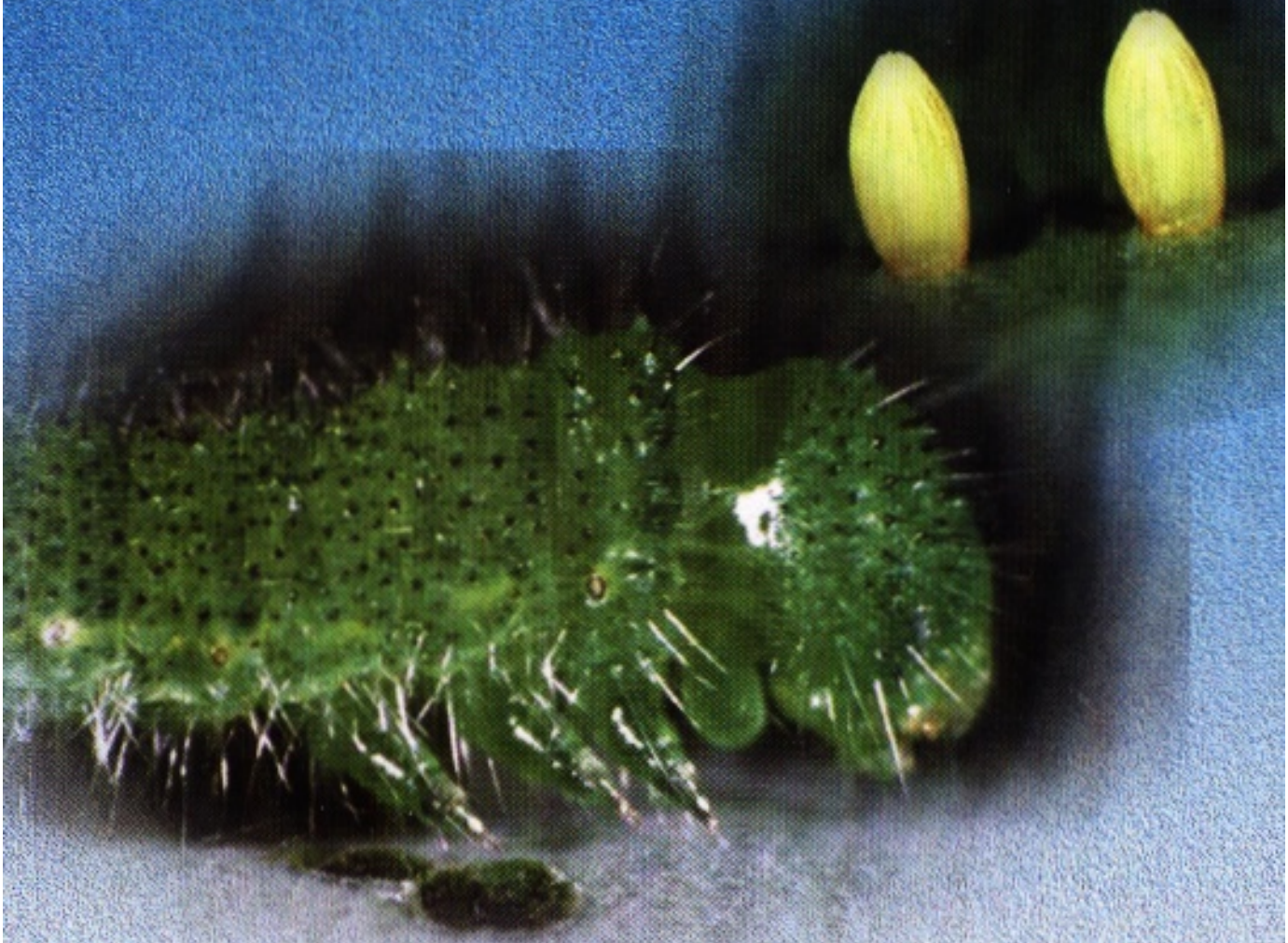
INSECTA

AN INTRODUCTION



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AEN 101 (1+1)

Fundamentals of Entomology

LECTURE SCHEDULE

1. Study of insects and their importance in Agriculture. History of Entomology in India – Position of insects in the Animal Kingdom – relationship with members of Arthropoda.
2. Insect dominance – structural, morphological and physiological factors responsible for dominance.
3. Insect body wall – its structure and function – moulting process in insects.
4. Structure of insect head, thorax and abdomen – their functions.
5. Digestive system in insects – structure of alimentary canal, modifications in certain groups, enzymes, digestion and absorption of nutrients.
6. Excretory system in insects – malpighian tubules – accessory excretory organs – physiology of excretion.
7. Respiratory system in insects – structure of trachea – tracheoles – types of respiratory system – types of spiracles – respiration in aquatic and endoparasitic insects.
8. Circulatory system in insects – haemocoel and dorsal vessel – circulation of blood – composition of haemolymph – blood plasma – haemocytes and their functions.
9. Mid-semester examination.
10. Nervous system in insects – structure of neuron – central nervous system – conduction of nerve impulses – axonic and synoptic transmission.
11. Male and female reproductive systems in insects – their structures – types of reproduction – oviparous, viviparous, paedogenesis, polyembryony and parthenogenesis.
12. Structure of sense organs – types of sensilla – photoreceptors, chemoreceptors and mechanoreceptors.
13. Structure of glands – exocrine and endocrine glands and their location and simple function – effect on metamorphosis and reproduction.
14. Tropism in insects - primary and secondary orientation – kinesis and taxis and their importance. Biocommunication in insects – sound and light production.
15. Classification and nomenclature of insects.
16. Important characters of insect orders – Exopterygota – Orthoptera Hemiptera and Thysanoptera ; Endopterygota – Lepidoptera and families of agricultural importance with significant characters.
17. Important characters of insect orders – Coleoptera, Diptera and Hymenoptera and families of agricultural importance with significant characters.

PRACTICAL SCHEDULE

1. Observations on external features of grasshopepr / cockroach

2. Methods of insect collection, preservation, pinning, labelling, display and storage
3. Mounting of types of insect head and types of antenna – making sketches
4. Mounting of insect mouth parts of cockroach – examining the modifications in the mouth parts of plant bug, female mosquito, honeybee, thrips, antlion grub, housefly, moths and butterflies
5. Structure of thoracic appendages – mounting and examining the modifications in insect legs and wings – wing venation, regions and angles – wing coupling.
6. Examining and sketching of modifications in the appendages of insect abdomen – pregenital and genital appendages.
7. Recording types of metamorphosis – observing and sketching the immature stages of insects *viz.*, egg, nymph, naiad, caterpilalr, maggot, grub and pupa.

8. Dissection of grasshopper / blister beetle / cockroach to note and sketch the alimentary canal.
9. Dissection of grasshopper / blister beetle / cockroach to observe and sketch the male and female reproductive systems.
10. Experimental studies on the location of sense organs – response to food, taste, light and defense behaviour of insects – behavioural, structural, chemical and colourational defense.
11. Observing the characters of important orders of Exopterygota – Orthoptera (Acrididae, Tettigonidae, Gryllidae and Gryllotalpidae), Hemiptera – Heteroptera (Reduvidae, Pentatomidae, Miridae, Coreidae, Pyrrhocoridae, Lygaeidae, Anthocoridae), Homoptera (Cicadellidae, Delphacidae, Aphididae, Aleyrodidae, Coccidae, Pseudococcidae and Psyllidae).
12. Observing the characters of orders Thysanoptera and Diptera (Cecidomyiidae, Agromyzidae, Tephritidae and Muscidae) and Hymenoptera (Tenthredinidae and Megachilidae).
13. Noting the external features of *Coleoptera* and study of important families of Agricultural importance (Curculionidae, Cerambycidae, Melalonthidae, Tenebrionidae, Bruchidae and Bostrychidae).
14. Observing the characters of Lepidoptera and its families of agricultural importance (Nymphalidae, Lycaenidae, Pieridae, Papilionidae, Crambidae, Pyraustidae, Noctuidae, Arctiidae, Sphingidae, Lymantriidae and Hesperidae)
15. Visit to different ecosystems to collect insects and study them in their natural habitat – Rice, Sugarcane, Orchard and Forest ecosystems.
16. Identification and naming of collected insects based on characters – order and family
17. Practical examination

SKILLS TO BE ACQUIRED

1. Collection and preservation of insects
2. Developing skill to identify insects
3. To become familiar with habitats

Contents

Acknowledgement

This book is compiled based on the information drawn from many different text books including those listed below. The authors /publishers of the original reference books are gratefully acknowledged.

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1. History of Entomology in India

Entomology is a biological science dealing with a specific group of organisms, the insects. Man originated about a million years ago, and insects at least 500 million years ago. Insects constitute the largest Class of the whole living organisms and about 72 per cent of all living animals are insects with 9-15 lakh known species. Insects are omnipresent and each crop we cultivate is being attacked by at least a dozen of insect species called as pests. Apart from the pest insects there are several productive and useful insects. Insects are considered as one of the major constrain in increasing agricultural productivity. Hence it is important to understand about the insects, their biology, classification and management.

Our earliest knowledge about insects dates back to 6000 yrs as our Indian ancestors were well versed in the art of rearing silk worms and weaving silk cloth. Even during 3870 BC an Indian king sent various silken materials as presents to a Persian king. There are lot of mentions about insects in our mythological epics, the Ramayana (2550-2150 BC) and Mahabharata (1424-1366 BC). Mentions about silk, honey and lac were found in these epics. The first detailed classification of insects was done by **Umaswati** (0-100 AD).Classification of bees by the Indian physician **Charaka** (1200-1000BC) and classification of ants, flies and mosquitoes by the surgeon **Sushruta** (100-200 AD) are the evidences for our earliest knowledge about insects.

Entomology in modern India must have taken its place in Natural History some time after the 16th century. It is possible to define the modern history of entomology in India under the following two headings.

1. From the advent of the early Christian Missions and the establishment of East India Company at Calcutta. The contributions made by several eminent amateur entomologists, otherwise serving in the army, Indian Forest Service, Indian Medical Service and Indian Civil service.
2. Entomology in India during 1900-1950.

1758- The beginning of the modern era of Indian Entomology came with the publication of the tenth edition of **Carl Linnaeus**'s "*Systema Naturae*". This contained the earliest record of 28 species of Indian insects. The first entomologist who made any extensive study of Indian Insects was **J.C.Fabricius**. He was a Danish Professor of political

economy turned in to a systematist and classified the insects in to 13 orders based on type of mouth parts .

1767-1779- J.G.Koenig, a medical Officer from Denmark, a student of Carl Linnaeus and friend of Fabricius, for the first time during the 18th century collected number of insects from Coromandel area and Southern Peninsular India and his collections were studied and named by Professor Linnaeus himself. He also published a special account of the termites of Thanjavur District. Fabricius, made Koenig's name remembered for ever by naming the well known and destructive red cotton bug of this country as *Dysdercus koenigi*.

1782 - Dr. Kerr published on account of lac insect.

1785- Asiatic Society of Bengal started in Calcutta.

1791- Dr. J. Anderson issued a monograph on Cochineal scale insects.

1799- Dr.Horsfield, an American doctor and first Keeper of the East India Museum published his famous book "A catalogue of the Lepidopterous Insects in the Museum of the Honourable East India Company, 2 vols. (1857, 1858-59).

1800- Buchanan (Traveler studying the natural wealth of India) wrote on the cultivation of lac in India and on sericulture in some parts of South India.

1800- Edward Denovan published an illustrated book entitled "An epitome of the natural history of insects of India and the Islands in the Indian seas" which was the first pictorial documentation on the insects of Asia and was revised in 1842 by West Wood.

1875- Foundation of the "Indian Museum" at Calcutta.

1883- "Bombay Natural History Society" was started. After the foundation of these two organisations scientific studies received greater attention in India. Numerous contributions of Indian insects were published in the Journal of the Bombay Natural History.

1883- Commencement of "Fauna of British India" series under the editorship of W.T.Blandford.

1892- Entomological part of the "Fauna of British India" (now Fauna of India) series started with Sir George **Hampson** contributed first of the four volumes on the moths of India.

1893- Rothney published on Indian Ants (earliest record of biological pest control in India) i.e. White ants attack on stationary items was kept free by red ants.

1889-1903 Indian Museum, Calcutta published the "Indian Museum Notes" in five volumes, which contributed much on economic entomology and applied entomology in India. 19th Century marks the major progress and expansions in the field of applied entomology.

1901- Lionel de Nicevelle was posted as the first entomologist to the Government of India

1903- Professor **Maxwell Lefroy** succeeded Nicevelle as Government Entomologist.

1905- Establishment of Imperial Agricultural Research Institute at Pusa, Bihar and Professor Lefroy became the first Imperial Entomologist. He convened a series of entomological meetings on all India basis to bring together all the entomologists of the country. From 1915 five such meetings were held at the Imperial Agricultural Research Institute at Pusa. While the Proceedings of the first meeting was not published, proceedings of subsequent four meetings became a treasure of entomolgical knowledge, which can never be overlooked by any student of Indian Entomology. Another contribution of Fletcher is the publication of series under the "Catalogue of Indian Insects" which marked another era in the history of Indian Insect Taxonomy.

1906- 'Indian Insect Pests' by Professor Lefroy.

1909- "Indian Insect Life"- Professor Lefroy.

Subsequently State Governments also took up entomological work. Madras, Punjab and Uttar Pradesh appointed their first State/ Provincial Government Entomologists in 1912, 1919 and 1922 respectively.

1912- Plant Quarantine Act was enforced.

1914- Destructive Insects and Pests Act was enforced.

1914- T.B.Fletcher, the first Government Entomologist of Madras State, published his book "Some South Indian Insects".

1914- 'Indian Forest Insects of Economic Importance: Coleoptera' was published by the first Imperial Forest Entomologist E.P.Stebbing

1916- Imperial Forest Research Institute was established at Dehra Dun, and E.P.Stebbing was appointed as Forest Zoologist.

1916- The Natural History Section of the Indian Museum was formed as the Zoological Survey of India.

1921- Indian Central Cotton Committee to investigate on pests of cotton.

1925- Indian Lac Research Institute started.

1934- Hem Singh Pruthi who succeeded Fletcher as Imperial Entomologist, made efforts to bring all the entomological workers still closer which resulted into the foundation of 'Entomological Society of India' in 1938. Afzal Hussain was the first President of the Entomological society of India and the Vice-President were Hem Singh Pruthi and Ramakrishna Ayyar. The official publication of the Society is the 'Indian Journal of Entomology'.

