



Indira Gandhi
National Open University
School of Sciences

BZYET-143 INSECT VECTORS AND VECTOR BORNE DISEASES

VOL

1

INSECTS: INTRODUCTION AND DISEASE VECTORS

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BZYET-143
INSECT VECTORS
AND VECTOR BORNE
DISEASES

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INSECT VECTORS AND VECTOR BORNE DISEASES

Over a period of tens of millions of years, the arthropods, on the one hand, and viruses, bacteria and parasites, on the other, have had ample time to come together and develop a variety of relationships. As each evolved, some of these relationships led to the establishment of vector systems involving vertebrates, arthropods (insects, mites) and microorganisms. Within these complex biological systems arthropods act as a 'vector' for the transmission, from one vertebrate to another, of microorganisms, which may or may not be pathogenic for the vertebrate concerned. In some cases, this vector can also serve as a reservoir or disseminator for the microorganism.

A distinction is made between 'mechanical vector', which are only carriers of infectious agents, and 'biological vector', within which the agent lives for part of its life cycle.

A great deal of human and animal diseases is due to pathogens transmitted by insects. Among the deadliest infectious diseases worldwide, malaria and dengue hemorrhagic fever (DHF) are vector-borne diseases. Many insect vectors belong to the Diptera Order, such as mosquitoes, biting midges, sandflies, blackflies, and tsetse-flies, but insects of other orders can also transmit important pathogens like the lice, fleas, and bloodsucking bugs. Pathogenic agents could be parasites (protozoan, filariae, cestods, etc.), bacteria (rickettsiae, *Borellia*, etc), viruses (arboviruses) that undergo a cycle of development inside the insect vector to reach their infective stage. Transmission can be done through the insect's bite with direct inoculation or with pathogens deposited by the insect saliva or faeces on the skin, and entering into their host either through scratching or by active action of the pathogen into the host wound. For these insect-borne diseases, vector control is one of the first preventive measure, if not the only one in most cases due to the lack of vaccine (except for Yellow Fever and Japanese Encephalitis) and resistance issues in chemoprophylaxis.

Therefore, vector control is an integral component of vector-borne disease control programme. However, in order to reach their full efficiency, vector control operations and programmes must be based on sound knowledge of the targeted vectors (species identification, biology, distribution, etc), of local and regional ecological context, and socio-cultural conditions of human populations.

This four semester elective course consists of two volumes. Volume one comprises Blocks 1 and 2 with total 9 units in all. Volume 2 comprises Blocks 3 and 4 and with total 6 units in all. Before studying about insects as vector, it is important to know about classification, morphology and physiology of insects. Hence Block 1 tells you about characteristics of insects.

Block 1 consists of five units. Unit 1 appraises about basic facts about insects, insect diversity and abundance. You will also study about reasons for success of insects on this planet. Adaptive radiations in insects will also be discussed.

Unit 2 talks about ametabolous, hemimetabolous, holometabolous insects. The general morphology of the insects is described in detail. Different types of antennae, mouth parts, legs and wings are present in the insects. The body is divided into head, thorax and abdomen. Legs are modified for walking, running, digging etc. in different insect groups, Eyes may be simple or compound.

Unit 3 appraises you about various physiological processes i.e. respiratory, digestive, circulatory, excretory and endocrine systems of insects.

Unit 4 discusses about classification of insects. The unit explains the basis of classification of insects and insect identification based on their characteristic morphological features. It further explains the detailed features of orders containing insect vectors.

Unit 5 speaks about concept of vectors. Two important terms are explained viz. vectorial capacity and vectorial competence. Distinction between mechanical and biological factors is also discussed.

Block 2 comprises four units in which you will study about four medically important orders. The representative vectors of three orders will be discussed in next 3 consecutive units i.e. Siphunculata, Siphonaptera and Hemiptera. The largest and most significant medically important order Diptera will be discussed in volume 2. Volume 2 will also discuss about Integrated Vector Management.

Objectives

After studying this course, you should be able to:

- appreciate the basic facts about insects,
- explain insect diversity and abundance,
- discuss the biological success of insects,
- describe the adaptive radiations in insects,
- distinguish between ametabolous, hemimetabolous and holometabolous insects,
- define moulting and tagmosis in insects,
- describe the body wall of insects,
- differentiate the body parts into head, thorax and abdomen,
- differentiate into different types of mouth parts based on the feeding habits,
- distinguish into the simple and compound eye,
- discuss the modification legs in insects,
- explain the internal and external morphology,
- describe feeding and digestion,
- apprehend excretion,
- explain circulation of haemolymph,
- describe respiration,
- apprehend musculature and locomotion,
- describe nervous system and sense organs,
- explain reproduction and metamorphosis,
- explain the basis of classification of the insects,
- identify the insects based on their characteristic morphological features,

- list the insect orders comprising disease vectors,
- explain the detailed features of orders containing insect vectors,
- differentiate between carrier and vector, and describe their types,
- discuss the mode of transmission, and
- explain the host-vector relationship, vectorial capacity with the factors affecting it.



Objectives

After going through this unit you should be able to:

- ❖ appreciate the basic facts about insects,
- ❖ explain insect diversity and abundance,
- ❖ discuss the biological success of insects, and
- ❖ describe the adaptive radiations in insects.

1.2 INSECT ABUNDANCE

The fact is, today's human population is adrift in a sea of insects. If we look at number alone, the estimated ratio of insects to humans is 200 million to 1, and there are about 40 million insects for each acre of land. Based solely on numbers and biomass, insects are the most successful animals on earth! This surprising achievement disproves the commonly held, biased belief that intelligence is a necessary component of evolutionary success. You will study about reasons for insects success later in this Unit.

1.3 INSECT DIVERSITY

Along with humans, insects live in almost every habitable place on the earth, except the ocean depths. According to the distinguished entomologists T. Eisner and E. Wilson, insects all but own the land. They are the chief consumers of plants; they are the major predators of plant eaters; they play a major role in decay of organic matter; and they serve as food for other kinds of animals.

Knowing these ecological facts, we might expect these organisms to be diverse and adaptable-and they are. Today, more than 900, 000 kinds (species) have been described, and it is widely believed that two-to ten-times as many are yet to be discovered. Indeed, in the Brazilian Amazon, scientists estimate that more than 90 percent of insect species remain to be found.

These statistics make other animal groups seem small by comparison. For instance, species in the class Mammalia, of which humans are members, count less than 1 percent of those in the class Insecta. Furthermore, insects boast more species than any other kind of organism, making up about three-fourths of the total number known. Indeed, it has been estimated that every fifth animal is a beetle, only one group in the class Insecta (Fig. 1.1). Without a doubt, this extraordinary diversity is yet another mark of insects' ecological success.

Insects are grouped with other animals sharing similar characteristics in the phylum Arthropoda. Arthropods, as they are known, are characterized as having a body divided by grooves to form **segments** and a well-developed covering, this **integument**, which makes up the outer shell, or **exoskeleton**. Some of the arthropod body segments possess one or more pairs of jointed appendages from which the phylum name was derived (from *arthro*, joint; *poda*, foot). In addition, arthropods other than insects include spiders, ticks, mites, shrimp, and centipedes.

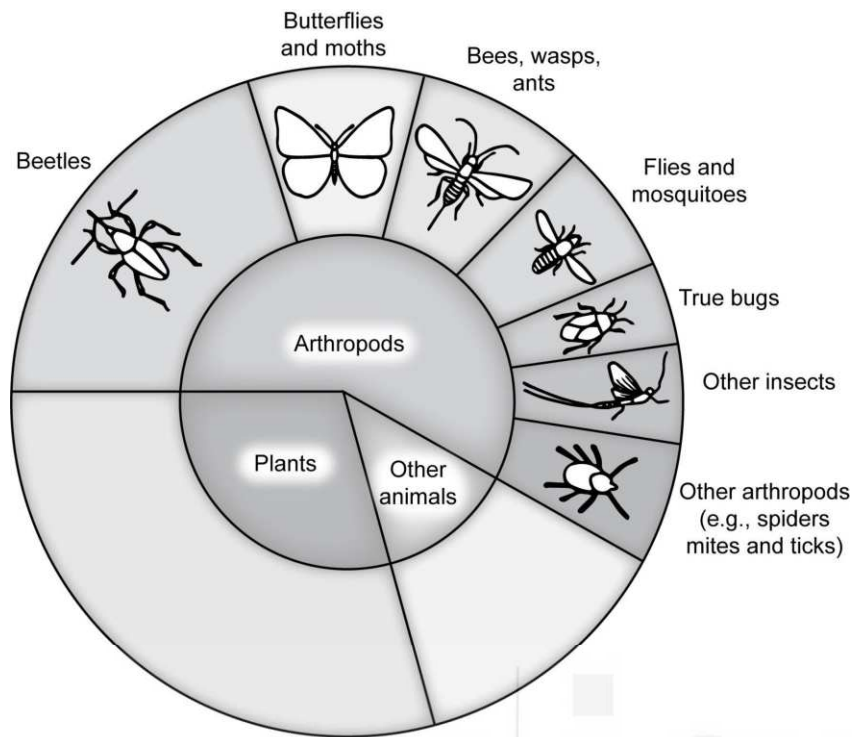


Fig. 1.1: Chart of showing size of various arthropod groups and other life forms. Pie slices are proportional to the number of species in the group. (Redrawn from Daly et al., 1978. *Introductions to Insect Biology and Diversity*. McGraw-Hill Book Company).

More specifically, insects belong to the class Insecta (from *insectum*, cut into).

1. A body divided into three distinct regions: **head, thorax, and abdomen** (Fig. 1.2);
2. A middle region, the **thorax**, bearing **three pairs of legs** and, **most often, two pairs of wings**; and
3. A system for breathing composed of air tubes.

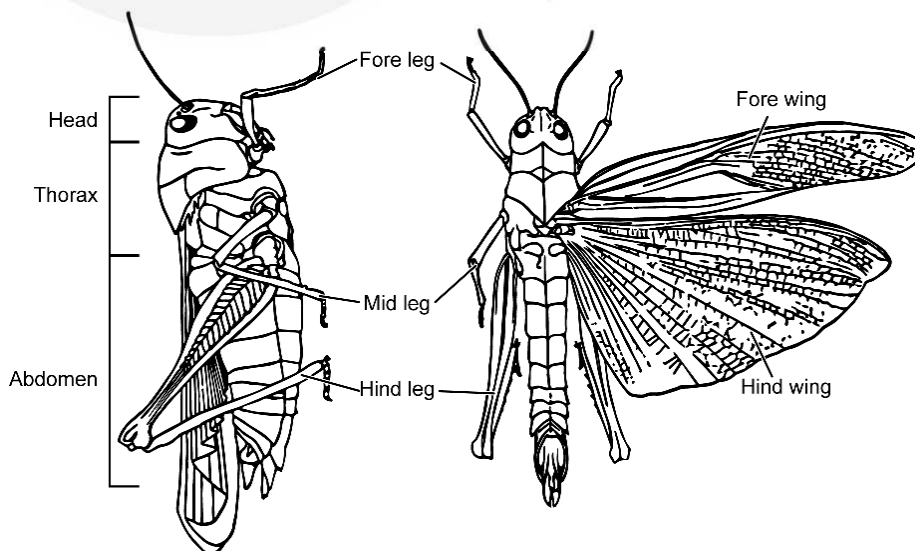


Fig. 1.2: Side (left) and top aspects of a grasshopper, showing important external body features of insects. (Redrawn from T. Nolan, 1970, Commonwealth Scientific and Industrial Research Organization, *The Insects of Australia*. Melbourne University Press).

What Entomology is

Entomology is the science of insects. **It is an organized study to obtain knowledge of all phases of insect life and to understand insects' roles in nature.** As in any science, entomology assumes that elements of the universe interact with one another in a predictable way and that insects, being one of these elements, can be understood relative to these interactions. From the knowledge obtained through *science*, insect events can be predicted and, if desired, modified with *technology*. Therefore, we can learn about insect feeding behavior and developmental rate from scientific study and apply this knowledge to alter these processes for plant and animal protection with technology.

Entomology is a biological science. It is the study of life, with its particular focus on one life form, the insect. More specifically, entomology is treated as a division of zoology, the study of animal life. In this context, we can think of entomology's position as one in a hierarchy of disciplines that become increasingly specific in their subject matter.

SCIENCE-study of the universe

BIOLOGY-study of life

ZOOLOGY-study of animals

ENTOMOLOGY-study of insects

Although, in the strictest sense, entomology is the study of insects, other arthropods usually are treated by the science. In particular, these include the terrestrial arthropods, such as mites and ticks, that share habitats and interact with insects and cause similar pest problems.

Relationships between Insects and People

It is usually with a great deal of hesitation that human beings share their habitats with insects. Because we have no choice in the matter, we have adjusted our existence because of insects, and many customs and lifestyles reflect the intimacy of our relationship with them.

Insects in antiquity: Insects have lived unhampered by human contrivances for most of their existence on earth. They were probably the first small animals to inhabit the land with complete success, having evolved from creatures that probably looked like our present-day earthworms.

1.4 KNOWING AN INSECT

Insects belong to the largest phylum **Arthropoda** characterized by jointed legs. The insects are a highly specialized group comprising the class **Insecta** or **Hexapoda**.

An insect is defined as an **air breathing arthropod** whose body is enclosed within a **chitinized exoskeleton**, body divisible into a distinct **head, thorax and abdomen, and having one pair of antennae, three pairs of legs**, and usually **two pairs of wings** (in the adult stage).

1.4.1 Exoskeleton – The Outermost Hard Covering of the Body

The entire body of an insect is covered by an exoskeleton which provides protection against moisture, dryness, diseases and natural enemies of many kinds. This exoskeleton also protects the soft tissues within and serves as the place of attachment for muscles.

The most characteristic chemical substance in the cuticle layer is chitin which is insoluble and is resistant to the action of water, alcohol, and dilute alkalies and acids.

1.4.2 The Body Regions

The body of a generalized insect (for example a grasshopper) is divided into three regions: the head, thorax and abdomen.

The **head** is in the form of a fused case or head capsule. It bears a pair of slender, jointed antennae, two lateral compound eyes, and three simple eyes (ocelli).

The **thorax** consists of three segments, the anterior prothorax, the middle mesothorax, and the posterior metathorax. Each thoracic segment bears a pair of jointed legs, while the mesothorax and metathorax each bears a pair of wings also.

The narrow forewings are parchment-like. The hindwings are broad and membranous, and fold under the forewings at rest.

The **abdomen** is slender and cylindrical, and consists of eleven segments, the terminal ones being modified for copulation or egg-laying.

SAQ 1

- i) Insects are also called as hexapods. Why?
 - ii) Name the three main regions of an insect body.
-

Classification of Insects

The classification of insects has passed through many changes and with the growth of detailed knowledge an increasing number of orders has come to be recognized. Most classifications of the insects have tended to reflect their authors' opinions on the evolutionary relationships of the major groups. Unfortunately, the paleontological record does not provide a very satisfactory basis on which to reconstruct insect phylogeny, while attempts to infer it from the comparative morphology of recent species are also subject to many uncertainties and qualifications. We have therefore simply enumerated the 29 orders of insects recognized in this Unit. The first four orders, **the Apterygote insects, are primitively apterous forms with only a slight metamorphosis; they usually moult several times after attaining sexual maturity and the adults have one or more pairs of pregenital appendages. The mandibles usually articulate with the head-capsule at a single point.**

Order 1. THYSANURA (Silver fish)

Order 2. DIPLURA

Order 3. PROTURA

Order 4. COLLEMBOLA (Spring tails)

The remaining 25 orders are the Pterygote insects and their adults are winged or secondarily apterous. Their metamorphosis is varied, the adults do not moult and they have no pregenital abdominal appendages. Unless highly modified, the mandibles articulate with the head-capsule at two points.

The Pterygotes fall into two sections. Orders 5 to 20 below constitute the Exopterygotes, normally with a simple, incomplete (hemimetabolous) metamorphosis. There is usually no pupal instar, the wings develop externally, and the immature stages (known either as larvae or nymphs) usually resemble the adults in structure and habits.

Order 5. May Flies

Order 6. Dragon Flies and Damselflies

Order 7. Stone Flies

Order 8. Icebugs

Order 9. Grasshoppers/ locusts

Order 10. Stick Insect/Leaf Insect

Order 11. Ear Wigs

Order 12. Web Spinners

Order 13. Cockroaches

Order 14. Termites

Order 15. Zorapterans

Order 16. Psocids

Order 17. Chewing lice

Order 18. Sucking Lice

Order 19. Bugs

Order 20. Thrips

The 9 remaining orders are the Endopterygotes, with a complete (holometabolous) metamorphosis, accompanied by a pupal instar. The wings develop internally and the larvae differ from the adults in structure and habits.

Order 21. Lacewings

Order 22. Beetles

Order 23. Stylops

Order 24. Scorpion Flies

Order 25. Fleas

Order 26. Mosquitoes and Flies

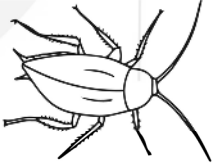
Order 27. Butter Flies and Moths

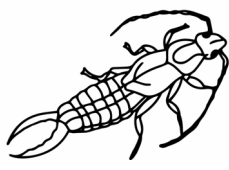
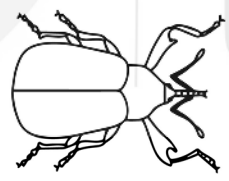
Order 28. Caddis Flies

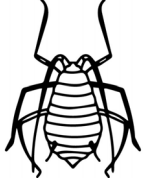
Order 29. Ants, bees, wasps

Table 1.1 depicts the major orders of pests and beneficial insects.

Table 1.1: Major orders of pests and beneficial insects.

Order	Common names	Examples	Mouthparts/ metamorphosis	Other diagnostics	Pest information
Ephemeroptera	Mayflies				Not considered pests
Odonata	Dragonflies and damselflies				Not considered pests
Plecoptera	Stoneflies				Not considered pests
Embioptera	Web spinners				Not considered pests
Blattodea	Cockroaches		Chewing. Partial metamorphosis	Long threadlike antennae	Human nuisance pests, not usually a problem in agriculture
Mantodea	Mantids		Chewing. Partial metamorphosis	Long grasping front legs, praying stance	Beneficials
Isoptera	Termites		Chewing. Partial metamorphosis	Relatively large head to accommodate jaw muscles; no eyes	Structural pests; large mounds cause serious problem in agriculture

Orthoptera	Grasshoppers Lucusts Crickets Katydid		Chewing. Partial metamorphosis	Strong back legs	Can be serious pests; locusts are in this order
Dermaptera	Earwigs		Chewing. Partial metamorphosis	Large pincer appendages at tail	Serious damage to intensive flower crops and seedling in small-scale farming
Thysanoptera	Trips		Resping/slurping. Partial metamorphosis	Small insects with fringed wings	Small group of pest and beneficial species
Neuroptera	Lacewings		Chewing as larvae, slurping as adults. Full metamorphosis	Large transparent wings with complicated vein pattern	Larvae are beneficial
Coleoptera	Beetles		Chewing. Complete metamorphosis	Front wings are hard covers called elytra	Many pests and many beneficials
	Snout beetles, or weevils		Chewing. Complete metamorphosis	Front of head extends forward to form a snout bearing the antennae and mouthparts	Many serious pests; e.g., cotton boll weevil
Diptera	Flies: examples Fruit Flower House Mosquitoes Midges Leaf miners		Slurping, sucking. Complete metamorphosis	Only one pair of wings	Many pests and beneficial

Homoptera	Aphids Scale insects Whiteflies Leafhoppers Cicadas		Piercing and sucking. Partial metamorphosis	Many aphids exhibit parthenogenic reproduction	Many serious pests; many transmit viruses
Homoptera, cont.				Aphids can be apterous (without wings) or alate (with wings)	
Lepidoptera	Butterflies and moths		Larvae chewing; adults slurping. Complete metamorphosis	Relatively large wings covered with scales, often have characteristic markings. Larvae are a caterpillar (often called worm)	Many serious pests
Hemiptera	True bugs		Piercing and sucking. Partial metamorphosis	Front wings form hardened covers	Many pests and beneficial
Hymenoptera	Bees Wasps Ants		Chewing Complete metamorphosis	Typically have constricted waist between thorax and abdomen. Many have sting	Numerous pests and many beneficial
Collembola	Springtails		Chewing. No metamorphosis	Lack wings. Abdomen has prong (furcula) folded back under body with which insect can spring. Colophore on first abdominal segment	A few are soil-borne pests

Arachnida	Spiders Spider mites Ticks Scorpions		Resping and slurping. No metamorphosis	Very small	Many pests species and many beneficial
Symphyla	Garden centipedes		Chewing. No metamorphosis	Multiple legs; do not possess wings	A few are soil-borne pests

1.5 MOUTH PARTS OF INSECTS

Insects feed on plants and animals in diverse of ways, and their mouth parts have become modified accordingly. Different insects have different mouthparts according to their feeding habits

- Biting and Chewing Type (e.g. grasshopper, cockroach):** The biting and chewing mouth parts are the most primitive types of mouth-parts. These are present in grasshopper and cockroach.
- Rasping-sucking Type (e.g. thrips):** Thrips (Thysanoptera) have this type of mouth-parts, which are used to rasp the surfaces of plants and suck the exuded sap.
- Piercing-sucking Type (e.g. bugs, mosquitoes):** Piercing-sucking are a very common and an extremely important type of mouth parts. These mouth parts have become greatly modified for puncturing the epidermis of plants or the skin of animals, and sucking up the sap or the blood. Mouth parts of the stink bug and the mosquito are of piercing sucking type.
- Sponging Type (e.g. housefly):** Mouth parts of the housefly that form a fleshy proboscis are of sponging type.
- Siphoning Type (e.g. butterfly):** This type of mouth parts is found in moths and butterflies.
- Chewing-lapping Type (e.g. honey bee):** Chewing lapping mouth parts are represented in the honey bee and bumble bee.

You will study in detail about mouthparts in later units of this courses.

SAQ 2

Name the type of mouth parts found in the following insects:

- Grass hopper:
- Mosquito:
- Housefly:
- Butterfly:
- Honey bee:

1.6 GROWTH AND METAMORPHOSIS OF INSECTS

1.6.1 Growth

Most insects lay eggs (oviparous). The eggs are usually laid, and hatching occurs after a variable length of time. In some cases the eggs are retained in the body of the female until hatched (ovoviviparous).

The eggs are small, and they vary considerably in size, shape, colour, and markings. They are covered with a shell, the chorion. Fertilization occurs at the time the eggs are being laid. In some insects viz., aphids, embryonic development occurs even without fertilization of eggs. Such a development is called parthenogenesis.

Although insect eggs are much alike, it is often possible to specifically identify them. This may be of much practical value in predicting outbreaks of certain pests, such as grasshoppers and the bollworms. In attempting to identify an insect in the egg stage several things should be noted—shape, size, color and sculpture, host, site of deposition, and whether they are laid singly or in batches.

The number of eggs an insect lays is variable. The true female of certain aphids may lay one over-wintering egg. The moth of the corn earworm may produce as many as 3,000 eggs and the cotton leaf worm moth averages about 600 eggs, while the queen of the honey bee may lay 1,500 to 2,000 eggs daily for several weeks. Eggs may be laid at one time; they may be deposited in batches, which are produced at varying intervals; or they may be laid in small numbers daily over a considerable period of time.

Site of egg-laying: Eggs are generally laid where the newly hatched young have ready access to suitable food. After the eggs are deposited, the female usually pays no attention to them and the young insects upon hatching, must care for themselves.

1.6.2 Metamorphosis

Upon hatching from the egg, the young insect is usually quite unlike the adult into which it develops. The changes which it undergoes during growth or development to the adult stage are termed '**metamorphosis**'. The young insect is quite small when it emerges from the egg. It feeds ravenously, but the extent of its growth is restricted by a rather rigid exoskeleton which encases the body. In order to continue to grow and develop, the insect must periodically replace the exoskeleton with one of larger size. This is accomplished by a process of shedding the outer skin, called 'moulting'. Thus the insect grows by a series of growing stages, called **instars**, or **moult**s. The number of moults is variable but quite constant for any one species. Insects ordinarily moult five to six times.

Types of Metamorphosis

All insects do not develop into the adult stage by the same series of changes or type of metamorphosis. Based on occurrence and the kind of metamorphosis there can be three conditions:

1. **No metamorphosis** (Ametabolous development). Stages of development are: (a) Egg, (b) Young, and (c) Adult. When hatched from the egg, the young insect looks just like the adult except in size. This type of development is represented by the Thysanura (silverfish), and Collembola (springtail). These groups of primitive insects are wingless (Fig. 1.3a).
2. **Incomplete metamorphosis** (Hemimetabolous development). Stages of development are: (a) Egg, (b) Nymph, and (c) Adult.

The young insect (called **nymph**) undergoes a series of feeding stages (instars), which in each case is followed by a moult. Both nymphs and adults have the same type of mouth-parts, food habits, and occur in the same habitat. Examples: grasshoppers, aphids, mayfly, dragonfly (Fig. 1.3b).

3. **Complete metamorphosis** (Holometabolous development). Stages of development are: (a) Egg, (b) Larva, (c) Pupa, and (d) Adult. Example: Housefly, Butterfly. Most species of insects undergo a complete metamorphosis, which includes four developmental stages, namely, egg, larva, pupa, and adult. The larva differs greatly in form from the adult into which it develops. It passes through a series of growing stages (instars) and moults, but unlike insects with gradual metamorphosis, the larva does not resemble the adult any more closely following a moult but remains wormlike or grub-like in form. The larval stage is primarily a feeding and growing stage. All larvae have chewing or modified chewing mouth-parts. Various names are applied to the larvae of insects of different orders. Beetle larvae are known as **grubs**, butterfly and moth larvae as **caterpillars**, and the larvae of flies are known as **maggots**.

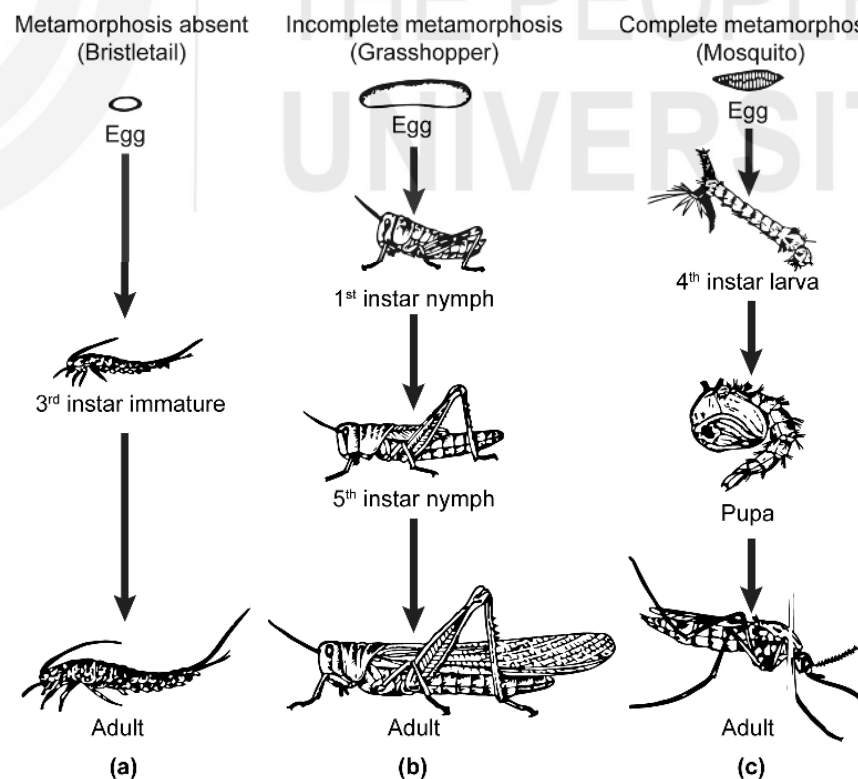


Fig. 1.3: Types of development a) Ametabolous development, b) Hemimetabolous development, c) Holometabolous development.

When the larva has attained the maturity, it ceases to feed and following a period of inactivity, transforms into the **pupa**. In this stage, the insect usually remains inactive, does not feed, but undergoes marked physiological and morphological changes. It is in this stage that the processes of changing a worm-like body into that of a moth, fly, bee, or beetle are completed. The adult emerges from the pupa (Fig. 1.3c).

SAQ 3

- i) Give one example of insect for each of the following types of metamorphosis:
 - a) No metamorphosis:
 - b) Incomplete metamorphosis:
 - c) Complete metamorphosis:
- ii) Give the different developmental stages in the following insects:
 - a) Silver fish:
 - b) Grass hopper:
 - c) Butterfly:

1.7 WHY ARE THE INSECTS SO SUCCESSFUL?

Among all the categories of animals, insects are the most dominant. No other group of organisms is adapted to live in such diverse habitats as the insects. They live in all corners of the earth from poles to equator, in soil, in fresh water, in hot spring, in live and dead plants and animals, in pools of crude petroleum etc. They are therefore a remarkably successful group of organisms and develop to huge numbers of species and individuals.

Apart from their small size, insects as a class have acquired many **structural**, **developmental** and **behaviouristic** perfections not found in any other group of animals or in plants. Some of the salient features which are responsible for their success are:

1.7.1 Structural Perfections

1) Exoskeleton

The exoskeleton or body wall or integument is made up of chitin. The advantages of exoskeleton are many, viz., it provides a large area for attachment of muscles, provides complete protection to the vital organs from external injury, controls evaporation and so affords an excellent mechanism to protect against desiccation. Further, the exoskeleton gives the insects much physical strength without their being too heavy and also allows enormous modifications.

2) Small Size

Small size of insects favours subsistence and shelter. The chances of survival of the species are increased, it is easier for the individuals to subsist on small quantities of **food** and to take **refuge** in small niches against the vagaries of nature. Both these advantages favour increase in the number of individuals in the insect populations.

With larger numbers resulting from smaller size the chances of **variability** and **mutation** also increase, thus making it possible for nature to conduct a larger number of trials in evolution. Lastly, the smaller size leads to greater proportionate efficiency.

3) Functional Wings

The power of flight greatly increased the statistical chances of survival and dispersal. Functional wings increased the feeding and breeding range, and provided a new means of eluding enemies, attacking a fast moving host, and finding a mate.

4) Hexapod (hexa-six, podos-leg) Locomotion

In insects the number of legs has reached an ideal stage of evolution. The large number of legs in millipedes makes locomotion cumbersome, but when the number of walking legs become less than 6, it creates a problem of balancing during locomotion. During insect movement the body always rests on three legs i.e. a tripod (front and hind leg of one side and the middle leg of the other) while the other three move forward. Thus 6 is the smallest number for a stable equilibrium during all phases of terrestrial locomotion.

5) Compound Eyes

The compound eyes consist of hexagonal areas each representing the cornea of a discrete visual organ called the ommatidium, all of which are compacted together. Thus, ants have 50 to 400 facets or corneas in each eyes, a housefly has 4000 and certain dragonflies more than 50,000. Therefore, it is obvious that an insect will not lose power of vision completely if a few ommatidia are injured.

6) Scattered Sense Organs

Except the eyes, none of the sense organs are concentrated on the head. For example, the organs of hearing are sometimes associated with the antennae and the organs of taste and smell may also be on the antennae, on mouthparts, or even tarsi or cerci. Such diffused and scattered sense organs is bound to be advantageous to the insects as this arrangement reduces the chances of all being injured at any one time.

7) Decentralised Nervous System

The central nervous system is a ladder-like chain of ganglia along the ventral side of the body, except one complex nerve center in the head, i.e. the brain. This system despite the highly evolved stage of the insects as a class, is so decentralized that brainless insects can be artificially simulated to walk, fly or even feed.

8) Direct Respiration

Respiration is independent of the mediation of the blood, and the respiratory gases are taken to and from every minute part of the system directly through the tracheae and the tracheoles, which have their openings called the spiracles on the body surface.

9) Enteronephric Excretion (excretory tubules opening into the gut)

Excretory wastes produced by the malpighian tubes are passed through the hindgut. This type of excretion is well suited for water conservation, since it makes the excretory function independent of water supply, and so water is not wasted.

1.7.2 Developmental Characteristics

The life - history of a vast majority of insects (moths, beetles etc.) consists of four well defined stages : the egg, the larva, the pupa and the adult. Two of these stages, mainly **feeding larval stage** and the mainly **reproductive adult stage** are so different from each other not only in structural details but also in requirements of food and habitat that competition between the parent and the offspring for food or shelter is completely eliminated. Further by the presence of the quiescent pupal stage with great resistance and practically no food requirement between the larval and adult stages, two active stages are best fitted into different sessions optimum for them. Thus, the development of metamorphosis has enabled insects to adapt themselves to varied situations of existence much better than animals not possessing this mechanism.

High Fecundity and Controlled Reproduction

The large number of eggs laid by the female and the quick rate of development make the insects very prolific. Individual queens of termites and some other social insects may lay as many as several hundred thousand eggs. Many moths, flies, stoneflies etc. deposit hundreds of eggs per day.

Some of the species have increased their prolificity by **polyembryony**, i.e. production of several embryos from a single egg, as in some chalcids; others reproduce even in the absence of males by **parthenogenesis**, i.e. development of the egg without fertilization by male sperm. At the other extreme, there is completely **controlled reproduction** as in some of the social hymenoptera, which have learnt to make their surroundings so safe as not to require wasteful reproduction. A number of social species of wasps, bees and termites have developed such a high degree of control on reproduction that all except one or a few females of the colony are rendered unfit for reproduction and constitute a class of sterile females. This strict division of labour between reproducing females known as queens and the workers represents the highest evolution of a special order in the entire animal kingdom.

1.7.3 Specificity of Feeding

While there is a vast diversity of food habits among insects, there being often some specific preference for one kind of food or the other, there are insects

which have overcome interspecific competition either by becoming polyphagous by living on almost any kind of vegetable matter, e.g., locust and army worms, or by taking to such food for which there is no competition, e.g., cellulose eating termites. There is sometimes extreme degree of specificity not only for different plant species or varieties but also for different parts of the same plant, as in the case of root-borers, stem-borers and top-borers of sugarcane.

1.7.4 Quicker Speciation

Owing to the mechanical rigidity of the chitinous exoskeleton, comparatively minute variations in the external genitalia have led to reproductive isolation and consequent fixation of the species. Another factor, viz., development of aerial mode of existence, especially acquisition of wings leading to life under diverse ecological habitats, has provided the trigger for variations. Both the factors together increased the chances of variability and mutation resulting into a large number of different species. This vast increase in the number of species immensely increased the economic potentialities of insects as a class.

SAQ 4

List the structural perfections, which make insects successful on this planet.

1.8 HARMFUL AND USEFUL INSECTS

Insects in recorded history have affected culture and lifestyle, but not only as adversaries. Humans prize some insects for the honey, silk, and other products they create. Other insects have been central figures in religion, such as the scarab beetle in ancient Egypt and butterflies that migrate to the sacred mountain, Samanala Kanda, in Sri Lanka. Insects have also been used in ornamental jewelry and wall decorations of many kinds. Humans even used them to forecast weather, using the width of a woollybear's band to predict the severity of coming winter.

Modern times: Today human relationships with insects are the sum of those that have been acquired since our existence together began. This accumulation of a relationships resulted primarily from our own activities to tame nature. In the history of this relationship, technology and insect encounters have developed a correlation. Because technology is an overpowering force today, we can expect to see continued modifications in the natural landscape. Consequently it seems likely that new associations, and perhaps confrontations, with insects are in the offing.

The Ledger

In analyzing the history of human and insect relationships, it might be tempting to believe that insects are our enemies incarnate and that their elimination would result in a better world. However, insects have redeeming values both for human existence and the overall ecology of our planet. An analysis, therefore, should picture human/insect associations as profits and losses, as

would a business enterprise. To do this, we might prepare a ledger showing black ink, the profits, and red ink, the losses, and then form a balance sheet to arrive at our conclusions about insects.

Black ink: the benefits: Insects can benefit humans by providing a product desired for human consumption, **a primary resource**, or by interacting with elements of our environment to yield a benefit, **an intermediate resource**. Probably the most valued primary resources insects provide today are **silk, honey, wax**, and their **bodies** for human consumption and experimentation. Among the intermediate resources are insect activities as **pollinators, natural enemies of pests, food for wildlife**, and **scavengers**.

