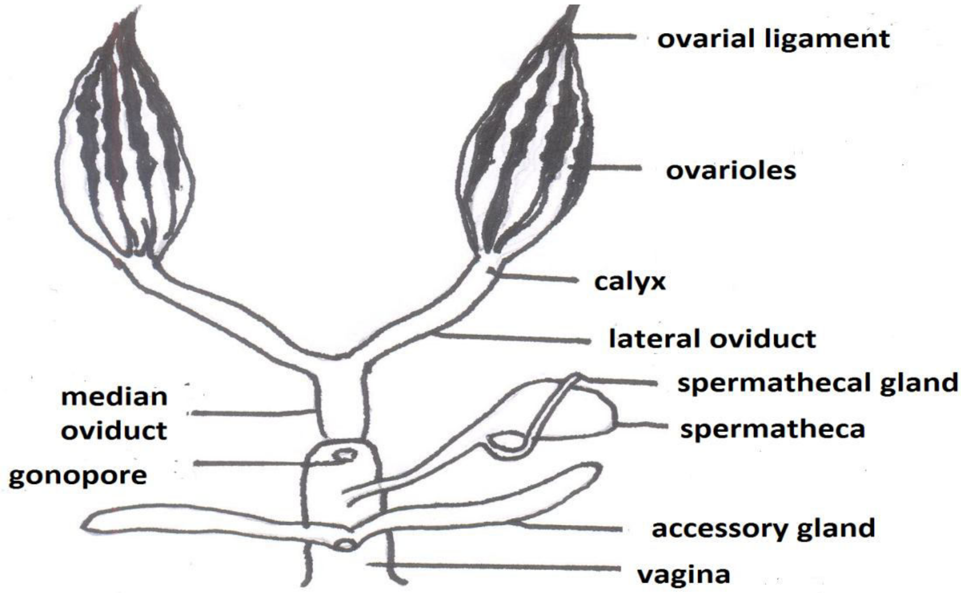


FiG 6.10: Female reproductive system of an insect.

Types of egg tube:

- **Panoistic type-** In these nutritive cells is absent and nutrition is directly absorbed by the follicular cells. Example, Apterygota, Odonata, Orthoptera, Isoptera (crickets, grasshoppers, termites, dragonflies, stoneflies and fleas, FIG 6.12, A).
- **Meroistic type-** Nutritive nurse cells are present.
  - **a) Polytrophic type-** Nurse cells are present in succession with the oocytes. Example: Neuroptera, Coleoptera, Lepidoptera, Hymenoptera, Diptera (antlions, moths, butterflies, wasp, bees, flies, FIG 6.12,C).
  - **b) Acrotophic/telotrophic-** Nurse cells are confined to the top of the egg tube and oocytes get their nutrition by nutritive cords. Example: Hemiptera, Coleoptera (bugs, most beetles, FIG 6.12,B).

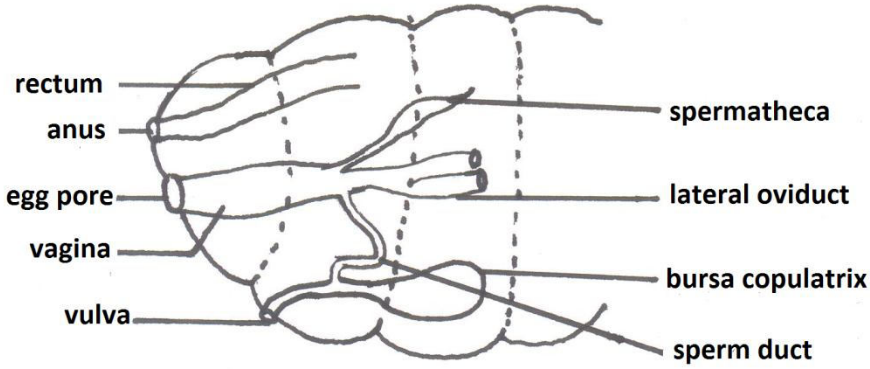
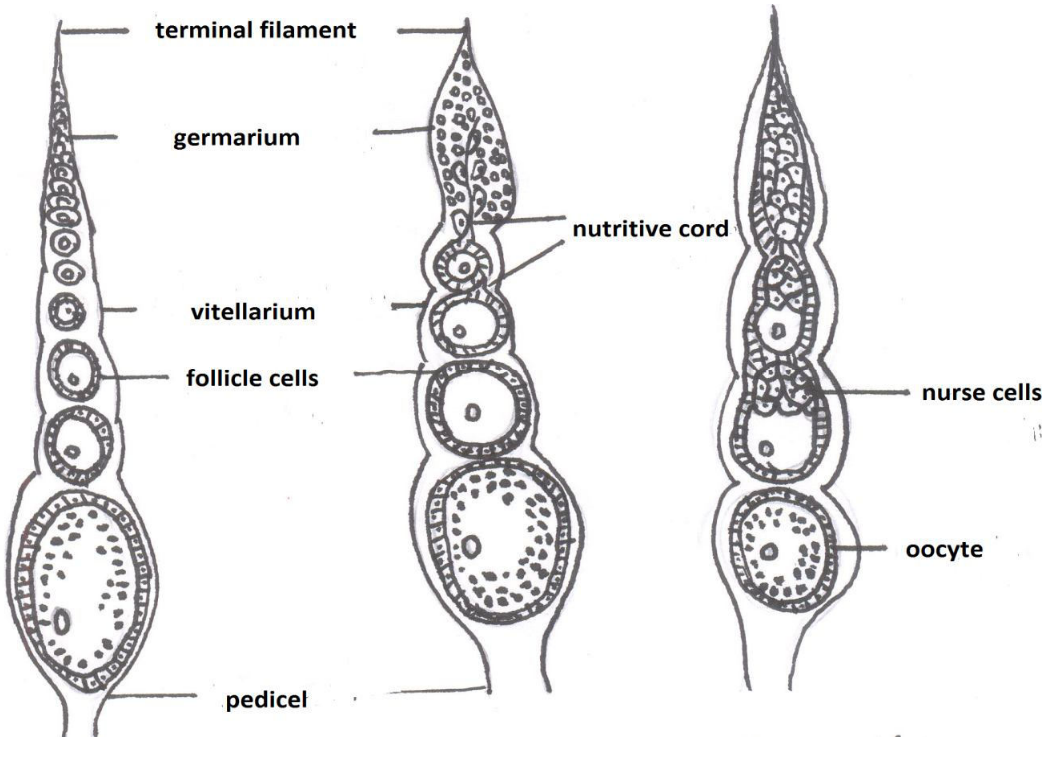


FIG 6.11: Lepidoptera female reproductive system



A B C

FIG 6.12: Types of ovariole A) panoistic B) telotrophic C) polytrophic

Mature eggs leave the ovarioles passing through the calyx and move towards short lateral oviducts. It is mesodermal in origin and muscular due to the presence of circular and longitudinal fibres. These lateral oviducts join to form a common median oviduct ectodermal in origin and muscular which opens into a genital chamber called the bursa copulatrix. Female accessory glands/collateral gland are also associated which supplies lubricants for the reproductive system and secrete a protein rich egg shell/chorion that surrounds the entire egg. It also forms ootheca. Poison gland in Hymenoptera is modification of these accessory glands. These glands are usually connected by small ducts to the common oviduct or the bursa copulatrix. Bursa copulatrix is a pouch like chamber meant for storage of sperms. During copulation, the male deposits his spermatophore in the bursa copulatrix. The protein coat of the spermatophore is digested by the enzymes secreted by spermathecal gland and nutrients for nourishing the sperm. Sperm may live in the spermatheca for weeks, months, or even years.

With some exceptions like flesh flies are viviparous and in them genital chambers enlarges to form uterus. In Lepidoptera and certain water beetles there are two openings one is oviporus where egg is discharged and vulva is a copulatory opening (FIG 6.11). In Ephemeroptera lateral oviducts opens independently to the exterior.

Male Reproductive System

Sperm development usually takes place by the time the insect reaches adulthood. Male reproductive system contains a pair of testes, vasa deferen, paired ejaculatory duct and accessory glands. Testes are usually paired except in Lepidopetra (locust and moth) where they are fused to form a single median organ. Each testis is subdivided into parallel arranged functional units called tubular follicles bounded by connective tissue sheath. The number of testicular follicle may vary as 1 in certain beetle, 2 in lice and upto 100 in grasshoppers. Spermatocytes formed in testicular follicles migrate toward the basal end of the follicle undergoes meiosis and yields four haploid spermatids which mature to form spermatozoa/sperms. Mature sperm pass out of the testes through short ducts called vas deferns to the seminal vesicles where they are stored. Vas deferns join one another near the midline of the body, and form a single ejaculatory duct that leads out of the body through the male's copulatory organ (called an aedeagus).

One or more pairs of accessory glands are connected with the male reproductive system through short ducts. They open near the testes or seminal vesicles or sometimes ejaculatory duct. The glands have function of manufacture of liquid seminal fluid that sustains and nourishes mature sperm while they are in the male's genital system (FIG 6.13). Vas deferens is mesodermal, ejaculatory duct is ectodermal and accessory glands may be ecto or mesodermal in origin. In Ephemeroptera vas deferens opens directly to outside without forming ejaculatory duct.

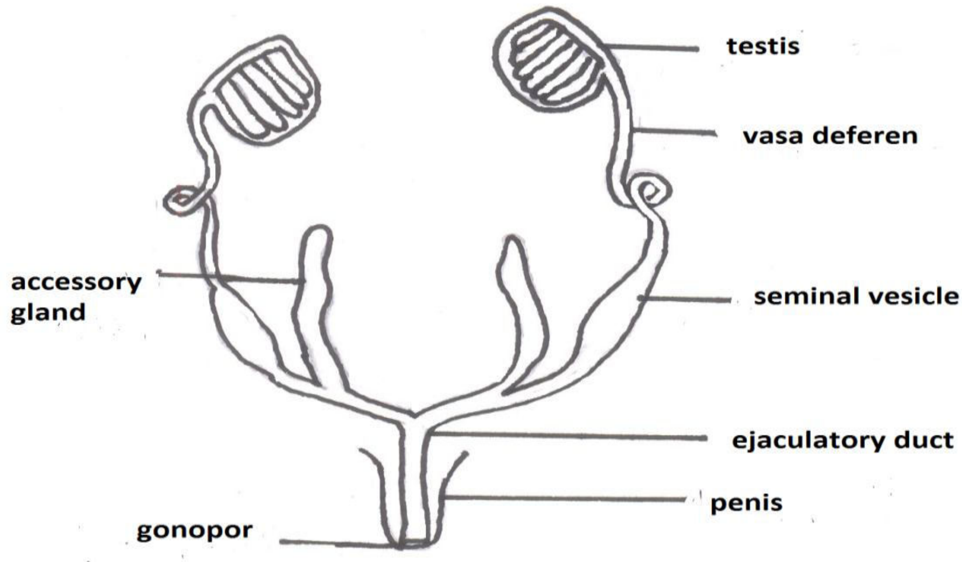


FIG 6.13: Male reproductive system of insect.

Spermatophores are pouch-like structures made up of protein that encase the sperms and protect them while delivering to the female's body during copulation.

Function:

The male's main reproductive function

- is formation of male gametes ;
- storage of spermatozoa and;
- to provide transport of the sperms to the reproductive tract of the female.

6.4.2- Role of pheromones in reproduction

The sexual maturation is effected by quantity, quality of food, population density, mating, temperature, humidity and also photoperiod. The two endocrine glands are also influencing the reproduction corpora allata producing hormones from ovaries in some insects; it also has both ganadotrophic and metabolic effect. In various insects different pheromones are secreted which are specific in their function.

- **Maturation accelerating pheromones**-In locust, *Schistocerca gregaria* if females are abundant, their egg matures faster than the isolated females due to their increase in endocrine activity. Here in the presence of mature male's egg development in females is promoted due to maturation accelerating pheromones. Greyish brown color of newly emerged insect changes to yellow color in mature males is identified in Acrididae.

- **Maturation inhibiting pheromones**-In social insects such as in honey bees there is only one queen per bee hive. This is due to the fact that queen secretes maturation inhibiting pheromones (9-oxodecenoic acid from her mandibular glands) that prevents the development of reproductive system in other workers.
- **Pheromones producing gland**- During sexual maturation certain changes may also occur in males as they develop characteristics behavior pattern and coloration.
- **Sex pheromones/ aphrodisiac**- Pheromones are also responsible for locating mate by producing signals. This signal or chemical or pheromone can be secreted by either by male or female or both. For example, *Bombyx mori* secretes bombykol, musculure from *Musca domestica,* male cockroach secretes seducing. Sex attractants pheromones used to locate mate from a distance followed by courtship pheromones used before mating. Butterfly *Danus gilippus* have several abdominal hair pencils produces pheromones that dusted on antenna of male while both are flying. Female then folds her wings and allows copulation. This pheromone is named as danaidone which is a pyrrolizidine alkaloid.
- **Fecundity enhancing pheromones**- In Diptera and Orthoptera these pheromones are likely to be produced in semen which stimulate female to produce oviposition hormone.
- **Spacing pheromones**- These are produced by some immature and adults that may be tactile or olfactory, may release to oviposition. *Rhagoletis pomonella* (apple maggot fly) females produces these chemicals to deter oviposition by other females. *Oecophylla longinoda* (African weaver ant) secretes for even dispersal of colonies. *Pieris brassica* larva secretes to inhibit egg laying of adult females in same place.

6.5- Summary

Neuro-endocrine system comprises of neurosecretory cells and hormones produced by endocrine glands. Different glands are prothoracic glands, corpora cardiac, corpora allata and neurosecretory cells of the brain. The hormones secreted by these glands are JH, ecdysone which are involved with the metamorphosis and moulting. Corpora allata are responsible for polymorphism in insects. Pheromones are trail making, territory making, sex pheromones, aggregation, alarm and caste differentiating pheromones. Sense organs are specialized structures which receive external stimuli and pass information to the central nervous system. Sense organs are mechanoreceptors, chemoreceptor, tactoreceptors, audio and visual receptors. Reproductive system is meant for mating and reproduces young ones. Although sexual reproduction is common to insects but there are many insects which have special type of development like parthenogenesis, polyembryony or paedogenesis. Male and female shows sexual dimorphism in many insects.

The female reproductive organs include, paired ovaries, and paired lateral oviducts that join to form the common oviduct. The external opening gonopore from common oviduct is concealed in a cavity called the genital chamber which serves as a copulatory pouch during mating. The spermatheca and accessory glands are meant for nourishing the spermatozoa in the vagina.

The male reproductive system contains two testes, consisting of follicles in which the spermatozoa are produced. Testes open individually into the vas deferens meant posteriorly for storage of the sperm. The vas deferents unite at posterior end to form a centrally placed ejaculatory duct, opens outside in the form of aedeagus or a penis. Accessory glands function to secrete fluid in the spermatophore which carry sperms and nourishes them.

6.7 Glossary

- **Hormones:** These are the chemicals which are secreted by endocrine glands and its function is to regulate internal environment of body.
- **Pheromones:** They are the chemical that triggers a natural behavioral response in another member of the same species.
- **Discontinuous polymorphism:** Termites and aphids shows discontinuous polymorphism as the forms are totally different to each other.
- **Continuous polymorphism:** Locust shows continuous polymorphism as the forms are slightly different.
- **Mechanoreceptors:** They are sense organs sensitive to physical touch.

- **Chemoreceptors:** They are the receptors deal with taste (gustatory) and smell (olfactory).
- **Audioreceptors:** They are sense organs sensitive to sound.
- **Hermaphroditism:** Male and female reproductive organs are found in same individual.
- **Panoistic type-** In these nutritive cells is absent and nutrition is directly absorbed by the follicular cells.
- **Meroistic type-** Nutritive nurse cells are present.
- **Moulting:** Insects have rigid exoskeleton and can grow only by periodically shedding their exoskeleton called moulting.

6.8 Self learning exercise

Section -A (Very Short Answer Type)

1. Where is brain hormone stored in insect body?
2. Which germ layer gives two prothoracic glands/ecdysial gland?
3. Two small glandular bodies named corpora allata present on either side of ………………..on sides of the oesophagus
4. The word hormone was given by which scientist?
5. Give the synonym of Prothoracicotropic Hormone (PTTH)?
6. What is composition of JH?
7. The term *pheromone* was introduced by …………………………?
8. Write other name of pheromones?
9. How many cycles beat in a second that produces sound in mosquitoes?

Section -B (Short Answer Type)

1. Define ectohormones and hormones?
2. What is Johnston’s organ?
3. Name some examples of sound producing organs?
4. What is difference between compound eye, stemmata and ocelli?
5. Define bioluminescence phenomenon?
6. What is the mechanism and function of light production?

Section -C (Long Answer Type)

1. Briefly explain male and female reproductive organs in insects?
2. Write a short note on mechanoreceptors and chemoreceptors?
3. What are different images formed by compound eye?

4. Write a note on sense organs?
5. What is the role of pheromones in reproduction?
6. How Endocrine control Polymorphism in insects?
7. What are ovarioles and its types?

Answer Key of Section-A

1. Neuro-haemal organs
2. Ectodermal layer
3. Corpora cardiac
4. C. M. Williams
5. Ecdysone
6. Non sterolic compound generally terpenoid
7. Peter Karlson and Martin Lüscher (1959)
8. Ectohormones
9. 280-340 c/sec

6.9 References

- Cedric Gillot: Entomolgy
- Kachhwaha N.: Principles of Entomology- Basic and Applied

Unit - 7

Insect Embryology

Structure of the unit

7.1 Objective

After going through this unit we will understand the

- How the egg of insect look like and a way it is different to others?
- The development of egg into advance stages.
- Special forms of embryonic development.

7.2 Introduction

Eggs are laid by female insects with the help of ovipositor external genital organs. In almost all insects sperms enter the egg via opening called **micropyle**. Male and female nuclei fuses after eggs are laid. Embryonic development starts with first mitotic division and ends at hatching. The eggs of exopterygotes have more yolk amount then that of endopterygotes which has less yolk in it. More yolk enhances more rapid formation in the egg. The eggs of endopterygotes are smaller in size in relation to body size of the insect so they develop more rapidly as compared to the exopterygotes. In case of parasitic Hymenoptera and viviparous Diptera eggs have no yolk. The size of the egg is inversely related to the developmental rate. Males and females are meant for sexual reproduction but there are some representatives in which males are rare or absent. So in these insects special forms of embryonic development takes place like parthenogenesis, polyembryony, viviparity and paedogenesis.

7.3 Egg

Insects are oviparous lays egg which hatch into larva/ nymph. It is the first stage of life cycle of an insect. Eggs are laid in groups or singly or in specialized egg case or bag called **ootheca** like cockroaches or in ground as in egg pods of grasshoppers or on water surface in case of mosquitoes. Their shapes also vary species to species may be oval, spherical, disc like, barrel shaped, sausage shaped or torpedo shaped (FIG 7.3). It is a single living female gamete cell. The size of egg varies between 0.02-20mm lengths and is comparatively larger as proportionate to the body size of female. Eggs are produced in female genital tract by the process **oogenesis** and are released through the ovipositor. The process of laying egg is known as **oviposition**. Egg is covered with two membranes of **chorion**/egg shell i.e outer exochorion and inner endochorion. Chorion is secreted by the follicle cells of ovary. Follicle cells are mesodermal in origin and cuticle like in nature made of protein and lipoprotein. Inner to the chorion a layer is present called **vitelline membrane** which the oocyte itself. Chorion forms a wax layer between outer chorion and inner vitelline membrane that makes the egg waterproof (FIG 7.1). Eggshell protects the egg from the surrounding and desiccation. The yolk is made of yolk protein, lipids, carbohydrates, special proteins and mRNAs that direct embryogenesis. There are also some **aeropyles** or holes from which air enters directly from the atmosphere.

Aquatic insects do not have aeropyles and dependent totally upon eggshell. One or more small openings called micropyle (FIG 7.2) present at one end of egg to facilitate the entry of sperm. Egg contains a cortical layer of protoplasm and centrally placed yolk. The nucleus is centrally placed but during fertilization it moves to periphery. Eggs are glued to the surface with the help of secretion by accessory glands of female. Some insects lay their eggs in clusters or some singly. The shape, size, number of egg laid differs with species. Eggs are so small in size that they can easily desiccate so female insect selects perfect site to lay their eggs on plant surface, water, fruits, pods, leaves and also on other insects or host. The number of eggs or offspring produced by an individual is called its fecundity. It is a figure which expresses the total output of a lifespan of insect.

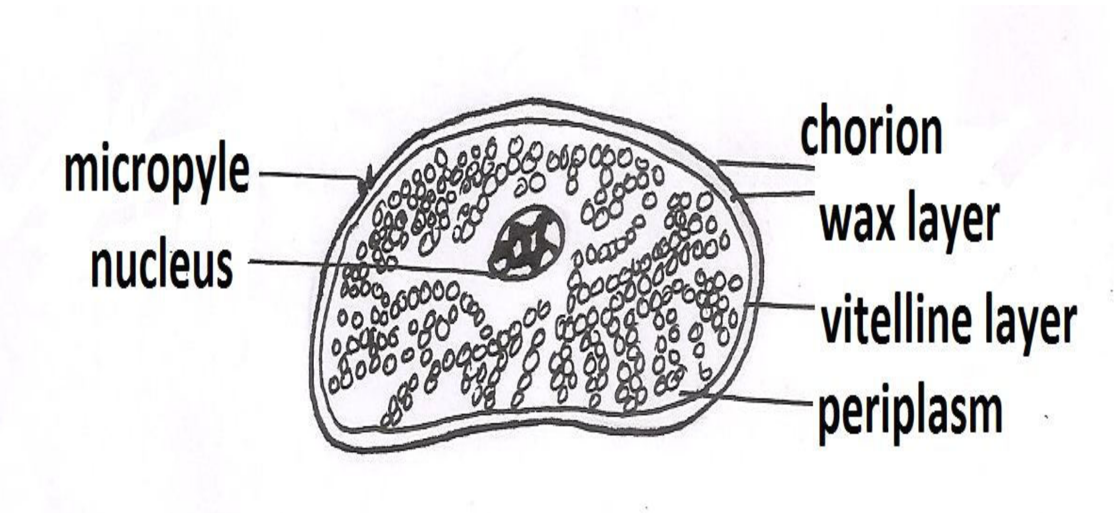


FIG 7.1: Structure of egg

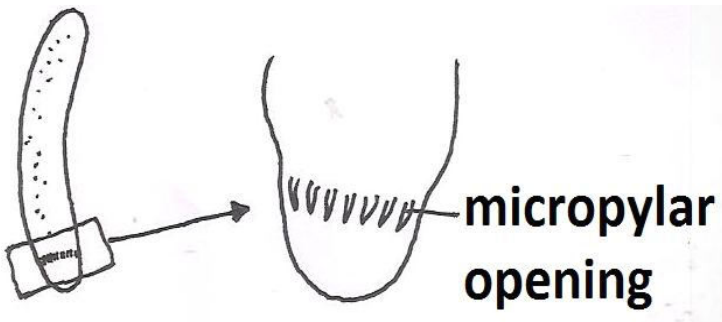


FIG 7.2: Egg of locust showing micropylar region

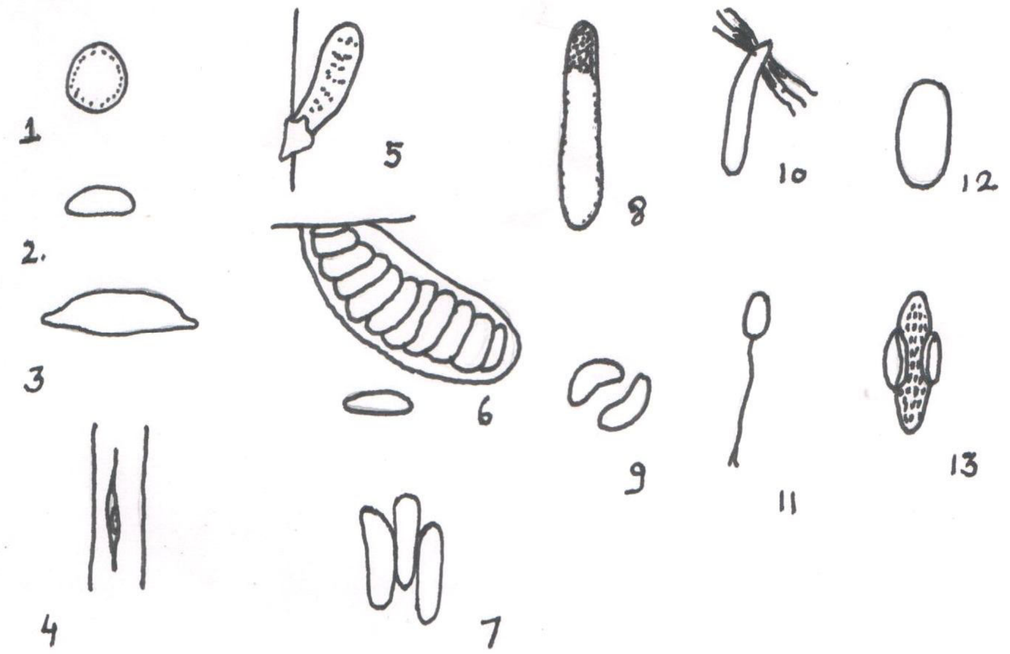


FIG 7.3: Different types of eggs 1. Springtail egg 2. Aphid egg 3. Ichneumon wasp egg 4. Weevil egg in stem 5. Cattle louseegg on hair 6. Grasshopper egg pod with a single egg 7. Housefly egg 8. Damsel fly egg 9. Eggs of thrips 10. Egg of plant bug 11. Egg of lace wing 12. Webbing cloth moth egg 13. Mosquito egg

7.4 Egg development

Embryogenesis is a process which starts once the egg becomes fertilized. One cell divides and redivides by cleavage to form hundreds of cells. It includes multiplication of cells by mitosis, their growth, movement and differentiation. The yolk protein present in the oocyte of insect are the stored nutrition required for embryogenesis. The degradation of yolk proteins triggers the ecdysteriod so that cuticle formation takes place. Egg development takes place in various steps as follows:

7.4.1Cleavage

After male and female nuclei fusion the zygote nucleus moves towards the centre. The zygote starts dividing by mitotic divisions and first cleavage is predetermined at the site called **cleavage centre** which is the future head region. This region id determined when the sperm enters the egg or egg are laid. Nuclear division not followed by cytoplasm division so that the condition is known as synctium (multinucleate condition) in early stages.

Synctial cleavage occurs in most insects except entognathous Collembola and sub phyla Onychophora where total cleavage occurs. While Chelicerates horseshoe crab, spider, scorpion, spider shows both synctial and total cleavage. At later stages nucleus moves towards periphery and surrounded by cytoplasm and now called cleavage energid. This type of cleavage is called as superficial cleavage. In case of exopterygotes and endopterygotes except apterygotes the energids are connected to the cytoplasmic bridges.

7.4.2 Blastoderm formation

The synctial cleavage rapidly gives up to 6000 nuclei. In some cases the nuclei moves to periphery after 64 energid stage and in sometimes after 1024 energid stage. In paleopterans and hemipteroids the energids are uniformly distributed but in case of orthopteroids the posterior pole of the egg receives first energid. The cleavage nuclei moves to periphery forming a continuous form of layer surrounded by yolk called blastoderm. It is a single thick layer of cells that surrounds the yolk. Mostly not all the cleavage energid moves towards periphery but some of the divided energid behaves as **primary vitellophages** which digest the yolk. In case of Lepidoptera and Diptera all the moves to periphery and then return back to centre known as **secondary vitellophages**. The secondary **v**itellophages are produced to supplement the primary vitellophages. Whereas tertiary vitellophages are also produced in some insects like cyclorrapha in order Diptera and apocrita in order Hymenoptera. The insect egg has a superficial area of cytoplasm which does not have yolk called **periplasm.** It surrounds the whole egg and cleavage takes place here. The centrally placed yolk enriched region is called **endoplasm** and this area is not involved in cleavage (FIG 7.4).

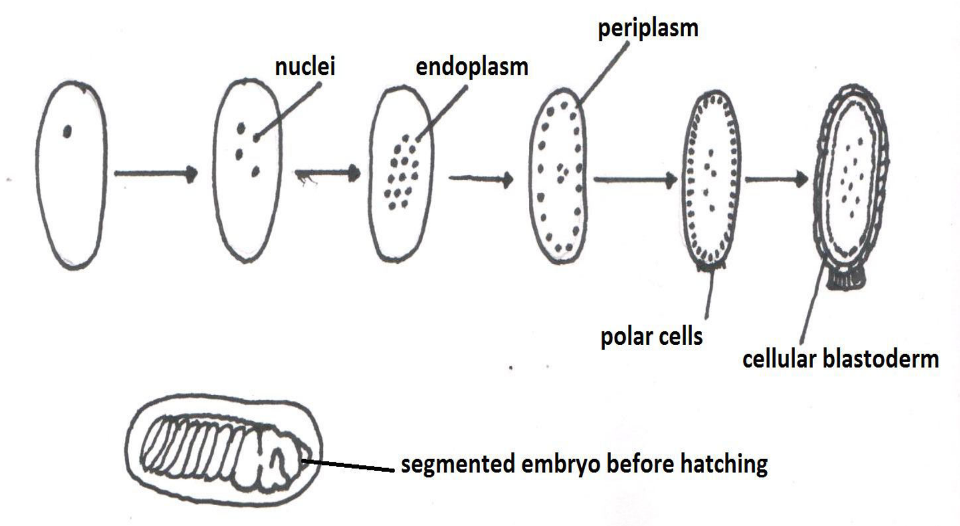


FIG 7.4: Diagram showing the cleavage in egg with cytoplasm divided into periplasm and endoplasm. Nuclei line up along surface to form cellular blastoderm.

7.4.3 Germ bands

The first cleaved nuclei do not travel to periphery instead they are reserved for future germ cells. They migrate into developing gonads to become primary oocytes and spermatocytes. The posterior mid ventral side of blastoderm forms thicken closely packed columnar cells known as embryonic primordium. In Diptera and Hymenoptera the primordium occupies both ventral and lateral areas of egg with dorsal extraembryonic ectoderm (FIG 7.5). The differentiation in insect development is triggered and controlled by two centers as activation center and differentiation center. The primordium elongates and differentiates into germ band. The bastoderm starts moving inside towards yolk by the process invagination or proliferation. This results in formation of two layered embryo outer ectoderm and inner meso-endoderm. Germ cells rarely grow or divide during process of embryogenesis. In Lepidoptera the movement of germ cells takes place in the middle of blastoderm which is exceptional to other insects where it moves to posterior end region of egg. As the germ band elongates and broader, segmentation and limb bud formation with initial development of somites are accomplished. In Paleopterans, most Orthopteran and Hemipterans shows a series of embryonic movement where **anatrepsis** i.e immersion of germ band and **katatrepsis** reverse process bringing the embryo back in position on surface. The function and requirement of these processes are still unknown.

7.4.4 Gastrulation and segmentation

Blastoderm formation is followed by gastrulation. As the blastoderm sinks it forms gastral groove that soon forms anterior stomodeum and posterior proctodeum. The mesodermal cells soon divide into segmental blocks/ somites. Germ band now elongate undergoes repeated units and forms the gnathal, thoracic and abdominal segmentation. This is followed by organogenesis (FIG 7.7).

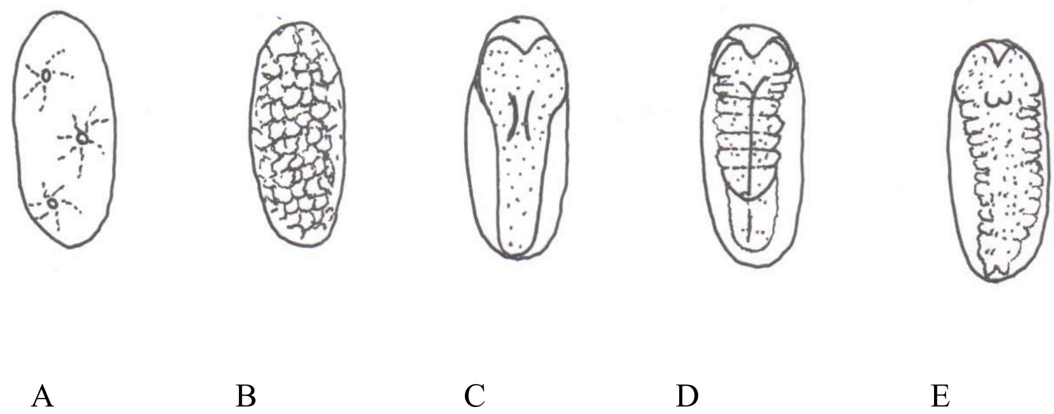


FIG 7.5: T.S of developing egg showing germ band and amniotic cavity A) Synctial cleavage B) formation of cellular blastoderm C) gastrulation D) germ band after gastrulation and amniotic fluid E) Advanced germ band stage

7.4.5 Extra embryonic membranes

With the formation of somite and gastrulation two extra embryonic membranes outer amnion and inner serosa (FIG 7.6) develop from ectoderm. Cells from the germ band moves on each side to give amniotic folds. These folds meet and fuse ventrally to form amnion and serosa. Amnion is continuous with the germ band and covers only embryo. Serosa is a layer which covers both embryo and yolk. In Apocrita (Diptera) extra embryonic membranesis, amniotic folds not formed in Cyclorrypha (Diptera) both amnion and serosa not formed. In Orthoptera third layer called indusium formed, in Strepsiptera anly amnion is present and in viviparous species a single trophamnion is present.

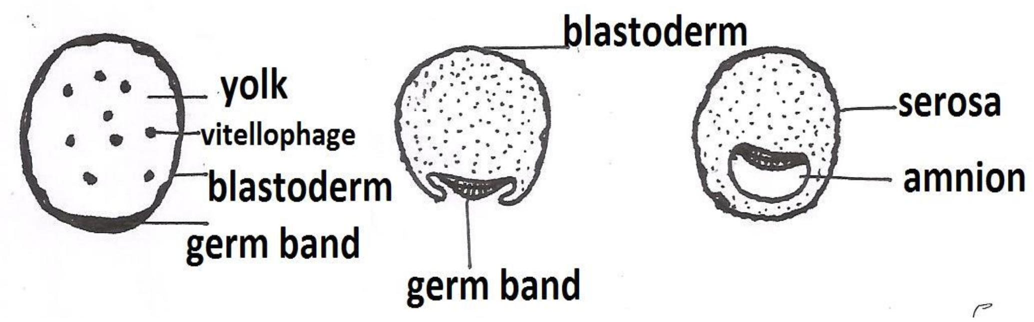


FIG 7.6: T.S of developing egg showing germ band and amniotic cavity

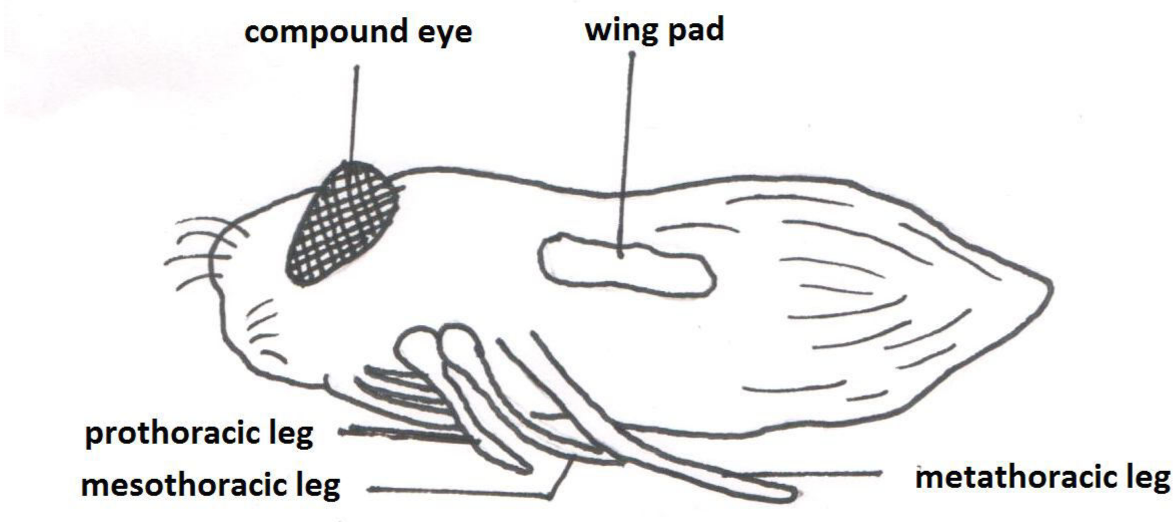


FIG 7.7: Diagram showing the early stage of developing wing, eye, legs

Factors affecting embryonic development:

- **Temperature**: It is the most important physical factors which is associated with the development. For every egg of specific genus there is certain lower and upper limit beyond which the development retards.
- **Water**: It is another important factor for development to takes place as sufficient amount of water is needed. If there is less moisture and water content the egg undergoes in diapauses state. The egg may remain in dormant state up to one year in case of *Aedes* egg.
- **Heat**: The total heat required is measured by minimum required temperature and duration of exposure to this temperature which can be measured in degree days.

7.5 Viviparity

Insects lay eggs means they are oviparous (FIG 7.8) but in some cases the offspring are retained in female genital tract and this phenomenon is called viviparity (FIG 7.10). Whole embryonic development is completed in the body of female and produces larva or nymphs. Diptera order consists of wide variation among viviparity.

7.5.1-Ovovivparity

It is the simplest form of viviparity where eggs are retained in female genital tract but the nourishment they get from yolk. These insects only provide a safe brood chamber for development and not provide oxygen and nutrients to the developing offspring (FIG 7.9). For example, in Family Tachinidae eggs are laid just before they hatch. In other family Sarcophagidae, flesh flies larva hatches from egg while they are in the reproductive tract of females; for this reason it is also called larviparous. They lay less number of offsprings 40-80 approximately. Sometimes the instar in newly laid egg moults inside into second (*Hylemya sps*.) or third instar stage (*Termitoxenia sps*.).

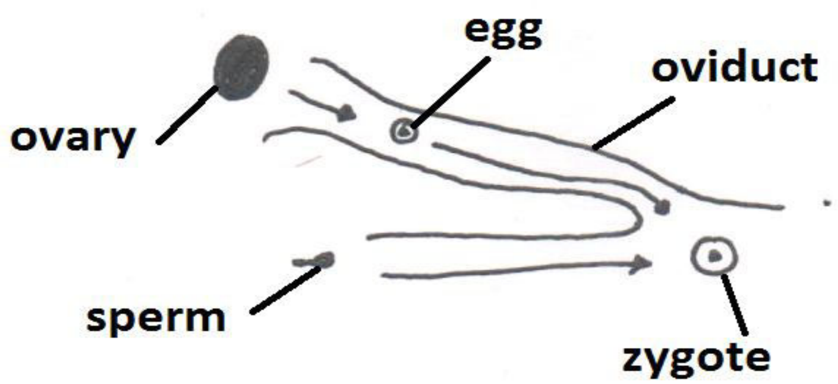


FIG 7.8: Oviparous (external fertilization and development external)

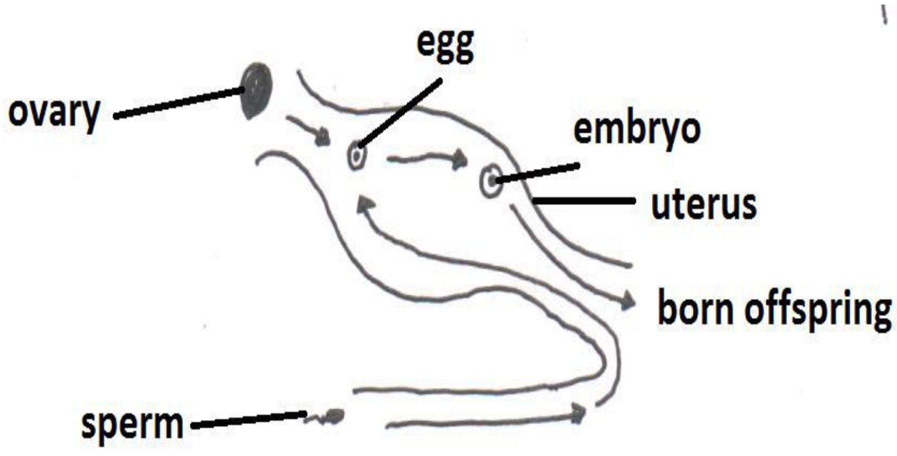


FIG 7.9: Ovoviviparous (internal fertilization and internal development)

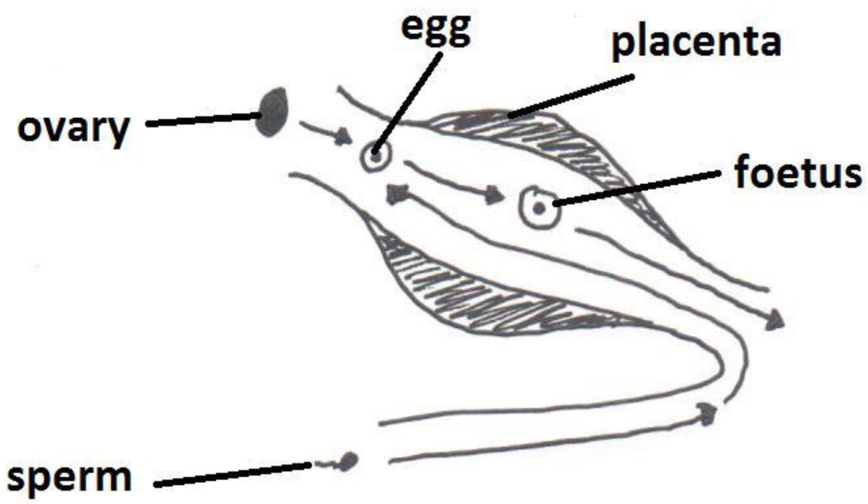


FIG 7.10: Viviparous (internal fertilization and internal development)

7.5.2 Pseudoplacental viviparity

In insects like aphids, Psocoptera, Dermaptera there is little or no yolk and with this also lacks chorion. Here follicles cell are supply some nourishment to the developing embryo. Follicle cells attaches to the embryonic membrane and forms pseudoplacenta. After supplying nutrient the follicle cells degenerate later. Grand daughter of a female aphid develop within the daughter embryo inside the mother. The mother receives environmental stimuli through the central nervous system (CNS). The mother converts this stimulus into signals which transmit to the daughter embryo in Aphids (FIG 7.11).