1939- Locust Warning Organisation was established.

1940- Dr. T.V. Ramakrishna Ayyar published the book "Handbook of Economic Entomology for South India" and revised second edition was published in 1963. Other useful publications by Indian authors were

1941- C.F.C.Beeson published "The ecology and control of the forest Insects of India and Neighboring countries"

1963- Text book of Agricultural Entomology by H.S.Pruthi

1968- Dr. M.S. Mani's "General Entomology"

1969- Dr. Pradhan's "Insect Pests of Crops"

1946- 'Directorate of Plant Protection, Quarantine and Storage' of GOI started.

1960- "The Desert Locust in India" monograph by Y.R. Rao.

1968- The Govt. of India enacted 'Central Insecticide Act'which came into force from 1st January, 1971.

1969- "The monograph on Indian Thysanoptera" was published by Dr.T.N.Ananthakrishnan.

2. Position of insects in animal kingdom and their relationship with other Arthropods

Insects are invertebrates grouped in the phylum **Arthropoda** (Arthro-joint, poda-foot) and subphylum Uniramia. Characters of the Phylum Arthropoda are

1. Segmented body
2. Segments grouped into 2 or 3 regions (tagma) known as Tagmosis.
3. Renewable chitinous exoskeleton
4. Grow by molting.
5. Bilateral symmetry of body.
6. Body cavity filled with blood and called as haemocoel.
7. Tubular alimentary canal with mouth and anus at anterior and posterior ends.
8. Dorsal heart with valve like ostia.
9. Dorsal brain with ventral nerve cord.
10. Striated muscles (with dark and light bands).
11. No cilia (hair like vibratile structure on the surface of the cell).
12. Paired, segmented appendages.

Phylum Arthropoda is Classified in to 7 classes.

1. Onychophora (claw bearing) e.g. Peripatus
2. Crustacea (Crusta - shell) e.g. Prawn, crab, wood louse
3. Arachnida (Arachne - spider) e.g. Scorpion, spider, tick, mite
4. Chilopoda (Chilo - lip; poda - appendage) e.g. Centipedes
5. Diplopoda (Diplo - two; poda- appendage) e.g. Millipede
6. Trilobita (an extinct group)
7. Hexapoda (Hexa- six; poda-legs) or Insecta (In- internal; sect – cut) e.g. Insects.

Relationship of insects with other arthropods

Characters	Onychophora	Crustacea	Arachnida	Chilopoda	Diplopoda	Insecta/ Hexapoda
1. Habit	Terrestrial	Aquatic and few terrestrial	Terrestrial	Terrestrial	Terrestrial	Many terrestrial and very few aquatic
2. Body regions	Not distinct	Two-Cephalothorax and abdomen	Three-Pro, Meso and Metasoma eg. Scorpion. Two-Pro and Opisthosoma eg. Spider	Two-Head and multisegmented trunk	Two-Head and multisegmented trunk	Three-Head, thorax and abdomen
3.Antenna	I pair	2 pair - Antennule and Antenna	No antenna	One pair	One pair	One pair
4. Visual organs	Not distinct	One pair - Stalked compound eyes	One pair - simple eyes	One pair-simple eyes	One pair-simple eyes	Both simple eyes and compound eyes (one pair)
5. Locomotor organs	Many pairs of unjointed legs	Minimum five pairs of biramous legs	Four pairs	One pair per segment (First pair of legs modified as poison claw)	Two pair per segment (No poison claws)	Three pairs of legs on three thoracic segments and two pairs of wings on meso and metathorax

6. MOUTH PARTS	Non mandibulate	Mandibulate (1 pair)	No mandibulate, but possess chelicerae	Mandibulate (I pair)	Mandibulate (1 pai r)	Mandibulate (1 pair)
7. RESPIRATION	Cutaneous	Gill breathing	Booklungs (Scorpion) and tracheal. (spiders)	Tracheal	Tracheal	Tracheal
8. Body fluid	Haemolymph	Haemolymph	Haemolymph	Haemolymph	Haemolymph	Haemolymph
9. Circulatory system	Heart with ostia	Heart with ostia	Heart With ostia	Heart with ostia	Heart With ostia	Heart With ostia
10. **Development**	Anamorphosis	Anamorphosis	Metamorphosis absent scorpion; Metamorphosis present-mites	Metamorphosis	Metamorphosis	Metamorphosis
11. **Habit**	Feed on organic matter	Herbivorus and Carnivorous	Phytophagous and predators	Carnivorous	Herbivorous	Phytophagous, predators and parasitoides
12. **Special features**	Link between Annelida and Arthropoda	Classification strengthens exoskeleton	Life cycle; Egg-larva-nymph-adult. larva With 3 pairs of legs and Nymph with 4 pairs of legs	Opisthogenital-gonopore present in the terminal segment	Progogenital-gonopore in 3rd segment	Genital structures on 8th and 9th abdominal segments. Brain with proto, deuto and tritocerebrum.

3. Insect dominance

Measures of dominance:

1. More number of species

2. Large number of individuals in a single species: e.g. Locust swarm comprising of 10^9 number of individuals, occupying large area.

3. Great variety of habitats

4. Long geological history

Reasons for dominance:

There are several structural, morphological and physiological factors responsible for insect dominance. They are:

1. Capacity for flight

2. More adaptability or universality

3. Smaller size: Majority of insects are small in their size conferring the following physiological and ecological advantages.

4. Presence of exoskeleton: Insect body is covered with an outer cuticle called exoskeleton which is made up of a cuticular protein called **Chitin**. This is light in weight and gives strength, rigidity and flexibility to the insect body.

5. Resistance to desiccation: Insects minimise the water loss from their body surface through prevention of water loss (wax layer of epicuticle, closable spiracles, egg shell) conservation of water (capable of utilizing metabolic water, resorption of water from fecal matter, use less quantity of water to remove the nitrogenous waste)

6. Tracheal system of respiration: This ensures direct transfer of adequate oxygen to actively breathing tissues. Spiracles through their closing mechanism admit air and restrict water loss.

7. Higher reproductive potential: Reproductive potential of insect is high

eg. Egg laying capacity (fecundity) of queen termite is 6000 - 7000 eggs per day for 15 long years.

Short development period. e.g., Corn aphid produces 16 nymphs per female which reaches the adulthood within 16 days.

Presence of special types of reproduction other than oviparity and viviparity like Polyembryony, Parthenogenesis and Paedogenesis

8. Presence of complete metamorphosis: More than 82 per cent of insects undergo complete metamorphosis (holometabolous insects) with four stages. As the larval and adult food sources are different, competition for food is less.

9. Presence of defense mechanisms: By different defense mechanisms, insects escape from the enemies to increase their survival rate.

10. Hexapod locomotion: Insects uses 3 legs at a time during locomotion, while the remaining 3 legs are static, which gives greater stability.

4. Body wall-its structure and function

Insect body wall is called as **Integument or Exoskeleton**. It is the external covering of the body which is ectodermal in origin. It is rigid, flexible, lighter, stronger and variously modified in different body parts to suit different modes of life.

Structure: Body wall consists of an inner cellular layer (**epidermis**) and an outer non cellular part (**cuticle**).

Epidermis: It is an inner unicellular layer resting on basement membrane with the following function.

i. Cuticle secretion

ii. Digestion and absorption of old cuticle

iii. Wound repairing

iv. Gives surface look

Cuticle: It is an outer non cellular layer comprising of three sub layers.

i. Endocuticle: It is the innermost and thickest layer. This layer is made up of chitin and arthropodin. This layer is colourless, soft and flexible.

ii. Exocuticle: Outer layer, much thicker with the composition of chitin and sclerotin. This layer is dark in colour and rigid.

Endocuticle and exocuticle put together are called as **procuticle**

iii. Epicuticle: Outer most layer which is very thin. Pore canals present in the exocuticle helps in the deposition of epiculticle. This layer is differentiated into the following layers.

a. Inner epicuticle: It contains wax filaments.

b. Outer epicuticle: It makes the contact with cuticulin.

c. Cuticulin : Non chitinous polymerised lipoprotein layer.

d. Wax layer: It contains closely packed wax molecules which prevents desiccation.

e. Cement layer: Outer most layer formed by lipid and tanned protein. It protects wax layer.

Composition of cuticle:

i.Chitin: It is the main constituent of cuticle, which is nitrogenous polysaccharide and polymer of N-acetylglucosamine. It is water insoluble but soluble in dilute acids, alkalies and organic solvents.

ii.Arthropodin: An untanned protein, which is water soluble.

iii.Sclerotin: Tanned protein, which is water insoluble.

iv.Resilin: An elastic protein responsible for the flexibility of wing sclerites.

Endoskeleton : Cuticular in growth of body wall providing space for muscle attachment is known as endoskeleton. There are two types

i. Apodeme: Hollow invagination of body wall (ridge like).

ii. Apophysis: Solid invagination of body wall (spine like).

Cuticular appendages:

Non-cellular: Non cellular appendages have no epidermal association , but rigidly attached. Eg. minute hairs and thorns.

Cellular: Cellular appendages have epidermal association and it may be unicellular, multicellular.

i. **Unicellular structures**:

a. Clothing hairs, plumose hairs. e.g. Honey bee.

b. Bristles. e.g.flies.

c .Scales - flattened out growth of body wall e.g. Moths and butterflies

d. Glandular seta. et. caterpillar

e. Sensory setae - associated with sensory neuron or neurons

f. **Seta** - hair like out growth from epidermis. Epidermal cell generating seta is known as **Trichogen**, while the socket forming cell housing trichogen is known as **Tormogen**. Study of arrangement of seta is known as **Chaetotaxy**.

ii. **Multicellular structures**: e.g. Spur – movable ; Spine- immovable.

5. Moulting (Ecdysis)

Ecdysis: Periodical process of shedding the old cuticle accompanied by the formation of new cuticle is known as moulting or ecdysis. The cuticular parts discarded during moulting is known as **exuvia**. Moulting occurs many times in an insect during the immatured stages before attaining the adult-hood. The time interval between the two subsequent moulting is called as **stadium** and the form assumed by the insect in any stadium is called as **instar**.

Steps in moulting:

1. Behaviroual changes: Larva stops feeding and become inactive.
2. Changes in epidermis: In the epidermis cell size, its activity, protein content and enzyme level increases.Cells divide miotically and increases the tension, which results in loosening of cells of cuticle.
3. **Apolysis**: Detachment of cuticle from epidermis
4. Formation of subcuticular space
5. Secretion of moulting gel in the sub cuticular space which is rich with chitinase and protease.
6. New epicuticle formation: Cuticulin layer is laid over the epidermis.
7. Procuticle formation: Procuticle is formed below the epicuticle.
8. Activation of moulting gel: Moulting gel is converted into moulting fluid rich in enzymes. This activates endocuticle digestion and absorption.
9. Wax layer formation: Wax threads of pore canals secrete wax layer.
10. Cement layer formation: Dermal glands secretes cement layer (**Tectocuticle**).
11. Moulting: This involves two steps

    i. Rupturing of old cuticle: Insect increases its body volume through intake of air or water which enhances the blood flow to head and thorax. There by the old cuticle ruptures along predetermined line of weakness known as ecdysial line

    ii. Removal of old cuticle: Peristaltic movement of body and lubricant action of moulting fluid helps in the removal of old cuticle. During each moulting the cuticular coverings of body, legs, internal linings of foregut, hindgut and trachea are discarded.

12. Formation of exocuticle: The upper layer of procuticle develops as exocuticle through addition of protein and tanning by phenolic substance.

13. Formation of endocuticle: The lower layer of procuticle develops as endocuticle through addition of chitin and protein. This layer increases in thickness.

Control of Moulting: It is controlled by endocrine glands like prothoracic gland which secrete moulting hormone. Endocrine glands are activated by prothoracico-tropic hormones produced by neurosecretory cells of brain.

6. Organisation of Insect Body
(Structure of Insect Head, Thorax and Abdomen)

Insect body is differentiated into three distinct regions called head, thorax and abdomen. Grouping of body segments into distinct regions is known as **tagmosis** and the body regions are called as **tagmata**.

1. **Head**: First anterior tagma formed by the fusion of six segments namely preantennary, antennary, intercalary, mandibular, maxillary and labial segments. Head is attached or articulated to the thorax through neck or **cervix**. Head capsule is sclerotized and the head capsule excluding appendages formed by the fusion of several sclerites is known as **cranium**.

Sclerites of Head

i. **Vertex**: Summit of the head between compound eyes.

ii. **Frons**: Facial area below the vertex and above clypeus.

iii. **Clypeus**: Cranial area below the frons to which labrum is attached.

iv. **Gena**: Lateral cranial area behind the compound eyes.

v. **Occiput** : Cranial area between occipital and post occipital suture.

Sutures of Head: The linear invaginations of the exoskeleton between two sclerites are called as suture (some times referred as sulcus).

i. **Epicranial suture/ ecdysial line**: Inverted `Y' shaped suture found medially on the top of head, with a median suture (coronal suture) and lateral sutures (frontal suture).

ii. **Epistomal suture/ Fronto clypeal suture**: Found between frons and clypeus. (epi –above; stoma- mouth parts)

iii. **Clypeo-labral suture**: Found between clypeus and labrum (upper lip).

iv. **Postoccipital suture**: Groove bordering occipital foramen. Line indicating the fusion of maxillary and labial segment.

Posterior opening of the cranium through which aorta, foregut, ventral nerve cord and neck muscles passes is known as **occipital foramen**. Endoskeleton of insect cuticle provides space for attachment of muscles of antenna and mouthparts, called as **tentorium**. The appendages like a pair of

compound eyes, 0-3 ocelli, a pair of antenna and mouth parts are called as cephalic appendages.

Functions of Head

i. Food ingestion

ii. Sensory perception

iii. Coordination of bodily activities

iv. Protection of the coordinating centers

2. Thorax: Second and middle tagma which is three segmented, namely prothorax, mesothorax and metathorax. Meso and metathorax which bear wings are called as **Pterothorax**. Thoracic segments are made up of three sclerites namely, dorsal body plate **tergum or nota**, ventral body plate **sternum** and lateral plate **pleuron**.

Thoracic nota: Dorsal body plate of each thoracic segments are called as pronotum, mesonotum and metanotum respectively.