As mentioned earlier, whole insects, in addition to their products, have been eaten by humans since the beginning of human life. Today, insects continue to serve as food directly, and edible insects are a source of protein and fat in otherwise deficient diets of people in many parts of the world.

A final example of a primary resource is the role insects play today as experimental animals. Many scientists use these six-legged guinea pigs to test theories and solve biological problems. For laboratory work, insects are small, require little space, and many such as large cockroaches, demand little care and maintenance. Indeed, insects used as experimental animals have been indispensable in such fields as genetics, toxicology, and neurobiology; they have allowed advance that would have been prohibitively costly or otherwise impossible. The science of genetics, in particular, has relied on insects, and probably no other species has been more important than the fruit, or pomace, fly, *Drosophila melanogaster*, in unraveling the complexities of inheritance.

Of all the ways insects serve as intermediate resources, probably none is more important than their plant pollination activity. Butterflies, bees, flies, and other groups of insects inadvertently pollinate plants when they feed on pollen and nectar of flowers. Moving from flower to flower to collect nectar, insects like bumble bees come into contact with pollen grains that adhere to their legs and body hair. With each visitation, some grains are left on the sticky female stigmata thereby cross-fertilizing the plant. In the process, other pollen grains are picked up and subsequently transferred to other plants. Such relationship are believed to have played an important role in the evolution of both insects and plants and have been used to account for some of the specialized forms, colors, and fragrances in flowers and behavior patterns of insects.

Equally important to human welfare is the activity of some insects that kill and eat (or vice versa) other kinds of insects. These insects, known as natural enemies, function as predators or parasites in reducing the numbers of harmful insects. For example, **ladybird beetles** feed voraciously on many species of aphids, sometimes averting the need for any pest management action. Parasites such as tiny *Trichogramma* wasps lay eggs inside the eggs of many moth pests, producing larvae that consume pest-egg contents and sometimes prevent pest populations from developing. Although the exact magnitude of natural enemy effects on all insect pests and potential pests cannot be measured, it is believed momentous: probably 30 to 40 percent of all insect species are natural enemies of other insects.

Yet another activity of insects that benefits humans is scavenging. When animals and plants die, the organic matter that makes up their bodies possesses energy in the form of chemical bonds. That energy is released via a step-by-step breakdown of body tissue constituents. Insects, in feeding on dead plant and animal tissue, often carry out the first stage of decomposition by predisposing matter for enhanced decay and ultimate breakdown by microorganism.

Red ink: the losses: Although insects are usually thought of as harmful to humans, probably **less than 1 percent of all insect species fall into the pest category.**

Nevertheless, these species we call pests have imposed and continue to impose burdens on human populations by causing:

1. Injury to crop, plants, forests, and ornamentals;
2. Annoyance, injury, and death to humans and domesticated animals; and
3. Destruction or value depreciation of stored products and possessions.

Injury to crop plants, forests, and ornamentals is one of the most conspicuous ways insects cause economic losses to humans. Because approximately one-half of all known insects are plant feeders, our greatest number of insect problems involve plants.

Insects injure plants by feeding on them and laying eggs in plant tissues. By far the more dangerous of these injuries is feeding. Insects consume plant tissues with various types of chewing mouthparts and remove plant juices with piercing-sucking mouthparts.

Insects as medical pests are much more important in an indirect way, as vectors of human pathogens. Here, some insects, ticks, and mites harbor nematodes, rickettsiae, viruses, protozoa, and bacteria. In some instances, part of the microorganism's life cycle, often including multiplication, occurs in the insect body. Among the most important diseases transmitted by insect vectors (mainly mosquito) are **malaria, yellow fever, filariasis, dengue**, and several types of **encephalitis**. The causes are malaria from an apicomplexan i.e. *Plasmodium*, filariasis from filarial worms, and dengue and encephalitis (plural of encephalitis) from viruses called **arboviruses**, and abbreviation of the term *arthropod-borne viruses*.

Other insects affect household possessions. Clothes moths and carpet beetles eat anything containing animal fibers, including woolens, upholstery, and carpet. Other insects such as cockroaches spot and taint food and living areas. Termites are another frequent household problem in many localities, consuming wood on foundations, in floors, and in walls that often require expensive repairs.

The key to this change in attitude is knowledge and understanding about insects and the important part insects play in the ecology of our planet. From past mistakes, it would seem that the most advantageous attitude should be to live in harmony as much as possible with all elements of nature, including insects. As T. Eisner has put it, **"Bugs are not going to inherit the earth. They own it now, so we might as well make peace with the landlord"**. Just how we can promote an attitude of harmony is the basis for insect pest management the sensible approach to insect problems.

1.9 SUMMARY

After studying this Unit, you have learnt that:

- Insects, belonging are the most successful animals on this planet. The body of an insect is divided into head, thorax and abdomen. The thorax bears 3 pairs of thoracic legs and mostly 2 pairs of wings.
- Insects are classified in 2 subclasses i.e. Apterygota and Pterygota. Apterygota are primitive, wingless insects and Pterygota are winged and secondarily wingless insects.
- In Pterygota, the insects with a simple form of body change during growth and external wing development belong to Division **Exopterygota** and those with complete changes in body form and internal wing development are placed in Division **Endopterygota**. These divisions are further classified into orders.
- Insects have unique mouth parts for feeding. Mouth parts vary in different insects based on their nature of feeding.
- Insect life cycle is very interesting, as one life form differs totally from others. The developmental process that takes place from eclosion of the free living insect till adulthood is called **metamorphosis**. This is under control of various hormones.
- Insects' success is due to their small size, high fecundity rate, unique developmental process, ability to fly, body architecture and thick chitinous exoskeleton. Their abundance and diversity is remarkable.
- Some insects are used by humans for honey, silk and other products. Others are used in jewelry, forensics and weather forecasting. Many insects serve as pollinators and scavengers.
- Some of the insects harm crops thereby causing tremendous losses in agriculture and many serve as vectors of human diseases like malaria, dengue, yellow fever etc.

1.10 TERMINAL QUESTIONS

1. Write a note on insect abundance and diversity.
2. Write differences between hemimetabolous and holometabolous development.
3. Discuss the harms and uses of insects for mankind.
4. Which structural, developmental and behavioristic characteristics make insects highly successful organisms on Earth?

1.11 ANSWERS

Self Assessment Questions

1. i) They have six legs.
ii) Head, thorax and abdomen.

2.
 - a) Biting and Chewing type.
 - b) Piercing and sucking type.
 - c) Sponging type.
 - d) Siphoning type.
 - e) Chewing and lapping type.
3.
 - i)
 - a) Silver fish (*Lepisma*)
 - b) Cockroach
 - c) Butterfly or Honeybee or housefly.
 - ii)
 - a) Egg → young → adult
 - b) Egg → nymph → adult
 - c) Egg → larva → pupa → adult
4. Structural perfections
 - Exoskeleton
 - Small size
 - Functional wings
 - Hexapod locomotion
 - Compound eyes
 - Scattered sense organs
 - Decentralised nervous system
 - Direct respiration
 - Enteronephric excretion

Terminal Questions

1. Refer to Section 1.2 and Section 1.3.
2. Refer to Subsection 1.6.2.
3. Refer to Section 1.8.
4. Refer to Section 1.7.

UNIT 2

INSECT MORPHOLOGY |

Structure

- | | | | |
|-----|----------------------|-----|--------------------|
| 2.1 | Introduction | 2.4 | Abdomen |
| | Objectives | 2.5 | Summary |
| 2.2 | General Features | 2.6 | Terminal Questions |
| | Tagmosis | 2.7 | Answers |
| | Body Wall | | |
| | Head | | |
| | Antenna | | |
| | Eyes | | |
| 2.3 | Thorax | | |
| | Legs | | |
| | Modification in Legs | | |
| | Wings | | |

2.1 INTRODUCTION

In Unit 1 of this course you have learnt about an insect, the reason for their abundance and diversity. There are insects of economical importance which includes agriculture and disease-transmitting agents that may cause damage to our crops as well as transmit diseases to humans and animals. There are large number of parasites and predators that play an important role in insect pest management programmes. Most of the insects are phytophagous feeding on the plant foliage. Before the identification of an insect, you must know about the external morphology of an insect. The different types of antennae, mouthparts, legs and wings present on the insects play a very important role in their identification and classification. However, some insects are eco-friendly such as honey bee, silkworm and lac insects. In a vector, the mouth parts, pulvilli and body hairs are very important organs in transferring the disease-causing organisms (pathogens) from one host to another or one place to another place. Therefore, in the present unit, we will study the unique knowledge of insect morphology for their identification.

Objectives

After reading this unit you should be able to:

- ❖ distinguish between ametabolous, hemimetabolous and holometabolous insects,
- ❖ define moulting and tagmosis in insects,
- ❖ describe the body wall of insects,
- ❖ differentiate the body parts into head thorax and abdomen,
- ❖ differentiate into different types of mouth parts based on the feeding habits,
- ❖ distinguish into the simple and compound eye, and
- ❖ discuss the modification legs in insects.

2.2 GENERAL FEATURES

Insects body is divided in three parts i.e. head, thorax and abdomen. Insects are segmented animals having an outer exoskeleton called the cuticle, mainly made up of chitin, which is a characteristic of phylum Arthropoda. The presence of three pairs of jointed legs in all the insects is the characteristic feature of class **Insecta** or hexapoda, to which all insects belong. Let us first discuss some of the basic classification and terminology used in the study of insect morphology. Most of the insects having wings belong to group **Pterygota** while another group Apterygota includes primitive wingless insects. Within the insects, we come across the three main types of developments: Ametabolous, Hemimetabolous and Holometabolous. **Ametabolous development**, in which insects exhibit very little change during development from larvae to adults, **hemimetabolous development** which includes insects exhibiting a gradual change in body during development; and whereas **holometabolous development**, shows an abrupt change from wingless immature insect to mature winged insect with intermediate pupal stage. Immature stages of hemimetabolous and holometabolous insects are called nymphs and larvae, respectively. In the following sub-sections, we will learn about the tagmosis, body wall, and structure of the head, thorax, and abdomen and their appendages.

2.2.1 Tagmosis

In insects, each apparent segment is earmarked as an area of sclerotization. Segments are separated from each other by an unsclerotized area called the intersegmental membrane. One of the striking external features is the combination of segments into functional units. This process of tagmosis has given rise to three tagmata (regions): head, thorax, and abdomen. In this process, the 20 original segments have been divided into an embryologically detectable six or seven segmented head, three segmented thorax, and nine to eleven segmented abdomen (plus telson). The body surface has four principal regions; the **dorsum** (upper surface), the **ventral** (lower surface), and the

two-lateral pleura, separating the dorsum from the venter to which, bases of appendages are articulated, if present. Sclerotization take place as distinctive areas on the body surface and gives rise to plates called sclerites (Fig. 2.1). Each segment has four sclerites: the tergum (dorsal plate), the sternum (ventral plate), and the two pleura (each pleuron on each lateral side). Head sclerites are articulated to each other and form a rigid capsule. Thorax and abdomen may remain membranous. Because of this, the terga, sterna, and pleura are rarely distinguishable.

Head bears main sense organs: one pair of compound eyes, generally up-to three ocelli, single pair of antennae except in order Protura where antennae are absent, and appendages modified for feeding. Thorax bears three pairs of legs and two pairs of wings almost in all adult insects. In many insects, one or both pairs of wings are absent. The abdomen usually consisted of 9 to 11 segments plus a telson. Adult abdomen bears a terminal pair of sensory cerci and the external genitalia in some insects.

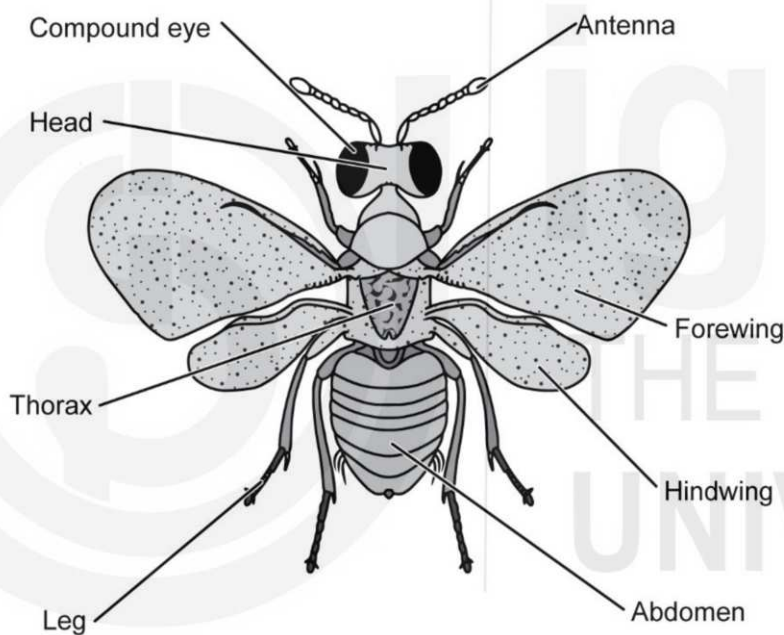


Fig. 2.1: A typical structure of insect.

2.2.2 Body Wall (Integument)

Integument covers the body of insects consisting of two layers, the epidermis (inner) and the cuticle (outer). Cuticle gives support, protection and prevents the loss of water from the body surface. Numerous ectodermal glands which are groups of specialized cells of the epidermis occur in the insects. The epidermal cells secrete their secretions externally. Some of the common ectodermal glands are the wax glands, lac glands, scent glands, poisonous glands, mucous glands etc. The cuticle is made up of two layers, **epicuticle** which is a thin, waxy and water proofing outer layer, and the layer beneath it is called the **procuticle** (Fig. 2.2). The cuticle is very hard and limits growth, so the insect must remove off its existing cuticle from time to time with another, which before it becomes hard, is very soft and results in some expansion. The new cuticle is developed before the old one is cast off. The old cuticle sloughed off from the body is called **exuviae**.

The epidermis is the outer cell layer of the insect and one cell thick, cytoplasmic processes of the epidermal cells of the epidermis extend into the pore canals, which run upto the inner layer of the epicuticle. Pore canals play an important role in the transport of cuticular material to the surface from the epidermal cells and in anchoring the cuticle to the epidermis. Glands are the derivatives of epidermis, which form the outer layer of cuticle, cement, Pore canals, basement membrane on which epidermis cells lie, and oenocytes associated with the secretion of lipoprotein of epicuticle. Bristles are also derivatives of the epidermis.

The water proofing cuticle is a key contributor to the success of the insects. Cuticle covers the whole of the outside of the body, limbs and wings as a strong exoskeleton and also lining the tracheal tubes, some gland ducts, alimentary canal and foregut and midgut of the digestive tract. The cuticle is very strong and armored like in most beetles but in some insects, it is very thin and flexible.

The cuticle is differentiated into two layers: Non-Chitinous, epicuticle, an outer layer and the layer underneath is chitinous and thicker than epicuticle called procuticle. Procuticle is made up of two layers, the outer is exocuticle and the inner one is the endocuticle. Epicuticle is made up of three layers, inner cuticulin, middle wax and outer cement. Wax consists of a long chain of hydrocarbons, and the esters of the fatty acids and alcohol molecules close to cuticulin form a monolayer resulting in orientation and absorbing their hydrophilic group onto the surface of cuticulin. Molecules of the monolayer lie very close to each other. This makes the layers water proof since water molecules are unable to pass through the wax molecules over the wax layer. The cement layer is very thin. This protects the underlying wax (Fig. 2.3).

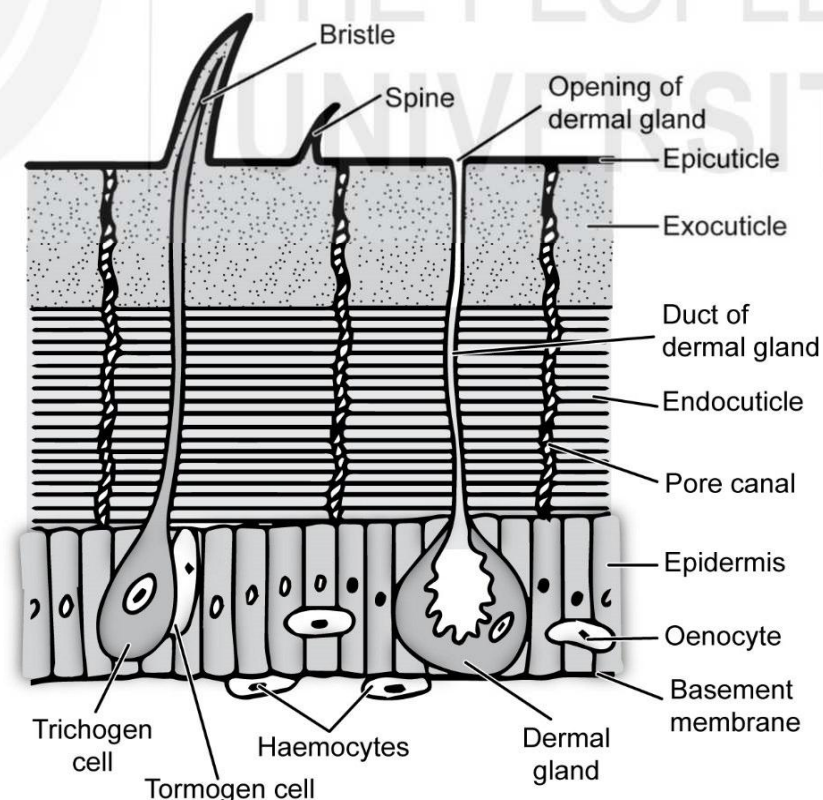


Fig. 2.2: Section through the bodywall of Cockroach (after R. F. Chapman, 4th ed., 1998).

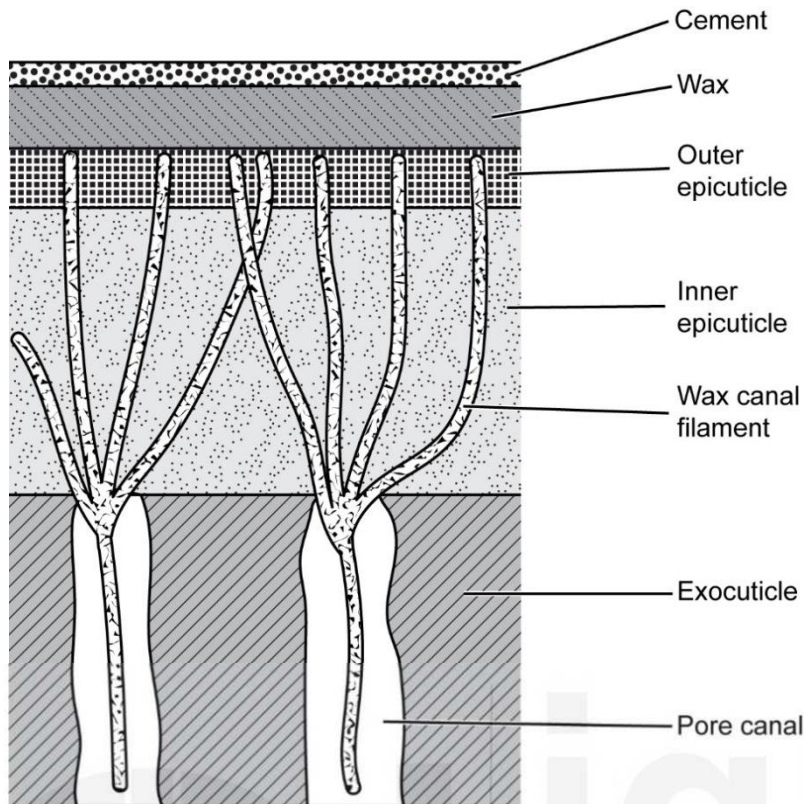


Fig. 2.3: Section through the epicuticle of insect. (after R. F. Chapman, 4th ed., 1998).

The tough and flexible endocuticle is built from chitin and protein while the exocuticle is rigid and sclerotized. In soft-bodied insects especially larval stages, exocuticle is required. Chitin is a long-chain polymer of N-acetylglucosamine. Cuticle provides muscular support. However, since it cannot grow, the external sclerotized part of the cuticle is periodically shed in the process called **moulting**.

2.2.3 Head

The Head comprises six body segments which are fused to form a compact head capsule. Based on the orientation, the position of the head with respect to the rest of the body varies. In beetles, mouthparts are directed forward, and this condition is called **prognathous**. In cockroaches and grasshoppers, mouthparts are pointed downward, and this condition is called **hypognathous**. In bugs, there is **opisthorhynchous** condition in which mouthparts are directed backward between the coxae of the fore-legs. The Head has two openings: one occipital foramen opens into the prothorax and another into the mouth parts. Head is a sclerotized capsule with no outward appearance of segments but marked by the grooves called sutures. Snodgrass (1960) named sutures as sulci (singular-sulcus). Several areas of the head marked by the sulci are given names. The posterior horse shoe-shaped posterior cranium (dorsally called as occipit) joins the vertex dorsally and the genae laterally; vertex contacts frons anteriorly and clypeus lies anterior to frons, both may be fused into a frontoclypeus. Head bears mouth parts, paired compound eyes dorsolaterally between the vertex and genae, pair of sensory antennae placed above and anterior to genae and light sensitive ocelli (simple eyes) between the compound eyes (Fig. 2.4).

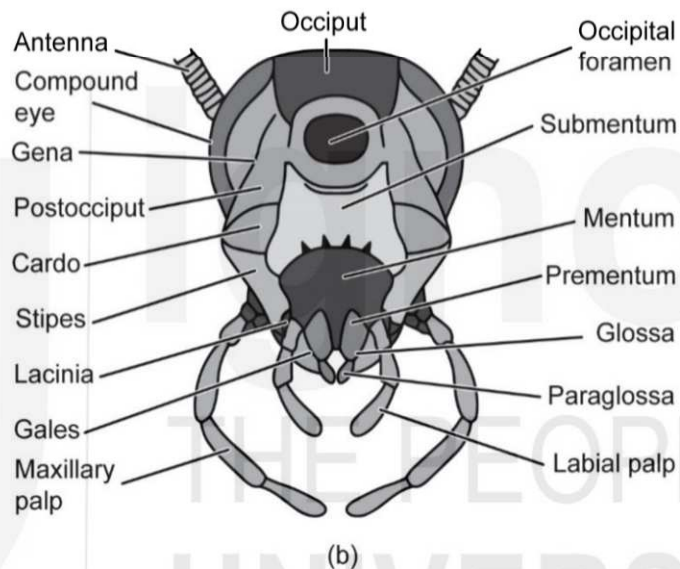
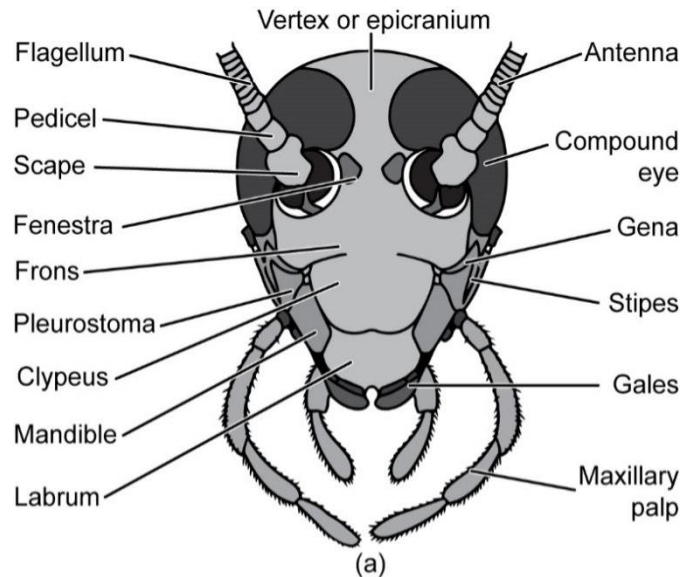


Fig. 2.4: Head of *Periplaneta americana*. A. Anterior view, B. Posterior view.

Mouth parts

Head is formed by the fusion of six segments and demonstrated by the mouth parts. These are: Labral, antennae, post antennae, mandibular, maxillary and labial segments. Mouth parts are usually the appendages of all the segments of the head except the second. Mouth parts consists of basic five components: Labrum forms the upper lip; hypopharynx, tongue-like structure; one pair of mandibles usually help in cutting and piercing; one pair maxillae and labrum form the lower lip. The mandibles, maxillae, and labium are the appendages of segments 4-5-6 and are different in structure among the insect orders. The labrum forms the roof of the preoral cavity and mouth. Anterior projection forming the back of preoral cavity is called **hypopharynx**. Maxillae is found to lie behind the mandibles (Fig. 2.5).

Maxillae consist of proximal cardo with which it is articulated to the head and distal stipes, which bear two lobes like structures, inner lacinia, and lateral galea and 5 segmented maxillary palps, lateral to galea. Lacinia hold and macerate the food whereas galeae and pulps bear chemoreceptors and mechanoreceptors which help in selecting the food before ingestion.

Labium is the fused form of appendages of 6th segment with sternum. It has a post mentum at the base which is subdivided into submentum and mentum. At the distal end, there is prementum typically bearing three-segmented palpi, one on each side. In some insects, prementum also bears lobes, called ligula, consisting of the outer lobes known as paraglossae and the inner lobes as glossae. Labial palps are also sensory in function similar to the maxillary palps. Modification in mouth parts is associated with specialized diets.

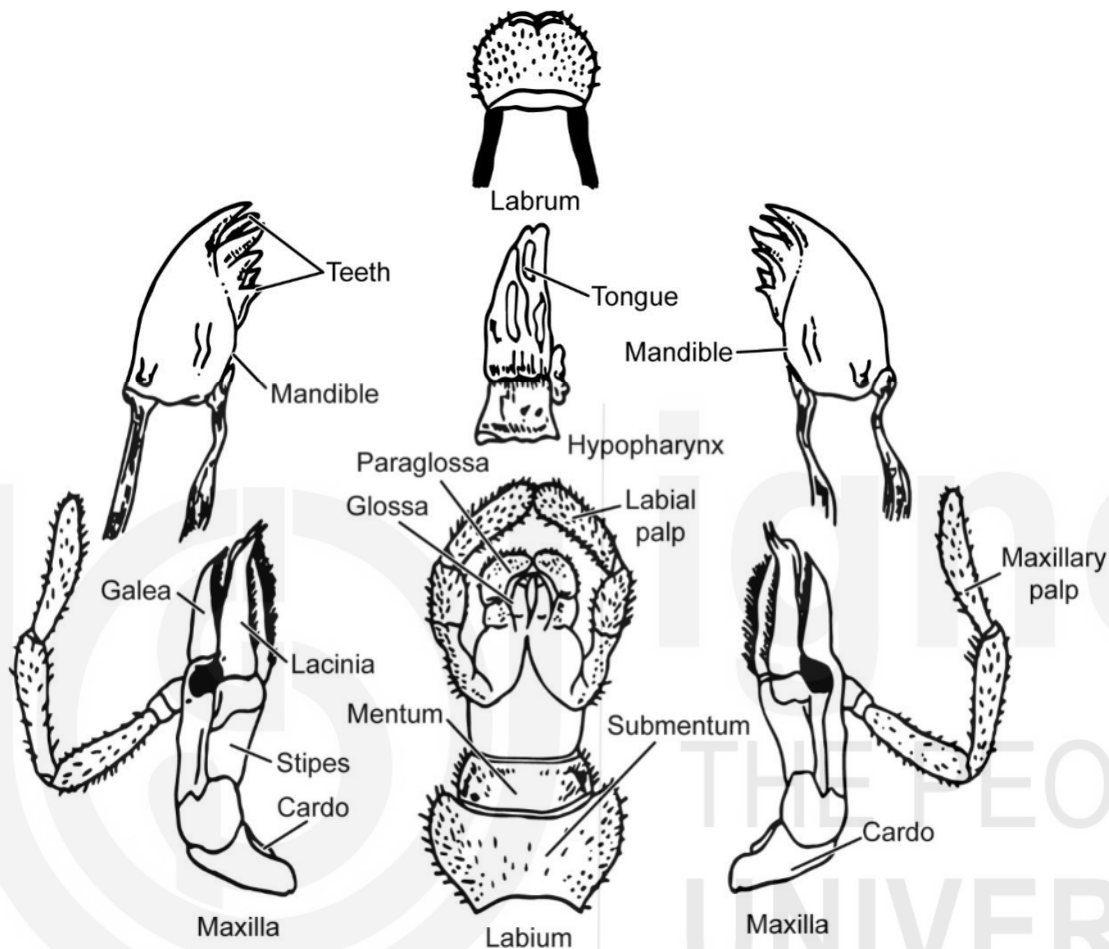


Fig. 2.5: Mouth parts of *Periplaneta americana*.

Mouth Part and its Modifications

i) Chewing-lapping type

These types of mouth parts are found in honey bees. Mouth parts in honey bees are modified for collecting the nectar and pollen grains from the flowers and for moulding the wax. Maxillary lacinia & palps are rudimentary and the para glossae are present at the base of glossae, (tongue). Labrum lies below the clypeus. Mandibles are short spoon like lying on either side of the labrum used in moulding the wax. Labium has reduced paraglossae but glossae are well developed and united and elongated to form a tongue-like structural form. At its tip, there is a small labellum (flabellum) or honey spoon. The labial palps are elongated. Galea and labial palps form a tube around the glossae and glossae move up and down in the tube to collect the nectar from the nectarines of flowers.

The mandibles and labrum are of the chewing type whereas the labium and maxillae are of lapping type (Fig. 2.6).

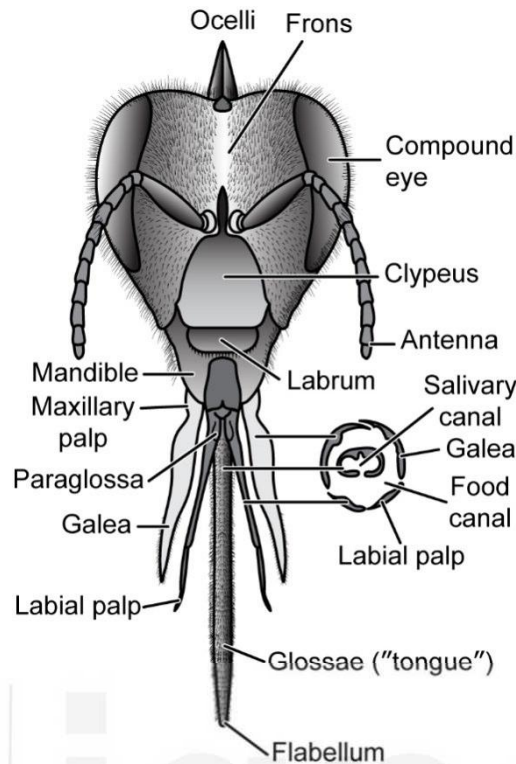


Fig. 2.6: Frontal view of the head of a worker honey bee, *Apis mellifera* (Hymenoptera: Apidae), with transverse section of proboscis showing how the "tongue" (fused labial glossae) is enclosed within the sucking tube formed by the maxillary galeae and labial palps. (Inset after P.J. Gullan, 3rd ed., 2004).

ii) Biting and chewing type

The labrum is rectangular flap-like structure. The mandibles are paired and have teeth at their inner side. Mandibles oppose each other and help in masticating the food. One pair of maxillae lies behind the mandibles. Each possesses tactile maxillary palp. Maxillary palps and labium help in holding the food and pushing the masticated food into the mouth, for example in cockroaches the salivary channel opens at the base of the hypopharynx which appears like a tongue (Fig. 2.7).

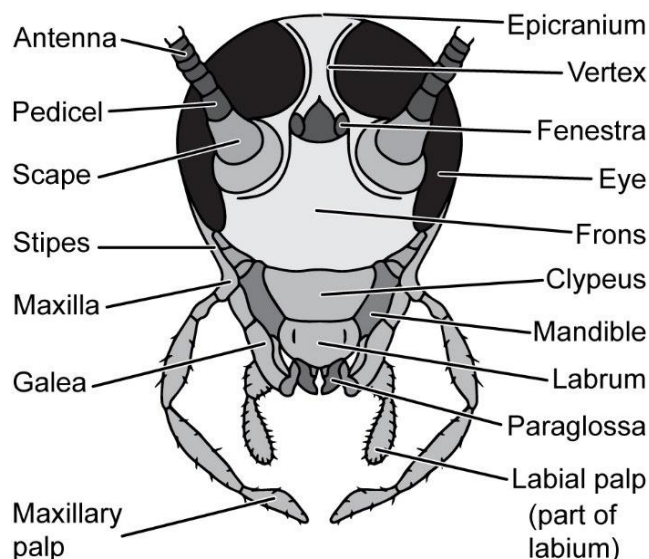


Fig. 2.7: The head and chewing mouthparts of the *Periplaneta americana*.

iii) Piercing and sucking type

Mosquitoes

The labium is modified to form an elongated, dorsally grooved, fleshy tube called proboscis. Labial palps are modified to form labella at the tip of proboscis. The labrum is a needle like and covers the labial groove dorsally. Mandibles, maxillae, hypopharynx are modified into the elongated structure and placed in the labial groove. While sucking the blood, stylets in the groove move apart from each other and form a food channel through which blood is sucked.

When a female mosquito bites a host, the labella is placed on the skin and labium, which cannot pierce the skin bends backward. This bonding helps the maxillae, mandibles and hypopharynx to penetrate the skin of the host. Hypopharynx has a salivary channel through which saliva is injected into the blood vessels, which prevents the blood from coagulation. Hypopharynx and mandibles are reduced in size in males so that they cannot bite/pierce the skin of the prey (Fig. 2.8).

Bed bugs

Bed bug has three segmented labium. The mandibles and maxillae are modified into elongated stylets, having a blade and saw-like tips, respectively.

The labrum covers the labial groove at the base only. The mandibles and maxillae lie externally and internally in the labial groove respectively. The maxillae are so grooved that form the upper food channel and lower salivary channel. Hypopharynx is altogether absent (Fig. 2.9).

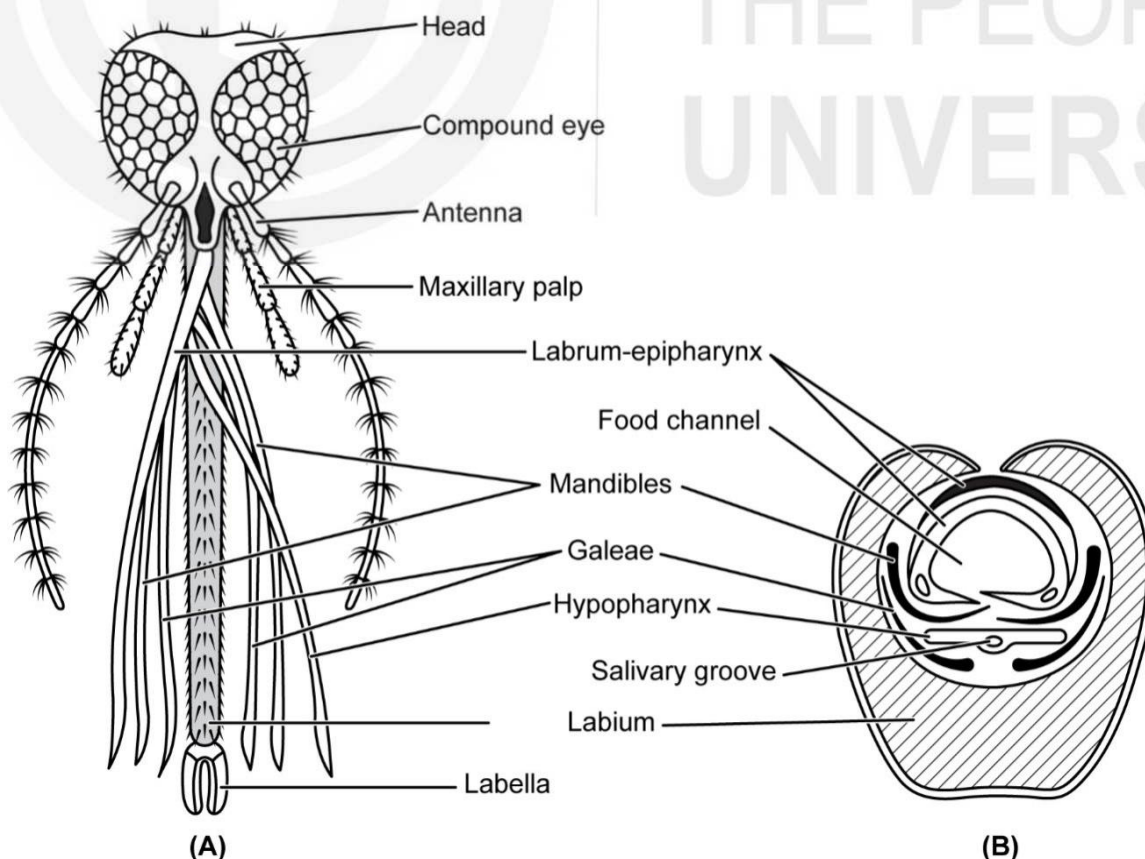


Fig. 2.8: *Culex* (female). (A) Head and mouth parts (B) T.S. of mouth parts.