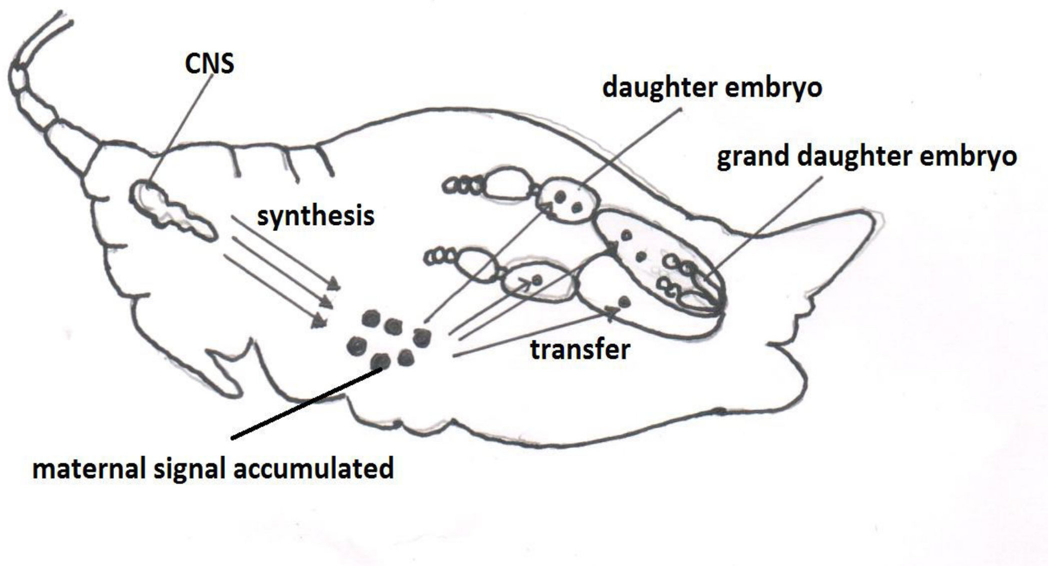


FIG 7.11: Transgenerational transfer of maternal signals in pseudoplacental viviparous Aphids

7.5.3 Adenotrophic viviparity

In some insects like *Glossina sps.* Egg consists of chorion and yolk but they are carried in expanded structure called uterus. Uterine milk is secreted by accessory glands for the larva that hatch within uterus. There is a transition state between lactation and non lactation period. During non lactation period called dry period lipid accumulates for the next lactation period (FIG 7.12). During lactation period lipolysis occurs and nutrient transfer to milk gland. After giving birth to the offspring they soon undergo pupation.

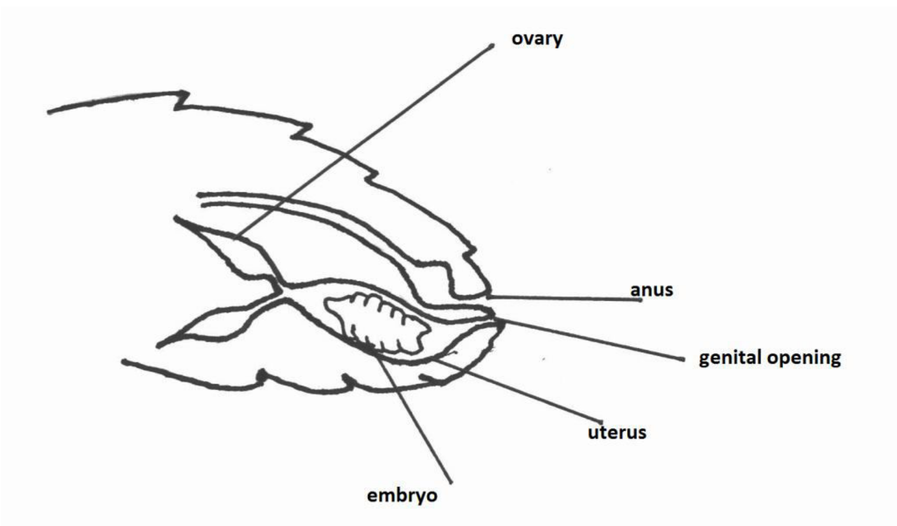


FIG 7.12: Tse tse fly showing developing embryo in uterus

7.5.4 Hemocoelomic viviparity

This is rather interesting phenomenon occurs in orders Strepsiptera and Diptera (Family Cecidomyiidae). In Strepsipterans ovarioles releases oocytes in haemocoel. Fertilization occurs within the body of female and nutrients are absorbed directly from hemolymph by the process of diffusion. Larva after hatching moves outside by genital pores. Well in case of Cecidomyiidae oocyte development takes place in ovarioles but after hatching larva move to hemocoel feed on her tissues and escape through integument just prior to pupation.

7.6 Polyembryony

It is the process in which several embryos form from one egg. For example, parasitic Hymenoptera as in case of Playgasteridae, Braconidae and Encyrtidae and one species of Strepsiptera. In these species eggs are small and lack yolk as they all are parasitic they depend upon host for their nourishment. In Hymeneoptera chorion is thin and permeable which soon disappears. After that serosa modify to form trophamnion which function to absorb nutrition from the host. Four cell stage of *Platygaster* which parasitize Hessian fly larvae separates into two embryos. In chacid hymenopterans which parasitize moth larva after 220-225 blastomere stage embryo formation takes place and may forms up to one thousand embryos. Most striking example of polyembryony is a competitive reproductive tool seen in family Encyrtidae of order Hymenoptera. These are parasitoid in which the progeny of splitted embryo develop into adult. Most of these parasitic wasp embryos develop into normal precocious larva which takes 30 days to develop and they do not undergo metamorphosis. When the precocious larva dies the normal larvae emerges from the first moult and develop further to normal adults. Polyembryonic wasp differs from other insects as it arises from a single egg that develops into many embryos (FIG 7.13).

Polyembryony started to be evolved parallel to the endoparasitism as the entire polyembryonic wasp and Strepsipterans are endoparasitic in nature. The eggs are laid into the egg or larval host and after oviposition egg develops into single embryo which clonally gives many additional embryos that together form a group called polymorula.

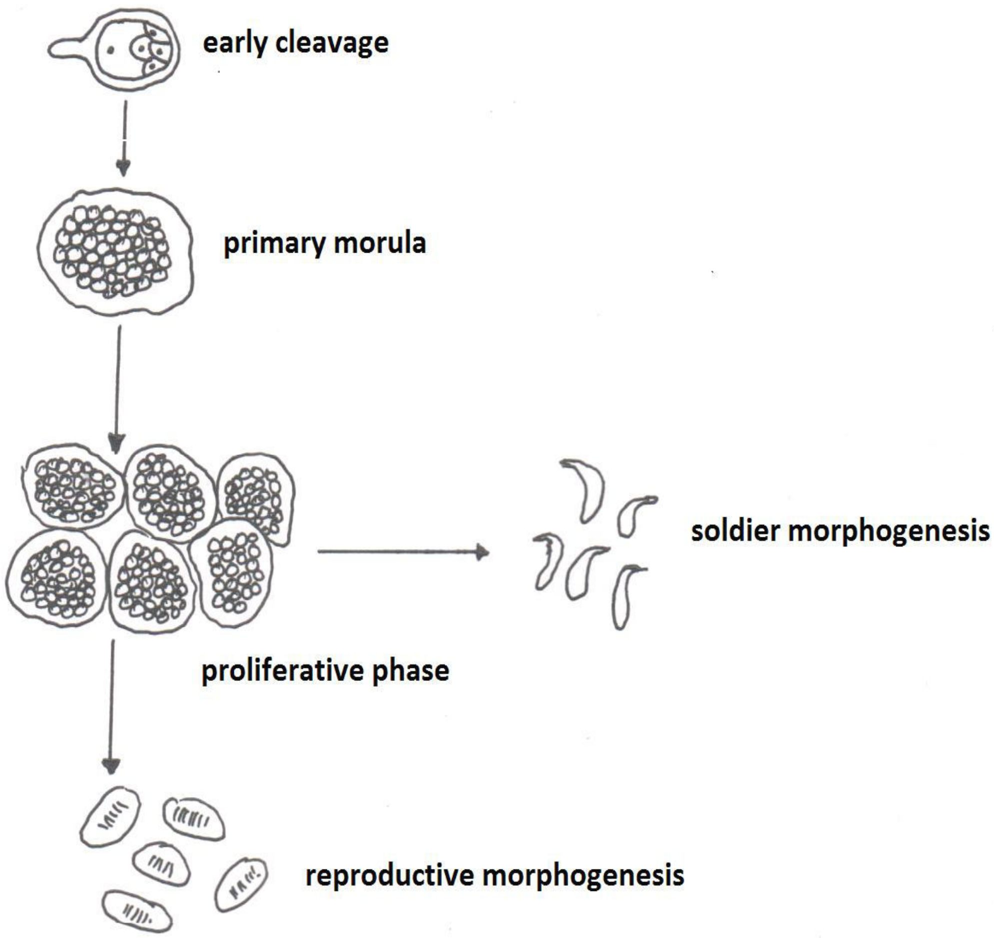


FIG 7.13: Diagram showing polyembryony in wasp *Copidosoma floridanum* in its host *Trichoplusia.* Egg undergoes early cleavage and formation of primary morula during host egg stage. Some embryo undergoes morphogenesis during this period and develops into soldier larva. Majority of embryo initiate morphogenesis at the end of 4th larval instar and develop into reproductive larva that consume the host at the end of 5th instar

7.7 Parthenogenesis

Parthenogenesis is a Greek word means partheno- virgin+ genesis – origin. The organisms going under this process are called **parthenotes**. There are some insects which under certain conditions shows normal mode of reproduction in the form of parthenogenesis. It is the ability of the egg undergoes development without fertilization. It can be classified into;

1. **Based on occurrence**

    a) **Facultative parthenogenesis**: It is not compulsory as a rule in insect development as in bees.
    b) **Obligatory parthenogenesis**: It can be induced naturally, constant and compulsory in insect's life called **obligatory parthenogenesis as in stick insect**.
    c) It can artificially produced called **induced parthenogenesis** by treating insects with weak salt solution, organic acids, electric shocks or irradiation.
2. **Based on generation**
    a) **Complete parthenogenesis**: The female insect is homogametic contains XX (2 x sex chromosomes) and male insect is heterogametic contains XY or XO. The natural parthenogenesis can be **complete parthenogenesis** (aphids) in which males are unknown and population consists of only females. It gives diploid offspring from diploid females.
    b) **Cyclic parthenogenesis:** The other type of natural parthenogenesis is **cyclic parthenogenesis** (bees and wasps) where sexual generation alternates with parthenogenetic generation. So if the female produces daughter offspring without involvement of males they can produces two three folds more offspring as compared to the normal sexual reproduction.
3. **Based on sex produced**
    a) **Arrhenotoky**: only males are produced as in bees
    b) **Theytoky**: only females are produced as in aphids
    c) **Deuterotoky**: both male and female are produced as in cynipid wasp.
4. **Based on meiosis**
    a) **Apomictic**: no meiosis occurs
    b) **Automictic**: meiosis occurs

7.7.1 Haploid parthenogenesis/ Arrhenotokous

Here haploid eggs are formed by normal oogenesis but it do not fertilize by sperms/male gametes. Hence the adults are also haploid consisting of half the number of chromosomes. It occurs in Hymenopterans (bees and wasps), Homopterans (white fly), Coleopterans and Thysanopterans. In bees two types of eggs are laid fertilized and unfertilized. From unfertilized eggs males develops which is haploid and from fertilized eggs females develops which is diploid.

Adult bee → haploid ovum → male haploid (no fertilization)

Meiosis → female diploid (fertilization occurs)

7.7.2 Diploid parthenogenesis/ Thelytoky

It is the case of insects in which embryos develop from diploid egg but it is unfertilized. It is differentiated into ameiotic and meiotic thelytoky (FIG 7.14).

a) **Ameiotic thelytoky**: In meiotic process the reductional division is completely suppressed so that it is like mitosis and therefore the diploid condition is maintained. Example, *Daphnia pulex* and long horn grasshoppers.

b) **Meiotic thelytoky**: In this type normal meiotic division takes place and the egg possess haploid number of chromosomes. Diploid condition is obtained either due to restitution (non disjunction of chromosomes) or by autofertlization (fusion of ovum with polar body). Example, aphids in winter and summer develop two types of eggs larger diploid egg (2NX) which are female producing and smaller eggs are (2NX-X) which are male producing.

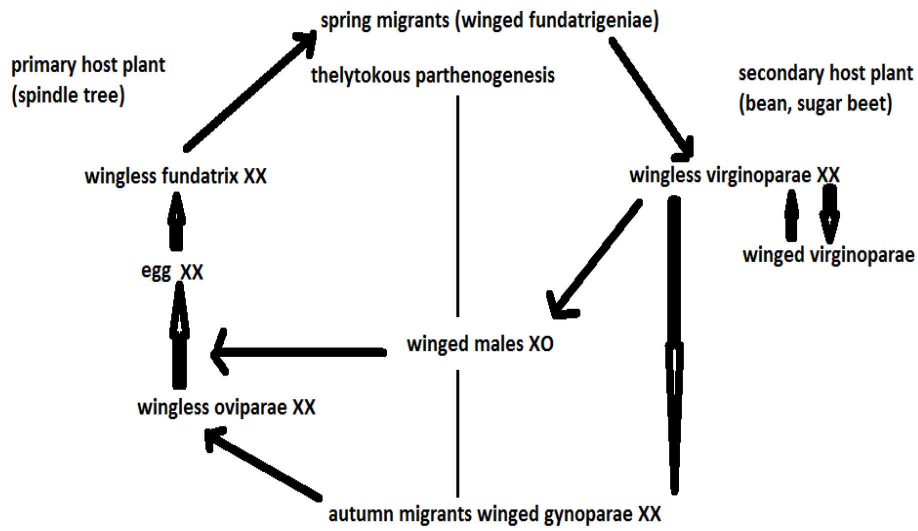


FIG 7.14: Life cycle of black bean aphid, *Aphis fabae*

7.7.3 Deuterotokous parthenogenesis

In these insects unmated female is able to produce male and female both progenies by parthenogenesis. Example, in lac insect there is no difference between sexually and asexually produced progenies except amount of lac produced, fertility and progeny sex ratio.

7.7.4 Significance

1. It gives an alternate mode of reproduction.
2. It is simpler and easier way or reproduction as compared to sexual reproduction.
3. It is a method which shows rapid mode of multiplication.
4. The individuals produced by these methods are alike and copies of parents.
5. It eliminates the disadvantages of non adaptive combination of genes.

7.8 Paedogenesis

Some insects cut short their life cycles by loss of some stages like pupa or adult. In this phenomenon the juveniles exhibit the power of reproduction by developing gonads and give birth to young ones. This term is given by **K.M. Bear** and **N.V. Vagner** discovered in the dipterous insect *Miasto*r of family cecidomyiidae for the first time. The ovaries in juvenile become functional and start reproducing (FIG 7.15). This is closely related to parthenogenesis and viviparity. Here the daughter larvae feed on the tissue of maternal larvae acting as endoparasite and came out by rupturing the host cuticle. It is an alternative to cope up with the inadequate fertility of adult forms. After several generation given by paedogenesis can retain normal sexual adult forms. There are two types of paedogenesis larval and pupal type.

- **Larval paedogenesis**: In this production of young by larval stages occurs. The representative is Ditera- Cecidomyidae, coleopteran- *Micromalthus debilis* (a beetle), gall midge, *Heteropeza pygmaea.* Here larval females produce more larva paedogenetically. This generation can give both types of larva male and females. Female larva can give rise to more female larva paedogenetically or adult females both but the male larva can only develop into adult male.
- **Pupal paedogenesis**: Occurs in gall midges *Miaster sps*. where embryo formed in haemocoel and term as hemipupa as it is different from normal pupa.

- **Neoteny**: the non terminal instar shows the reproductive properties of adult like ability to locate mate, copulate, deposition of egg as in case of scale insect and strepsiptera. Here female development stops at puparium stage and in male one or two instar stage is omitted and forms final immature instar.

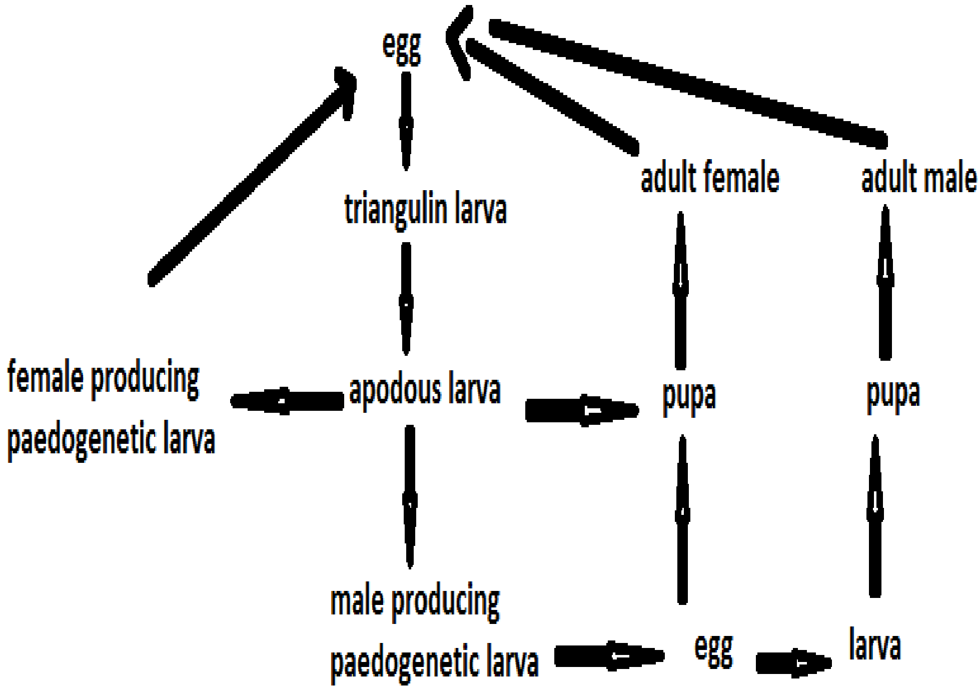


FIG 7.15: Paedogenesis

7.9 Summary

The structure of egg is specialized covered by layers chorion and vitelline membrane. It has a micropyle for entry of sperms during fertilization and contains yolk in it. Soon after fertilization cleavage is of superficial type where cleaved nuclei moves to periphery. The development of egg includes cleavage, one layered thick blastoderm formation surrounding the yolk, germ band formation (blastoderm of one side enlarge and multiply to give ventral plate germ band), the rest of the blastoderm forms serosa, gastrulation, segmentation and formation of extra embryonic membranes. There are various methods of development without undergoing the process of sexual reproduction. In some insects it occurs naturally because males are unknown and in others it occurs to fight against unfavorable condition. These special types of reproduction are viviparity giving birth to young ones and may be of different types as pseudoplacental, adenotropic, ovoviviparity and haemocoleomic types. Paedogenesis defines as reproduction by juveniles and may occur in larva or pupa or neoteny. Parthenogenesis is an unusual mode of reproduction in which development of egg without fertilization is of different type's arrhentokous, deuterotokous and thelytokous type. Polyembryony in which two or more embryos develop from a single egg and occurs in the parasitic Hymenopteras.

7.10 Glossary

- **Amnion**- inner extra embryonic membrane surrounding the embryo.
- **Chorion**- outer extra embryonic membrane.
- **Cleavage**- successive mitotic cell division of fertilized egg.
- **Complete parthenogensis**- diploid females give diploid offsprings.
- **Cyclic parthenogensis-** sexual generation alternate parthenogenetic generation.
- **Deuterotokous parthenogensis:** In these insects unmated female is able to produce male and female both progenies by parthenogenesis.
- **Diploid parthenogensis/ Thelytoky**: It is the case of insects in which embryos develop from diploid egg but it is unfertilized.
- **Haploid parthenogensis/ Arrhenotokous**: Here haploid eggs are formed by normal oogenesis but it do not fertilize by sperms/male gametes.
- **Hemocoelous viviparity**: Embryos develop in haemocoel.
- **Larval paedogenesis**: In this production of young by larval stages.
- **Neoteny**: the non terminal instar shows the reproductive properties of adult.
- **Oviparity**: insects which lays egg.
- **Ovovivparity**: Egg containing yolk incubates inside female tract and hatch soon after hatching or prior to hatching.
- **Paedogenesis**- reproduction by juveniles.
- **Parthenogenesis-** development of egg without fertilization.
- **Parthenotes-** the organisms going parthenogenesis.
- **Polyembryony**- two or more embryo from a single egg.
- **Pseudoplacental viviparity**: placenta like tissue develops in genital tract of females to nourish yolk deficient eggs.

- **Pupal paedogenesis:** Hemipupa behaves as adult and produces young ones.
- **Synctial cleavage**: karyokinesis not followed by cytokinesis.
- **Viviparity**- embryonic development inside body of female.

7.11 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Which type of cleavage insect egg undergoes after fertilization?
2. Name the pore present at one end of egg to facilitate the entry of sperm?
3. Chorion is secreted by which part of ovary?
4. In which order third layer of extraembryonic membrane called indusium is formed?
5. Give some examples of paedogenesis?
6. Give examples of ovoviviparity?
7. Give one example of larval paedogenesis?
8. Give one example of pupal paedogenesis?
9. Give example of Facultative parthenogenesis?
10. Give example of Obligatory perthenogenesis

Section -B (Short Answer Type)

1. What is trophamnion?
2. Define superficial cleavage?
3. Differentiate between meiotic thelytoky and a meiotic thelytoky?
4. What is the difference between induced and obligatory parthenogenesis?
5. What is hemocoelomic viviparity?
6. Explain different parts of insect egg?
7. Explain meiotic thelytoky while taking example of aphids?
8. What is the significance of parthenogenesis?
9. Define synctial cleavage?
10. What are different types of paedogenesis?
11. Name some unusual types of reproduction?
12. Differentiate meiotic and ameiotic parthenogenesis?

Section -C (Long Answer Type)

1. What is parthenogenesis and what are their types?
2. Explain types of viviparity with examples?
3. Briefly explain the steps involved in egg development?

4. Draw a neat and labeled diagram of egg?
5. What are the insect's special forms of embryonic development? Also give examples while explaining?
6. Honey bee produces fertilized and unfertilized egg, what is its significance?
7. Diagramatically give the details of embryogenesis?
8. Explain polyembryony in wasp *Copidosoma floridanum**?***

Answer Key of Section-A

1. Superficial cleavage
2. Micropyle
3. Follicle cells of ovary
4. Orthoptera
5. aphids, *Micromalthus debilis* (a beetle), some bugs, thrips
6. Family Tachinidae and Sarcophagidae
7. coleopteran- *Micromalthus debilis* (a beetle)
8. gall midges *Miaster sps*
9. bees.
10. in stick insect

7.12 References

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- Kachhwaha N.: Principles of Entomology-Basic and Applied

Unit 8

Post-Embryonic Development

Structure of the Unit

8.1 Objectives

After reading this unit students will be able to:

- Describe the process of hatching and physiology of integument..
- Describe the process of moulting.
- Know, describe and understand Metamorphosis, larval development and types of larvae, pupal development.
- Understand the Control of post-embryonic development.
- Describe the diapause and its types.

8.2 Introduction

When the larva is fully developed within the egg it hatches out by rupturing the egg membrane and sometimes it has some special device which assists this process. In the course of hatching or immediately afterwards many insects shed the embryonic cuticle.

Once it is hatched, the larva begins to feed and grow, however the cuticle will o stretch up to a limited extent growth is punctuated by a series of moults. The number of moults that occur is variable, but is generally less in more advanced insects. In general, weight increases progressively, but linear measurements may increase in a series of steps corresponding with the moults, or more or less continuously if the cuticle is membranous, as it is in many larvae. It is common for different parts of the body to grow at different rates. Growth of the epidermis and internal organs may entail an increase in cell size or an increase in cell number.

Growth from larva to adult usually involves some degree of metamorphosis. In many insects the larval form is tied to that of the adult by morphogenetic considerations, but in others a pupal instar interposed between the last larval instar and the adult has permitted a great divergence of form and habitat between larva and adult. Sometimes the larva changes its habits during the life history and there is a corresponding change of form, a phenomenon known as heteromorphosis.

8.3 Hatching

Hatching stimuli

The fully developed larva within the egg escapes by rupturing the vitelline membrane the serosal cuticle when it is present and the chorion. The stimuli which promote hatching are largely unknown and in many cases insects appear to hatch whenever they are ready to do so. Even in these instances, however it is possible that some external stimulus influences hatching.

In a few specific hatching stimuli are known. These vary but ate relevant to the insect concerned. The eggs of some insects (Odonata) species hatch when they are wetted provided the temperature is above a certain level, *Aedes* eggs hatch when immersed in deoxygenated water, the lower the oxygen tension the greater the percentage hatching, but the responsiveness varies with age. The larvae are most sensitive soon after development is complete and will then hatch even in aerated water, but if they are not wetted for some time they will only hatch at very low oxygen tensions. The low oxygen tension is perceived by a sensory centre in the head or thorax and maximum sensitivity coincides with a period of maximum activity of the central nervous system as indicated by the concentration of acetylcholine. Low oxygen tension has completely the opposite effect on the hatching of *Agabus* larvae, which only occurs in oxygenated water.

Amongst terrestrial insects the eggs of *Dermatobia* (Diptera) are stimulated to hatch from the warmth of host, while in grasshoppers the mechanical disturbance produced by one larvae hatching activities effects other unhatched larvae in the egg pod so that they all hatch within a short time. Suitable temperatures are necessary for all insect eggs to hatch and there is a threshold temperature below which hatching does not occur. This temperature varies in different insects, but is about 8°C for Cimex, 13°C for Oncopeltus and 20°C for Schistocerca. It is independent of the threshold temperature for full embryonic development, which may be either higher, as in Cimex (13°C), or lower, as in Schistocerca (about 15°C). The failure to hatch at low temperatures may be related to the inactivity of the larva. Newly emerged Schistocerca larvae, for instance, are not normally active below about 17°C and their activity remains sluggish below 24°C and Cimex is not normally active below 11°C. Further, temperatures must be sufficiently high for the enzyme digesting the serosal cuticle to function efficiently.

The larvae of *Schistocerca* hatch mainly at about dawn. This is not an immediate response to the changing temperature of the surrounding soil but results from an entrainment of activity to the 24-hour cycle of temperature change during the last phase of embryonic development.

Mechanism of hatching

Most insects force their way out of the egg by exerting pressure against the inside of the shell, which comprises the serosal cuticle and the chorion. The volume of the body is increased by swallowing the extra embryonic fluid and in some cases by swallowing air which diffuses through the shell. Then waves of muscular contraction pump Haemolymph forwards and result in the head and thoracic region being pressed tightly against the inside of the shell. In acridids these muscular waves are interrupted periodically by a sudden simultaneous contraction of the abdominal segments which causes a sudden increase in pressure in the anterior region. Within the neck and thorax are accessory muscles, some of which degenerate soon after hatching and which prevent expansion of the lateral and ventral body wall but permit expansion dorsally of the neck membrane. This is developed into a pair of lobes, the cervical ampullae, which are inflated by the increase in pressure and which serve to focus the pressure on a limited area of the shell. If the shell does not split, the ampullae are withdrawn and a further series of posterior anterior waves of contraction follows, ending with another sudden abdominal contraction. It is one of these sudden contractions which ultimately rupture the shell.

Special muscles which break down soon after hatching are known to occur in Acheta as well as in acridids and may occur in other groups of insects. Muscles which are functional only at the time of the moult are known in other insects.

In acridids the chorion is split transversely above the ampullae, in *Agabus* the split is longitudinal while in other cases it varies in position depending on where the pressure is exerted. In some species the split occurs along a predetermined line of weakness in the structure of the chorion. The egg of *Calliphora* has a pair of hatching lines running longitudinally along its length and in Heteroptera a hatching line runs round the egg where the cap joins the body of the egg shell. *Aedes* has line of weakness in the serosal cuticle and a split in the chorion follows this passively, perhaps because the serosal cuticle and chorion are closely bound. In Acrididae, and probably in Carausius and in the Hereroptera which have a thick serosal cuticle, hatching is aided by an enzyme which digests the serosal endocuticle in the two days before hatching movements begin. The enzyme is produced by the pleuropodia, which are not covered by the embryonic cuticle and so they secrete it directly into the extra-embryonic space.

In a number of insects hatching is aided by cuticular structures, usually on the head known as egg bursters. These are on the head of the embryonic cuticle of Odonata, Orthoptera, Heteroptera, Neuroptera and Trichoptera, but on the cuticle of the first instar larva in Nematocera, Carabidae and Siphonaptera. Their form varies, but in pentatomids they are in the form of a T-or Y-shaped central tooth. Often, as in the fleas, mosquitoes and *Glossina*, the tooth is in a membranous depression which can be erected by blood pressure. In *Agabus* the egg burster is in the form a spine on either side of the head, while in *Cimicomorpha* a row of spines runs along each side of the face from near the eye to the labrum. Polyplax (Siphunculata) has a pair of spines with lancer shaped blades arising from depressions above them while in *Pediculus*(Siphunculata) there are five pairs of these blades and in Haematopinus nine or ten pairs.

Many Polyphaga have egg bursters on the thoracic or abdominal segments of the first instar larva. For instance, in *Meligethes* there is a tooth on each side of the mesonotum and metanotum, while larval tenebricnids have a small tooth on either side of the tergum of these and the first eight abdominal segments.

It is not clear how these various devices function and Jackson(1908) believed that in *Agabus*, the egg of which has a soft chorion, they are no longer functional. In other cases they appear to be pushed against the inside of the shell until finally they pierce it and then a slit is cut by appropriate movements of the head. The larva of *Dacus* (Diptera) uses its mouth hooks in a similar way, repeatedly protruding them until they tear the chorion. The blades in Polyplax and the spines in Cimex are used to tear the vitelline membrane, the chorion then being broken by pressure.

Larval Lepidoptera gnaw their way through the chorion and after hatching they continue to eat the shell until only the base is left In *Pieris brasicae*, where the eggs are laid in a cluster, a newly hatched larva may also eat the tops off adjacent unhatched eggs.

8.4 Physiology of integument

The integument is the outer layer of the insect, comprising the epidermis (hypodermis) and the cuticle. The cuticle is a characteristic feature of arthropods and is, to a large extent, responsible for the success of insect as terrestrial animals. It affords support and protection through its rigidity and hardness and is of primary importance in restricting water loss from the body surface. It is secreted by the epidermis and oenocytes and consists of a number of layers serving different functions.

As first secreted cuticle is soft and flexible, but the outer part subsequently becomes hardened by a process known as tanning or sclerotisation. which involves the production of chemical bonds between the protein chains which make up a large part of the cuticle. Another important constituent of cuticle is chitin, which acts as a packing material conserving the amount of protein used. The whole of the cuticle does not become hardened since flexible joints must occur between the hard plates for the insect to be able to move and in some joints a specialised rubber-like cuticle,resilin is present.

The hardened cuticle by itself is not particularly waterproof. The waterproofing is provided by a thin but complex epicuticle which is secreted to the outside. The shape of the epicuticle also determines the form of the cuticle and especially its surface appearance.

Since hard cuticle will not expand, it limits growth. Hence it is necessary for the insect to shed the existing cuticle from time to time and replace it with another, which before it hardens, is sufficiently flexible to permit same expansion. To conserve as much material as possible the untanned parts of the old cuticle are digested by moulting fluid and resorbed. The new cuticle is laid down, at least in part, before the old one is shed and the first layer to be produced is a layer of the epicuticle which protects the newly developing cuticle from digestion by the moulting fluid. Wax secretion is advanced by the time the old cuticle is shed so that water loss is restricted even at this time. The old cuticle is ruptured along lines of weakness by outward pressure exerted by the insect. This and the subsequent expansion of the new cuticle may involve swallowing air or water and the presence of special muscles which degenerate soon after the moult.

The whole of the life history of the insect is geared to the moulting cycle and coordination of the various aspects of moulting involves a number of hormones.

The integument consists of (1) cuticle, (2) epidermis or hypodermis and (3) basement membrane.

1. Cuticle

It is secreted by the underlying epidermis and is a non-cellular layer. It covers the whole of the body and its appendages. The cuticle also forms the lining of the fore-and hindgut, tracheal system and parts of the reproductive tract. The rectal glands and anal glands are also lined by the cuticle.

Composition of the cuticle

The cuticle is composed of two main layers viz. (1) an outer epicuticle and (2) inner procuticle

(A) Epicuticle

It is the outermost layer 0.03μ to 4 μ in thickness and its detailed structure varies from insect to insect. It is very thin and nonchitinous in nature. It is composed of 4-layers. The first is a cement layer which is lipoprotein in character, second is wax or lipid layer which helps in preventing the loss of water through it. Thus it provides the water conserving properties to epicuticle. Hence waxes of the epicuticle play a very important part in protecting the insects from loss of water. The appearance of greasy layer on the body of cockroaches is due to the wax or lipid secreted by epidermal cells. The third is a polyphenol layer responsible for the hardening of the cuticle and the fourth is the cuticulin layer, lipoprotein in nature.

(B) Procuticle

It is secreted by the epidermal or hypodermal cells. It is a thick layer which is composed of chitin, protein and a number of other substances. The procuticle shows a multi lamillar structure, arranged more or less parallel to the surface. It is also traversed by pore canals running through all or only the outer layer of the procuticle. The pore canals lie perpendicular to the surface, and each one of them is initially occupied by thread like cytoplasmic extensions of the epidermis although at the later stage they may become filled with cuticular materials. These are very narrow, even less than 1μ in diameter. They are not straight but are variously coiled. The pore canals helps in transporting the material to the epicuticle or outer procuticle layer e.g. the wax in secreted by way of the pare canals and crystallizes on the surface. Thus the insect is rendered water proof before moulting.

In the case of soft transparent membrane, the procuticle remains unchanged after the formation. But in other cases the outer part becomes changed into a hard, dark, sclerotized protein known as exocuticle while the inner part which remains unchanged is known as endocuticle. In this way the procuticle gets differentiated into two portions namely, (1) exocuticle and (2) endocuticle.

(1) Exocuticle

It is a thick layer which consists of mainly chitin and proteins. The proteins get tanned by phenolic substances to produce hard, brown material known as sclerotin. It is this sclerotin which gives rigidity to the hard parts like head capsule segments of the limbs and other parts of the cuticle. In more flexible region of the integument, the exocuticle is absent or reduced or it may be altogether absent from the insects with a soft and thin cuticle. This is the region in which cross-linking of proteins occurs to give cuticle hardness. This region is not broken down by proteases at moult and it usually remains in form of exuviae. Melanin and other pigments are found in this area. Sclerotization mainly occurs here.

(2) Endocuticle

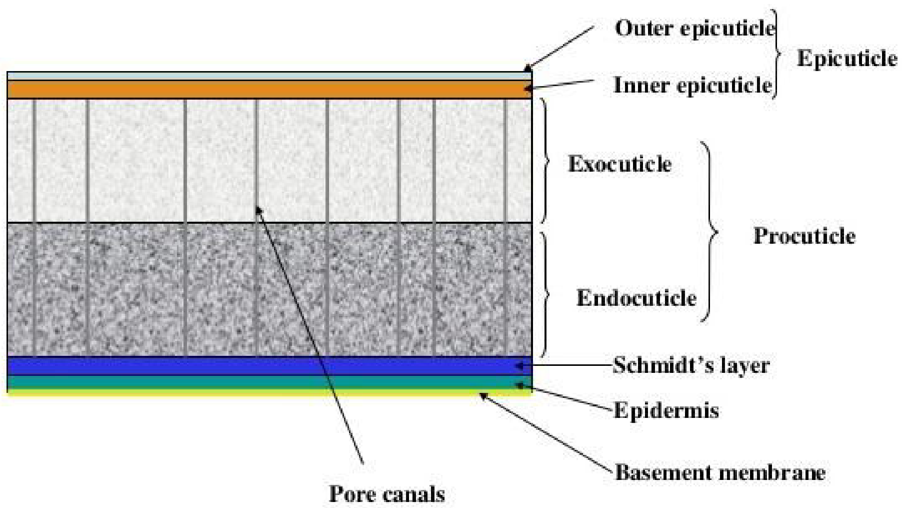
It is the thickest layer of integument and also contains chitin and proteins. The proteins in the endocuticle are not tanned and thus this part of the cuticle is very soft and responsible for the extensibility of the integument and for combining toughness with flexibility.

This region is directly above the hypodermal cells. It is continually being synthesized (in a dark/light way-24 hrs) and often is laid down in layers, thus can often be used to age-grade some insects. It contains most of the chitin, which is broken-down at the moult by chitinase. It has little crosslinking of proteins, thus most is broken-down at moulting and reabsorbed. In soft-bodied insects and regions of flexibility (eg. Arthrodial membranes or inter segmental membranes), this layer is well developed and not the exocuticle.

The inner major constituents of the exocuticle and endocuticle are the chitin and the protein. The two substances i.e., chitin and protein are chemically combined to form a glycoprotein. The exocuticle is distinguishable from the endocuticle by its darker pigmentation and denser structure. It is this layer of the body wall which contains the hardening substances that forms the sclerites.

Chitin

According to Campbell (1929) the chitin is the nitrogenous polysaccharide making 25-60% of the body weight of cuticle. On hydrolysis it yields acetic acid and glucosamine the nitrogenous polysaccharide. It is insoluble in water, alcohol, ether, diltute acid and dilute or concentrated alkalies but it dissolve with decomposition in concentrated mineral acid and sodium hypochlorite. When treated with KOH or NaOH at higher temperature, it is hydrolysed producing a substance known as chitosan and acetic acid.



Resilin

The protein of the cuticle occurs in many forms i.e. the ordinary protein of the cuticle, which is tanned to form sclerotin is called arthropodin. In addition to arthropodin, there is always present rubber like another protein called resilin. This is an elastic substance in which protein chains are bound together in uniforms 3 - dimensional network so as to form a rubber like structure. Resilin may be deposited between the chitinous lamellae and provides the elasticity of the cuticle, or it may exist in pure state to form elastic hinges at the base of wing, and elastic tendons for muscles connected to the wings.

Histological appearance of the cuticle varies in different insects and sometimes even in the different part of the same insect e.g. some of the Coleoptera have a highly specialized structure but this holds good for all the insects, of course, with minor changes here and there.

Epidermis

The cell layer of the body wall is called epidermis or hypodermis. The cells are arranged in the single continuous layer and in most places they form a simple epithelium. In the growing stages of the insects, the epidermal cells are usually cubical or columnar in shape with the nuclei near their bases(Snodgrass, 1935). In adult insects, they become more or less indistinct and the cell areas are marked only by the presence of nuclei. There are specialized gland cells scattered amongst the normal epidermal cells. In addition to the inter gland cells, there are others cells which are concerned with the formation of cuticular sensilla. In the epidermis are also seen the fibres of the muscle attachment, the myofibrillae associated with the tonofibrillae that run through the epidermis and into the procuticle. It has also been suggested that the oenocytes which originate from the epidermis remain associated with this layer.

The epidermis secretes the greater part of the cuticle, it also produces the moulting fluid which dissolves the old cuticle before the immature insect moults. It also absorbs digestion products of the old cuticle and repairs the wounds and differentiates so as to determine the surface pattern of the insect.

Basement membrane

The basement membrane, about 0.5µ thick forms the innermost lining of the body wall. It is very closely attached to the epidermis. It is a mucopolysaccharide layer that is secreted by the hemocytes, is penetrated by nerves and tracheae going to hypodermis, and is a selective barrier between hemolymph and epidermal cells. Hormones and other nutrients can pass through this selectively permeable layer to reach the hypodermal cells. Is important in the recognition of 'self'; thus, the insect's blood cells do not recognize it as 'foreign.' Molecules in this layer are charged and probably act like a molecular sieve.

Significance of each layer of the epicuticle

1. **Cement layer**

Thin outside layer. Closely associated with wax layer and may serve to protect it. Not found in all insects.

2. Wax layer

Hydrocarbons constitute 90% of this layer. It provides waterproofing of cuticle. In some insects (e.g., Fulgoridae and scales), the insects produce a large bloom of wax on outside. Bees have special glands, wax glands, on ventral abdominal segments 4-7 that produce wax, which is then formed into flakes used by the bees to make their cells. Hydrocarbons present in this layer that are used by insects for both inter and intra specific communication signals. Systematists use these cuticular hydrocarbons. They are important communication molecules especially for social insects .

3. Outer epicuticle

First layer formed following the moult and it is the layer that protects the new procuticle from digestion by moulting enzymes (i.e. chitinases and proteinases). It is also called cuticulin layer.

4. Inner epicuticle

Function not that clear but it is a much thicker layer than the outer epicuticle.

5. Wax canal filament

A filament of wax that is produced by the hypodermal cells and extends to the inner part of the epicuticle. Probably it is a filament that continually moves towards the surface of the cuticle.

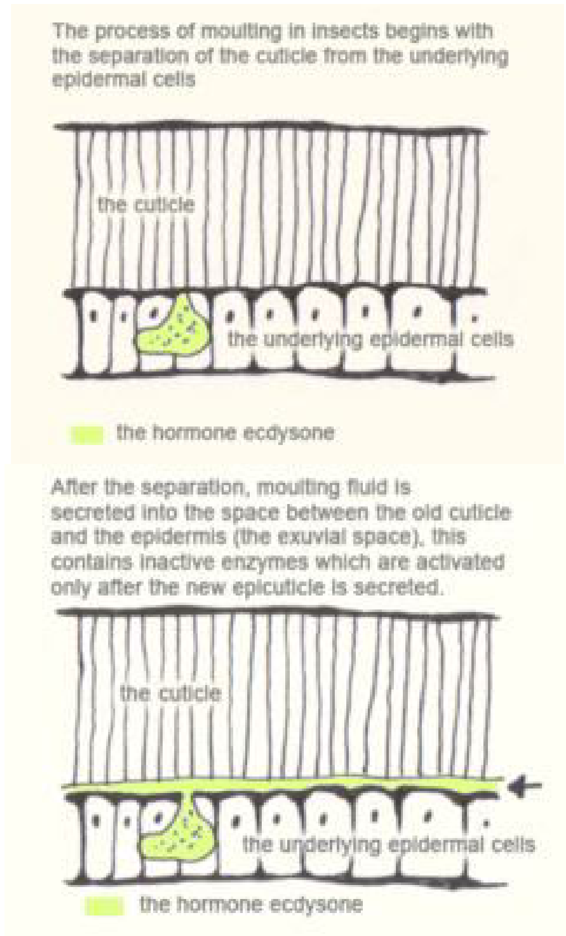
6. Pore canals

They are tiny pores that run from the hypodermal cells to the inner part of the inner epicuticular layer. Inside the canals are wax filaments that extend up to the epicuticular layer. It probably serve as a transport passage for wax from hypodermal cells up to wax layer.