Pronotum: This sclerite is undivided and saddle shaped in grasshopper and shield like in cockroach.

Pterothoracic notum: Have 3 transverse sutures (antecostal, prescutal and scuto-scutellar) and 5 tergites (acrotergite, prescutum, scutum, scutellum and post-scutellum).

Thoracic sterna: Ventral body plate of each thoracic segments are called as prosternum, mesosternum and metasternum. Thoracic sterna is made up of a segmental plate called **eusternun** and an intersternite called **spinasternum**. Eusternum is made up of three sternites viz., presternum, basisternum and sternellum.

Thoracic pleura: Lateral body wall of thoracic segment between notum and sternum. Selerites of pleuron is called as pleurite and they fuse to form pleural plate. Pleural plate is divided into anterior **episternum** and posterior **epimeron** by **pleural suture**. Pterothoracic pleuron provides space for articulation of wings and legs.

Thoracic appendages are three pairs of legs and two pairs of wings. Two pairs of spiracles are also present in the mesopleuron and metapleuron.

Functions of thorax: Mainly concerned with locomotion.

3. Abdomen: Third and posterior tagma of insect body. This tagma is made up of 9-11 uromeres (segments) and is highly flexible. Abdominal segments are telescopic in nature and are interconnected by a membrane called **conjunctiva**. Each abdominal segment is made up of only two sclerites namely dorsal body plate (tergum) and ventral body plate (sternum). In grass hopper eight pairs of spiracles are present in the first eight segments, in addition to a pair of tympanum in the first segment. Eight and ninth abdominal segments bears the female genital structure and ninth segment bears male genital structure. Abdominal appendages in adult insects are genital organs and cerci.

Function: Concerned with reproduction and metabolism.

7. Types of insect heads and antennae

Based on the inclination of long axis of the head and orientation of mouth parts there are three types of insects heads.

1. Hypognathous: (Hypo-below ; gnathous-jaw)

This type is called orthopteroid type. The long axis of the head is vertical, it is at right angles to the long axis of the body. Mouth parts are ventrally placed and project downwards. E.g. grasshopper, cockroach.

2. Prognathous: (Pro-infront ; ganthous-jaw)

This type is also called coleopteroid type. The long axis of the head is horizontal. It is in line with the long axis of the body. Mouth parts are directed forward. e.g. ground beetle.

3. **Opisthognathuos**: (Opistho-benind; gnathuos-jaw)

This is also called hemipteroid type or opisthorhynchous type. Head is deflexed. Mouthparts are directed backwards and held in between the forelegs. e.g. stink bug.

Structure of insect antenna: Antennae are also called feelers. They are paired, highly mobile and segmented. Antennae are located between or behind the compound eyes. All insects except protura have a pair of antennae. Antennae are well developed in adults and poorly developed in immature stages. The antenna is set in a socket of the cranium called antennal socket. The base of the antenna is connected to the edge of the socket by an articulatory membrane. This permits free movement of antennae. The basal segment is called **scape**. It is conspicuously larger than succeeding segments. The second antennal segment is called **pedicle** whcih immediately follow the scape. A mass of sence cells called **Johnston's organ** is present in the pedicel, which is used as a chordatonal organ in some of the insects like mosquitoes. Both scape and pedicel are provided with intrinsic muscles. The remaining annuli or flagellomeres are known as **flagellum** or **clavola** which lack individual muscle. Surface of the flagellum is supplied with many sensory receptors that are innervated by the duetocerebrum of brain. Flagellum may very in size and form.

Function: Antenna is useful to detect chemicals including food and pheromones (chemicals secreted into air by opposite sex). It perceives smell,

humidity changes, variation in temperature, vibration, wind velocity and direction. Antenna is useful to perceive the forward environment and detect danger. It is useful for hearing in mosquitoes and communication in ants. Rarely it is also useful to clasp the mate (e.g. Flea) and grasp the prey.

Types of antennae:

1. Setaceous: (Bristle like) Size of the segments decreases from base to apex. e.g. Leafhopper, Dragonfly, Damselfly.

2. Filiform: (Thread like) Segments are usually cylindrical. Thickness of segments remains same throughout. e.g. Grasshopper.

3. Moniliform: (Beaded) Segments are either globular or spherical with prominent constriction in between e.g. Termite.

4. Serrate: (Saw like) Segments have short triangular projections on one side. e.g. Longicorn bettle

5. Unipectinate: (Comb like) Segments with long slender processes on one side e.g. Sawfly

6. Bipectinate: (Double comb like) Segments with long slender lateral processes on both the sides e.g. Silkworm moth

7. Clavate: (Clubbed) Antenna enlarges gradually towards the tip. e.g. Blister beetle

8.Capitate: (Knobbed) Terminal segments become enlarged suddenly e.g. butterfly

9. Lamellate: (Plate like) Antennal tip is expanded laterally on one side to form flat plates e.g. lamellicorn beetle

10. Aristate: The terminal segment is enlarged. It bears a conspicuous dorsal bristle called arista e.g. House fly

11. Stylate: Terminal segment bear a style like process eg. Horse fly, Robber fly.

12. Plumose: (Feathery) Segments with long whorls of hairs e.g. male mosquito

13. Pilose: (Hairy) Antenna is less feathery with few hairs at the junction of flagellomeres. e.g. Female mosquito.

14. Geniculate: (Elbowed) Scape is long remaining segments are small and are arranged at an angle to the first resembling an elbow joint. e.g. Ant, weevil and honey bee.

8. Types of insect mouthparts

Mouthparts of insects vary to a great extend among insects of different groups depending upon their feeding habits. They are mainly of two types viz., Mandibulate (feeding mainly on solid food) and haustellate (feeding mainly on liquid food).

1. **Biting and chewing type**: e.g. Cockroach & grasshopper. It is the primitive type of mouth part and consists of the following parts.

i. **Labrum** : (Upper lip) It is flap like, bilobed and attached to the clypeus by an articular membrane. It is movable. It covers the mouth cavity from above. It helps to pull the food into the mouth. It holds the food in position so that mandibles can act on it. It forms the roof of the pre oral food cavity.

ii. **Labrum-epipharynx**: Inner surface of the labrum is referred to as epipharynx. It is frequently membranous and continuous with the dorsal wall of pharnyx. It is an organ of taste.

iii. **Mandibles**: There is a pair of mandibles. They are the first pair of jaws. They are also called as primary jaws or true jaws. Mandibles articulate with the cranium at two points. They are heavily sclerotised. They are toothed on their inner border. There are two types of teeth. Distal are sharply pointed and are called incisor or cutting teeth and proximal teeth are called molar or grinding teeth. They act transversely to bite and grind the food into small fragments.

iv. Maxillae: They are paired and more complicated than mandibles. They are called secondary jaws or accessory jaws. At proximal end the first sclerite **cardo** joins the maxilla to head. The second sclerite is called **stipes** which articulates with cardo. Stipes carries a lateral sclerite called **palpifer** which bears a five segmented antenna like **maxillary palp**. On the distal end of the stipes, there are two lobes. The outer lobe is called **galea** and inner lobe is **lacinia** which is toothed. Maxille direct the food into the mouth. They hold the food in place when the mandibles are in action. They act as auxillary jaws and assist in mastication of food. Sense organs connected with the perception of touch, smell and taste are abundantly found in palpi.

v. Hypopharynx : It is a tongue like organ. It is located centrally in the preoral cavity. Salivary gland duct opens through it.

vi. **Labium /lower lip:** It is a composite structure formed by the fusion of two primitive segmented appendages. It bounds the mouth cavity from below or behind. It forms the base of the preoral cavity. It consists of three median sclerites *viz*., **submentum** (large basalsclerite), **mentum** (middle sclerite) and **prementum** (apical sclerite). On the lateral side of the prementum there are two small lateral sclerites called **palpiger** bearing three segmented **labial palpi.** Distally prementum bears two pairs of lobes. The other pair of lobes is called **paraglossae** and inner pair of lobes, **glossae**. Both pairs when fused are called **ligula**.

2**. Piercing and sucking / hemipterous / bug type** e.g. Plant bugs.

Labium projects downwards from the anterior part of the head like a beak. Beak is four segmented and grooved throughout its entire length. At the base of the labium there is a triangular flap like structure called labrum. Labium is neither involved in piercing nor sucking. It functions as a protective covering for the four **stylets** (fascicle) found with in the groove. Both mandibles and maxillae are modified into long slender sclerotized hair like structure called stylets. They are lying close together and suited for piercing and sucking. The tips of the stylets may have minute teeth for piercing the plant tissue. The inner maxillary stylets are doubly grooved on their inner faces. When these are closely opposed they form two canals viz., food canal and salivary canal through sap and saliva are conducted respectively. Saliva contains enzymes or toxins that can distort plant cell wall to permit the stylets to penetrate down and reach phloem for suking the sap. Both palps are absent.

3. Piercing and sucking / dipterous / mosquito type : e.g. Female mosquito

Mouthparts of female mosquito consists of an elongate labium which is grooved forming a gutter which encloses six stylets. The stylets are composed of labrum - epipharynx (enclosing the food canal), the hyphophrynx (containing the salivary canal), two maxillae and two mandibles. Both the ends of maxillary stylets and mandibular stylets are saw like and suited piercing flesh. The stylets are inserted into host's skin by a strong downward and forward thrust of body. Both mandibles and maxillae are reduced in male and they feed on plant nectar and juices of decaying fruits. Female pierces the skin of human beings into which it injects saliva containing an anticoagulant (to keep

the blood flowing without clotting) and an anesthetic (to keep the victim unaware of the bite) and sucks up the blood. Labium does not pierce but folds up or back as stylets pierce. Maxillary palpi are present.

4. **Chewing and lapping type** : e.g. honey bee.

Labrum and mandibles are as in biting and chewing type of mouth parts. But mandibles are blunt and not toothed. They are useful to crush and shape wax for comb building; ingest pollen grains and other manipulative functions. Maxillolabial structures are modified to form the lapping tongue. The tongue unit consists of two galea of maxillae, two labial palpi and elongated flexible hairy glossa of labium. The glossa terminates into a small circular spoon shaped lobe called spoon or bouton or flabellum which is useful to lick the nectar.

5. **Rasping and sucking** : e.g. Thrips

Mouth cone consists of labrum, labium and maxillae. There are three stylets derived from two maxillae and left mandible. Right mandible is absent. Stylets are useful to lacerate the plant tissue and the oozing sap is sucked up by the mouth cone. Both maxillary palpi and labial palpi are present.

6. **Mandibulosuctorial type** : e.g. grub of antlion

Mandibles are elongate sickle shaped and grooved on the inner surface. Each maxilla is elongated and fits against the mandibular groove to from a closed food canal. The body of the insect victim is pierced by the opposing mandibles and fluids are extracted.

7. **Sponging type** : e.g. House fly

The proboscis is fleshy, elbowed, retractile and projects downwards from head. The proboscis can be differentiated into basal rostrum and distal haustellum. The proboscis consists of labium which is grooved on its anterior surface. Within this groove lie the labrum-epiphraynx (enclosing the food canal) and slender hypopharynx (containing the salivary canal). Mandibles are absent. Maxillae are represented by single segmented maxillary palpi. The end of the proboscis is enlarged, sponge like and two lobed which acts as suction pads.

They are called oral discs or labella. The surfaces of labella are transvered by capillary canals called pseudotracheae which collect the liquid food and convey it to the canal. Labella function as sponging organs and are capable of taking exposed fluids. These insects often spit enzyme containing saliva onto solid foods to liquify them.

8. **Siphoning type** : e.g. Moths and butterflies

Mouth parts consists of elongate sucking tube or proboscis. It is formed by two greatly elongated galeae of maxillae which are zippered together by interlocking spines and hooks. Galeae are grooved on their inner surface and when they are fitting together closely they form a suctorial food canal through which the nectar is sucked up. The proboscis is coiled up like watch spring and kept beneath the head when it is not in use. By pumping of blood into galeae, the proboscis is extended. The other mouth parts are reduced or absent except the labial palpi and smaller maxillary palpi.

9. Types of insect legs

Structure:

In almost all insects all the three thoracic segments *viz*., pro-, meso- and metathorax bear a pair of segmented legs. Each leg consists of five segments viz., coxa, trochanter, femur, tibia and tarsus.

Coxa : (Pl. coxae) It is the first or proximal leg segment. It articulates with the cup like depression on the thoracic pleuron. It is generally freely movable.

Trochanter: It is the second leg segment. It is usually small and single segmented. Trochanter seems to be two segmented in dragonfly, dameselfy and ichneumonid wasp. The apparent second trochanter is in fact a part of femur, which is called trochantellus.

Femur: (Pl. femora) It is the largest and stoutest part of the leg and is closely attached to the trochanter.

Tibia: (Pl. tibiae) It is usually long and provided with downward projecting spines which aid in climbing and footing. Tibia of many insects is armed with large movable spur near the apex.

Tarsus: (Pl. tarsi) It is further sub-divided. The sub segment of the tarsus is called tarsomere. The number of tarsomeres vary from one to five. The basal tarsal segment is often larger than others and is named as basitarsus.

Pretarsus: Beyound the tarsus there are several structure collectively known as pretarsus. Tarsus terminates in a pair of strongly curved claws with one or two pads of cushions at their base between them. A median pad between the claws is usually known as arolium and a pair of pads, at their base are called pulvilli (Pulvillus-singular). Leg pads are useful while walking on smooth surface and claws give needed grip while walking on rough surface. When one structure is used, the other is bent upwards.

Types or modifications

Legs are modified in to several types based on the habitat and food habit of insect and used for a wide variety of functions.

1. **Ambulatorial** (Ambulate - to walk; Walking leg) e.g. Fore leg and middle leg of grasshopper. Femur and tibia are long. Legs are suited for walking.

2. **Cursorial**: (Cursorial = adapted for running : Running leg) e.g.All the three pairs of legs of cockroach. Legs are suited for running. Femur is not swollen.

3. **Saltatorial:** (Salatorial = Leaping : Jumping Leg) e.g. hind leg of grasshopper.

4. **Scansorial**: (Scansorial = Climbing; climbing or clinging leg) e.g. all the three pairs of legs of head louse.

5. **Fossorial**: (Forrorial = Digging; Burrowing leg) e.g. Fore legs of mole cricket.

6. **Raptorial**: (Raptorial = predatory ; Grasping leg) e.g. Forelegs of preying mantis.