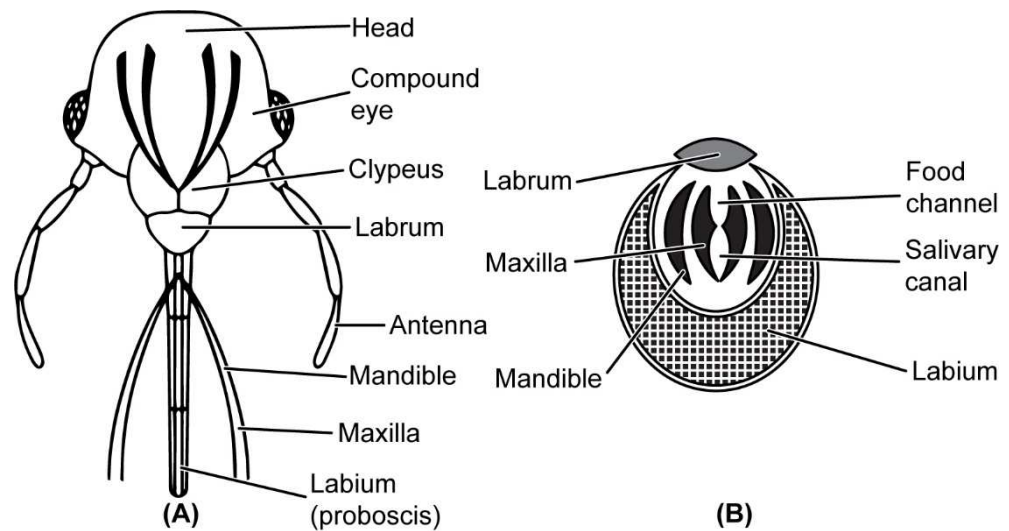


Fig. 2.9: Bed bug. Mouth parts. (A) Head and mouth parts in frontal view, (B) T.S. of mouth parts.

Lice

Lice have three stylets, one dorsal and two ventral, lie in the ventral sac of the head. Mouthparts consist of a sucking snout-like projection called **haustellum**, which has a circle of teeth on its inner surface. The stylets are protrusible, while feeding, the stylets protrude out of the head and are thrust into the skin, and saliva is injected into the wound to prevent the blood from coagulation. After piercing the stylets are retracted back into the sac. The blood oozed on the surface is sucked in by the suctorial pharynx (Fig. 2.10).

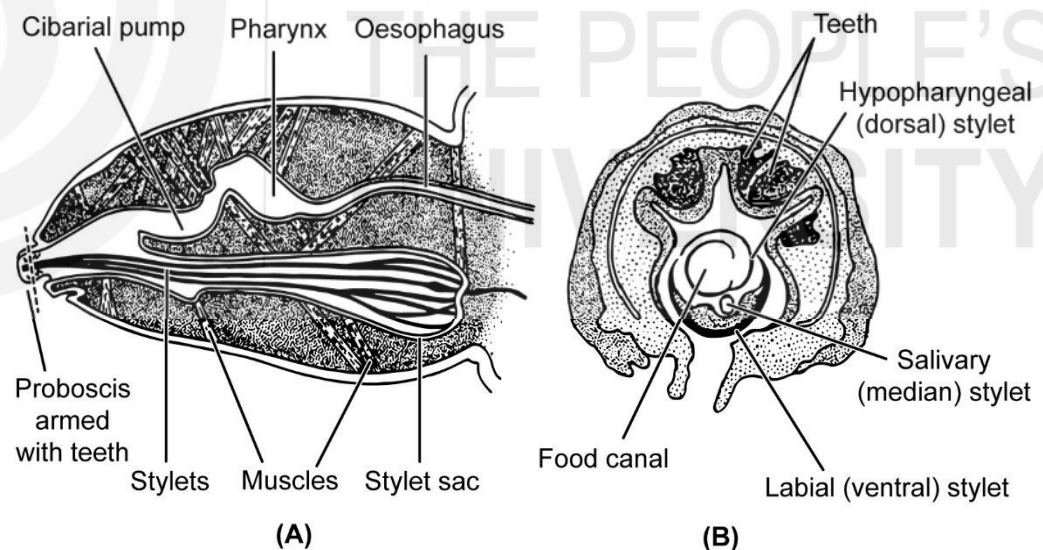


Fig. 2.10: Sucking louse. (A) Longitudinal section of head. (B) Transverse section through eversible proboscis. The plane of the transverse section is indicated by the dashed line in A (after R. E. Snodgrass, 1st ed., 1935).

Fleas

Flea has a single stylet derived from the epipharynx and laciniae of the maxillae forming two long cutting blades, which are enclosed by the labial palps. Epipharynx and laciniae form the food channel through which blood is sucked (Fig. 2.11).

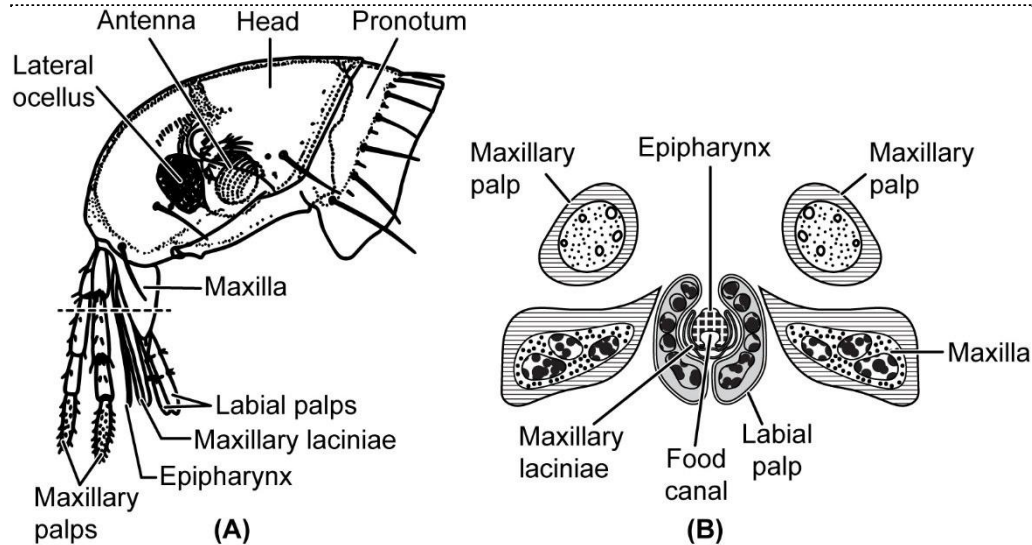


Fig. 2.11: Human flea. (A) lateral view of head (B) transverse section through mouthparts. The plane of the transverse section is indicated by the dashed line in (A). (After Snodgrass 1946; Herms & James 1961).

iv) Sponging type (House fly)

Mouth parts of house flies are adapted for sucking liquid or semiliquid food. Mouth parts consist of Labrum- Epipharynx, Maxillae, Labium and hypopharynx. Mandibles are absent, the Labium is modified and forms a long, fleshy and retractile proboscis. The Proboscis is divided into three parts: Rostrum, a haustellum and labella. The rostrum is conical in shape and proximally articulated with the head. Maxillae are reduced as maxillary palps and lie on the rostrum. The **haustellum** is a middle part of the proboscis having a mid-dorsal oral groove. Blade-like hypopharynx is located deep inside the oral groove. It has a salivary channel and covers the labrum and epipharynx groove ventrally. Labrum-epipharynx covers the oral groove dorsally. Thus labium-epipharynx and hypopharynx form the food channel. The distal part of the proboscis consists of a pair of oval-shaped fleshy labella having very fine channels called pseudotracheae. These open externally by which fluids are sucked. The pseudotracheae meet in the mouth lying between the two lobes of the labella which lead into the food canal (Fig. 2.12).

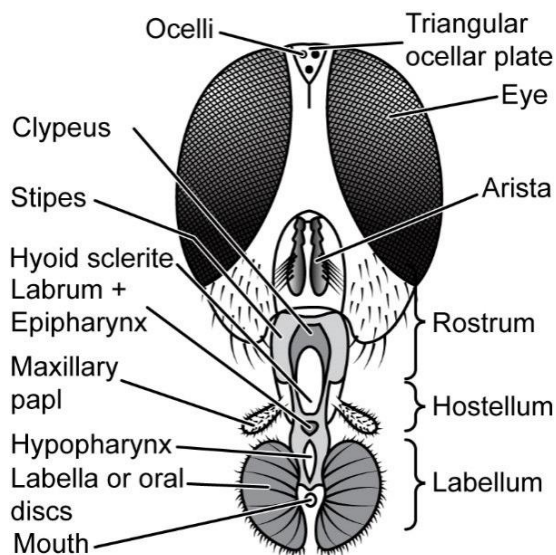


Fig. 2.12: House fly. Head and mouth parts.

v) Siphoning type

Such type of mouth parts is adapted for sucking flower nectar and fruit juices and are found in butterflies and moths. Mouth parts consist of the small labrum and coiled proboscis. Mandibles and labium are reduced. Hypopharynx and epipharynx are absent. The labrum is triangular and articulated to the clypeus. The proboscis is well developed and elongated, formed from the modified galeae of maxillae. Each galea has a lateral longitudinal groove. Both galeae are opposed to each other and form a food channel. During resting, the proboscis is coiled beneath the head, however, during the feeding, it becomes straight and placed on the food. The food is drawn up just like a capillary action (Fig. 2.13).

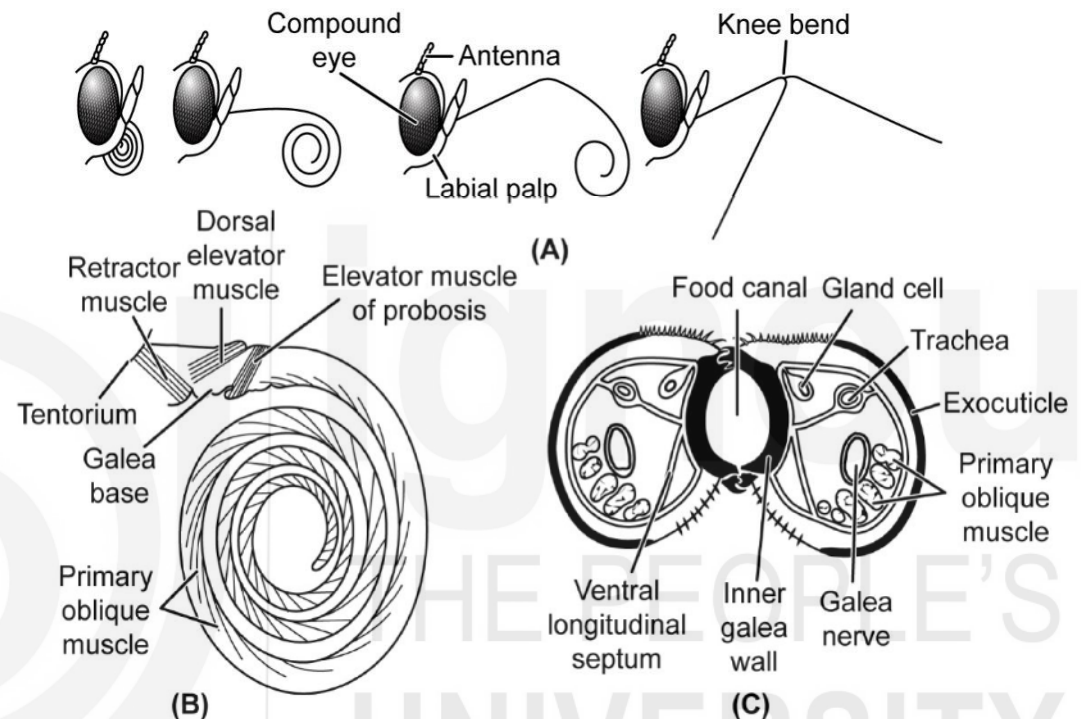


Fig. 2.13: Mouthparts of the cabbage white or cabbage butterfly, *Pieris rapae* (Lepidoptera: Pieridae.) (A) Position of the proboscis showing, from left to right, at rest, with proximal region uncoiling, with distal region uncoiling, and fully extended with tip in two of many possible different positions due to flexing at knee bend. (B) Lateral view of proboscis musculature. (C) Transverse section of the proboscis in the proximal region. (after Eastham & Eassa 1955).

2.2.4 Antenna

One pair of antennae are present in all insects except in order Protura. A typical antenna consists of a basal single-segmented scape articulated with the head, single-segmented pedicel and a flagellum which is divided into a number of similar annuli/units. The antenna is pivoted on a single point on a head capsule called as antennifer. A groove around the antenna is called an **antennal suture** which gives strength to the antenna. In Pterygota and Thysanura, each scape and pedicel are supplied with pair of muscles that play an important role in the movement of antennae. The annuli of the flagellum are without muscles and the nerve innervated is purely sensory. This type of antenna is called **annulated**. In Diplura and Collembola, scape and pedicel

have similar musculature as found in **pterygote insects**. But in the flagellum, each unit has intrinsic musculature in each annulus and is regarded as a true segment. This type of antenna is called segmented. The number of annuli/units in flagellum varies from insect to insect. Antennae are regarded as sense organs. In annulated antenna, pedicel has a sense organ, Johnston's organ which is a chordotonal organ, responding to the movement of the flagellum. Numerous sensory organs or **sensilla** occur on the various parts of the antenna, function as **chemoreceptors**, **mechanoreceptors**, **thermoreceptors**, and **hygroreceptors** (Fig. 2.14).

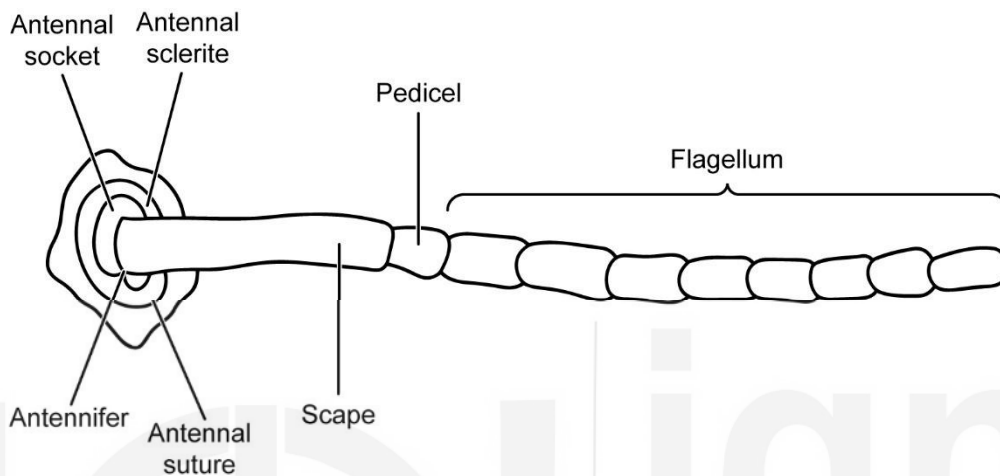


Fig. 2.14: A typical structure of antenna.

Modifications in antennae

Setaceous: Setaceous type of antenna is found in cockroaches. In this type, the width of each segment gradually decreases until the apex is reached.

Filiform: Filiform type of antennae is found in grasshoppers. All the annuli of the flagellum are of the same width and antennae appear as rod-like structures.

Moniliform: Moniliform type of antenna is found in termites. In this type, annuli of the flagellum are ovoid or bead-like.

Pectinate: This type of antenna is found in sawflies, beetles and moths. In this type annuli of the flagellum have a row of projections on one side. The antenna appears comb-like.

Serrate: Serrate type of antenna is found in pulse beetle. In this type, annuli of flagellum have tooth-like projections on one side.

Clavate: Clavate (club-like) type of antennae is found in butterflies and moths. In this type, distal annuli of the flagellum are gradually broadening and forming club-like structure.

Capitate: A capitate type of antenna is found in the Khapra beetle. In this type of antenna end (distal annuli) of the flagellum is abruptly clubbed.

Geniculate: In this type, pedicel joins flagellum in elbow joint manner and found in ants.

Lamellate: Lamellate type of antenna is found in ber beetle. In this type distal annuli are drawn out into leaf-like compact plates.

Plumose: Plumose type of antennae is found in female mosquitoes. In this type, at the bases of annuli of flagellum have thick, large and long whorl of hairs.

Pilumose: Pilumose or feathery type of antenna is found in female mosquitoes. In this type, at the bases of the annuli of flagellum have short, thin and few whorls of hair.

Flabellate: Flabellate type of antennae is found in stylops (male). In this type basal annulus is modified into fan-like structure.

Bi-pectinate: Bipectinate type of antennae is found in silk moths. In this type annuli of flagellum have long stiff projections on both sides.

Aristate: Aristate type of antennae is found in housefly. In this type, flagellum is single-segmented bearing single stiff hair called an arista. Arista has hair on both the lateral sides (Fig. 2.15).

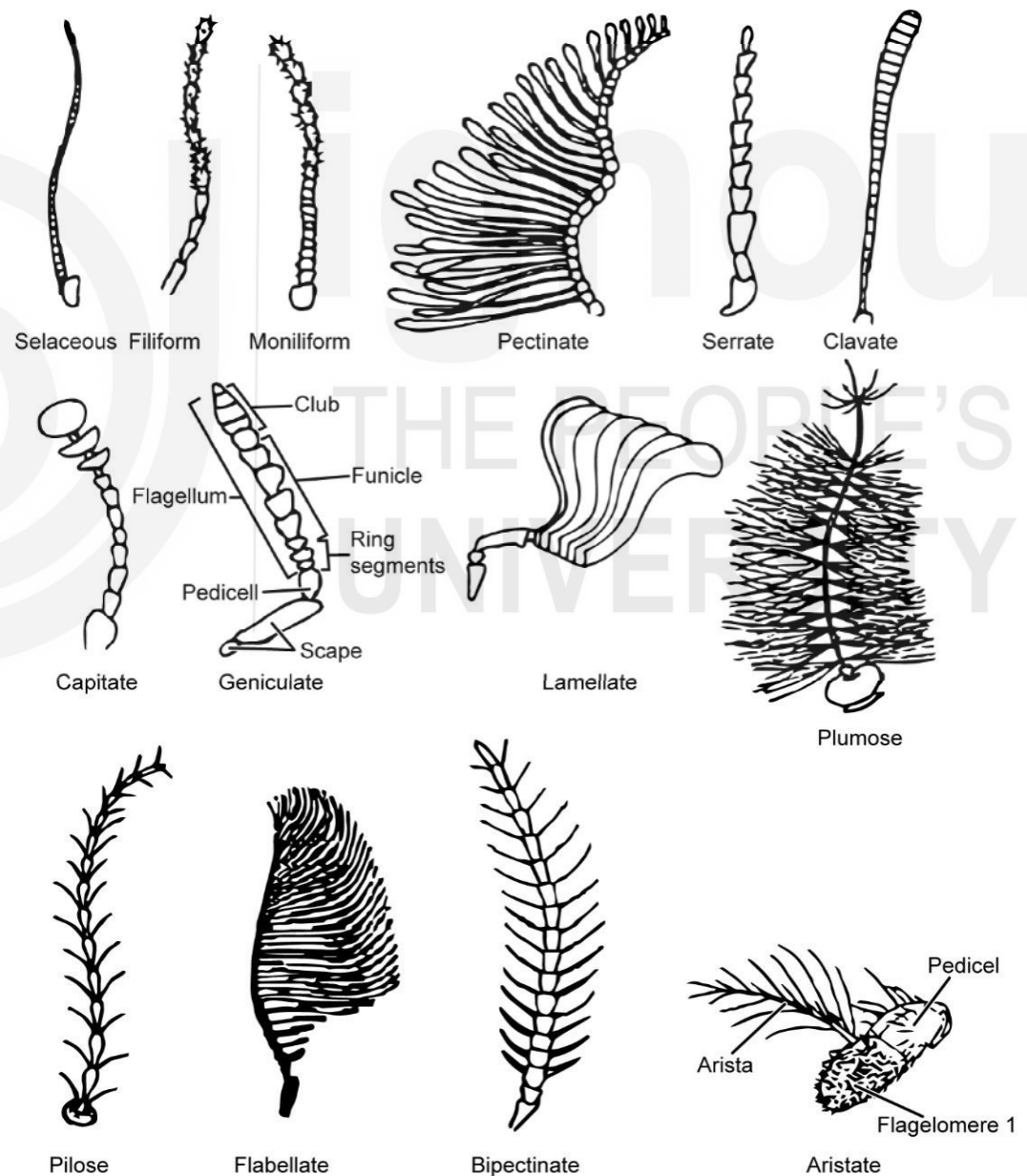


Fig. 2.15: Types of antennae. [after A. D. Imms, 1957. *A General Textbook of Entomology*, 9th ed. (revised by O. W. Richards and R. G. Davies), Methuen and Co.

2.2.5 Eyes

In insects, light is perceived by different sense organs but important ones are simple eyes or dorsal ocelli and compound eyes.

Ocelli (Simple eyes)

Simple eyes in many adult insects and some nymphs, typically, three lie in a triangle between the compound eyes on the head. The transparent area of the cuticle covering the ocellus is regarded as a lens. The epidermis beneath the lens is transparent and colourless. Beneath the epidermis, the nerve cells are grouped in two or more numbers. Distally, within each group, cells form the rhabdomeres and pigment may be present between the groups. Fibers of the cells pass out at the back of the ocellus and run at least halfway down the ocellar cells. The lens does not form the image. The ocelli are not concerned with vision. Ocelli are capable of perceiving a change in light intensity. The ocelli are not designed for high-resolution vision. Lateral ocelli also called stemmata, are found in larvae of some insect orders. The stemmata are regarded only as a visual organ (Fig. 2.16).

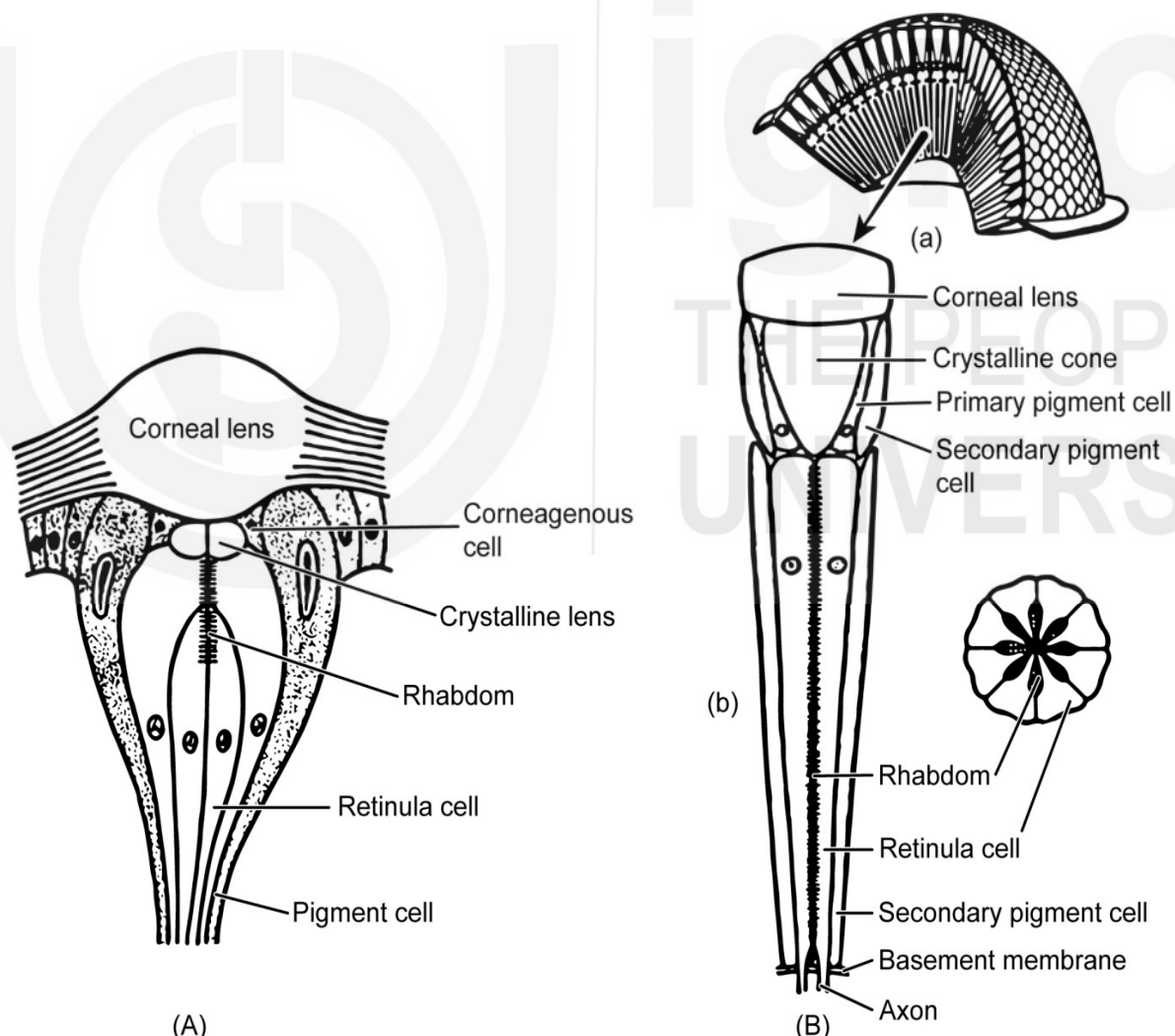


Fig. 2.16: The structure of ocelli and compound eye. (A) The schematic diagram of ocelli (B) Details of the compound eye (a) a cutaway view showing the arrangement of the ommatidia and the facets; (b) a single ommatidium with an enlargement of a transverse section. (After CSIRO 1970; Rossel 1989).

Compound eyes

Compound eyes are the organs of vision in insects and crustaceans. A compound eye is characterized by having numerous similar repeating units, simple eyes called **ommatidia**. The number of ommatidia varies from one to thousands. The ommatidia function as an independent photoreception unit with an optical system and light photoreceptor cells. Ommatidia appear as facets that are usually hexagonal in shape. Each ommatidium has its focusing system, a rigid transmitting system, a collection of light-sensitive cells and screening pigment to distinguish the units from each other. Each has its field of vision. The exposed, transparent colourless and biconvex cuticular distal end of the ommatidia called the lens (cornea) which forms the part of the focusing system. The cornea is rigid and fixed. The cornea has a fixed focal length. The cornea, like the cuticle, is epidermal in origin. Each is produced by two cells called cornea cells which also form the primary pigment cells around the ommatidium. An image formed by the compound eye in bright light is a mosaic image. Each ommatidium forms an image of a single point of light that originated from an object in the visual field. All points from all the ommatidia are combined by the brain and form a composite image made up of numerous spots of light. Compound eyes are very good for vision and detecting motion. Compound eyes are of two types: light adapted and dark adapted, which are called appositional and superpositional, respectively. The differences between these two types of eyes can be seen in Fig. 2.17.

Apposition eyes

Both screening pigments are maximally dispersed in their cells. Because of this, the ommatidia are separated from each other, and light entering the cornea remains to one ommatidium and does not stimulate the **rhabdomes** of nearby ommatidia. Apposition eyes work well in bright light. Each ommatidium is stimulated by a single point of light and sends one signal to the brain, which is registered as a single point in the mosaic image e.g., Honeybees and locusts.

Beneath the cornea is four semper cells from the crystalline cone, which is also the part of the focusing system and serves as a second lens. Immediately behind the lens, there are 6 to 8 elongated light-sensitive nerve cells called reticular cells, which form the sensory complex of ommatidium. The reticular cells form the reinula. The membranes of reticular cells having microvilli nearest the ommatidial axis are differentiated to form the rhabdomeres which run the whole length of the cells.

The microvilli of retinula cells pointed toward the central axis of the retinula are inter-coupled from rhabdome in the center of the retinula. So, the rhabdome is the mass of microvilli and has a high density of rhodopsin. The reticular cells also have screening pigments at their proximal end. Axone from each corneal cell passes out through the basement membrane at the back of the eye and synapses with optic ganglion. All the axons from all the ommatidia of the eye constitute the optic nerve which runs from the eye to the protocerebrum.

Superposition eyes

In poor light, pigment is contracted, and light passes obliquely through the eyes without being absorbed. Because of this rhabdome might receive light from a number of lenses and the image is formed as a result is called a superposition image. In this way, the more available light is used. Since little light is absorbed by the pigments. Nocturnal insects are very active, enter in dim light. Difference between apposition and superposition eyes is given in Table 2.1.

Table 2.1: Difference between apposition and superposition eyes.

Sl. No.	Apposition eyes	Superposition eyes
1.	Rhabdome of each ommatidium receives light entering its own cornea.	Rhabdome receives light from several corneas.
2.	Cone stalk is absent.	Cone stalk is present.
3.	Screening pigments are well developed and form a curtain of pigment separating adjacent ommatidia.	Screening pigments are concentrated and do not form a curtain of pigment between adjacent ommatidia.
4.	The length of the crystalline cone is approximately equal to its focal length.	The length of the crystalline cone is twice its focal length.
5.	The lower end of the cone and the upper end of the rhabdom are contiguous.	Cone and rhabdom are discontinuous and connected by a cone stalk.
6.	Reticular cells are quite long extended from the crystalline cone to the basement membrane.	Reticular cells are short and not extended upto the basement membrane and are confined to the bases of the ommatidia.
7.	A single point of light is associated with a single point in a mosaic image.	The single point of light is not associated with a single point in a mosaic image.
8.	A complete image of the visual field is formed.	A blurred image or no image is formed but the brain is aware that there is light in the environment.
9.	Such eyes are adapted to the bright light	Such eyes are adapted to the weak or dim light
10.	Diurnal insects. Example; Honey bees.	Nocturnal insects. Example; Moths.

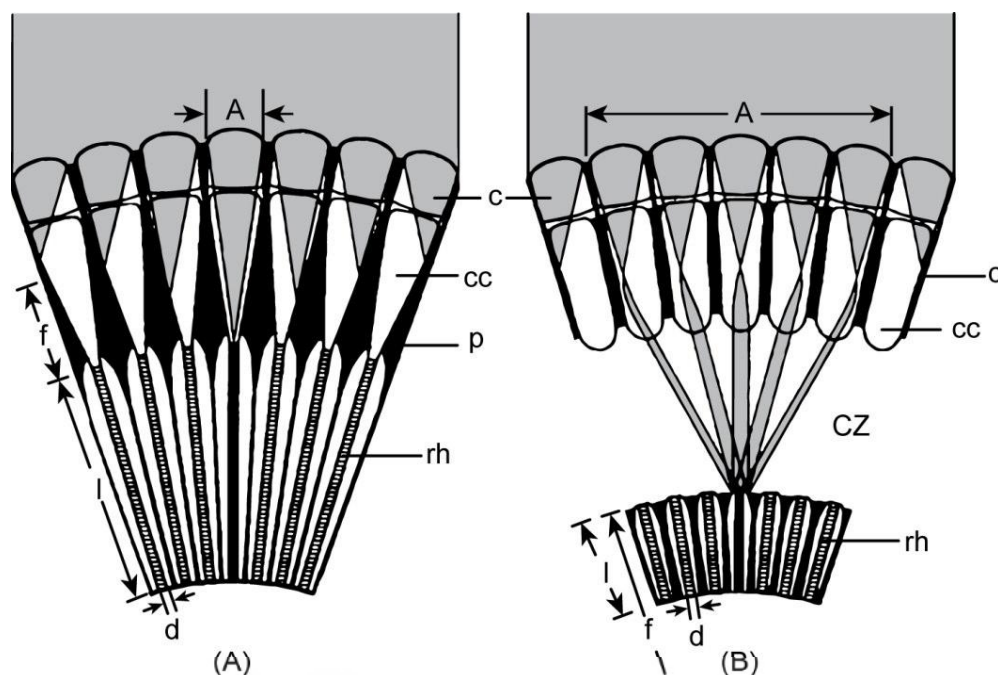


Fig. 2.17: Schematic Diagrams of the Two Main Compound-Eye Designs (A) Apposition Eye. (B) Superposition eye (of the refracting type, relying on crystalline cones with internal gradients of refractive index). The paths and fates of parallel light rays, incident on the external eye surface, are indicated in each (shaded area). For each design, the target rhabdom is shaded black. A = diameter of the aperture, f = focal length (which, in superposition eyes, is measured from the eye's center of curvature [not indicated]), c = corneal facet lens, cc = crystalline cones, p = screening pigment, rh = rhabdom, cz = clear zone, l = rhabdom length, and d = rhabdom diameter. (after Eric J. Warrant et al., 2004, current biology).

SAQ 1

1. Match Column 'A' with Column 'B'.

Column 'A'

- i) Holometabolous development
- ii) Hypognathous
- iii) Honeybee
- iv) Sponging type
- v) Lamellate type of antenna
- vi) Plumose type of antenna
- vii) Superimposition
- viii) Opisthorhynchous

Column 'B'

- a) Backwardly directed mouth parts between coxae of forelegs
- b) Housefly
- c) beetle
- d) Mosquito
- e) Nocturnal insects
- f) Chewing-lapping
- g) Mouthparts pointed downwards
- h) Change from wigless immature to matured winged insect

2.3 THORAX

The thorax is made up of three segments: Prothorax, (first segment), Mesothorax (second segment), and metathorax (third segment). In Apterygotes, all three segments are equal in size. But in winged pterygote insects, mesothorax & metathorax are enlarged in comparison to prothorax and collectively known as pterothorax having wings. Each segment of the pterothorax has one pair of wings. Thorax has three pairs of legs, one pair on each thoracic segment. Typically, legs are locomotory in function besides other functions. The second and third thoracic segments have spiracles: one pair per segment, each on the lateral side. In ametabolous insects, tergal plates are simple structures but in winged insects, tergal plate are variously modified.

Each thoracic segment has four regions: tergum (dorsal region) also called notum, two lateral regions called pleuron, and ventral region called the sternum. The pronotum (tergum of the thorax) of the prothorax is generally simple in structure and small in comparison with the other nota. But in cockroaches, the pronotum is expanded and modified as a shield, covering the head anteriorly and mesothorax posteriorly.

Each winged notum has two main divisions: anterior wing bearing alinotum and posterior phragma-bearing postnotum. Notum of pterothoracic segments is divided into three sclerites, the prescutum, scutum and scutellum. Pleuron is divided into two sclerites an anterior episternum and a posterior epimeron. Sternum is divided into four sclerites: prosternum, basisternum, sternellum and spina-sternum. The head joins the thorax by a membranous structure called the cervix (Neck). Notum, pleura, and sternum of each segment have (pteron-wing) a variety of sclerites varying greatly from order to order. The legs arise from the pleura of thoracic segments (Fig. 2.18).