8.5 Moulting

It is the periodic shedding of cuticle followed by formation of new cuticle is a mechanism that facilitates growth despite a more or less inflexible integument. At the onset of moulting the epidermal cells show much activity in increasing in size and number. The process of moulting in insects begins with the separation of the cuticle from the underlying epidermal cells (apolysis) and ends with the shedding of the old cuticle (ecdysis). Each stage of development between moults for insects in the taxon Endopterygota is called an instar, or stadium, and each stage between moults of insects in the Exopterygota is called a nymph: there may be up to 15 nymphal stages. Endopterygota tend to have only four or five instars. Endopterygotes have more alternatives to moulting, such as expansion of the cuticle and collapse of air sacs to allow growth of internal organs. After apolysis the insect is known as a pharate.

In many species it is initiated by an increase in the hormone ecdysone. During moulting epidermal cells separate from the old cuticle (apolysis) and begin to secrete the new. Then the epidermal cells secrete moulting fluid that contains chitinase and protease digesting about 80-90 % of the endocuticle. The digested material is then absorbed by them. At apolysis a thin homogenous, transparent excuvial membrane appears between epidermis and old cuticle. It is resistant to moulting fluid.



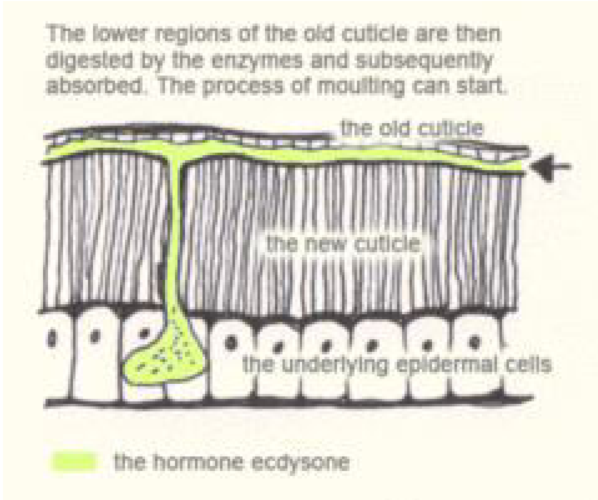


Fig. Various steps of moulting.

Exo and epicuticles are also resistant to the action of the moulting fluid and make up the portion of the integument that is shed at ecdysis. As the old endocuticle is digested forming the excuvial space, new cuticle is deposited, cuticulin layer first, then the protein epicuticle and finally exo and endocuticle. The new cuticle is typically wrinkled beneath the old indicative of the greater surface area to be occupied in the expanded insect after the remaining old cuticle is shed that determines the maximum to which cuticle can be expanded.

The wax layers are laid down shortly before ecdysis, assuring the water proofing of the newly emerged insect. The cement layer is last secreted by the dermal glands, the canal of which perforates the wax layer and hence allow the cement layer to be formed over the wax layer. Pore canals apparently serve as routes for secretion of the wax layer.

When the secretion of the new cuticle is complete the insect performs the act of ecdysis, leaving behind remains of the old cuticle and the tracheal and gland duct linings, e.g. exuvia. This process is facilitated by ecdysial lines beneath which only epicuticle and endocuticle are present. Since the endocuticle is digested during the moulting process a line of weakness develops. When ready to emerge the insect may gulp air or water or increase the hydrostatic pressure of the blood by contracting body muscles. These actions exert an internal force of the ecdysial lines and subsequently the old cuticle splits whenever they are located. These lines of weakness are usually located on the dorsum of the head and thorax with an anterior and posterior orientation. Following ecdysis an insect may consume the exuviae and hence reclaim nearly all nutrients that may have been lost during moulting. Sclerotisation and melanistion follow subsequent to ecdysis.

8.6 Metamorphosis : larval development and types of larvae

Metamorphosis is a biological process by which an animal physically develops after birth or hatching, involving a conspicuous and relatively abrupt change in the animal's body structure through cell growth and differentiation. The developing stages (larva, pupa) are morphologically different from the adult. The degree of difference varies from slight to extreme, with many intermediates. 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. This process may take place gradually, with the immature being in general appearance comparatively similar to the adult (e.g., cockroaches) or it may be quite abrupt the immature instars being drastically different from the adult (e.g., butterflies).

Types of metamorphosis

Depending upon the degree of metamorphosis insects may be grouped as follows:

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 many respects, 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.

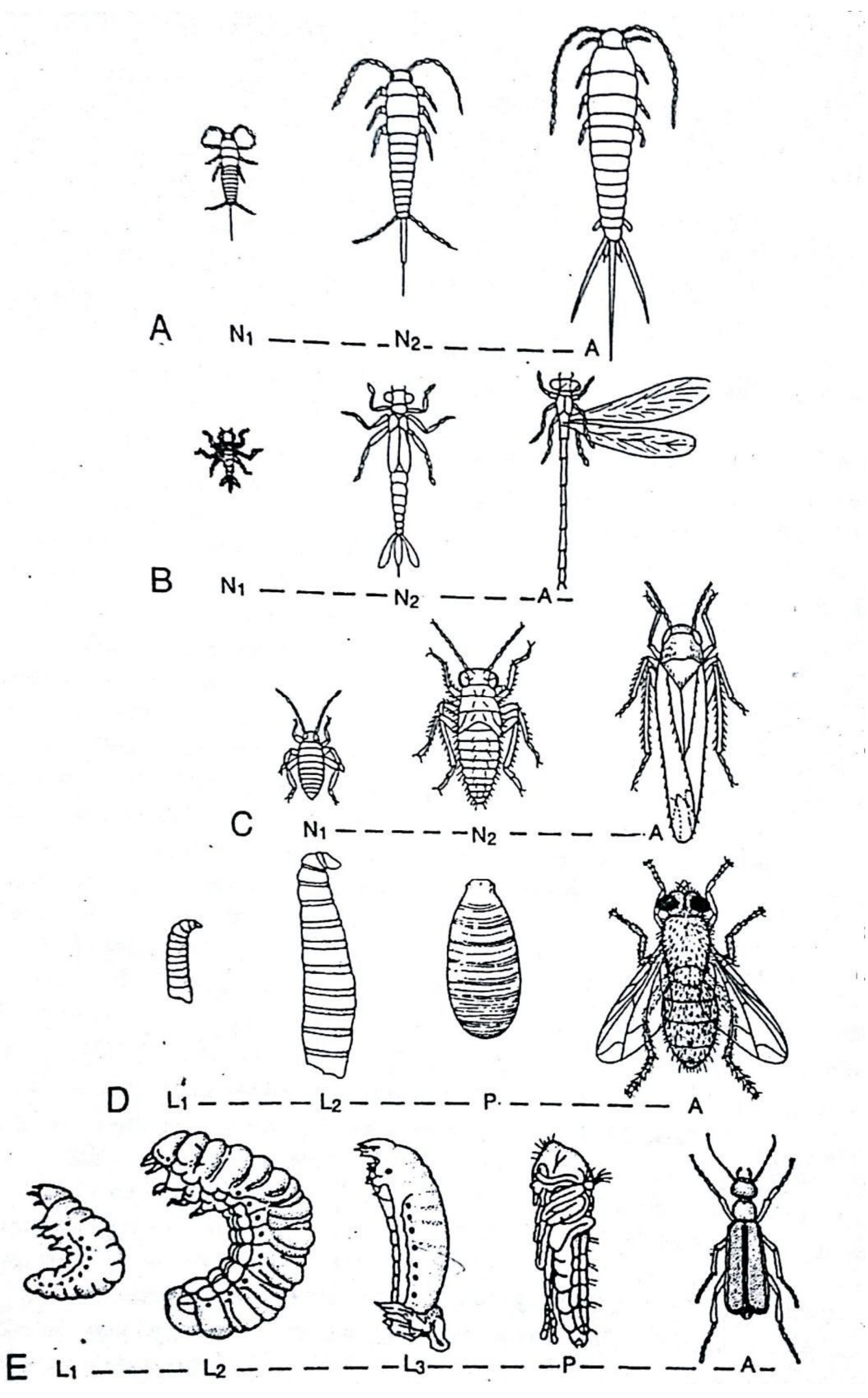


Fig. Types of metamorphosis. (A) Ametamorphosis, (B) Hemimetamorphosis, (C) Paurometamorphosis, (D) Holometamorphosis, and (E) Hypermetamorphosis. (N1...Nn: number of nymphal instars; L1...L3: number of larval instars; P: pupa and A: adult).

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 (e.g., immature stoneflies, with highly specialised ventilatory gills). 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:** This type of metamorphosis, also known as complete metamorphosis takes place in endopterygote insects in which the immature instars (called larvae) are distinctly different from the adults and generally are adapted to different environmental situations. The larvae typically lack compound eyes and usually have biting and chewing mouthparts. There is a pupal instar between last larval instar 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 (e.g., 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 immature stages of insects have a wide variety of forms. In most instances the nymphs of hemimetabolous species closely resemble the adults, but in the holometabolous species, the larvae are often drastically different from the adults. There are different names for the larvae of certain group of insects, e.g., naiad (larva of dragonflies and mayflies), nymph (larva of grasshoppers, cockroaches, termites, bugs), maggot (larva of flies), wriggler (larva of mosquitoes), crawler (larva of lac insects), grub (larva of beetles, wasps, bees), caterpillar (larva of moth, butterflies) etc.

There are many different larval forms amongst the holometabolous insects. Some types of larvae are as follows:

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 or rudimentary. These larvae are found among certain parasitic Hymenoptera that larviposit in the haemocoel of other insects placing the embryo in the only kind of environment possible for survival, e.g. larvae of *Platygaster*.
2. **Oligopod larvae:** The larvae are characterised by the absence of abdominal prolegs, however thoracic legs are well developed. Depending upon the different forms, these larvae are of following types :

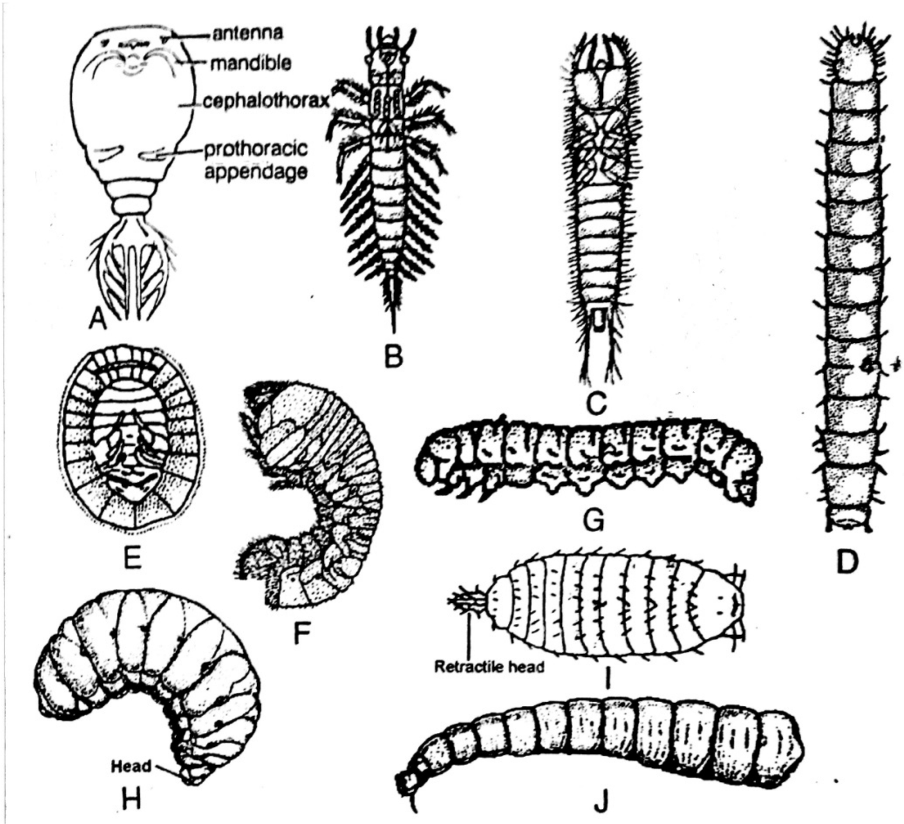


Fig. Types of larvae. (A) Protopod, (B) Campodeiform, (C) Carabiform, (D) Elateriform, (E) Platyform, (F) Scarabeiform, (G) Eruciform, (H) Eucephalous, (I) Hemicephalous and (J) Acephalous.

a) **Campodeiform larvae:** The larvae resemble diplurans in the genus Campodea, having flattened bodies, long legs and usually long antennae and cerci e.g. several beetles, Neuroptera and Trichoptera.

b) **Carabiform larvae:** The larvae resemble the larvae of carabid beetles (ground beetles), which are similar to the campodeiform type but have shorter legs and cerci e.g. several beetles.
c) **Elateriform larvae :** The larvae resemble the larvae of click beetle (Elateridae) and have cylindrical bodies with a distinct head, short legs and a smooth and hard cuticle e.g. certain beetles.
d) **Platyform larvae:** The larvae have flattened bodies with or without short thoracic legs e.g. certain Lepidoptera, dipteral and Coleoptera.
e) **Scarabaeiform larvae:** The larvae are the grubs and have a cylindrical body typically curled into a C-shame with a well developed head and thoracic legs e.g. several beetles.

3. **Polypod or Eruciform larvae :** The larvae are typical caterpillars or caterpillar like larvae and have a cylindrical body with a well developed head, short antennae and short thoracic and abdominal legs (prolegs) e.g., moths, butterflies, certain hymenopterans.
4. **Apodous or Vermiform larvae:** The larvae have worm like bodies with no legs and eyes. On the basis of degree of sclerotisation of the head they are of three types :
   a) Eucephalous larvae: They have more or less well sclerotised head capsule with relatively less reduction in cephalic appendages e.g. larvae of mosquitoes and wasps.
   b) Hemicephalous larvae: The head capsule and its appendages are reduced and can be retracted into the thorax e.g. larvae of certain dipterans.
   c) Acephalous larvae: The head capsule is absent but some cephalic appendages may be present e.g. larvae of house flies.

8.7 Pupa development

Types of pupa

All endopterygote insects pass through pupal stage during development in between the last larval stage and adult stage. Based on the presence and absence of the articulated mandibles that are used in escaping from a cocoon or pupal cell, the pupae are classified as decticous and adecticous.

1. **Decticous pupae**

   These are of primitive type and have functional mandibles. The appendages are always free, i.e. exarate (pupae of Neuroptera, Trichoptera, Mecoptera, Coleoptera and certain Lepidoptera).

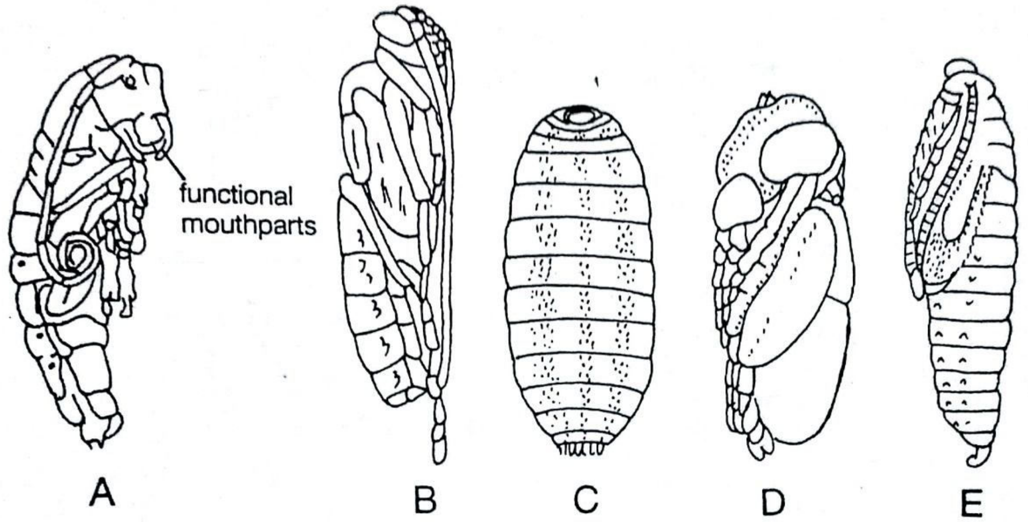


Fig. Types of pupae. (A) Decticous exarate, (B) Adecticous exarate, (C) Obtect, (D) Coarctate, (E) Puparium removed.

2. **Adecticous pupae**

   These pupae do not have functional mandibles, e.g. Strepsiptera, Coleoptera, Hymenoptera, Diptera and Siphonaptera. Based on whether the appendages are free or adherent to the body, adecticous pupae are classified into exarate and obtect types.

   a) **Exarate pupae:** The appendages are free and are usually not covered by a cocoon e.g., the pupae of Siphonaptera, Coleoptera, Hymenoptera and Cyclorrhapha. The exarate pupae when encased in the hardened cuticle of the next to last (penultimate) larval instar, the puparium, is known as coarctate pupae e.g. pupae of house fly.

   b) **Obtect pupae:** The appendages are adhered closely to the body of the pupae and are commonly covered by a cocoon e.g. pupae of moths and butterflies.

During the transition from immature to adult many histological changes occur. These changes are comparatively gradual in hemimetabolous insects, being expanded throughout the nymphal instars, however more changes are recognised during the last instar than during the earlier ones. In holometabolous insects, these changes occur mostly in the pupal stage by means of histolysis (breakdown of the larval tissues) and histogenesis (reconstruction of the adult tissue through tissue reorientation, growth and differerntiation). The histolysed tissues are usually removed by the haemocytes. Holometabolous insects have developed a mechanism in which specific primordial or progenitor cells are set aside in the larval stage for later use during the pupal period. The masses of such undifferentiated cells are called as imaginal discs. They are used for constructing adult organs or appendages. From a developmental standpoint it is an ideal evolutionary strategy for setting aside the building blocks early in the life cycle of the insect which are carried by the insect through the embryonic and larval stages and are not used until the pupal stage.

8.8 Hormonal control of metamorphosis

Insect metamorphosis is controlled by a variety of hormones of which the most important are

a. Brain hormone
b. Ecdysone and
c. Juvenile hormone.

Most of the work with insect hormones has been carried out by ligaturing the larvae or pupae at various levels between anterior and posterior ends by making grafts or by the injection of extracts of endocrine glands or synthetic hormones.

a. Brain hormone

This is secreted by the neurosecretory cells of the brain which are usually 4-clusters a pair of medial and a pair of lateral cluster. The hormone secreted by these cells pass down the nerve axons of these cells and accumulates in the corpus cardiacum. Release of the hormone into the blood occurs at the corpus cardiacum level through several ways i.e. either by disintegration of granules and their diffusion into the blood or by means of exocytosis. Experimental investigations in Cecropia silkworm show that both the median and lateral neurosecretory cells are necessary for formation of this hormone. In fact the brain hormone is a mixture of several hormones secreted by different types of neurosecretory cells present in the brain.

Role of brain hormone in metamorphosis

This hormone has an indirect effect on metamorphosis. The chief function of this hormone to control the secretion of the prothoracic glands. Consequently, the removal of the brain has the same result as the removal of the prothoracic glands. In both cases the secretion of ecdysone is stopped and the insect enters into a state of diapause. Thus, diapause is due to the failure of the endocrine activity.

b. Ecdysone

This is also known as moulting hormone. Fraenkel (1935) found that when mature fly larvae were legatured, only the front end was able to form a puparium while the hinder part remained unchanged. Blood transfusion from the front to the hind end even in the legatured fly larvae immediately caused a change resulting in the pupation of the posterior part. From these observation, Fraenkel suggested that the growth of the larva into the pupa was dependent on a hormone secreted somewhere in the anterior end. Fukuda (1940) clearly demonstrated that it is secreted by the prothoracic glands or ecdysial glands. Finally it was Karlson (1964) who isolated the hormone in a highly purified stage and named it as "Ecdysone". Chemical study of ecdysone has clearly revealed that it is composed of two closely related molecules viz. α- ecdysone and β- ecdysone and it is steroidal in nature.

Effect of ecdysone on metamorphosis

Ecdysone is the only hormone which has a central control on developmental events at the cellular level in insects. When the prothoracic glands stop the secretion of ecdysone the result is developmental stand still. This is what happen during diapause. It must be mentioned here however that the development of muscles during metamorphosis is not governed by ecdysone alone. There is another factor called neurosecretory factor or a neurosecretory control (hormone) which when produced during the same period when ecdysone is released in the blood causes muscle development. This observation clearly points that there is a close integration of the prothoracic secretory process with the activity of the neurosecretory system. Further integration is through the neurosecretory control of the brain over the prothoracic gland.

c. Juvenile hormone

This is secreted by corpora allata, a paired or unpaired small cephalic endocrine glands. The hormone is known juvenile hormone (JH), corpus allatum hormone or neotenin which prevents the real change of stage in the developing insect.

Wigglesworth (1934) was the first to demonstrate this function of the juvenile hormone in his experiments with *Rhodnius prolixus*. However other workers such as Bounhiol (1938) and Fukuda (1944) and several others have confirmed the observations of Wigglesworth by their experiments on caterpillars. The JH is terpenoid in chemical nature.

Role of Juvenile hormone in metamorphosis

Its chief function is to maintain the immature stages i.e. larvae or nymphs of insects without causing pupation or the development of adult stage i.e. the actual metamorphosis is blocked. In a normal metamorphosing insect the corpora allata decline its secretory activity and thus a sudden change from an immature young stage to adult happens. Removal of corpora allata in the juvenile period of growth in insects have clearly shown a precocious metamorphosis in the life history.

In short the process of metamorphosis takes place as described below:

The brain hormone secreted by the neurosecretory cells stimulates the prothoracic glands to secrete ecdysone or moulting hormone, but moulting occurs only when the juvenile hormone is either absent or present in very small amounts. In the last larval instar of Holometabola the corpora allata becomes almost inactive, hence a low concentration of JH is present causing larva to moult into a pupa. Similarly during later part of the pupa or late pupa, again the corpora allata become inactive and in total absence of JH the pupa moults into an adult insect. In Hemimetabolous insects also the same phenomena is repeated i.e. the corpora allata become inactive in the last instar nymphs and in the complete absence of JH imaginal ecdysis take place. Thus metamorphosis in insects is controlled by a delicate balance in the timing of secretion and concentration of two hormones viz. JH and MH secreted by the corpora allata and ecdysial or prothoracic glands. The total absence of JH is the most significant factor for imaginal ecdysis in both. Hemimetabolous and Holometabolous insects.

If much JH is present then larva will moult into a larva, if small amount of JH is present then pupation takes place and in the total absence of JH is present then pupation takes place and in the total absence of JH adult emergence occurs. And if the balance of hormones is disturbed then monsters, intermediate between larva and pupa or between pupa and adult are produced and the phenomena is termed as prothetely or metathetely.

8.9 Diapause

Hormonal control of diapauses

The period of suspended development at any stage of the life cycle, under adverse condition accompanied by greatly decreased metabolism is called diapause. This phenomenon is governed by a variety of external and internal factors. This is an adaptation to tide over unfavourable environmental conditions like cold, draught, extremes of temperatures, humidity, photoperiod, nutritional, vitamin and other deficiencies. The other factor which determine the diapause and are equally responsible are the endocrine glands.

The hormonal regulation of diapause was earlier proposed by Wigglesworth (1943) and was confirmed by the experiments of Williams (1946) on *Hyalophora cecropia* which normally enters diapause just after pupation and may be induced to resume development by several months of chilling at 3-5^{0}C. In Saturniids, the pupal diapause is cauaed by the absence of ecdysones, which results from inactivity of the neurosecretory cells of the pars intercerebralis. Diapause has been broken in a number of species by the injection of α or β-ecdysone, with the onset of adult development. A permanent diapause may be produced even in related non - diapausing species by brain removal. This response will vary from species to species.

Thus, the neurosecretory cells of the brain are the controlling elements in the initiation and termination of hormonally regulated diapauses. However, developmental arrest is not necessarily the result of a lack of ecdysone in all cases. Adult diapause may be brought on by corpora allata inactivity under the control of neurosecretory cells of the protocerebrum. In this case also as in the case of ecdysone regulated diapause, reactivation of the neurosecretory cells in the brain is required to terminate the conditions and restore reproductive activity.

Three principal types of diapause can be distinguished on the basis of their hormonal mechanism:

1. Diapause caused by a lack of brain hormone and moulting hormone. According to Novak (1975), to this category belong all cases of larval and pupal diapause known so far and doubtless also, embryonic diapause.
2. Diapause caused by lack of brain hormone and juvenile hormone ,this mechanism is concerned with imaginal diapause.

3. Diapauses caused by the the action of neurosecretory factor produced by the suboesophageal ganglion of the female and affecting the development of the eggs. This category comprises early embryonic diapause.

The diapause caused by a deficiency of the brain hormone and moulting hormone is the most common type of diapause and the type so far most thoroughly investigated. It consists of an arrest of growth and development primarily due to the absence of moulting hormone itself is and inhibition of brain hormone production. It is likely that the majority of both the pupal and the larval diapause results from the failure of the cerebral neurosecretory cells to produce thoracotropic hormone.

Adult Diapause

The adult diapause is the result of a deficiency in the brain hormone and juvenile hormone i.e. inactivity of the neurosecretory cells of the pars intercerebralis and corpora allata. Morphologically the adult diapause is only seen in the interruption of growth of the ovaries and in the suppression of the functions of the accessory glands of both the male and female individuals. In the fly *Calliphora,* the implantation of corpora allata can induce the ripening of some of the eggs but complete termination of diapause is possible only by the simultaneous action of juvenile hormone and brain hormone. A part from this, the presence of BH seems indispensable for the activity CA. Evidences for CA(JH) regulation of adult diapause comes from a number of other species e.g., *Pyrrhocoris apterus. Hypera postica, Necrophorus fossor, Galeruca tenaceti. Pterostichus nigrita, Leptinotarsa decemlineata, Aedes aegypti. Culex pipiens, Calliphora and Gryllodes sigillatus* etc. The experimental evidences clearly suggest that the basic intrinsic factor of imaginal diapause lies in the neurosecretory cells(NSCs) of the brain which appears to be part of the mechanism of action of external stimuli.

Pupal Diapause

The principal cause of pupal diapause is the failure of endocrine activity i.e. activity of the NSCs of the brain and the ecdysial glands Thus, to break the pupal diapause, presence of active ecdysial glands EGs) is necessary in addition to BH. Implantation of active EGs also breaks the diapause. It is important to note that implantation of one or more active brains into an isolated abdomen in Hyalophora has no effect whereas the implantation of active EGs breaks the diapause and development continues. Injection of ecdysone has the same effect as the implantation of EGs. Pupal diapause can take place at any point during the pupal stage. Its occurrence in a given species is bound to be in the same phase of the pupal period and in most species it is genetically fixed. The common example of pupal diapausing insects are *Amsacta moorei, Amsacta collaris, Achaea janata* and others.

Larval Diapause

It has been found that in the diapausing penultimate instar nymphs of *Gryllus campestris* ecdysial glands show reduced secretory activity and the brain appears to be responsible for this. Both the brain and the EGs have also been shown to control diapause in larvae of *Sialis lutaria*. It has been remarked that the brain controls the activity of the EGs and CA, and is the principal control centre of diapausing larvae.

Early Embryonic Diapause

The early embryonic diapause is associated with the diapausing hormone (DH) secreted by the sub oesophageal ganglion. Removal of the sub oesophageal ganglion from diapause producing pupae shortly after pupation completely eliminates diapause from the eggs eventually produced. When the operation is delayed, a progressively larger proportion of eggs enter diapause. The incidence of the diapause in the eggs is conditioned by endocrine activity of the neurosecretory cells of the sub oesophageal of females. The extirpation of suboesophageal ganglion at the beginning of the pupal stage causes eggs which were determined for diapause through their mother(e.g. female *Bombyx mori*), to develop without diapause. In the same way univoltine females can be caused to lay non diapausing eggs, a thing which they never do under normal condition, conversely if upto a critical period a female pupa which has been conditioned to lay non-diapausing eggs receives a suboesophageal ganglion from female which would have laid diapausing eggs, it also will lay diapausing eggs. The same effect can be produced by the implantation of the suboesophageal ganglion of either females or males of a univoltine race. The relevant DH non-specific for species, genus or family was shown by implantations of the suboesophageal ganglion from other Lepidoptera. But in this case also the neurosecretory cells of the brain play a key role. In diapause producers, the brain stimulates the production and release of DH from the suboesophageal ganglion, in nondiapause producers the brain inhibits hormone production and release from suboesophageal ganglion.

8.10 Summary

- Growth of the epidermis and internal organs may entail an increase in cell size or an increase in cell number.
- The fully developed larva within the egg escapes by rupturing the vitelline membrane the serosal cuticle when it is present and the chorion. The stimuli which promote hatching are largely unknown and in many cases insects appear to hatch whenever they are ready to do so.
- The integument is the outer layer of the insect, comprising the epidermis (hypodermis) and the cuticle. The cuticle is a characteristic feature of arthropods and is, to a large extent, responsible for the success of insect as terrestrial animals.
- The process of moulting in insects begins with the separation of the cuticle from the underlying epidermal cells (apolysis) and ends with the shedding of the old cuticle (ecdysis).
- Metamorphosis is a biological process by which an animal physically develops after birth or hatching, involving a conspicuous and relatively abrupt change in the animal's body structure through cell growth and differentiation.
- Insect metamorphosis is controlled by a variety of hormones of which the most important are : Brain hormone, Ecdysone and Juvenile hormone.

8.11 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Define metamorphosis.
2. What is hatching?
3. Define diapauses.
4. Which hormone involves in the process of metamorphosis?
5. What is moulting?

Section -B (Short Answer Type)

1. Describe moulting process in insects.
2. Write short notes on:
    a. Hatching
    b. hemimetamorphosis
3. Describe various types of pupa found in insects.
4. Write short notes on :

a. Ecdysone hormone
b. holometamorphosis

Section -C (Long Answer Type)

1. Give a detailed account on physiology of integument.
2. Write short notes on :
    a. Types of larvae
    b. Moulting
    c. Hormonal control of metamorphosis
3. Define metamorphosis. Describe the types of metamorphosis found in insects.
4. What is diapause? Describe various types of diapauses.

8.12 References

- Introduction to general and applied Entomology by V.B. Awasthi
- Rajendra kumar
- https://en.wikipedia.org/wiki/Ecdysis#Insects
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Unit - 11

Social life of insects

Structure of the Unit:

11.1 Objectives

After completing the unit, you will be able to understand about-

- Social life, behaviour and different caste system of termites of order Isoptera.
- Social life, behaviour and different caste system of bees of order Hymenoptera.
- Bee communication
- Social life, behaviour and different caste system of Wasps of order Hymenoptera.
- Social life, behaviour and different caste system of Ants of order Hymenoptera.
- Role of various factors like pheromones and nutrition in caste determination of different social insects.
- General introduction about aphids and its life cycle.

11.2 Introduction

Insects show a variety of social behaviours. Some of the social insects lives together in large groups, communicates, shares food, feed and protect the young ones and the eggs. The social behaviours are usually found in bees, ants, wasps and termites. The permanent living together of the insects is known as the colonies. They also work together for the survival.

In insects, females are mainly responsible for the foundation of the social colonies. The single female insect which is usually the founder of the social colony is termed as gyne the queen. It is termed the queen because after mating is the one which builds the nests where it will start with the laying of the eggs. After the young insects have been raised, they take the responsibilities of the queen, so that the queen may continue with her concentration on the reproduction.

One of the most significance of the social behaviour of the insects is communication. Insects communicate with each other in different patterns and modes. It is said that during darkness and in the crowd while they are in the nest, touch and smell are the most usefully used in conveying the messages. The queen as the mother of the nest release pheromones which is a chemical used to stimulate other members of the colony to act as unit among themselves.

11.3 Order – Isoptera

Social Life of Termites

In order Isoptera only one member 'Termite' exhibit social habit very similar to ants, bees and wasps. Termites are commonly known as “Deemak" or "White ants". Termites are found throughout India and are usually detected in natural habitats by their conspicuous earthen mounds, which may be as high as 3 or 4 metres in some areas depending on the species. Some termites build smaller earthen nests in trees while others construct a complex network of subterranean tunnels connecting larger galleries. Wood dwelling species do not build nests but live within the galleries they have excavated in the wood they feed on.

Characteristics of Termites

Termites are small to medium sized insects ranging form 3-20 millimetres in body length. These insects are not often seen although evidence of their presence is observable in the large mounds they construct or the damage they do to wood products and structures.

Termites consists of the following characteristic features:

- Pale, elongate body
- 2 pairs of membranous wings of equal length. Wings are present in reproductive castes only and they are shed after mating
- Mandibulate (chewing) mouthparts
- Antennae about the same length as the head

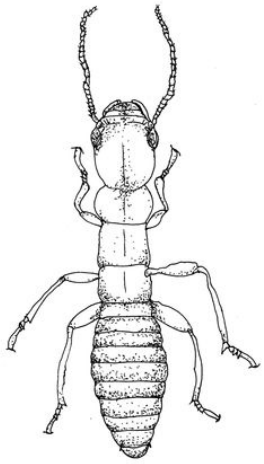

Figure - Termite (Worker)

Termites survives exclusively on cellulose and carry cellulose-digesting flagellates(Protozoa) inside their intestines. They make underground nests called **termatorium**, in which they maintain constant temperature and humidity, even when outside ground temperature rises to above 60 degrees, by constructing intricate overground natural air conditioners called termite-hills. As the wind passes through the ventilation galleries of the termite hill, the temperature of the nest drops fast. They never venture out in the open and construct earthen passageways on the trees, walls or on ground and move in the darkness of these tunnels. No wonder their eyes are rudimentary and they communicate almost exclusively in the chemical language. This peculiar underground habitat and shy nature has evolved in them due to a large number of predatory animals like giant anteaters, scaly anteaters, spiny anteaters etc. which exclusively live on termite diet and are always looking for them.

Difference between Ants and Termites

Although. Termites are termed as white ants but they are not ants. They are distinguished from ants by the absence of a constriction or peduncle between the thorax and the abdomen. Ants have unequal wings, their anterior pair of wing is larger, whereas the termites have equal wings. Termites live on wood and are nocturnal, whereas the ants live on sweet chemicals and organic matter and are diurnal. *Microtermes obesi* and O*dontotermes obsus* are two common species of termites found in India.

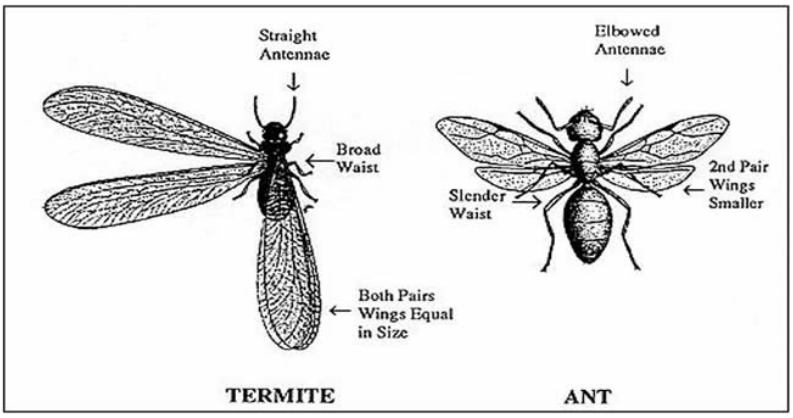

Figure – Comparison Of Termite And Ant

Termites were the first animals which started living in colonies and developed a well organised social system about 300 million years ago, much earlier than honey bees and ants. Although termites do not exceed 3-4 mm in size, their **queen** is a 4 inch long giant that lies in the royal chamber motionless since its legs are too small to move its enormous body. This phenomenon of enormous enlargement of abdomen in termite queen is called **physogastry**. Workers have to take care of all its daily chores. Termite queen is an egg-laying machine that reproduces at the astonishing rate of one egg per second, 24 hours a day and for about 20 years of life. Some Australian species are known to lay up to 60,000 eggs per day. Producing eggs is the only mission in the life of a termite queen. The other castes, **workers** and soldiers are highly devoted to the colony, working incessantly and tirelessly, demanding nothing in return from the society. **Soldiers** have long dagger-like mandibles (Mandibulate type)with which they defend their nest and workers chew the wood to feed to the queen and larvae and grow fungus gardens for lean periods. **Nasutes** are specialized soldiers having produced head that emits chemicals which help in further proliferation of tunnels in wood or soil .They are also specialized in chemical warfare. They are bulldozers of the colony.

Caste Differentiation

The colony of termites is managed by division of labour by caste differentiation. Termites exhibit polymorphism. Colony comprises two major castes (A) Fertile caste (B) Sterile Caste.

(A)**Fertile castes**: The fertile caste is of the following three forms:

a. Long winged adults or colonizing Adults: winged adults are produced in good number in rainy season and are actually winged males and female. Male and female individuals go on nuptial flight and copulate in the sky. After fertilization the female may have a new colony separately. Males have well developed eyes and wings. Long winged adults are of two types.

i. Queen: The queen of *M. abesi* is 5 to 7.5 cm. in length. The sole function of the queen is egg laying. She lays about 70,000 to 80,000 eggs in 24 hours. The life span of a queen is recorded to be 5 to 10 years. The queen lives n royal chamber of the nest and feeds royal jelly. The queen is well served by the workers.
ii. King: The king is father of the colony living with the queen in the royal chamber. It is developed from an unfertilized egg by feeding on nutritive diet. It fertilizes the queen repeatedly to produce fertilized eggs for the hatching of the winged male, female and workers. Life of the king is shorter than the queen. So the king is replaced by a new one.

Both true kings and queen have two pairs of wings in the beginning but wings are ultimately discarded and only their truncated base remains present.

b. Short-winged adults (Brachypterous): These are supplementary or substitute or neotenic king and queen. Body is less pigmented. The two pairs of wing are short, vestigial and pad-like.
c. Wingless form (Apterous): There are worker-like substitute kings and queens which occurs in the more primitive species. The body is without pigmentation. There are no traces of wings.

(B) **Sterile castes**: These are form with rudimentary reproductive organs. This is of three types:

a. Workers: The workers are numerous and they perform all the duties of the colony except reproduction. The body has little or no pigmentation. The workers are commonly dimorphic, but sometimes trim orphic comprising small, intermediates and large individuals.
b. Soldiers: The soldiers are highly specialized. They are concerned with the defense of the colony against predictors. They are pigmented and large handed individuals with projected prominent mandibles. In some species three grades of soldiers-small, medium and large are present.
c. Nasutes: In higher genera (*Edutermes*) the mandibulate soldiers are replaced by other form called the nasutes. Their head is prolonged into a rostrum, bearing the opening of a large frontal gland at its

apex. The sticky secretion of the gland is inflicted upon their enemies in warfare and is used to dissolve hard substances, like concrete which fall in the way of the workers when building nest.

In breeding season which usually coincides with the rains, newly produced **males** and **females** grow wings and have nuptial flight to disperse to long distances. They make pairs and find a new place to start a colony by digging a shallow gallery and laying eggs that all hatch into workers to expand the nest.

Termite **nymphs** are diploid males as well as females that develop into sterile adults except those growing into nuptials in rainy season. There are 7 instars of nymphs and the last three instar nymphs function as workers. Unlike honey bees, termite adults are diploid in both sexes as they develop from fertilized eggs. Queen secretes inhibiting hormones that do not allow nymphs to develop into new queens. Differentiation of different castes in termites takes place by feeding the larvae with saliva of workers. Larvae that are fed on more saliva develop into sexual forms while nymphs that are fed on wood and fungus develop into workers and soldiers.

Swarming and mating

During rainy season, the winged forms of termites i.e. queen and king take a nuptial flight known as swarming. After a brief flight, these winged forms land on the ground and shed their wings. The flight is not a true nuptial flight, but only a dispersal flight since mating does not take place in the air. Mating takes place after they have descended to the ground, but before shedding their wings. unlike honeybee, mating is further repeated at irregular intervals. The generation of kings lives with the queen for whole life however have quite short life span and replaced by another male.

Founding new colonies

Each colony is founded by a royal couple. Together they excavate a small burrow or cavity in the ground called the nuptial chamber. The first laid eggs, by the young couple develop into workers. The Workers performs all the major duties of nest.

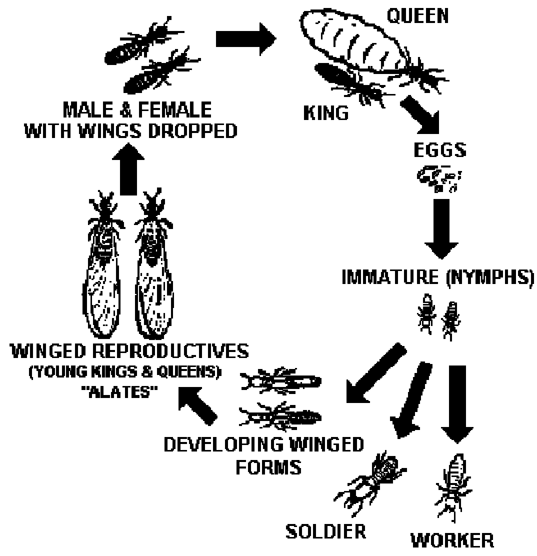

Figure – Life cycle of Termites

11.4 Order - Hymenoptera

Social Life of Honeybee

Honey bees are social or colonial insects that visit flowers, collect nectar and convert it into a golden-yellow aromatic viscous fluid called honey, which is also called the liquid gold of nature. Nearly 17,000 species of bees are found all over world out of which only 100 species are honey bees and some are stingless social bees which makes a permanent house , made up of sheets of wax. In the spring, a honeybee colony that has grown sufficiently large will split in two, with the old queen and half her worker along with a daughter who will become a new queen make chambers in the ground in cliff, and in hollow tree. There are often many such sites within range of the waiting swarm, but only some motivate a worker to perform a dance back at the swarm a dance that communication information about the distance and quality of the potential new home. Other workers attend to a dancing scout and may be sufficiently stimulated to fully out to the spot themselves. If it is attractive to them they too will dance and send still more workers to the area then the swarm leaves its temporary perch and flies to the most popular nest site.

The worker bees produce wax for the formation of the new hive and are known as builders. New hive is made hanging vertically from rock buildings or branches of trees consist of thousands of hexagonal chambers of cells made up of wax secreted by the builder's abdomen. The resins and gums secreted by plants are also used for construction and repair of the hive.

The larvae are kept in the lower and central cells in the hive which are the "Brood cells" In *Apis dorsata* a brood cells are similar in shape and size but in other species brood cells are of three types viz worker cell for workers drone cells for drones and queen cell for the queen cell is used once only while rest are used a number of times there are no cells for lodging the adults. They generally keep moving about on the surface of the hive. The cells are mainly intended for the storage of honey and pollen especially in the upper portion of the comb. Colony of honeybees consists of three castes Queen Drone and workers.

A bee colony has about 20,000 workers, one queen and about two dozen drones. If there is more than one queen in a hive, as happens in breeding season, then the phenomenon is known as **pleometrosis**.