7. **Natatorial**: (Natatorial = pertaining to swimming; Swimming leg) e.g. hing legs of water bug and water beetle.

8. **Sticking leg**: e.g. all the three pairs of legs of house fly.

9. **Basket like leg:** e.g. Legs of dragonfly and damselfly.

10. **Clasping leg**: e.g. Forelegs of male water beetle.

11. **Foragial leg**: (Forage = to collect food material) e.g. Legs of honey bee.

i. **Forelegs** : The foreleg has three important structures (Eye brush

b. Antenna cleaner or strigillis:

c. Pollen brush:

ii. **Middle legs** : It has two important structures.

a. **Pollen brush**: Stiff hairs on basitarsus form pollen brush which is useful to collect pollen from middle part of their body.

b. **Tibial spar**: At the distal end of the tibia, a movable spur is present which is useful to loosen the pellets of pollen from the pollen basket of hind legs and to clean wings and spiracles.

iii. **Hind legs**: It has three important structures viz., pollen basket, pollen packer and pollen comb.

a. **Pollen basket**: It is also called corbicula. The outer surface of the hind tibia contains a shallow cavity. The edges of the cavity are fringed with long hairs. The pollen basket enables the bee to carry a larger load of pollen and propolis from the field to the hive.

b. **Pollen packer**: It is also called pollen press. It consists of pecten and auricle. Pecten is a row of stout bristles at the distal end of tibia. Auricle is a small plate

fringed with hairs at the basal end of basitarsus. Pollen packer is useful to load pollen in corbicula.

c. **Pollen comb**: About ten rows of stiff spines are present on the inner side of hind basitarsus. The pollen comb is used to collect pollen from middle legs and from posterior part of the body.

12. **Prolegs** or **False legs** or **Pseudolegs**: e.g. abdominal legs of caterpillar.

There are two to five pairs of abdominal legs termed prolegs in caterpillar. Prolegs are thick, fleshy and not segmented. They are shed with last larval moult. One pair of prolegs on the last abdominal segment are called anal prolegs or claspers. The tip of proleg is called planta upon which are borne hooks or claws known as crochets which are useful in crawling or clinging to surface.

10. Types of insect wings

Among invertebrate animals, only insects posses wings. Wings are present only in adult stage. Number of wings vary from two pairs to none. Certain primitive insects like silverfish and spring tail have no wings (apterous). Ectoparasites like head louse, poultry louse and flea are secondarily wingless. Wings are deciduous in ants and termites. There is only one pair of wings in the true flies. Normally, two pairs of wings are present in insects and they are borne on pterothoracic segments viz., mesothorax and metathorax. Wings are moved by thoacic flight muscles attached to their bases.

Wing is a flattened double - layered expansion of body wall with a dorsal and ventral lamina having the same structure as the integument. Both dorsal and ventral laminane grow, meet and fuse except along certain lines. Thus a series of channels is formed. These channels serve for the passage of tracheae, nerves and blood. Wing is nourished by blood circulating through veins. Later the walls of these channels become thickened to form veins or nervures. The arrangement of veins on the wings is called venation which is extensively used in insect classification. The principal longitudinal veins arranged in order from the anterior margin are costa (C), sub costa (Sc), radius (R), median (M), cubitus (Cu) and anal veins (A). Small veins often found inter connecting the longitudinal veins are called cross veins. Due to the presence of longitudinal veins and cross veins, the wing surface gets divided into a number of enclosed spaces termed cells. In insects like dragonfly and damesefly, there is an opaque spot near the coastal margin of the wing called pterotigma.

Margins and angles: The wing is triangular in shape and has therefore three sides and three angles. The anterior margin strengthened by the costa is called coastal margin and the lateral margin is called apical margin and the posterior margin is called anal margin. The angle by which the wing is attached to the thorax is called humeral angle. The angle between the coastal and apical margins is called apical angle. The angle between apical and anal margins is anal angle.

Wing regions: The anterior area of the wing supported by veins is usually called remigium. The flexible posterior area is termed vannus. The two regions are separated by vannal fold. The proximal part of vannus is called jugum, when well developed is separated by a jugal fold. The area containing wing articulation sclerites, pteralia is called axilla.

Wing types:

1. Tegmina : (Singular : Tegmen) Wings are leathery or parchment like. They are protective in function. They are not used for flight. e.g. Forewings of cockroach and grasshopper.

2. Elytra : (Sigular : Elytron) The wing is heavily sclerotised. Wing venation is lost. Wing is tough and it is protective in function. It protects hind wings and abdomen. It is not used during flight. But during flight they are kept at an angle allowing free movement of hind wings. e.g. Fore wings of beetles and weevils.

3. Hemelytra : (Singular : Hemelytron) The basal half of the wing is thick and leathery and distal half is membranous. They are not involved in flight and are protective in function. e.g. Fore wing of heteropteran bugs.

4. Halteres: (Singular : Haltere) In true flies the hind wings are modified into small knobbed vibrating organs called haltere. Each haltere is a slender rod clubbed at the free end (capitellum) and enlarged at the base (scabellum). On the basal part two large group of sensory bodies forming the smaller hick's papillae and the large set of scapel plate. They act as balancing organs and provide the needed stability during flight. e.g. true flies, mosquito, male scale insect.

5. Fringed wings: Wings are usually reduced in size. Wing margins are fringed with long setae. These insects literally swim through the air. e.g. Thrips.

6. Scaly wings: Wings of butterfly and moths are covered with small coloured scales. Scales are unicellular flattened outgrowth of body wall. Scales are inclined to the wing surface and overlap each other to form a complete covering. Scales are responsible for colour. They are important in smoothing the air flow over wings and body.

7. Membranous wings: They are thin, transparent wings and supported by a system of tubular veins. In many insects either forewings (true flies) or hind wings (grass hopper, cockroach, beetles and earwig) or both fore wings and hind

wings (wasp, bees, dragonfly and damselfly) are membranous. They are useful in flight.

Wing coupling: Among the insects with two pairs of wings, the wings may work separately as in the dragonflies and damselflies. But in higher pterygote insects, fore and hind wings are coupled together as a unit, so that both pairs move synchronously. By coupling the wings the insects become functionally two winged.

Types of wing coupling

1. **Hamulate** : A row of small hooks is present on the coastal margin of the hind wing which is known as hamuli. These engage the folded posterior edge of fore wing. e.g. bees.

2. **Amplexiform** : It is the simplest form of wing coupling. A linking structure is absent. Coupling is achieved by broad overlapping of adjacent margins. e.g. butterflies.

3. **Frenate** : There are two sub types. e.g. Fruit sucking moth.

   i. Male frenate : Hindwing bears near the base of the coastal margin a stout bristle called frenulum which is normally held by a curved process, retinaculum arising from the subcostal vein found on the surface of the forewing.

   ii. Female frenate : Hindwing bears near the base of the costal margin a group of stout bristle (frenulum) which lies beneath extended forewing and engages there in a retinaculum formed by a patch of hairs near cubitus.

4. **Jugate :** Jugam of the forewings are lobe like and it is locked to the coastalmargin of the hindwings. e.g. Hepialid moths.

11. Abdominal structures in insects

Basic structures

Segmentation is more evident in abdomen. The basic number of abdominal segments in insect is eleven plus a telson which bears anus. Abdominal segments are called uromeres. On eighth and nineth segment of female and nineth segment of male, the appendages are modified as external organs of reproduction or genitalia. These segments are known as genital segments. Usually eight pairs of small lateral openings (spiracles) are present on the first eight abdominal segments. In grasshoppers, a pair of tympanum is found one on either side of the first abdominal segment. It is an auditory organ. It is obliquely placed and connected to the metathoracic ganglia through auditory nerve.

Modifications:

Reduction in number of abdominal segments has taken place in many insects. In spring tail only six segments are present. In house fly only segments 2 to 5 are visible and segments 6 to 9 are telescoped within others. In ants, bees and wasps, the first abdominal segment is fused with the metathorax and is called propodeum. Often the second segment forms a narrow petiole. The rest of the abdomen is called gaster. In queen termite after mating the abdomen becomes gradually swollen due to the enlargement of ovaries. The abdomen becomes bloated and as a result sclerites are eventually isolated as small islands. Obesity of abdomen of queen termite is called physogastry.

Abdominal appendages

i . Pregenital abdominal appendages in wingless insects:

1) **Styli** : (Stylus : Singular) Varying number of paired tube like outgrowths are found on the ventral side of the abdomen of silverfish. These are reduced abdominal legs which help in locomotion.

2). **Collophore or ventral tube or glue peg**: It is located on the ventral side of the first abdominal segment of spring tail. It is cylindrical. It is protruded out by the hydrostatic pressure of haemolymph. It might serve as an organ of adhesion. It aids in water absorption from the substratum and also in respiration.

3). **Retinaculum or tenaculum or catch**: It is present on the ventral side of the third abdominal segment. It is useful to hold the springing organ when not in use.
4). **Furcula or Furca**: This is a 'Y' shaped organ. It is present on the venter of fourth abdominal segment. When it is released from the catch, it exerts a force against the substratum and the insect is propelled in the air.

ii) **Abdominal appendages in immature insects**:

1) **Tracheal gills**: Gills are lateral outgrowths of body wall which are richly supplied with tracheae to obtain oxygen from water in naiads (aquatic immature stages of hemimetabolous insects). Seven pairs of filamentous gills are present in the first seven abdominal segments of naiads of may flyand are called as lateral gills. Three or two leaf like gills (lamellate) are found at the end of adbomen of naiad of damselfly and are called as caudal gills. In dragonfly the gills are retained within the abdomen in a pouch like rectum and are called as rectal gills.

2) **Anal papillae**: A group of four papillae surrounds the anus in mosquito larvae. These papillae are concerned with salt regulation.

3) **Dolichasters**: These structures are found on the abdomen of antlion grub. Each dolichaster is a segmental protuberance fringed with setae.

4) **Proloegs**: These are present in the larvae of moth, butterfly and sawfly. Two to five pairs are normally present. They are unsegmented, thick and fleshy. The tip of the proleg is called planta upon which are borne heavily sclerotised hooks called crochets. They aid in crawling and clinging to surface.

iii) **Abdominal appendages in winged adults** :

1) **Cornicles**: Aphids have a pair of short tubes known as cornicles or siphonculi projecting from dorsum of fifth or sixth abdominal segment. They permit the escape of waxy fluid which perhaps serves for protection against predators.

2) **Caudal breathing tube**: It consists of two grooved filaments closely applied to each other forming a hollow tube at the apex of abdomen. e.g. water scorpion.

3) **Cerci** : (Cercus - Singular) They are the most conspicuous appendages associated normally with the eleventh abdominal segment. They are sensory in function. They exhibit wide diversity and form.

Long and many segmented :- e.g. Mayfly

Long and unsegmented :- e.g. Cricket

Short and many segmented :- e.g. Cockroach

Short and unsegmented :- e.g. Grasshopper

Sclerotised and forceps like : e.g. Earwig. Cerci are useful in defense, prey capture, unfolding wings and courtship.

Asymmetrical cerci :- Male embiid. Left cercus is longer than right and functions as clasping organ during copulation.

4) **Median caudal filament**: In mayfly (and also in a wingless insect silverfish) the epiproct is elongated into cercus like median caudal filament.

5) **Pygostyles**: A pair of unsegmented cerci like structures are found in the last abdominal segment of scoliid wasp.

6) **Anal styli**: A pair of short unsegmented structure found at the end of the abdomen of male cockroach. They are used to hold the female during copulation.

7) **Ovipositor**: The egg laying organ found in female insect is called ovipositor. It is suited to lay eggs in precise microhabitats. It exhibits wide diversity and form. Short and horny : e.g. Short horned grasshopper

Long and sword like : e.g. Katydid, long horned grasshopper

Needle like : e.g. Cricket

Ovipositor modified into sting : e.g. Worker honey bee.

Pseudoovipositor: An appendicular ovipositor is lacking in fruit flies and house flies. In fruit flies, the elongated abdomen terminates into a sharp point with which the fly pierces the rind of the fruit before depositing the eggs. In the house fly the terminal abdominal segments are telescopic and these telescopic segments aid in oviposition. The ovipositor of house fly is called pseudoovipositor or ovitubus or oviscapt.

Male genitalia: External sexual organs of male insects are confined to ninth abdominal segment. In damselfly, the functional copulatory organ is present on the venter of second abdominal segment

12. Digestive system

The alimentary canal of insects is a long, muscular and tubular structure extending from mouth to anus. It is differentiated into three regions viz., Foregut, midgut and hindgut.

1. **Foregut**: It is ectodermal in origin. Anterior invagination of ectoderm forms foregut (Stomodeum). Internal cuticular lining is present. Terminal mouthparts leads into a preoralcavity. Preoralcavity between epipharynx and hypopharynx is called as Cibarium. Preoralcavity between hypopharynx and salivary duct is Salivarium. Behind the mouth a well musculated organ called Pharynx is present which pushes the food into oesophagous. Pharynx acts as a sucking pump in sap feeders. Oesophagous is a narrow tube which conduct food into crop. Crop is the dilated distal part of oesophagus acting as food reservoir. In bees crop is called as honey stomach where nectar conversion occurs. Proventriculus or Gizzard is the posterior part of foregut and is musculated. It is found in solid feeders and absent in fluid feeders or sap feeders. Food flow from foregut to midgut is regulated through cardial or oesophageal valve. The internal cuticle of gizzard is variously modified as follows.

i. Teeth like in cockroach to grind and strain food.

ii. Plate like in honey bee to separate pollen grains from nectar

iii.Spine like in flea to break the blood corpuscles

2. **Midgut**: It is endodermal in origin and also called as mesentron. This part contains no cuticular lining. Midgut is made up of three types of epithelial cells. (i) Secretory cells (Columnar cells) (ii) Goblet cells (aged secretory cells), (iii) Regenerative cells which replaces secretory cells. Important structures present in midgut are as follows:

a. **Peritrophic membrane**: It is the internal lining of midgut, secreted by anterior or entire layer of midgut epithelial cells. Present in solid feeders and absent in sap feeders. This layer is semipermeable in nature to digestive juices and digestion products. It lubricate and facilitate food movement. Envelops the food and protects the midgut epithelial cells against harder food particles.