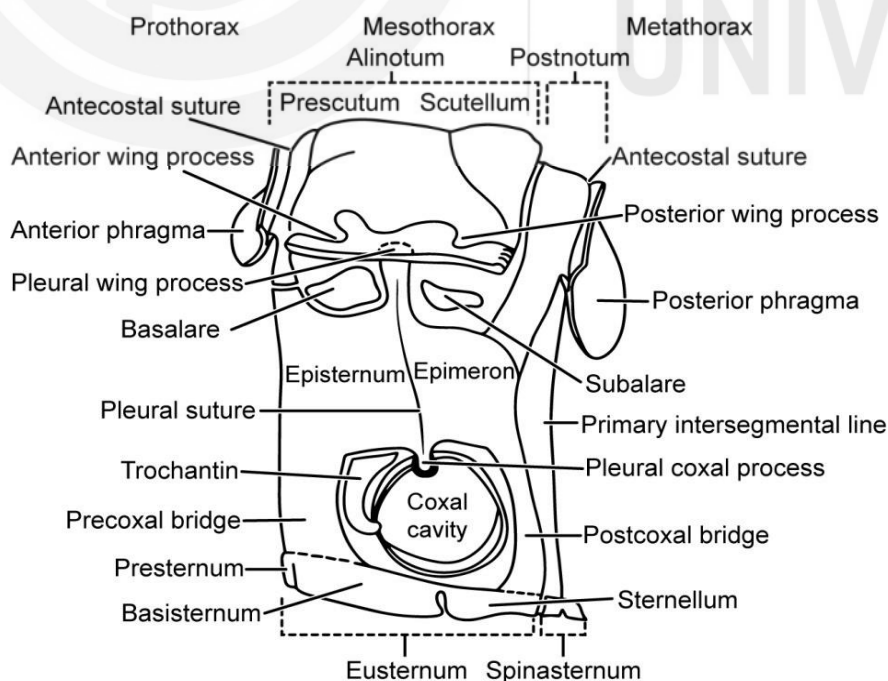


Fig. 2.18: Diagrammatic lateral view of a wing-bearing thoracic segment, showing the typical sclerites and their subdivisions. (after R. E., Snodgrass 1935).

2.3.1 Legs

Insects are hexapods having three pairs of jointed legs, articulated to the pleura of the thorax. Each leg has 6 components. In sequence from the body, they are coxa, trochanter, femur, tibia, tarsus and pretarsus. Each is single-segmented except tarsus which usually consists of 3 to 7 segments called tarsomeres.

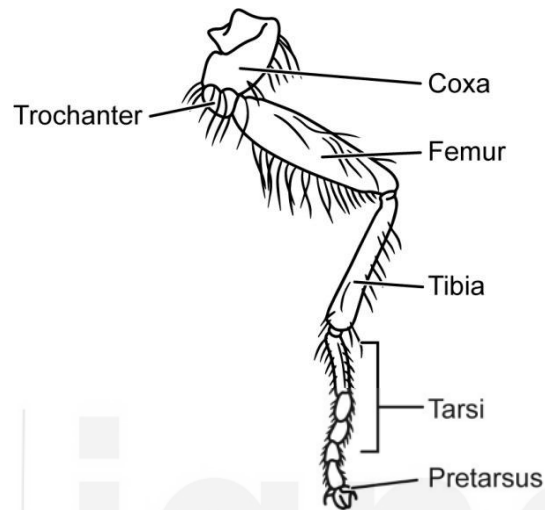


Fig. 2.19: Diagram showing the various parts of the leg of an insect.

Coxa: It is a proximal segment. It articulates with the pleuron. It is believed that it is derived from ancestral pre-coxa, but in some insects with sternite as well.

Trochanter: Trochanter has dicondylar articulation with the coxa and joint rigidly to the femur. In Odonata and some hymenopterans, there are two trochanters.

Femur: The femur is the largest stouter segment of the legs in most insects. The femur is fixed to trochanter.

Tibia: Tibia has dicondylar articulation with the femur. It is slender in comparison to the femur. On the inner edge at distal ends tibia generally has spur.

Tarsus: Ancestral tarsus was single segmented, but in modern insects, tarsi are divided generally into five subsegments (Tarsomeres). The number of tarsi plays an important role in the identification of insects.

Pre-tarsus: The distal segment of the typical insects is pretarsus. Collembola, Protura and some larvae of Endopterygota have single claw. But most insects have a pair of claws and unguis between the claws. There is a pre-tarsus supporting plate called unguitractor. Above the unguitractor, there is a forward lob-like extension from the distal end of the pre-tarsus called arolium. Underneath the pretarsus, in the members of the Diptera, there are two lobes called pulvilli, below each claw. Instead of arolium in some insects, a median bristle is present between the pulvilli called empodium. The arolium and pulvilli act as adhesive organs which help in climbing on smooth and steep surfaces. The Pulvilli in house flies play an important role in picking up the pathogens from the infected places.

Modification in legs

Insects have different types of modified legs based on adaptation to their habit and habitats.

Ambulatorial: Found in a black field cricket. The legs are long and cylindrical and adapted for walking.

Cursorial: Found in cockroaches. The legs are cylindrical and long and the coxae are well developed. Legs are adapted for fast running.

Saltatorial: Found in grasshoppers. The hind femur is greatly enlarged and contains strong muscles. Such legs are adapted for jumping.

Scansorial (clinging): Found in lice. Tibia is stout and one side bears a thumb-like process called tibial thumb. Tarsus is single-segmented and bears a curved claw called tarsal claw. They are both opposed to each other and can grasp the hair of the host or fibers of cloths. Such legs are adapted for clinging the hair fibers.

Fossorial: Found in mole cricket and are adapted for digging into the ground. The tibia and tarsus are flattened and bear blunt spines. The legs are shaped like a shovel for digging.

Raptorial: Found in mantis and are adapted for catching and holding the prey between the ventrally grooved femur and sickled-shaped tibia of forelegs.

Web-spinning: Found in *Embiomazor* (order-Embioptera). Metatarsus, the first segment of the tarsus is enlarged to accommodate the silk glands, secretion of which form the silk threads used in the spinning of the web.

Natatorial: This occurs in *Belostomaindica*. The legs are broad and flattened and marginally fringed with dense hair, forming oar-like structures. Such legs are adapted for swimming.

Scooping: This type is found in dragon and damselflies. The legs are anterior in position. The legs are long having rows of stiff bristles and are closely placed used in seizing the prey during the flight.

Bladder footed: Found in thrips. Distal tarsomeres bear vesicles to enable a firm hold on to the surface on which insects feed.

Antennae cleaning: Found in fore-legs of honey bee workers and are adapted in the cleaning of the antennae. The metatarsus has a semicircular bristle notch on its inner edge. Tibia has a spur on its inner edge. Into that notch, the base of the antenna is fitted and the opening of this notch is covered with spur. The pollen grains adhered to on the surface of antennae are cleaned in the notch when the antenna is wiped out.

Pollen brushing: Found in honey-bee workers. The surface of the metatarsi of middle legs has rows of bristles on its inner surfaces, which are adapted to brush the pollen into the heap. Middle legs also have spurs on the inner edge of the tibia. These spurs are used to remove the pollen and wax from the pollen basket and ventral surface of the abdomen, respectively.

Pollen collecting: They are also found in the hind legs of the honey bee worker. The outer surface of the tibia has a concave cavity fringed marginally with hair called a pollen basket. The cavity is used to store the pollen grain by the rows of hair pollen combs present on the inner surface of the metatarsus (Fig. 2.20).

2.3.2 Wings

Adults insects have two pairs of wings articulated to pterothorax. Insects are the only invertebrates to have the ability to fly, which has played an important part in their dispersal. Wings are the lateral cuticular projection from the pterothorax and have the lateral hollow veins through which blood flows.

There are three sclerites and two median plates at the base of each wing articulating with the thorax, which plays a role in the movement of wings during the flight and enables them to be folded back over the body when at rest. The muscles, moving the wings are directly inserted to the base of the wings or otherwise move the wings indirectly by distorting the thorax.

Each wing consists of a thin membrane supported by the veins. The membrane is formed by two layers of cuticle closely apposed. The veins are formed where two cuticles separate. The veins are connected to the hemocoel, from which hemolymph can flow into the wings. The lumen of the major veins contains nerves and tracheae. A thick cuticle around the veins provides strength and rigidity to the wing. In some insects, hair and scales are present on the wings in trichopteran and lepidopteran, respectively (Fig. 2.21).

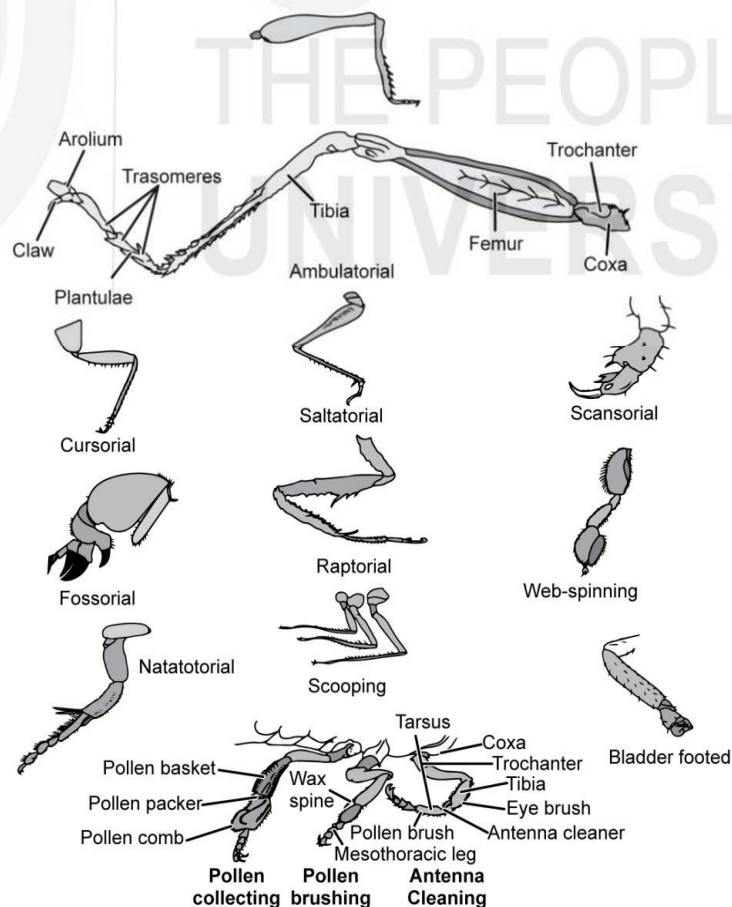


Fig. 2.20: Modification of legs in insects. (after R. F. Chapman, 4th ed., 1998. & Alka Prakash, 2001).

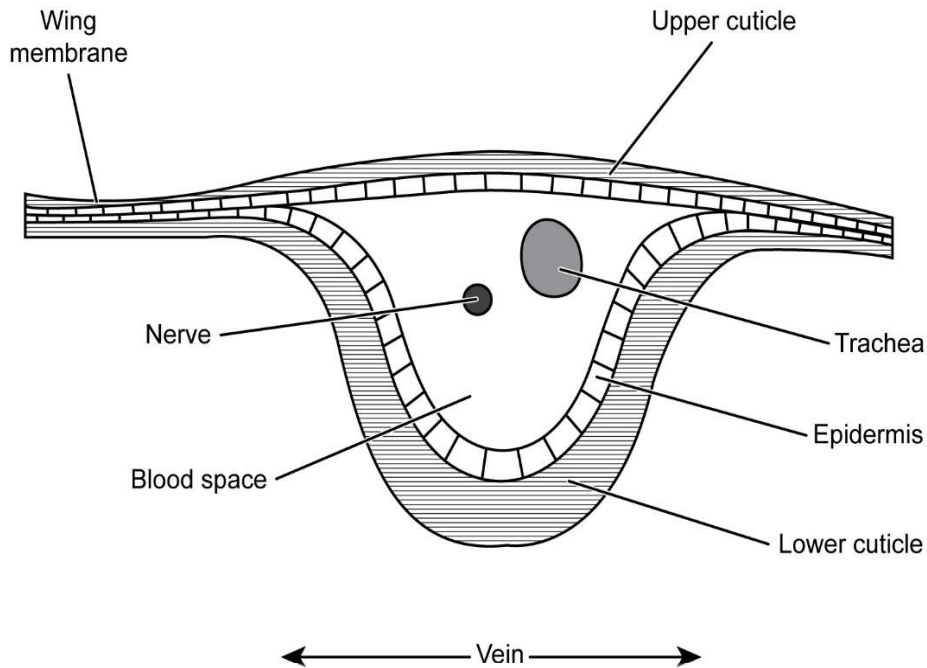


Fig. 2.21: Diagrammatic section through part of a wing including a transverse section of a vein. (after R. F. Chapman, 4th ed.,1998).

Venation

In some insects, venation may be greatly reduced as in some wasps conversely, in some insects, an increase in venation occurs by the branching of existing veins or by the development of additional veins between the original veins as in wings of grasshoppers. In dragonflies and damselflies, the wings have cross veins and form a reticulum. The archedictyon is the name given to a hypothetical scheme of wing venation proposed for the very first winged insect. According to this, there are 6-8 longitudinal veins. Veins are named according to the Comstock Needham system devised by Comstock and Needham.

Precosta (P)- Present anterior to costa.

Costa (C)- The anterior-most vein or leading marginal vein.

Sub Costa (S)- Second longitudinal and unbranched.

Radius (R)- Third longitudinal and branched vein, one to five branches reach the wing margin.

Media (M)- Fourth longitudinal and branched vein, one to four branches reach the wing margin.

Cubitus- Fifth longitudinal and branched vein, one to three branches reach the wing margin.

Anal veins- Unbranched veins behind the cubitus.

Jugal veins- Jugal lobe of the wings is often occupied by a network of irregular veins called Jugal veins.

The precosta is fused with the costa in almost all existing insects and the Jugal vein is also rarely visible (Fig. 2.22; 2.23).

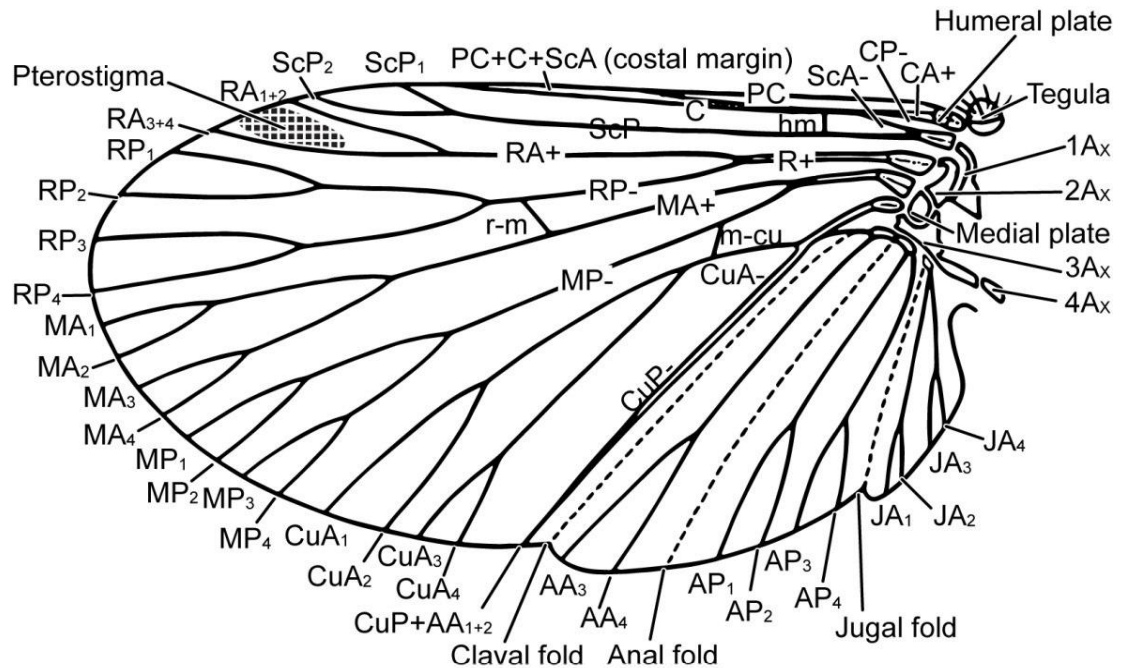


Fig. 2.22: A generalized wing of a neopteran insect (any living winged insect other than Ephemeroptera and Odonata), showing the articulation and the Kukalova-Peck nomenclatural scheme of wing venation. Notation as follows: AA, anal anterior; AP, anal posterior; Ax, axillary sclerite; C, costa anterior; CP, costa posterior; CuA, cubitus anterior; CuP, cubitus posterior; hm, humeral vein; JA, jugal anterior; MA, media anterior; m-cu, cross-vein between medial and cubital aea; MP, media posterior; PC, precosta; R, radius; RA, radius anterior; r-m, cross-vein between radial and median areas; RP, radius posterior; ScA, subcostal anterior; ScP, subcostal posterior. Branches of the anterior and posterior sector of each vein are numbered, e.g. CuA (After CSIRO 1991, adopted from P. J. Gullan, 3rd ed., 2005).

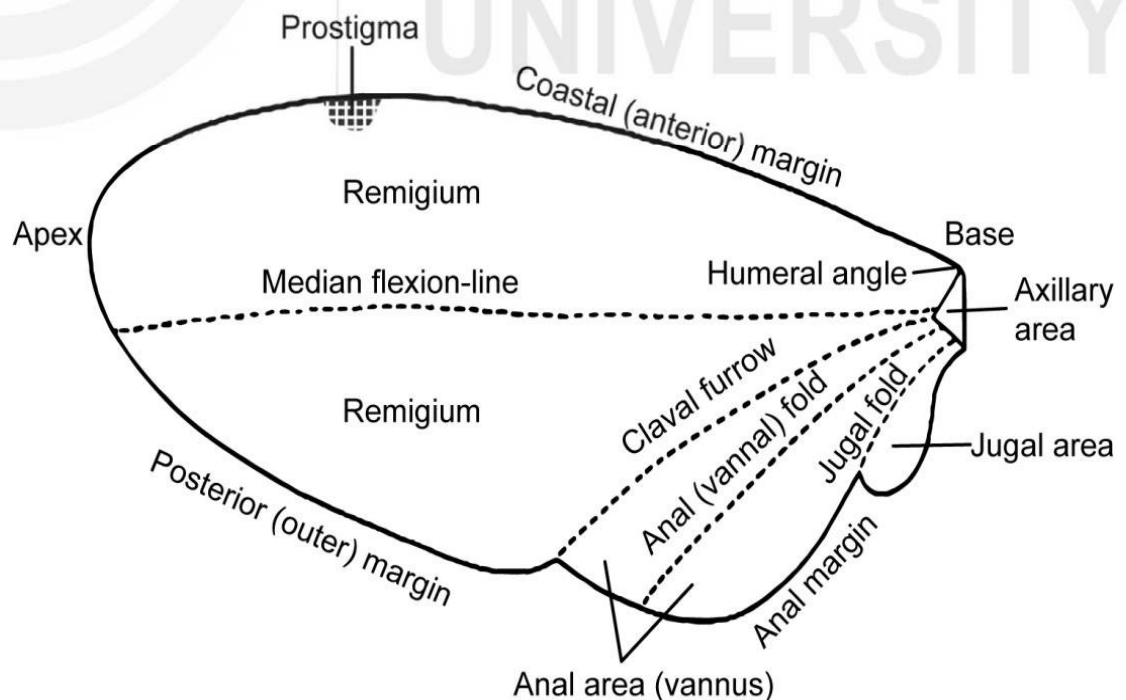


Fig. 2.23: Nomenclature for the main areas, folds, and margins of a generalized insect wing. (after P. J. Gullan, 3rd ed., 2005).

Areas of the wings

Most of the veins concentrate in an anterior area of the wing called remigium. The area posterior to remigium sometimes called Clavus, which has mostly two areas recognized as the anterior anal area (vannus) and a posterior membranous jugal area. Wing areas are subdivided by fold lines, at which the wing can be folded, and flexion lines, at which the wing bends during the flight. The claval furrow, a flexion-line, and the jugal fold, fold lines are almost constant in their position in different insects. The median flexion line and anal (vanal) fold line form variable and unsatisfactory area boundaries.

Coupling mechanism

In **order Orthoptera**, the forewing and hindwing are not linked to each other and beat completely independently of each other. Insects having two wings are more efficient in flying than four-winged insects. Lobes or spines or hooks at the base of wings play an important role in the coupling of the wings.

In honey bees, coupling of the wings is occurred by catching a fold along the posterior margin of the hindwing by the hooks or hamuli, present along the costal margin of the fore-wing called **hamulate coupling**. In many Lepidoptrans; one or more hind wing bristles (frenulum) engage with a catch or reticulum present on the underside of the forewing and wings are firmly coupled.

Frenate coupling

In some mecopterans, Lepidopteran & trichopterans, a strong jugal lobe lies beneath the coastal margin of the hind wing while coupling (**Jugal coupling**). In citrus butterfly and silkmoth, the posterior margin of the forewing and anterior margin of the hind wing overlap broadly while coupling (**amplexiform coupling**) (Fig. 2.24).

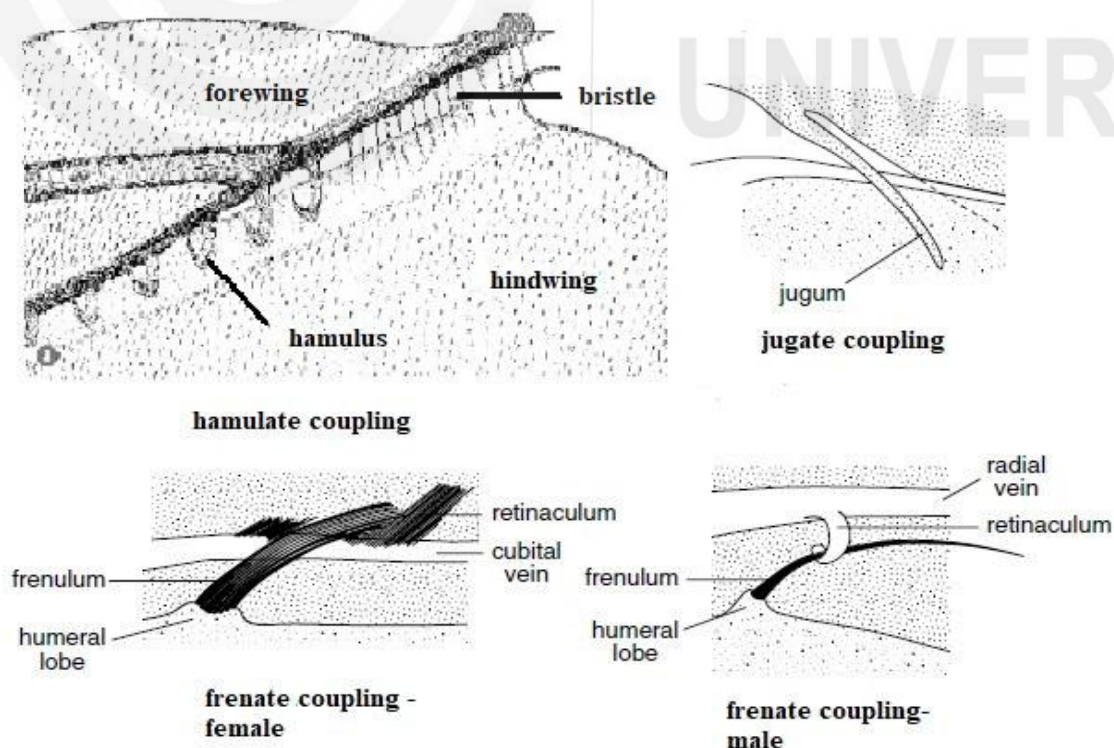


Fig. 2.24: Types of coupling mechanism in insects. (after R. F. Chapman, 4ed. 1998).

Modification in wings

Tegmina: In grasshoppers and cockroaches, thickened and leathery forewings are called tegmina. Tegmina are overlapped to each other.

Elytra: Hardened forewings of beetles are called elytra. Elytra are arched, laterally and meet at the mid-dorsal line. Elytra are not overlapped with each other.

Hemelytra: In plant bugs, the basal part of the wing is leathery and the apical part is membranous, such wings are known as hemelytra.

Halters: The hind wings in a dipteran insect are modified to form halters which act as sense organs. The halters play an important role in maintaining the balance of the body while flying. Halters consist of a basal lobe, a stalk, and an end knob. Halters are found in dipterans such as mosquitoes, housefly, etc.

Pseudohalters: Fore wings in strepsipteran insects are called pseudohalters. They do not play an important role in balancing the body while flying and do not act as a sense organ (Fig. 2.25).

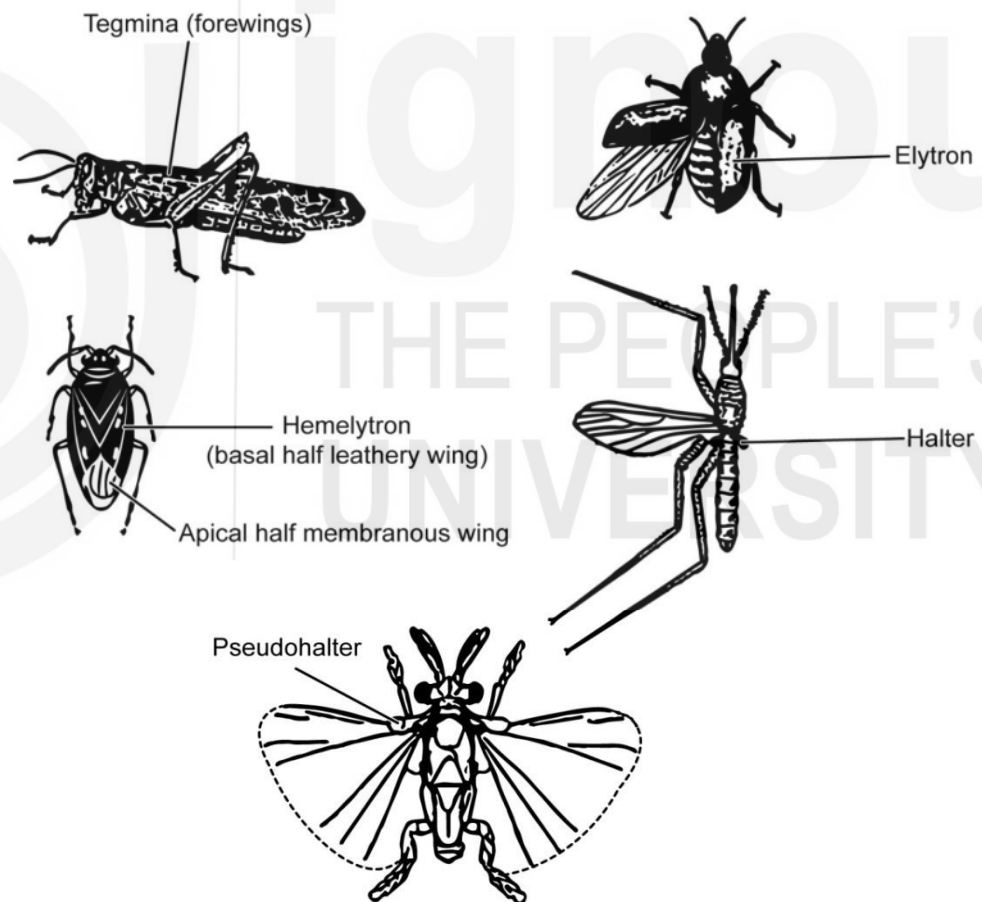


Fig. 2.25: Wing modifications in insects.

Thrips have very slender wings and have a fringe of long cilia. The veins are almost reduced. In termites and ants, reproductive castes have well-developed wings, which are shed after the nuptial flight from the sutures present at the base of each wing. In ametabolous insects, wings are absent (Apterous) primitively but in fleas and Lice, wings are absent secondarily, which evolved from winged ancestors. In termites, secondarily partial wing reduction (brachypterous) occurs.

The names of wing margins and angles are also given. Anterior, posterior, and outer edges are named as costal, anal, and apical margins, respectively. The angle between costal and apical margins is called apical angle, that between the outer and anal margin is the anal angle, while the angle at the base of the wing is called humeral angle.

The proximal region of the wing is membranous and contains three axillary sclerites, by which the wing is articulated to the thorax and allows the wings to move freely on the thorax. The first sclerite is articulated proximally the anterior notal process and distally with subcostal vein and second sclerite. The second sclerite articulates ventrally with the pleural wing process, distally with the base of radius, and connected to the third sclerite. The third sclerites articulate proximally with the posterior notal process and distally with anal veins. At the base, there are two median plates from which media and cubitus arise. At the base of the costa there is a humeral plate and proximal to it there is another plate called tegula (Fig. 2.26).

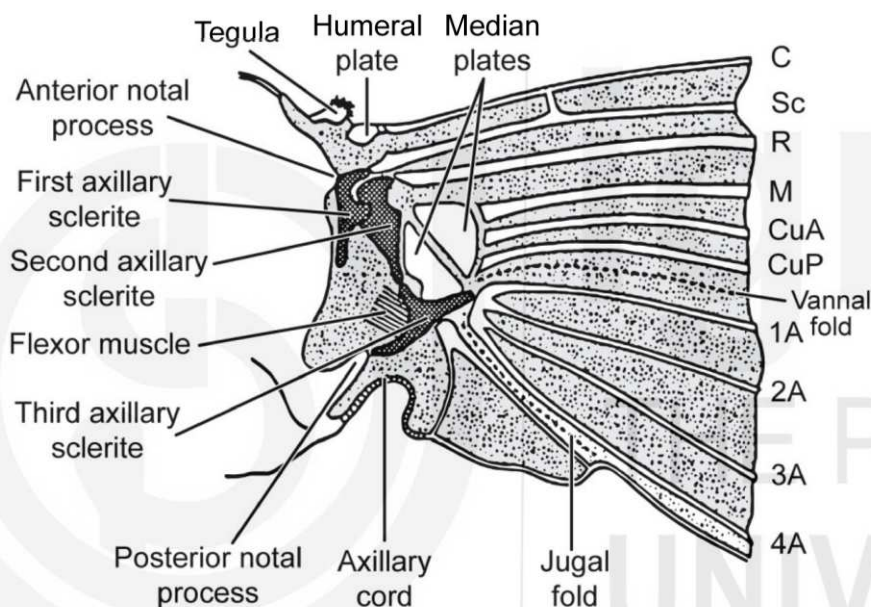


Fig. 2.26: Wing articulation with the thorax. (After Snodgrass, 1935).

SAQ 2

1. Fill in the blanks with the appropriate alternative given in the parenthesis.
 - i) (Trochanter/Tibia) has dicondylar articulation with coxa and jointed rigidly to the femur.
 - ii) In cursorial insects, legs are adapted for fast (running/jumping).
 - iii) (Scansorial/Fussorial) type of legs is found in lice.
 - iv) In (*Belostoma indica*/Embiomazot) the 1st segment of the tarsus is enlarged to accommodate the silk glands.
 - v) The hind wings in dipteran insects are modified to form halter to act as (sense/round producing) organ.

2.4 ABDOMEN

The abdomen typically consists of 6-11 segments plus one post segmental telson, which bears the anus. All the segments plus telson are visible in adult Protura and some hemimetabolous embryos. In Acrididae, all the eleven segments are visible whereas in Muscidae (house flies) 2-5 segments are visible and the remaining segments (6-9) are telescopic. The order collembola has six abdominal segments, both in adults as well as in embryos. The abdomen is marked off from the thorax in almost all insects but in Hymenoptera, the first abdominal segment is incorporated into the thorax and is called propodium. There is a constriction between the first and second abdominal segments and is called the petiole, joining the first and second abdominal segments. A typical abdominal segment has dorsal tergum; lateral, one pair pleural region each one on the side and ventral, sternum. Typically, the posterior part of each segment overlaps the anterior part of the next segment. These segments are joined to each other by the membrane, but in some, they may be fused.

Generally, the first seven abdominal segments of adults are similar in structure and are without appendages. But apterygotes and many immature aquatic insects have abdominal appendages. The more anterior segments have spiracles in the pleural membrane (Fig. 2.27).

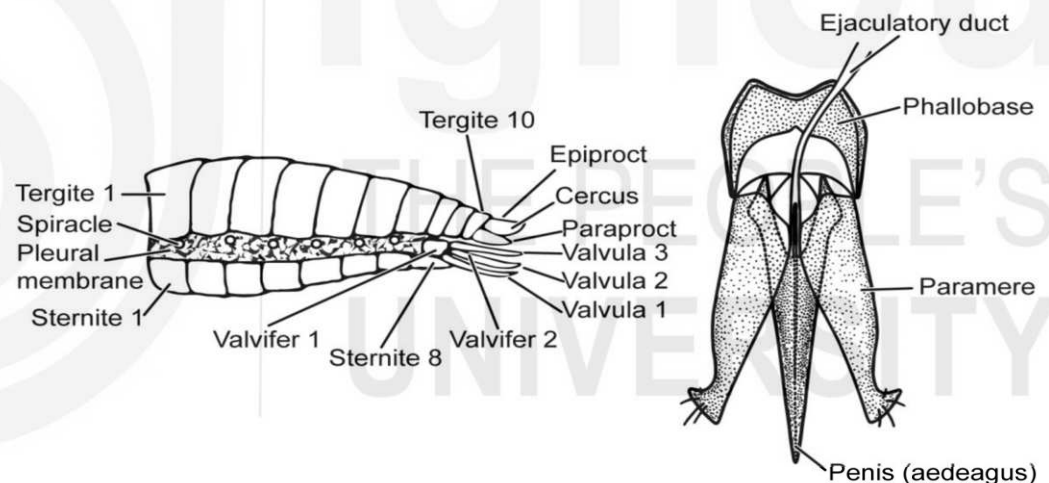


Fig. 2.27: (A) general structure of abdomen (lateral view). (B) Aedeagus of a click beetle (After Snodgrass 1957.)

The anus is located at the rear end of the abdomen. The anus is surrounded by the three protective sclerites: one dorsal epiproct and two lateral paraprocts. At the anterior margin of the paraprocts, a pair of sensory organs, the cerci are present. Just beneath the anus, genital opening lies. It is surrounded by specialized sclerites that form the external genitalia. In females: appendages of the eighth and ninth abdominal segments collectively form an egg-laying structure called an ovipositor. These appendages consist of four valvifers and six valvulae. In males: genital opening usually lies in a tube-like structure called aedeagus (penis) which thrusts into the female's body while copulation. The external genitalia may also include other structures such as claspers, styli, etc. The pincers, median caudal filaments, cornicles, abdominal prolegs, sting, abdominal gills and furcula, etc. may also be present in some insects.

SAQ 3

1. Write True (T) or False (F) against each statement after having read:

- i) All segments plus telson are not visible in adult Protura. []
- ii) The abdomen is marked off from the thorax in Hymenoptera. []
- iii) The anus is located at the rear end of the abdomen. []
- iv) External genitalia may include other structures like claspers and styli etc. []

2.5 SUMMARY

Let us summarise what we have learnt so far in this.

- Insects have an outer hard exoskeleton called cuticle which is made up mostly of chitin. The cuticle protects and supports the body and prevents the evaporation of water from the body.
- The body segments in insects are organized into three regions: head, thorax, and abdomen.
- The head is specialized for having sense organs: antennae, mouthparts and compound eyes, and food intake.
- The thorax is an anchor point to which legs and wings are articulated, and used for locomotion, and the abdomen for digestion, reproduction respiration, and excretion.
- In all insect species, the general functions of the three body parts are the same, there are differences in their basic structure, with antennae, mouthparts, legs, and wings being highly variable from order to order.

2.6 TERMINAL QUESTIONS

1. Define the following:

- (i) Tagmosis
- (ii) Moulting
- (iii) Exuviae
- (iv) Ommatidium

2. Write the exact location of the following:

- (i) Pollen collection
- (ii) Halter
- (iii) Cercus
- (iv) Tegmina

3. Distinguished the following:
 - (i) Hemimetabolism and holometabolism
 - (ii) Opisthorhynchous and hypognathous head
 - (iii) Plumose and pilose antenna
 - (iv) Tegmina and elytra
 - (v) Apposition and superposition eyes
4. Describe the detailed structure of cuticles of insects with the help of suitable well labeled diagrams.
5. Write short notes on the following:
 - (i) Mouthpart modification in insects.
 - (ii) Types of antennae in insects.
 - (iii) Leg modification in insects. Typical structure of the wing.