Caste Differentiation

1. QUEEN(Gyne)

Queen is the fertile female only that can lay up to 3000 eggs per day, which is twice the weight of her body but normal fecundity is about 600 eggs per day. The size of the queen is largest among other castes of bees Queen can be easily identified by its long abdomen strong legs and short wings. The queen has ovipositor on the tip of the abdomen It is the egg laying organ. The contribution of queen for its scullery is to lay eggs.

Queen can produce male or female offspring . Unfertilized eggs develop into males and fertilized ones into females. Growing larvae, both of which are genetically females, can be developed into queens or workers by feeding them with royal jelly or pollen and honey by the workers.

Queen produces a number of pheromones which attract workers and keeps the colony together. The secretions of **mandibularglands**, **tergal** and **tarsal glands** of queen are licked by the workers and passed to other members of the colony and larvae through food exchanges called **trophallaxis**. If a queen is killed, workers in the absence of queen pheromones, rear a new queen from the developing female larvae. Queen pheromone also inhibits development of ovaries in workers. Queen pheromone has stimulating effect on the activities of workers, such as comb building, brood rearing, foraging and honey making. If a queen dies or disappears, workers rear a new queen by selecting a larva and modifying its cell to make a queen cell and feed it exclusively with royal jelly.

2. DRONE (Aners)

Males members are called as **drones**, which are darker, robust and hairy and larger than workers. Drones are haploid fertile males the size of drone is smaller than queen but larger than sterile females' i.e. workers.. They are developed from unfertilised eggs. There are about two dozen of them in a hive and chase the queen in air every time she ventures on nuptial flight. The secretions of **mandibular glands** and that of sting apparatus of queen attract drones during nuptial flight. They copulate with the queen and fertilize her eggs. Drones are not tolerated in the hive once the queen is fertilized and are generally driven out of hive, where they eventually die of starvation.

3. WORKERS(Ergates)

These are diploid sterile females and are smallest in size. They are sterile because of diet effect, queen substance and the pheromone. Their number in colony is the highest

The **workers** are genetically females but sterile as they are not fed on royal jelly in the larval stage. They have a lifespan of 6 weeks, the first half of which is spent in the hive attending to household chores, secreting wax and building hive, producing a highly nutritious royal-jelly and converting nectar into honey. They become foragers in the later part of life and tirelessly collect nectar and pollen throughout life. They eventually die during performing their duties, an excellent example of honest and selfless service for the society. An amazing phenomenon that has been observed in honeybees is their capacity to reverse their age should a catastrophe struck the colony. In case of a crisis, such as destruction of the hive, the 4-5 week old foragers start reversing their age and become younger to secrete **royal jelly** and wax, repair their hive, rear a new queen from the larvae and rebuild their colony. Members of a colony are heavily dependent on one another and cannot survive in isolation, even if kept in the best of conditions. They communicate by ultrasound signals, pheromones, dancing and gestures.

Workers possess numerous morphological adaptations to carry out their duties effeciently. Their **mandibular glands** secrete wax softening substance, **pharyngeal glands** secrete a gelatinous highly nutritious substance called Royal Jelly and stomach contains several glands that help in converting nectar into honey. There are **wax glands** on abdominal segments 4-7 which open by several ducts on to the sternites 4-7. Hind legs have tibia and basitarus modified to form a **pollen basket** . Mouth parts of workers bees are of chewing and lapping type. Workers are sterile females and hence their ovipositors are modified in **sting** and accessory reproductive glands get modified to form alkaline and poison glands. A worker in its entire lifespan makes about a spoonful of honey. To make 500 grams of honey, bees have to extract nectar from more than 4 million flowers, for which they have to make about 50,000 trips of the foraging area ranging between 5 km .

In bee body the legs are modified and are hairy. When workers visit a garden of flower and sit on a flower pollen grains adhere to these hairs and other parts of the body Worker clean off pollen with the help of a special structure (the cleaners) present on each fore legs. Pollen brushes are present on every leg and pollen grains are stored in the pollen basket present on the outer surface of metatarsi on hind legs Nectar and water is collected in crop by sucking through mouth parts.

Worker bees possess **Nabokov scent gland** in their abdominal region which acts as a defensive organ and is modified ovipositor having a large poisonous storage sac and a sting. Poison storage sac contains a poisonous chemical. This chemical is injected into the body of enemy through sting. Worker bees attack collectively to the intruder and sting the intruder collectively.However, the tip of sting usually breaks into the body of intruder and the remaining secretion of alkaline gland mixed with that of poison gland (active poison) gets injected in her body thus it is killed by her own venom. Alarm and aggression pheromones are released by the worker bees from the abdomen by raising the tip of abdomen and protruding the sting apparatus.

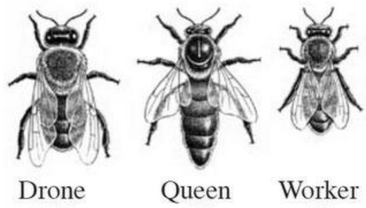

Figure – Caste differentiation of honey bee

Bees Terminology

Alates - the young winged reproductives of both sexes. From time to time about 100 to 1000 alates leave the colony for a mating and colonising flight. After mating a pair settles down at a suitable site like a rotting scar on a tree in order to establish a new colony.

De-alates, alates that cast their wings after the colonising flight and successively turn into queens and kings. Initially only a few eggs are laid and brought up by a female de-alate. As the number of individuals in the colony grows, the more workers are available to help the young queen to care for the brood. After three to five years the number of individuals is already so large, that the colony of a useful species can turn into a damaging stage.

Neotenics :assist the queen in laying eggs, once her productivity decreases. When the queen has died or deteriorated, one of the neotenics takes her place. That is the reason why the removal of a queen from her colony does not necessarily mean the end of the colony.

Attendants: Worker bees that are attending the queen. When used in the context of queens in cages, the workers that are added to the cage to care for the queen.

Abscond :When the entire colony of bees abandons the hive because of pests, disease or other adverse conditions.

Nasonov : A pheromone used given off by a gland under the tip of the abdomen of workers that serves primarily as an orientation pheromone. It is essential to swarming behavior and nasonoving is set off by disturbance of the colony. It is a mixture of seven terpenoids, the majority of which is Geranial and Neral, which are a pair of isomers usually mixed and called citral. Lemongrass (Cymbopogon) essential oil is mostly these scents and is useful in bait hives and to get newly hived bees or swarms to stay in a hive.

Colony collapse disorder (**CCD**) is the phenomenon that occurs when the majority of worker bees in a colony disappear and leave behind a queen, plenty of food and a few nurse bees to care for the remaining immature bees and the queen.

Nuptial Flight

Most interesting part in the life cycle of honeybee is its way of mating. Mating takes place during a flight called nuptial flight. Virgin queen takes a flight followed by males. A few males only succeed in mating. Queen and other males return to their comb. But now worker bees allow only the queen and all males are driven away and they die in nature. Polyandry is relatively rare in insects where a single female mates with several mates. But polyandry is common phenomenon in honeybee. Queen honey bee mates with several drones in succession during her nuptial flight.

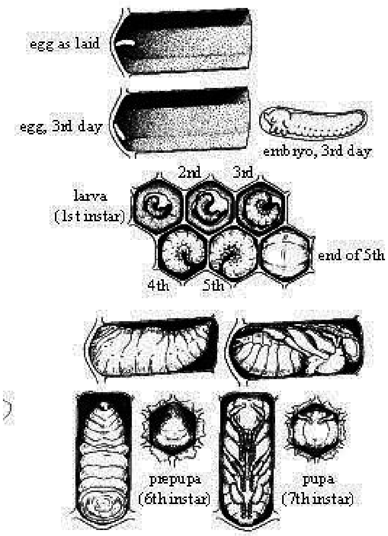

Figure – Developmental stages of honey bee inside hive cells

Bee Dance

Social behaviour in bees has a number of advantages. One of the most important of these is the ability to quickly mobilize a large number of foragers to gather floral resources that may only be available for a short period of time. The ability to communicate location with such precision is one of the most interesting behaviours of a very interesting insect honey bee.

The recruitment of foragers from a hive begins when a scout bee returns to the hive engorged with nectar from a newly found nectar source. She begins by spending 30-45 seconds regurgitating and distributing nectar to bees waiting in the hive. Once her generosity has garnered an audience, the dancing begins. There are 2 types of bee dances: the round dance and the tail-wagging or waggle dance, with a transitional form known as the sickle dance.

In all cases the quality and quantity of the food source determines the liveliness of the dances. If the nectar source is of excellent quality, nearly all foragers will dance enthusiastically and at length each time they return from foraging. Food sources of lower quality will produce fewer, shorter, and less vigorous dances; recruiting fewer new foragers.

Honeybee scouting means the individual bees which are searching for the environment without prior information about the possible location of food sources or nest sites. Although it is very difficult to study, the details of the bee communication or bee dance were worked out by Karl von Frisch and his colleagues and are detailed in his 1967 book *The Dance Language and Orientation of Bees.* Von Frisch was able to watch the bees perform dances by replacing one of the walls of the hive with glass.

1) The Round Dance

The round dance is used for food sources 25-100 meters away from the hive or closer. After distributing some of her new-found nectar to waiting bees the scout will begin running in a small circle, switching direction every so often. After the dance ends food is again distributed at this or some other place on the comb and the dance may be repeated three or rarely more times.

The round dance does not give directional information. Bees elicited into foraging after a round dance fly out of the hive in all directions searching for the food source they know must be there. Odour helps recruited bees find the new flowers in two ways. Bees watching the dance detect fragrance of the flower left on the dancing bee. Additionally, the scout bee leaves odour from its scent gland on the flower that helps guide the recruits.

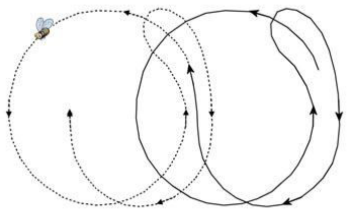

Figure – Round Dance

2) The Waggle Dance

As the food source becomes more distant the round dance is replaced by the waggle dance. There is a gradual transition between the round and waggle dance, taking place through either a figure eight or sickle shaped pattern.

The waggle dance includes information about the direction and energy required to fly to the goal. Energy expenditure or distance is indicated by the length of time it takes to make one circuit. For example a bee may dance 8-9 circuits in 15 seconds for a food source 200 meters away, 4-5 for a food source 1000 meters away, and 3 circuits in 15 seconds for a food source 2000 meters away.

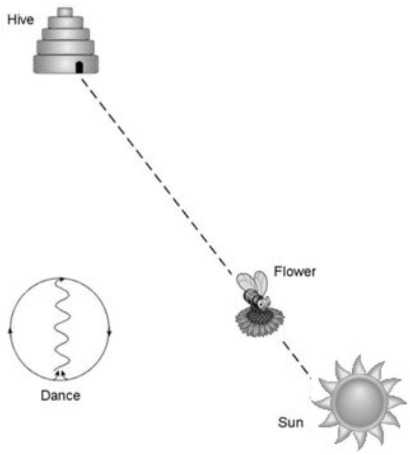

Figure -Direction of the food source is indicated by the direction the dancer faces during the straight portion of the dance when the bee is waggling. If she waggles while facing straight upward, than the food source may be found in the direction of the sun.

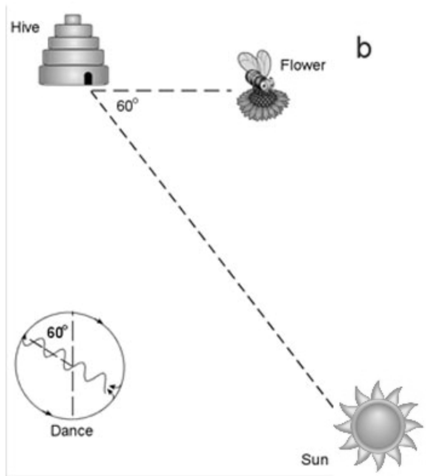

Figure - If she waggles at an angle 60 degrees to the left of upward the food source may be found 60 degrees to the left of the sun.

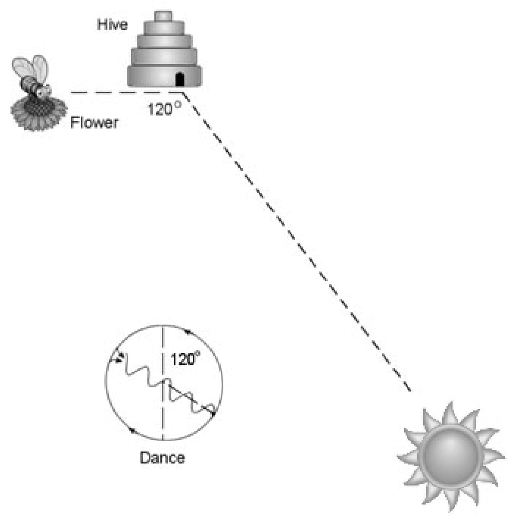

Figure -If the dancer waggles 120 degrees to the right of upward, the food source may be found 210 degrees to the right of the sun. The dancer emits sounds during the waggle run that help the recruits determine direction in the darkness of the hive.

Order – Hymenoptera

Social Life of Wasp

Eusocial behaviour among wasps is found only in certain members of the family Vespidae. These insects are commonly called paper wasps, hornets, and yellowjackets. They build communal nests by mixing wood fibres with saliva to form a paper-like material that can be moulded into brood cells and other nest components. The brood comb, where larvae are reared is always constructed like an inverted umbrella with open ends of the hexagonal cells facing downward. Workers usually cling to the underside of the comb as they guard the nest, feed the larvae, and perform other housekeeping chores. All social wasps are carnivores; their prey consists mostly of caterpillars and flies. The wasps chew up their victims' bodies into a paste that can be fed to their larvae and, in return, the larvae produce nutritional syrup that is consumed by the adults. A small colony of 200 yellowjackets may kill and eat about 5000 caterpillars over the course of a summer.

Wasps show transition from the solitary (non social) to the social life. During evolution transition from solitary to social life, species would have gone through different stages

1. Nesting together without much interaction

⬇

2. Nesting together with interaction and some division of labour

⬇

3. Nesting together with one morphologically specialized queen or a small number of such queens, that can lonely reproduce.

Wasps cooperate together in nest building and brood care, and show some division of labour. But there is no morphologically differentiated queen. If workers get opportunity most, can become queens. Any female member of the colony can start a nest and bring up her offspring by herself without participating in social life. Thus wasps live in a primitive society. There are only two social aspects in context of social behaviour of wasps:

(i) The relationship between workers and grubs

(ii) The division of labour amongst their co-workers.

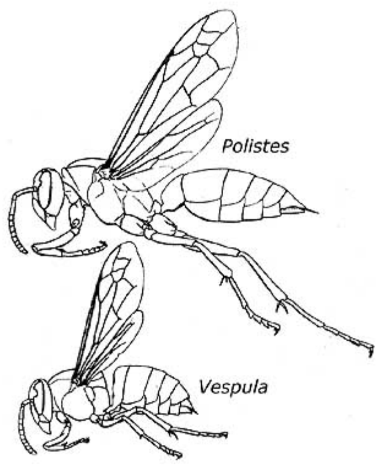

Figure – Common Indian Wasp species

One Indian species of wasps *Polistes herbreus* (Fabricius) shows social behaviour. The adults are smaller and yellowish in colour. The most prominent social wasp is *Vespa orientalis.* It is brownish and larger than yellow wasp. *Vespa niagnirica* is largest social wasp and it is dark brown in colour-

Wasps prepare their nests over walls, ceilings, and trees near human habitats. Nests of French wasps *(Polistes)* and Indian wasps *(Ropalidia)* have some hexagonal chambers in which embryos are reared. Wasps remain active in summer and hibernate in winter.

Through aggressive interactions the caste structure of the wasp's social system is maintained primarily among the colony members. If a queen fails to sustain her dominant role, she will be replaced by another fertile female who assumes primary responsibility for egg production. Males develop only from unfertilized eggs which are usually laid by unmated workers.

In tropical climates, social wasps are active throughout the year. New colonies often form by fission or swarming in which a fertile queen and a group of workers leave a large parent nest and set up housekeeping for themselves. In temperate climates, wasp colonies are founded in early spring by one or more queens who mated the previous summer and hibernated throughout the winter. The foundress queen constructs a small nest containing just a few brood cells. After laying a small complement of eggs, she feeds and cares for her offspring until they emerge as adults. These individuals (all females) become her workers. They assume all brood care, foraging, and housekeeping duties.

The queen continues to lay eggs and the colony grows larger throughout the summer. In early fall, the colony structure begins to break down. Unfertilized eggs give rise to males who mate with newly emerging females that will overwinter and found new colonies the following year.

Types of social wasps. There are about 9700 species of wasps world-wide. They can be divided into three groups:

- **Yellowjackets.** Nests are usually built in underground cavities, such as old rodent burrows.
- **Hornets.** Nests are always located above ground. Some species colonize hollow trees while others hang brood comb from a tree branch and surround it with paper walls for protection against the weather and natural enemies.
- **Common paper wasps.** Nests are typically found under sheltered overhangs where they are protected from wind and rain.

Caste Differentiation

Wasps show different castes differentiation in comparison to bees. Generally wasp colonies do not have a well - differentiated queen. All wasps in a colony look alike. She may be queen for some time only because she is often challenged and driven away by one of the others, who then become the next queen. The individuals who are not queens at any given time act as workers. They do not reproduce but perform all the works of the nest such as to build the nest, forage for food, care for the brood and defend the colony.

New nest can be managed by one female or a group of females. If it is a single foundress colony, the foundress acts as queen and manages all by herself to bring her eggs to adulthood.

In case of more than one or multiple foundress in the nest, one of the foundresses assumes the role of queen while the others assume the-role of-workers. In some wasp speciesqueens mate with a minimum of 3 males and simultaneously use sperm from different males and produce a mixture of full and half sisters among their daughters.

The queen lays eggs in the cells of the nest, when the eggs hatched out into larvae they are fed on a diet of hemipteran bugs, spiders, and caterpillars and occasionally some nectar, by the queen herself in single foundress nests and by workers in multiple foundress nests under normal conditions. Some of the workers or foragers search food and building material. Other members stays in home and working on the nest and on the brood. Among these, some are more aggressive toward other members of the colony, and these are called **fighters**. The remaining wasps work on the nest quietly and spend much time just sitting and grooming themselves, called as **sitters**, Larvae pupate in the same cell. Pupa metamorphoses into an adult. The entire process of maturing from an egg into an adult wasp, may take about 2 months.

Generally if the wasp emerging from the pupa, it will stay on the nest for about a week and then leave to lead a wandering life, mate with some foraging female wasp, and die. But in some species males also spend their whole life in the colony except for brief periods when they leave the nest apparently to mate with wasps from the colonies. Mating never take place on the nest.

If the female wasp is emerging, she may leave to start a new nest all by herself or she may leave with a group of females to do so, or she may join females from other colonies to start a new nest. She may remain on the nest and assume the role of a worker in the colony of her birth. She may remain on the nest, work for some time, and eventually drive away the queen and take charge as the next queen in the colony of her birth. Such a power struggle may also take place between the co-foundresses in a new colony, so that one foundress may replace another even before producing any offspring.

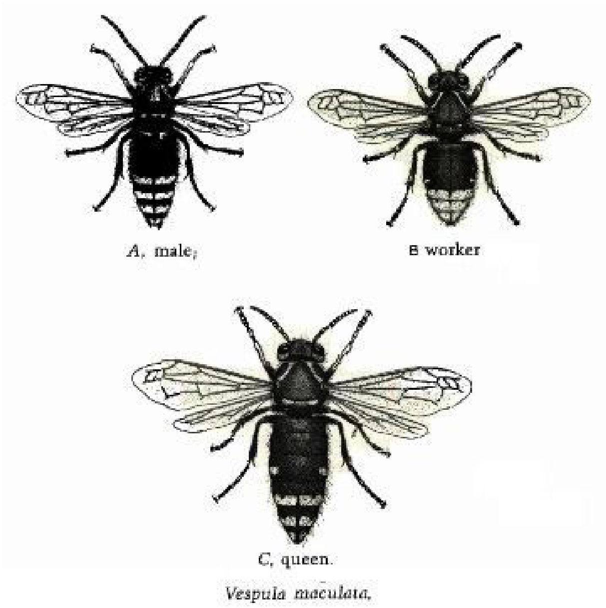

Figure – Caste differentiation of Wasp *Vespula maculata*

Nest of Wasp

Queens survive the winter by nesting in protected places such as under the bark of trees, or in cracks and crevices around structures. In the spring, several queens commonly get together to start a new nest. Eventually, one queen will dominate the others, making them serve as workers for the new colony.

By scraping and chewing wood into a pasty pulp, paper wasps make paper-like nests in the shape of an umbrella. These nests are built in protected locations including in shrubs, on tree branches, on porch ceilings, window and door frames, roof overhangs, attic rafters, and under decks, joists or railings. The queen deposits eggs in the brood cells on the underside of the nest. After the eggs hatch, the larvae are mostly fed other insects, such as caterpillars, that the worker wasps collect. Once the larvae have matured, they pupate in their cells and join the colony as an adult. Adult paper wasps mainly feed on nectar.

Southern Indian species of wasps *Ropalidia marginata* and *R. cyathiforrids,* are primitively social. These wasps build their nest from paper which they themselves manufacture from cellulose fibers scraped from plants. The size of the nest is very small, rarely exceeding 500 hexagonal cells.- Except for the brood, the wasps move on the surface of nest and not in it. The number of wasps in a colony rarely exceeds 100. This makes it easy to mark every individual wasp and make detailed observations on its behaviour, its interactions with other members of the colony, and its contribution to the welfare of the colony.

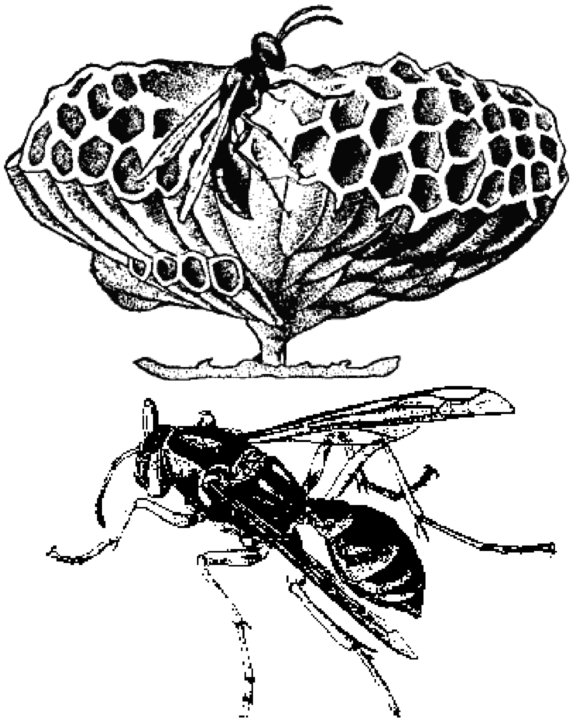

Figure- Paper Wasp Nest and Builder Social wasp

Order - Hymenoptera

Social Life of Ants

The ants are among the most highly evolved social insects. Like honeybee and termites they also have a very complex social organization. About 90% ant species are social. Ants live in colonies and a perfect division of labor exists amongst them. Ants are cousins of honeybees as they belong to the same order Hymenoptera, but the honeybees are diurnal and sleep in the night ants are busy working day and night. Ants have no wings, except in winged sexual forms that are produced in breeding season.

Ants have the highest developed social system, next only to man, with no apparent conflict seen in the society. A colony may have few thousand to over 500,000 individuals. The nests are built in various designs and are called **formicaria**. Like honeybees, they shows **polyethism**, which means castes are specialized to carry out specialized duties in the colony. For example, the queen has large abdomen to lay a lot of eggs approximately 2-3 million in a year, males fertilize her, workers have broad, sharp mandibles for cutting and chewing and the soldiers have large head that bears sharp dagger-like mandibles for fighting. Workers and soldiers are sterile females. Soldiers have giant heads that they use it for blocking the entrance of the nest. They are extremely powerful creatures that can easily lift 20 times their own weight.

Ants have poorly developed senses of sight and hearing but have a highly sophisticated chemical language for communication. They possess glands that secrete pheromones or messengers of chemical language that is perceived by one of antennae or feelers located on head. They trade food, glandular secretions and enzymes, which is called **tropholaxis**.

The path of migrating ant columns is directed by the chemical trail of pheromones left by the scouts and constant body contacts among the following foragers. Sometimes if their chemical trail is washed away by rain, they are doomed to follow each other's trail in circular tracks with eccentrically high speed.

Most species constructs their nests in the ground or wood but some construct suspended nests on trees made of earth, carton, wax or silk, while some species of safari ants, do not build nests at all. Desert ants build crater-like nests or mounds in which they are able to maintain temperature much below the outside heat of deserts. However, workers of the colony are allowed entry after they gently tap on the head of doorkeeper soldier. The tropical ant *Oecophylla* makes nest by webbing the leaves together with silken thread that is produced by their larvae. While many workers hold the leaves close together, some workers hold the larvae in their mandibles and use them like living thread balls to spin web to attach the leaves together.

Almost all ants store food for the lean periods but in the Australian honey pot ants *(Myrmecocystus hortideorum* and *Camponotus inflatus),* some colony members are specially modified to store honey. Their bodies are sac-like and appendages modified as hooks. Their abdomen is enormously large to store honey and they remain hanged from the ceiling and perform no other apparent function. These casts are called **Repletes** which are specially adapted to store honey stolen by foragers from the bee hives.

Ants are also good gardeners like a man. They are known to cultivate grasses and harvest and store their seeds. Some species raid the nests of other species of ants and rob them of stored food and keep their members as slaves in their own nests.

Nest (formicaria) formation

SIMILARLY like other social insects, in ants also the new colony is founded by a single newly fertilized queen. Some species do not construct nests. They simply take abode in cervices, holes under stones, or logs. Some species temporarily occupy nests other ants, a relationship termed piesiobiosis. Most species make their own nest. The nests or formicaries are of different types located in different places. Ants make subterranean nests excavating galleries and c1am-ben in the-grounds, used as nurseries for brood, granaries for storing food. Many species make mound nests. Such mound nests are well exhibited by species of *Formica*. *Formica rufa* make mounds of 60-160cm. in diameter. Some species construct suspended nests made of earth cartoon (Saliva mixed with Vegetable matter) or silk hanging from trees in tropics and containing anastomosing galleries and chamber.

African weaver ants (*Oecophylla longinoda*) and Asian weaver ant (*Oecophylla smaragdina*) construct large conspicuous nests on tree by weaving together several leaves with silk. They obtain the silk from their own larvae. The colony of weaver ants consists of a single queen and two kinds of workers, the larger major workers who forage, construct the nest, and take care of the queen, and the smaller minor workers who care for the eggs and young larvae. The adult worker cannot product silk. The silk is produced by the larvae. It is well known to us that in most insect species the larvae use their silk to spin cocoon inside which the pupae undergo metamorphosis. The major weaver ant workers who need silk, hold larvae together during nest construction to obtain silk from these larvae. While some major workers maneuver and hold leaves together, other major workers hold larvae in their mandibles and weave them across the leaf. This makes the larvae release strands of silk from silk glands underneath their mouth. Male larvae have smaller silk gland and contribute less silk for nest construction or cocoon.

Castes Differentiation

According to Imms (1948) at least 29 distinct types of morphologically different individuals are known. The ants shows an extreme case of polymorphism. The main castes of ants are queens, workers and mates.

1. **Queen or Gynes**

   Queens are the fertile females. Queen is largest in size in comparison to other castes of their species. The antennae and legs are relatively shorter and stouter and the mandibles are well developed. Some species are winged while some species are wingless. Usually large individuals are termed macrogynes, and dwarf ones, microgynes. Unlike honeybees, a colony of ants contains several queen.

An egg laying worker, gynaecoid, occurs in colony. She becomes normal queen if queen is lost due to any reason. Rarely there occur some peculiar individuals called gynandromorphy. They bear external secondary sexual characters of both male and female.

2. **Workers of Ergates**

   Sterile female members of ant colony are called workers or ergates. Ergates are smallest in size and are characterized by a reduced thorax, and small eye. Workers shows mostly dimporphism i.e. large and dwarfs. The larger workers are called the macregates and dwarf individuals as micregates. Macregates are called the wrestlers of the colony for their ability to lift too many weights. They also have amazing sense of direction. Soldiers are modified workers (sterile female). They are without wings, with distinct heads and powerful. They protect the colony from enemies. Besides protection they serve to crush seeds and other hard food material.

   In an ant colony number of army ants is very huge, it can be up to 22 million individuals. While on march they eat up everything edible in their path. Army ants (Eelton) have three types of workers. Small worker perform the task of feeding the developing broods. Intermediate size of workers works as foragers or scout ants. They search for the food site. Largest size of workers serves as soldiers who defends their colony. Some soldiers attack the colony of the insects and capture the young larvae and pupae of other ant colonies. Their captured larvae and pupae after hatching works as slaves in colony.

3. **Males or Aners**

   These are small, fertile winged individuals. They bear proportionately smaller head, reduced mandibles, longer antennae, well developed reproductive organs and genitalia. The larger individuals arc called the macraners and the smaller one micraners.

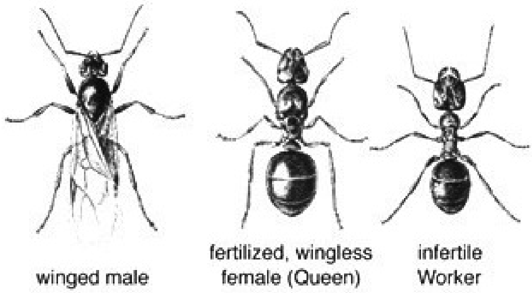

Figure – Caste differentiation of Ants

Life Cycle

Mating between male and queen occurs during nuptial fight. The queen lays eggs of about 0.5 mm size. The eggs hatch into larvae. The body of larva is legless and cylindrical. The queen feeds them with her saliva until the pupa stage. In a short time they change into the perfect insects. The earlier generations are of wingless worker which soon take over the charge of the colony, feeding and attending the queen and the brood. The winged males and females are produced later. Usually the ant colonies are perennial and continue to grow in size for many years. The population of nest of ant vary from a few thousand up to 5,00,000.

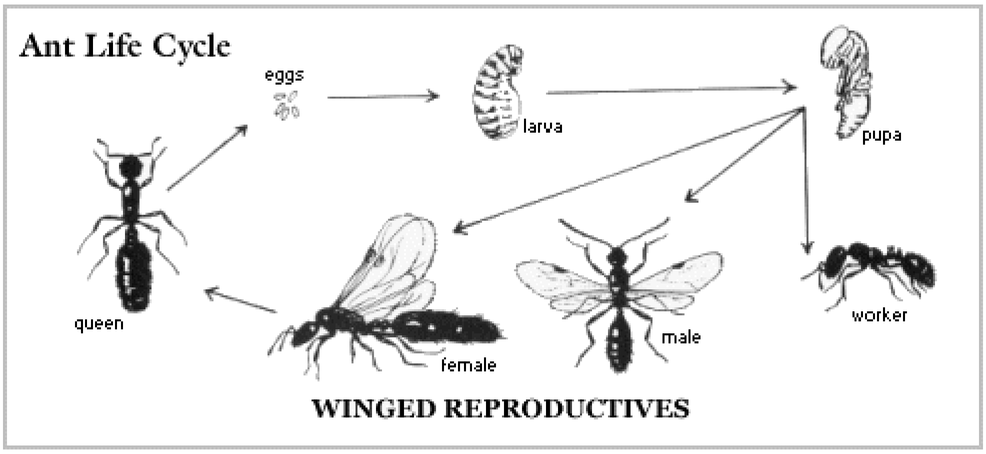

Figure – Life cycle of Ant

Caste Determination in Social Insects

Involvement of Pheromones

Pheromones are thought to play an important role in the physiological mechanisms underlying the development and maintenance of eusociality. In social insects very few members of a colony can become sexually matured because their reproductive development being inhibited by pheromones, so these individuals can perform other activities for the benefit of the colony as a whole by forming the worker caste. The regulation of caste differentiation in social insects is a morphogenetic phenomenon, just as are the changes from larva to larva, larva to pupa, and pupa to adult. Such changes depend on the activity of the corpora allata which controls the level of juvenile hormone in the hemolymph for their manifestation.

BEES

The most well-studied queen pheromone system in social insects is that of the honey bee *Apis mellifera*. Queen mandibular glands were found to produce a mixture of five compounds, three aliphatic and two aromatic, which have been found to control workers. Mandibular gland extracts inhibit workers from constructing queen cells in which new queens are reared which can delay the hormonally based behavioral development of workers and can suppress ovarian development in workers. The levels of two of the aliphatic compounds increase rapidly in virgin queens within the first week after eclosion i.e. emergence from the pupal case, which is consistent with their roles as sex attractants during the mating flight. These behavioural effects are mediated by the nervous system often leading to recognition of queens as a releaser and physiological effects on the reproductive and endocrine system as primer are attributed to the same pheromones. It is only after a queen is mated and begins laying eggs, however, that the full blend of compounds is made. The physiological factors regulating reproductive development and pheromone production are unknown.

ANTS

In several ant species, reproductive activity has also been associated with pheromone production by queens. In general, mated egg laying queens are attractive to workers whereas young winged virgin queens, who are not yet mated, elicit little or no response. However, very little is known about when pheromone production begins during the initiation of reproductive activity or about the physiological factors regulating either reproductive development or queen pheromone production in ants.

Among ants, the queen pheromone system of the fire ant *Solenopsis invicta* has been well studied. Both releaser and primer pheromones have been demonstrated in this species. A queen recognizing releaser hormone is stored in the poison sac along with three other compounds. These compounds were reported to elicit a behavioral response from workers. Several primer effects have also been demonstrated. Pheromones initiate reproductive development in new winged females, called female sexuals. These chemicals also inhibit workers from rearing male and female sexuals, suppress egg production in other queens of multiple queen colonies and cause workers to execute excess queens. The action of these pheromones together maintains the eusocial phenotype which includes one queen supported by sterile workers and sexually active males i.e. drones. In queenless colonies that lack such pheromones, winged females will quickly shed their wings, develop ovaries and lay eggs. These virgin replacement queens assume the role of the queen and even start to produce queen pheromones. There is also evidence that queen weaver ants *Oecophylla longinoda* have a variety of exocrine glands that produce pheromones, which prevent workers from laying reproductive eggs.

WASPS

Similar mechanisms are used for the eusocial wasp species *Vespula vulgaris*. In order for a *Vespula vulgaris* queen to dominate all the workers, usually numbering more than 3000 in a colony, she exerts pheromone to signal her dominance. The workers were discovered to regularly lick the queen while feeding her, and the air-borne pheromone from the queen's body alerts those workers of her dominance.

The mode of action of inhibitory pheromones which prevent the development of eggs in workers has been convincingly demonstrated in the bumble bee *Bombus terrestris*. In this species, pheromones suppress activity of the corpora allata and juvenile hormone secretion. The corpora allata is an endocrine gland that produces juvenile hormone, a group of hormones that regulate many aspects of insect physiology. With low juvenile hormone, eggs do not mature. Similar inhibitory effects of lowering juvenile hormone were seen in halictine bees and polistine wasps, but not in honey bees.

TERMITES

In addition to the worker caste, there exists in termites and ants a soldier caste. The number of soldiers present is proportional to the size of the colony, a feature suggesting that soldiers regulate the numbers in their ranks by production of a soldier inhibiting pheromone. However, the situation is made more complicated by a positive influence on soldier production by influence of pheromones on the part of the reproductives.

The pheromones regulating caste differentiation including the development of reproductives exert their effect, ultimately, via the corpora allata. In lower termites, for example, soldier formation can be induced in experimental colonies by administration of juvenile hormone through feeding, topical application, or as vapor. Thus, the soldier-inhibiting pheromone may act by inhibiting the corpora allata or by competing with juvenile hormone at its site of action

INVOLVEMENT OF DIET

Caste determination in most social insects likely involves both nature and nurture. Diet and nutrition in addition to the pheromones plays an important role in caste differentiation. Diet had evolved the queens of different species of social insects a measure of reproductive control over their nest mates.

In highly eusocial wasps where castes are morphologically dissimilar, both the quantity and quality of food seem to be important for caste differentiation. Recent studies in wasps suggest that differential larval nourishment may be the environmental trigger for larval divergence into one of two developmental classes destined to become either a worker or a gyne.

All honey bee larvae are initially fed with **royal jelly**, which is secreted by workers, but normally they are switched over to a diet of pollen and honey as they mature; if their diet is exclusively royal jelly, however, they grow larger than normal and differentiate into queens. This jelly seems to contain a specific protein, designated as royalactin, which increases body size, promotes ovary development and shortens the developmental time period. Furthermore, the differential expression in *Polistes* of larval genes and proteins also differentially expressed during queen versus caste development in honey bees indicate that regulatory mechanisms may occur very early in development.

In a beehive, the larvae are destined to be sterile females in form of strong workers if they are given the heartiest meals, packed full of not only processed pollen, called 'beebread,' but also a substance known as 'royal jelly. This is believed that larvae destined to be queens are exclusively fed royal jelly not a beebread for royalty, it contains powerful nutrients.

Mysterious milky substance is largely just water and sugar, and contains only one key ingredient called **royalactin**, is also present which somehow influences queen growth. Royalactin is a trace amount of a protein commonly present. A recent study shows that royal jelly lacking royalactin cannot make a queen.

It was found that phytochemical p-coumaric acid is found in beebread and honey which interfere with the path to queen development. Specifically, about a third of the honeybee genome is upregulated to make a strong worker, while another third are downregulated, changing the landscape of proteins available to help fight disease or develop the bees' reproductive parts.

Larvae become modified into different castes like small workers, large workers, or new queens which are based largely on the nutrition they receive. Those fed more insects than seeds are more likely to become larger individuals (queen > large worker > small worker). However, genetic differences also contribute and bias the larva's developmental pathway. Even once caste is determined, nutritional, colony size, and genetic factors all contribute, but in different ways, to how big an individual grows.

Although genetic factors contribute to what caste an individual becomes, the environment of the larva is controlled by the workers. Quite generally, ant colonies are supreme examples of both conflict and cooperation each extreme of the nature-nurture continuum.

11.5 Order – Hemiptera

Aphids

Aphids are known as plant lice, greenflies, blackflies, or whiteflies, (not jumping plant lice or true whiteflies). These are small sap-sucking insects, and members of the superfamily Aphidoidea. Aphids are among the most destructive insect pests on cultivated plants in temperate regions. The damage they do to plants has made them enemies of farmers and gardeners the world over. From a zoological standpoint they are a highly successful group of organisms. Their success is due in part to the asexual reproductive capabilities of some species.

About 4,400 species are known, all included in the family Aphididae of order Hemiptera, the mouth parts of which are modified to form piercing and sucking tubes, the insects obtaining their food by sucking plant juices or the blood of other animals. There are over 400 species and varieties of aphids but around 250 species are serious pests for agriculture and forestry as well as an annoyance for gardeners. This group of insects has an incomplete metamorphosis, there being no pupal stage but a series of moults in which the nymph gradually becomes a mature adult.

Aphid are with a complex lifecycle found widespread throughout cold, temperate, and warm climates across Europe, Asia, Africa and the American continents. The species can cause economic damage to plant crops as a result of its direct feeding activity. In high enough densities it can remove plant nutrients which can potentially cause a reduction in the number of heads, the number of grains per head, and a reduced seed weight

It may cause yellowing to upper leaves and ears, symptoms which are common to many aphid species and plant pathogens. Indirect damage can be caused by excretion of honeydew, and as a vector for viruses. It is found on many widely cropped species throughout the world.

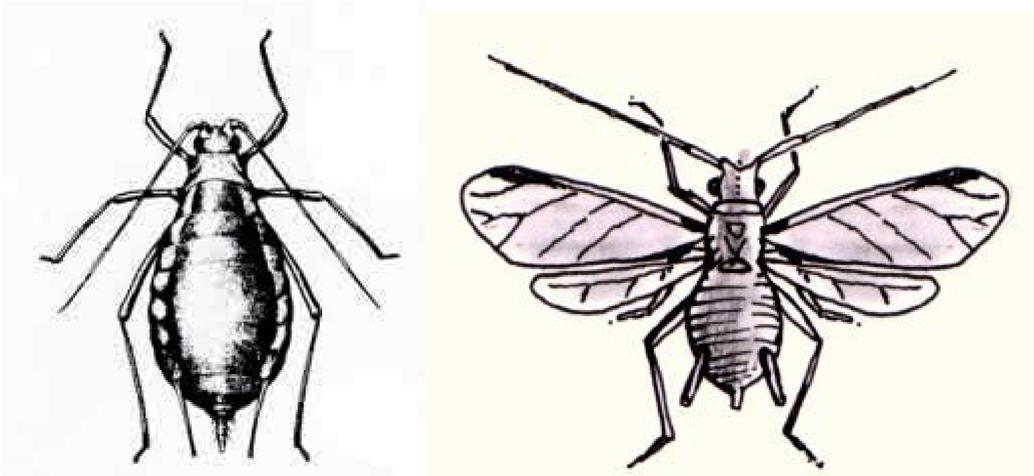

Figure – Aphids : Wingless and Winged form

Nymphs and adults feed in the similar way. Their mouth parts consist of a slender tube with two sharp stylets running down each side. All these are enclosed in the sheath-like labium and are held horizontally below the thorax when not in use. During feeding the labium is bent and shortened as the stylets and central tube are pushed through the epidermis of the leaf or stem until they reach the sieve tubes of the phloem in a vascular bundle. Saliva is injected through the puncture to begin the digestion of the sap and cytoplasm, and the fluids are then pumped up by muscular movements of the gullet into the alimentary canal. The fluid pressure existing in most plant cells probably assists the flow of liquid through the aphid's mouth parts. Most aphids seem to take in from the plant sap more sugar than they can assimilate, so that their faeces consist of a sweet syrup, honey dew, that is passed out of the anus. Some species of ant like to feed on this exudation and may be seen clambering over the colonies of aphids on nettles and other plants to collect it. Other species of ants 'farm' aphids by keeping them in the nest below ground where they suck fluids from roots, the ants then collect the honey dew as it is egested.

Life Cycle

Aphid species have unusual and complex reproductive adaptations, while some species have fairly simple reproduction. Adaptations include having both sexual and asexual reproduction, creation of eggs or live nymphs, and switches between woody and herbaceous types of host plants at different times of the year.

When a sophisticated reproductive strategy is used, only females are present in the population at the beginning of the seasonal cycle (although a few species of aphids have been found to have both male and female sexes). The overwintering eggs that hatch in the spring result in females, called fundatrices. Reproduction is typically parthenogenetic and viviparous.

In October the females lay eggs usually on the stems of trees or shrubs. The eggs are black, with thick shells and can withstand extremes of temperature. It is in the egg form only that aphids pass the winter. In March the eggs hatch out into wingless female nymphs which are similar to the adults, with three pairs of legs, compound eyes, antennae, etc. There is no larval or pupal stage comparable to those of the butterfly, but with successive moults and continuous growth the nymphs become mature females. No males are hatched at all.