(ii) **Gastric caecae**: (Enteric caecae or Hepatic caecae) Finger like outgrowths found in anterior or posterior ends of midgut. This structure increases the functional area of midgut and shelter symbiotic bacteria in some insects.

(iii) **Pyloric valve**: (Proctodeal valve) Midgut opens into hindgut through pyloric valve, which regulate food flow. In certain immature stages of insects midgut is not connected to hindgut till pupation. e.g. Honey bee grub.

(iv) **Filter chamber**: It is a complex organ in which two ends of ventriculus and the begining of hind gut are enclosed in a sac. This is useful to short circuit excess water found in liquid food in homopteran insects. This process avoids dilution of digestive enzymes and concentrates food for efficient digestion. Also helps in osmoregulation by preventing dilution of haemolymph.

3. **Hindgut**: It is ectodermal in origin and produced by the posterior invagination of ectoderm. Internal cuticular lining is present, which is permeable to salts, ions, aminoacids and water. The main functions of hindgut are the absorption of water, salt and other useful substances from the faeces and urine. Hindgut is differentiated into three regions viz., **ileum, colon and rectum**. In the larva of scarabids and termites, illeum is pouch like for housing symbionts and acts as fermentation chamber. Rectum contains rectal pads helping in dehydration of faeces and it opens out through anus.

Gut physiology: Primary functions of the gut is to digest the ingested food and to absorb the metabolites. Digestion process is enhanced with the help of enzymes produced by digestive glands and microbes housed in special cells.

Digestive glands:

a. **Salivary glands**: In Cockroach a pair of labial glands acts as salivary gland where the salivary ducts open into salivarium. In caterpillars mandibular glands are modified to secrete saliva, where the salivary glands are modified for silk production. Functions of saliva:

1. To moisten and to dissolve food
2. To lubricate mouthparts
3. To add flavour to gustatory receptors
4. In cockroach the saliva contains amylase for the digestion of starch.
5. In honey bee saliva contains invertase for sucrose digestion

6. In Jassid saliva contains lipase and protease for lipids and protein digestion. Jassid saliva also contains toxins which produces tissue necrosis and phytotoxemia on the plant parts.

7. In plant bug saliva contains pectinase which helps in stylet penetration and extra intestinal digestion.

8. In mosquito, saliva contains anticoagulin which prevents blood clotting.

9. In gall producing midges saliva contains Indole Acetic Acid (IAA).

10. In disease transmitting ectors the saliva paves way for the entry of pathogens.

b. **Hepatic caecae and midgut epithelial cells**: It secretes most of the digestive juices. Two types of cells were involved in the enzyme secretion.

Holocrine : Epithelial cells disintegrate in the process of enzyme secretion.

Merocrine : Enzyme secretion occurs without cell break down.

Digestive enzymes

Insect Group	**Enzyme**	**Substrate**
Phytophagous larvae	Amylase	Starch
	Maltase	Maltose
	Invertase	Sucrose
Omnivorous insects	Protease	Protein
	Lipase	Lipid
Nectar feeders	Invertase	Sucrose
Wood boring insects and Termites	Cellulase	Cellulose
Meat eating maggots	Collagenase	Collagen and elastin
Bird lice	Keratinase	Keratin

C. Microbes in digestion: In the insect body few cells were housing symbiotic microorganisms called as mycetocyte. These mycetocytes aggregate to form an organ called mycetome.

(i) Flagellate protozoa - It produces cellulase for cellulose digestion in termites and wood cockroach.

(ii) Bacteria - It helps in wax digestion in wax moth.

(iii) Bed bug and cockroach obtain vitamin and aminoacids from microbes.

These microbes were transmitted between individuals through food exchange (mouth to mouth feeding) called **trophallaxis** and through egg called as **transovarial** transmission. In plant bug and ant lion grub partial digestion occurs in the host body prior to food ingestion called as extra intestinal digestion. In most of the insects digestion occurs in mid gut.

Absorption: In many insects absorption of nutrients occurs through microvilli of midgut epithelial cells by diffusion. Absorption of water and ions occur through rectum. In cockroach lipid absorption occurs through crop. In termites and scarabaeids (White grubs) absorption occurs through ileum. In solid feeders, resorption of water from the faeces occurs in the rectum and the faeces is expelled as pellets. In sap feeders (liquid feeders) the faeces is liquid like. The liquid faeces of homopteran bugs (aphids, mealy bugs, Scales and psyllids) with soluble sugars and amino acids is known as honey dew, which attracts ants for feeding.

13. Excretory system

Removal of waste products of metabolism, especially nitrogenous compounds from the body of insects is known as excretion. The excretion process helps the insect to maintain salt water balance and thereby physiological homeostasis. Following are the excretory organs.

1. **Malpighian tubules**: Thin, blind-ending tubules, originating near the junction of mid and hindgut, predominantly involved in regulation of salt, water and nitrogenous waste excretion. This structure was discovered by Marcello Malpighi.
2. **Nephrocytes**: Cells that sieve the haemolmph for products that they metabolize (pericardial cells).
3. **Fat bodies** : A loose or compact aggregation of cells, mostly trophocytes, suspended in the haemocoel, responsible for storage and excretion.
4. **Oenocytes**: These are specialised cells of haemocoel, epidermis or fat body with many functions. One of the function is excretion.
5. **Integument**: The outer covering of the living tissues of an insect.
6. **Tracheal system**: The insect gas exchange system, comprising tracheae and tracheoles.
7. **Rectum**: The posterior part of hind gut.

Among the above organs, malpighian tubules are the major organ of excretion.

Excretion and Osmoregulation: Insect faeces, either in liquid form or solid pellets, contains both undigested food and metabolic excretions. Aquatic insects excrete dilute wastes from their anus directly into water by flushing with water. But, Terrestrial insects must conserve water. This requires efficient waste disposal in a concentrated or even dry form, simultaneously avoiding the toxic effects of nitrogen. Both terrestrial and aquatic insects must conserve ions, such as sodium (Na^+), potassium (K^+) and chloride (Cl^-), that may be limiting in their food or lost into the water by diffusion. Therefore the production of insect excreta (urine or pellets) is a result of two related processes: excretion and osmoregulation (maintenance of favourable osmotic pressure and ionic concentration of body fluid). The system responsible for excretion and osmoregulation is referred to as excretory system and its activities are performed

largely by the Malpighian tubules and hindgut. However in fresh water insects, haemolymph composition is regulated in response to loss of ions to the surrounding water, with the help of excretory system and special cells. Special cells are called Chloride cells which are present in the hindgut, capable of absorbing inorganic ions from the dilute solutions. (e.g. Naids of dragonflies and damselflies).

Malpighian Tubules: The main organ of excretion and osmoregulation in insects are the malpighian tubules, acting in association with rectum or ileum. Malpighian tubules are outgrowths of the alimentary canal and consist of long thin tubules formed of a single layer of cells surrounding a blind-ending lumen, they are absent in spring tail and aphids, 2 numbers in scale insects, 4 in bugs, 5 in mosquitoes, 6 in moths and butterflies, 60 in cockroach and more than 200 in locusts. Generally they are free, waving around in the haemolymph where they filter out solutes. Each tubule is externally covered by peritonial coat and supplied with muscle fibres (aiding in peristalsis) and tracheloes. Functional differentiation of the tubules was seen, with the distal secretory region and proximal absorptive region.

Physiology: The malpighian tubules produce a filtrate (the primary urine) which is isosmotic but ionically dissimilar to the haemolymph and selectively reabsorbs water and certain solutes, but eliminates others. The malpighian tubules produces an iosmotic filtrate which is high in K^+ and low in Na^+ with Cl^- as major anion. The active transport of ions especially K^+ into the tubule lumen generates an osmotic pressure gradiant for the passive flow of water.

Sugars and most amino acids are also passively filtered from the haemolymph via junctions between the tubule cells, where as amino acids and non-metabolizables and toxic organic compounds are actively transported into the tubule lumen. Sugar is resorbed from the lumen and returned to the haemolymph. The continuous secretory activity of each malpighian tubule leads to a flow of primary urine from its lumen towards and into the gut. In the rectum, the urine is modified by removal of solutes and water to maintain fluid and ionic homeostasis of the body.

Nitrogenous excretion: Terrestrial insects excrete waste products as uric acid or certain of its salts called urates, which were water insoluble and requires less amount of water for waste product removal. This type of excretion is known as **Uricotelism**. In aquatic insects ammonia is the excretory product, which is freely soluble in water and requires more amount of water for waste product removal. This type of excretion is known as **Ammonotelism**.

Cryptonephry: The distal ends of the Malpighian tubules are held in contact with the rectal wall by the perinephric membrane, which is concerned either with efficient dehydration of faeces before their elimination or ionic regulation. (e.g. Adult Coleptera, larval Lepidoptera and larval symphyta).

Functions of malphighian tubule: Excretory in function, mainly concerned with removal of nitrogenous wastes. The other accessory functions are as follows:

1. Spittle secretion in spittle bug
2. Light production in Bolitophila
3. Silk production in larval neuroptera

Storage Excretion: The excretory waste materials are retained within the body in different sites.

i. Uric acid is stored as urates in the cells of **fat body** e.g., American cockroach.

ii. Uric acid is stored in the **body wall**, giving white colour. e.g. Red cotton bug.

iii. Uric acid is stored in the **male accessory glands** to produce the outer coat of spermatophore, which is excreted during copulation.

iv. Uric acid is stored in the **wing scales** giving white colour. e.g., Pierid butterflies.

v. Waste products of pupal metabolism (**Meconium**) is stored and released during adult emergence.

14. Respiratory system

Similar to aerobic animals, insects must obtain oxygen from their environment and eliminate carbon dioxide respired by their cells. This is gas exchange through series of gas filled tubes providing surface area for gaseous exchange (Respiration strictly refers to oxygen-consuming, cellular metabolic processes). Air is supplied directly to the tissue and haemolymph (blood) is not involved in the respiratory role. Gas exchange occurs by means of internal air-filled tracheae. These tubes branch and ramify through the body. The finest branches called tracheole contact all internal organs and tissues and are numerous in tissues with high oxygen requirements. Air usually enters the tracheae via spiracular openings positioned laterally on the body. No insect has more than ten pairs (two thoracic and eight abdominal).

Based on the number and location of functional spiracles respiratory system is classified as follows

1. Holopneustic:10 pairs, 2 in thorax and 8 in abdomen. e.g. grasshopper
2. Hemipneustic: Out of 10 pairs, one or two non-functional
3. Peripneustic: 9 pairs - 1 in thorax 8 in abdomen e.g. Caterpillar
4. Amphipneustic 2 pairs - One anterior, one posterior, e.g. maggot.
5. Propneustic: 1 pair -anterior pair e.g. Puparium
6. Metapneustic: 1 pair - posterior pair e.g.Wriggler
7. Hypopneustic:10 pairs - 7 functional (1 thorax + 6 abdominal), 3 non functional. e.g. head louse
8. Apneustic: All spiracles closed, closed tracheal system e.g. naiad of may fly.

Organs of respiration

Spiracles: Spiracles have a chamber or **atrium** with a opening and closing mechanism called **atrial valve**. This regulate air passage and minimise water loss. Each spiracle is set in a sclerotized cuticular plate called a **peritreme**. **Tracheae** are invaginations of the epidermis and thus their lining is continuous with the body cuticle. The ringed appearance of the tracheae is due to the spiral ridges called **taenidia**. This allow the tracheae to be flexible but resist compression. The cuticular linings of the tracheae are shed during moulting.

Tracheoles are less than 1 μm in diameter and they end blindly and closely contact the respiring tissues. Taenidia and waxlayer is absent. Cuticulin layer is permeable to gases. It is intracellular in nature, but enclosed only in the cytoplasm of tracheal and cell called tracheoblast. Gaseous exchange occurs across tracheoles. There are four tracheal trunks viz., lateral, dorsal, ventral and visceral, helping in the passage of air. In the trachea, thin walled-collapsable sac like dilations are present, called as airsacs where taenidia is absent. **Airsacs** acts as oxygen reservoir. Provide buoyancy to flying and aquatic insects. Provide space for growing organs. Acts as sound resonator and heat insulators.

Mechanism of respiration

Oxygen enters the spiracle and passes through the length of the tracheae to the tracheoles and into the target cells by a combination of ventilation and diffusion along a concentration gradient, from high in the external air to low in the tissue. Where as the net movement of oxygen molecules in the tracheal system is inward (Inspiration), the net movement of CO_2 and water vapour molecules is outward (Expiration).

Respiration in aquatic insects:

1.**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.

Lamellate gills - mayfly naiad

Filamentous gills - damselfly naiad

Rectal gills - dragonfly naiad

2. **Open tracheal system**:

i. **Air store**: Air bubble stored beneath wings acts as physical gill, e.g. water bug.

ii.**Respiratory siphon** - e.g. Wriggler

iii.**Caudal breathing tube** -e.g. Water scorpion

iv. **Plastron** : Closely set hydrofuge hairs of epicuticle hold a thin film of air indefinitely.

15. Circulatory system in insects

Circulation in insects is maintained by a system of muscular pumps moving haemolymph through compartments separated by fibromuscular septa or membranes. The main pump is the pulsatile dorsal vessel. The anterior part may be called **aorta** and the posterior part the **heart**. The dorsal vessel is a simple tube, generally composed of one layer of myocardial cells and with segmentally arranged openings called **ostia**. The ostia permit the one-way flow of haemolymph into the dorsal vessel due to valves that prevent backflow. There may be up to three pairs of thoracic ostia and nine pairs of abdominal ostia. The dorsal vessel lies in the **pericardial sinus**, a compartment above a dorsal diaphragm (a fibromuscular septum - a separating membrane) formed of connective tissue and segmental pairs of alary muscles. The alary muscles support the dorsal vessel but their contractions do not affect heartbeat.

Haemolymph enters the periocardial sinus via segmental openings in the diaphragm and then moves into the dorsal vessel via the ostia during a muscular relaxation phase. Waves of contraction start at the posterior end of the body, pump the haemolymph forward in the dorsal vessel and out via the aorta into the head. Next the appendages of the head and thorax are supplied with haemolymph as it circulates posteroventrally and finally returns to the pericardial sinus and dorsal vessel.