2.7 ANSWERS

Self Assessment Questions

1. i) h, ii) g, iii) f, iv) b, v) c, vi) d, vii) e, viii) a.
2. i) Trochantor
ii) Running
iii) Scansorial
iv) Embiama
v) Sense
3. i) F, ii) F, iii) T, iv) T

Terminal Questions

1. Refer to Sub-Section 2.2.1, 2.2.2 and 2.2.5.
2. i) Hind legs of Honey worker.
ii) Behind the fore-wings.
iii) Paraproct.
iv) Thickened and leathery forewing.
3. i) Refer to Section 2.2
ii) Refer to Sub-Section 2.2.3
iii) Refer to Sub-Section 2.2.4

- iv) Refer to Sub-Section 2.3.2
- v) Refer to Sub-Section 2.2.5
- 4. Refer to Sub-Section 2.2.2.
- 5
 - i) Refer to Sub-Section 2.2.3
 - ii) Refer to Sub-Section 2.2.4
 - iii) Refer to Sub-Section 2.3.1.
 - iv) Refer to Sub-Section 2.3.2



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INSECT LIFE PROCESSES |

Structure

3.1	Introduction	3.6	Respiration
	Objectives		Other functions of the tracheal system
3.2	Internal organization	3.7	Musculature and Locomotion
3.3	Feeding and Digestion	3.8	Nervous system and Sense Organs
	Movement of food in the gut		Nervous system
	Extra-intestinal digestion		Glial cells
	Absorption		Peripheral Nervous system
3.4	Excretion	3.9	Reproduction and Metamorphosis
	Nitrogenous Excretion	3.10	Summary
	Excretory products	3.11	Terminal questions
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3.5	Circulation of Haemolymph		
	Organs of circulatory system		
	Functions of hemocytes		
	Functions of haemolymph		

3.1 INTRODUCTION

Insects are the most diverse groups of animals on this planet, with an estimate of 5.5 million species, 80% of which remain to be discovered. However, insects adopt different life processes to establish in various environmental conditions. This is most probably due to their small size combined with short life cycle coupled with capability to disperse widely. The insects have more capabilities and capacity to build up huge population of their respective species on wide range of hosts due to well developed sensory organs, reproductive system, metamorphosis, evolutionary interactions with plants and other organisms, and their ability to utilize diverse food resource during immature and adult life that made them one of the most successful life forms to survive in adverse conditions on earth.

In Units 1 and 2 of this course, you have learnt about an insect, reason for their abundance and diversity and their external morphological structures like the different types of antennae, mouthparts, legs and wings.

Insects are important for research due to variety of reasons. Their ecosystems are extremely varied. Insects have the potential to dominate food chains and webs in terms of both volume and population. Insects can spend part or all of their life on land, in water, or in soil. They can live solitary, gregarious, subsocial, or highly social lives. Insect life cycles have evolved to allow them to survive in a variety of environments, including extremes of heat and cold, wet and dry conditions, and unpredictably changing climates.

A study of insect physiology and metamorphosis, as well as different life processes, can help in understanding a great deal about the phenomenon of life and help entomologists to control insect pests. In this Unit, we will study the insect life processes.

Objectives

After reading this unit you should be able to:

- ❖ explain the internal and external morphology,
- ❖ describe feeding and digestion,
- ❖ apprehend excretion,
- ❖ explain circulation of haemolymph,
- ❖ describe respiration,
- ❖ apprehend musculature and locomotion,
- ❖ describe nervous system and sense organs, and
- ❖ explain reproduction and metamorphosis.

3.2 INTERNAL ORGANIZATION

We can see a complicated and compact marvel of useful design after dissecting an insect. There are three primary portions of the digestive system, which comprise salivary glands and an elongated gut. Storage, biochemical breakdown, absorption, and excretion are all functions of these. Each gut segment serves multiple physiological functions, which may be reflected in local structural changes such as gut wall thickening or diverticula (extensions) from the main lumen. In males, they may be dominated by highly conspicuous accessory glands, especially as many adult insects' testes are degenerate or nonexistent because the spermatozoa are produced during the prepupal or pupal stage. At various phases of development, the body cavity of fertilised female insects can be filled with eggs, covering other internal organs.

Endoderm and ectoderm line the insect's body cavity, which is called the hemocoel (haemocoel) and filled with fluid hemolymph (haemolymph). It's not a real coelom, which is a cavity lined with mesoderm. Hemolymph (so-called

by the fact that it combines several functions of vertebrate blood (hem/haem) and lymph) bathes all internal organs, provides nutrition, eliminates metabolites, and performs immune activities. In contrast to vertebrate blood, insect haemolymph lacks respiratory pigments and so plays little or no function in gaseous exchange.

The tracheal system, a ramification of air-filled tubes (tracheae) that distributes fine branches throughout the body, performs this role in insects. Spiracles, sphincter-like structures that open through the body wall, govern the entry of gas as well as exit from the tracheae. Filamentous Malpighian tubules with free ends that are scattered throughout the hemocoel filter non-gaseous wastes from the haemolymph. Their contents are emptied into the gut, where wastes are eventually expelled via the anus after additional alteration.

The nervous system, in concert with hormones (chemical messengers), controls all motor, sensory, and physiological activities in insects. In dissected insects, the brain and ventral nerve cord are easily visible, but most endocrine and neurosecretion sites, numerous nerve fibres, muscles, and other tissues are invisible to the naked eye. The present Unit describes insect internal structures and their functions.

3.3 FEEDING AND DIGESTION

Insect adapted different type of the mouth parts according to their feeding habits such as chewing, biting and sucking. Based on specificity of plant species consumed phytophagous insects can be categorized into monophagous (feed on single plant species, e.g. *Bombyx mori* feed exclusively on mulberry), oligophagous (feed on the plants belonging to one genus of species, e.g. Cabbage butterfly larva on Brassicaceae) or polyphagous (feed on plants belonging to different families, e.g. Locust, mealybug).

Digestion can begin before the food is consumed via the ingestion or regurgitation of enzymes onto the food, or in the foregut if the insect is a sap feeder. The midgut is where the majority of the enzymes are created, hence it is where most of the digestion takes place. Mastication of food begins not only in the buccal cavity but also in the proventriculus in insects with biting and chewing mouthparts. This not only makes it easier to travel through the alimentary canal, but it also expands the surface area available for enzyme action. Digestion is accomplished through a sequence of enzymatically catalysed stages, each of which produces a simpler material until molecules of absorbable size or nature are formed.

The digestive system depends on large number of enzymes secreted by epithelial cells of its midgut lining and associated glands. The digested products are absorbed by alimentary canal through different cells present in the intestine.

Food and feeding habits bear a direct relation to the morphology and physiology of insects in which digestive system and mouth parts have undergone adaptive modification.

3.3.1 Movement of Food in the Gut

After feeding the food passes through the entire length of the alimentary canal with such a rate that the digestion and absorption take place at proper sites. The peristaltic and anti-peristaltic types of movements cause forwards and backward agitation of the food to ensure proper mixing of digestive enzymes.

3.3.2 Extra-Intestinal Digestion

Before feeding, certain insects inject saliva into their hosts, which softens the tissues as it contains enzymes that helps indigestion. Extra-intestinal (or extra-oral) digestion may account for a significant portion of whole digestion (e.g. In ant lion grub and plant bug partial digestion occurs in the host body prior to food ingestion).

3.3.3 Absorption

Many insects absorb nutrients via diffusion through the microvilli of midgut epithelial cells. The rectum is where water and ions are absorbed. Lipid absorption in cockroaches occurs through the crop. Absorption occurs through the ileum in termites and scarabaeids (White grubs). In solid feeders, the rectum absorbs water from the faeces, and the faeces are released as pellets.

Water: In the insect gut, there are two major water absorbing zones: one in the midgut, where water is absorbed from food, and the other in the rectum, where water is absorbed from faeces before they exit the body. The rectum's absorption is an essential component of the body's water regulation. The anterior midgut of most Homoptera creates a filter chamber (Fig. 3.1) that wraps around the posterior midgut and the proximal ends of the Malpighian tubules, facilitating water to pass straight from the anterior midgut to the Malpighian tubules. The food is concentrated this way, and the haemolymph is not diluted.

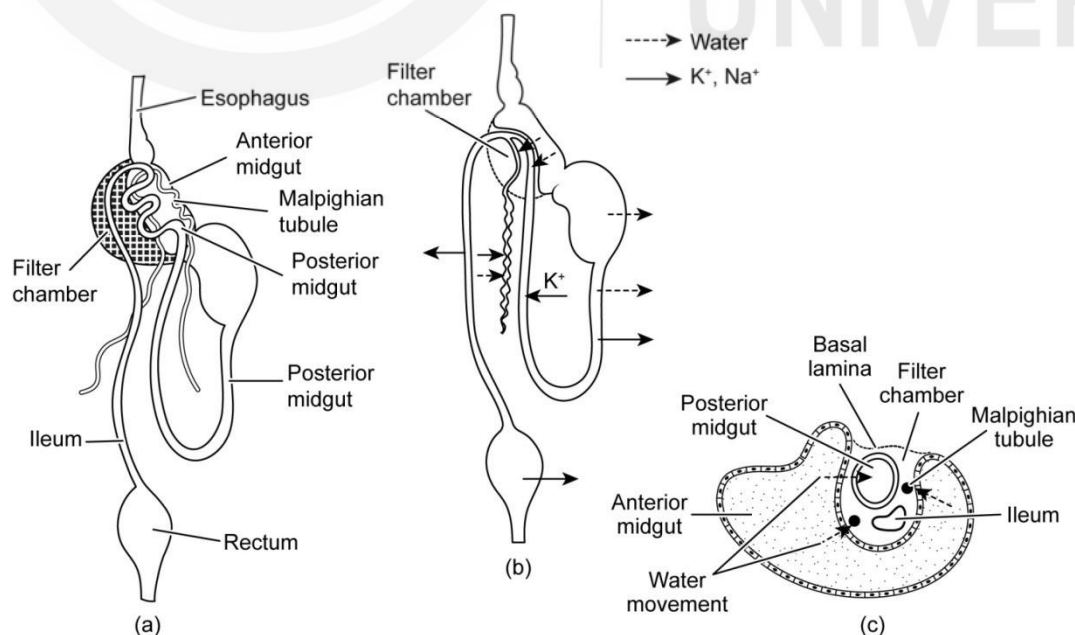


Fig. 3.1: Water absorption from the midgut of a cercopid (a) General arrangement of the gut showing the filter chamber (b) Postulated movement of salts and water across the wall of the gut (c) Transverse section of the filter chamber.

Efficiency of Digestion and Absorption

The efficiency with which food is digested and absorbed is usually expressed as:

Approximate digestibility (AD) = $[(\text{Weight of food ingested} - \text{weight of feces}) \times 100 / \text{Weight of food ingested}]$. For phytophagous insects, AD is often in the range 40–50%.

SAQ 1

1. Fill in the blanks:

- a) Insects that feed on single plant species are called _____.
- b) Insects that feed on one genus of plant species are called _____.
- c) Insects that feed on plants belonging to different families are called _____.

3.4 EXCRETION

The process of the elimination of waste products is known as excretion. The eliminated substances of insects might be solid, liquid or gaseous forms. The principal gas expelled is carbon dioxide and the liquid is water. Solid excreta of nitrogenous and non-nitrogenous salts are given off mostly in crystalline form or aqueous solutions. **Important excretory organs are Malpighian tubules (Fig. 3.1), integument, tracheal system, wall of the alimentary canal, nephrocytes, fat bodies, Oenocytes and cephalic glands.**

The Malpighian tubules make the main urine of insects. It is made up of branching tubules that arise from the alimentary canal and absorb solutes, water, and wastes from the haemolymph in the nearby area. The preservation of a consistent level of salts, water, and osmotic pressure in the haemolymph, as well as the elimination of toxic nitrogenous wastes produced from amino acid metabolism and other harmful substances acquired or consumed from the environment, are all part of homeostasis. Homeostasis is often controlled by the excretory system. Outside the gut, epidermal cells in aquatic insects may also help to regulate the insect's ion homeostasis.

3.4.1 Nitrogenous Excretion

Terrestrial insects excrete waste products such as uric acid or specific salts of uric acid known as urates, which are water-insoluble and require less water to remove waste. Uricotelism is the name for this sort of excrement. Ammonia is the excretion of aquatic insects, and it is easily soluble, requiring additional water for waste clearance. Ammonotelism is the term for this type of excretion.

3.4.2 Excretory Products

Protein and purine metabolism produce ammonia as the principal nitrogenous end product. Since it is highly poisonous, it must either be excreted quickly or converted into a less hazardous compound. As a result, insects with a plentiful supply of water, such as those living in fresh water, and others, such as blowfly larvae, that dwell in excessively damp environments, excrete large amounts of ammonia (*Lucilia* larva).

Water conservation is important in most terrestrial insects, and excretion losses must be kept to a minimum. As a result, it is commonly assumed that terrestrial insects create less waste than ammonia, mainly in the form of uric acid. Uric acid is insoluble and retained for a longer period.

3.4.3 Excretion and Osmoregulation

Insect excrement contains both undigested food and metabolic excretions, whether in liquid form or solid pellets. By flushing their anus with water, aquatic insects defecate dilute faeces directly into the water. The majority of terrestrial insects have to save water. This requires effective waste removal in a concentrated or even dry state while avoiding nitrogen's harmful effect. Both terrestrial and aquatic insects must conserve ions like sodium (Na^+), potassium (K^+), and chloride (Cl^-) that may be scarce in their feed or lost to water through diffusion. In freshwater insects, however, the composition of the haemolymph is regulated by the excretory system and specific cells in response to ion loss to the surrounding water. Chloride cells are a type of unique cell that can be found in the hindgut and can absorb inorganic ions from the dilute solutions (e.g. damselflies and Nais of dragonflies).

SAQ 2

1. Fill in the blanks:
 - a) _____ is the main organ involved in making urine of insects.
 - b) In aquatic insects, _____ cells help to regulate the insects ion homeostasis.
 - c) Terrestrial insects excrete waste products commonly called as _____.
 - d) Protein and purine metabolism produce _____ as the principal nitrogenous end product.

3.5 CIRCULATION OF HAEMOLYMPH

Many organisms, including vertebrates, circulation of blood occurs via vessels (veins, arteries, and capillaries), called a closed system. Insects have an open system of circulation to circulate haemolymph through the open body cavity, the hemocoel. In an open system, haemolymph flow freely within body cavities where it makes direct contact with all internal tissues and organs.

Haemolymph comprises liquid plasma, and about 10 percent of its volume is made up of blood cells, or hemocytes. The pericardial cavity, which surrounds the dorsal aorta, the perivisceral cavity, which surrounds the alimentary canal, and the perineural cavity, which surrounds the nerve cord, are the three principal compartments of the thoraco abdominal body cavity (**Fig.3.2**).

3.5.1 Organs of Circulatory System

1. Dorsal Vessel/ Dorsal Aorta/Heart Dorsal Aorta

The dorsal vessel is the main organ of circulation in insects. It is a longitudinal tube that lies at the top of the hemocoel and extends from the back of the abdomen to the head and constitutes a major structural component of an insect's circulatory system. To ensure unidirectional haemolymph flow, the dorsal aorta is further divided and often restricted into 5 to 6 heart chambers separated by valves (ostia).

2. Ostia

The heart is a chambered organ, drawing blood in through openings in each chamber, called ostia and contracting to pump it forward to the aorta. The aorta is usually a simple tube that carries blood forward and dump it into the head capsule. These ostia open during each diastolic phase/relaxation to enable haemolymph inflow from the body cavity, then close during cardiac contraction, allowing haemolymph to flow forward.

3. Alary/ Aliform Muscles

The heart of most insects is bordered below by bands of wing-shaped muscles known as alary muscles. These connect the heart to lateral portion of the terga. These muscles form an almost complete known as dorsal diaphragm between the heart and the body cavity and are associated with peristaltic contractions which force the haemolymph forward from one chamber to another.

4. Accessory Pulsatile Organs

In some insects, accessory pulsating organs exist in the thorax and lower body cavity which are concerned with circulation of haemolymph into legs/ wings/ antenna. Pulsatile organs can be found on the base of the wings, appendages, or antennae of some insects, such as grasshoppers and cockroaches. Although pulsatile organs do not contract regularly, they do drive haemolymph out into the extremities.

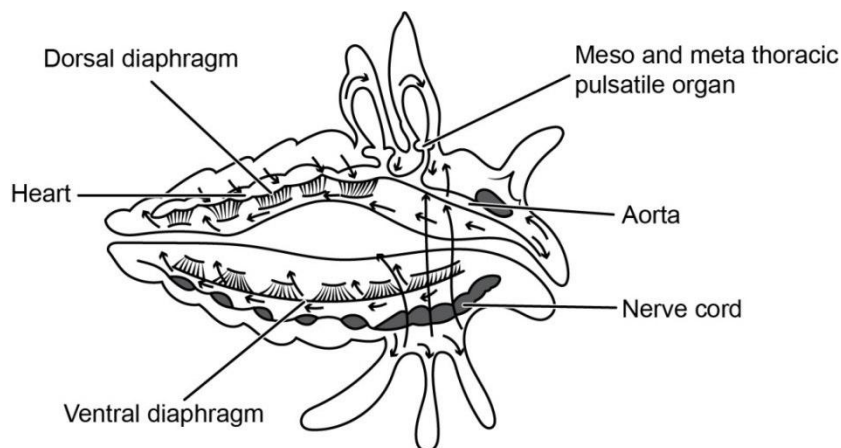


Fig. 3.2: Direction of circulation of haemolymph in L.S. of an insect.

3.5.2 Functions of Hemocytes

Hemocytes have a wide range of functions. Wound repair and protection against parasites and pathogens are two of the most evident, but they also play a part in many other areas of the insect's normal functioning. A haemolymph clot forms below the wound if the epidermis is injured. Both hemocytes and plasma components are involved in the formation of the clot. Granulocytes secrete a substance that produces a gel.

3.5.3 Functions of Haemolymph

1. Internal cells are kept wet by haemolymph, which also facilitates the movement of internal organs.
2. The main function of haemolymph is to transport nutrients from the digestive system and carries them through the body cavity, feeding tissues and organs.
3. The water levels in the tissues are maintained by haemolymph, which serves as a reservoir of water. Body water is obtained via food, however many insects will suck fluid/sap in dire circumstances.
4. Hydrostatic pressure developed due to haemolymph pumping that is useful in the following processes.
 - (a) Ecdysis (moulting)
 - (b) Wing expansion in adults,
 - (c) Ecdysis in dipteran,
 - (d) Eversion of osmeteria in papilionid larvae,
 - (e) Eversion of mask in naiad of dragonfly,
 - (f) Maintenance of body shape in soft bodied caterpillars.
5. It aids phagocytosis, encapsulation, detoxification, coagulation, and wound healing in the cellular response. Invading bacteria are also killed by enzymes such as lysozymes.
6. Haemolymph movement also has a role in thermoregulation in the circulatory system to regulate the body heat.

SAQ 3

1. Fill in the blanks:
 - a) Insects have an open system of circulation to circulate _____.
 - b) The heart is a chambered organ, drawing blood in through openings in each chamber, called _____.
 - c) _____ have a role in wound repair and protection against parasites and pathogens.

3.6 RESPIRATION

Free energy is required to perform life functions in insects, and it is derived mostly from the oxidation of nutrients. Respiration provides the necessary supply of oxygen for this purpose. Insects, like aerobic animals, must collect oxygen from their surroundings and expel carbon dioxide produced by their cells. In insects, the primary mode of respiration is the diffusion of atmospheric gases directly across membranes into the cells. Insects have special openings called spiracles present on the sides of the thorax and abdomen. These spiracles open into tracheal trunks, large tracheae on each side that run the length of the body and connect the grouped tracheae on each segment. The trachea is a series of gas-filled tubes that provide surface area for gaseous exchange and allow oxygen to enter the tracheal system from the air. The trachea runs the length of the hemocoel and is especially visible around internal organs. The trachea is a tube that transports oxygen to interior organs and tissues.

The tracheal trunk branches frequently, forming a complex network of tracheal tubes that subdivide into smaller and smaller diameters and reach each trachea as tracheoles. Flight muscles, ovaries, fat body, malpighian tubules, rectal papilla, and gut epithelium all have a lot of tracheoles, which are 0.2- 1 mm in diameter and found in organs with a lot of oxygen demand (**Fig. 3.3**).

In some areas, however, there is no trachea, and the tube swell to form an air sac, which is capable of storing/conserving air. Where the trachea is lacking, flying insects have air sacs as a distinguishing feature. The air sac expands the volume of air, which serves a variety of purposes including preventing collapse, preserving heat, and forming the tympanic chamber.

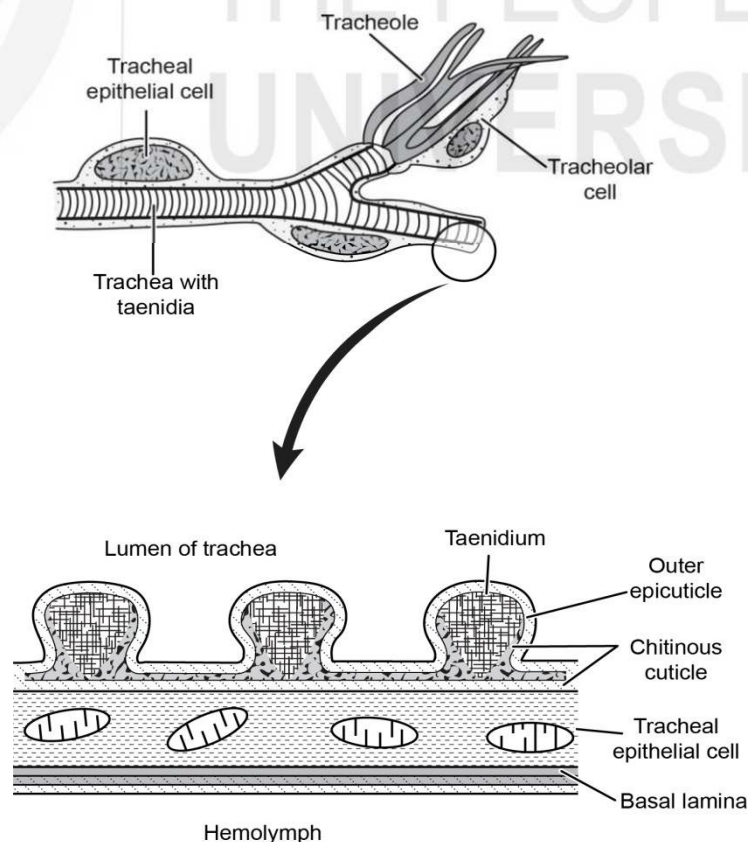


Fig. 3.3: Tracheal System showing trachea and tracheoles.

On the basis of spiracles Tracheal system can be divided into **Open tracheal system and closed tracheal system**. In open tracheal system spiracles are present.

Closed tracheal system: In some aquatic and many endoparasitic larvae spiracles are absent and the tracheae divide peripherally to form a network. This covers the body surface, allowing cutaneous gas exchange (e.g. Gills: tracheated thin outgrowth of body wall). Gills may be of the following types: Lamellate gills - mayfly naiad; Filamentous gills - damselfly naiad; Rectal gills - dragonfly naiad

3.6.1 Other Functions of the Tracheal System

Apart from gaseous exchange, the tracheal system has a number of other functions. In aquatic insects, airsacs provide buoyancy by lowering the insect's specific gravity. As airsacs are collapsible, they allow for the expansion of organs within the body without causing significant changes in body shape. As a result of feeding, the airsacs also allow for variations in stomach volume. In several insects, the tracheal system plays an important role in haemolymph circulation. When an insect inflates itself after a moult, expansion of the tracheal system may help. Tracheae and tracheolar cells have a general function of acting as connective tissue, holding other organs together.

SAQ 4

1. Fill in the blanks:
 - a) The _____ is a series of gas-filled tubes that provide surface area for gaseous exchange and allow oxygen to enter the tracheal system from the air.
 - b) Flying insects have _____ as a distinguishing feature that expands the volume of air, and helps preventing collapse, preserving heat, and forming the tympanic chamber.
 - c) Tracheal system can be divided into open and closed tracheal system on the basis of _____.

3.7 MUSCULATURE AND LOCOMOTION

The movement of the insect body and its appendages is produced by an intricate system of musculature. The coordinated movement of muscles and appendages is critical to important activities such as feeding, walking, jumping, and flying. Each muscle is made up of long fibres, or multinucleate cells, that run the length of the muscle. Myofibrils, which are embedded in the cytoplasm (sarcoplasm) and stretch continuously from one end of the fibre to the other, are characteristic of these muscle fibres. These fibrils are long organized in serial arrays of contractile units known as sarcomeres. Each sarcomere is composed of interdigitated molecular filaments, consisting mainly of two proteins: Myosin and Actin, which through their cyclical, ATP-dependent interactions generate the contractile forces and movements that shorten each sarcomere and the overall myofibril, producing muscle contractions.

Walking and running

Mobility is a trait shared by all animals at some point in their lives. Mobility is a trait shared by all animals at some point in their lives. They must move in order to find food and a mate. Insects' success as terrestrial animals is due to their high degree of mobility which stems from their ability to fly, but smaller movements such as walking or swimming are also crucial. The majority of insects walk or run across the ground's surface. The legs move in a series of sequences that vary in pace in such a way that stability is usually maintained. Central mechanisms are involved in the coordination of these movements, but segmental reflexes are also significant.

Jumping

To push themselves into the air, most jumping insects use their hindlegs and, in some cases, their middle legs. Catapult mechanisms are vital to most proficient jumping insects, such as Diptera larvae (fruit fly larvae), Locusts, and Grasshoppers, since they allow gradual muscular contractions to build up and store elastic energy.

Crawling

Many holometabolous insects' larvae move by changing the shape of their bodies. Crawling is a term used to describe this style of mobility. The cuticle is fragile and flexible in most crawling forms, such as Ants and Bruchids, and does not provide a suitable skeleton on which the muscles may function. Instead, the body's haemolymph serves as a hydrostatic skeleton.

Movement due to elasticity: The ability to store elastic energy and then release it at rapid rates is a crucial component of most insects' flying mechanisms. Energy is expended at the start of a wing stroke (up or down) to overcome the wing's inertia, whereas at the end of a stroke, the wing has momentum and must be stopped. The energy gained from this momentum is stored by insects in elastic structures, which can be found in the cuticle or in the flying muscles themselves. On the return stroke, this energy is utilised.

SAQ 5

1. Fill in the blanks:
 - a) _____ are embedded in the cytoplasm (sarcoplasm) and stretch continuously from one end of the fibre to the other, are characteristic of these muscle fibres.
 - b) Each sarcomere is composed of interdigitated molecular filaments, consisting mainly of two proteins called _____ and _____.
 - c) _____ mechanisms are vital to most proficient jumping insects.
 - d) The haemolymph serves as a _____ in the insects that lacks suitable skeleton on which muscles may function.

3.8 NERVOUS SYSTEM AND SENSORY ORGANS

3.8.1 Nervous System

The central nervous system is ultimately responsible for producing behavior response in response to the external stimuli. It synthesizes inputs from arrays of sensory neurons and produces sophisticated representations of the outside environment and the internal state of the insect. It is responsible for integration of different sensory inputs and organization for appropriate behavioral responses. Both nerve cells and the supporting glial cells, are the basic cellular components of the nervous system.

The nerve cells or neuron consists of a cell body containing the nucleus from which one or more long cytoplasmic projections extend to make contact with other neurons or with effector organs. Neurons typically have distinct regions called dendrites, which are specialized for the reception of incoming signals, and a long process called an axon, which conducts signals over long distances and which terminates in regions for the passing on of signals to other neurons or effectors. But the greater part of the nerve cells and their processes are massed in a series of segmental ganglia, which are united by longitudinal connectives, which constitute the central nervous system. Mostly all insect central nervous system neurons are, monopolar, having only a single projection from the soma (**Fig 3.4**).

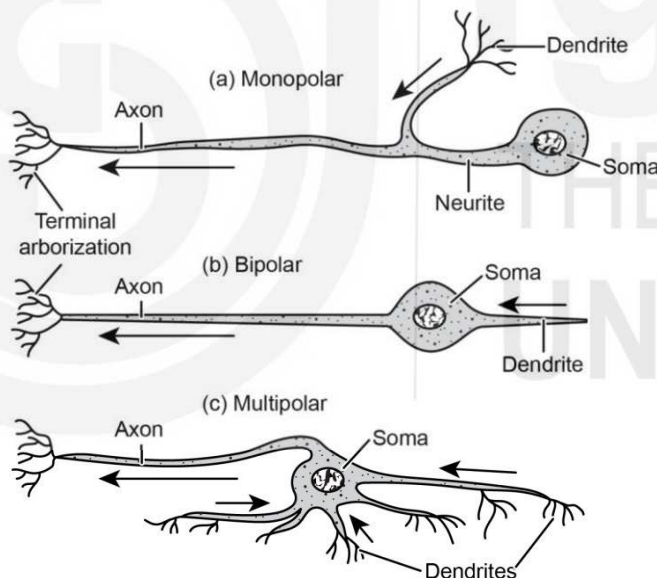


Fig. 3.4: Neurons: Diagrammatic representation of basic types of neuron.

Synapses are the places where neurons receive information from or transmit it to other cells. At most synapses, where a chemical messenger is used to transmit information from one cell to another, the plasma membranes of the two cells are parallel and close together, separated by a 20–25 nm gap known as the synaptic cleft.

3.8.2 Glial Cells

Glial cells are more abundant than neurons in the central nervous system. They are tightly connected with the somata, while others are found near the neuropile's surface, with processes reaching inward to invest the axons and dendrites. Glial cells have a large glycogen reserve and transport nutrients to

the neurons. Finger-like inpushings into the neuronal somata enable nutrition transfer. They are far more plentiful in neurons with big somata. Glial cells play a crucial role in the formation and, possibly, repair of the central nervous system.

Insect nervous system can be divided into three major parts : 1) The central nervous system 2) The visceral (sympathetic or stomatogastric) nervous system and 3) The peripheral nervous system.

The brain and a ventral nerve cord with segmental ganglia connected by lateral and longitudinal connectives are the primary elements of the central nervous system (CNS). During development, the merger of three of the most anterior paired segmental ganglia results in the construction of the brain, which can be separated into three distinct lobes: protocerebrum, deutocerebrum, and tritocerebrum. The optic lobes, ocellar centres, central body, protocerebral bridge, pars intercerebralis, and corpora pedunculata are all innervated by the protocerebrum, which is the largest and most complex region of the brain. The antennae are innervated by the deutocerebrum, which is located behind the protocerebrum. The labrum is innervated by the tritocerebrum, which is a bilobed structure (Fig 3.5).

Visceral Nervous system: The visceral nervous system is in charge of some of the gut's involuntary actions as well as the dorsal blood vessel. It is made up of three separate subsystems: stomatogastric (stomodaeal), ventral visceral and caudal visceral nervous systems.

3.8.3 Peripheral Nervous System

The peripheral nervous system is made up of all the nerves that emerge from the ganglia of the central and visceral nervous systems. The sensilla are connected with the dendrites of sensory neurons within these nerves, but the axons normally synapse with neurons inside a ganglion of the CNS. Motor fibres are found in nerves.

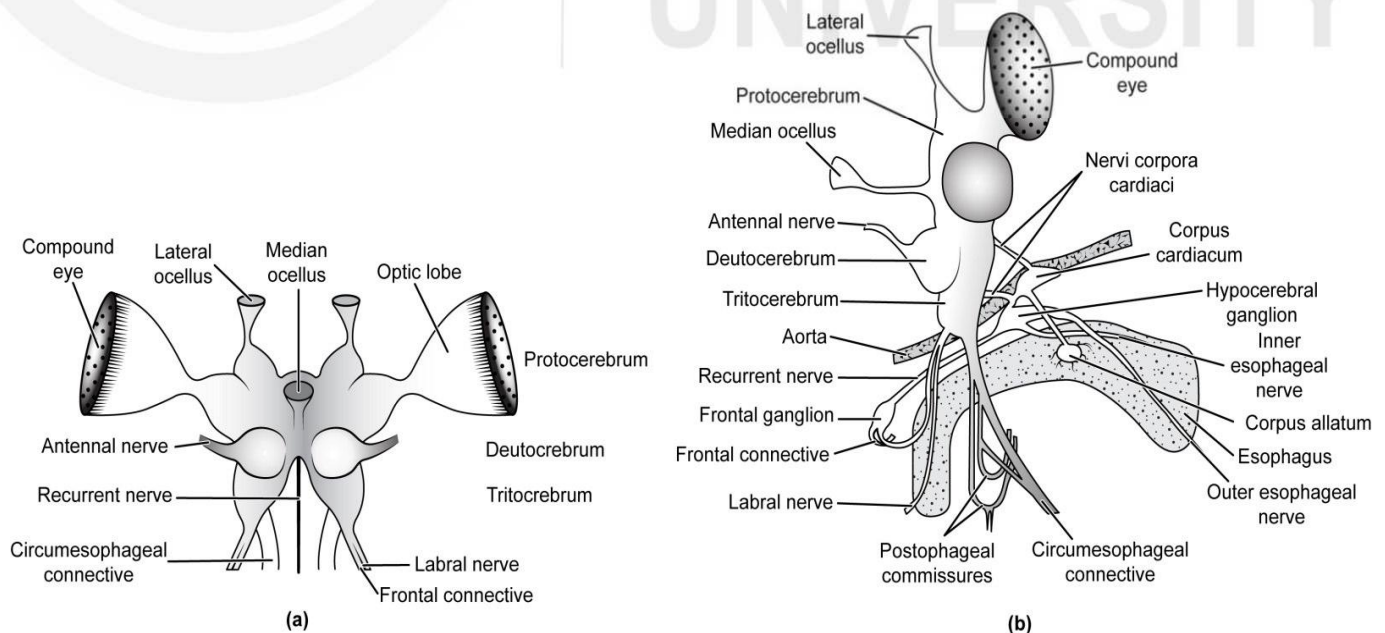


Fig. 3.5: Brain. Diagrammatic representations (Locusta) (after Albrecht, 1953).

(a) Anterior view; (b) lateral view, which also shows the major ganglia of the stomodeal nervous system.

i) Sense organs

Sensilla are the organs associated with sensory perception and develop from epidermal cells that detect the mechanical forces. The different types of sense organs are: **mechanoreceptors, auditory receptors, chemoreceptors, thermo receptors and photo receptors.**

Auditory receptors

These receptors detect sound waves and include the following types:

- a) Delicate tactile hairs: Present in plumose antenna of male mosquito.
- b) Tympanum: The tympanum is a membrane that spans the tympanic cavity and responds to noises that are produced at a distance and conveyed by airborne vibration. The chordotonal organs are related to the tympanal membranes, which improve sound reception.

ii) Stretch Receptors

Stretch receptors vary from other insect's mechanoreceptors in consisting of a multipolar neuron with free nerve endings, while all the others contain a bipolar neuron. Stretch receptors have a variety of forms.

iii) Chemoreceptors

Chemical stimulation involves the sensations of smell (olfaction) and taste (gustation). The ability to identify substances in a gaseous state is referred to as olfaction. Insects have similar receptors on various regions of their bodies, which they often use for functions other than eating, and they can detect chemicals on dry surfaces as well as in solution. For these reasons, it is usual to refer to 'contact chemoreception' in insects rather than 'taste'.

iv) Thermoreceptors

These kinds of receptors detect heat and are present in poikilothermic insects such as bed bugs and are sensitive to temperature changes.

v) Photoreceptors

Insects have a variety of receptors that they use to receive light. Most adult insects and larval hemimetabolous insects have three ocelli and a pair of compound eyes. On the sides of the head, larval holometabolous insects have one or more single-lens eyes called stemmata. Some insects are also known to possess epidermal light receptors, and, in some cases, light is known to have a direct effect on cells in the brain.

vi) Compound Eyes

Compound eyes are so called because they are constructed from many similar units called ommatidia (**Fig. 3.6 a, c**). In the eyes of dragonflies and drone honeybees, there are roughly 10,000, 5500 in worker honeybees, and 800 in *Drosophila*. They are present in most adult pterygote insects and the larvae of hemimetabolous insects, but are strongly reduced or absent in wingless parasitic groups, such as the Lice and Flea, and in female coccids. Compound eyes are considerably reduced or nonexistent in termite stages that are normally underground. Amongst Apterygota, compound eyes are lacking in some Thysanura.

vii) Ommatidia

The compound eye is based on many individual units called ommatidia. Each ommatidium is marked externally by a hexagonal area called facet. Compound eye is made up of two parts called optic part and sensory part (**Fig.3.6**).