The female nymphs feed on the shoots and leaves of the tree on which they hatch, at the time when the buds are sprouting. After a series of ecdyses (moults) they become mature and give birth to daughter aphids without any fertilization. This kind of reproduction is called **parthenogenesis**. Eggs are parthenogenetically produced without meiosis and the offspring are clonal to their mother. The embryos develop within the mothers' ovarioles, which then give live birth to first-instar female nymphs (viviparous). The offspring resemble their parents in every way except size, and are called virginoparae. The daughters, moreover, are not produced from eggs but are born alive as nymphs though they are surrounded at first by a transparent capsule like an egg membrane.

The daughters grow quickly and themselves have offspring by parthenogenesis. Some of these develop wings which grow larger at each **ecdysis**. These winged daughters fly off to an herbaceous plant such as a rose tree or bean plant. The winged forms have two pairs of wings of which the hind pair are quite small. Both pairs are transparent with few veins. The aphids are not strong fliers but tend to be carried by chance air currents rather than make direct flights.

When the winged generation reach the new food plant they give birth to wingless daughters parthenogenetically. In warm weather these may mature in 8 to 10 days and begin to reproduce in the same way by bearing winged daughters which fly off and infest new plants. This process of parthenogenesis goes on all through the summer months, winged and wingless generations more or less alternating. Enormous numbers of aphids are produced in this way, though a great many are killed by birds, ladybirds and their larvae, lace-wing larvae, and cold weather.

In October the first males appear. They have wings, and fly to a tree. Winged females fly to the same tree and there give birth to wingless daughters. The males mate with these when mature, and the wingless females subsequently lay eggs on the twigs of the tree. The eggs remain dormant until the following spring when the tree buds begin to sprout.

Some species produce winged females in the summer, sometimes in response to low food quality or quantity. The winged females migrate to start new colonies on a new plant, often of quite a different kind. For example, the apple aphid (*Aphis pomi*), after producing many generations of wingless females on its typical food plant, gives rise to winged forms which fly away and settle on grass or corn stalks.

Some aphids have telescoping generations, that is, the parthenogenetic, viviparous female has a daughter within her, who is already parthenogenetically producing her own daughter. Thus, a female's diet can affect the body size and birth rate of more than two generations (daughters and granddaughters).

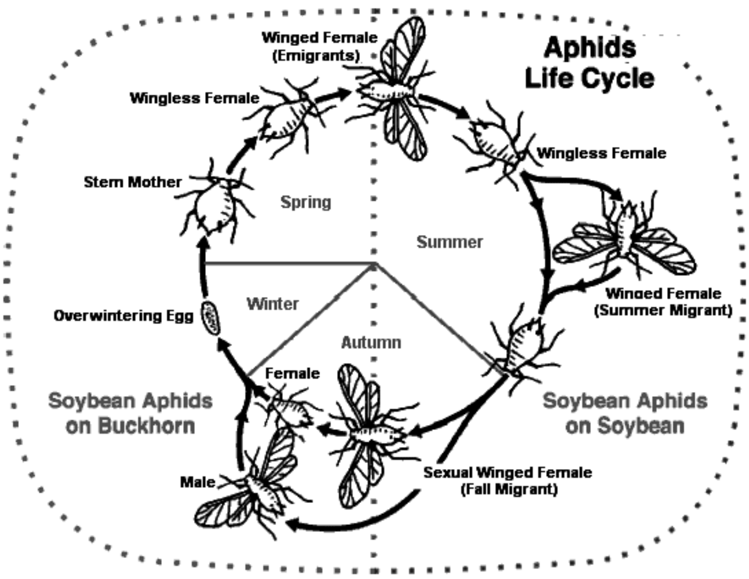

Figure – Generalized Life cycle of Aphid

Parthenogenesis

This is a natural form of asexual reproduction in which growth and development of embryos occur without fertilization. In animals, parthenogenesis means development of an embryo from an unfertilized egg cell and is a component process of apomixis. Parthenogenesis occurs naturally in many social insects like aphids, some bees and parasitic wasps.

Normal egg cells form after meiosis and are haploid, with half as many chromosomes as their mother's body cells. Haploid individuals, however, are usually non-viable, and parthenogenetic offspring usually have the diploid chromosome number. Depending on the mechanism involved in restoring the diploid number of chromosomes, parthenogenetic offspring may have anywhere between all and half of the mother's alleles. The offspring having all of the mother's genetic material are called full clones and those having only half are called half clones. Full clones are usually formed without meiosis. If meiosis occurs, the offspring will get only a fraction of the mother's alleles.

Arrhenotoky

This is a form of parthenogenesis in which unfertilized eggs develop into males. Arrhenotoky may be restricted to the production of males that are haploid, or include diploid males that permanently inactivate one set of chromosomes (parahaploidy) or be used to cover all cases of males being produced by parthenogenesis (e.g. aphids). Arrhenotoky occurs in members of the insect order Hymenoptera (bees, ants, and wasps) and the Thysanoptera (thrips). This system also occurs sporadically in some spider mites, Hemiptera, Coleoptera (bark beetles), and rotifers.

Thelytoky

This is a type of parthenogenesis in which females are produced from unfertilized eggs, as for example in aphids. Thelytokous parthenogenesis is rare among animals, but it is more common in invertebrates, like arthropods. It can also occur in vertebrates, It can be induced in Hymenoptera by the bacteria *Wolbachia* and *Cardinium*, and has also been described in several groups of Hymenoptera, including Cynipidae, Tenthredinidae, Aphelinidae, Ichneumonidae, Apidae and Formicidae

Hymenopterans have a haplodiploid sex-determination system. They produce haploid males from unfertilized eggs through arrhenotokous parthenogenesis. However, in a few social hymenopterans, queens or workers are capable of producing diploid female offspring by thelytoky. The daughters produced may or may not be complete clones of their mother depending on the type of parthenogenesis that takes place. The offspring can develop into either queens or workers. Examples of such species include the Cape bee, *Apis mellifera capensis*, *Mycocepurus smithii* and clonal raider ant, *Cerapachys biroi*.

Pseudo-Arrhenotoky

It is the phenomenon where males develop from fertilized eggs but where the paternal genome is heterochromatinized or lost in the somatic cells and not passed on their offspring. This phenomenon occurs in certain mites, beetles and mealybugs and scale insects.

Deuterotoky

When both males and females develop from unfertilized eggs, the term "deuterotoky" is usually used .

11.6 Summary

Social insects are among the most dominant and prolific of all organisms on earth. Many insects exhibit "social" behaviours like feeding aggregations, parental care of the nest sites. In a broad sense, any insect that interacts with another member of its own species could be called a social insect. Insect society is more organized and functional in many ways in comparison to any other society. Most species of honeybees, ants and wasps of order Hymenoptera and termites of order isoptera of class Insecta are perfectly social . There are various advantages and disadvantages both for living in social groups. Large colonies are especially vulnerable to the spread of contagious pathogens, nest sites may be exploited by social parasites who steal food or attack the brood, and member individuals must compete with each other for space and resources. But on the other hand, cooperation among different members can help them to do activities like construction of huge nest sites, widespread foraging for food, and constant vigilance against predation or parasitism which is impossible for solitary insects. Social behavior is an adaptation that promotes survival and reproductive success of the species. Every social insect colony member ceaselessly keeps on contributing for the welfare of the society and race continuity without any personal greed, lust of jealousy.

11.7 Self-Assessment Questions

1. Define polymorphism with suitable examples of insects.
2. Describe the life cycle of termites.
3. What do you mean by pleometrosis?
4. Define trophallaxis
5. What is royal jelly ? explain its importance for social bees.
6. What is Nabokov scent gland**?**
7. Explain the social organization and caste differentiation in termites in

details.

8. Describe the role of pheromones in caste dertermination.
9. Write an essay on Social life of bees.
10. Write a note on different types of parthenogenesis.
11. Differentiate between ants and termites.
12. Explain the caste differentiation of termites.
13. Describe the Social life of ants in details with its different castes.
14. Explain the role of nutrition in caste determination of social insects.
15. Define neotenics
16. What is nuptial flight?
17. What do you mean by colony collapse disorder?
18. Write a note on “Bee dance”
19. Describe the caste differentiation of social wasps

11.8 References

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Unit - 12

Origin and evolution of insects

Structure of the Unit

12.1 Objective

The objective of this unit is to know

- About the starting of insects life
- How the insects had evolved from various groups?
- Why the insects are most successful of all the organisms?
- Fossil insect discoveries gave the answers of many questions about insects.
- Insects are majority in number as far as taxa are concerned.

12.2 Introduction

The entire unit includes system of insect classification based on their evolutionary history. Insects impact the entire food chain, food web, have economic importance and the fossil record of insects tells us much about other life on Earth as well. Insects are continuosly evolving even today . This unit relates the origin and evolution of insects and how insects are changing today. The diversity of form and habitat results in presence of insects everywhere in air, water and land. The insects coming under phylum Arthropoda share some common character with other arthropodan classes. Insect fossils were abundant in the Silurian and Devonian period. The major advancement in insects were the origin of wings that facilitate dispersal, helped them to occupy new niche, being first flight organism it reduced their enemies in air and increased their chances of survival. In the Carboniferous and Permian periods evolution of winged form insects occured with hemimetabolous and holometabolous type of metamorphosis. The pupal stage development gave advantage as larva and adult forms differ in their habitat so competition among the same resources declined. The development of wing and pupal stage cause a profound effect on the success of insect world, diversity and survival.

12.3 Origin and evolution of insect orders

Before going through the origin and evolution of various insect orders we must understand the evolution of arthropods and insects. The evolution deals with three terms viz. **microevolution** when changes occurs in a population or species due to the selection pressure, **macroevolution** when changes occurs in class, order or family i.e larger than the microevolution and **megaevolution** when changes occur in phylum or more large phylogenic patterns.

12.3.1 Theories of phylogeny

The pattern of evolution shows similarities between Annelides, Arthropods and Onychophorans as they have common ancestry. **Snodgrass** (FIG 12.1) kept these three groups in superphylum Annulata. **Cuvie**r divided them into two subphylum Articulata having Annelida and Onychophorans while other being Arthropoda. Snodgrass later supported **Sharov** who said that all the segmented worm like animals diverge into two groups as one gave Polychaete annelids and other gave lobe like paired legs. Lobopods which again divided into two branches Arthropods and Onychophorans.

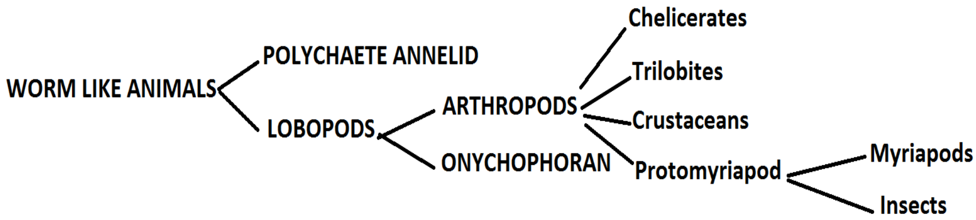


FIG 12.1: Monophyletic origin (Snodgrass and Sharov)

The origin of Arthropods seem to be monophyletic or share a common ancestry i.e. polyphyletic. On the basis of limbs, mandible and movement ,Manton grouped into two branches of polyphyletic origin :uniramous terrestrial line and biramous aquatic line. Uniramous includes Onychophora, Myriapoda and Insecta and biramous includes Crustacea, Trilobita and Chelicerata. Monophyletic all develops from worm like lobopods (FIG 12.2). Polyphyletic origin supported by hemolymoph, paired jointed appendages, trachea, malphigain tubes, compound eyes and cuticle. Monophyletic origin is supported by head ,embryology, eye structure, visceral anatomy and sensilla.

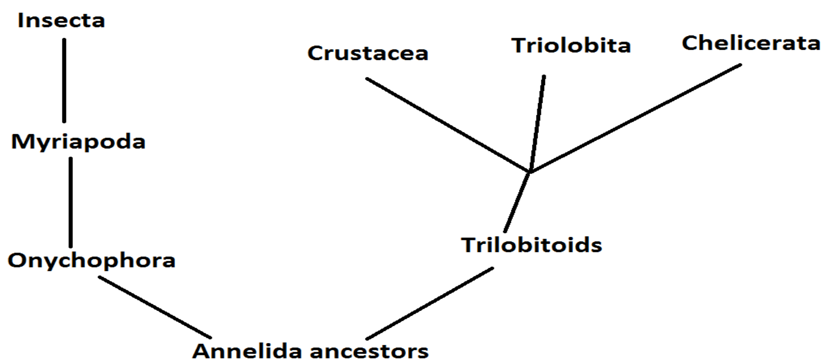


FIG 12.2: Polyphyletic origin (Given by Tiegs and Manton)

12.3.2 Major steps in evolution of insects

The class Insectais supposed to be developed from myriapods or protomyriapods during the Devonian period. Major steps involved in the origin and evolution of insects are (FIG 12.3);

- Appearance of primitive wingless insects in Devonian period
- Development of wings in late Devonian or lower Carboniferous period
- Wing folding on abdomen in lower Carboniferous period
- Complete metamorphosis in Upper Carboniferous period

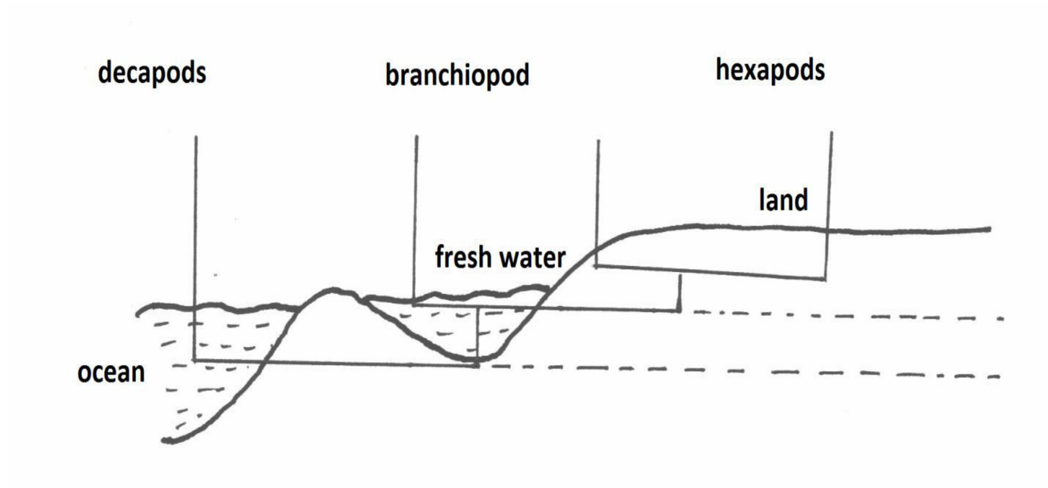


FIG 12.3: Showing the origin of hexapods

Step I- Appearance of primitive wingless insects

Carpenter gave all the major steps in the origin of primitive wingless insects. The first step in their evolution is the segmented, legless, worm like annelid stage, in which each segment is known as somite/metamere, the first segment is prostomium or acron and the last segment is periproct or telson. In the next stage the animal consists of paired lobe like appendages with simple eyes and antenna on first and second segment. The third stage protomyriapod or protoinsect as the name refers consist of insectan character like segmented appendages, somites 4,5 and 6 reduced, primitive head performing the function of food mastication and last appendage performing sensory function. Further stage refers to myriapod stage with 7,8,9 somites becoming primitive mandibulate type of mouth parts. In the next stage pauropod, chilopod or insectan level body divided into head, thorax and abdomen,abdominal segment 8 and 9 modiflied into external genitalia, `cerci on 11 abdominal segment and telson is lost. These insect resembles those of Archeognatha and Thysanura which are wingless or apterygotes, soft bodied and most of them are fossils today.

The theory of the fusion of segments is supported by the fact that the thorax has six legs derived from three segments, and the head has five fused **ganglia** and the thorax has three. Ganglia are nerve bundles, of which there is one in each segment of the annelid worms. The ganglia serve the purpose of brains in worms and play a lesser role, subordinate to the brain. One of the earliest steps in insect evolution was the development of the compound eye. Every terrestrial animal and many insects have **simple eye** only sensitive to the intensity of light and allow it to discern objects more**.** But some orders (e.g. bees) are known to need them for navigation. So the compound eyes develop for vision (FIG 12.4).

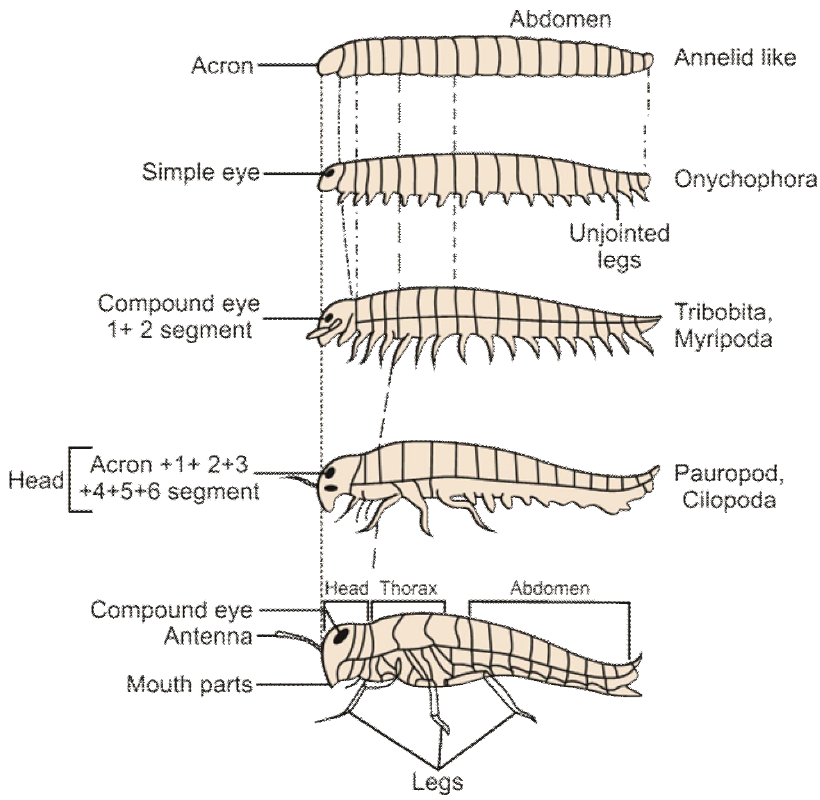


FIG 12.4: Trends of evolution in insects.

Step II- Development of wings

The development of wing was the major step in insect evolution as they were the organisms having power of flight for the first time even before birds. Flight mechanism gave success to the insect as they can escape easily when in danger and no competition is found in air. But the wings were not capable to flex on the abdomen while it remains expanded on rest. They comprised of Paleopterous primitive insects including Odonata and Ephemeroptera which were dominant in Carboniferous and Permain period. Wings were found in the thorax region not due to loss of walking appendages as that in case of vertebrates but they were added to thorax. Widely accepted theory of wing origin , the paranotal theory states that wings are the bilateral extensions of the thoracic nota. Then the wings developed articulation and neuromuscular arrangement for the gliding movement of wings. At the same time tracheal gills also developed in larval aquatic stages.

Step III- Wing folding on abdomen

Next step was the development of wing flexion mechanism which helped the insect to fold their wings on the abdomen**.** This is the character of neopteran insect group term refers to new winged form. This advantage added a significant change in survival of insect because it allowed more efficient escape and hide in the cracks and crevices and thus they become the dominant group of present day insects. As 90% of the all the orders and 97% of all the insect species belong to the Neopteran type e.g. Hemiptera, Dipteral, Hymenoptera, Siphonaptera, Anoplura, Neuropteran,Lepidoptera, Strepsiptera etc.

Step IV- Complete metamorphosis

Due to the evolution of complete metamorphosis, the different stages as larva and adult do not share common habitat and different habitat (aquatic larva and terrestrial-aerial adults) allowed them more efficient life, benefits in their predators danger, more dispersal potential, high fecundity, readily available nutrients.

With all these changes some more changes like tracheal system evolution (allows terrestrial gas exchange), impermeable cuticle (that do not allow water to escape and interrupt invasion of parasites) and fat body (help them to survive in drought and unfavorable condition) also developed.

All these changes divided insects into major groups as follows(FIG 12.6):

1. **Apterygote**s- primitive wingless insect
2. **Pterygotes-**winged insects
    i) **Peleopterous exopterygotes**- wing flexion mechanism absent, simple metamorphosis.
    ii) **Neopterous exopterygotes**- wing flexion mechanism present, simple metamorphosis.
    iii) **Neopterous endopterygotes**- wing flexion mechanism present, complete metamorphosis.

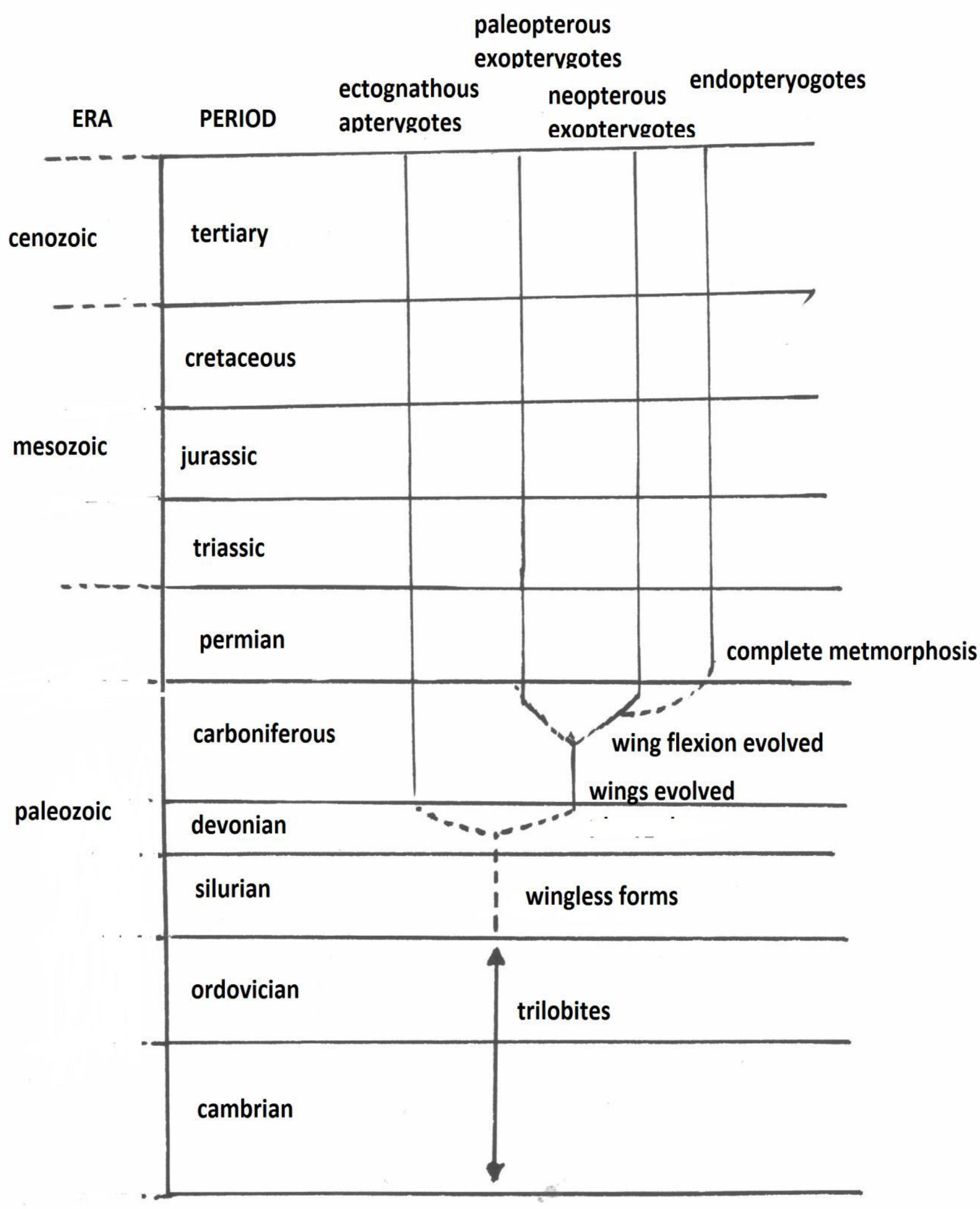


FIG 12.5: Major steps in insect evolution on a Geological time scale

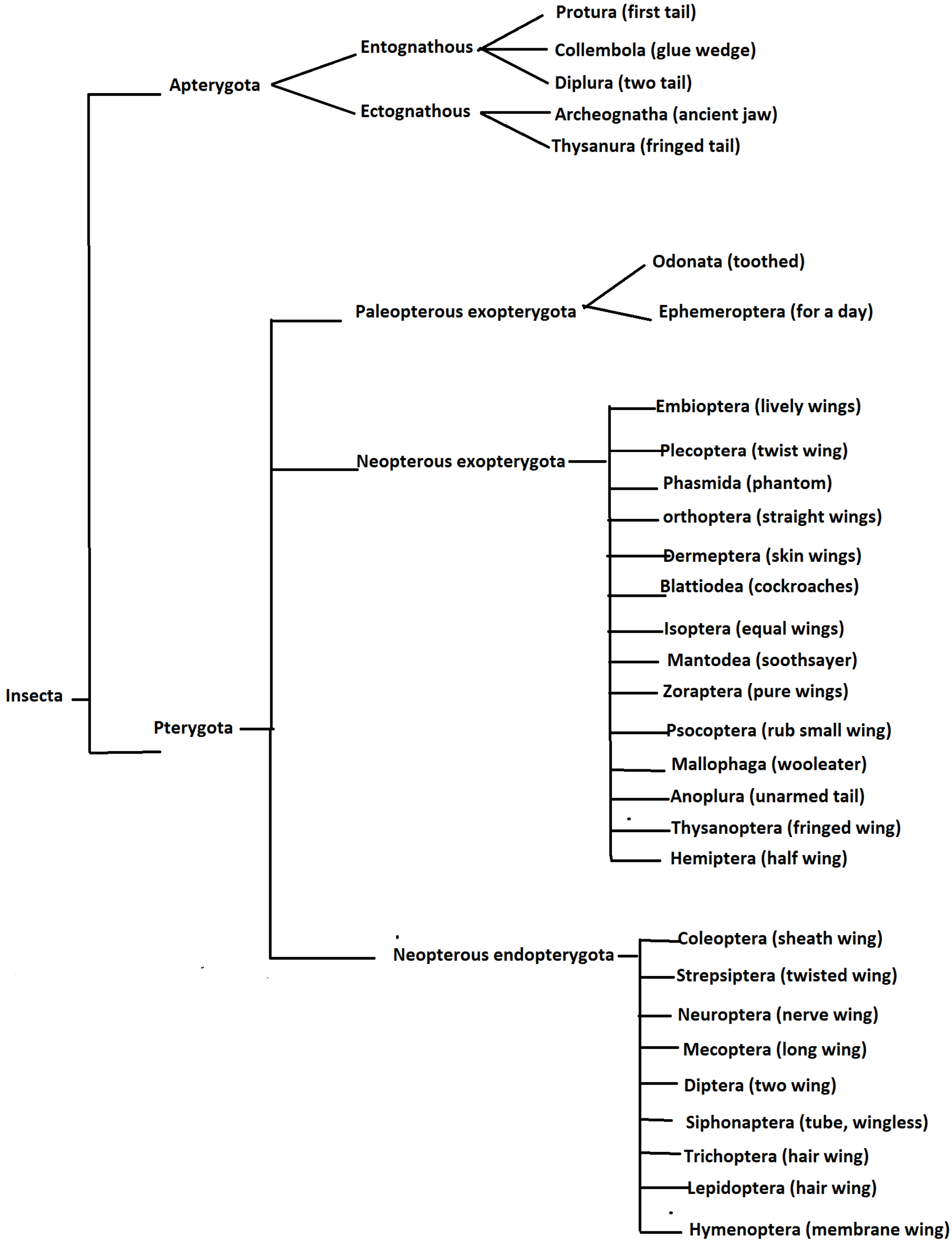


FIG 12.6: The classification of class Insecta showing all order name with their meanings

The orders of insects: Endopterygota (internal wing development) are separated from the Exopterygota (external wing development). Examples of endopterygota are the Coleoptera, Lepidoptera etc . and exopterygota are the Hemiptera, Homoptera, Orthoptera and Isoptera. The insects of Endopterygota underwent major radiation in the Permian. Most modern insect families appeared in the Jurassic, and further diversity probably in genera occurred in the Cretaceous.

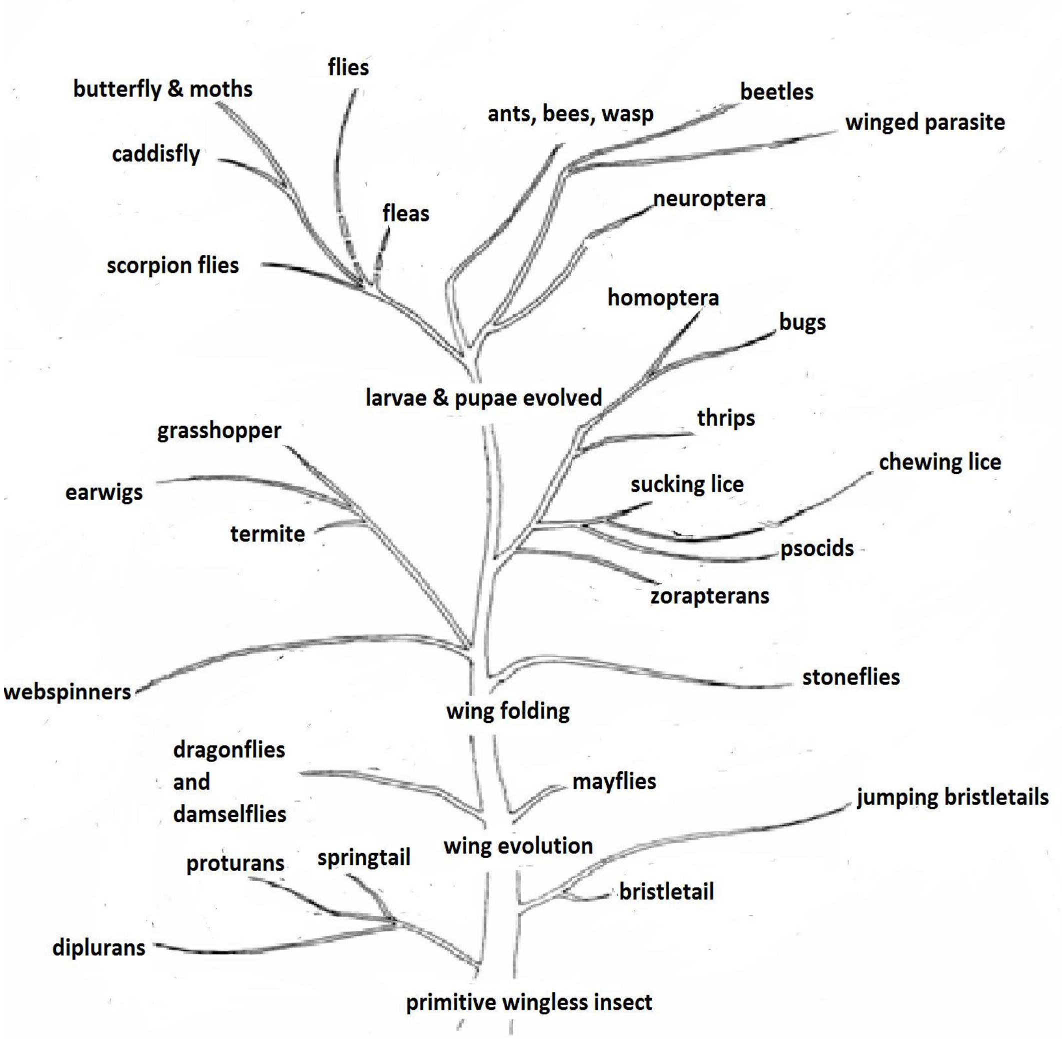


FIG 12.7: A hypothesized tree showing insect evolution

Insect evolution is characterized by rapid adaptation with selective pressures exerted by environment high fecundity, appearance of new species, diverse environmental niches and parallel evolution of flowering plants . (FIG 12.7).

So far there is nothing that suggests that the insects were a particularly successful group of animals before they got their wings. The members of the entognathous (mouthparts pulled into the head) apterygote orders include Protura, Collembola and Diplura and ectognathous (mouthparts not pulled into the head) apterygotes Archeognatha and Thysanura. The evolution of the orders of Pterygotes is described as Exopterygotes, Paleopterous endopterygotes and Neopterous endopterygotes.

Class Insecta	**Subclass: Apterygota**	Order: Thysanura (Bristletails) Order: Diplura (Two-pronged Bristletails) Order: Protura Order: Collembola – Springtails Order: Archeognatha
	Subclass Pterygota	Order: Ephemeroptera – Mayflies Order: Odonata - Dragonflies and Damselflies Order: Plecoptera – Stoneflies Order: Grylloblattodea Order: Orthoptera (Crickets, Short-horned Grasshoppers and Locusts) Order: Phasmida - Stick Insects and Leaf Insects Order: Dermaptera – Earwigs Order: Embioptera - Web-spinners Order: Dictyoptera - Cockroaches and Mantids Order: Isoptera - Termites or White Ants Order: Zoraptera Order: Psocoptera - Psocids or Booklice Order: Mallophaga - Biting Lice Order: Siphunculata (= Anoplura) - Sucking Lice Order: Hemiptera - True Bugs Order: Thysanoptera – Thrips

	Subclass: Pterygota	Order: Neuroptera - Lacewings, Alder Flies and Snake Flies Order: Coleoptera – Beetles Order: Strepsiptera - Stylopids (or Stylops) Order: Mecoptera - Scorpion Flies Order: Siphonaptera – Fleas Order: Diptera - True Flies Order: Lepidoptera - Butterflies and Moths Order: Trichoptera - Caddis Flies Order: Hymenoptera - Sawflies, Wasps, Ants & Bees

Table.1 : Classification of Insecta

12.4 Fossil insects

Insects of the primitive times are known as **Prehistoric insects** which are recorded in many groups in a past history. Some of them are extinct now; some are living fossils while others are in a group of recent evolution. The study of fossil insect is known as **Paleoentomology.** Insect shows their presence since the world of dinosaurs existed. The oldest known fossil insect was *Rhyniognatha hirsti* from the period of Devonian in the Paeleozoic Era about 400 million years ago. It is found that the modern insects have already evolved before the dinosaurs came in existing. Like today insects were the important part of the food chain and food web in the past.

The paleoentomological study shows that there are some differences between the modern insects and prehistoric insects. The primitive or prehistoric insects were larger as compared to modern insects due to the absence of the predators like bird, higher temperature that enhanced metabolism and higher atmospheric oxygen. The insect's exoskeleton is made up of chitin which in comparison to other vertebrate body is different in their burial processes. Insect remains were preserved in sap of trees like amber, in sedimentary rocks, between hard surfaces and ice.

Insects were the most successful group from the ancient times as they were the first organism capable of flight. Their number in the present status is much more than all the other living animals combined together. The fossil records are limited and only 7,000 species are known from the ancient world. Insect fossils study made some views that insects were probably fragile, lacking hard parts and lived on land in the case of wingless forms.

The primitive wingless insects like silverfish and springtail lived in the middle Devonian period about 395 million years ago. These fossil were found in the rocks of Scotland, New York and Quebec. Due to these fragments of fossil insects it was estimated that they started evolving prior to the Devonian period may be at the end of Silurian period (FIG 12.5).

Fossil wing and many specialized structures about 300 million years old were found in **Pennsylvanian rocks** . They were found in a large gap between Devonian fossil insects and Pennsylvanian fossil insects as there is no fossil record between the two in the Mississippian rocks. Therefore the origin of insect and evolution of Pterygote forms is a mystery.

Insects coming under Phylum Arthropods (jointed appendages) are relatively simple organism with a pair of antenna, chitinous body, jointed appendages, thorax with legs and wings, abdomen 10-11 segmented. As the wing contains many veins and a blood vessel therefore they can resist deterioration better than rest of the body and are commonly fossilized. They are delicate in appearance than also they can hold better compression as strengthened by network of veins. The other reason of known fossil insect by their wing alone is that the predator prefers the body of the insect to eat rather than wings.

The famous **Kansas rocks near the town of Elmo** is considered as the world's richest source of Permian fossil insects that lived between 300-250 million years ago. This area yielded thousands of the specimens. In the time of Permian period the Elmo sites were swampy, forest in the lower land and a freshwater lake nearby. This allows most efficient preservation of Elmo fossils as they got buried quickly in the fine grained sediments before they were consumed by the predators or scavengers. The insects like giant dragonfly *Meganeuropsis permiana* which is 29 inches with its wing span and it is the largest known insect ever known to us. It was predatory and got extinct in the world's largest mass extinction, a catastrophe that killed over 90% of the living creatures.

Another famous fossil site is the **limestones beds of Hamilton quarry** in the Greenwood country which includes fossils of dragonflies, crickets, cockroaches etc. A specific character of fossil insect was that they consisted of dicondylic mandibles i.e. mandibles were attached to the head by two condyles or articulation. Dicondylic mandibles are found in Thysanura (silverfish) while Archeognatha (bristletail) are monocondylic.

The winged form Pterygotes appeared in the Carboniferous period and Thysanura are more closely related to the Pterygote insects than the Acheognatha orders. The reason for their close resemblance is both of them kept a primitive anatomy as in case of Ephemeropterans representatives which are morphologically and physiologically similar to that of wingless insects, e.g mayflies larva resemble that of Thysanurans. Archeognatha and Thysanura still consist of rudimentary abdominal appendages called styli and extinct insect known as Monura had much more developed abdominal appendages. Archeognatha group generally found near the coastal region which suggests that the insects developed from marine environment and later become terrestrial and aerial.

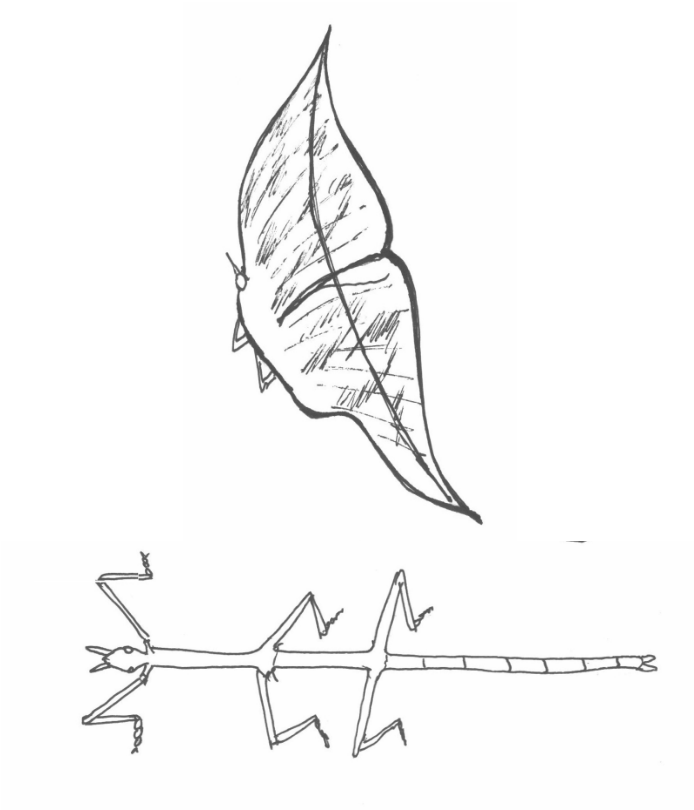
Apterygote fossil found mostly in range between Upper Carboniferous period and Lower Permian, it includes various species of *Dasyleptus* belonging to the extinct order of Monura. They lack anal cerci when compared to modern Archeognatha. Fossil Peleopterous Exopterygota orders were Paleodictyoptera, Megasecoptera, Disphanoptera which were terrestrial as their larva lacks gills, herbivorous, piercing sucking mouthparts, long cerci, external ovipositor and Protodonata similar to Odonata order. Neopterous exopterygote extinct orders includes Protothoptera (largest order, most diverse extinct group), Caloneurodea (FW and HW similarin size or shape), Miomoptera (mandibulate mouthparts, short cerci) and Protelytroptera (hard elytra, wing venation similar to Dermeptera). Neopterous endopterygote extinct orders includes only one order Glosselytrodea having hairs on wings, head and thorax similar to Neuroptera but venation is more specialized.

12.5 Causes of success of insects

There are certain factors due to which insects are the most abundant and most diverse group of organisms on earth. They have maintained their position in ecological system for about 400 million years. They were present at the time when rise and fall of dinosaurs happened. They have survived at least four major cataclysms that resulted in planet-wide extinctions; and they continue to thrive despite mankind's best efforts at eradication. There is no single factor behind the success of insects but mixer of various factor that evolve with time as mentioned above in the topic origin and evolution of insects. In short, the factors include an exoskeleton, small sized body, capability of flying, a high rate of reproductive, metamorphosis, and adaptations in an ever-changing environment.

12.5.1Exoskeleton

Like vertebrates, insect's do have supporting skeleton covering the body entirely. Exoskeleton gives shape and support to the body's soft tissues and also provides protection from attack or injury. It minimizes the loss of body fluids in both arid and freshwater environments. It gives mechanical advantage for the attachment of muscle to provide strength and movement. Exoskeleton can resist both physical and chemical attack as it is covered by impermeable layer of wax that prevents desiccation. Much of the exoskeleton is made up of chitin which is a polymer of N-acetyl-D-glucosamine, a polysaccharide similar to glucose that binds with various protein molecules to form a body wall. It may be flexible and elastic or hard and rigid due to the type of protein present in it, sclerotin protein gives hardness and resilin protein gives flexibility. The cuticular outgrowth like campaniform sensilla, trichoid sensilla and chordonotal organs acts as sensors to environmental changes. Some insects deposits excretory products below cuticle so acts as an accessory excretory organ. The scales, hairs and color are some of the external features which help in behavior modulation during mating. The color of the integument is useful in mimicry as in case of dead leaf butterfly, stick insects (FIG 12.8), that resembles those of surrounding and help them to hide from their predators, this increases the chances of survival and warning predators. Usually the chromophore is conjugated with the chromo proteins. The change in color called iridescence is common in Coleoptera and Lepidoptera. Muscles attached gives maximum strength for example in ant they can lift up to 50 times its own body weight.