Another important component of the insect circulatory system is the **ventral diaphragm**, a fibromuscular septum that lies in the floor of the body cavity associated with the ventral nerve cord. Circulation of the haemolymph is aided by active peristaltic contractions of the ventral diaphragm which direct the haemolymph backwards and laterally in the **perineural sinus** below the diaphragm. These movements are important in insects that use the circulation in thermoregulation. Ventral diaphragm also facilitates rapid exchange of chemicals between the ventral nerve cord and the haemolymph.

Haemolymph is generally circulated to appendages unidirectionaly by various tubes, septa, valves and pumps. The muscular pumps are termed **accessory pulsatile organs** and occur at the base of the antennae and legs. Antennal pulsatile organs releases neurohormones that are carried to the antennal

lumen to influence the sensory neurones. Circulation occurs in the wings of young adult. In wing circulation is sustained by influxes of air into the wing veins, rather than any pulsatile organs. Pulses of air in the fine tracheal tubes of the veins push the haemolymph through the enclosed space of the veins.

The insect circulatory system shows high degree of co-ordination between dorsal vessel, fibro-muscular diaphragms and accessory pumps.

Haemolymph and its functions

Haemolymph is a watery fluid containing ions, molecules and cells. It is often clear and colourless but may be variously pigmented or rarely red due to haemoglobin in the immature stages of few aquatic and endoparasitic flies (e.g., Chironomid larva). Haemolymph performs the function of both blood and lymph. It is not involved in gas transporting function (respiration). Haemolymph contains a fluid portion called plasma and cellular fractions called haemocytes.

1.**Plasma**: Plasma is an aqueous solution of inorganic ions, lipids, sugars (mainly trehalose), amino acids, proteins, organic acids and other compounds. pH is usually acidic (6.7). Density is 1.01 to 1.06. Water content is 84-92 per cent. Inorganic ions present are `Na' in predators and parasites, `Mg' and `K'in phytophagous insects. Carbohydrate is in the form of trehalose sugar. Major proteins are lipoproteins, glycoproteins and enzymes. Lipids in form of fat particles or lipoproteins. Higher concentration of amino acids leads to a condition called aminoacidemia which effects the osmosis process. In high altitude insects glycerol is present which acts as a anti freezing compound. Nitrogenous waste is present in the form of uric acid.

2. **Haemocytes**: The blood cells or haemocytes are of several types and all are nucleate. Different types of haemocytes are as follows:

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

b. Plasmatocyte (Phagocyte) aids in phagocytocis

c. Granular heamocyte: Contains large number of cytoplasmic inclusions

d. Spherule cell: Cytoplasmic inclusions obscure the nucleus

e. Cystocyte(Coagulocyte): Role in blood coagulation and plasma precipitation.

f. Oenocytoids: Large cells with ecentric nucleus

g. Adipo haemocytes: Round or avoid with distinct fat droplets

h. Podocyte: Large flattened cells with number of protoplasmic projections.

i. Vermiform cells: Rare type, long thread like.

Functions of haemolymph

1. **Lubricant** : Haemolymph keeps the internal cells moist and the movement of internal organs is also made easy.

2. **Hydraulic medium** : Hydrostatic pressure developed due to blood pumping is useful in the following processes.

a) Ecdysis (moulting)
b) Wing expansion in adults
c) Ecolosion in diptera (adult emergence from the puparium using ptilinum)
d) Eversion of penis in male insects
e) Eversion of osmeteria in papilionid larvae
f) Eversion of mask in naiad of dragonfly
g) Maintenance of body shape in soft bodied caterpillars.

3.**Transport and storage** : Digested nutrients, hormones and gases (chironomid larva) were transported with the help of haemolymph. It also removes the waste materials to the excretory organs. Water and raw materials required for histogenesis is stored in haemolymph.

4.**Protection**: It helps in phagocytocis, encapsulation, detoxification, coagulation, and wound healing. Non celluar component like lysozymes also kill the invading bacteria.

5. **Heat transfer**: Haemolymph through its movement in the circulatory system regulate the body heat (Thermoregulation).

6. **Maintenance of osmotic pressure**: Ions, amino acids and organic acids present in the haemolymph helps in maintaining osmotic pressure required for normal physiological functions.

7. **Reflex bleeding**: Exudation of heamolymph through slit, pore etc. repels natural enemies. e.g. Aphids.

8. **Metabolic medium:** Haemolymph serves as a medium for on going metabolic reactions (trahalose is converted into glucose).

16. Nervous system

The basic component in the nervous system is the nerve cell or neuron, composed of a cell body with two projections (fibers) the dendrites that receive stimuli and the axon that transmits information, either to another neuron or to an effector organ such as a muscle. Axon may have lateral branches called Collateral and terminal arborization and synapse. Insect neurons release a variety of chemicals at synapses either to stimulate or to inhibit effector neurons or muscles. Acetylcholine and catecholamines such as dopamine are the important neurotransmitters involved in the impulse conduction. Neurons are of following types based on structure and function.

A. On structural basis

i. Monopolar: neuron with a single axon

ii. Bipolar: neuron with a proximal axon and a long distal dendrite.

iii. Multipolar: neuron with a proximal axon and many distal dendrites.

B. Functional basis

i. Sensory neuron: It conducts impulse from sense organs to central nervous system (CNS).

ii. Motor neuron: It conducts impulse from CNS to effector organs

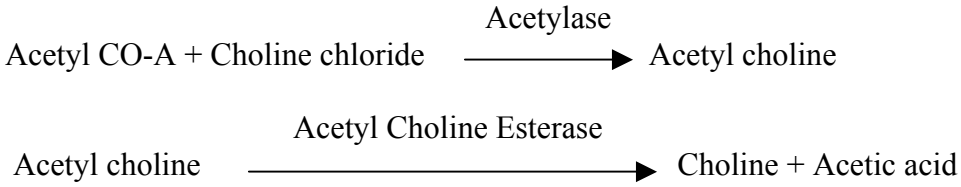
iii. Inter neuron (association neuron): It inter-links sensory and motor neurons.

The cell bodies of inter neurons and motor neurons are aggregated with the fibers inter connecting all types of nerve cells to form nerve centers called **ganglia.**

Mechanism of impulse conduction: Impulses are conducted by the neurons by two means.

Axonic conduction: Ionic composition varies between inside and outside of axon resulting in excitable conditions, which leads to impulse conduction as electrical response.

Synaptic conduction: Neurochemical transmitters are involved in the impulse conduction through the synaptic gap. Neurotransmitters and the type of reactions helping in the impulse conduction are as follows.



Nervous system can be divided in to three major sub-systems as

i. Central nervous system (CNS)

ii. Visceral nervous system (VNS)

iii. Peripheral nervous system (PNS)

i. Central nervous system: It contains double series of nerve centers (ganglia). These ganglia are connected by longitudinal tracts of nerve fibers called **connectives** and transverse tracts of nerve fibers called **commissures**. Central nervous system includes the following.

a. **Brain**: Formed by the fusion of first three cephalic neuromeres.

Protocerebrum: Large, innervate compound eyes and ocelli.

Deutocerebrum: Found beneath protocerebrum, innervate antennae.

Tritocerebrum: Bilobed, innervate labrum.

Brain is the main sensory centre controlling insect behaviour.

b. **Ventral nerve cord**: Median chain of segmental ganglia beneath oesophagus.

c. **Sub esophageal ganglia**: Formed by the last three cephalic neuromeres which innervate mandible, maxillae and labium.

d. **Thoracic ganglia**: Three pairs found in the respective thoracic segments, largest ganglia, innervate legs and muscles.

e. **Abdominal ganglia**: Maximum eight pairs will present and number varies due to fusion of ganglia. Innervate spiracles.

f. **Thoraco abdominal ganglia** : Thoracic and abdominal ganglia are fused to form a single compound ganglia. Innervate genital organs and cerci.

ii. Visceral nervous system: The visceral (sympathetic) nervous system consists of three separate systems as follows: (1) the stomodeal/stomatogastric which includes the frontal ganglion and associated with the brain, aorta and foregut; (2) Ventral visceral, associated with the ventral nerve cord; and (3) Caudal visceral, associated with the posterior segments of abdomen. Together the nerves and

ganglia of these subsystems innervate the anterior and posterior gut, several endocrine organs (Corpora cardiaca and Corpora allata), the reproductive organs, and the tracheal system including the spiracles.

iii. Peripheral nervous system: The peripheral nervous system consists of all the motor neuron axons that radiate to the muscles from the ganglia of the CNS and visceral nervous system plus the sensory neurons of the cuticular sensory structures (the sense organs) that receive mechanical, chemical, thermal or visual stimuli from an environment.

17. Sense organs

Sensilla are the organs associated with sensory perception and develop from epidermal cells. The different types of sense organs are:

1. Mechanoreceptors
2. Auditory receptors
3. Chemoreceptors
4. Thermo receptors and
5. Photo receptors.

1. Mechano receptors (detect mechanical forces)

i. **Trichoid sensilla**: Hair like little sense organ. Sense cell associated with spur and seta. These cells are sensitive to touch and are located in antenna and trophi (mouth parts).

ii. **Campaniform sensilla** (Dome sensilla): Terminal end of these sensilla is rod like and inserted into dome shaped cuticula. These cells are sensitive to pressure and located in leg joints and wing bases.

iii. **Chordotonal organ**: The specialized sensory organs that receive vibrations are subcuticular mechano receptors called chordotonal organ. An organ consists of one to many scolopidia, each of which consists of cap cell, scolopale cell and dendrite. These organs are interoceptors attached to both ends of body wall.

Functions :

i. Proprioception (positioning of their body parts in relation to the gravity).

ii. Sensitive to sound waves, vibration of substratum and pressure changes.

iii. Johnston's organ: All adults insects and many larvae have a complex chordotonal organ called Johnston's organ lying within the second antennal segment (Pedicel). These organs sense movements of antennal flagellum. It also functions in hearing in some insects like male mosquitoes and midges.

iv. Subgenual organ: Chordotonal organ located in the proximal tibia of each leg, used to detect substrate vibration. Subgenual organs are found in most insects, except the Coleoptera and Diptera.

2. Auditory receptors (detect sound waves)

i. Delicate tactile hairs: Present in plumose antenna of male mosquito.

ii. Tympanum: This is a membrane stretched across tympanic cavity responds to sounds produced at some distance, transmitted by airborne vibration. Tympanal membranes are linked to chordotonal organs that enhance sound reception. Tympanal organs are located

* Between the metathoracic legs of mantids.
* The metathorax of many nectuid moths.
* The prothoracic legs of many orthopterans.
* The abdomen of short horned grasshopper, cicada.
* The wings of certain moths and lacewings.

3. Chemoreceptors (detect smell and taste)

Detect chemical energy. Insect chemoreceptors are sensilla with one pore (uniporous) or more pores (multiporous). Uniporous chemorceptors mostly detect chemicals of solid and liquid form by contact and are called as **gustatory receptor**. Many sensor neurons located in antenna are of this type. Multiporous chemoreceptors detect chemicals in vapour form, at distant by smell and are acalled as **olfactory receptor**. Few sensory neurons located in trophi and tarsi are of this type. Each pore forms a chamber known as **pore kettle** with more number of pore tubules that run inwards to meet multibranched dendrites.

4. Thermoreceptors (detect heat)

Present in poikilothermic insects and sensitive to temperature changes. In bed bug it is useful to locate the host utilizing the temperature gradient of the host.

5. Photoreceptors (detect light energy)

a. Compound eyes: 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. **Optic part** contains a cuticular lens called **corneal lens** secreted by corneagenous cells and **crystalline cone** covered by **primary pigment cells**. Function of the optic part is to gather light. **Sensory part** contains six to ten

visual cells called **retinular cells** covered by secondary pigment cells which collectively secrete a light sensitive rod at the centre called **rhabdom**. Rhabdom contains light sensitive pigments called **rhodopsin**. Each ommatidium is covered by a ring of light absorbing pigmented cells, which isolates an ommatidium from other. Nerve cells are clustered around the longitudinal axis of each ommatidium.

Types of ommatidia

i. **Apposition type** (light tight): Due to the presence of primary pigment cells light cannot enter the adjacent cells. 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.

ii. 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.

b. Lateral ocelli (Stemmata): Visual organs of holometabolous larva. Structure is similar to ommatidium. It helps to detect form, colour and movement, and also to scan the environment.

c. Dorsal ocelli: Visual organs of nymph and it vary from 0-3 in numbers. It contains a single corneal lens with many visual cells individually secreting the rhabdomere. Dorsal ocelli perceive light to maintain diurnal rhythm and is not involved in image perception.

18. Reproductive system

In insects male and female sexes are mostly separate. Sexual dimorphism is common where the male differ from the female morphologically as in bees, mosquito and cockroach. The other types are:

Gynandromorph: (Sexual mosaic) Abnormal individual with secondary sexual characters of both male and female. e.g. mutant Drosophila.

Hermaphrodite: Male and female gonads are present in one organism. e.g. Cottony cushion scale.

Female reproductive system

The main functions of the female reproductive system are egg production and storage of male's spermatozoa until the eggs are ready to be fertilized. The basic components of the female system are paired **ovaries**, which empty their mature oocytes (eggs) via the calyces (Calyx) into the lateral **oviduct** which unite to form the common (median) oviduct. The **gonopore** (opening) of the common oviduct is usually concealed in an inflection of the body wall that typically forms a cavity, the **genital chamber**. This chamber serves as a copulatory pouch during mating and thus is often known as the **bursa copulatrix**. Its external opening is the vulva. In many insects the vulva is narrow and the genital chamber becomes an enclosed pouch or tube referred to as the **vagina**.

Two types of ectodermal glands open into the genital chamber. The first is the **spermatheca** which stores spermatoza until they are needed for egg fertilization. The spermatheca is single and sac-like with a slender duct, and often has a diverticulum that forms a tubular spermathecal gland. The gland or glandular cells within the storage part of the spermatheca provide nourishment to the contained spermatozoa.

The second type of ectodermal gland, known collectively as **accessory glands**, opens more posteriorly in the genital chamber. Each ovary is composed of a cluster of egg or ovarian tubes, the **ovarioles**, each consisting of a terminal filament, a germarium (in which mitosis gives rise to primary oocytes), a vitellarium (in which oocytes grow by deposition of yolk in a process known as **vitellogenesis**) and a pedicel. An ovariole contain a series of developing oocytes each surrounded by a layer of follicle cells forming an epithelium (the

oocyte with its epithelium is termed a **follicle**), the youngest oocyte occur near the apical germarium and the most mature near the pedicel. There are different types of ovarioless based on the presence or absence of specialized nutritive cells called trophocytes / nurse cells for nourishment of oocytes.