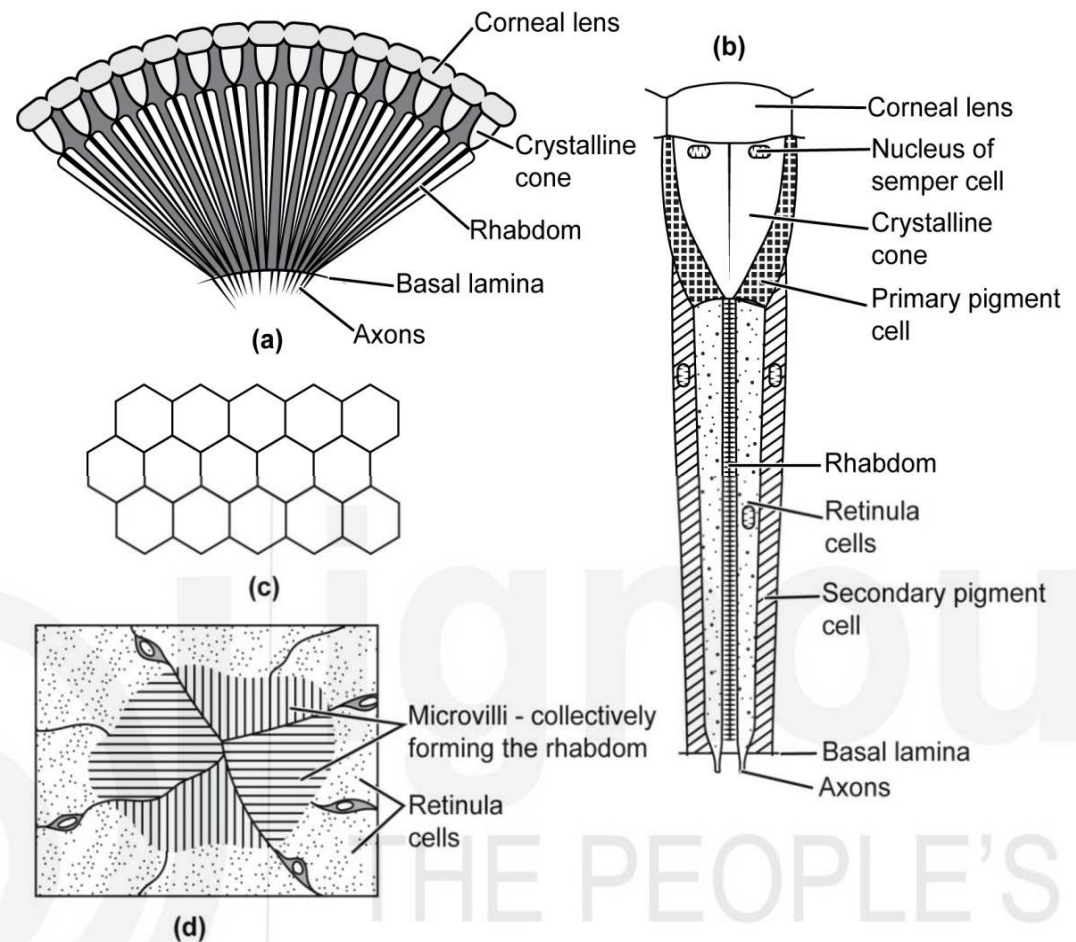


Fig. 3.6: Apposition eye: (a) diagrammatic section through an apposition eye showing the rhabdoms extending to the crystalline cones.; (b) ommatidium; (c) surface view of part of an eye showing the outer surfaces of some corneal lenses (facets); (d) cross-section through a fused rhabdom (Apis) (after Goldsmith, 1962).

viii) Types of ommatidia

Two types of ommatidia are recognized.

- a) Apposition type:** Due to the presence of primary pigment cells light cannot enter the adjacent cells (Fig. 3.6). The mosaic image formed is very distinct. The image formed by the compound eye is of a series of opposed points of light of different intensities. This functions well in diurnal insects.
- b) Super position type:** Primary pigment cells are absent allowing light to pass between adjacent ommatidia. Image formed in this way are indistinct, bright and blurred. This type is seen in nocturnal and crepuscular insects.

Each ocellus contains a large number of retinula cells packed closely together without any regular arrangement. A rhabdomere is formed on at least one side

of each retinula cell, and the rhabdomeres of between two and seven cells combine to form rhabdoms. The structure of the rhabdomeres in the dorsal ocelli is the same as that in the compound eye.

SAQ 6

1. Fill in the blanks:

- a) _____ and the supporting _____, are the basic cellular components of the nervous system.
- b) _____ are the places where neurons receive information from or transmit it to other cells.
- c) The _____ consists of three distinct lobes called as protocerebrum, deutocerebrum, and tritocerebrum.
- d) Compound eyes are constructed from many similar units called _____.

3.9 REPRODUCTION AND METAMORPHOSIS

Insects have a well-developed reproductive system that allows them to reproduce and reproduce young. Although sexual reproduction is typical in insects, there are certain exceptions, such as parthenogenesis, polyembryony, and paedogenesis. The two individual male and female shows sexual dimorphism in many insects but in others sexual dimorphism is not so prominent as they cannot be differentiated. In some insects, such as *Drosophila* and scale insects, male and female reproductive organs are found in the same insect, a trait known as hermaphroditism. Reproductive organ produces ova and sperms like that of vertebrates.

A pair of ovaries on either side of the abdomen, as well as paired lateral oviducts that unite to form the common oviduct, make up the female reproductive system. During mating, the external opening gonopore from the common oviduct is hidden in the genital chamber, which serves as a copulatory pouch.

By the time the insect reaches adulthood, sperm development is usually complete. A pair of testes, vas deferens, paired ejaculatory duct, and accessory glands make up the male reproductive system. Testes are usually paired except in order Lepidoptera (locust and moth) where they are fused to form a single median organ. Each testis is further differentiated into tubular follicles, which are functional units separated by a connective tissue sheath. Spermatocytes are formed in testicular follicles undergoes meiosis and yields four haploid spermatids which mature to form spermatozoa/sperms.

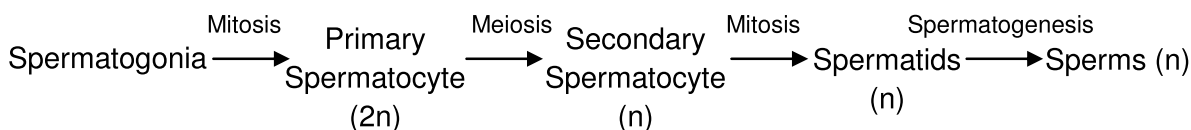
Physiologically reproduction starts with oogenesis and spermatogenesis.

Spermatocytes are produced in the testes.

Oogenesis: Oogenesis primarily occurs inside egg tube where ovum is produced from Oogonia in the following process:



Spermatogenesis: Spermatogenesis primarily occurs inside sperm tube where sperm is produced from spermatogonia in the following process:



Insemination: In insects, insemination (the transfer of sperm to the female) is a different process from fertilisation (the fertilisation of the eggs), which can take months or even years. During this interval the sperm are stored in the female's spermatheca. Sperm can be transported via a spermatophore produced by the male or straight into the spermatheca without the use of a spermatophore.

Fertilization: Sperm enter into egg to produce morphogenesis. Egg nucleus divides meiotically into female gamete nucleus and polar body. Then the fertilization occurs by the fusion of male and female gamete nuclei.

Eggs and embryonic development

The first stage of development in all insects is egg. Majority of insects are oviparous. Egg stage is inconspicuous, inexpensive and inactive. Yolk contained in the egg supports the embryonic development. Eggs are laid under conditions where the food is available for feeding of the future young ones. Eggs are laid either individually or in groups. The outer protective shell of the egg is called chorion.

Hatching

Most insects force their way out of the egg by exerting pressure against the inside of the shell. The bug expands its size by ingesting extra-embryonic fluid and, in certain cases, air that has diffused through the shell.

Metamorphosis and immature stages in insects

The transformation of an insect's growth and development from birth to maturity is known as metamorphosis. In insects, there are four basic types of metamorphosis.

1. **Ametabola** (No or very little metamorphosis): These insects have only three stages in their life namely egg, young ones and adult. It is most primitive type of metamorphosis. The hatching insect resembles the adult in every way except size, and is referred to as a juvenile. Moulting continues throughout the life. At each molt the larva grows bigger and the genitalia develop progressively (Fig. 3.7). Adults and larvae live in the same habitat. e.g. Silver fish.

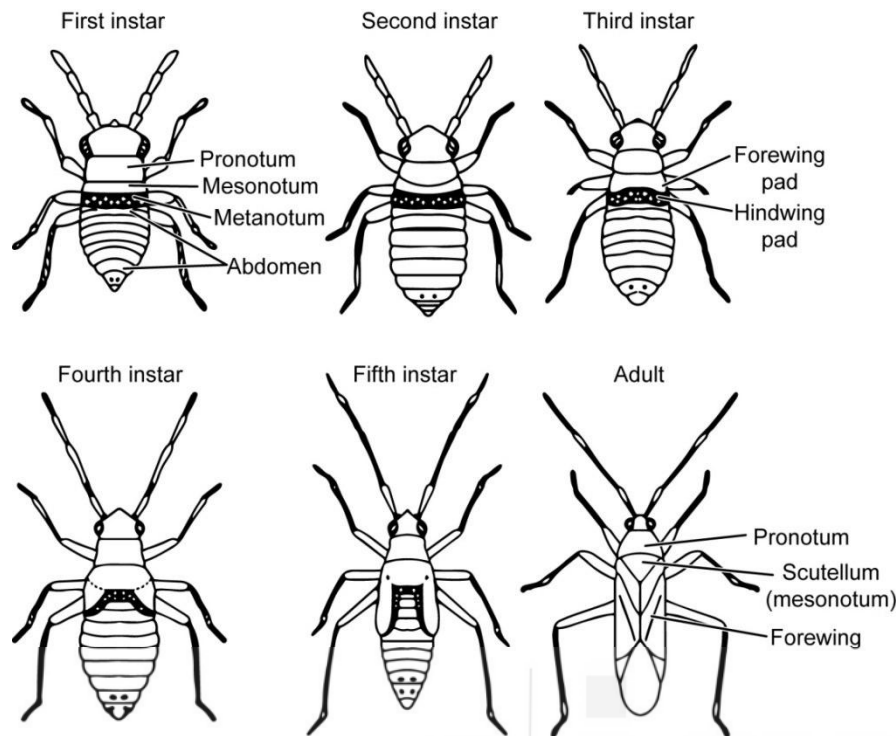


Fig. 3.7: Successive stages in the postembryonic development of a hemimetabolous insect. The horizontal line under each stage represents 0.5mm (*Cyllecoris*, Heteroptera) (after Southwood & Leston, 1959).

2. **Hemimetabola** (Incomplete metamorphosis): These insects also have three stages in their life namely egg, young one and adult. The young are known as naiads and are aquatic. They are different from adults in habit and habitat. They breathe by means of tracheal gills. The insects have completely grown wings that are suitable for aerial life after their last moult. e.g. Dragonfly, damselfly and may fly.
3. **Paurometabola** (Gradual metamorphosis): The young ones are called nymphs. They are terrestrial, with the exception of their wings and external genitalia, and resemble adults in general body appearance. Their compound eyes and mouth parts are similar to that of adults. Both nymphs and adults live in the same habitat. Later instars develop external wing buds. The genitalia develops with time. Later instar nymphs closely resemble the adult with successive moults. e.g. Cockroach, grasshopper, bugs.
4. **Holometabola** (Complete metamorphosis): These insects have four life stages namely egg, larva, pupa and adult. Majority of insects undergo complete metamorphosis. Larvae of butterflies are called caterpillar. Larva differs greatly in form from adult. Compound eyes are absent in larva.

Lateral ocelli or stemmata are the visual organs. Their mouth parts and food habit differ from adults. Wing development is internal. When the larval growth is completed, it transforms into pupa. During the non-feeding pupal stage, the larval tissues disintegrate and adult organs are built up. e.g. Butterfly, moth, fly and bees (**Fig. 3.8**).

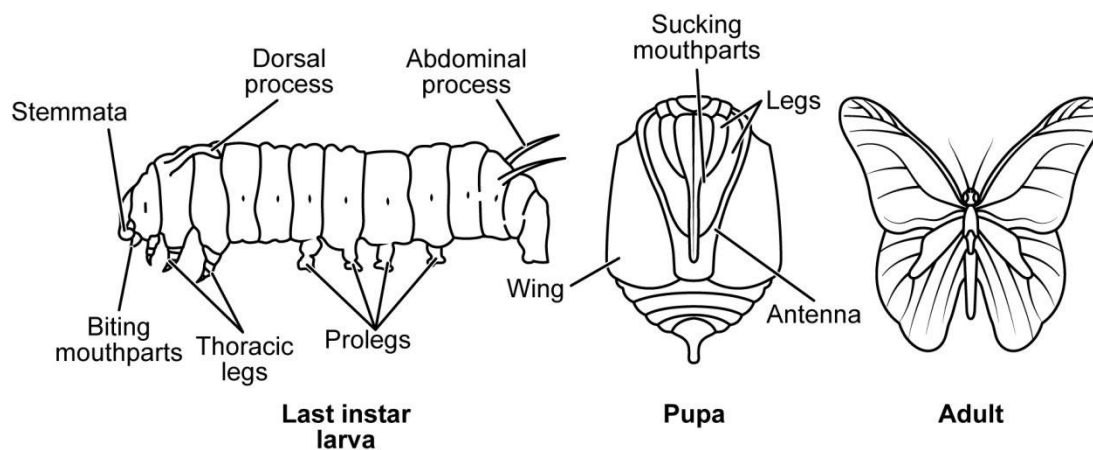


Fig. 3.8: Successive stages in the postembryonic development of a holometabolous insect. Adaptive features of the larva are indicated in heavy type. Only one larval stage is shown (*Danaus*, *Lepidoptera*) (after Urqhart, 1960).

The term 'molt' refers to two independent processes: apolysis, which involves the separation of the epidermis from the existing cuticle, and ecdysis, which involves the casting of the old cuticle after the formation of a new one. The insect is considered to be pharate in the period between apolysis and ecdysis, which can be rather protracted.

The cuticle of one developmental stage hides the presence of the next at this time. The pharate period is very short in most hemimetabolous insects and holometabolous larval stages, but it is frequently extended during the larval/pupal moult and pupal/adult moult (eclosion)

Larva

Larval stage is the active growing stage. It is the immature stage between the egg and pupal stage of an insect having complete metamorphosis. This stage differs radically from the adult.

Heteromorphosis

Most insects evolve through a sequence of essentially similar larval forms before metamorphosis, however subsequent larval instars can take on very distinct appearances. Development which includes such marked differences is termed heteromorphosis. In predaceous and parasitic insects, heteromorphosis refers to a change in behaviour that happens during larval development.

Numbers of instars

More larval instars are found in primitive insects than in advanced species. Ephemeroptera can moult up to 40 times, while cockroaches can moult up to 10 times. In contrast, most hemipteroid insects and endopterygotes have five or fewer larval stages.

Pupa

The term pupa is used with reference to the resting inactive instar in all holometabolous insects. The pupa takes on all of the characteristics of the

adult, and as a result, it resembles the adult more than the larva. At the larva/pupa molt, the wings and other features that up to now have been developing internally are everted and become visible externally although not fully grown to the adult form.

Eclosion: The escape of the adult insect from the cuticle of the pupa or, in hemimetabolous insects, of the last larval stage is known as eclosion. When a pupa is enclosed in a cell or cocoon, the adult must also find a way out.

Diapause

Diapause is a developmental pause that has evolved in response to regularly recurring periods of adversity in the environment. It is distinct from a delay caused by present adverse environmental conditions, such as low temperature, in that it does not refer to immediately prevailing adverse environmental conditions. Diapause helps insects survive the winter in temperate climates and related with survival during dry seasons. Diapause also helps to synchronise adult emergence, increasing the chances of finding a mate.

SAQ 7

1. Fill in the blanks:

- a) In some insects, such as *Drosophila* and scale insects, male and female reproductive organs are found in the same insect, a trait known as _____.
- b) During insemination, sperm can be transported via a _____ produced by the male or straight into the _____.
- c) The transformation of an insect's growth and development from birth to maturity is known as _____.
- d) In predaceous and parasitic insects, _____ refers to a change in behaviour that happens during larval development.
- e) The term _____ is used with reference to the resting inactive instar in all holometabolous insects.

3.10 SUMMARY

In this unit you have learnt that

- Important insect life processes are feeding and digestion, excretion, circulation of haemolymph, respiration, musculature and locomotion, nervous system and sense organs, and reproduction and metamorphosis.
- The digestive system is mainly concerned with changing the food in an assimilable form with the help of a large number of enzymes secreted by epithelial cells of its midgut lining and associated glands.

- The digested products are absorbed by special midgut cells and transferred to the haemolymph. Most of the enzymes are secreted by the midgut which is the main seat of digestion and absorption.
- The process of the elimination of the waste products is known as excretion. Moreover, knowledge of insect excretion and detoxification is useful in understanding host plant resistance as we need to understand how specialized insects can cope up with the phytotoxins produced by host plants while others are susceptible to such plant defense.
- The haemolymph, circulates round the body, bathing the tissues directly. Haemolymph is a watery fluid containing ions, molecules and cells. It act as a hydraulic medium facilitating transport and storage of essential molecules including water. As primary organ, it is involved in wound healing and immune response through cellular and humoral response.
- Respiratory system is involved in gaseous exchange through the network of tracheae and tracheoles.
- Among invertebrate animals, only insects posses wings and this unique feature is considered as one of the main reason behind their wide diversity and dispersal.
- Insect nervous system and network of sense organ help it to perceive external stimuli like light, sound, taste, smell, vibration etc. and coordinate different life process to interact with external environment.
- High reproductive potential coupled short generation times are considered as a main factor behind success of insects as most diverse group in this planet. Unique process of metamorphosis enables holometabolous insects to exploit different food and habitat during immature and adult life stages.

3.11 TERMINAL QUESTIONS

1. Discuss feeding and digestive system of insects
2. Discuss the excretory system of insects.
3. Describe the circulatory system in insects.
4. Discuss the different methods of respiration in insects.
5. Discuss the different types of locomotion in insects.
6. Write a note on the nervous system and sensory organs in insects.
7. Discuss the reproduction and metamorphosis in insects.

3.12 ANSWERS

Self Assessment Questions

1. (a) Monophagus, (b) Oligophagus, (c) Polyphagus.

INSECT CLASSIFICATION |

Structure

4.1	Introduction	Order Diptera
	Objectives	Order Siphonaptera
4.2	Basic Classification of Class Insecta	4.6 Summary
4.3	Subclass Apterygota	4.7 Terminal Questions
4.4	Sub-class Pterygota	4.8 Answers
	Division – Exopterygota	
	Division – Endopterygota	
4.5	Insect Orders Comprising Disease Vectors	
	Order Siphunculata	
	Order Hemiptera	

4.1 INTRODUCTION

Insects are perhaps the most eminently successful animals due to their vast number of species, wide distribution, reproductive capacity and adaptability to survive in extreme conditions. With roughly 1 million recognized species and 5-10 million estimated actual number of species, they dominate the current land fauna.

Insects are known to perform a variety of functions. Many insects are beneficial for human beings. They are excellent pollinators, environmental quality indicators, produce commercially important substances, act as scavengers, and are exceptional research models. On the other hand, several species of insects are devastating crop pests, household pests and even some are the significant disease carriers. For example; bedbugs, mosquitoes, houseflies, fleas, etc., transmit deadly diseases among human beings. The insect-borne diseases, such as dengue, malaria, typhus fever, plague, Chagas, etc. are some of the prevalent diseases worldwide.

In the previous units, you have learnt about the general features of insects, variation in the morphology of insects based on their habit and habitat, and the

concept of carrier and vector of various diseases. This unit will explain the basis of insect classification, the features which distinguish these insects from one another and the detailed features of those orders which include disease vectors.

Objectives

After studying this Unit, you should be able to:

- ❖ appreciate the extensive diversity in insects,
- ❖ understand the basis of classification of the insects,
- ❖ identify the insects based on their characteristic morphological features,
- ❖ list the insect orders comprising disease vectors, and
- ❖ explain the detailed features of orders containing insect vectors.

4.2 BASIC CLASSIFICATION OF CLASS INSECTA

You are aware that insects are the only winged invertebrates. Therefore, classification of insects is based on primarily, presence or absence of wings, its types, texture, shape, size, etc. The widely accepted classification of insects was proposed by the eminent insect taxonomist, A. D. Imms. The basic structure of classification of insects is presented in Fig. 4.1

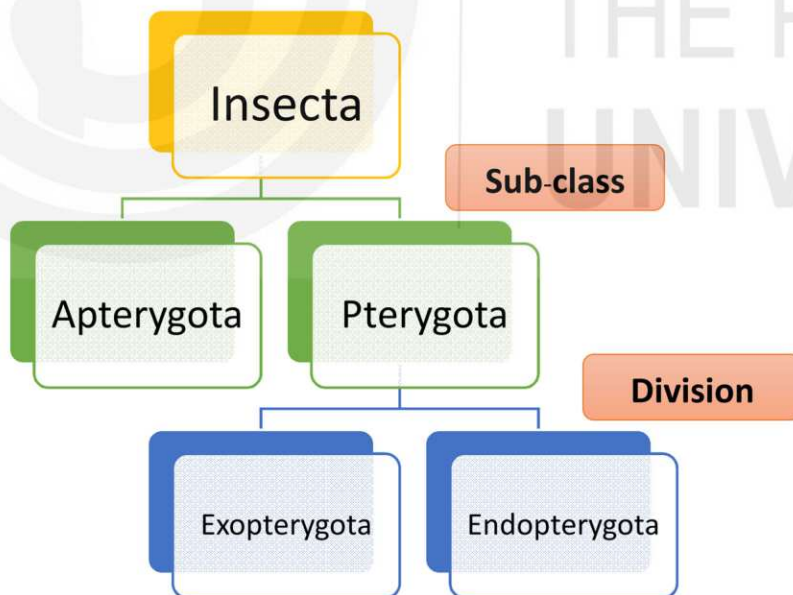


Fig. 4.1: Basic classification of Class Insecta.

Class Insecta is categorized into two sub-classes; Apterygota and Pterygota; based on the presence of absence of wings.

a) Sub-class Apterygota (Ametabola)

These are small insects which are primitively wingless insects. They never had wings in their evolutionary history. The adults possess variable number of

pregenital abdominal appendages. The head is **prognathous** with mouth parts directed anteriorly and generally concealed (**Entognatha**). Mandibles are attached to the head at one only point and are thus, **monocondylic**. The nymphs develop through slight or without any metamorphosis, and thus, resemble adults.

b) Sub-class Pterygota (Metabola)

Pterygotes includes the winged or secondarily wingless insects. *i.e.* the insects whose ancestors once had wings but that have lost them during subsequent evolution. Head may be **prognathous**, **opisthognathous** or **hypognathous**. The mouthparts are **ectognathous** with **dicondyllic** mandibles. The abdominal pregenital appendages are absent. **The immature stages become mature through metamorphic development which is either incomplete without a pupal stage or complete with a pupal stage.**

The pterygotes are further divided into two divisions, namely, **Exopterygota** and **Endopterygota**.

(i) Division Exopterygota (Hemimetabola)

The Exopterygota represents the insects which

- exhibit external development of wings in the form of wing buds and are also called “external winged forms”.
- develop through incomplete metamorphosis without a transitional pupal stage. Instead, they pass through a series of immature nymphal instars which resemble the adult in structure.

(ii) Division Endopterygota (Holometabola)

The Endopterygota represents the insects which

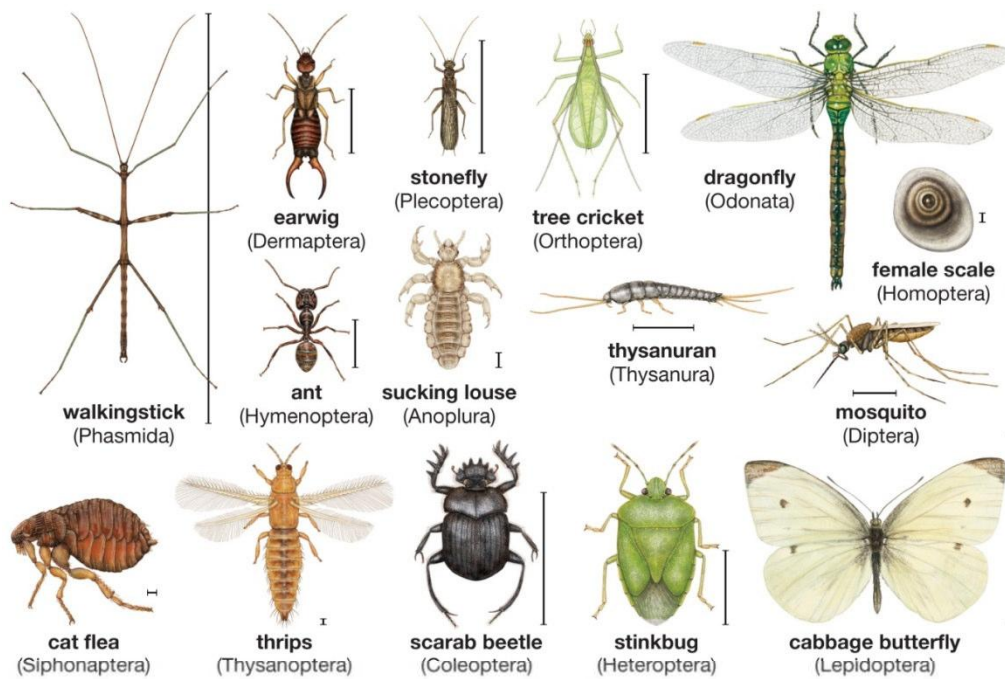
- exhibit internal development of wings in the form of wing discs and are also called “internal winged forms”.
- develop through complete metamorphosis including a series of larval instars and a transitional pupal stage, which differ from the adults in form and structure.

The extensive diversity of insects in habit and habitats has resulted in the several adaptive features (Fig. 4.2). To study them systematically and to understand their evolutionary relationships, the Divisions of pterygote insects are further categorized into Insect orders which are described in the next section.

SAQ 1

Mark the following statements as *True* or *False*.

- The hemimetabolous insects are internal winged forms.
 - Winged insects have ectognathous mouth parts and dicondyllic mandibles.
 - Endopterygotes develop through a series of nymphal instars and a pupal stage.
-



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Fig. 4.2: Diversity in insects – Basis of classification.

4.3 SUBLCLASS APTERYGOTA

The subclass Apterygota comprise four orders; Protura, Collembola, Diplura and Thysanura. The characteristic identifying features of each order are described below.

Order 1: Protura (Gr., *proto-* = "first"; *ura* = tail); **Common Name** = Coneheads

Proturans are numerous found in moist soils, mosses, leaf litter, turf and decomposing logs; and feed on decomposing organic matter and fungal spores. They are found worldwide and at present, approximately 200 species are known.

Characteristic Features

- a) Proturans are minute (< 2 mm long) whitish/pale insects, with piercing mouth parts.
- b) Head is conical and lacks antennae and eyes.
- c) Abdomen is 11-segmented with first 3 segments having a pair of small pregenital appendages. Abdomen is terminated by a telson and cerci are absent.
- d) Forelegs are held forward and are primarily sensory in function (Fig. 4.3 a).
- e) Metamorphosis is accompanied by increase in the number of abdominal segments after each moult, termed as **anamorphosis**.

Example: *Eosentomon indicus*, *Acerentomon doderoi*

Order 2: Collembola (Gr., *coli* = glue; *embol* = a wedge/peg); Common name: Springtails, Snow flea

Collembola are found in diverse but moist habitats; especially in soil, leaf litter and decaying organic matter. These are widely distributed in arctic, tropic and temperate regions. At present, approximately 6,000 species are known.

Characteristic Features

- a) These are minute insects (< 6 mm), with **biting type mouth parts** and 4-segmented antennae.
- b) Compound eyes are absent. One to several pairs of lateral ocelli form an eye patch.
- c) Abdomen is 6-segmented with three pregenital appendages.
- d) **Ventral tube (Collophore or Glue peg)** is a bilobed structure present on the first abdominal segment and helps in balancing, excretion, respiration, adhesion and water absorption.
- e) **Retinaculum (Hamula or Tenaculum)** is present on the III abdominal segment. It holds the next appendage, furcula.
- f) **Furcula** or springing organ is a forked jumping organ present on the IV abdominal segment. When released, it snaps against the ground helping animal to jump (Fig. 4.3 b).

Example: *Isotoma viridis*, *Anurida maritima*

Order 3: Diplura (Gr., *dip*= two; *ura*= tail); Common name: Two-pronged bristle tails

These are found in damp places in the soil, under bark, under stones or logs, in rotting wood, in caves, and in similar moist situations. About 800 species have been described so far.

Characteristic Features

- a) These are small to large (<5- 50 mm), pale, narrow-bodied insects.
- b) The antennae are moniliform and multi-segmented while compound eyes and ocelli are absent.
- c) Abdomen is 10-segmented, with lateral appendages on most of the pregenital segments.
- d) A pair of cerci is present at the abdominal end (Fig. 4.3 c).

Example: *Campodea staphylinus*, *Japyx diversiungus*

Order 4: Thysanura (Gr., *thysan* = fringe; *ura* = tail); Common name: Silverfish, Firebrats, Bristle tails

Silverfishes prefer moist places, such as soil, leaf litters, rotting wood, under stones or logs, etc. They can also be located behind old paintings, books, etc. On the other hand, firebrats are found in warmer places, such as around steam pipes, furnaces, etc. Currently, about 550 species are known.

Characteristic Features

- These insects are believed to be linking order between apterygotes and pterygotes.**
- They are approximately 6–18 mm long with metallic lustre of grey, brown or white scale and mandibulate mouth parts.
- Antennae are long, multi-segmented with basal segment provided with muscles.
- Compound eyes may be present or absent.
- Abdomen is 11-segmented with variable number of lateral pregenital appendages. The last segment ends in a pair of cerci and a median filament (Fig. 4.3 d).

Example: *Lepisma saccharina*, *Thermobia domestica*



(a) *Acerentomon doderoi*



(b) *Isotoma viridis*



(c) *Campodea staphylinus*



(d) *Lepisma saccharina*

Fig. 4.3: Apterygote insects belonging to different orders; (a) Protura, (b) Collembola, (c) Diplura, (d) Thysanura.

SAQ 2

Answer the following questions.

- What is anamorphosis? Which order exhibits this phenomenon?
- Name the organ after which Collembolans are named.
- Write one common morphological feature of all apterygote orders.

4.4 SUBCLASS PTERYGOTA

The subclass Pterygota comprises a total of twenty-five orders. Out of these, 16 orders containing hemimetabolous insects are kept under the Division Exopterygota and 9 orders including holometabolous insects are placed under the Division Endopterygota. Let's try to understand the characteristic identifying features of each order.

4.4.1 Division Exopterygota

Order 5: Ephemeroptera (Gr., *ephemeros* = for a day; *ptera* = wing);

Common name: Mayflies, Shadflies, Dayflies

Mayflies are short-living and the only insects that moult again after wings are developed. The adults can be located near lakes, streams and ponds; where females lay eggs and naiads develop. About 2,000 species have been described.

Characteristic Features (Fig. 4.4)



Fig. 4.4: *Ephemera danica*.

- a) These are small to medium-sized (average size = 15 mm wing span) soft-bodied insects.
- b) They have large compound eyes, three ocelli, and short and setaceous antennae.
- c) Mouthparts are atrophied in the adults because of which they live only for a short period.
- d) Wings are membranous and held vertically over the abdomen, when at rest. Hind wings are considerably reduced and even absent in some species.
- e) Slender abdomen is terminated by a pair of long cerci with/without a median caudal filament.
- f) Metamorphosis is incomplete with aquatic nymphal stage (naiad) characterized by biting mouthparts and 4-9 pairs of lateral abdominal gills.
- g) Adult stage is preceded by a transitional subimago (pre-adult) stage, exhibiting opaque wings, shorter legs and underdeveloped cerci.

Example: *Ephemera*, *Hexagenia*

Order 6: Odonata (Gr., *odon* = a tooth); Common name: Dragonflies, Damselflies

Odonates are highly predaceous and feed upon any suitable prey they can locate. They are found in vicinity of water and some species even feed upon aquatic organisms, such as tadpoles, fishes, etc. Around 6,000 species of Odonata are known from all over the globe



Fig. 4.5: *Coenagrion mercurial*.

Identifying Features (Fig. 4.5)

- a) Medium to very large-sized insects with average size of 150 mm wing span.
- b) The head is large, globular with a narrow constricted petiolate neck. The head is characterized by short and filiform antennae, prominent and quite large compound eyes, three ocelli and mandibulate mouthparts.
- c) Wings are membranous, equal (damselflies) or subequal (dragonflies), and possess a complex network of veins with several cross veins. A dark

pterostigma towards the costal apex and a **nodus** at the end of sub costa are specific features.

- d) Abdomen is extremely long and slender with 1-segmented cerci in males.
- e) Metamorphosis involves aquatic naiad with rectal or caudal gills.

Example: *Cordulegaster bidentata*, *Lestes fusca*

The largest living odonate is the giant damselfly *Megaloprepus coerulatus* found in moist forests of South and Central America. The male fly has a wing span of 19 cm, the largest among other odonates

Order 7: Plecoptera OR Perlaria (Gr., *pleco*= folded; *ptera* = wing);

Common name: Stoneflies

Stoneflies are feeble fliers. They occur near the cold streams, lakes, waterfalls, etc. with stony banks or beds. Naiads live beneath the stones present in well-oxygenated water. Approximately 3,500 species have been described worldwide

Characteristic Features (Fig. 4.6)

- a) Stoneflies are soft-bodied insects of moderate to large size body and long, multi-segmented, setaceous antennae.
- b) Mouth parts are weak, biting type with normal or vestigial.
- c) Wings are membranous, and are held flat over the body at rest. Hind pair of wings is larger, pleated with well-developed anal lobes and remain folded beneath the fore wings at rest.
- d) Abdomen is 10-segmented with reduced 11th segment and ends in a pair of long, multi-articulate cerci.
- e) Development includes aquatic naiads which breathe through filamentous tracheal gills present in variable positions.



Fig. 4.6: *Perla perla*.

Example: *Perla perla*, *Hemoura punjabensis*

Plecoptera cannot survive in deoxygenated or polluted water. Thus, their occurrence in a water body is typically an indicator of pollution-free water quality

Order 8: Grylloblattodea (Gr., *gryll*= cricket; *blatta*= cockroach); **Common name:** Rockcrawlers

Rock crawlers live beneath stones or ice caves of high mountains. They are mainly nocturnal, and feed on dead insects and other organic matter found on the snow and ice fields. There are only 25 species of living rock crawlers in the world

Characteristic Features (Fig. 4.7)**Fig. 4.7: *Grylloblatta* sp.**

- a) Rock crawlers are slender, pale-coloured, apterous insects, usually about 15-30 mm in length.
- b) Eyes are reduced or absent, and ocelli are lacking.
- c) These have moderately long, filiform antennae and mandibulate mouth parts.
- d) Legs are almost similar to each other and are cursorial in function.
- e) Abdomen is 11-segmented and is terminated by 5-8 segmented long cerci.

Example: *Grylloblatta* sp.