A B

FIG 12.8: A) dead leaf butterfly B) stick insect

12.5.2 Small sized body

In general, the insects are very minute organisms and most of them ranges between 2 to 20 mm (0.1 - 1.0 inch) in length. Great variation like giant moths *Attacus atlas* which is more or less equal to nearly equal to computer screen and as small as tiny parasitic wasps (FIG 12.9), *Dichomorpha echmepterygis* which is like that of the all pin head also exist in them. Discovered in 1997, this Costa Rican wasp of the family Mymaridae is a parasite on other insect eggs. Adult males may be only 0.139 mm (0.00055 inch) in length nearly one third to some single celled protozoan.

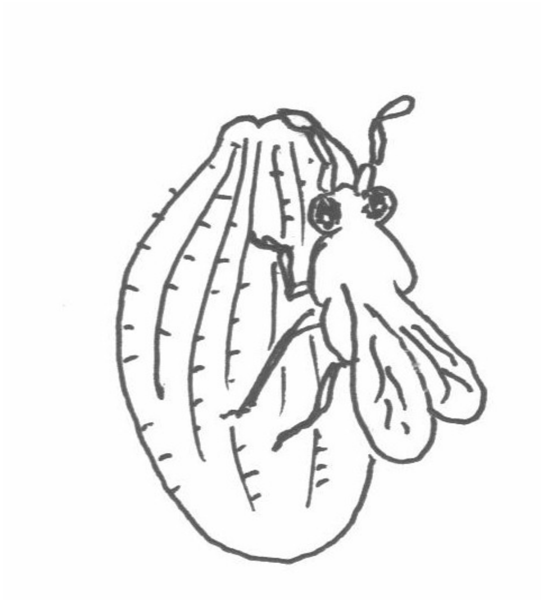


FIG 12.9: Parasitic wasp ready to lay egg on butterfly egg

Exoskeleton of small size is a distinct advantage, because if the insect is large sized then exoskeleton should be proportionately thicker to support the additional mass of body tissue. Thicker exoskeleton causes body to be heavier, which would require a larger muscle volume and consume more energy. So, two-fold increase in body length typically results in a four-fold increase in surface area and an eight-fold increase in volume and mass. If the insect becomes larger, heavier and muscular it will limit the power of flight. There is an upper limit to how large insects can become somewhere around 125-150 grams in case of heaviest insect *Golianth* (FIG 12.10) beetle which is not an efficient flier.

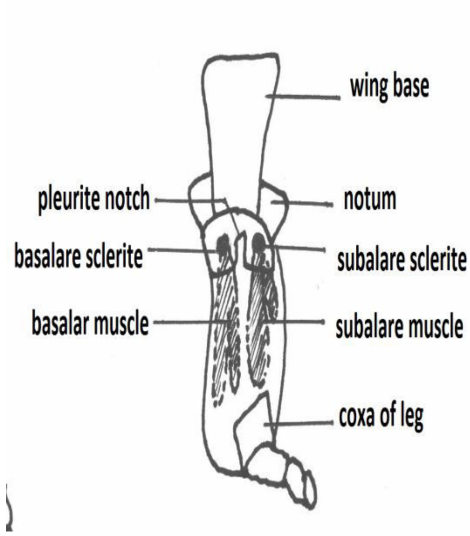
FIG 12.10: Golianth beetle

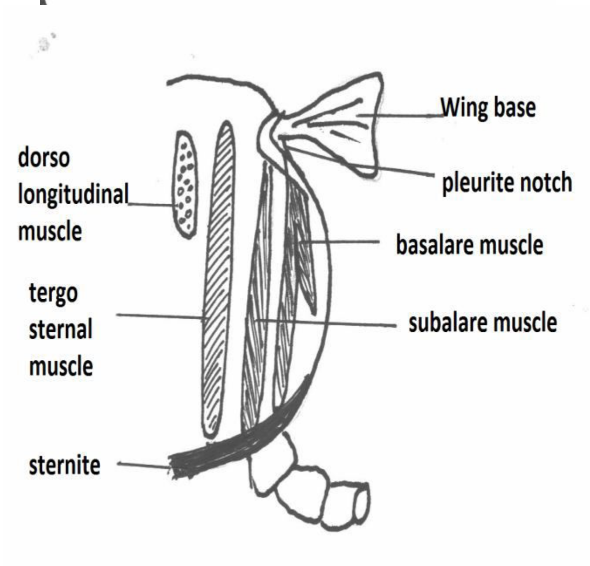
Another advantage of small size is that they can easily hide in cracks, crevices, below the stones, beneath the stone, below bark of the tree and this helps them from predators, parasites and other natural enemies. Some insects are so small that they cannot be seen with naked eyes. Small size means minimal resources for survival and reproduction. The insect may live on a single plant or animal or host for its entire life and never exhaust its food supply. For example, a leaf miner spends its entire larval stage in tunnels of parenchyma between the upper and lower epidermis of a single leaf. In some ant species, thousands of members of the entire colony may live inside a single plant gall/ hive or termatorium. Parasitic wasps (seven families of Hymenoptera) are a good example where they complete their entire development within the eggs of other insects.

Hard exoskeleton help them against injury during burrowing in between grains of sand, burrows, and other host body. Combination of small size with adaptations in body shape and coloration, gives many species the ability to mimic so well with their environment that they become virtually undetectable.

12.5.3-Capability of flying

Insects are the only exception in invertebrates that can fly. Starting from the fossil record, they acquired this flight ability about 300 million years ago and nearly 100 million years before the origin of the first flying reptiles. Flight gave one of the most important reasons in success of insects which provides a highly effective mode of escape from predators that roamed the prehistoric landscape. It also plays an important role in origin and evolution of insects. The class Insecta Is divided into subclasses and infraclasses on the basis of wings so it is a major character for classifying the insects.





A B

FIG 12.11: Insect flight muscle- A) left side of winged thoracic segment B) front view of winged thoracic segment

It is an efficient means of transportation, allowing populations to disperse more quickly into new niche and exploit new resources. The energy of flight in terms of calories per unit of lift is similar to that of birds and bats, an insect's flight musculature produces at least 2X more power per unit of muscle mass. The characteristics property of insect is largely due to elasticity of the thorax as 90-95% of the potential energy absorbed by flexion of the exoskeleton is released as kinetic energy during the wing's downstroke (FIG 12.11). Prolin is the amino acid used in flight in insects to travel great distances or remain airborne for long periods of time. Above 200 species, including moths, dragonflies, locusts, flies, butterflies are known to migrate over long distances by air. The migratory locust, *Schistocerca gregaria*, can fly for up to 9 hours without stopping and thus causing damage to large fields away from their infestation. Monarch butterflies, *Danaus plexippus* makes annual migration from North America from summer feeding grounds to overwintering sites in California and Mexico. Some primitive insects notably the dragonflies are remarkably agile fliers as they can catch its food like mosquito, horse flies while they are flying therefore it is known as **mosquito hawks**. Large hawker dragonflies (family Ashnidae) have been clocked at a top speed of 58 km/hr in comparison with the fastest human sprinters run only about 36 km/hr. The wings of a large insect can carry load on them as in case of green darner dragonflies (*Anax junius*) which are able to fly carrying a load up to 15 times their body weight. Insects having smaller wings have to work much harder than with large wings to remain airborne as tiny biting midges (like *Forcipomyia* spp.) beat their wings over 1000 times per second. A special type of muscle tissue is needed to sustain this rapid rate of contraction.

12.5.4 High rate of reproduction

Insects are having high rate of reproduction i.e reproductive potential is high. Reproductive potential is defined as the rate at which the insects add offspring to the population. This high rate causes insects to be more successful in the changing environment. Female insects have high fecundity (produce large numbers of eggs) and high fertility (most of the eggs hatch) in a short life cycle. Together, these three characteristics enable insects to produce remarkably large numbers of offspring. A typical female lays on an average about 100-500 eggs in her lifetime (FIG 12.12), but numbers in the thousands or crorers are not uncommon. The queen of an African termite colony produces more than ten million workers during her 20-25 year lifespan with only one time mating with its partner.

Antony van Leeuwenhoek, the Dutch scientist who first discovered single-celled organisms, was probably the first person to comprehend the reproductive potential of insects. In 1687, he reared blow flies (probably *Calliphora erythrocephala*) on owl meat and found 144 progeny half of which are male, half female with no mortality. So, a single female could give rise to 10,368 offspring in the third generation, 746,496 in the fourth generation, 53,747,712 in the fifth generation, and 3,869,835,264 in the sixth generation. But as the theory of natural selection given by Darwin follows the growth of larva is limited by all the limiting factors like food supply, predation, climate, and disease that keep natural populations below a certain level. This explains a quick insect population growth can cause a sudden outbreak of a pest. Since most insects die before they reach to reproduce many adaptations help maximize this potential. Most females, can store sperm for months or years within the spermatheca, a special accessory organ meant for receiving sperms of the reproductive system. A single mating can supply a female with enough sperm to fertilize all the eggs she will produce in her lifetime. There are a number of insects where males are rare, uncommon or absent e.g. aphids, scale insects, thrips, and midges contribute offspring through a process of asexual mode of reproduction like parthenogenesis, paedogenesis, polyembryony etc.

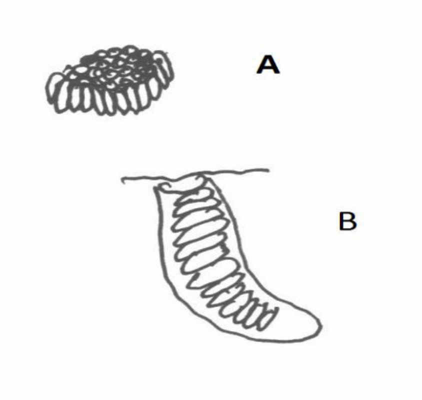


FIG 12.12: Number of eggs lay per individual in case of mosquito (A) and Grasshopper (B)

12.5.5 Metamorphosis

Metamorphosis is a process of change in shape and forms during the life cycle. Insects undergo significant developmental changes as they hatch fro egg and grow from immature to adults. These developmental changes may involve physical, biochemical, behavioral that promote survival, dispersal, and reproduction of the species. In the more primitive insects nymphs are similar to the adults except, their organs of reproduction is poor or underdeveloped and absence of wings as it develop slowly during the immature stages and become functional only in adults. Since this slow transformation does not include all body tissues and shows incomplete metamorphosis, the immature and adult share similar habitats and type of food.

More advanced insects undergo complete metamorphosis in which transformation in form and function between the immature and adult stages of development are different. In these insects, function of larva is primarily adapted for feeding and growth. It stores energy reserves which sustain the insect for the rest of its life. When fully grown larva moults into a transitional quiescent stage, called the pupa, and begins a period of massive internal and external reorganization. An adult insect called imago eventually emerges from pupal exoskeleton bearing no resemblance to its larval form. Its primary function is dispersal and reproduction. In the class Insecta, only 9 out of 29 orders undergo complete metamorphosis, these 9 orders contribute about 86% of all insect species alive today. The obvious advantage to this type of development is the differences in their food, form, shape, habitat, behavior and function of each stage larval form, pupal form and adult form are different. Each stage of the life cycle has different way to adapt to its own ecology.

12.5.6 Adaptability

Many factors discussed above like large and diverse populations, high reproductive potential, and relatively short life cycles, has lead to the most insects with the genetic resources to adapt quickly in the changing environment. Their record details give information that they were first aerial animals to adapt in the air. They were the first animals to use wings as flight organ and as an escape from predators. Even they were the first organisms to live in a complex social group with division of labor and gives parental care to the eggs or young ones. Over the ages there have been many drastic changes that have occurred including the evaporation of inland seas, formation of mountain ranges, shifts in continental plates, onset of ice ages, and the fallout from cosmic impacts but these adaptation keep the insect populations more or less constant. Perhaps the most remarkable example of insect adaptation in this century is the development of resistance to a broad range of chemical and biological insecticides used in the past years. After World War II, United States eradicated the house fly (*Musca domestica*) with DDT but with several years fly populations decreased and a few resistant flies managed to survive because they were carrying an enzyme that could detoxify DDT. These survivors reproduced and passed this resistant trait to their offspring. In time, DDT-resistant flies reestablished their environment. Significant levels of pesticide resistance have now been reported in over 500 insect species, and many of these animals are resistant to compounds from more than one chemical group.

12.6 Summary

The insects are diverse group of organism whose evolution and interrelationship with other arthropodan classes are evident from the study some fossil insects and the similar characters they share. The recent functional morphology and comparative morphology widely accepts polyphyletic theory which includes three distinct phyla Chelicerata, Crustacean and Uniramia. This theory has high degree of convergence. Hexapods or insect evolved from many legged segmented soft bodied Onychophora like organisms through a process of continuous cephalization. Insecta evolved into five groups Collembola, Protura, Diplura, Thyasanura and Pterygota. First three groups are different from each other and last two groups had a common ancestor. Thysanura like organism underwent a wide adaptive radiation into many orders to become most successful living group. The origin and evolution of insects are due to the reduction in appendages, wing development and holometamorphosis type of development. The success of insect world and diversity is due to their small size, adaptability, capablity of flight, high reproductive potential, metamorphosis and exoskeleton.

12.7 Glossary

- **Microevolution:** When changes occurs in a population or species due to the selection pressure.
- M**acroevolution:** When changes occurs in class, order or family *i.e* larger than the microevolution.
- M**egaevolution:** When changes occur in phylum or more large phylogenic patterns.
- **Apterygote**s- Primitive wingless insect.
- **Pterygote**s- All winged insect.
- **Prehistoric insects:** Insects of the primitive times are known as Prehistoric insects
- **Paleoentomology :** The study of fossil insect is known as Paleoentomology.
- **Monocondylic:** Mandibles are attached to head through one articulation or condyle.

- **Dicondylic:** Mandibles are attached to head through two articulation or condyle.

12.8 Self Learning Exercise

Section -A (Very Short Answer Type)

1. Name the smallest insect?
2. Can you give a name of heaviest beetle?
3. What was the first fossil insect identified?
4. Which place is called the world's richest source of Permian fossil insects?
5. Name the largest known insect ever known from the history to till date?
6. Which insects show mimicry?
7. *Musca domestica* is resistant to which insecticide?
8. Name the author who wrote Slient Spring?
9. Which category comprises 90% of the all the orders and 97% of all the insect species?
10. Give one example of order having dicondylic mandible?

Section -B (Short Answer Type)

1. Define Paleoentomology and prehistoric insects?
2. Give the differences between monophyletic and polyphyletic theory?
3. How will you differentiate between monocondylic and dicondylic mandibles? Give example?
4. What is the difference between the Exopterygotes and Endopterygotes? Give example of each group?

Section -C (Long Answer Type)

1. What are causes of insect's success?
2. Name all the orders of Insecta class with their meaning?
3. Give the theories related to the evolution of insects?
4. Define fossil insects? Write a brief note on insect fossils?
5. Describe the origin and evolution of various insect groups?

Answer Key of Section-A

1. *Dichomorpha echmepterygis*
2. *Golianth* beetle
3. *Rhyniognatha hirsti*

4. Kansas rocks near the town of Elmo
5. *Meganeuropsis permiana*
6. Stick insect, dead leaf butterfly
7. DDT
8. Rachel Carlson
9. Neopteran
10. Thysanura, silverfish

12.9 References

- Cedric Gillot : Entomolgy
- Kachhwaha N.: Principles of Entomology-Basic and Applied

Unit - 13

Insect Ecology-I

Structure of the Unit

13.1 Objectives

By the end of the chapter, the student would acquaint himself with the different aspects of interactions of insects with different abiotic factors of ecosystem like temperature, relative humidity, light, air and water currents, influence of biotic Factors like intraspecific Interactions – Competition, Sex relations, Reproduction, Parental care, Cooperation, aggregation, colonial and social life and interspecific interactions like competition, Commensalism, Symbiosis, Parasitism – host interactions, Predators-prey interaction. The concept of population dynamics, different modes for sampling, population Growth, Causes of Population Fluctuations, Host plant insect interactions, Biochemical adaptation against environmental stress – Hibernation, Aestivation, Dormancy, Quiescence, Diapause, Polymorphism and Swarming in different insects

13.2 Introduction

Ecology is a science, emerged as a distinct discipline only at the turn of the 20th Century and became prominent in the second half of the 20th Century. **Ernst Heinrich Philipp August Haeckel**, was an eminent German biologist, naturalist, philosopher, physician, professor and artist who described this term first time. The **insect ecology** is the scientific study of how insects, individually or as a community, interact with the surrounding environment or ecosystem. In a broader perspective the ecology is a study of the structure and function of nature as proposed by some earlier ecologists. Ecology the study of organism in relation to their environment has developed in recent years from the descriptive attempt to describe nature, the natural history of yesterday.

Ecosystem, the basic functional unit of ecology, is composed of abiotic (non-living) components of the environment and biotic (living) community both interacting with each other. An insect being the member of the biotic community interacts with other living members of the community as well as with the non-living (abiotic) components of the environment. The outcome of these interactions is the population dynamics, the positive or negative growth of the population. Hence the life system, existence, abundance, and evolution of insects can be understood by the study of interactions between insects and abiotic factors and insects and biotic factors and population dynamics.

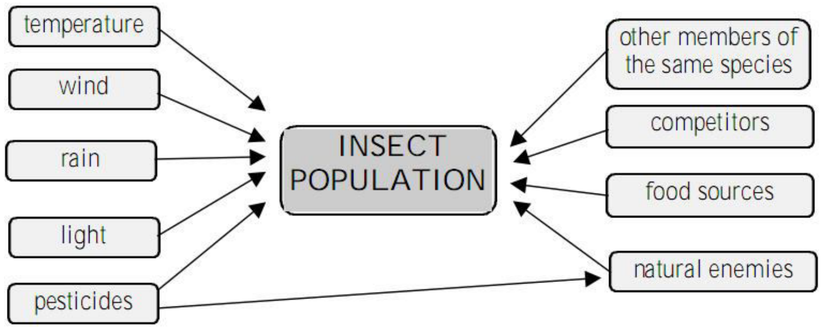
Insects are the dominant group of organisms on earth, in terms of both taxonomic diversity and ecological function. Insects play significant roles in the ecology of the world due to their vast diversity of form, function and life-style; their considerable biomass; and their interaction with plant life, other organisms and the environment. Since they are the major contributor to biodiversity in the majority of habitats, except in the sea, they accordingly play a variety of extremely important ecological roles in the many functions of an eco-system. Taking the case of nutrient recycling; insects contribute to this vital function by degrading or consuming leaf litter, wood, carrion and dung and by dispersal of fungi.

Insects form an important part of the food chain, especially for entomophagous vertebrates such as many mammals, birds, amphibians and reptiles. Insects play an important role in maintaining community structure and composition; in the case of animals by transmission of diseases, predation and parasitism, and in the case of plants, through phytophagy and by plant propagation through pollination and seed dispersal. From an anthropocentric point of view, insects compete with humans; they consume as much as 10% of the food produced by man and infect one in six humans with a pathogen.

13.3 The environment of an insect population consists

•**Physical factors (abiotic factors)** such as temperature, wind, humidity, light and pesticides

•**Biological factors (biotic factors)** such as other members of the same insect species; food sources; natural enemies (including predators, parasitoids and diseases) and competitors (other organisms that use the same space or food sources).



13.3 Abiotic factors

The Abiotic components of the insect environment, mainly include temperature, moisture, light, air and water currents and others. These have been found to be significant in their influence on insect.

The abiotic factors like temperature, moisture and light are not uniform throughout an ecosystem. They are variable not only in different parts of ecosystem but also in different parts of a plant. And therefore, the effect of an environmental component, like temperature, may be described accurately only in terms of the temperature in a specific part of an ecosystem. This has led to develop the concept of microenvironment which implies the variation in environmental component within the ecosystem.

The main abiotic factors influencing insects are temperature, moisture, light and air and water currents.

Temperature

Insect maintain body temperatures within certain boundaries. The temperature in the environment is variable. Thus the insects have to bear the effects of constant temperature which may at times be below or above the optimum temperature range as well as the varying temperature.

Insects have traditionally been considered as **poikilotherms** which means animals in which body temperature is variable and dependent on ambient temperature as opposed to being **homeothermic** animals which maintain a stable internal body temperature regardless of external influences. However, the term thermoregulation, is currently used to describe the ability of insects and other animals to maintain a stable temperature either above or below ambient temperature, at least in a portion of their bodies by physiological or behavioural means. While many insects are ectotherms, the animals in which their heat source is primarily from the environment, others are endotherms, the animals which can produce heat internally by biochemical processes. These endothermic insects are better described as regional heterotherms because they are not uniformly endothermic. When heat is being produced, different temperatures are maintained in different parts of their bodies, for example, moths generate heat in their thorax prior to flight but the abdomen remains relatively cool.

The various factors of Insects influenced by temperature are as follows-

Distribution of Insects

- The distribution of insects is affected by abiotic factor temperature particularly in low temperature zones. The distribution limit of insects in the northern extreme in temperate zones is determined by the low temperature extremes. Below the extreme distribution limits there is a zone which is densely populated during summer but during winter the insects usually die. The insects are abundant in high temperature zones because of variations in the temperature. As insect in north has less number of generations in a year as compared to the insect of southern zone. The rate of dispersal of insects is dependent on the temperature. Insects are more active in tropical zone than in temperate zone.

Insect Body Temperature

- Sun radiations and metabolic rate are major sources of heat gain. It is due to solar radiation that the temperature of the insect body becomes different from the ambient temperature. The different factors like size, color, and shape of the insects and orientation with respect to sun, influence the effect of solar radiation on the insect body temperature. A larger surface area having insect is more affected than the smaller insect. As per the scientific principle the colour and energy are interdependent therefore the insects colours of lighter colours absorb less radiations, than the dark ones. The insect with more surface exposed to radiation absorbs more heat.

- Heat loss in an insect is caused by various processes like evaporation, convection, conduction and long-wave radiation. In case of solar radiation the metabolic heat is the only source of heat during movement of insects. The break-down of complex organic molecules results in metabolic heat stored in the high energy bonds of ATP. In the absence of solar radiation the major loss of heat from the body takes place by evaporation. The rate of evaporation is dependent partly on the size of the insect. A smaller insect loses more water than the larger insect as the smaller insect has a larger ratio of surface area to volume.
- The movement of air also increases the heat loss as a steep gradient is maintained on insect and its surroundings. Hairs and scales present on the body of insects prevent the heat loss. In the event of a fall in surrounding temperature the insect maintains its body temperature by active body movement and muscles contractions. For example in Sphingididae family moths the body is kept warm by continuous wings movements. The activity of insects is directly proportional to the body temperature. When the body temperature falls, the metabolism slows down and its activity retards whereas on rise in the body temperature, the insects become more active until at a certain temperature it becomes inactive. A further rise in temperature causes death.

Vital Temperature

- The highest temperature limit at which the insect just lives and dies beyond it, is known as a vital temperature maximum while the lowest temperature at which the insect can live but may not exhibit any activity is called the vital temperature minimum. Usually 46^{D} C is the vital temperature maximum in insects but it varies in different species under different conditions. For example stored grain pest *Rhizopertha dominica* dies at a temperature of 62.8 ^{D} C exposed for 5 minutes. Hibernating insects can survive at a very low temperature of -50^{D} C.

Insects Mortality

- Insects survives themselves within the particular optimum range of temperature. An exposure to the temperatures above or below the extremes of optimum range is always fatal to insects. The optimum range of temperature depends on the specific species. It also depends on the physiological state of the individual insect. Some insects can tolerate the lower temperature during fall and winter than in the spring or summer. Insects of tropics tolerate less of cold than those of temperate areas.

Survival Range

- The insects remain active between the upper and lower tolerable limits of temperature but become inactive at both the extremes. Most of the insects survives in temperature between 0 and 50^{D} C, with few exceptions that can survive even beyond the extremes of this range. Certain larvae of dipteran insects can survives even at the temperatures of 55^{D} C or higher. Insects living at high altitude can complete their entire life cycle at temperatures of even below 0^{D} C.

Acclimation

- Acclimation is the process in which an individual organism adjusts to a gradual change in its environment such as a change in temperature, humidity, photoperiod, or pH, allowing it to maintain performance across a range of environmental conditions.

Low Temperature Acclimation

- The insects have been found adapted in the arctic by showing cold hardiness. Certain insects like *Aedes aegypti* can survive at low temperatures for a longer period and even show acclimation to cold but die due to freezing of the body fluids. Some insects can withstand super cooling thus can prevent freezing. The presence of some cryoprotective compounds in haemolymph such as sorbitol, glycerol and erythritol which depresses the haemolymph freezing point are helpful in freezing tolerant insects. During their inactive stage, the glycerol appears in the tissue and disappears soon after this state is over.

High Temperature Acclimation

- High temperature acclimation is useful to insects living under natural circumstances of daily high temperatures.It has also been observed in certain insects like *Calliphora* and *Phormia*.

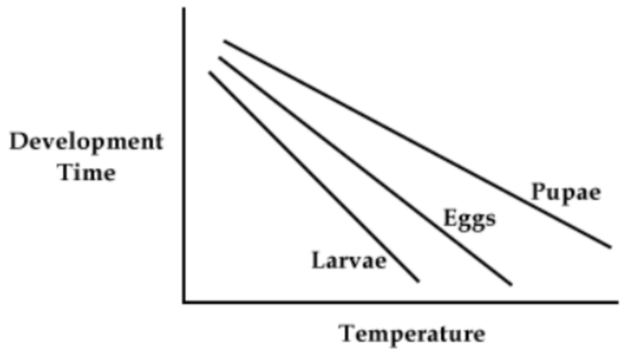
Temperature and consumption of Food Reserves

- When only limited quantity of food is available, the rate of consumption of food reserves is also dependent on the temperature. This in turn affects the survival of the insect. For example *Glossina spp*. fly depends on food reserves between two meals. If after one meal the food reserve is completely consumed and the fly does not get another meal immediately it will die.

Reproduction and Development

- The effect of temperature on reproduction and development rate vary within the species and between the species. The insects fertility its development ceases beyond the tolerable temperature range for reproduction and development. Within the tolerance range the development of eggs, the rate of oviposition, and larval and pupal development normally increase with the increase in temperature. Some interesting examples are of *Pediculus* which does not lay eggs below 25 ^{D} C and *Tenebrio molitar* which shows a considerable decrease in the pupal period with the increase in temperature within tolerable range.

- Within the optimum temperature range during which the reproduction and development ranges are maximum. Under fluctuating temperature the development rate is higher than under constant temperature, for example the eggs of grasshoppers. Such a situation is common under field conditions. The moulting process in insects is also affected by temperature. In some insects the number of moults increases at high temperature whereas in other it decreases. For example at a temperature of about 22 ^{D} C, 6 moults are recorded but at 32-37 ^{D} C there are only 7 moults by grasshopper.



Graph shows the relationship between temperature & development time of insects.

13.4 Relative Humidity (Moisture)

Environmental moisture factors are continuously variable. Therefore an insect has to face the extremes of these changes. All moisture factors also vary from time to time and spatially. The different factors related to moisture includes precipitations, humidity, condensation and available surface water. Snow fall provides solid precipitation whereas rainfall is the most common fluid precipitation. This depends upon air movement and the topography of the regions. These factors saturate the atmosphere with water vapour which results in the condensation through dew, fog and frost. All these factors cause the creation of dry and wet regions with many gradations between them. The amount of water vapour present in the air is considered as humidity which depends on the atmospheric pressure and temperature. For example there is always variation in relative humidity in different locations, time of day or year, topographical situation etc.

The various factors of Insects influenced by moisture are as follows-

Body Water Content

- Water is a important for life. The different insect's metabolic activities are dependent upon water. A suitable balance is always maintained between the water content of the internal environment of the body and the moisture present in the external environment of atmosphere which includes humidity and rainfall.

- In insect body the water content varies from insect to insect from less than 50 percent to more than 90 percent of total body weight. Caterpillars comparatively have larger amount of water whereas the insects with hard bodies have lesser amount of water. More water is present in the active stages in insects in comparison to inactive stages.

Water Source

- The main source of water is food for most of the insects. The quantity of water depends on type of food intake by insects. Those feeding on the succulent tissues of the plants have sufficient water whereas those that feed on dry food have little water. For arid zone insects the main source of water is obtained from metabolic process in the body. Some insects obtain water by absorbing it from the soil and atmosphere. The terrestrial insects living in dry areas obtain water by oxidation of the food within the body. Even fat is oxidised to produce water under certain conditions. The water from metabolic wastes is also utilized by *Tenebrio molitor*.

Insect Mortality

- Insect mortality is dependent upon the moisture in surroundings. There is always an optimal range of moisture which is suitable for insects. Excess of optimal range kill the insects. At extreme low moisture the active stages of insects in particular are killed. Mortality also occurs at extreme high moisture. The death at extreme low temperature is due to excess loss of water and at high temperature the causes for death are variable, such as spread of viral, fungal and bacterial diseases etc.

Longevity

- Environmental moisture determines the survival and length of life of insects. It is adversely affected by excess moisture. For example *Locusta migratoria* live longer at lower humidity.

Feeding Behaviour

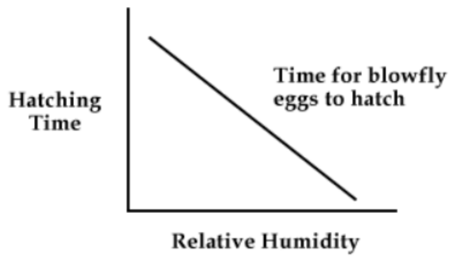
- At extreme moisture content in the environment the feeding activity of the insects is hindered. The larvae of spruce budworm stop feeding in water saturated air. The *Tsetse* fly does not feed at a relative humidity of 88 percent.

Reproduction

- Insect reproduction is also affected by moisture presence or absence. Excess moisture contents affect the reproduction. The Oviposition rate is adversely affected by low humidity. Infertility is shown by newly emerged adult migratory locusts, when relative humidity is below 40 percent.

Insect Development

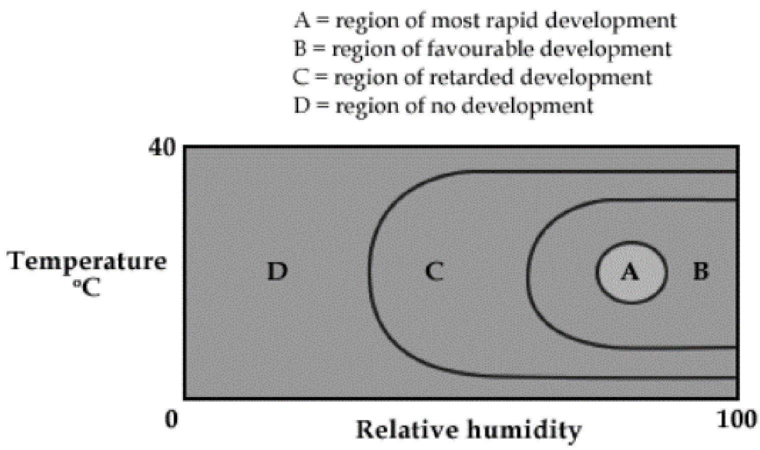
- Insect development and moisture relation is specific to species. The high moisture content decrease the rate of development which may even be completely halted. On the other side the silkworm larvae do not pupate at higher humidity. The incubation time for eggs is reduced at higher humidity for example in spider beetle. The developmental stages prefer higher humidity.



Graph shows the relationship between humidity and development time for blowfly eggs.

Combined Effect of Temperature and Humidity

- Insect interaction is always shown to a large extent between the effects of temperature and humidity. The humidity exerts a relatively greater effect on insects at the extreme temperatures and vice versa. For example, the boll weevil can survive in the high temperatures at comparatively low humidity as compared to high humidity. The same temperature has different effects at different humidity. Both temperature and humidity ecologically are interlinked.



Graph illustrates the interaction between temperature, moisture and insect development.

Light

Light is very important factor for insects. Its different parameters like photoperiod, illuminance, wave length, intensity etc. affects various activites of insects more or less. Rarely, the light acts as a lethal factor. The reactions of insects to photoperiod light and other parameters vary between the species and between different life stages of the same species.

Factors of Insects influenced by light

- Light has a great influence on the different factors of Insects like the swarming, egg laying, changes in flight, prolongation of life, the emergence of many species, stimulating effect on insects etc. For example the light stimulates egg laying in Praying Mantis and some other insects whereas it inhibits Oviposition in case of *Periplaneta.*
- The diapause is stimulated by the photoperiod. The feeding mating etc. are regulated by the daily circadian rhythms with dawn and dusk periods in between which functions as a biological clock.
- The plant feeding insects have senses of different wave-lengths of reflected light for host location. The direction of movement is affected by the position of sun and degree of polarization of light in different parts of the sky.
- Many insects are dependent upon plants for their food. The light have indirectly impact on the insects by affecting both terrestrial as well as aquatic plants. In aquatic ecosystem the main source of food are plants, the amount of light affects the photosynthesis in plants, and releasing

more oxygen, the aquatic insect life depends on the oxygen concentration in water to a very great extent.

Air and water currents

- Insects are influenced by both air and water currents. These are determined by geographic conditions of particular insect habitat.
- The insect mortality is caused by the air movement. Severe winds may cause mortality. The movement of air also kills the insects due to desiccation. However when the humidity is high the movement of air is beneficial.
- The distribution of several insects such as leafhoppers, aphids and many more insects is also influenced by winds. Sometimes wind is helpful in their dispersal while sometimes many insects are also killed by the strong winds by moving towards unfavourable environment.
- Water currents determines the existence of insects in different areas. The insects adapt themselves to face the water currents, for example Caddis flies get attached to submerged objects by their cases. The mosquito larvae and some other aquatic insects fail to survive in moving water. The black fly larvae get attached to stones or other material in water.

13.5 Biotic Factors

The influence of living organisms is said to be biotic factors. These factors have a profound influence on vegetation not only by their direct interaction but also through their effect on soil and therefore determine the nature of vegetation that can exist in a place. Biotic factors can be plants, other insects, wild animals, man etc.

Ecosystem existence is based on an effective interrelation between the insects and the biotic components. If the interaction is between the members of the same species it is called as intraspecific interactions and if the interaction is between the members of different species of insects it is called as interspecific interaction. Insects are also interrelated to plants as well as man. Interrelations of the insects to living environment are for the advantage of the insects.

Intraspecific Interactions

The main advantages of intraspecific interactions are high population density include availability of mates and the survival of potential predation. Intraspecific competition becomes more prominent when the availability of limited sources and when there is competition for same needs. These include associations for reproduction such as for mating, competition, pupation, parental care and cooperation, aggregation, colonial and social life.

Competition

Same species individuals lives in the same habitat, with similar requirements for food, protection and reproduction. There is a very tough competition for limited resources amongst them. The competition for food is very tough. Such a competition is disadvantageous to whole population. The fast feeders develop faster and may survive at the expense of slower individuals. The rule in the nature is survival of the fittest and weaker members are eliminated.

Sex relations

Sexual dimorphism is shown by different insects. In most of the insect species the males and females are of different sizes but in some species both are of equal size. Generally females have to breed, nourish eggs and young ones, therefore they are larger in size than males. And males members role is only to fertilize females or eggs, therefore they are smaller in size. Sexual ratio is also different in different species. In some it may be equal in number whereas in others they may be different in ratio. In aphids population males are absent.

Reproduction

In insects population pheromones plays a very important role in reproduction. Pheromone that serves as a chemical attractant to attract the other sex. The production of pheromone leads the insects to mate, copulate and reproduce. Moths depend on odour to seek their mates. Mostly nocturnal insects such as crickets make use of auditory signals to find out their mates. While some insects depend on visual stimuli to seek their mates. For example the male flies of the family Dolicopodidae, fire flies also depend on visual stimuli for finding their mates. The male flies flashes its lantern rapidly and the female sitting nearby glows at intervals. The light serves as visual signal. Among diurnal insects the colours and peculiar patterns are used for attracting mates. In tree cricket the male with upraised wings and loud singing approaches the female.

Parental care

Parental care in insects ranges from covering eggs with a protective coating to remaining to feed and protect young, to forming eusocial societies with alloparental care and lifelong associations of parents and offspring. Most commonly, care is provided solely by females; males rarely care for eggs and young alone, but in some cases males and females form long associations to rear young to adulthood. Various forms are widespread taxonomically and care is most developed in Hemiptera (true bugs), Thysanoptera (thrips), Embiidina (webspinners), Coleoptera (beetles), Hymenoptera (ants, bees, and wasps) and Isoptera (termites).

Parental care is exhibited by almost all the different species of insects. The variation is only of degree. Some exhibit parental care of a very high degree others simply just care for the offspring. The parental care varies from providing the shelter and suitable conditions for the development of the eggs to nursing, feeding, guarding, watching etc. of eggs, larvae, nymphs and imago. Almost complete care to the offsprings is provided by some insects.

The care of the eggs, laying of eggs at a suitable place having optimum conditions for incubation, sufficient food for the young ones and proper protection from the natural enemies. To provide protection, the eggs are hidden in crevices in walls, furniture and other household objects, underside of the leaves, stem tunnels, hollow seeds and fruits, under the bark and stones, underground and others. Some insects like lepidopterans glue the eggs to some objects, while others provide protecting cells or silken web made of various materials etc. The examples are ootheca of the praying mantid and cassididae, the former is made of solidified foam and the latter of faecal pellets. Some insects protects their eggs as well as larvae by preparing brood nest in which they also store food for them.

Some insects are very clever. They do not build their own nest but deposit eggs in the nest of other insects where the newly emerged larvae feed on the food stored by the insect that had built the nest. The example is of robber fly. It drops her eggs on the housefly paralysed by a wasp which he carries to his nest as food for the larvae. The beetle larvae cling to the hairs of the bee and along with it move to its nest where they feed on the nectar as well as the eggs of the bee. Some insects like cuckoo wasp leave their eggs in the nest of several other bees. Such habit has also been exhibited by robber and certain parasitic bees.

Forms of parental care

Maternal Care

The most rudimentary form of maternal care is provided by females that incorporate toxins into their eggs, oviposit them in protected places, or cover their eggs with a hard shell or wax-like compound before abandoning them For example, embiopteran webspinner females, *Antipalurai urichi*, cover their eggs with layers of macerated bark and other substrate materials and silk to protect them from hymenopteran parasites. Many species of insects guard their young against predators by using chemicals or defensive behaviors. Care may end when young hatch, or it may extend until larvae or nymphs are mature. For example, eggplant lace bugs, *Gargaphia solani*, guard their eggs and gregarious nymphs until maturity; if a predator approaches, the female rushes at it, fanning her wings.

A second major function of maternal care is to facilitate feeding. A plant-feeding membracid bug, *Umbonia crassicornis*, cuts slits in the bark with her ovipositor to facilitate nymphal feeding. She remains with the nymphs, actively maintaining feeding aggregations until the young reach adulthood. Parental care often comprises a suite of adaptations of multiple behaviours that serve multiple functions. A well-cited example of a complex of behaviours is the female salt-marsh beetle, *Bledius spectabalis*, which maintains a burrow shaped in a way that prevents flooding during high tide. She also provisions the young with algae, prevents mold, and protects the vulnerable first instars from attack by parasitic wasps.

The oviparous German cockroach, *Blattella germanica*, carries her egg sac externally until nymphs hatch, and *Blattella vaga* produces maternal secretions on which her neonates briefly feed. In ovoviviparous species, eggs develop inside the body of the mother and have sufficient yolk to complete development. The viviparous cockroach, *Diploptera punctata*, displays a remarkable form of parental care. Females undergo a 60-day "pregnancy" during which highly nutritious milk, secreted from the walls of the brood sac, is ingested orally by the developing young. At birth, young are in an advanced state of development, and care is terminated shortly after birth.

Paternal Care

Paternal care of eggs or young is restricted to about 100 species of insects, almost all within the Hemiptera. For example, in a giant water bug, *Abedus herberti*, females adhere their eggs to the wing covers of a male, who stops feeding and instead spends his time until eggs hatch aerating and protecting them from predators. Males of the subsocial spider-hunting wasp, *Trypoxylon superbum*. are an unusual example from the Hymenoptera. After females provision and seal the cells, males remain to guard nests against parasitism and ant predation. Males may care their offspring with nutritional offerings. They may transfer proteins or protective substances in a spermatophore. Male katydids, for example, provide a spermatophore during copulation that may be as much as 40% of their body mass; spermatophore nutrients have been shown to be important to the reproductive success of females. Male arctiid moths, *Utetheisa ornatrix* provide a different sort of indirect paternal contribution when they transfer protective pyrrolizidine alkaloids to females during mating. These alkaloids are passed to the eggs, which are then unappealing to predators.

Biparental Care

In case of biparental care both male and female members cares for offspring. This type of care is restricted to beetles, termites, and cockroaches, and may include earwigs. It can be very elaborate and extensive. For example, the woodroach, *Cryptocercus punctulatus*, and all termites form life-long family associations. Male and female construct and guard an extensive tunnel system or a nest, and they protect and facilitate feeding of young until the offspring reach maturity. Woodroaches care for a single brood for 3 or more years, feeding them on hindgut secretions containing symbiotic fauna necessary to digest their wood diet. In many of the "higher termites," (e.g., Rhinotermitidae and the Termitidae), few or no workers or soldiers reproduce; rather, they remain as alloparents. In the burying beetle, *Nicrophorus orbicollis*, males commonly remain in the nest until larvae are half-grown and the carcass is substantially consumed; females remain until larval development is complete and may even accompany larvae during the wandering stage. As with most species with biparental care, male and female burying beetles do not have exclusive, specialized tasks.

Cooperation, aggregation, colonial and social life

Cooperation

Animals have a tendency to cooperate with each other. Insects also cooperate with each other for different activities of the life. Initially insects Cooperates, then aggregates after this they becomes colonial and finally start living social life. Cooperation is considered as a compulsory part in the society. Without cooperation, the division of labour cannot be successful. The example of cooperation is provided by certain insects. A best example of cooperation is seen amongst ants. A worker ant while bringing the food, guides to its fellows the number of workers required to carry the food discovered by it. In case of injury they also show cooperation by carrying the injured fellows and also lick and clean their fellows.

The wasps collect and seal the food with the eggs. Some wasps continue to be with the eggs and assist the larvae in feeding. The wasps provide not only entire ordinary food but the specially prepared food also to the larvae.

Aggregation

For the profit of each other or for self only, the insects assemble in groups. The collective living may be on a permanent or temporary basis. Insects usually aggregates for defence from enemies, for breeding, for feeding, due to similar or limited habitat, because of the division of labour some animals, although independent individually, live together, due to responses to unfaviourable conditions, visual stimuli etc.

Colonial life

Insects shows some extent of the division of labour which lead to a colonial life. Colonies are organised group of individuals showing considerable specialization towards division of labour and cooperation.

Social life

Some insects like the termites, bees, wasps and ants lead a social life. The social insects exhibit the division of labour, cooperation and polymorphism. Social insects live in the colonies comprised of a large progeny, the individuals of which live together along with the mother. The works of the colony like feed collection, defence, care of the eggs, larvae and pupae are taken over by newly emerged progeny leaving mother for enlarging the nest and egg laying.