Paniostic ovariole: Lacks specialized nutritive cells so that it contains only a string of follicles, with the oocytes obtaining nutrients from the haemolymph via the follicular epithelium. e.g. Cockroach.

Telotrophic ovariole: (Acrotrophic) The trophocyte is present and its location is confined to the germarium and remain connected to the oocytes by cytoplasmic strands as the oocytes move down the ovariole. eg. bugs.

Polytrophic ovariole: A number of trophocytes are connected to each oocyte and trophocytes moves down along with the ovariole, providing nutrients until depleted. Thus individual oocytes are alternated with groups of smaller trophocytes in the ovarioles. e.g. moths and flies.

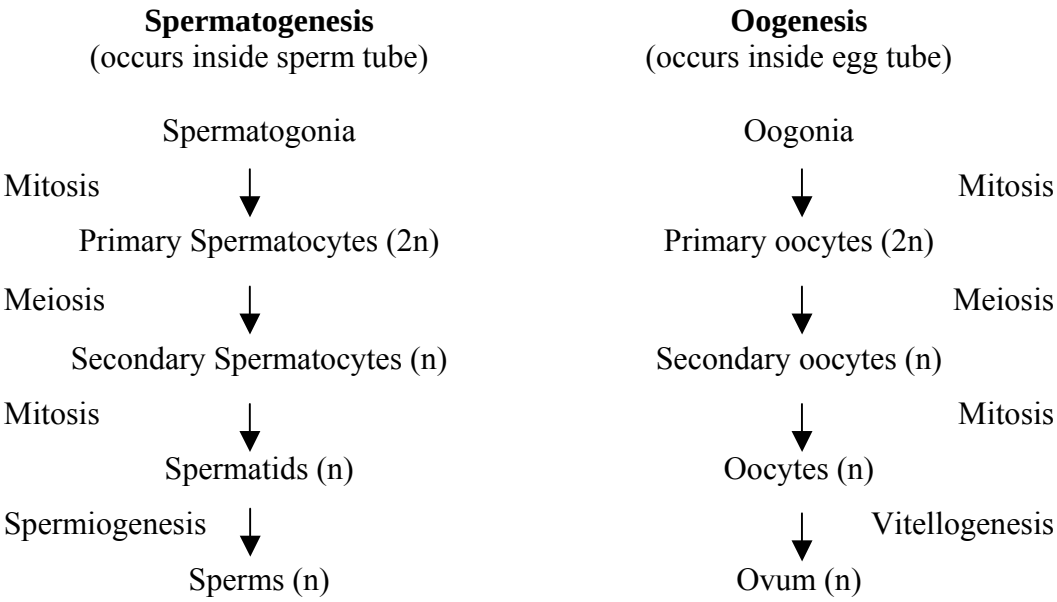
Accessory glands of the female reproductive tract are often called as **colleterial or cement glands**, because their secretions surround and protect the eggs or cement them to the substrate. e.g. egg case production in mantis, ootheca formation in cockroach, venom production in bees.

Male reproductive system

The main functions of the male reproductive system are the production and storage of spermatozoa and their transport in a viable state to the reproductive tract of the female. Morphologically, the male tract consists of paired **testes**, each containing a series of **testicular tubes or follicles** (in which spermatozoa are produced) which open separately into the **sperm duct or vas deferens.** This vas deferens expands posteriorly to form a sperm storage organ or **seminal vesicle**. Tubular paired **accessory glands** are formed as diverticula of the vasa deferentia. Some times the vasa deferentia themselves are glandular and fulfil the functions of accessory glands. The paired vasa deferentia unite where they lead into **ejaculatory duct** (the tube that transports the semen or the

sperm to the gonopore). Accessory glands are 1-3 pairs associated with vasa deferentia or ejaculatory duct. Its function is to produce seminal fluid and **spermatophores** (sperm containing capsule).

Physiology of reproduction



3. Sperm transfer:

(i) Intragenital: Common method, through, aedeagus via vaginal orifice into female genital passage.

(ii) Haemocoelous : Sperms transfered into the body cavity e.g. Bed bug.

(iii) External: Spermatophores are ejected out into open place by male while female walk over it and gets inseminated e.g. Silver fish.

4. 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.

19. Types of reproduction

1. **Oviparity**: Majority of female insects, are oviparous, lay eggs. Embryonic development occurs after oviposition by utilizing the yolk, e.g.Head louse, moths.
2. **Viviparity**: Unlike oviparous, here initiation of egg development takes place within the mother. The life cycle is shortened by retention of eggs and even developing young within the mother. Four main types of viviparity are observed in different insect groups.

i. **Ovoviviparity**: Fertilized eggs containing yolk are incubated inside the reproductive tract of the female and hatching of egg occur just prior to or soon after oviposition e.g. Thrips, some cockroaches, few beetles, and flesh fly. Fecundity of this group is low.

ii. **Pseudoplacental viviparity**: This occurs when a yolk deficient egg develops in the genital tract of the female. The mother provides a special placenta-like tissue, through which nutrients are transferred to developing embryos. There is no oral feeding and larvae are laid upon hatching. e.g. aphids, some earwigs, psocids and polytenid bugs.

iii. **Haemocoelous viviparity**: This involves embryos developing free in the female's haemolymph with nutrients taken up by osmosis. This form of internal parasitism occurs only in sterpsiptera and some gall midges.

iv. **Adenotrophic viviparity**: This occurs when a poorly developed larva hatches and feeds orally from accessory gland (milk gland) secretion within the uterus of the mother. The full grown larva is deposited and pupates immediately (e.g.) Tsetse flies, louse, ked, bat flies.

3.**Parthenogenesis** : Reproduction without fertilization is parthenogenesis. Different types of parthenogenesis are as follows:

a. **Based on occurrence**

i. Facultative (not compulsory) e.g. bee.

ii. Obligatory or constant (compulsory) e.g. stick insect

iii. Cyclic/ sporadic: alternation of gamic and agamic population. e.g.aphid.

b. **Based on sex produced**:

i. Arrhenotoky: Produce male e.g. bee

ii. Thelytoky: produce female e.g. aphids

iii. Amphitoky / deuterotoky: produce both male and female e.g. Cynipid wasp.

c. **Based on meiosis**:

i. Apomictic : no meiosis occurs

ii. Automictic : meiosis occurs, but diploidy is maintained

4. **Polyembryony**: This form of asexual reproduction involves the production of two or more embryos from one egg by subdivision. Mostly observed in parasitic insects (e.g. *Platygaster*). Nutrition for a large number of developing embryo cannot be supplied by the original egg and is acquired from the host's haemolymph through a specialized enveloping membrane called **trophamnion.**

5. **Paedogenesis**: Some insects cut short their life cycles by loss of adult and pupal stages. In this precocious stage gonads develop and give birth to young one by parthenogenesis ie. reproduction by immature insects.

i. Larval paedogenesis - e.g. Gall midges

ii. Pupal paedogenesis – eg. *Miaster* sp.

20. Glandular system

Glandular system is otherwise called as secretary system and is dicvided in to two major groups based on the presence or absence of ducts.

A. **Exocrine glands** (glands with duct)

1. Salivary glands: Salivary glands are modified labial glands which secrete saliva and open beneath hypopharynx.
2. Mandibular glands: Secrete saliva in caterpillars when salivary glands are modified into silk glands. In queen bee it secretes queen substance.
3. Maxillary glands: Secretions are useful to lubricate mouth parts.
4. Pharyngeal glands: Secrete bee milk or royal jelly in nurse bee.
5. Frontal glands: Secrete sticky defensive fluid in nasute termites.
6. Setal glands: Glandular seta (Scoli) secrete irritant fluid in hairy/slug caterpillar.
7. Tenant hairs: Secrete sticky fluid found in pulvilli of legs and helps in ceiling walking in house flies.
8. Moulting glands: Modified glandular epidermal cells, secrete moulting fluid necessary for moulting.
9. Stink glands (Repugnatorial glands): Secrete bad smelling substance. e.g. Stink bugs, bed bugs.
10. Osmeteria (Forked gland): Eversible gland in the thorax of papilionid larva with defense function. e.g. Citrus butterfly larva.
11. Androconia (Scented scales): Secretions of glandular scales of male pierid butterflies to attract the opposite sex.
12. Pheromone glands: Found in abdominal terminalia of one sex and its secretions are released outside to attract opposite sex of the same species.
13. Wax glands: Dermal glands producing wax in bees and mealy bugs.
14. Sting glands: Modified accessory glands secreting venom in worker bees and wasps.
15. Lac glands: Dermal glands secreting resinous substances in lac insect.
16. Milk glands: Modified accessory gland nourishing larva developing in uterus. e.g. Sheep ked.

B. **Endocrine glands** (glands without duct):

1. **Neurosecretory cells**: A pair of median neuro-secretory cells and lateral neurosecretory cells are present. The axons of these neurosecretory cells form two pairs of nervi corpora cardiaci ending in carpora cardiaca. This structure influence the functioning of other endocrine glands.

2. **Corpora cardiaca**: It consist of paired bodies fused in middle and have both nervous tissues and glandular tissues. It acts as a conventional storage and release organ for neurosecretory cells. It controls heart beat and regulate trehalose level in haemolymph.

3. **Corpora allata**: It is a paired gland attached to corpora cardiaca and secretes juvenile hormone (**JH**) there by inhibit metamorphosis. It is needed for egg maturation and functioning of male accessory glands. Practically JH analogues interfere with insect development. **Precocene** is an anti JH which induce precocious metamorphosis and death in insects.

4. **Prothoracic glands**: Paired gland present in ventrolateral part of prothorax of larva and is degenerated in adults. It secretes the moulting hormone **ecdysone**. Neurosecretory cells activate prothoracic glands to secrete ecdysone.

5. **Weismann's ring**: Formed by the fusion of carpora cardiaca, carpora alleta, prothoracic glands and hypocerebral ganglion to secrete puparium hardening hormone. Present in maggots of Dipteran flies.

21. Metamorphosis and immature stages in insects

Metamorphosis is the change in growth and development an insect undergoes during its life cycle from birth to maturity. There are four basic types of metamorphosis in insects.

1. **Ametabola:** (No metamorphosis) e.g. Silver fish. 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 all respects except for the size and called as juveniles. Moulting continues throughout the life.

2. **Hemimetabola**: (Incomplete metamorphosis) e.g. Dragonfly, damselfly and may fly. These insects also have three stages in their life namely egg, young one and adult. The young ones are aquatic and are called as **naiads**. They are different from adults in habit and habitat. They breathe by means of tracheal gills. In dragonfly naiad the lower lip (labium) is called mask which is hinged and provided with hooks for capturing prey. After final moult, the insects have fully developed wings suited for aerial life.

3. **Paurometabola**: (Gradual metamorphosis) e.g. Cockroach, grasshopper, bugs.

The young ones are called **nymphs**. They are terrestrial and resemble the adults in general body form except the wings and external genitalia. Their compound eyes and mouth parts are similar to that of adults. Both nymphs and adults share the same habitat. Wing buds externally appear in later instars. The genitalia development is gradual. Later instar nymphs closely resemble the adult with successive moults.

4. **Holometabola**: (Complete metamorphosis) e.g. Butterfly, moth, fly and bees.

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.

1. **Eggs**: 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 Youngones. Eggs are laid either individually or in groups. The outer protective shell of the egg is called chorion. Near the anterior end of the egg, there is a small opening called micropyle which allows the sperm entry for fertilization. Chorion may have a variety of textures. Size and shape of the insect eggs vary widely.

TYPES OF EGGS :

a) SINGLY LAID :

1) Sculptured egg : Chorion with reticulate markings and ridges e.g. Castor butterfly.

2) Elongate egg : Eggs are cigar shaped. e.g. Sorghum shoot fly.

3) Rounded egg : Eggs are either spherical or globular. e.g. Citrus butterfly

4) Nit : Egg of head louse is called nit. It is cemented to the base of the hair. There is an egg stigma at the posterior end, which assists in attachment. At the anterior end, there is an oval lid which is lifted at time of hatching.

5) Egg with float : Egg is boat shaped with a conspicuous float on either side. The lateral sides are expanded. The expansions serve as floats. e.g. *Anopheles* mosquito.

b) EGGS LAID IN GROUPS :

1) Pedicellate eggs : Eggs are laid in silken stalks of about 1.25mm length in one groups on plants. e.g. Green lacewing fly.

2) Barrel shaped eggs : Eggs are barrel shaped. They look like miniature batteries. They are deposited in compactly arranged masses. e.g. Stink bug.

3) Ootheca (Pl. Oothecae) : Eggs are deposited by cockroach in a brown bean like chitinous capsule. Each ootheca consists of a double layered wrapper protecting two parallel rows of eggs.Each ootheca has 16 eggs arranged in two rows. Oothecae are carried for several days protruding from the abdomen of female prior to oviposition in a secluded spot. Along the top,there is a crest which has small pores which permit gaseous exchange without undue water loss. Chitinous egg case is produced out of the secretions of colleterial glands.

4) Egg pod : Grasshoppers secrete a frothy material that encases an egg mass which is deposited in the ground. The egg mass lacks a definite covering. On the top of the egg,the frothy substance hardens to form a plug which prevents the drying of eggs.

5. Egg cass : Mantids deposit their eggs on twigs in a foamy secretion called spumaline which eventually hardens to produce an egg case or ootheca. Inside the egg case, eggs are aligned in rows inside the egg chambers.

6. Egg mass: Moths lay eggs in groups in a mass of its body hairs. Anal tuft of hairs found at the end of the abdomen is mainly used for this purpose. e.g. Rice stem borer.

Female silk worm moth under captivity lays eggs on egg card. Each egg mass is called a dfl (diseases free laying).

7. Eff raft : In *Culex* mosquitoes, the eggs are laid in a compact mass consisting of 200-300 eggs called egg raft in water.

II. LARVAE

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.

TYPES OF LARVAE: There are three main types of insect larvae namely oligopod, polypod and apodous.