Order 9: Phasmida (Gr., *phasm*= an apparition or phantom); Common name: Stick insects, Leaf insects

Phasmids are phytophagous insects and live on foliage or twigs of vegetation, predominantly in tropical regions. These have developed protective resemblance to twigs and leaves of the plants to easily escape from the predators. Approximately 3,284 species have been recognized worldwide

**Fig. 4.8: *Phyllium bioculatum*.****Characteristic Features (Fig. 4.8)**

- a) These are large, apterous or winged, with cylindrical stick-like or leaf-like body, which may reach up to 30 cm in length.
- b) These insects have mandibulate mouthparts, well developed eyes, short prothorax while long meso- and metathorax are fused with the first abdominal segment.
- c) Legs are long and slender resembling twigs in stick insects while legs of leaf insects have lamellate expansion on each side.
- d) Wings may be present or absent. If present, forewings are reduced and modified into **tegmina**. The wing venation, in leaf insects, mimics leaf venation.
- e) Abdomen is 11-segmented with short cerci.
- f) They possess great power of regeneration, especially legs.

Example: *Carausius morosus*, *Phyllium bioculatum*

Order 10: Orthoptera (Gr., *ortho*= straight; *ptera* = wing); Common name: Grasshoppers, Locusts, Cricket

The orthopterans are typically terrestrial and can be easily found in grasses, bushes, other vegetation and on/above ground. A few species are aquatic or semi-aquatic. More than 20,000 species have been described till date

Characteristic Features (Fig. 4.9)

- They are minute to large-sized insects, with mandibulate mouthparts, well developed eyes and filiform antennae.
- The prothorax is large with curved pronotum.
- They may be winged, brachypterous or apterous. Forewings are small, thickened and leathery forming tegmina, while hindwings are membranous and are folded like pleats beneath the tegmina.
- Hind legs are large, modified for jumping (saltatorial). In some, forelegs are fossorial type.
- Specialized stridulatory (sound-producing) and auditory (hearing) organs are developed.
- Abdomen is 11-segmented with short and unsegmented cerci. Females have large, well developed ovipositor.
- In many species, the first instar nymphs are covered by loose cuticle, which covers the appendages. These are called pronymphs.

**Fig. 4.9: *Locusta migratoria*.**

Example: *Hieroglyphus banian*, *Gryllus campestris*, *Schistocerca migratoria*

Locust, generally a solitary form, becomes gregarious under some circumstances. Their swarms can fly rapidly across great distances. In 2020, locust swarms have invaded vast stretches of land in India since April 11th. They entered several districts of Rajasthan via Pakistan's Sindh province and later spread in Gujarat, Madhya Pradesh and Uttar Pradesh; devastating cultivation and croplands.

Order 11: Dermaptera (Gr., *derma*= skin; *ptera* = wing); Common name:
Earwigs

Earwigs are primarily nocturnal insects. During the daytime, they hide away in soil, under bark, hollow stems, stones or vegetation. They feed upon small living or dead insects, decaying or living plant material. Approximately 1,200 species of earwigs are known worldwide.

**Fig. 4.10: *Forficula auricularia*.****Characteristic Features (Fig. 4.10)**

- They are generally elongate insects with chewing mouthparts and a distinct 'Y' shaped epicranial suture on head.
- Prothorax is large, well developed and mobile, while mesothorax and metathorax are fused with the first abdominal segment.
- These may be apterous or winged forms. Forewings are short and leathery protective tegmina, are devoid of vein and meet along a mid-dorsal line. Hindwings are large, membranous, semi-circular with radially arranged veins. At rest, they are kept folded fan-like, beneath the forewings.
- Abdomen is 11-segmented and is terminated by unjointed, highly sclerotised and forceps-like cerci. Males have large and curved cerci, while females possess nearly straight cerci.
- Ovipositor may be reduced or lacking.

Example: *Forficula auricularia*, *Hemimerus hansenii*

Order 12: Embioptera (Gr., *embia*= lively; *ptera*= wing); Common name:
Webspinners

Embiids are gregarious insects. They live inside tubular silken tunnels spun by them beneath stones, logs and bark of trees; for protection, providing a humid atmosphere and preventing excessive water loss from the body. They feed on decaying plant matter. Approximately 400 species are known.

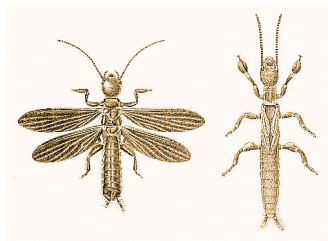


Fig. 4.11: *Embia major* (male and female).

Characteristic Features (Fig. 4.11)

- These are small, soft-bodied brown/yellowish-brown insects with filiform antenna and mandibulate mouthparts.
- Female is apterous while male has 2 pairs of similar well-developed elongated wings with reduced wing venation.
- Males have remarkable speed of movement both forward and backward.
- Hind femur is enlarged and helps in backward running.
- Abdomen is 10-segmented with asymmetrical cerci in males and symmetrical in females.

Example: *Embia major*, *Oligotoma saundersii*

SAQ 3

Answer the following questions:

- Why do mayflies live only for a short duration?
- Name any two orders with aquatic nymphs.
- The organisms of which order are characterized by the presence of a pterostigma and a nodus in their wings?
- Name any organism which has sound-producing organs.
- How are cerci of earwigs different from the cerci of other insects?

Order 13: Dictyoptera (Gr., *dictio*= net; *ptera* = wing); Common name:
Cockroaches, Mantids



Fig. 4.12: *Mantis religiosa*.

Dictyopterans are abundantly found in temperate and tropical countries. Cockroaches are generally found in sewer pipes, litter and low vegetation etc., while mantids are arboreal in habitat though some apterous forms are found on ground. Cockroaches are omnivorous while mantids are carnivorous. Approximately 3,250 species are described.

Characteristic Features (Fig. 4.12)

- These are medium to large-sized insects with mandibulate mouth parts and multi-segmented filiform antennae which are sensory in nature.
- Compound eyes are well developed.

- c) Legs are similar to each other or forelegs are raptorial.
- d) Forewings are modified in thickened tegmina while hindwings are membranous.
- e) Abdomen of females is 7-segmented terminated by a pair of many segmented cerci, while abdomen of males is 9-segmented and ends in a pair of cerci and a pair of anal styles.

Example: *Periplaneta americana*, *Mantis religiosa*

Order 14: Isoptera (Gr., *iso*= equal; *ptera* = wings); Common name:

Termites or White ants

Termites are mostly tropical or sub-tropical and live in large communities in termitaria. They can form their nests underground or above-ground in dry wood, on cemented walls, etc. they feed on cellulose-containing materials, fungi and dry organic remains of organisms. They harbour *Trichonympha*, a protozoan, in their gut which helps in cellulose digestion. Till date, more than 3,000 species of termites are known.

Characteristic Features (Fig. 4.13)

- a) Termites are social, polymorphic species which live in large communities.
- b) These are small pale yellow, soft-bodied insects with mandibulate mouth parts and short, moniliform antennae.
- c) Compound eyes are present in winged, sexually mature forms and usually absent in apterous forms. Antennae are short and moniliform.
- d) The alate forms have two pairs of identical and membranous wings with indistinct venation. Wings are superposed over the back, when at rest. Wings are capable of shedding along the basal suture, after swarming.
- e) Abdomen is broadly jointed to the thorax without constriction. Cerci are short.

Example: *Isotermes*, *Odontotermes badius*

Order 15: Zoraptera (Gr., *zor*= pure; *aptera* = wingless); Common name:

Angel insects

These insects occur under bark, decaying wood, leaf litter, vegetation, etc. They can also be observed near termite colonies. Till date, 55 species have been described so far.

Characteristic Features (Fig. 4.14)

- a) The zorapterids are minute insects, 3 mm or less in length
- b) Head has a Y-shaped ecdysial suture and 9-segmented moniliform antennae.
- c) These occur as darkly-coloured winged forms or pale wingless forms.



Fig. 4.13: *Odontotermes badius*.

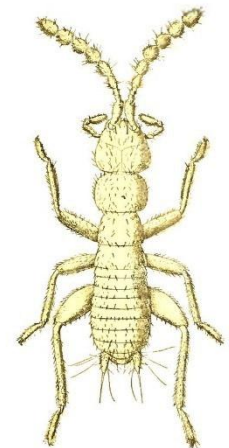


Fig. 4.14: *Zorotypus guineensis*.

- d) Alate forms have membranous wings with reduced venation that can be shed along basal fracture line leaving small stubs. The hindwings are smaller than the forewings.
- e) Eyes are developed only in alate forms, wingless forms lack both compound eyes and ocelli.
- f) The abdomen is 11-segmented, short, oval and terminates in short cerci with long bristles.

Example: *Zorotypus guineensis*

Order 16: Psocoptera (Gr., *psocos*= gnawed/rubbed; *ptera* = wing);

Common name: Book lice, Bark lice, Dust lice

Psocids are frequently gregarious. They feed on paper paste of book binding, fragments of animal and vegetable matter, starchy material, wallpaper paste and stored grains, etc. They can also damage dry preserved specimens of insects and herbarium. Approximately 5,500 species are known at present.



Fig. 4.15: *Liposcelis* sp.

Characteristic Features (Fig. 4.15)

- a) Psocids are minute (1-10 mm in length) and soft-bodied insects.
- b) Head has a distinct 'Y' shaped epicranial suture, mandibulate mouthparts and filiform antennae with 12-50 segments.
- c) Eyes are large-sized and protrude from the sides.
- d) These occur as macropterous, brachypterous as well as apterous forms. At rest, wings are held over the abdomen like a roof.
- e) Abdomen is without any cerci.
- f) In some psocids, dorsal pair of labial glands are modified into silk glands and they have the ability to spin silken webs.

Example: *Liposcelis bostrychophila*, *Psocus leidy*

Order 17: Mallophaga (Gr., *mallo*= wool; *phaga* = feed);

Common name: Chewing lice, Biting lice, Bird lice

Mallophaga comprises parasitic insects which feed on bits of feathers, skin, blood, etc. of host. These show symbiotic association with bacteria, in the absence of which they die soon. A total of 2,800 species are known worldwide.



Fig. 4.16: *Colonicola columbae*.

Characteristic Features (Fig. 4.16)

- a) These comprise apterous, minute forms, the size ranges from 0.5 -10 mm long.
- b) Body is dorso-ventrally flattened and they live as ectoparasites of birds, sometimes of mammals.
- c) Head contains biting mouth parts and 3-5-segmented antennae which may be of capitate or filiform types. The compound eyes are reduced and ocelli are wanting.

- d) The last tarsus of legs bears 1-2 claws which help to cling them to the fur or feathers of the host.
- e) Abdomen is without any cerci.

Example: *Colombicola columbae*, *Goniocoles bidentatus*

Order 18: Anoplura OR Siphunculata (Gr., *anopl*= fringe; *ura* = tail);

Common name: Sucking lice

Anoplurans are host-specific and occur only on mammals. A total of 540 species have been described worldwide.

Characteristic Features (Fig. 4.17)

- a) Anoplurans are apterous, small-sized, sanguivorous insects living as ectoparasites of mammals.
- b) Body is dorso-ventrally flattened with a narrow head and 3-5 segmented antenna.
- c) Mouthparts modified for piercing and sucking, and can be retracted when not in use.
- d) Tarsi are 1-segmented with single claws.
- e) Abdomen is without any cerci.

Example: *Pediculus humanus*, *Phthirus pubis*



Fig. 4.17: *Pediculus humanus*.

Order 19: Thysanoptera (Gr., *thysan* = fringe; *ptera* = wing); **Common name:** Thrips

Thrips are fragile insects which feed on plant tissues, most often flowers and foliage. A few species feed on mites and other small insects. They are weak fliers and often fly passively along with the wind. At present, > 5,000 species are described worldwide.

Characteristic Features (Fig. 4.18)

- a) Thrips are minute (0.5 - 0.8 mm), slender, soft-bodied insects with 6-10 segmented antenna.
- b) They have asymmetrical mouthparts which are adapted for rasping and sucking.
- c) Wings are long, narrow and fringed with hairs. Apterous forms are also common.
- d) The apex of each tarsus has a protrusible adhesive bladder which facilitates thrips to walk on smooth surfaces.
- e) Abdomen is often pointed and without cerci.
- f) Nymphal stage is followed by prepupal and pupal stages which are analogous to the pupae of endopterygote insects. Thus, **thrips are considered as connecting link between hemimetabola and holometabola.**



Fig. 4.18: *Thrips tabaci*.

Example: *Thrips tabaci*, *Scirothrips citri*

Order 20: Hemiptera OR Rhyncota (Gr., *hemi*= one-half; *ptera* = wing);**Common name:** True bugs, Scale insects, Aphids, White flies

Hemiptera is the largest exopterygote order. Most hemipterans are phytophagous, sucking plant sap. A few species feed on small insects and are predatory, while some are parasitic on vertebrates and may transmit diseases. There are about 80,000 species recognized till date.

Characteristic Features (Fig. 4.19)

Fig. 4.19: *Cimex lectularius*.

- a) Hemipterans are small to large-sized insects (1 – 110 mm long).
- b) They usually have two pairs of wings. Forewings are of harder consistency than hindwings.
- c) Adult true bugs have a triangle structure, scutellum between their wings.
- d) Head is hypognathous or prognathous with a well-developed rostrum, and piercing and sucking mouthparts.
- e) Pronotum may be small or large.
- f) Hemipterans exhibit various modes of locomotion, such as swimming, skating on a water surface, jumping, walking and flying.

Example: *Cimex lectularius*, *Pyrilla perpusilla*, *Bemisia tabaci*, *Aphis gossypii*

The male cicadas produce sound, the loudest of any insect. The sound producing organ, tymbal organ is present on the underside of the abdomen, and is used to attract mates.

SAQ 4

Fill in the blanks by choosing the correct word from the parentheses.

- a) The forewings of the cockroaches are modified into (elytra/tegmina).
- b) Termites digest cellulose with the help of symbiotic (*Trichonympha*/*Trypanosma*).
- c) Organisms of Order have biting mouth parts while that of Order have piercing and sucking types. (Anoplura/Mallophaga/Thysanoptera).
- d) Bugs are characterized by the presence of (clawed legs/scutellum).

4.4.2 Division Endopterygota

The Division Endopterygota or Holometabola, which exhibits complete metamorphosis comprises 9 distinct orders.

Order 21: Neuroptera (Gr., *neuro*= nerve; *ptera* = wing); Common name:

Alder flies, Antlions, Snake flies, Lace wings

Neuropterans are weak fliers often found on vegetation. The larvae can be found on certain soil types, freshwater habitats, sandy habitats, shrubs, trees, plant roots, freshwater streams, under rocks or in leaf litter along the shore. Worldwide, over 5,500 species are recognised.

Characteristic Features (Fig. 4.20)

- a) They are small to large soft-bodied insects with filiform antenna and mandibulate mouth parts.
- b) They have two pairs of similar membranous wings which are held in a roof-like manner over the abdomen.
- c) Wing veins are extensively branched because of which wings are termed as nerve wings.
- d) Cerci are absent.
- e) Larva is campodeiform and pupa is exarate. Pupation takes place in a silken cocoon spun by the larvae through anal spinnerets.

Example: *Chrysopa vulgaris*, *Distoleon tetragrammicus*

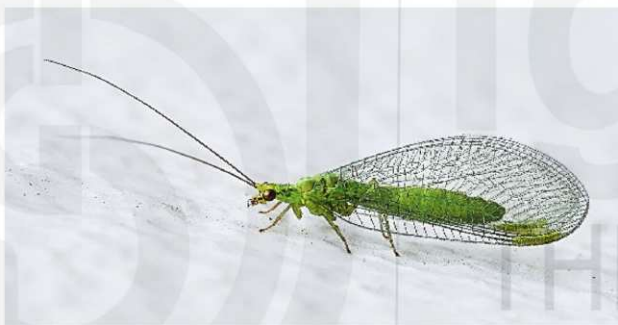


Fig. 4.20: *Chrysopa* sp.

Order 22: Coleoptera OR Elytroptera (Gr., coleo= sheath; ptera = wing);

Common name: Beetles, Weevils

Coleoptera is the largest endopterygote order with more than 3,50,000 species distributed worldwide. They can be found in water, air or land in mostly concealed habitats. Most of these are phytophagous, while others can be found in stored grains, wool, furniture, oilseeds, etc. A few act as predators and scavengers in nature.

Characteristic Features (Fig. 4.21)

- a) Beetles are minute to large-sized (0.3 mm – 15 cm) insects with forewings modified into leathery **elytra**. These are not used in flight, never overlap and always meet to form a straight mid-dorsal suture.
- b) Hind wings are membranous, useful in flight and are kept folded transversely beneath the elytra during repose. In a few species, hindwings are either reduced or absent.
- c) Antennae are variable, usually 11-segmented and mouthparts are chewing type.



Fig. 4.21: *Coccinella septempunctata*.

- d) Prothorax is large while mesothorax and metathorax are reduced. A small triangular part of the mesothorax, scutellum, is visible between the bases of elytra.
- e) Legs are diverse types with features and functions according to the habitat.
- f) Cerci are absent.
- g) Larvae are often called grubs. Pupae are usually exarate.

Example: *Coccinella septempunctata*, *Tribolium castaneum*, *Scarabaeus viettei*, *Sitophilus oryzae*

Order 23: Strepsiptera (Gr., *strepsi*= twisted; *ptera*= wing); Common name: Stylops, Twisted wing parasites

Stylopids are endoparasites in other insects, such as bees, wasps, ants, cockroaches, leaf hoppers, etc. Females of most of the species pass their whole life as parasites and never emerge from the host body. Approximately 600 species have been described till date.

Characteristic Features (Fig. 4.22)

- a) Stylops are minute insects (1.5 – 4.0 mm) living in other insects.
- b) Male is free living, pterous with degenerated mouth parts and thus, live for only a few hours. Forewings are reduced to club-shaped structures, called pseudohalteres while hind wings are large, membranous and fan-like.
- c) Female is long-lived, apterous, apodous and live a permanent parasitic life, enclosed in a puparium.
- d) Antennae are conspicuous and flabellate type.
- e) The development is hypermetamorphic with maggot-like larvae and exarate pupa.

Example: *Stylops melittae*, *Neostylops shannoni*

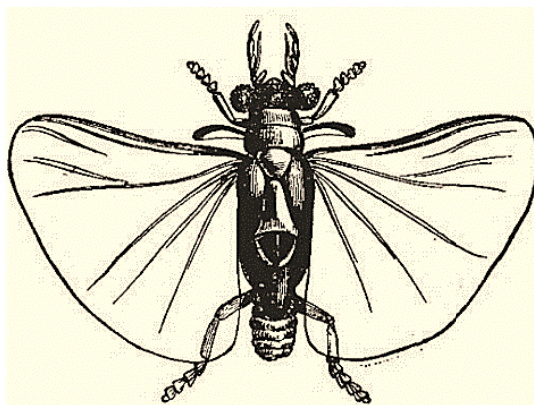


Fig. 4.22: *Stylops children*.

Order 24: Mecoptera (Gr., *Thysan* = fringe; *ura* = tail); Common name: Scorpion flies

Mecopterans mostly inhabit moist environments, generally broad-leaf woodlands, forests, caves and grasslands with plentiful damp leaf litter and high moisture levels. Adults feed on decaying vegetation and the soft bodies of dead invertebrates. They are called the scorpion flies due to the shape of the male's genitalia as scorpion sting. Currently, about 600 species have been described.

Characteristic Features (Fig. 4.23)

- These are moderate to small-sized (9-25 mm long), slender-bodied insects with filiform antennae.
- Head is prolonged into a vertically deflected rostrum (beak) with mandibulate mouthparts.
- Compound eyes and three ocelli are well developed.
- Most of these flies have 2 pairs of similar and membranous wings.
- Abdomen is 11-segmented with short cerci and first segment fused with metathorax.
- The genitalia, of male flies is distinct and held like a scorpion sting at the terminal segment of abdomen.
- Larva is eruciform and pupa is exarate.

Example: *Panorpa communis*, *Hylobittacus apicalis*

Order 25: Diptera (Gr., *di* = two; *ptera* = wing); Common name: True flies, Mosquitoes, Midges, Gnats

Dipteran flies are the swiftest among all insects. They are present in aquatic, semi-aquatic or moist terrestrial habitats. They can be traced in soil, plant/animal tissues, dung or decaying organic matter. Most of the species feed on dead and decaying organic matter and are parasitic on other organisms. A few species are phytophagous. Approximately, 1,20,000 species are described.

Characteristic Features (Fig. 4.24)

- Diptera are small to medium-sized and soft-bodied insects with generally sponging and rarely piercing mouth parts.
- Antennae are often annulate or aristate type.
- These insects are characterized by a single pair of membranous forewings which are used for flight. Hind wings are reduced, called haltere.
- Head is often hemispherical and attached to the thorax by a slender neck.
- All thoracic segments are fused together, largely made up of mesothorax.



Fig. 4.23: *Panorpa communis*.



Fig. 4.24: *Musca domestica*.

Parasitoid is an insect whose larvae feed and develop within or on the bodies of other arthropods.

- f) Metamorphosis is complete. Larvae are apodous and acephalous, known as maggots. Pupa is free or enclosed in the hardened last larval skin.

Example: *Musca domestica*, *Anopheles stephensi*, *Aedes aegypti*, *Drosophila melanogaster*.

Order 26: Hymenoptera (Gr., *hymen*= membranous; *ptera* = wing);

Common name: Bees, Ants, Wasps, Sawflies, Ichneumon flies

Hymenopterans are found in almost all terrestrial habitats; soil, vegetation, flowers, leaf litters, near water, etc. A few species live a social life while many species live as parasitoids on other insects. These insects feed on a wide range of food, such as honeydew, nectar, seeds, fungus, decaying organic matter, etc. Roughly, 1,50,000 species are known throughout the world.

Characteristic Features (Fig. 4.25)



Fig. 4.25: *Vespa orientalis*.

- Hymenopteran are common insects with mandibulate, lapping or sucking mouthparts.
- They have 2 pairs of membranous wings with reduced venation. Forewings are larger than the hindwings and interlocked with each other by a row of hooklets (hamuli) present on the front margin of the hindwing.
- Abdomen is basally constricted with the first segment fused with the metathorax. The second segment, called pedicel, connects the thorax and abdomen. Rest of the abdomen is slightly curved upwards and is called gaster.
- Ovipositor of females is variously modified for oviposition or stinging, sawing or piercing the plant tissue.
- Larva is apodous and eucephalous; while pupa is exarate and often enclosed in a silken cocoon.

Examples: *Apis indica*, *Vespa orientalis*, *Monomorium destructor*

Order 27: Lepidoptera (Gr., *lepto*= scale; *ptera* = wing); Common name: Butterfly, Moths



Fig. 4.26: *Papilio demoleus*.

Body, wings, appendages, are densely clothed with overlapping scales, which give colour, rigidity and strength. They insulate the body and smoothen air flow over the body. Most lepidopteran species feed on flowering plants. The larval stages voraciously feed on different plant parts while adults generally feed on plant juices and nectar. Approximately 1,75,000 species have been described

Characteristic Features (Fig. 4.26)

- Butterflies and moths are efficient flying insects with siphoning type of mouthparts. Mandibles are absent, while maxilla is modified into a suctorial proboscis which is coiled up like a watch spring beneath the head when not in use.

- b) These have 2 pairs of membranous wings covered with overlapping pigmented scales. Forewings are larger than hindwings.
- c) Larvae are polypodous and eruciform with mandibulate mouthparts. They are characterized by 3 pairs of 5-segmented thoracic legs ending in claws and 4-5 pairs of fleshy unsegmented abdominal prolegs.
- d) Pupa is generally obtect and is either naked or enclosed in a cocoon composed of soil, frass, silk or larval hairs.

Example: *Papilio demoleus*, *Pieris brassicae*, *Danaus chrysippus*, *Corcyra cephalonica*

Order 28: Trichoptera (Gr., *tricho*= hair; *ptera* = wing); Common name:
Caddisflies

Trichopterans, hairy-winged are terrestrial insects with aquatic larvae. The larvae can be found in all kinds of freshwater habitats. They feed on organic matter, plants, algae and other organisms that grow on underwater objects. There are approximately 14,500 described species.

Characteristic Features (Fig. 4.27)

- a) Caddisflies are small to moderate-sized, slender moth-like insects.
- b) They have thread-like setaceous antennae usually as long as or even longer than the body.
- c) Mandibles are vestigial or absent.
- d) The wings are 2 pairs, membranous, more or less densely hairy and held roof-like over the back at repose.
- e) Larvae aquatic, eruciform, respire through tracheal gills, live in cases of variable materials and have hooked caudal appendages at the abdominal end. Pupa is exarate.

Example: *Georgium japonicum*, *Hydropsyche cinerea*



Fig. 4.27: Caddis fly.

Order 29: Siphonaptera (Gr., *siphon* = a tube; *aptera* = wingless);
Common name: Fleas

Fleas are ectoparasitic insects which feed on the blood of endotherms, mostly mammals. They transmit several fatal diseases to human beings, such as typhus and plague. Approximately 2,400 species have been described inhabiting temperate regions.

Characteristic Features (Fig. 4.28)

Fig. 4.28: *Xenopsylla cheopis*.

- a) Fleas are small, apterous, laterally compressed insects with highly sclerotized integument and backwardly directed spine-like setae arranged in rows.
- b) Antennae are clavate, short and stout, concealed in grooves. Antennae of males are much longer than females.
- c) Mouth parts adapted for piercing and sucking. Compound eyes are wanting.
- d) Hindlegs are strong adapted for jumping.
- e) Larvae are eruciform, eucephalous, blind and apodous, while pupa is enclosed in cocoons.
- f) Both sexes suck blood from mammals and birds.

Example: *Pulex irritans*, *Xenopsylla cheopis*

SAQ 5

Answer the following questions.

- a) Give one point of difference between the wings of Diptera and Strepsiptera.
 - b) Why are wings of Neuroptera called nerve wings?
 - c) According to the number of species, which insect order is the largest?
 - d) Write the characteristic shape of male genitalia of flies in Order Mecoptera.
 - e) Give one characteristic feature of Caddisfly wings which distinguishes them from others.
-

4.5 INSECT ORDERS COMPRISING DISEASE VECTORS

The insects are important disease vectors which transmit several diseases of variable severity to human beings, such as malaria, filariasis, dengue, typhus, relapsing fever, trench fever, plague, etc. In the previous sections, you learnt about different insect orders and their characteristic features. Among these, four orders comprise vectors transmitting these diseases. You will learn about biology of vectors and the ways of disease transmission in the subsequent chapters. Let us try to understand features of these orders in details, especially those which make them efficient vectors.

4.5.1 Order Siphunculata (Anoplura)

Order Siphunculata or Anoplura comprise sucking lice. They comprise head louse, body louse and pubic louse. The detailed characteristic features of anoplurans are as follows.

- All anoplurans are **ectoparasitic** on mammals and survive by sucking their blood.
- These are all very small insects and do not have wings.
- They have short antennae, small heads, and reduced or no eyes.
- They are generally grey in colour, but their precise colour varies according to the environment in which they were raised. After feeding, they become reddish in colour.
- The body is flattened dorsoventrally enabling them to lie close along the hairs or seams of the clothes for attachment or feeding.
- The mouthparts are **piercing and sucking** types. They pierce the mammalian skin through delicate stylets. A salivary secretion containing anticoagulant is injected to let the blood flow freely for sucking easily. The mouthparts are retracted within the head when louse is not feeding.
- The legs are short and stumpy which render them incapable of jumping, or even walking efficiently on flat surfaces.
- The legs are **clinging** types. Each leg terminates into strong claws by which they hold onto the hair of a host and are called hair-clasping organs. Thus, it becomes quite difficult to dislodge them. They move from hair to hair using clawed legs.
- The abdomen has eight to 10 visible segments.
- There is one pair of thoracic spiracles and six pairs of abdominal spiracles.
- Males are slightly smaller than females and are characterized by a pointed end of the abdomen.
- A well-developed genital apparatus is visible inside the abdomen of males while females are characterized by two gonopods in the shape of a W at the end of their abdomens.
- The anterior legs of males are much stouter and larger than the rest two pairs. This specialized pair of legs is used for holding the female during copulation.
- The louse lays eggs on the hair of its host, sticking them directly to the hair shaft. These eggs, called nits, are even harder to remove from the host's hair than the adults, which makes it very difficult to completely eliminate all lice from a host.
- The anoplurans **transmit serious diseases** in human beings; such as typhus fever, relapsing fever and trench fever.

4.5.2 Order Hemiptera

Order Hemiptera comprises true bugs, scale insects, aphids, white flies. A few hemipterans are beneficial for human beings, while others are either phytophagous causing harm to different parts of the plants, act as predators or

disease vectors in human beings. The common examples of disease vectors include sanguivorous bugs, such as bedbugs and kissing or vampire bugs.

The detailed characteristic features of hemipterans are as follows.

- Hemipterans are small to large-sized insects commonly present in our surroundings.
- The head is hypognathous or prognathous with a distinctive rostrum, and piercing and sucking mouthparts.
- The mandibles and maxillae are modified and form a stylet sheathed within a modified labium. The stylet can pierce plant or animal tissues. It contains a channel through which it can release the saliva and suck the fluids.
- The antennae typically consist of four or five segments, though they can be quite long.
- Most of the hemipterans have two pairs of wings. The forewings are of harder consistency than hindwings; which may or may not be uniform. Based on this, hemipterans are of two kinds.
 - (a) **Homoptera**: The hemipterans with forewings of uniform consistency; either toughened or membranous; are termed as homoptera. At rest, all four wings are held over the body like a tent.
 - (b) **Heteroptera**: The forewings of these insects are divided into two distinct regions; a harder and leathery basal region and the membranous apical region. These are called hemelytra (singular; *hemelytron*). At rest, all four wings are folded flat over their back.
- The hemelytra of adult true bugs cross over to form “X”-pattern on back forming a triangle structure, **scutellum**, at the centre of their back.
- Hemipterans are **hemimetabolous** and develop through a series of nymphal instars which look like the adults. During development, the nymphs moult several times, and gradually resemble adult more. A few hemipterans, such as aphids develop **parthenogenetically**.
- Hemipterans exhibit various modes of locomotion, such as swimming, skating on a water surface, jumping, walking and flying.
- Some species, such as aphids are significant **agricultural pests** and damage crops by sucking sap and transmitting serious viral diseases. A few species, such as bed bug and kissing bugs can **transmit serious diseases** to human beings. Various species are predators of insect pests and are used in biological control. Hemipterans have also been cultured for **beneficial purpose**, such as lac insects for shellac and cochineal scale insect for dye, etc.

4.5.3 Order Diptera

The order Diptera includes all true flies, mosquitoes, gnats and midges, etc. They live in variety of habitats and perform diverse functions of human importance. The detailed characteristic features of dipterans are as follows:

- The most distinctive feature of all dipterans is presence of only forewings, which assist in flight. The hind wings are reduced to small, drumstick-shaped structures called **halteres**. These vibrate during flight producing a buzzing sound and also help the flies to maintain balance. Their wing arrangement gives them great manoeuvrability in flight.
- Flies have a mobile head, with a pair of large compound eyes.
- Major part of the thorax is made up by mesothorax, though all thoracic segments are fused together.
- The **haustellate mouthparts** of dipterans have diverse modifications.
 - (a) A few species; such as mosquitoes, sand flies, robber flies, etc.; have **piercing and sucking** mouthparts. These flies include vectors, parasites or predators of small arthropods.
 - (b) Many species of flies have mouthparts modified for **lapping and sponging**. These flies survive on honeydew, nectar or the exudates of dead or alive plants and animals.
- The tarsi are provided with claws and pads which enable them to cling to smooth surfaces.
- Flies undergo **complete metamorphosis**. The larvae lack true limbs (apodous) and can be found in aquatic, semi-aquatic, or moist terrestrial environments. The pupa is enclosed in a tough capsule, called **puparium**.
- A few dipteran species are herbivores. They help to pollinate plants and also act as pests of agricultural plants.
- Some dipterans parasitize other organisms, especially vertebrates, molluscs and arthropods; and transmit diseases to humans and domestic animals. The human diseases include dengue, Chikungunya, Filariasis, encephalitis, malaria, Zika, etc.
- Most of the flies, however, feed on dead and decaying organic matter. These not only help in the decomposition of organic matter, but also act as carriers of disease agents.

4.5.4 Order Siphonaptera

Order Siphonaptera comprises fleas, the sanguivorous ectoparasitic insects. The detailed characteristic features of these are as follows:

- Fleas are small (3 mm long), apterous, active, brown-coloured insects with highly sclerotized exoskeleton.
- They have a laterally compressed body which helps them to slip easily within the fur or feather of host.
- The fleas are characterized by the presence of backwardly directed spine-like setae arranged in rows. Large bristles present on the head or thorax are called genal and pronotal combs.

- Only adult fleas live on the blood of their hosts; mammals or birds. Adults may live for a year or more and can survive for weeks or months without a blood meal.
- The mouthparts are adapted for piercing skin and sucking host blood.
- Antennae are clavate, short and stout, concealed in grooves. Antennae of males are much longer than females.
- The legs of fleas are quite long. Hind legs have large coxae and are extremely well adapted for jumping. They are able to leap a distance of some 50 times their body length.

A flea can jump vertically up to 7 in (18 cm) and horizontally up to 13 in (33 cm), a distance of more than 50 times their body length

- Their legs have strong claws which prevent them from being dislodged from the host body by clinging to the host hair and feathers.
- The fleas are holometabolous. Their larvae have a vermiform body, with sparse bristles, reduced head, mandibulate mouthparts and lack eyes. Instead of living on the host body, they are found in its nest or bedding and feed on adult faeces and organic debris left on their host's skin.
- The pupation takes place within a thin silken cocoon.
- Fleas inflict irritating bites on the host and transmit pathogens cause deadly disease in humans and other animals. These include typhus fever and plague.

SAQ 6

Mark the following statements *True* or *False*.

- a) The hindwings of heteropterans are modified as scutellum.
 - b) While sucking blood, anoplurans inject anticoagulant in the host blood to let the blood flow.
 - c) Fleas spend their whole life on their hosts.
 - d) Halteres and hemelytra perform same function in insects.
-

4.6 SUMMARY

Let us summarise what you have learnt so far:

- The vast number of species, wide distribution, reproductive capacity and adaptability to survive in extreme conditions make insects the most successful animals on the Earth.
- They are immensely significant in human life as they are economically important pests, good pollinators, environmental quality indicators, commercially important, exceptional research models and also dreadful disease carriers.

- The insects are categorized primarily based on presence or absence of wings and then sub-categorized various morphological features, especially of wings, and their development.
- The two sub-classes under Class Insecta include; Apterogota comprising primitively wingless insects and Pterygota comprising winged or secondarily wingless insects.
- The pterygotes are further divided into two Divisions; Exopterygota which are hemimetabolous insects exhibiting external development of wings and Endopterygota which are holometabolous insects with wings developing externally.
- Apterogotes include four orders; Protura, Collembola, Diplura and Thysanura; while pterygotes include 25 orders; a total of 16 in exopterygota and 9 in endopterygota.
- Among 29 orders of insects; four orders are considered medically significant containing important diseases vectors. These include Hemiptera, Siphunculata, Diptera and Siphonaptera.
- Order Hemiptera contains sanguivorous bugs; Order Siphunculata includes lice; Order Diptera has mosquitoes, sand flies, etc.; and Order Siphonaptera encompass fleas. All these vectors and blood-sucking and release pathogen while feeding on human blood.

4.7 TERMINAL QUESTIONS

1. Illustrate the basic classification of Class Insecta with the help of a flow chart. Write at least two features of each category. Support your answer with suitable examples.
2. Identify the Insect order based on the following features.
 - a) Apterogotes with a springing organ on their fourth abdominal segment.
 - b) Endoparasitic forms with forewings reduced to pseudohalteres.
 - c) Insects with equal wings characterised by a dark stigma and a nodus.
 - d) Holometabolous with forewings modified as elytra.
 - e) Social insects with identical wings in alate forms.
 - f) Insects with siphoning mouthparts and scaly wings.
3. Distinguish between the following insect orders based on the clue given in parentheses.
 - a) Mallophaga and Anoplura (Mouth parts)
 - b) Heteroptera and Homoptera (Forewings)
 - c) Diptera and Strepsiptera (Reduced wings)
 - d) Isoptera and Hymenoptera (Joining of thorax and abdomen)

4. Name the apterygote orders and explain the features of **any two**.
5. Discuss the morphological features of the insect order which is the largest endopterygote order.
6. Describe the characteristic features of two hemimetabolous orders comprising important disease vectors.
7. Write the important features of Order Siphonaptera which make them important disease vectors.