The ant colonies shows the most developed social life behaviour, their number varies from dozens to millions. The colony includes polymorphic forms and is developed by the fertilized queen or by the migrants of an initial parent colony. The sites of the colony include underground, under stones, in the open, in the trees and various other places. The workers collect the food for the colony. Like termites several species of ants cultivate fungi. A tendency of mutual feeding i.e. division of food between the individuals of a community is also developed amongst them.

The termites construct the termitarium with various facilities like controlled temperature and defence against predators and harmful fungi. The social organization of termite includes queen, the sexually matured female and her progeny which is comprised of mature males and sterile females (workers and soldiers). The colony lives in the nest which is composed of a queen chamber in the centre and many galleries with ventilators. The colonies are found in humid situations under stones, in the wood and on the wall of buildings. The vegetable matter collected by the workers forms the food of the colony. The larvae and queen feed on specific secretion by the workers. The *Ambrosia* fungus is grown in the fungus gardens in the nest which is used as a food.

The social structure in bees includes a single fertile female or queen bee along with a large number of sterile and winged workers, the females. The colony dwells in a nest made of wax combs. The workers collect the food which consists of pollen and nectar. The social structure in wasp is somewhat different from termite colony. It includes one or more queens and workers which are sterile and winged. The colony dwells in a nest made of wood pulp. It is comprised of numerous cells which are arranged in combs.

Pollution

If the population is high then their outcome will also be high, as a result there will be a pollution. For example in case of densely populated flour beetles huge pollution is caused by their metabolic wastes.

Interspecific interactions

Interspecific interactions takes place between different insect species like competition, commensalism, symbiosis, parasitism-host interactions and predator-prey interactions.

Competition

The interspecific competition between two or more different species is due to overlapping of their niches means when they have common needs for food, shelter, or any other resources. In such a situation no two species can occupy the same niche at the same time for very long, fittest species will capture the resource and eliminate the other weaker species. In the competition for food, a small species requires less food, they usually have an advantage over a large species that requires more food. Similarly a species that completes development in short time has an edge over a large species that takes a longer time. Competition is chiefly for food. If this food is sufficient just for one, then out of two individuals who will compete, only one will be winner.

Commensalism

Commensalism term was coined by Van Beneden for the animals who share common food. In this type of association one or more than one insect species may be benefitted but others are not injured or even affected adversely. In a way a species tolerates the presence and act of others. An example of commensalism is rat, in whose nest a large number of different types of insects take shelter.

Symbiosis

It is an association of different insects and other animals for mutual benefit. All the associates are called as symbionts and are benefitted. Symbiotic relations among different insects and other animals are established for different interests such as for food, protection, luxuries of life and even by accident. An interesting example is of a certain beetle that lives in the termite nest and gives off some secretion through a glandular knob of the abdomen. The secretion is continuously licked by termites. Symbiotic relations between ants and termites with several animals have been reported by several entomologists, for example nesting of many birds in association with wasps, ants and termites giving mutual protection. Ants have been reported to care for and receive food from aphids, membracids and scale insects.

Parasitism – host interactions

Parasitism is the association between two or more different animals in which one is benefitted and the other is harmed. In size a parasite is always smaller than its host. Parasites are dependent on hosts for food, shelter and protection. A parasite gives nothing in return to host. It becomes so much dependent on the host that it is rendered incapable of independent existence. A parasite does not kill the host but continuously feeds on the living substance for whole life. Various groups of animals are parasitized by the insects. They may even parasitize fellow insects. Parasitism is common in insects of the orders Neuroptera, Hymenoptera, Strepsiptera, Diptera and some Lepidoptera.

Types of parasites

- Ectoparasites -Those live externally on the host.
- Endoparasites -Those live within the host body.
- Facultative parasites-Those which need not to lead such a life. These may have life apart from the host.
- Obligatory parasites-These parasites can exist only when in close association with their usual hosts.
- Permanent parasites-Those parasites continually remain associated with their hosts.

- Transitory parasites-Those come in contact with their hosts occasionally or during certain stages in their life histories.
- Social parasites-Those attack societies and live at the expense of community.
- Accidental parasites-Those which are normally not parasites but due to some unusual circumstances become associated with the hosts.
- Monogenetic parasites-Those having a simple life history and all stages associated with a single host.
- Di- or Tri- genetic parasites-Those having alternation of generations and relations with two or more hosts.
- Temporary parasites-Those live a free life for some time.
- Hyper-parasitism-A parasite of an insect is itself attacked by another insect parasite.
- Multi-parasitism-In this case a host is attacked by several different species of parasites.
- Super-parasitism-In this case different individuals of some species attack the same individual of the host.
- Clepto-parasitism- is a kind of social parasitism which involves robbing.

Examples of parasites

Ectoparasites include mostly the blood sucking insects. These include lice infesting bats, and bed bugs, mosquitoes, fleas etc. which do not stick permanently on any host.

Insect parasites that are parasitic on other insects include predatory wasps and other insects that paralyze the host by stinging. They even lay eggs on them. The larvae feed on paralyzed host.

Some of them deposit eggs within different developmental stages of various insects. The larvae develop on these stages and finally kill them. Such a parasitic mode of life remains confined to the larvae and the adults lead a free life. Insects having such parasitic mode of life are met in the orders Hymenoptera, Diptera, many Neuroptera and some Lepidoptera.

Example of Hyper-parasitism is provided by a species of the Chalcid Perilampus which are often parasitic on the Ichneumonoids which are parasites of caterpillars of Lepidopetra. Ectoparasitism is common among hyper-parasites.

Clepto-parasitism is shown by bee lice that invade the nests of bees and consume the food stored by them. Social parasitism is seen amongst ants. The ant Anergates invades the nests of Tetramorium to take away the brood to its own nest.

Interactions

Insects are the organisms that parasitize insects, micro-organisms, mites and nematodes. Microbes and nematodes parasitize both insects and vertebrates. These insects play an important role of vectors carrying parasites to their vertebrate hosts. Microbes gain entry into insect either by penetrating the integument, or orally or through wounds. They may even pass on to offspring via eggs in some instances for example arboviruses in mosquitoes.

Bacillus thuringiensis is the best known bacteria that infects the insects. It forms the spores and is also used in bio-control. *Bacillus* larvae causes serious disease of honey bee larvae. Amongst other insect pathogens are *Clostridium* and *Streptococcus.* Insects also transmit certain bacterial pathogens of vertebrates for example rat flea causes plague in human.

Many known viruses have been found in insects of the orders Lepidoptera, Diptera, Hymenoptera, Neuroptera and Coleoptera. It has been found that a virus or a bacterium separately fails to produce a disease syndrome but the same is produced when a virus acts in conjunction with a bacterium, for example two diseases gattine and flacherie in silkworm involving *Streptococcus bombycis* and *Bacillus bombycis* respectively. Several viruses such as arboviruses, and those that cause yellow fever, encephalitis and dengue are carried to humans and other vertebrates by the insect vectors.

Amongst microbes, fungi include maximum species which are pathogenic to insects. Fortunately insects are not the vectors of those fungi that cause diseases in human and other vertebrates. Insects are the vectors of fungi pathogenic to plants.

Different protozoans of the group sarcodina, Mastigophora, and Sporozoa are insect pathogens. *Nosema apis* is pathogenic to silkworms and honey bee. Some protozoans found in the gut of termites helps in the digestion of cellulose by providing cellulase to their host. Insects also act as vectors for several protozoa pathogenic for humans and other vertebrates for example *Plasmodium spp*. causing malaria is vectored by *Anopheles* spp. mosquitoes. Other examples include *Tsetse* flies, the vectors of *Trypanosoma gambiense* and *T. rhodesiense*, causing African sleeping sickness and blood sucking bugs of the order Hemiptera, the vectors of *Tryanosoma cruzi* that causes “Chagas” disease.

Numerous nematodes are also associated with many insects. These are entomophilic nematodes that cause damage which is followed by death of the insects. Nematodes have also been found useful in insect bio-control. Some attack humans also, for example *Wuchereria bancrofti* (filarial worms). Amongst gall inducers, besides fungi, nematodes, mites and other organisms, the insects are the most common ones. Some specific galls are caused to develop by the insects.

Predators-prey interaction

Predator is an organism that eats another organism. The prey is the organism which the predator eats. Predator and prey evolve together. The prey is part of the predator's environment, and the predator dies if it does not get food, so it evolves whatever is necessary in order to eat the prey: speed, stealth, camouflage (to hide while approaching the prey), a good sense of smell, sight, or hearing (to find the prey), immunity to the prey's poison, poison (to kill the prey) the right kind of mouth parts or digestive system, etc. Most common relation between different species is that of predator and prey. Among insects, the predation is considered as the most primitive mode of feeding. Predaceous species are always less in number as compared to herbivorous animals and scavengers to avoid the extermination of the prey.

Prey capturing

The predator insects safe their prey by different ways. Odonates capture the preys on wing and praying mantis by lying in wait. The predators usually hunt by using their sense organs except antlions that capture by snaring the prey in pits or in webs for example Trichoptera. Cicindellid beetles secure their prey by springing, water striders by gliding on the surface of water, carabids by running down and dytiscids by swimming. In certain other insects such as Nepa, Mantispa etc. the forelegs are modified as raptorial appendages armed with spines and teeth.

Predators of insects

All the predators are found in abundance and consume a very large number of insects thereby exerting a natural force against insect population and regulate them. The main predator examples of the insects are mites, spiders, scorpions and pseudoscorpians amongst arthropods and fishes, amphibians, reptiles, birds and mammals amongst vertebrates. Insectivorous plants, such as pitcher plant, venus flytrap, bladderworts and sundews also trap and digest the insects. Man also use the predators to sustain the insect population.c threshold.

Predators like the beetles of the families Carabidae and Staphylinidae feed on both larval and adult stages. Other predators are nclude, wasps, larvae of certain families of Diptera such as Tabanidae, Dolichopodidae etc. nymphs and adults of damsel flies and dragonflies, certain hemipterans such as assassin bugs (Reduviidae), ambush bugs (Phymatidae), plant bugs (Miridae) and many other insects. Predatory anthocorid bugs on entering the galls feed on a few aphids present therein but those not attacked by them also die. Their death ensues by the funigant effect of chemicals which are produced by the stink glands of the bugs.

In vertebrates, may fishes, sun fish, perch, sheepshead, *Gambusa*, feed on insects. Reptiles and amphibians are very common insect feeders. Predaceous mammals include mice, shrews, skunks, ant eaters, bats and moles that consume large number of insects. Many birds eat insects. Amongst birds, fly catchers, night hawks, robins, wrens, cuckoos, quails etc. are outstanding insect eaters.

13.6 Population dynamics

Population dynamics is the branch of life sciences that studies the size and age composition of populations as dynamic systems, and the biological and environmental processes driving them (such as birth and death rates, and by immigration and emigration).The study of population growth and its causes is population dynamics. The growth may be positive or negative resulting into rise or fall in the number of individuals in a population. To understand the fluctuations in a population, different types of sampling methods are used. Sampling is the process of selecting participants from the population. The target population is the total group of individuals from which the sample might be drawn.

Different Methods for Sampling

Insect population in a natural habitat is dense, it is not feasible to determine the density of population just by counting. It can be done by dividing the whole observing area into small units, called samples. These samples are then analysed and the insect population is estimated in the vast area on the basis of number of individuals in different samples.

Systematic sampling

- When the habitat is homogeneous, the sampling is done by dividing the area into different units or samples having uniform spacing between them.

Random sampling

- When the habitat is heterogeneous the area is divided into units or samples in a random fashion.

Selective sampling

- In this case known insects which are habitants of certain locations in a sample area, the samples are picked up by selective sampling as the efficiency of sampling is increased by the selection of such locations. If the effect of different ecological factors in an area is to be assessed, the selective sampling is done. For example the samples are taken from the locations with a particular vegetation in a vast area.

Actual Count

- Actual count means the calculated count in different samples areas of population of insects in the whole area.

Relative count

- It means comparison of the count of two different areas. When the population in two areas is to be determined on a relative basis i.e. one area is with more or fewer insects than the other area, the sampling procedure includes the determination of the number of individuals for a given period of time in both the areas.

Population estimation by indirect methods

The population can be indirectly estimated by observing the different activities of the insects and not the insect counts. The activities may include different types of crop damages, defoliated leaves, injured field crops and fruits, faecal pellets, empty cocoons etc.

Population Growth

When there are favourable conditions, there will be a remarkable rise in the population which may even reach to millions, if the fecundity of female insect species is full and there is no mortality in all the young ones. The relationship between the population size and time is simple exponential. Total eggs laid by a female insect species have 50 percent females, then the population of the offspring in 20 generations will exceed millions. All the insect species will increase and reach the huge number if the environmental conditions are optimum and favourable. But in reality this is very rare that the insect species attains full fecundity and complete survival of young leading to maturity even when there are favourable environmental conditions. In environment the favourable conditions are not constant they are variable. because both biotic and abiotic factors in an environment varies from time to time and a population on reaching the high density itself creates adverse conditions making the environment unfavourable. The unfavourable environment factors reduces fecundity and also causes mortality in different developmental stages. The stages in the life cycle, if escape death, show poor growth and ultimately die. Thus the population of insects in different generations keep fluctuating. It may be increased in one year and decreased in other years but returns back to normal over a period of several years.

Natural Balance

The balance of populations of two successive generations is maintained by the mortality ratios of balance which varies from species to species. It is directly proportional to fecundity. There will be a fall in the population if the mortality ratio becomes higher than that for balance. The relationship implies that the mortality may be higher or lower than the ratio of balance in different years but ultimately the long-term mortality ratio comes to the balance level. This phenomenon is known as the natural balance.

Causes of Population Fluctuations

- Fluctuations in insect population is mainly caused due to the changes in environmental conditions but these changes depends on the sensitivity of the insects.

Sensitivity to Individual Environmental Factors

- Insect species are sensitive to particular environmental factors. A fluctuation in such factors causes a variation in the population of that particular insect species.

Sensitivity to collective environmental factors

- Insect species are influenced by different environmental factors collectively. In such cases a change in one or the more factors of the group to which a particular insect species is sensitive causes fluctuations in its population. The insects exhibit frequent fluctuations which may be irregular and cannot be predicted.

Sensitivity to individual large number of environmental factors

- Few insect species are sensitive to one or few factors but are tolerant to most of the factors. In such cases it is possible to predict fluctuations based on the degree to which such factors favour fluctuations. These are known as key factors.

Magnitude of fluctuation

- In case of small magnitude population species are able to tolerate most of the environmental factors continuously while big magnitude leads to population crash. This may be due to high rates of parasitism, food shortage, epidemics of disease etc.

Balance with the Environment

The population of different insects is kept balanced with the environment at different population levels. The various factors behind this environmental balance are such as natural enemies, genetic change, food, habitat, mortality etc.

- **Natural enemies**
  Many insect species shows population growth at exponential rates due to favourable environmental factors due to absence of natural enemies in the area. As soon as their natural enemies are introduced in the area their population shows a declination.

- **Genetic change**

  The natural selection results in the genetics structure changes of a strain. Since the change tends to be an adaptation to a favourable environment a high level of population is maintained. A limiting factor is that which limits the population even if all other factors are favourable, would improve and bring a remarkable increase in the population, for example increase in soil moisture for wire-worms. On the other side it can acts also as a degradation factor in spite of other factors that remain favourable as shown in the effect of resistant wheat varieties on Hessian fly.

- **Food**

  If suitable food is available for feeding then insect species may increase extremely in number to the extent that it becomes a pest. They may even extend their distribution. In such situation the insect species maintains a balance with the environment at a high density. For example Colorado potato beetle.

- **Habitat**

  Habitat fluctuation may also influences the population density. For example good irrigation of crop lands may increase certain insects number and become a major pest like wire-worms. Oxygen concentration in water influences the population of Mayflies, they increases in more quantity of oxygen but may be reduced by the eutrophication of rivers and lakes whereas the population of Chironomids increases in low concentration of oxygen.

- **Mortality**

  Mortality factors exert different effects on population dynamics, having different characteristics.

  There are three main causes for mortality in the insect population.

  1. Mortality due to shortage of food and other resources.
  2. Mortality caused by natural enemies.
  3. Mortality due to severe physical conditions which insects fail to tolerate.

- Consistency – The consistency of different mortality factors may be different. The variable factors are more effective and crucial than the constant factors.
- Specificity – Different mortality factors may differ in specificity. For example, if a general parasite attacks before the specific parasite the mortality will be higher.
- Density relationship – The density relationship of different mortality factors may be different. The factors that are density-dependent cause higher mortality with the increase in insect density. The factors that are density-independent cause constant mortality regardless or insect density.
- Effect on different insect stages – Different stages of insects may be affected by mortality factors.

There is need for designing the insect management programmes which must have an ecosystem approach. The study of population dynamics shows the ecological relationship of insects with their environment,

Host plant insect interactions

Approximately 30 -40% of all insect species feeds on plants and the remaining ones are carnivores, parasitoids, parasites, saprophages etc. In other words plant feeders are "parasites" of plants. Plants don't move so insects have to come near plants. Insects use all parts of the plant as food but there is not a single insect species which can consume all plant parts.

Leaves

a) Feed from/on surface

Leaf feeders (whole or portions of leaf)- e.g. Colorado potato beetle, grasshoppers, lepidopteran larvae, leaf feeders (skeletonizers), beetle larvae.

Sap suckers – These types of insects have a piercing and sucking type of mouth parts which help to enterinto individual cells or vascular system of plants. - aphids both direct and indirect damage.

The insects can assimilate plant and spread plant diseases. Any insect that moves from plant to plant may spread disease.

b) Feed inside- leafminers - serpentine, blotch mines, protected by leaf tissue, implications for control. E.g. - caterpillars, fly larvae, sawflies - birch leafminers.

Stems/Stalks

Insects can cause excessive damage to stem parts of plant with limited feeding.

a) Feed from/on surface - cutworms - also feed just below soil surface and on foliage, aphids etc.

b) feed inside -bark beetles – stem, stem or stalk borers - major pests in corn, also were in wheat.

Roots

Its usually very difficult to detect root insect infestation**.**

a) feed from/on surface - fly larvae - roots (cabbage maggots) also provide wounds, beetle larvae - wireworms - root damage, aphids - phylloxera.

Reproductive Tissues -Pollen feeders insects usually acts as pollinators, and seed eaters.

Factors which influence insect host plant interactions

1. Low nutritional quality (available nitrogen).

- Lower protein content than animals.
- Different ratios and proportions of amino acids, salts, etc.
- Phytophagous insects often have low assimilation and growth efficiencies (study: 2% - 38%).
- Assimilation and growth rates can be linked with plant nitrogen content:
- Effects of fertilizer- from increasing nitrogen content, overall many insects show "better" growth with increased nitrogen but not all.

2. Physical defences

- hooks, spines, trichomes - sticky exudates
- leaf toughness
- can be age-related (of plant). e.g. pubescence may increase with age.

3. Plant environment

- Plants in absence of phytophagous insects may flourish in a wide range of conditions. E.g. Klamath weed (introduced to North America). *Hypericum perforatum*
- Widespread plant in drier sunny exposure; acceptable to beetles (beetles destroy it). *Chrysolina spp* found in moist, shaded area - less or barely acceptable to beetles.

Plant chemistry

Plants contains various biochemicals that were used as medicines and poisons against insects

- **Loaded with bioactive substances**
  - Drugs/medicines - morphine, quinine.
  - Insecticides-pyrethrum
  - Many appear to be defensive material (against insects)
- **Effects of bioactive substances**
  - Cause disease in insect.
  - Inhibit feeding, reduce growth and fecundity.
  - interactions of these organisms may be driving the co-evolution of these systems.
  - Coupled to assumption that all the major plant components **(primary compounds)** and their effects on insects are similar then
  - Minor components **(secondary compounds)** influence insect specificity.
    - E.g. Amino acids - influence aphids.
    - Acceptable part of the time - then move to new host.
    - Secondary plant compounds - play a major role in specificity.
    - E.g. Alkaloids - over 5,000 known, Glucosinolates, phenolics (tannins).
    - These can be repulsive, unpalatable, poisonous or interfere with nutrient assimilation.
    - Prevents feeding by most phytophagous insects.

        - Some insects develop mechanisms to overcome defences
        - These plants then serve as important food source.

Host-plant resistance

Nonpreference (Antixenosis)

- Variation among group of plants makes some plants unacceptable.
- Lack of positive stimuli.
- Behaviour of insect changes.
- Stem-borers - tougher stems may reduce insect success.

Antibiosis

    - Consumption leads to disease/death.
    - Presence of xenobiotics (physiological disruption).
    - Most plant breeders manipulate these.

Tolerance

    - Can tolerate greater amounts of damage.
    - Plant variation.
    - Compensatory growth.

Host Plant Selection

Insects with their well-developed sensory systems select their host plants-

- Long distance –
    - Vision attractive colour - limitations.
    - Olfaction - large number of volatiles like mustard oils, thiocyanates - generated from glucosinalates, crucifer feeders
- Close to plant - olfaction - leaf alcohols (different blends - insects may differentiate between host and nonhost.
- Arrives on host (or similar to host) - taste and olfaction

Insect Behaviour on Plant

Colorado potato beetle

- Squeeze leaf with mandibles (especially marginal host)
- Small bite - marginal host - may take several bites before rejecting
- Feed - detect stimulants - feeding.

- Similar process for Oviposition.
- Detects deterrents.

13.7 Biochemical adaptation against environmental stress (hibernation, aestivation, diapause, polymorphism, swarming)

Hibernation

Insects are well hidden in winter, but there are several locations in which they can reliably be found. Ladybugs practice communal hibernation by stacking one on top of one another on stumps and under rocks to share heat and buffer themselves against winter temperatures. The female grasshopper, family Tettigoniidae, in an attempt to keep her eggs safe through the winter, tunnels into the soil and deposits her eggs as deep as possible in the ground. Many other insects, including various butterflies and moths also overwinter in soil in the egg stage. Some adult beetles hibernate underground during winter; many flies overwinter in the soil as pupae. Other methods of hibernation include the inhabitancy of bark, where insects nest more toward the southern side of the tree for heat provided by the sun. Cocoons, galls, and parasitism are also common methods of hibernation.

During winter hibernation is a physiological condition of retardation or arrest of growth, primarily to overcome lower temperature conditions. For surviving many insects regularly hibernate in the egg, larval, pupal or adult stage. Many insects enters into the hibernating state even when it is quite warm. The eggs of grasshoppers are laid during early summer and are subjected during the summer and autumn to temperatures well above those at which the hatching occurs in next spring. The hibernating pupae of most Lepidoptera cannot develop and reproduces if they are exposed to higher temperatures. It is necessary to chill the eggs of most of the hibernating insects before the hatching. Even if hibernation can be broken by application of high temperatures, high mortality or abnormal individuals result. The hibernating pupae of *Mamestra brassicae*, exposed to high temperatures throughout the winter, do not show any considerable reduction of the pupal period.

For the insect normal development heat acts as a disturbing factor. The role of low temperature in winter is very important for stimulating factor on development. Hibernation is also associated with other complex factors like atmospheric humidity. It was observed that pupae of *Saturnia*, which hibernate, may be induced to develop by moistening them several times. When hibernating codling moth larvae is soaked with water it shows high degree of survival. The hibernating larvae of *Pyrausta nubilalis* are sensitive to changes in contact moisture. Desiccation during hibernation retards pupation in this insect. The termination of hibernation of the adults of *Epilachna corrupta* is influenced by precipitation in spring. In the absence of moisture insects shows the prolonged hibernation and high mortality. Sometimes an abundance of moisture may prevent hibernation. Reduction of water content of the body increase resistance to cold and may perhaps be also an immediate cause of dormancy.

Aestivation

This behaviour is shown by insects during summer season. Aestivation is a state of animal dormancy, similar to hibernation, characterized by inactivity and a lowered metabolic rate that is entered in response to high temperatures and arid conditions. It takes place during times of heat and dryness, the hot dry season, which are often the summer months. Insects are known to enter this state to avoid damage from high temperatures and the risk of desiccation. Both terrestrial and aquatic insects can undergo aestivation. Some insects have ability to remain dormant during unfavourable summer months when there is water scarcity or intense heat. In hot and dry places, insects are usually more abundant during spring and autumn than at the height of summer. During the extreme high temperature they aestivate even in the presence of moisture. Aestivation is also perhaps an inherited cycle, which cannot be broken within a single generation. Normally in insects, during summer the adults die but the eggs & pupae survive by remaining dormant.

Dormancy

Insects exhibit different adaptive mechanisms for surviving and anticipating the various changes in ecosystem, with reference to dormancy. Dormancy is occurred in embryonic, larval, pupal or adult stages of the life cycle and is generally distinguished as **quiescence** or **diapause**, depending upon its termination in response to changes in environmental conditions. Dormancy results in the retardation of development and growth or their total arrest. A variety of natural and artificial stimuli are capable of terminating dormancy. Most insects seem to have more than one mechanism for anticipating the return of favourable conditions. The nature of dormancy depends upon the nature and complexity of physiological, biochemical and hormonal conditions, determined in their turn by external environmental conditions. Dormancy is the result of variations of atmospheric temperature, and may be distinguished as hibernation and aestivation.

Quiescence

The term, first used by Shelford in 1929, is a condition of retardation of growth, induced directly by environmental conditions. The distinction between quiescence and diapause is difficult and is based largely on the relative speed of their termination. Quiescence may be considered as due to an abrupt, non-cyclic and brief deviation of environmental factors and may occur in any stage. There is no end of synthetic processes, but only slight slowing down.

Diapause

Diapause is a suspension of development that can occur at the embryonic, larval, pupal, or adult stage, depending on the species. In some species, diapause is facultative and occurs only when induced by environmental conditions; in other species the diapause period has become an obligatory part of the life cycle.

Diapause is the condition of dormancy for overcoming prolonged, cyclic and unfavourable environmental conditions and may be induced well before the onset of adverse conditions and even continue for some time irrespective of these conditions. Diapause is a spontaneous arrest of development and occurs at any stage of development. Auto-intoxication with metabolic wastes, enzymes and external factors have all been attributed to be important factors that determine diapause.

The diapause is a specific physiological condition, quite different from the arrest of activity often induced by unfavourable external conditions. Many insects interrupt their development at certain stages by a diapause, during which the development comes to a standstill, metabolism is reduced to minimum and the insect is wholly insensitive even to unfavourable external conditions. The diapause sets in, independently of external factors, at a definite developmental stage in each species. In addition to the species that undergo obligatory diapause, there are also others which undergo facultative diapause. The influence of external factors on some sensitive phase of development often determines whether diapause shall occur or not in such species. This sensitive phase lies far before the time of beginning of diapause. In the case of the silk moth it may indeed be a whole generation before. In all cases, the end of diapause is more or less pronouncedly influenced by external factors. Unlike the arrest of activity brought about by unfavourable external conditions, which disappears only when the favourable conditions return, diapause may end even under most unfavourable external conditions, such as, for example, in a period of cold. There are numerous gradations between true diapause and the arrest of development under unfavourable conditions. The adults of many beetles, overwintering in the diapause state, show atrophy of their gonads and hypertrophy of the fat body. In *Anthonomus grandis* there is an increase in the water content and a decrease in fat content in early spring and this is followed by the beginning of spermiogenesis. The oogenesis takes place only after the female has taken food. In *Letinotarsa decemlineata* the development of gonads begins at the end of diapause.

The end of diapause is brought about in different insects of different ways. In Lepidoptera it is ended by the previous action of cold, so that the brain influences the prothoracic glands. It is, therefore, the action of prothoracic glands hormone, which terminates diapause. The adult diapause of *Leptinotarsa decemlineata* is broken by the gonadotrophic hormone of the corporaallata. The egg diapause of the grasshopper *Melanoplus* is broken by the removal of the waxy-layer cover, thus permitting the penetration of water through the micropyle. The egg diapause of the mosquito *Aedes hexodontus* is not ended by absorption of water and not also be changes of the photoperiod but only by cold treatment. The egg diapause of the grasshopper *Acheta commodus* is also broken by the action of cold. It is, therefore, evident that not only the external factors but also the physiological mechanism is important in breaking diapause.

Phases of insect diapause

Diapause in insects is a dynamic process consisting of several distinct phases. While diapause varies considerably from one taxon of insects to another, these phases can be characterized by particular sets of metabolic processes and responsiveness of the insect to certain environmental stimuli. Diapause can occur during any stage of development in arthropods, but each species exhibits diapause in specific phases of development. Reduced oxygen consumption is typical as is reduced movement and feeding. In *Polistes exclamans* only the queen is said to be able to undergo diapause. The sensitive stage is the period when stimulus must occur to trigger diapause in the organism. Examples of sensitive stage/diapause periods in various insects

1. **Induction phase :** The induction phase occurs at a genetically predetermined stage of life, and occurs well in advance of the environmental stress. This sensitive stage may occur within the lifetime of the diapausing individual, or in preceding generations, particularly in egg diapause. During this phase, insects are responsive to external cues called token stimuli, which trigger the switch from direct development pathways to diapause pathways. Token stimuli can consist of changes in photoperiod, thermoperiod, or allelochemicals from food plants. These stimuli are not in themselves favourable or unfavourable to development, but they herald an impending change in environmental conditions.
2. **Preparation phase :** The preparation phase usually follows the induction phase, though insects may go directly from induction to initiation without a preparation phase. During this phase, insects accumulate and store molecules such as lipids, proteins, and carbohydrates. These molecules are used to maintain the insect throughout diapause and to provide fuel for development following diapause termination. Composition of the cuticle may be altered by changing hydrocarbon composition and by adding lipids to reduce water loss making the organism resistant to desiccation. Diapausing puparia of the flesh fly *Sarcophaga crassipalpis* increase the amount of cuticular hydrocarbons lining the puparium, effectively reducing the ability of water to cross the cuticle.
3. **Initiation phase :** Photoperiod is the most important stimulus initiating diapause. The initiation phase begins when morphological development ceases. In some cases, this change may be very distinct and can involve moulting into a specific diapause stage, or be accompanied by color change. Enzymatic changes may take place in preparation for cold hardening. For example, only diapausing adults of the fire bug, *Pyrrhocoris apterus*, have the enzymatic complement that allows them to accumulate polyhydric alcohols, molecules that help to lower their freezing points and thus avoid freezing. Insects may also undergo behavioural changes and begin to aggregate, migrate, or search for suitable overwintering sites.

4. **Maintenance phase :** During the maintenance phase, insects experience lowered metabolism and developmental arrest is maintained. Sensitivity to certain stimuli which act to prevent termination of diapause, such as photoperiod and temperature, is increased. At this stage, insects are unresponsive to changes in the environment that will eventually trigger the end of diapause, but they grow more sensitive to these stimuli as time progresses.
5. **Termination phase :** In insects that undergo obligate diapause, termination may occur spontaneously, without any external stimuli. In facultative diapausers, token stimuli must occur to terminate diapause. These stimuli may include chilling, freezing, or contact with water, depending on the environmental conditions being avoided. These stimuli are important in preventing the insect from terminating diapause too soon, for instance in response to warm weather in late fall. In the Edith's Checkerspot butterfly, individuals must receive enough sunlight in order to terminate the diapause stage and became a fully grown butterfly. Termination may occur at the height of unfavourable conditions, such as in the middle of winter. Over time, depth of diapause slowly decreases until direct development can resume, if conditions are favourable.
6. **Post-diapause quiescence phase :** Diapause frequently ends prior to the end of unfavourable conditions and is followed by a state of quiescence from which the insect can arouse and begin direct development, should conditions change to become more favourable. This allows the insect to continue to withstand harsh conditions while being ready to take advantage of good conditions as rapidly as possible.

Factors regulating diapause

Diapause in insects is regulated at several levels. Environmental stimuli interact with genetic pre-programming to affect neuronal signalling, endocrine pathways, and, eventually, metabolic and enzymatic changes.

- **Environmental Factors (External)**

Environmental regulators of diapause generally display a characteristic seasonal pattern. In temperate regions, photoperiod is the most reliable cues of seasonal change. Depending on the season in which diapause occurs, either short or long days can act as token stimuli. Insects may also respond to changing day length as well as relative day length. Temperature may also act as a regulating factor, either by inducing diapause or, more commonly, by modifying the response of the insect to photoperiod. Insects may respond to thermoperiod, the daily fluctuations of warm and cold that correspond with night and day, as well as to absolute or cumulative temperature. Food availability and quality may also help regulate diapause. In the desert locust, *Schistocerca gregaria*, a plant hormone called gibberellin stimulates reproductive development. During the dry season, when their food plants are in senescence and lacking gibberellin, the locusts remain immature and their reproductive tracts do not develop.

- **Neuroendocrine factor (Internal)**

The neuroendocrine system of insects consists primarily of neurosecretory cells in the brain, the corpora cardiaca, corpora allata and the prothoracic glands. There are several key hormones involved in the regulation of diapause: juvenile hormone (JH), diapause hormone (DH), and prothoracicotropic hormone (PTTH).

Prothoracicotropic hormone stimulates the prothoracic glands to produce ecdysteroids that are required to promote development. Larval and pupal diapauses are often regulated by an interruption of this connection, either by preventing release of prothoracicotropic hormone from the brain or by failure of the prothoracic glands to respond to prothoracicotropic hormone.

The corpora allata is responsible for the production of juvenile hormone (JH). In the bean bug, *Riptortus pedestris*, clusters of neurons on the protocerebrum called the pars lateralis maintain reproductive diapause by inhibiting JH production by the corpora allata. Adult diapause is often associated with the absence of JH, while larval diapause is often associated with its presence.

In adults, absence of JH causes degeneration of flight muscles and atrophy or cessation of development of reproductive tissues, and halts mating behaviour. The presence of JH in larvae may prevent moulting to the next larval instar, though successive stationary moults may still occur. In the corn borer, *Diatraea gradiosella*, JH is required for the accumulation by the fat body of a storage protein that is associated with diapause.

Diapause hormone regulates embryonic diapause in the eggs of the silkworm moth, *Bombyx mori*. DH is released from the subesophageal ganglion of the mother and triggers trehalase production by the ovaries. This generates high levels of glycogen in the eggs, which is converted into the polyhydric alcohols glycerol and sorbitol. Sorbitol directly inhibits the development of the embryos. Glycerol and sorbitol are reconverted into glycogen at the termination of diapause.

Polymorphism

Polymorphism (from Greek: *poly,* meaning "many" and *morph,* meaning "form") is a discontinuous genetic variation where two or more forms, stages, or types exist in the same species within the same population. It can apply to biochemical, morphological, and behavioral characteristics.

Polymorphism represents another level of specialization, above the level of cell, tissue, and organ specialization found in insects individuals, and below the species level. It refers to specialization of insects within a species. The larva, pupa or adult represent different forms in a polymorphic insect. These forms may be color polymorphism, mimetic polymorphism, wing dimorphism (alate and apterous dimorphism or macropterous and brachypterous dimorphism), sexual and parthenogenetic forms and caste polymorphism. The control factors included genetic factors, endocrinal factors, exocrinal factors and environmental factors (light quality, light intensity, photoperiod, temperature, humidity, host, nutrition and population density).

The social insects are the most prominent examples of polymorphism. They are found in Isoptera (termites), which have typical sexual reproduction, and in Hymenoptera (ants, bees and wasps), which have haplodiploid sex determination and some other insects species.

Honey bees build their nest combs on the trees. They are highly colonial, social and polymorphic insects. The honey bees have best developed social life. Mainly there are three types of individuals or castes are found in the colony of honey bees;

1. Queen is a fertile female which lays eggs. Normally one queen is found in one nest.
2. Drones are males which mate with queen. Their number in the colony is not much. Drones are produced by parthenogenesis.
3. Workers are sterile females and perform various duties of the colony. The queens and drones are fed by the workers. The worker bees are smallest members of the colony. They have chewing and lapping type of mouth parts, modified for collecting nectar and pollen of the flowers. The abdomen contains the wax glands and the sting.

Eggs of queen hatch into white, legless larvae which spin delicate silken cocoons around themselves and turn into pupae. Each pupa develops into an adult. The adult comes out by cutting wall of cocoon first and secondly by breaking the wax cap of the cell. During first 2 to 3 days, all larvae of bee are fed on a special proteinaceous food, called "Royal jelly" or bee milk which is secreted by the hypo pharyngeal glands of the young workers. After that coarser food, the "Bee Bread", which is mixture of honey and pollen grain, is given. However, the queen forming larvae are fed on royal jelly for the full larval life and these larvae are also taken for further development into a special chamber called the queen's chamber or cell.

Swarming

Swarming, is a collective behaviour exhibited by entities, particularly animals, of similar size which aggregate together, perhaps milling about the same spot or perhaps moving or migrating in some direction. As a term, swarming is applied particularly to insects, but can also be applied to any other entity or animal that exhibits swarm behaviour.

The behaviour of insects that live in colonies, such as ants, bees, wasps and termites, has always been a source of fascination for children, naturalists and artists. Individual insects seem to do their own thing without any central control, yet the colony as a whole behaves in a highly coordinated manner. Researchers have found that cooperation at the colony level is largely self-organized. The group coordination and interactions can be remarkably simple, such as one ant merely following the trail left by another insect. The organised behaviour that emerges in this way is sometimes also called as a swarm intelligence.

Swarming in honey bee

Swarming is the natural means of reproduction of honey bee colonies. In the process of swarming the original single colony reproduces to two and sometimes more colonies. Swarming is the process by which a new honey bee colony is formed when the queen bee leaves the colony with a large group of worker bees. In the prime swarm, about 60% of the worker bees leave the original hive location with the old queen. This swarm can contain thousands to tens of thousands of bees.

Swarming is mainly a spring phenomenon, usually within a two- or three-week period depending on the locale, but occasional swarms can happen throughout the producing season. Secondary afterswarms may happen but are rare. Afterswarms are usually smaller and are accompanied by one or more virgin queens. Sometimes a beehive will swarm in succession until it is almost totally depleted of workers.

For instance, one species of honey bee that participates in such swarming behavior is *Apis cerana.* The reproduction swarms of this species settle 20–30 m away from the natal nest for a few days and will then depart for a new nest site after getting information from scout bees. Scout bees search for suitable cavities in which to construct the swarm's home. Successful scouts will then come back and report the location of suitable nesting sites to the other bees.

Initially the worker bees of colony forms **queen cups** throughout the year. When the hive gets ready to swarm the queen lays eggs into the queen cups. New queens are raised and the hive may swarm as soon as the queen cells are capped and before the new virgin queens emerge from their queen cells. A laying queen is too heavy to fly long distances. Therefore, the workers will stop feeding her before the anticipated swarm date and the queen will stop laying eggs. Swarming creates an interruption in the brood cycle of the original colony.

During the swarm preparation, scout bees will simply find a nearby location for the swarm to cluster. When a honey bee swarm emerges from a hive they do not fly far at first. They may gather in a tree or on a branch only a few metres from the hive. There, they cluster about the queen and send 20 - 50 scout bees out to find suitable new nest locations. This intermediate stop is not for permanent habitation and they will normally leave within a few hours to a suitable location. It is from this temporary location that the cluster will determine the final nest site based on the level of excitement of the dances of the scout bees. It is unusual if a swarm clusters for more than three days at an intermediate stop.

Swarming creates a vulnerable time in the life of honey bees. Cast swarms are provisioned only with the nectar or honey they carry in their stomachs. A swarm will starve if it does not quickly find a home and more nectar stores. This happens most often with early swarms that are cast on a warm day that is followed by cold or rainy weather in spring. The remnant colony after having cast one or more swarms is usually well provisioned with food, but the new queen can be lost or eaten by predators during her mating flight, or poor weather can prevent her mating flight. In this case the hive has no further young brood to raise additional queens, and it will not survive. An afterswarm will usually contain a young virgin queen.

Absconding - Absconding is a process where the whole hive leaves rather than splits like in swarming. Africanized bees are notable for their propensity to swarm or abscond. Being tropical bees, they tend to swarm or abscond any time food is scarce, thus making themselves vulnerable in colder locales. Mainly for lack of sufficient winter stores, the Africanized bee colonies tend to perish in the winter in higher latitudes. Generally, a weak bee colony will not swarm until the colony has produced a larger population of bees. Weak bee colonies can be the result of low food supply, disease such as Foulbrood Disease, or from a queen that produces low quantities of eggs.

Nest site selection

The scout bees are the most experienced foragers in the cluster. An individual scout returning to the cluster promotes a location she has found. She uses a dance similar to the waggle dance to indicate direction and distance to others in the cluster. The more excited she is about her findings the more excitedly she dances. If she can convince other scouts to check out the location she found, they may take off, check out the proposed site and promote the site further upon their return. Several different sites may be promoted by different scouts at first. After several hours and sometimes days, slowly a favourite location emerges from this decision making process. In order for a decision to be made in a relatively short amount of time, a decision will often be made when somewhere around 80% of the scouts have agreed upon a single location. When that happens, the whole cluster takes off and flies to it. A swarm may fly a kilometer or more to the scouted location. This collective decision making process is remarkably successful in identifying the most suitable new nest site and keeping the swarm intact.

Locusts

Locusts are the swarming phase of the short-horned grasshoppers of the family Acrididae. Some species can breed rapidly under suitable conditions and subsequently become gregarious and migratory. They form bands as nymphs and swarms as adults both of which can travel great distances, rapidly stripping fields and greatly damaging crops. The largest swarms can cover hundreds of square miles and contain billions of locusts. A locust can eat its own weight (about 2 grams) in plants every day. That means one million locusts can eat about one ton of food each day, and the largest swarms can consume over 100,000 tonnes each day.

Swarming in locusts has been found to be associated with increased levels of serotonin which causes the locust to change colour, eat much more, become mutually attracted, and breed much more easily.

Ants swarming

Many ant species exist and as a part of their seasonal activity, ants will produce a swarm of winged flying ants, known as swarmer ants. Swarming is also known as reproductive flight, as the ants are out to start new colonies. Swarming is seasonal, often taking place in the spring, and can occur once to a few times a year. It typically lasts for one day and happens simultaneously for all colonies in an area, which increases the chance of a queen finding a mate from a different colony. Most ant species release swarmers in the late afternoon, typically after a shower of rain followed by sun.

Swarmer ants are sexually developed females and males that separate from established colonies to start new colonies. Ideally they will mate with ants from another swarm to strengthen their genetics. Mating often occurs in flight; then the female pulls her own wings off and finds a place to form a brood chamber, where she will lay eggs. Most will not succeed in successfully establishing a new colony, instead getting eaten by predators or dying of starvation.

13.8 Summary

Insects are the dominant group of organisms on earth, in terms of both taxonomic diversity and ecological function. Insects play significant roles in the ecology of the world due to their vast diversity of form, function and life-style; their considerable biomass; and their interaction with plant life, other organisms and the environment. Insects form an important part of the food chain.