4.8 ANSWERS

Self Assessment Questions

1. a) False, b) True, c) False.
2. a) When metamorphosis is accompanied by increase in the number of abdominal segments after each moult, it is termed as anamorphosis. It is shown by Order Protura.
b) Furcula
c) All apterygotes have pregenital appendages on their abdomen.
3. a) The mouth parts of mayflies are atrophied and they cannot feed.
b) Order Ephemeroptera, Odonata, Plecoptera (Any two)
c) Order Odonata
d) Grasshoppers, Locusts, Cricket (any one)
e) The cerci of earwigs are unjointed, highly sclerotised and forceps-like.
4. a) Tegmina, b) *Trichonympha*, c) Mallophaga, Anoplura, d) scutellum.
5. a) In Diptera, hindwings are reduced to club-shaped structures, while in Strepsiptera, forewings are reduced.
b) Wing veins are extensively branched like nerves.
c) Coleoptera.
d) The male genitalia of flies in Order Mecoptera are shaped as scorpion's sting.
e) The wings are more or less densely hairy and held roof-like over the back at repose.
6. a) False; b) True; c) False; d) False.

Terminal Questions

1. Refer to Section 4.2.

2. a) Collembola, b) Strepsiptera, c) Odonata, d) Coleoptera,
e) Isoptera, f) Lepidoptera.
3. a) Mallophaga - biting; Anoplura – Piercing and sucking
b) Heteroptera – non-uniform thickness with apical part more membranous; Homoptera – Uniformly thick
c) Diptera – Hindwings as halteres; Strepsiptera – Forewings as pseudohalteres
d) Isoptera – Broad; Hymenoptera – Constricted
4. Refer to Section 4.3.
5. Order Coleoptera; Refer to the sub-section 4.4.2.
6. Refer to the sub-sections 4.5.1 and 4.5.2.
7. Refer to the sub-section 4.5.4.

Acknowledgement of Figures

Fig. 4.2: <https://www.britannica.com/animal/insect>

Fig. 4.3: (a) https://commons.wikimedia.org/wiki/File:Protura_from_Durham,_NC,_USA..jpg;
(b) <https://www.flickr.com/photos/micks-wildlife-macros/3163104863/>;
(c) <https://pt.m.wikipedia.org/wiki/Ficheiro:Diplura.jpg>;
(d) <https://commons.wikimedia.org/wiki/File:LepismaSaccharina.jpg>

CONCEPT OF INSECT VECTORS |

Structures

5.1 Introduction	5.5 Host-Vector Relationship
Objectives	5.6 Vectorial Capacity
5.2 Carrier and Vector	5.7 Vector-Pathogen Relationship
5.3 Types of Vectors (Mechanical and Biological Vector)	5.8 Summary
Mechanical	5.9 Terminal Questions
Biological	5.10 Answers
5.4 Mode of Transmission of Disease	
Propagative Transmission	
Cyclo-propagative Transmission	
Cyclo-developmental Transmission	
Vertical and Direct Transmission	

5.1 INTRODUCTION

You have studied that insects are found in abundance compared to any other group of animals. They appeared on the earth prior to human existence. Therefore, they are more adapted. Subsequently, many parasites and viruses have also co-evolved with many insects and used them for their life cycle and dispersal. An insect may be a vector or carrier of certain pathogens that render them as insect of public health importance or as insect of economic importance.

Vector-borne diseases are responsible for human illnesses caused by parasites, viruses and bacteria that are transmitted by mosquitoes, sandflies, triatomine bugs, blackflies, ticks, tsetse flies, mites, snails and lice. Every year there are more than 700 000 deaths, globally from diseases like malaria, dengue, schistosomiasis, human African trypanosomiasis, leishmaniasis, Chagas disease, yellow fever, Japanese encephalitis and onchocerciasis (Table 5.1).

Table 5.1: List of Vector Borne Diseases, according to their vector and pathogen.

Vector	Disease Caused	Type of pathogen
Mosquito <i>Aedes</i>	Chikungunya	Virus
	Dengue	Virus
	Lymphatic filariasis	Parasite
	Rift Valley fever	Virus
	Yellow Fever	Virus
	Zika	Virus
	<i>Anopheles</i>	Lymphatic filariasis
		Parasite
		Malaria
		Parasite
<i>Culex</i>	Japanese encephalitis	Virus
	Lymphatic filariasis	Parasite
	West Nile fever	Virus
Aquatic snails	Schistosomiasis (bilharziasis)	Parasite
Blackflies	Onchocerciasis (river blindness)	Parasite
Fleas	Plague (transmitted from rats to humans)	Bacteria
	Tungiasis	Ectoparasite
Lice	Typhus	Bacteria
	Louse-borne relapsing fever	Bacteria
Sandflies	Leishmaniasis	Parasite
	Sandfly fever (phlebotomus fever)	Virus
Ticks	Crimean-Congo haemorrhagic fever	Virus
	Lyme disease	Bacteria
	Relapsing fever (borreliosis)	Bacteria
	Rickettsial diseases (eg: spotted fever and Q fever)	Bacteria

	Tick-borne encephalitis	Virus
	Tularaemia	Bacteria
Triatome bugs	Chagas disease (American trypanosomiasis)	Parasite
Tsetse flies	Sleeping sickness (African trypanosomiasis)	Parasite

Vector-borne diseases are a major concern of public health at a global scale. These diseases are unpredictable and very difficult to be controlled. However, the implementation of good management practices in different economic, environmental and agricultural sectors could prove effective in slowing down their progress in relation to effects owing to climate change and globalization (Fig. 5.1). In the present unit we shall discuss the difference between carriers and vectors of the pathogens and their relationship with the host. Host-vector relationship and vector adaptations will be also discussed.

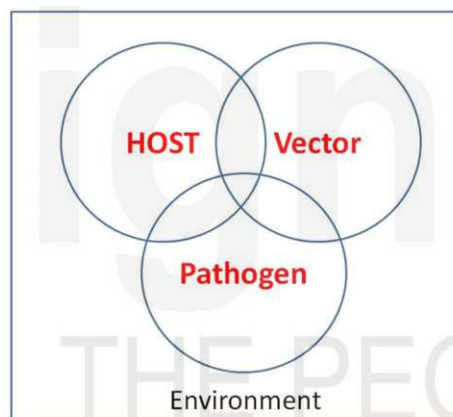


Fig. 5.1: Elements of vector borne disease transmission.

Objectives

After you have read this unit you should be able to:

- ❖ differentiate between carrier and vector,
- ❖ describe the types of carriers and vectors,
- ❖ discuss the mode of transmission,
- ❖ explain the host-vector relationship, vectorial capacity with the factors affecting it, and
- ❖ discuss the adaptation as vectors.

5.2 CARRIER AND VECTOR

5.2.1 Carrier

If an insect is having any pathogen associated with its life cycle or carries any pathogen symbiont/parasite (ecto or endo) and harbours these pathogens of a disease without manifestation of symptoms and is capable of transmitting the

infection; the condition of such an individual is referred to as the **carrier**. **A carrier can transmit the pathogen to its offspring.** The carriers can or cannot become a vector as it depends upon several factors.

Transient carrier: The host can be infectious for a short period in transient carriers, or over a prolonged period in a chronic carrier.

Asymptomatic carriers: The person or animal infected with pathogen can potentially spread its pathogen, but does not show clear symptoms. The symptoms may be mild, or may be completely absent. These hosts are called carriers, or **asymptomatic carriers**.

Incubating carriers: The person or animal has been infected and can spread the pathogen, but do not yet show the symptoms of the illness.

Convalescent carriers: These types of carriers continue to spread the pathogen even though they have recovered from illness.

Perfect example in humans for carrier is Mary Mallon, known as "Typhoid Mary", who was an asymptomatic carrier of typhoid fever. She worked as a cook for several families in New York City at the beginning of the twentieth century and she also cooked for the soldiers. Several cases of typhoid fever in members of those families were traced to her by the Health Department. It appeared that she "carried" the infectious agent of typhoid without becoming sick. When found responsible for many deaths around her she was quarantined in islands surrounding Manhattan throughout her life. Typhoid Mary appeared perfectly healthy, but infected about 50 people before she was quarantined.

SAQ 1

Write the difference between asymptomatic and convalescent carrier.

5.2.2 Vector

A disease vector (Vector is a Latin word which means 'bearer') is any agent (a human, animal or microorganism) that carries and transmits an infectious pathogen into another living organism, either directly via the blood flow or indirectly via the food, water or any other element of a susceptible organism which may be in contact with it.

Better way to understand is the organism which is able to hold pathogen in live form and may or may not increase its population and/or helps to change non infective stage of pathogen to infective stage and is able to transmit the pathogen to other organism. How good is a vector that depends upon how efficiently it transmits the disease pathogen to the healthy person / animal and how many of such healthy person/animals it infects. You can also say number of secondary cases produced from one single case by a vector is also called as vectoral capacity. You will read about vectorial capacity later in this Unit.

Arthropods form a major group of pathogen vectors with mosquitoes, flies, sand flies, lice, fleas, ticks, and mites transmitting a huge number of pathogens. Many such vectors are haematophagous (blood feeding), which

feed on blood at some or most stages of their life. During the feeding process, the pathogen enters the blood stream of the host. Fig. 5.2 depicts how disease is transmitted from an infected person to a healthy person.

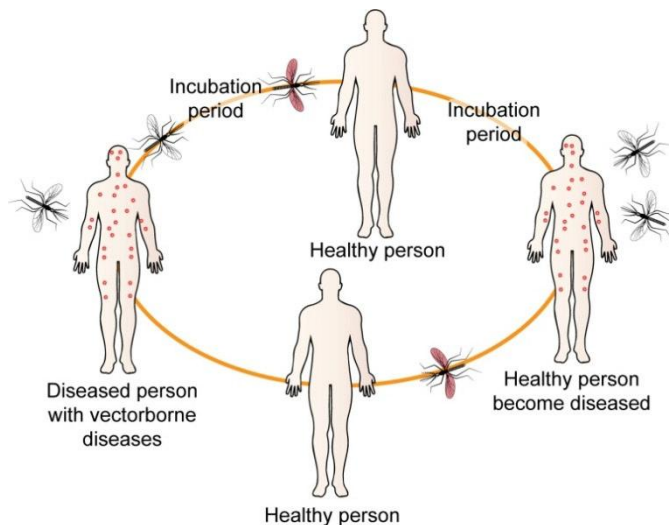


Fig. 5.2: Transmission of disease from infected person to healthy.

So let us summarise the difference between carrier and vector.

Carrier is an individual who has the disease but no symptoms. It is capable of transmitting the disease to a new individual. **Vector** is an organism which is capable of transmitting the diseases without having the disease itself.

5.3 TYPES OF VECTORS (MECHANICAL AND BIOLOGICAL VECTORS)

Insects as vectors can assume different roles according to the relationship they establish with the infectious agent they carry.

5.3.1 Mechanical

The only function of these vectors is to transport the infectious agents, which don't really need vectors to complete their life cycle (that is, the insect isn't a host of the pathogen). For example some flies transport infectious agents/pathogens of some intestinal infections, but these agents/pathogens do not need flies to complete their life cycle. That means the transmission is not dependent on the vector specification; it could have been transmitted with bare hands or any other means. Therefore, **the mechanical transmission is the transmission which occurs by contamination of pathogen through mechanical means like a fly sitting on infected wound/garbage/faeces etc. and contaminating the food article by just sitting on them.**

Flies can carry human pathogens on the sponging mouthparts, on body and leg hair (i.e., setae), or on the sticky pads of the feet (i.e., tarsi). Fine hair on the pads of a fly's feet are coated with a sticky substance which improves the fly's ability to adhere while resting or climbing on non-horizontal surfaces. This substance also enhances the adhesion of particles, i.e., viruses, bacteria, and protozoan cysts, to fly's legs, which then can be directly transported to the next visited person where it can be dislodged. Small particles readily adhere to a fly's exterior surfaces due to the electrostatic charge of fly exoskeleton and any particle with a different charge or a neutral charge will adhere to the fly surface (Fig. 5.3a).

Protozoan parasites can pass through the fly gastrointestinal tract without alteration of their infectivity and can be subsequently deposited on visited surfaces in “faecal spots”. Sometimes, the parasites present in fly alimentary tracts can be regurgitated, i.e., vomit drops, on a surface perceived by a fly as a meal (regurgitation always precedes feeding). Frequent meals on contaminated substrates together with alternating regurgitation and ingestion cause progressive accumulation of human pathogens in the fly alimentary system.

5.3.2 Biological

Vector is an essential element in the pathogen’s life cycle, which needs the insect (that is, the vector) to complete its development before being transmitted to another organism. All intermediate hosts are biological vectors but all biological vectors are not necessarily intermediate hosts. Most of infectious agents travel inside insect’s hemolymph (the liquid equivalent to blood in insects). This is the case of the pathogen (an apicomplexan from the genus *Plasmodium*), responsible for malaria which travels from an organism to another inside the hemolymph of different mosquito species from the genus *Anopheles*.

In biological transmission the biology and the behaviour of vector play a vital role in transmission of disease. Table 5.2 depicts various insect vectors, diseases caused by them and mode of transmission. Most arthropod vectors transmit the pathogen by biting the host, creating a wound that serves as a portal of entry. The pathogen may go through part of its reproductive cycle in the gut or salivary glands of the arthropod to facilitate its transmission through the bite (Fig. 5.3b). For example kissing bug transmits **Chagas disease** to humans by defecating when they bite, after which the human scratches the infected faeces into mucous membrane or break in the skin.

Biological transmission, because it involves survival and reproduction within a parasitized vector, complicates the biology of the pathogen and its transmission.

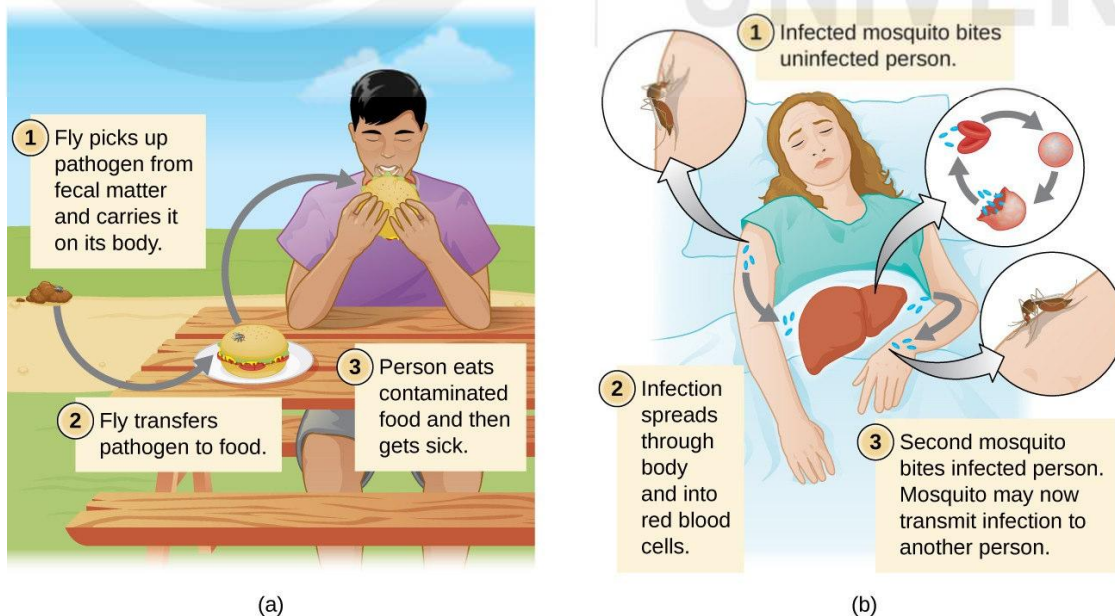


Fig. 5.3: a) A mechanical vector carries a pathogen on its body from one host to another (not as an infection) b) A biological vector carries a pathogen from one host to another after becoming infected itself.

Table 5.2: Insect vectors and diseases caused by them.

Vectors	Species/ Genera	Disease	Mode of Transmission
Fly	House fly (<i>Musca</i>) 	Typhoid Cholera Dysentery Anthrax Tuberculosis	Mechanical Transmission
Mosquito	<i>Aedes</i> 	Chikungunya Dengue fever Rift Valley fever Yellow fever Zika	Infective bite Biological
	<i>Anopheles</i> 	Malaria Lymphatic filariasis	Infective bite Biological
	<i>Culex</i> 	Japanese Encephalitis Lymphatic filariasis West Nile fever	Infective bite Biological
Sandflies	<i>Phelebotomus</i> 	Leishmaniasis Sandfly fever (<i>Phelebotomus</i> fever)	Infective bite Biological
Blackflies "buffalo gnats" & "turkey gnats,"		Onchocerciasis or river blindness Africa, America, Latin and Yemen	Infective bites Biological
Tse tse fly		Sleeping Sickness Africa	Infective bite Biological

Triatomine bugs		Chagas disease (American trypanosomiasis)	Infective bite Biological
Fleas		Plague rickettsiosis	Transmitted by fleas from rats to humans Biological
Lice		Typhus and louse-borne relapsing fever	Infective bite Biological
Ticks (These are arachnids).		Crimean-Congo haemorrhagic fever Tick-borne encephalitis	Infective bite of larval stage Biological

SAQ 2

Write differences between mechanical and biological vector with one example each.

5.4 MODE OF TRANSMISSION OF DISEASE

There are various modes of transmission of pathogens by the biological vectors stated as under:

5.4.1 Propagative Transmission

Propagative transmission occurs when the organism/pathogen ingested with the blood meal undergoes multiplication in the body of the arthropod. Arboviruses (eg. Dengue, JE virus, Chikungunya, Zika), for example, replicate extensively in various tissues of mosquitoes and are transmitted to a new host in the salivary fluid of the mosquito when it takes a blood meal. The agent undergoes no cyclical changes but simply grows and multiplies in body of vector (Plague bacilli in rat flea).

5.4.2 Cyclopropagative Transmission

In this type of transmission, the pathogen undergoes a developmental cycle (changes from one stage to another) as well as multiplication in the body of the arthropod. The best example of a disease transmitted in this way is **malaria**, in which a single zygote may give rise to as many as >200,000 sporozoites (Fig. 5.3). The agent undergoes cyclical changes and also multiplies in the body of arthropods.

5.4.3 Cyclodevelopmental Transmission

In cyclodevelopmental transmission **the pathogen undergoes developmental changes from one stage to another, but does not multiply**. For example in filaria, a single microfilaria ingested by a mosquito (*Culex*) may result in only one third-stage of infective larva. Essentially however, the number of infective larvae is significantly lower than the number of microfilariae ingested with the blood (Fig. 5.4). The agent undergoes cyclical changes but does not multiply in the body of arthropods.

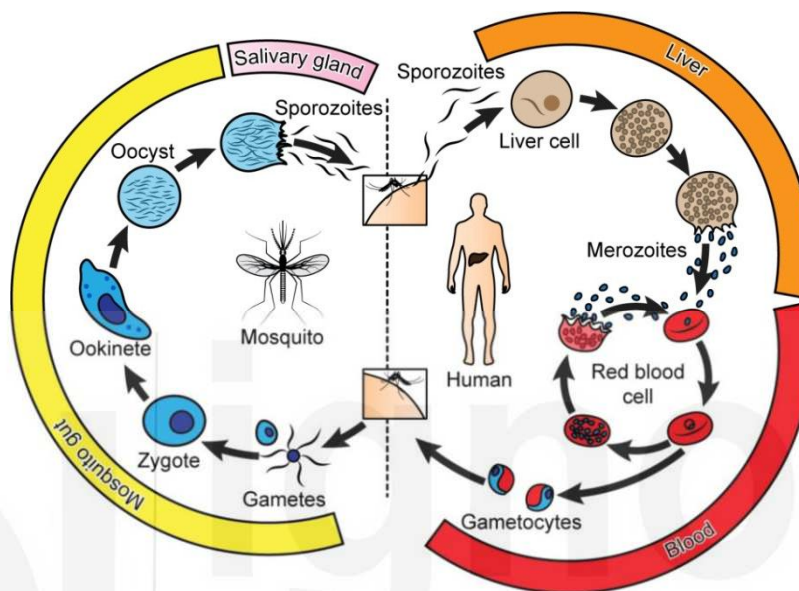


Fig. 5.4: Showing Malaria life cycle and different developmental stages of malarial parasite in mosquito.

5.4.4 Vertical and Direct Transmission

Some viruses and rickettsiae are transmitted from the female parent arthropod through the eggs to the offspring. If the pathogen actually infects the developing egg, this is termed 'transovarial transmission' (TOT). TOT or Vertical transmission is the spread of pathogen from parent to offspring. The developing ovum is infected and agent is present in interior of egg (Fig. 5.5).

In either case, the newly hatched arthropod larval stages are infected with the pathogen, which is then transmitted to subsequent developmental stages of the arthropod ('trans-stadial transmission').

Veneral transmission of certain viruses has also been documented. Thus, male mosquitoes that become infected transovarially or vertically can transfer the virus to uninfected female mosquitoes in the seminal fluid during copulation. Finally, certain **arboviruses** have been shown to infect their tick or mosquito vectors when infected and uninfected arthropods co-feed in close proximity to each other on the same vertebrate host in the absence of viraemia (Viruses present in the blood stream) in that host. The virus is apparently attracted to the uninfected female arthropod through a chemo-tactic response to the salivary fluid injected into the bite wound. These latter types of transmission have obvious epidemiological importance in the ultimate infection of humans or other animals and in the maintenance of the pathogen in nature.

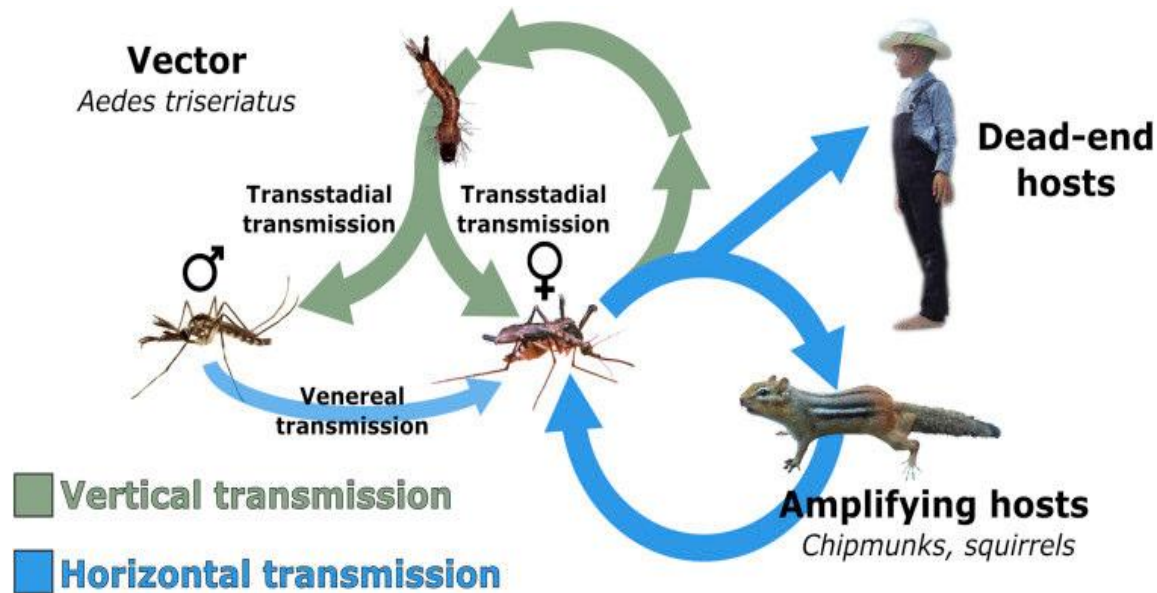


Fig. 5.5: Vertical and Horizontal Transmission.

SAQ 3

Read the following sentences and tick mark the correct alternative.

- Incubating/Convalescent carriers** are infected and can spread the pathogen, but do not show the symptoms of illness.
- The only function of **mechanical/biological** vectors is to transport the infectious agents which don't really need vectors to complete their life cycle.
- In **propagative/cyclopropagative transmission** the pathogen undergoes a developmental cycle and multiplication in the body of arthropod.
- Some virus and rickettsiae are transmitted from **male/female** parent through the **sperms/eggs** to the offspring.

5.5 HOST-VECTOR RELATIONSHIP

Host is a main factor which receives the pathogen from vectors. There is a mutual parasitic relationship of vector with its host. There we can say a **host is an organism that harbours a parasitic, a mutual, or a commensal guest or symbiont, typically and providing nourishment and shelter in or on its body.**

There are different types of hosts on which the transmission dynamics also depend, the vectors of certain types are dependent on the availability, status, habits, habitats and physiological conditions of the host. For example *Plasmodium* parasite's **primary host** and transmission vector is female *Anopheles*. Humans and other vertebrates are secondary hosts. *Anopheles* mosquitoes (the vector) are the **definitive hosts** in which sexual life cycle of parasite is completed. Humans are intermediate asexual hosts.

5.6 VECTORIAL CAPACITY

Vectorial capacity is a measurement of the efficiency of vector-borne disease transmission. **It is the capability of a vector for disease transmission to a host, as influenced by behavioural, ecological and environmental factors, such as population density, host preference, feeding habits or frequency, duration of latent period, or longevity.**

There is one more term “**vector competence**” which refers to an evaluation of the vector’s capability (mechanical or biological) to transmit a pathogen. **It is the physiological ability of a vector organism to acquire, maintain and transmit an infectious agent, as described by susceptibility to a pathogen, immune response, and sustaining infection long enough for disease transmission to occur. Therefore, vector competence is actually an additional component of vectorial capacity.** Vectorial capacity is a measurement of the efficiency of vector-borne disease transmission.

How efficient is a vector calculated by its efficiency to produce number of secondary cases from single primary case per day till its life time which may be calculated by a formula given as below :

$$VC = \frac{ma^2cP^n}{-\log_e P}$$

VC = Vectorial capacity, the number of infective bites received daily by a single host,

m = Density of vectors in relation to density of hosts, a = Proportion of vectors feeding on a host divided by the length of gonotrophic cycle in days,

C = Vector competence,

P = Daily survival of vectors,

n = Extrinsic incubation period (the time taken by an organism to develop in the intermediate host)

SAQ 4

State difference between vectorial capacity and vectorial competence.

Factors affecting vectorial capacity

- **Anthropophilic / Zoophilic biting:** Efficient vector should bite human preferably (anthropophilic nature like mosquito species *Anopheles stephensi* and *Aedes aegypti*) whereas some species like to bite animals as first choice they are called as zoophilic in nature like species of mosquito *Anopheles culicifacies*. The efficiency of vector is high as we are considering vectors for human health therefore **more efficient will be that vector whose preference is human for feeding.**
- **Longevity:** It is referred to the life expectancy of a insect vector in days. But why it is important for vectorial capacity, there are two important factors for vectorial capacity: 1) the life span of the insect vector must be higher than the incubation period of pathogen so that pathogen can come as expressive in the salivary glands of the insect to get inside the

host. For example, the incubation period of malarial parasite is 10-16 days and similarly for dengue virus it is 8-12 days and life span of the vector is higher than that of about 30-40 days. 2) if vector lives longer as infected with parasite/virus it will feed more on host and spread the diseases more.

- **High productivity:** The vectors should be produced in high number for their survival and transmission.
- **Daily survival of vectors:** The vectors should be able to survive on daily basis from their natural enemy and climatic conditions.
- **Facilitate pathogen:** Physiology of vector should support the lifecycle and should be able to increase the pathogen numbers to a threshold of transmittable level and should be able to keep pathogen in it body throughout its life span for transmission.
- **Density of Vector:** Density of vectors is very important for transmission of diseases, high density is directly related to high infection rates in community in a particular location.
- **Bio-rhythm with host:** The vector is efficient if it has smooth and efficient biorhythm with the host on which it is dependent for blood. Some of the mosquitoes for example *Anopheles* bite in late night to give least disturbance to the host and keep them selves safe also. Similarly some species like *Aedes* have habit of biting in the day time but they have developed painless biting and also release a local anaesthesia (numbness) chemical so that the host does not know the mosquito has bitten till the signals of bite reach to host brain. By that time the mosquito has already taken its blood meal.
- **Transovarial Transmission:** In some of the viral transmission the vectors become efficient not only by getting infected from the infected host but the virus/pathogen transmit themselves from one generation to the next through their eggs, such type of transmission is called as vertical transmission also. This type of transmission can make vector infected from the time of emergence into adult and may also not require incubation period as required in the case of transmission through the patient for example in *Aedes* species.
- **Environmental factors:** Temperature plays vital role in the life cycle of insects in their aquatic forms. With optimum temperature the development of pathogen inside the vector is increased (Fig. 5.6).

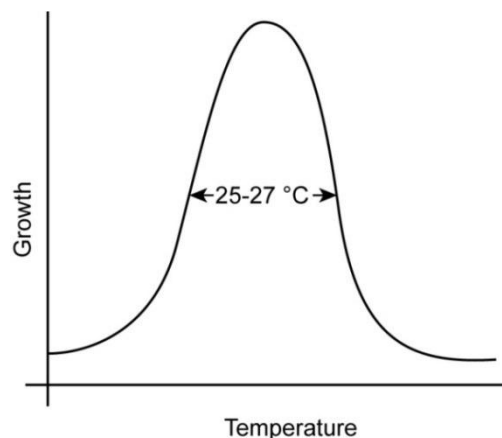


Fig. 5.6: Normal growth curve of pathogen with respect to temperature.

- **Intrinsic factors:** The susceptibility status of vector to provide better opportunity for pathogen to grow depends on immune response and is sub-specific.

Why mosquitoes are good vectors?

Mosquitoes are considered “vectors” because they can carry diseases and transmit them to humans. There are over 2500 species of mosquitoes found on 6 continents, but not all mosquitoes are created equal. There is incredible diversity in their abilities to carry and transmit disease, a property called **vectorial capacity**. Vectorial capacity can be affected by their geographic range, when and if a mosquito species bites humans and animals, how and when mosquitoes reproduce, and even their resistance to insecticides. One approach to look at how mosquitoes change is **genomics**. Genomics is the study of the structure and function of an organism’s total genetic material—all of its genes encoded in DNA made up of A, C, T, and G nucleotides. This approach allows scientists to rapidly pull out some of the most relevant genes, or groups of genes, that may contribute to mosquitoes’ ability to transmit disease. For example, genomics has shown us that mosquitoes like *Anopheles gambiae* and *Aedes aegypti*, some of the most effective disease vectors, are constantly evolving. Mosquitoes are organism whose fertility, behavior susceptibility to infection, and other characteristics important for vector competence are strongly influenced by a number of factors throughout larval and adult development.

A number of characteristics can make a mosquito species a better disease vector than others. These include a preference for biting humans (anthropophilic) over animals (zoophilic) and how the biting behavior corresponds to human behavior. *Anopheles gambiae* are indoor biters, for example, whereas *Anopheles arabiensis* are outdoor biters – some malaria vectors may bite at different times of the day. The reproductive rate of a given mosquito species also affects disease transmission (more mosquitoes = greater transmission).

5.7 VECTOR-PATHOGEN RELATIONSHIP

Blood-feeding insects transmit numerous viruses, bacteria, protozoans and helminths to vertebrates. The developmental cycles of the microorganisms in their vectors and the mechanisms of transmission are generally extremely complex and are the result of a long-lasting co-evolution of vector and its pathogen based on mutual adaptation. Insects adaptations to become a vector are multiple but require an innate **vector competence** as a genetic basis. Next to the vector competence plenty of entomological, ecological and pathogen-related factors are decisive, given the availability of **infection sources**. The various modes of pathogen transmission by vectors are connected to the developmental routes of the microorganisms in their vectors. In particular, pathogens transmitted by saliva encounter a lot of cellular barriers during their migration from the insect's midgut through the hemocoel into the salivary fluid, including components of the insect's immune system. The intracellular development, receptor-mediated invasion mechanisms are of great relevance provided by vector to pathogen.

The temperature has an impact on vectorial capacity of hematophagous insects. Not only has it a considerable influence on the duration of a pathogen's development in its vector (extrinsic incubation period) but it can render putatively vector-incompetent insects to vectors. Behaviour of both vector and the pathogen for host preferences, seasonal appearance and circadian biting activity of the vector and diurnal/nocturnal periodicity on the pathogens which facilitate a contact.

5.8 SUMMARY

Let us summarise what we have studied so far:

- Vector-borne diseases (VBDs) are a major concern of public health at a global scale. They are caused by parasites, viruses and bacteria that are transmitted by vector, which are mostly insects.
- A carrier can transmit the pathogen to its offspring. It can be **transient, asymptomatic, incubating or convalescent**.
- A vector is any agent that transmits the infection pathogen into other living organisms directly or indirectly.
- Vector can be **mechanical** or **biological**. Biological transmission can be propagative, cyclopropagative, cyclodevelopmental or vertical.
- Vectorial capacity is a measurement of the efficiency of VBDs. This is affected by many factors like vector density, high productivity, environmental and intrinsic factors.

5.9 TERMINAL QUESTIONS

1. Enumerate differences between Carrier and Vector.
2. What is a vector? Explain vectorial capacity with formula.
3. Write factors affecting vectorial capacity.
4. Explain vector-pathogen relationship.
5. Differentiate between:
 - i) Propagative Transmission and Cyclopropagative Transmission
 - ii) Cyclodevelopmental Transmission and Vertical Transmission

5.10 ANSWERS

Self Assessment Questions

1. **Asymptomatic carriers:** The person or animal infected with pathogen can potentially spread its pathogen, but does not show clear symptoms. The symptoms may be mild, or may be completely absent. These hosts are called carriers, or **asymptomatic carriers**.

Convalescent carriers: These types of carriers continue to spread the pathogen even though they have recovered from illness.

2. The mechanical transmission is the transmission which occurs by contamination of pathogen through mechanical means like a fly sitting on infected wound/garbage/faeces etc. and contaminating the food article by just sitting on them.

Vector is an essential element in the pathogen's life cycle, which needs the insect (that is, the vector) to complete its development before being transmitted to another organism.

3.
 - i) Incubating carrier
 - ii) Mechanical vectors
 - iii) Cyclo-propagative transmission
 - iv) Female, eggs
4. It is the capability of a vector for disease transmission to a host, as influenced by behavioural, ecological and environmental factors, such as population density, host preference, feeding habits or frequency, duration of latent period, or longevity.

It is the physiological ability of a vector organism to acquire, maintain and transmit an infectious agent, as described by susceptibility to a pathogen, immune response, and sustaining infection long enough for disease transmission to occur. Therefore, vector competence is actually an additional component of vectorial capacity.

Terminal Questions

1. Refer to Section 5.2
2. A disease vector is any agent that carries and transmits an infectious pathogen into another living organism. For vectorial capacity refer to Section 5.6.
3. Refer to Section 5.6.
4. Refer to Section 5.7.
5.
 - i) Refer to Sub Sections 5.4.1 and 5.4.2.
 - ii) Refer to Sub Sections 5.4.3 and 5.4.4.

2. (a) Malpighian tubules, (b) Epidermal, (c) Urates, (d) Ammonia.
3. (a) Haemolymph, (b) Ostia, (c) Hemocytes.
4. (a) Trachea, (b) Air sacs, (c) Spiracles.
5. (a) Myofibrils, (b) Myosin, actin, (c) Catapult, (d) Hydrostatic skeleton.
6. (a) Nerve cells, glial cells, (b) Synapses, (c) Brain, (d) Ommatidia.
7. (a) Hermaphroditism, (b) Spermatophore, spermatheca,
(c) Metamorphosis, (d) Metamorphosis, (e) Pupa.

Terminal Questions

1. Refer to Section 3.3.
2. Refer to Section 3.4.
3. Refer to Section 3.5.
4. Refer to Section 3.6.
5. Refer to Section 3.7.
6. Refer to Section 3.8.
7. Refer to Section 3.9.