13.9 Self Assessment Questions

1. Describe the role of various abiotic factors in insect life.
2. Describe the interspecific interactions in insects.
3. What do you mean by Vital Temperature? How it effects on insect life?
4. Explain the details of intraspecific interactions of insects
5. Explain the acclimation in insects.
6. Describe the different factors influenced by moisture in insect life?
7. Write an essay on biotic factors in insect ecosystem
8. Write a short note on effect of light on an insect.
9. Describe the parental care in different insects?
10. Explain the different stages of diapause.
11. Explain Cooperation, aggregation, colonial and social life
12. Explain in brief the Predators-prey interaction
13. Give examples of various predators of insects.

14. Write an essay on population dynamics of insects.
15. Describe the various methods used for sampling
16. What are the different causes of population fluctuations?
17. Write a short note on host plant insect interactions
18. Explain the various biochemical adaptations of insects against environmental stress.

13.10 Reference Books

- Elements of Entomology- Dr. Rajendra Singh
- A Text Book of General Entomology - M.S. Mani
- A Text Book of Applied Entomology (Vol.II) - K.P. Shrivastava,
- Introduction to General and Applied Entomology - V. B. Awasthi
- Biology of Insects – S.C. Saxena

Unit - 14

Insect Ecology-II

Structure of the Unit

14.1 Objectives

After going through this unit you will be able to understand

- How Insects distributed in different Biogeographical regions.
- Basic factors governing the interspecific interactions.
- Role of Mimicry
- Role of Couloration

14.2 Introduction

Insects are the Animals who are successfully dominating the Animal Kingdom on the basis of their largest number. Their distribution in different Biogeographical area is important to know their diversity. Many adaptive featureless like Mimicry and Coulration are important one in the Insects. This chapter will help to understand above phenomenon.

14.3 Biogeographical Regions of India

India can be divided into ten major regions, based on the geography, climate, pattern of vegetation seen and the communities of mammals, birds, reptiles, amphibia, insects and other invertebrates that live in them. Each of these regions contains a variety of ecosystems such as forests, grasslands, lakes, rivers, wetlands, mountains and hills, which have specific plant and animal species. Insects are Important fauna resides in the all regions of India.

14.3.1 India's Biogeographical Zones

Our Country is mainly divided into 10 Biogeographical Zones as -

1. The cold mountainous snow covered Trans Himalayan region of Ladakh.
2. The Himalayan ranges and valleys of Kashmir,Himachal Pradesh, Uttarakhand, Assam and other North Eastern States.
3. The Terai, the lowland where the Himalayan rivers flow into the plains.
4. The Gangetic and Bhramaputra plains.
5. The Thar Desert of Rajasthan.
6. The semi arid grassland region of the Deccan plateau Gujarat, Maharashtra, Andra Pradesh, Karnataka and Tamil Nadu.
7. The Northeast States of India,
8. The Western Ghats in Maharashtra, Karnataka and Kerala.
9. The Andaman and Nicobar Islands.
10. The long western and eastern coastal belt with sandy beaches, forests and mangroves.

14.4 Insect Biodiversity

14.4.1 Role of Biodiversity

Diversity of species as well as of ecosystems is essential at global, regional and local levels. As production of oxygen, reducing carbondioxide, maintaining the water cycle, protecting soil are important services provided by the both. The world community now acknowledges that the loss of biodiversity contributes to global climatic changes. Forests are the main resourses for the conversion of carbon dioxide into carbon and oxygen. The loss of forest cover along with the increasing release of carbon dioxide and other gases through industrialization contributes to the 'greenhouse effect'. Global warming is melting ice caps, resulting in a rise in the sea level which will submerge the low lying areas in the world. This is causing major atmospheric changes, leading to increased temperatures, serious droughts in some areas and unexpected floods.

Biological diversity of insects plays an important role in preserving ecological processes, such as fixing and recycling of nutrients, soil formation, circulation and cleansing of air and water, global life support, maintain the Environment.

14.4.2 Indian Insect Biodiversity

The Indian region is recognized as one of the major centres of biodiversity in the world. The diversity of country is equally rich at the ecosystem level and at the species level has been well documented by field work carried out by experts and professional field biologists. The habitat diversity offered by alpine ecosystem to mangrove ecosystem through a wide range of tropical forest ecosystem, freshwater and marine ecosystem, desert and island ecosystem found expression in richness of faunal elements in all groups. Today India, occupying 2 percent of global space (Ghosh, A.K. 1990, 1994), documents nearly 7 percent of global faunal diversity. In Phylum Arthropoda, India has 6.13 percent of total species recorded so far in the world (60,383 species out of 98, 3744 (ZSI, 1991; Gosh A.K. 1996). The total numbers of Insect Species are highest with compare to other Animal Taxa all over world. An estimate of the numbers of species by group in India is given below. This is based on Alfred, 1998.

Taxonomic Group	World species	Indian species	% in India
PROTISTA			
Protozoa	31250	2577	8.24
Total (Protista)	31250	2577	8.24
ANIMALIA			
Mesozoa	71	10	14.08
Porifera	4562	486	10.65
Cnidaria	9916	842	8.49
Ctenophora	100	12	12
Platyhelminthes	17500	1622	9.27
Nemertinea	600		
Rotifera	2500	330	13.2
Gastrotricha	3000	100	3.33
Kinorhyncha	100	10	10
Nematoda	30000	2850	9.5
Nematomorpha	250		
Acanthocephala	800	229	28.62
Sipuncula	145	35	24.14
Mollusca	66535	5070	7.62
Echiura	127	43	33.86
Annelida	12700	840	6.61
Onychophora	100	1	1

Taxonomic Group	**World species**	**Indian species**	**% in India**
Arthropoda	987949	68389	6.9
Crustacea	35534	2934	8.26
Insecta	853000	53400	6.83
Arachnida	73440		7.9
Pycnogonida	600		2.67
Pauropoda	360		
Chilopoda	3000	100	3.33
Diplopoda	7500	162	2.16
Symphyla	120	4	3.33
Merostomata	4	2	50
Phoronida	11	3	27.27
Bryozoa (Ectoprocta)	4000	200	5
Endoprocta	60	10	16.66
Brachiopoda	300	3	1
Pogonophora	80		
Praipulida	8		
Pentastomida	70		
Chaetognatha	111	30	27.02
Tardigrada	514	30	5.83
Echinodermata	6223	765	12.29
Hemichordata	120	12	10

Taxonomic Group	World species	Indian species	% in India
Chordata	48451	4952	10.22
Protochordata (Cephalochordata+Urochordata)	2106	119	5.65
Pisces	21723	2546	11.72
Amphibia	7533	350	4.63
Reptilia	5817	456	7.84
Aves	9026	1232	13.66
Mammalia	4629	390	8.42
Total (Animalia)	1196903	868741	7.25
Grand Total (Protosticta+Animalia)	1228153	871318	7.09

As you have already studied that Class Insecta is most diverse class among Animals and also you have already studied about different species found in class Insecta. For easy understanding, we are discussing here only order Orthoptera where 1033 species and subspecies belonging to 398 genera and 21 families to this order from India. The order Orthoptera is further divided into two suborders namely Caelifera and Ensifera. The forst suborder Caelifera includes short-horned grasshoppers, locusts and grouse locusts; similarly suborder Ensifera includes long-horned grasshoppers, katydids, crickets and mole crickets.

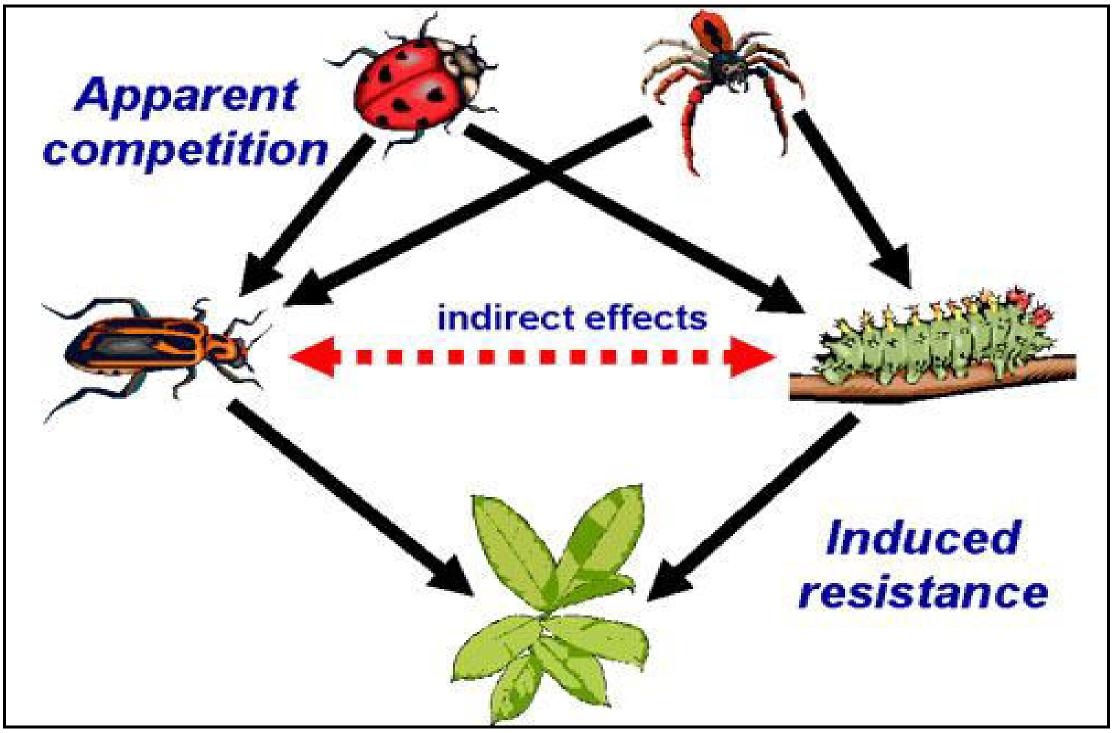
The suborder Caelifera is having 518 species under 214 genera and 11families viz. Acrididae (285 species and 134 genera), Dericorythidae (04 species and 02 genera), Pamphagidae (01 species and 01 genus), Chorotypidae (09 species and 07 genera), Eumastacidae (08 species and 04 genera), Mastacideidae (08 species and 02 genera), Pyrgomorphidae (47 species and 21 genera), Tetrigidae (137 species and 39 genera), Tridactylidae (19 species 04 genera).

The suborder Ensifera is represented by 515 species, 184 genera and 10 families namely Gryllidae (231 species and 72 genera), Trigonidiidae (22 species and 08 genera), Gryllotalpidae (08 species and 02 genera), Mogoplistidae (14 species and 07 genera), Myrmecophilidae (04 species and 01 genera), Prophalangopsidae (01 species and 01 genus), Rhaphidophoridae (14 species and 04 genera), Schizodactylidae (03 species and 01 genus), Anostostomatidae (06 species 05 genera), Gryllacrididae (49 species and 14 genera), Stenopelmatidae (03 species and 01 genus) and Tettigoniidae (160 species and 68 Genera; Kailash Chandra et.al. ZSI Jabalpur).

14.5 Interspecific Interactions and Their Types (Classification)

Ecology is a branch of science that deals with the study of distribution as well as abundance of organisms in the ecosystem, and their interactions with the environments. The environment includes two factors 1. Abiotic and 2. Biotic. You know that all living things in an ecosystem are interdependent, the associations existing between the different organisms in the ecosystem influences the survival of organisms and the functioning of the ecosystem as a whole. To understand the overall dynamics of the ecosystem, it is important to consider the impact of both environmental factors and multispecies interactions, which will have both ecological and evolutionary effects as well. It has been observed that some of the ecological interactions are mutually beneficial, or mutually detrimental or neutral.

Biological interactions are the effects that the organisms in a community have on one another in a particular area. In the natural environment no organism exists in absolute isolation. Every organism interacts with the environment and other organisms. Interactions of an organism with its environment are fundamental to the survival of that organism and the functioning of the ecosystem as a whole. Not only animals do interact with each other whereas plants do also interact during interspecific interactions. The black walnut secretes a chemical from its roots that harms neighboring plants, an example of Antagonism. There is mutualism interaction between the red-billed oxpecker and the giraffe. In Environment, Biological interactions can involve individuals of the same species-Intraspecific interactions or individuals of different species -Intersecific interactions. Both can be further classified by either the mechanism of the interaction or the strength, duration and direction of their effects. Species may interact once in a generation as during Pollination or live completely within another as during Endosymbiosis. Effects range from consumption of another individual as during predation, herbivory, or cannibalism, to mutual benefit as observed during mutualism. Interactions need not be direct; individuals may affect each other indirectly through intermediaries such as shared resources or common enemies in ecology.



(Source : https://www.entm.purdue.edu/ecolab/competition.php)

14.6 Lotka-Volterra Model of Competition

14.6.1 Introduction

Interspecific competition refers to the competition between two or more species for some limiting resource in a given area. This limiting resource may be food or nutrients, space, mates, nesting sites or anything for which demand is greater than supply in the area. When a perticular species is a better competitor, interspecific competition negatively influences the other species by reducing population sizes and/or growth rates, which in turn affects the population dynamics of the competitor in the area. The Lotka-Volterra model of interspecific competition is a simple mathematical model used to understand how different factors affect the outcomes of competitive interactions in an area.

This was proposed in 1925 by the American biophysicist Alfred Lotka and the Italian mathematician Vito Volterra.

14.6.2 Importance

Competitive interactions between organisms have a good deal of influence on species evolution, the structuring of communities, and the distributions of species. Modeling these interactions provides a useful framework for predicting outcomes of competition among species.

Species do not exist in isolation of one another in an area. The simple models of exponential and logistic growth fail to capture the fact that species can-

- Compete for resources in an area
- Assist one another
- Exclude one another
- Kill one another

Here we will generalize the logistic model to take into account resource competition between two species in an area.

Model Parameters

Let us use $N_{1,}$ $N_{2,}$ $r_{1,}$ $r_{2,}$ K_1 and K_2

N_1 = No. of individuals of species 1

N_2 = No. of individuals of species 2

r_1 = Intrinsic growth rate of species 1

r_2 = Intrinsic growth rate of species 2

K_1 = Carrying capacity of species 1 when species 2 is absent

K_2 = Carrying capacity of species 2 when species 1 is absent

The assumption underlying the Lotka-Volterra competition equations is that competing species use of some of the resources available to a species in an area (as if there were actually more individuals of the latter species):-

No. of individuals using resources of species 1 = $N_1 + \alpha_{12} N_2$

α_{12} is called the Competition Coefficient measuring the effect of an individual of species 2 on an individual of species 1. Similarly,

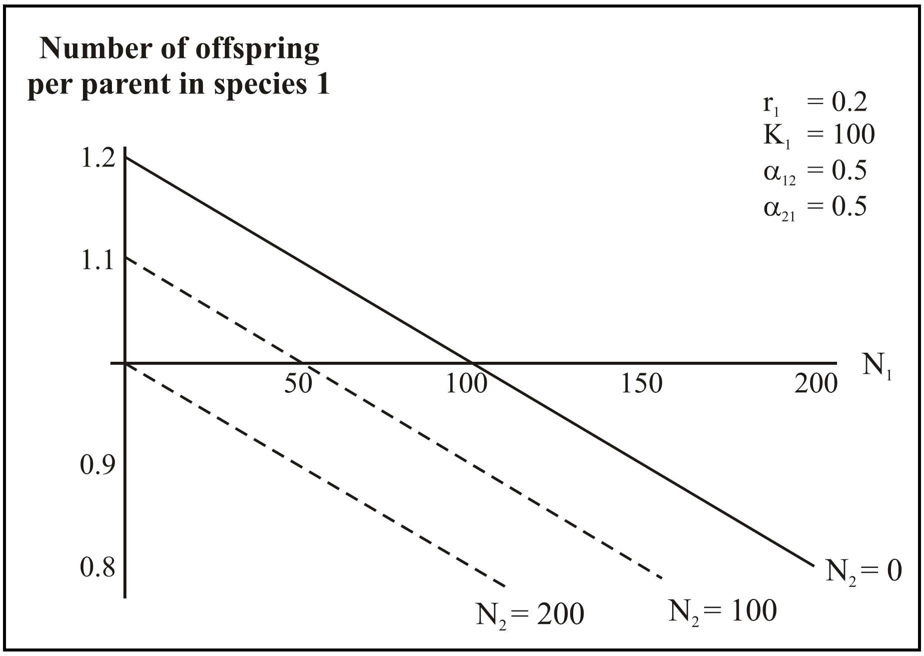
No. of individuals using resources of species 2 = $N_2 + \alpha_{21} N_1$

Discrete Model

The assumption of the logistic model is that the number of offspring per parent decreases linearly with the number of individuals (of species 1) currently in the population in an area.

With a second competing species also present, the number of offspring per parent depends not only on N_1, but also on the value of N_2:

No. of offspring per parent in species 1= $1 + r_1 \left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right)$



Therefore the population size in the next generation will equal:

$$N_1[t+1] = N_1[t] \left(1 + r_1 \left(1 - \frac{N_1[t] + \alpha_{12} N_2[t]}{K_1}\right)\right)$$

Similarly,

$$N_2[t+1] = N_2[t]\left(1 + r_2\left(1 - \frac{N_2[t] + \alpha_{21} N_1[t]}{K_2}\right)\right)$$

Continuous Model

In this case, it is assumed that the individual's contribution to the population growth rate in the area is

$r_1\left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right)$ for species 1

$r_2\left(1 - \frac{N_2 + \alpha_{21} N_1}{K_2}\right)$ for species 2

Therefore the growth rate of the entire population is equal to:

$\frac{dN_1}{dt} = N_1 r_1\left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right)$ for species 1

$\frac{dN_2}{dt} = N_2 r_2\left(1 - \frac{N_2 + \alpha_{21} N_1}{K_2}\right)$ for species 2

We'll focus on the discrete case in class.

Note:

In both the discrete and continuous cases,

- If α_{12} equals zero, then the dynamics of species 1 will follow the logistic equation we have analysed before.
- If α_{21} equals zero, then the dynamics of species 2 will follow the logistic equation we have analysed before.
- If α_{12} equals one, then individuals of species 2 compete for the resources of species 1 just as strongly as do members of species 1 (*interspecific* competition is as strong as *intraspecific* competition).
- If α_{12} is negative, then the presence of species 2 increases the resources available to species 1.
- If both α_{12} and α_{21} are negative, the species are said to have a *mutualistic* relationship.

- If α_{12} or α_{21} is negative and the other is zero (or very nearly zero), the species are said to have a *commensal* relationship.
- If one of the two is positive and one is negative, the species are said to have a *parasitic* relationship.
- If both are positive, the species are said to have a *competitive* relationship.
- We will also analyse the effects of competition (with $\alpha_{12} > 0$ and $\alpha_{21} > 0$) on the dynamics of two species.

Preliminary Graphical Analysis

The first step of an analysis may be to graph examples to see what happens to each of the species under different parameter conditions as:

```
clear[pop1,pop2]

pop1[r1_,r2_,k1_,k2_,a12_,a21_,t_]:=pop1[r1,r2,k1,k2,a12,a21,t]=pop1[r1,r2,k1,k2,                    a12,a21,t-1]*(1+r1*(1-(pop1[r1,r2,k1,k2,a12,a21,t-1]+12*pop2[r1,r2,k1,k2,a12,a21,t]=

pop2[r1_,r2_,k1_,k2_,a12_,a21_,t_]:=pop2[r1,r2,k1,k2,a12,a21,t]=pop2[r1,r2,k1,k2,                    a12,a21,t-1]*(1+r2*(1-(pop2[r1,r2,k1,k2,a12,a21,t-1]+a12*pop1[r1,r2,k1,k2,a12,a21,t-1])/k2))

pop1[r1_,r2_,k1_,k2_,a12_,a21_,0]: =10

pop2[r1_,r2_,k1_,k2_,a12_,a21_,0]: =10
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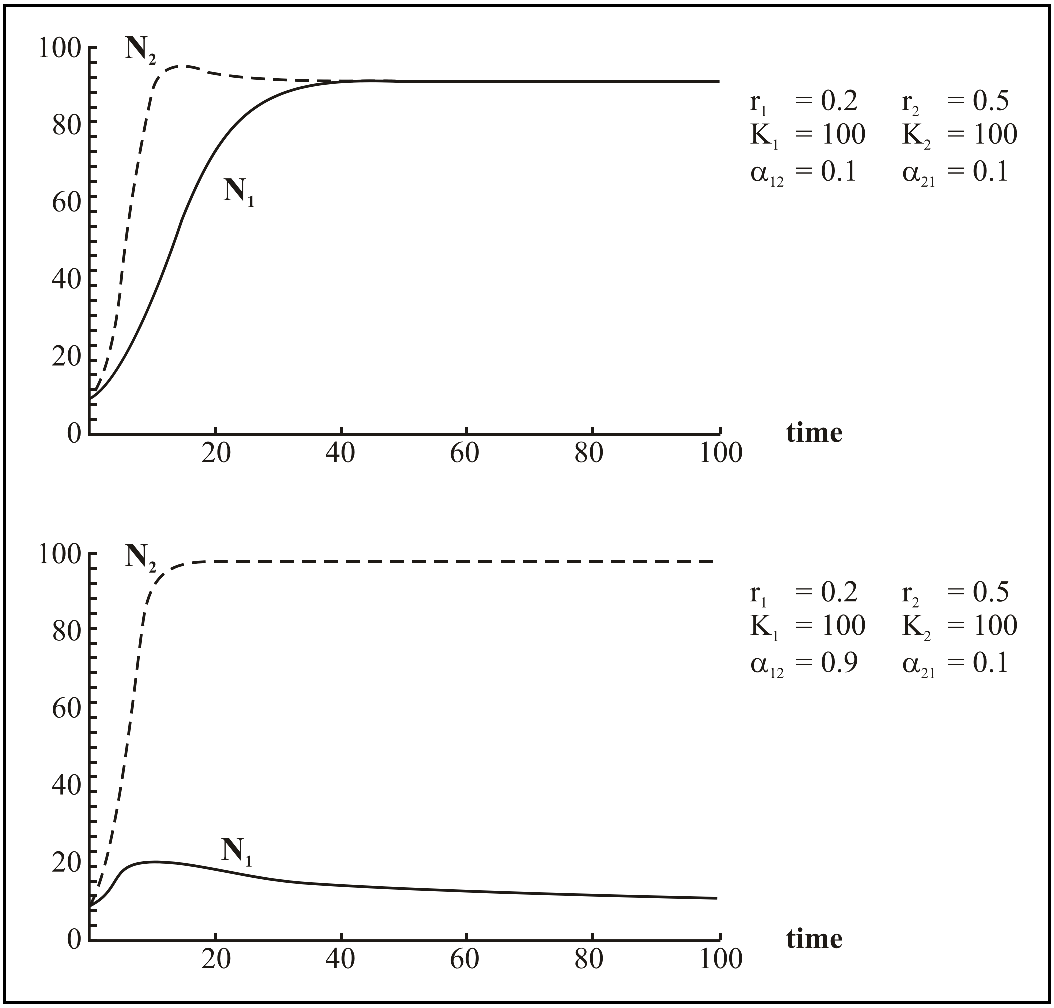

When α_{12} and α_{21} are small, both species approach an equilibrium level near their carrying capacities. If α_{12} is much higher than α_{21} (species 2 impacts more strongly on the resources of species 1 than vice versa), then species 1 will be kept at low numbers by the competitive superiority of species 2.

Such a graphical method is only useful for specific examples, however, does not give us a general picture of what will happen and when.

Identification of Equilibria-

As have discussed already, we determine equilibria by finding out when the variables will stay constant over time.

Unlike the case of a single variable and a single function, however, we must find an equilibrium solution where all of the variables remain constant over time.

For the continuous model of competition, this requires that $dN_1/dt = 0$ and that $dN_2/dt = 0$.

For the discrete model of competition, this requires that $N_1[t+1] = N_1[t]$ and that $N_2[t+1] = N_2[t]$.

Setting $N_1[t+1] = N_1[t] = \hat{N}_1$ in the discrete equation for species 1 gives:

$$\hat{N}_1 = \hat{N}_1 \left(1 + r_1 \left\{1 - \frac{\hat{N}_1 + \alpha_{12}\ \hat{N}_2}{K_1}\right\}\right)$$

There are two ways in which this equation can be satisfied:

$$\hat{N}_1 = 0 \qquad \text{or} \qquad \left(1 + r_1\ (1 - \frac{\hat{N}_1 + \hat{}\ \alpha_{12}\ N_2}{K_1})\right) = 1$$

Rearrange

$$r_1 \left(1 - \frac{\hat{N}_1 +\ \alpha_{12}\ \hat{N}_2}{K_1}\right) = 0$$

Rearrange

$$K_1 - \hat{N}_1 +\ \alpha_{12}\ \hat{N}_2\ = 0$$

Setting $N_2[t+1] = N_2[t] = \hat{N}_2$ in the discrete equation for species 2 gives:

$$\hat{N}_2 = \hat{N}_2 \left(1 + r_2 \left\{1 - \frac{\hat{N}_2 + \alpha_{21}\ \hat{N}_1}{K_2}\right\}\right)$$

Again, there are two ways in which this equation can be satisfied:

$$\hat{N}_2 = 0 \qquad \text{or} \qquad \left(1 + r_2\ (1 - \frac{\hat{N}_2 + \hat{}\ \alpha_{21}\ N_1}{K_2})\right) = 1$$

Rearrange

$$r_2 \left(1 - \frac{\hat{N}_2 +\ \alpha_{21}\ \hat{N}_1}{K_2}\right) = 0$$

Rearrange

$$K_2 - \hat{N}_2 +\ \alpha_{21}\ \hat{N}_1\ = 0$$

At equilibrium, there are four ways to ensure that both N_1 and N_2 remain constant over time:

1. both species are extinct ($\hat{N}_1 = 0$ and $\hat{N}_2=0$)
2. species 1 is extinct ($\hat{N}_1 = 0$ and $\hat{N}_2= K_2$)
3. species 2 is extinct ($\hat{N}_1 = K_1$ and $\hat{N}_2 = 0$)
4. both species are present.

To get both species to persist at equilibrium requires that both

$$K_1 - \hat{N}_1 + \alpha_{12}\,\hat{N}_2 = 0 \quad \text{and} \quad K_2 - \hat{N}_2 + \alpha_{21}\,\hat{N}_1 = 0$$

To solve both equations simultaneously:

- Solve one equation for $\hat{N}_2$ in terms of $\hat{N}_1$.
- Plug this value for $\hat{N}_2$ into the other equation.
- Solve the resulting equation for $\hat{N}_1$ in terms of the parameters of the model.
- Finally, put this equilibrium value for $\hat{N}_1$ into one of the above equations to get an equation for $\hat{N}_2$.

$$\hat{N}_1 = \frac{K_1 - \alpha_{12}\,K_2}{1 - \alpha_{12}\,\alpha_{21}} \quad \text{and} \quad \hat{N}_2 = \frac{K_2 - \alpha_{21}\,K_1}{1 - \alpha_{12}\,\alpha_{21}}$$

Only at this point will both species be present in constant numbers over time in an area. This mathematical equation is very useful to study Biological Interactions in Ecology.

14.7 Mimicry

The word mimicry has been used since 1637. It derives from the Greek term mimetikos, "imitative", in turn from mimetos. Originally it is used to describe people; "mimetic" was used in zoology from 1851, "mimicry" from 1861.

Mimicry may be of different types; it may be defensive or protective. Defensive or protective mimicry may be noticed when organisms are able to avoid harmful encounters in given time by deceiving enemies where treating them as something else.

Three types of Mimicry being discussed here to explain mimicry by the organisms protected by warning coloration:

A. Batesian mimicry - A harmless mimic poses as harmful

B. Müllerian mimicry - Two or more harmful species mutually advertise themselves as harmful

C. Mertensian mimicry - A deadly mimic resembles a less harmful but model teaches a lesson.

D. Vavilovian mimicry- weeds resemble crops, is important for several reasons, and in this case humans are the agent of selection.

Evolution of Mimicry:

It is widely accepted that mimicry evolves as a positive adaptation in Nature. The lepidopterist and novelist Vladimir Nabokov argued that although natural selection might stabilize a "mimic" form, it would not be necessary to create it in the Nature.

The widely accepted model used to explain the evolution of mimicry in butterflies is the two-step hypothesis-1. The first step involves mutation in modifier genes that regulate a complex cluster of linked genes that cause large changes in morphology. 2. The second step consists of selections on genes with smaller phenotypic effects, creating an increasingly close resemblance. This model is supported by empirical evidence that suggests that a few single point mutations cause large phenotypic effects, while numerous others produce smaller effects. Some regulatory elements collaborate to form a supergene for the development of butterfly color patterns. The model is supported by computational simulations of population genetics in nature. On other hand the Batesian mimicry in Papilio polytes is controlled by the doublesex gene.

Some mimicry is seen imperfect in nature. Natural selection drives mimicry only far enough to deceive predators in nature. For example, when predators avoid a mimic that imperfectly resembles a coral snake, the mimic is safely protected.

14.8 Aposematism Or Warning Colouration

Aposematism word derived from Greek was a new term coined by Edward Bagnall Poulton for Alfred Russel Wallace's concept of warning coloration. Warning colouration may be effective in animals; here we shall study this in detail-

The function of Aposematism is to prevent attack by the prey species, by warning the predators that the prey animal has defenses such as being unpalatable or poisonous. The easily observed warning is a primary defence mechanism, and the non-visible defences are secondary one. Aposematic signals are primarily observed visually, using bright colours and high-contrast patterns such as stripes on the body. Warning signals are clear indications of noxious prey, because conspicuousness evolves simultaneously with noxiousness. It is also observed that the brighter and more conspicuous the organism, the more toxic it usually they are.

The most common as well as effective colours are red, yellow, black and white. These colours provide strong contrast with green foliage, resist changes in shadow and lighting, have strong contrast, are highly chromatic, and provide distance dependent camouflage in nature. Some forms of warning colouration provide this distance dependent camouflage in nature by having an effective pattern and colour combination that do not allow for easy detection by a predator from a distance. Whereas warning-like from a close proximity, allowing for an advantageous balance between camouflage and aposematism. Warning colouration evolves in response to background, light conditions, and predator vision in a specific place. Sometimes visible signals may be accompanied by odours, sounds or behaviour to provide a multi-modal signal which is more effectively detected by predators.

Unpalatability by the animals can be also created in a variety of ways. Some insects such as the ladybird or tiger moth have bitter-tasting chemicals, whereas the skunk produces a noxious odour, and the poison glands of the poison dart frog, the sting of a velvet ant or neurotoxin in a black widow spider make them dangerous or painful to attack at times. Tiger moths advertise their unpalatability by either producing ultrasonic noises which warn bats to avoid them for attack, or by warning postures which expose brightly coloured body parts, or exposing eyespots as well. A wasp among 'Velvet ants' such as Dasymutilla occidentalis both have bright colours and produce audible noises when grabbed using stridulation, which serve to reinforce the warning.

14.9 Predator Satiation

Predator satiation; also less called predator saturation; is an antipredator adaptation in which prey occur at high population densities, reducing the probability of an individual organism being eaten. When predators have good number of potential prey, they can consume only a certain amount, so by occurring at high densities prey benefit from a safety in numbers effect. This strategy has evolved in a diverse range of prey, including notably many species of plants, insects, and fish. Predator satiation can be considered a type of refuge from predators.

It is a well established fact that if available food increases, a predator has more chances of survival, growth, and reproduction. As food supply begins more the predator's ability to consume and process it begins down.

You will see that periodical cicada (Magicicada) species erupt in large numbers from their larval stage at intervals of 13 or 17 years. In this case at high-density sites, research finds that the number eaten by birds does not increase with the number of cicada individuals as well as the risk of predation for each individual decreases.

14.10 Summary

Insects have diverse groups and distributed in many biogeographical regions. Thus insects play a major role in biodiversity. Interspecific interactions among insects and other species play a important role in environment. Lotka-Voltera Model well explains the interaction among prey and predator. Mimicry, Colouration, Predator satiation are important protective measure in Insects.

14.11 Self Learning Exercises

Section -A (Very Short Answer Type)

1. Which class (Taxon) of Animal is largest on the basis of number ?
2. Different forms of life is also known as ……………….
3. Lotka-Volterra model was proposed in the year----------------
4. Interaction among two or more than two species is known as …………..

Section -B (Short Answer Type)

1. Define Interspecific Intraction ?
2. Write any two benefits of Interspecific Intraction.
3. Write names of any two Zoogeographical regions.
4. Name the scientist who proposed Lotka-Volterra model.

Section -C (Long Answer Type)

1. Write a note on Zoogeographical regions and Insect Biodiversity.
2. Explain Lotka-Volterra model.
3. Write Short notes on Mimicry and Warning Colouration.

Answer of Very Short Answer Questions

1. Insects

2. Biodiversity
3. 1925
4. Interspecific Intraction

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Unit 15

Post-embryonic development

Structure of the Unit

15.1 Objectives

After going through this unit you will be able to understand

- How Insects distributed in different in different region and completion among them.
- Basic factors governing the pest Management.
- Role of Dyer's law

15.2 Introduction

The concept of Guild holds a central place in community ecology. Huchinson's ratio as well as Dyer's law play an important role in community ecology. Insect pest management is also considered equally in community Ecology.

15.3 Guild Concept

The concept of Guild is defined as a group of species that exploit the same class of environmental resources in a similar way. This concept holds a central place in community ecology.

A wide range of concepts as well as criteria being used to describe the groupings of species. A conflict is observed between Beta (environmental conditions) and Alpha (resource use) guild concepts. It has been observed that Species that are in the same Beta (environmental conditions) guild, prefer the same conditions and will remain together. As well as; Species that are in the same Alpha (resource use) guild will not necessarily occur together; in fact, if the resource is limiting, competitive exclusion would tend to lead to their not being found together. One another aspect is also there that- the classification takes into account the intention and ecological concept behind the classification and also the type of information and the method used to make the classification. In ecology there are intermediate sexist. Guilds are classified into five kinds of Beta guild and four kinds of Alpha guild:

A. **Beta guilds** (based on distribution according to environmental conditions):

1: Spatial distribution guilds

2: Temporal distribution guilds

3: Subjective beta character guilds

4: Objective beta character guilds

5: Response guilds

B. **Alpha guilds** (based on resource type used, within communities):

l: Subjective a priori Rootian guilds

2: Tested a priori Rootian guilds

3: Objective character Rootian guilds

4: Intrinsic guilds

15.4 Hutchinson Ratio among Communities Organization

Hutchinson Ratio is ratio of size differences. G. Evelyn, (1959) was first person who used this phenomenon for ratio of larger to the smaller at each pair of species to characterize to living together as compared to when they were isolated. He concluded that various key attributes in species varies according to ratio of 1:1.1 to 1:1.4.

Hutchinson found for a variety of animal groups that a length ratio of 1.3 allow for the coexistence for a variety of congeners based on a size difference only.

15.5 Dyar's Law

Dyar's law suggests that a particular Sclerotized part at the body (such as head or leg) increases in linear dimensions from one Instar to the next by a ratio that is constant throughout (1.2 to 1.4) the development; for example the increasing ration of hind femur of locust's often in the range of 1.36 to1.46 from one instar to the next while Prazibram rule suggested that the ratio by which cuticular size increases in length will be constant (1.26) during each ecdysis.

Dyar's law is applied on the food preferences and application of different hopper instar of Orthopteran group family Acrididae. There is a influence of diet on different parameter at life of grasshopper.

15.5.1 Experiment by Dyar

He carried out the effect of crowding and temperature on growth of larval stage. They tested and observed that *Brassica oleracia var. botrytis* was most preferred by the animals of both sex, with minimum hopper development period of 44 days in male and 53.6 days in females. It was prolonged on *Andropogon odoratus* with the maximum development of 70-90 days in male and 78-90 days in females. Similarly maximum development of hoppers was 2.31% per day in males which were feeding on *Brassica oleracia var. botrytis* while it was 1.89% per day in females.

Dyar's law applied in Lepidopteron larvae assumes a geometric progression of size measures. It is significant in the case of members of family Acrididae. The head width were measured during successive moulting, the average ratio is increasing in each instar male was 1.264 (min.) at 27^{o}C under isolated atmosphere which is relatively increased 1.309 (Max.) at 37^{o}C at highly crowded conditions. Whereas female hoppers showing 1.233 (min) at 37^{o}C under crowded condition and reached 1.409 (max.) at 27^{o}C under same crowded conditions before reaching the adult stage.

15.6 Prazibram's Law

Prazibram observed the study of insect community that phytophagous insects assemblage pattern are similar to those displayed in many other groups at species. He found that large area supports more species while small area supports less species, likewise complex habitats are more preferred by many species than simple habitats. The species compete most strongly with close relatives such insect shows niche separation within the community of the same habitats.

The folivorous insects show weak competition for food, instead of these groups of the insects living on the plants are affected by climate change and host plant phaenology. Seasonal sequence of chemical and physical change in host tissue is also responsible for the same. They also alter their habitat against their enemy in the form of Parasitoids and Predators.

15.7 Concept of Diversity- The Wallacian View

Wallace (1860) explained that almost everything in nature but there is one class at phenomenon I cannot bring under it –"The repetition of forms and colors of the animals in distinct groups, but the two always occurring in the same country generally and on the very same spot. These are most striking in the insects." He constantly observed the fresh instances like Moths resembles butterflies of the same country i.e. *Papilios* in the east resemble *Euploess* in America Heliconias. He suggested that new species can not be proved to be established as such unless it found in company with a sister form which has a similar origin and maintaining itself distinct from other one.

Wallace was the first person who appreciated Darwin's idea of species being morphologically different from one another are problematic for a group of special cases. For example Mimetic butterfly *Pappilio merrnon* males appears to be different species from the females as they have entirely different colour pattern.

Wallace was thinking different thought with Darwin in a number of issues, such as the evolution of man and sexual selection by female choice, but he never seems to have had strong disagreement with Darwin as species.

Wallace also demolished a later theory to explain hybrid sterility between species by natural selection .

Wallace rejected the old idea that species inter-sterile, while verities within species were inter-fertile.

15.8 Pest Management Measures

As you are aware pests are controlled by many ways. We are discussing the major part of the this aspect-

Natural Control

Pests are controlled by Nature's own ways where populations within bounds. Any condition of the environment may checks insect population and cannot be altered will by man. Natural control faces all the factors included in the environmental resistance. The factors may be as adverse weather, climate and physical environment and of biological factors such as predators, parasites, disease and food supply.

Climate and weather : Climate will determine what insects will be present and how many generations will be possible in a single active Season, while weather is the short term or day-to-day effect, but it also plays primary role in influencing insect abundance and damage. These two probably are the most important factors that directly or indirectly limit the abundance of pest Insect.

Temperature : Temperature is the most important factor in climatic influence on insects. High Temperture prevent the existence of certain species in some areas, even the insect is unable to be noticed by man. The exposed life stages of insects are especially vulnerable in such cases. Prolonged periods of high (44-52 O C) or low (0-24 O C) temperature greatly reduce insect populations. Sudden changes in temperature also responsible for control. On the other hand, optimum effective temperature range (21to35 O C) includes temperature where insects will thrive and multiply at the maximum rate. Optimum conditions vary from temperature – 34.4 to 10 C. Above 44.C, temperature is sometimes detrimental to insects. We may expect to have less trouble from most insect pests under very hot or very could conditions, and a major amount of trouble when temperature falls within optimum effective range.

Other ecological factors : The temperature and moisture both in combination with the air and soil also influence the development of insects. Most insects that attack plants cannot tolerate very low humidity or dry conditions as well. In summer insects go aestivation in response to low humidities and high temperatures. Relative air humidities from 50 to 80 per cent are probably the best range for most pests feeding on external plant. Sometimes the plants also help to maintain favourable humidities for most plant pests attacking them internally. High humidity and normal or high temperatures tend to induce bacterial or fungal disease epidemics among insects. Severe draughts conditions are just as hard on some insects as they are on plants. Precipitation in the form of heavy wind-driven rains is very destructive to small insects, but in spring, precipitations, in the form of warm rains help in bringing insects out of Hibernation.

Topographic factors: The barriers that interfere with free migration from one region to another. Oceans, mountain ranges, deserts, broad rivers and zones with prohibitively unfavourable climate make up the list of natural barriers also.The physical and chemical nature of the soil has a direct bearing not only on the suitability of the environment for insects but also on their food supply.

Biotic factors : Such factors of biological nature and may be divided into following groups : predators, parasites, natural resistance of plants, and competition between the same of different species for a given food supply. Any animal as a predator is a living active animal that catches and devours usually smaller or more helpless animals. Lady bird feed on insects. Some birds which also feed on insects are : warblers, night hawks, gulls, wood peckers, starlings and blackbirds. Many mammals such as squirrels, bats moles mice, etc. feed on insect life stages. Other amphibians like frog and toads, reptiles and lizards consume many insects. Spiders feed adult house flies, mosquitoes etc are also important biotic factor.

You have already studied Biological, Chemical, Physical as well as Integrated Pest Management in last chapters. You are advised to correlate these practices with this chapter of Community Ecology.

15.9 Summary

The concept of Guild is defined as a group of species that exploit the same class of environmental resources in a similar way. This concept holds a central place in community ecology.

Hutchinson found for a variety of animal groups that a length ratio of 1.3 allow for the coexistence for a variety of congeners based on a size difference only.

Wallace was the first person who appreciated Darwin's idea of species being morphologically different from one another are problematic for a group of special cases. For example Mimetic butterfly *Pappilio merrnon* males appears to be different species from the females as they have entirely different colour pattern.

Pests are controlled by Nature's own ways where populations within bounds. Any condition of the environment may checks insect population and cannot be altered will by man.

15.10 Self Learning Exercises:

Section A- Objective type questions (With Answers)

1 “Niche” was coined by-

(a) Huxley (b) Grinell

(c) Transtey (d) Nicholson

2 Hutchinson ratio is based on-

(a) Size difference of same species (b) Body weight of same species

(c) size difference of different species (d) Nane of above

3 “Ecosystem” was coined by

(a) Huxley (b) Transley

(c) Maxwell (d) Nicholson

4 Hyperparasites are .... consumers

(a) Primary (b) Secondary

(c) Tertiary (d) Nane of above

5 Lakes or Ponds are example of

(a) Lentic habitats (b) Eusturine habitats

(c) Lotic habitats (d) None of above

Answers-

1. b
2. a
3. b
4. c
5. a

Section-B Short Answers types questions

1. Define the Syntopic species.
2. Communities which are considered to be transitional between two biomass are known as----------
3. What is Altruism?
4. Define the mimicry?
5. What do you mean by “guild” ?

Ans.

Hint to Answers-

(a) A Species present in same micro habital

(b) Ecotone

(c) Self sacrifice in favour of colony

(e) Groups of organisms exploiting a comma resource in a similar manner is known as guild

Section-C Long Answer Type Questions

1. Describe the Dyar's Law with Suitable example.
2. Explain the Wallacian view of diversity.
3. Write short Notes on

(1) Concept of guild

(2) Hutchinson ratio

15.11 Reference Books

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