1. OLIGOPOD : Thoracic legs are well developed. Abdominal legs are absent. There are two subtypes.

a. Campodeiform : They are so called from their resemblance to the dipluran genus Campodea. Body is elongate, depressed dorsoventrally and well sclerotised. Head is prognathous. Thoracic legs are long. A pair of abdominal cerci or caudal processes is usually present. Larvae are generally predators and are very active. e.g. grub of antlion or grub of lady brid beetle.

b. Scarabaeiform : Body is `C' shaped, stout and subcylindrical. Head is well developed. Thoracic legs are short. Caudal processes are absent. Larva is sluggish, burrowing into wood or soil. e.g. grub of rhinoceros beetle.

2. POLYPOD or ERUCIFORM : The body consists of an elongate trunk with large sclerotised head capsule. Head bears a pair of powerful mandibles which tear up vegetation. Two groups of single lensed eyes (Stemmata) found on either side of the head constitute the visual organs. The antenna is short. Three pairs of thoracic legs and upto five pairs of unjointed abdominal legs or prolegs are present. Thoracic legs are segmented and they end in claws which are used for holding on to the leaf. Bottom of the proleg is called planta which typically bears rows or circlet of short hooked spines or crochets which are useful in clinging to the exposed surface of vegetation and walking. Abdominal segments three to six and ten typically bear prolegs. e.g. Caterpillar (larvae of moths ad butterflies).

a. Hairy caterpillar : The body hairs may be dense, sparse or arranged in tufts. Hairs may cause irritation, when touched. e.g. Red hairy caterpillar.

b. Slug caterpillar : Larva is thick, short, stout and fleshy. Laval head is small and retractile. Thoracic legs are minute. Abdominal legs are absent. Abdominal segmentation is indistinct. Larva has poisonous spines called scoli distributed all over the body. Such larva is also called platyform larva.

c. Semilooper : Either three or four pairs of prolegs are present. Prolegs are either wanting or rudimentary in either third or third and fourth abdominal segments. e.g. castor semilooper.

d. Looper : They are also called measuring worm or earth measurer or inch worm. In this type, only two pairs of prolegs are present in sixth and tenth abdominal segments. e.g. Daincha looper.

3. APODOUS: They are larvae without appendages for locomotion. Based on the degree of development and sclerotization of head capsule there are three subtypes.

a. Eucepalous : Larva with well developed head capsule with functional mandibles, maxillae, stemmata and antennae. Mandibles act transversely. e.g. Wriggler (larva of mosquito) and grub of red palm weevil.

b. Hemicephalous : Head capsule is reduced and can be withdrawn into thorax. Mandibles act vertically.

e.g. Larva of horse fly and robber fly.

c. Acephalous : Head capsule is absent. Mouthparts consist of a pair of protrusible curved mouth hooks and associated internal sclerites. They are also called vermiform larvae. e.g. Maggot (larva of house fly).

III. PUPA : It is the resting and inactive stage in all holometabolous insects. During this stage, the insect is incapable of feeding and is quiescent. During the transitional stage, the larval characters are destroyed and new adult characters are created. There are three main types of pupae.

1. OBTECT : Various appendages of the pupa viz., antennae, legs and wing pads are glued to the body by a secretion produced during the last larval moult. Exposed surfaces of the appendages are more heavily sclerotised than those adjacent to body. e.g. moth pupa.

a. Chrysalis : It is the naked obtect pupa of butterfly. It is angular and attractively coloured. The pupa is attached to the substratum by hooks present at the terminal end of the abdomen called cremaster. The middle part of the chrysalis is attached to the substratum by two strong silken threads called gridle.

b. Tumbler : Pupa of mosquito is called tumbler. It is an obtect type of pupa. It is comma shaped with rudimentary appendages. Breathing trumpets are present in the cephalic end and anal paddles are present at the end of the

abdomen. Abdomen is capable of jerky movements which are produced by the anal paddles. The pupa is very active.

2. EXARATE : Various appendages viz., antennae, legs and wing pads are not glued to the body. They are free. All oligopod larvae will turn into exarate pupae. The pupa is soft and pale e.g. Pupa of rhinoceros beetle.

3.COARCTATE : The pupal case is barrel shaped, smooth with no apparent appendages. The last larval skin is changed into case containing the exarate pupa. The hardened dark brown pupal case is called puparium. e.g. Fly pupa.

PUPAL PROTECTION

In general pupal stage lacks mobility. Hence it is the most vulnerable stage. To get protection against adverse conditions and natural enemies, the pupa is enclosed in a protective cover called cocoon. Based on the nature and materials used for preparation of cocoons, there are several types.

Types of cocoon	Materials used	Example
silken cocoon	Silk	Silk worm
Earthen cocoon	Soil + saliva	Gram pod borer
Hairy cocoon	Body hairs	Woolly bear
Frassy cocoon	Frass + saliva	Coconut black headed caterpillar
Fibrous cocoon	Fibres	Red plam weevil
Puparium	Hardened last larval skin	House fly

22. Tropism in insects

The majority of plant species support complex fauna of herbivores and are defined in relation to the range of plants used viz., monophages, oligophages and polyphages. Many plants have developed defences against insects during the co-evolutionary process. These defences are either physical (spines, pubescence on stems and leaves, silica or sclerenchyma in leaf tissue etc.) or chemical (secondary plant compounds-tannins, terpenoids, alkaloids etc.) in nature. Secondary plant compounds may either repel an insect for feeding and oviposition or affect the biology of an insect due to antibiosis.

Insects are intimately associated with plant and are important to many plants in their reproduction, through pollination or seed dispersal.

Entomophily - Insect pollination
(i)Cantharophily -beetle pollination
(ii)Myophily -fly pollination
(iii)Sphecophily- Wasp pollination
(iv)Myrmecophily- ant pollination
(v)Melittophily-bee pollination
(vi)Phalaenophily-moth pollinated
(vii)Psycophily- butterfly pollinated

Insect-plant interactions associated with pollination are clearly mutualistic. The plant is fertilized by appropriate pollen, while the insect obtains food.

e.g. (i) Fig species pollinated by fig wasp.

(ii) Correlation between moth proboscis length and flower depths - Madagascar star orchid with 30 cm length of flower parts is pollinated by giant hawk moth with long proboscis.

Figs and fig wasps: The female wasp enters the fig syconium via the ostiole (small hole), pollinates the female flowers, oviposit in some of them and dies. Each wasp larva develops within the ovary of a flower. Female flowers not oviposited by wasps will from seeds. Month after oviposition, emerging wingless male wasps mate with female. Shortly after male phase of the flower starts and this female wasp gather pollen and move out of this flower to locate another figtree in the female phase to continue this process.

Ants and seed dispersal: Many ants feed on seeds and also helps in dispersal of seed, known as myrmecochory.

Ants plant interactions involving "domatia" (Domatia-little houses). Plants with true domatia are called myrmecophtes. These myrmecophytes receive some benefits from occupancy of their domatia. e.g. Acacia plant and Pseudomyrmex ants. Ants protect the plants from herbivores and the plant derives mineral nutrients and nitrogen from ant colony waste through the inner surface of domatia (Myrmecotrophy).

‘Phytotelmata' (Plant held water containers): Many plants support insect communities in structures that retain water. In this process plant also derive some nutrition from insects. e.g. Pitcher plants.

23. INSECT COMMUNICATION

Insects generally communicate to locate their food source and mate, using
(i)Semiochemicals
(ii)Light Production
(iii)Sound Production
(iv)Body language

I. SEMIOCHEMICALS

a. Pheromones: "substances that are secreted to the outside by an individual and received by a second individual of the same species in which they release a specific reaction".

Pheromones are mostly volatile but sometimes they are liquid. All pheromones are produced by exocrine glands, derived from epidermal cells. The scent organs may be located anywhere on the body.

(eg) (i) Female lepidoptera - eversible sacs or pouches between the 8th and 9th abdominal segment.
(ii) Female honey bee - mandibular glands
(iii) Female aphids - hind tibia
(iv) Female cockroach - midgut
Further classification of pheromones is based on categories of behaviour associated with sex, aggregation, spacing, trial forming and alarms.

(i) Sex Phermones : Used for mate location and courtship (eg) Queen butterfly Danaus gilippus : Male insect produces courtship pheromone an alkaloid called danaidone.

(ii) Aggregation pheromones: Causes insects of both sexes to crowd around the source of the pheromone. This may lead to increased chances of mating. The other benefits being, security from predation, maximum utilization of scarce food resource, overcoming of host resistance and cohesion of social insects. e.g. Cockroaches and scolytid beetles.

(iii) Spacing phermones: Produces appropriate spacing on food resources. (eg) Many □Tephritid□ flies lay eggs singly in fruit where a single maggot is to develop. Here the female deposits an oviposition deterrent pheromone on the fruit to avoid subsequent oviposition.

(iv) Trial - marking pheromones : Many social insects use this pheromone to mark their trails to food and the nest. This pheromone is volatile and short-lived. (eg) In ants the trial pheromone are commonly metabolic waste products excreted by the poison gland. These need not be species specific - several species share some common chemicals.

(v) Alarm pheromones : This causes alarm behaviour. Alarm is provoked by the presence of predator or in many social insects by the threat to the nest.

II. Light production: The principal role of light emission is in courtship signalling and prey finding. This involves species specific variation in

duration, number and rate of flashes in a pattern and the frequency of repetition of the pattern. (eg) Lampyrid beetle (fire fly)

$$\text{Luciferin} \xrightarrow[\text{ATP} + O_2]{\text{Luciferase}} \text{Oxy-luciferin} + CO_2 + \text{light}$$

Variation in ATP release controls the rate of flashing and differences in pH, controls frequency and colour of light emitted.

III. Sound Production: It is useful in location of mate. (eg) Mosquitoes, Cicada.
IV. Body Language (The dance language of bees)
(i) Round dance: Nearby food is communicated by a simple round dance, the incoming worker exchanges nectar and makes tight circles with frequent reversals for few seconds. The quality of nectar or pollen is communicated by the vigour of the dance.

(ii) Waggle dance: More distant sources are identified by this dance which involves abdomen shaking during a figure-of-eight circuit. Informative characteristics of the dance include the length of the straight part (measured by number of comb cells traversed), the dance tempo (number of dances per unit time) and the duration of waggling and noise production (buzzing) during straight line section. Messages conveyed are the energy required to get the source, quality of forage and direction relative to sun's position.
(iii) Vibration dance: It is useful in regulating the daily and seasonal foraging patterns in relation to fluctuating food supply. More vibration Indicates colony needs more foraging.
Vibration with Queen:To increase queen rearing
No vibration:To swarm with queen or for a mating flight of new queens.

24. OFFENSE AND DEFENSE BEHAVIOUR IN INSECTS

Insects exhibit several types of defense mechanisms to escape from their natural enemies. Insect defense can be grouped into four types as follows.

i Behavioural defense
ii Structural defense
iii Chemical defense
iv Colourational defense

1. BEHAVIOURAL DEFENSE: Insect exhibit several kinds of escape reactions.
1. JUMPING : It is an effective form of escape
2. Reflex dropping : Caterpillars often drop from their food on a strand of silk when disturbed and reel themselves back up when the danger has passed. e.g. Mango shoot webber.

3. Thanatosis : Many beetles and weevils feign dead which is a form of defense against a predator which prefers live prey

4. Threatening pose : The insects frighten their enemies by threatening pose. e.g. gingelly sphingid and stag beetle.
5. Protective constructions :
Eggs : Stalked eggs gain protection from predators. e.g. green lace wing fly.
Nymph : Frothy secretions produced by the nymph of spittle bug protects it against predators and desiccation.
Larva : Bag worms live in portable cases made out of plant materials along which they move, feed and finally pupate inside the cases.
Pupa : several materials like silk, frass, soil, body hairs and fibres are used for forming protective cocoons. In flies the last larval skin hardens to form chitinous protective puparium. Mosquito pupa is unusually active thereby it escapes from aquatic predators.
Adult : In mealy bug, waxy threads covering the body afford protection. Hard shell like covering protects the soft bodied insects e.g. female scale insect.

II. STRUCTURAL DEFENSE
1. Horny integument : The integument is hard and highly sclerotised. Hence it can resist beak penetration by insectivorous brids, e.g. jewel beetle.
2.Sclerotised cerci : In earwings, the cerci are foreceps like which are organs of defense.
3.Raptorial leg : The grasping legs of preying mantis are also useful to attack its enemy.
4.Tentacles : Varying number of paired movable processes are present on the body of the larvae of butterflies grouped in the family Danaidae. They are useful to brush off the enemies.

III. CHEMICAL DEFENSE: It is the primary mechanism of defense in many insects. Defensive chemicals may be of two types viz. venom and odoriferous compounds. The venom is injected into the body of the enemy. e.g. Honey bee. Bee venom is produced from acid glands which are the modified accessory glands. The ovipositor is modified into sting which is the organ of defense.

Odoriferous or repugnatorial substances are not injected into the body of the enemy, but they may be acquired from the food source (exogenous) or produced inside the body (endogenous).

EXOGENOUS:
1) Osmeteria: (Osmeterium - Singular) Odoriferous plant components accumulated in thoracic pouches are expelled by the eversion of a pair of coloured protrusible structures called osmeteria releasing a disagreeable odour in response to a disturbance.

ENDOGENOUS
1. Stink glands: In stink bugs and rice earhead bug, a stink gland is present in metathorax emanates a bad odour when handled.
2. Poisonous setae : They are present in the body wall of certain caterpillar e.g. castor slug. The setal tip breaks off issuing the poison from the poison gland cell.

IV. COLOURATIONAL DEFENSE
1. Cryptic colouration : By the deceptive look, the insect gains protection. The insect looks like a particular object that forms a common component of the environment or the colour of the insect blends with the background. There are three types.

Homochromism : Colour is similar e.g. Preying mantis.
Homomorphism : From is similar e.g. cowbug.
Homotypism : Both colour and form are similar e.g. stick insect.

2. Revealing colouration: e.g. Giant silk worm. Forewings are crypticaly colured. Hind wings are attractively coloured. If once the bird locates the insect, the prey insect exposes the bright hind wings with eye spots to startle the predator.

3. Warning colouration: Butterflies are usually attractively coloured. The bright colour serves as a warning to the predator. Larva of monarch butterfly while feeding on the milk weed plant, ingests cardiac glycodides. As a result, both the larva and adult become unpalatable.
4. Mimicry : One species of animal imitates the appearance of another better protected animal species, thereby sharing immunity against destruction. The former is called mimic and the latter is known as model. There are two types of mimicry.

Batesian mimicry: Mimic is restricted to palatable species. Mimic alone gets protection because the predators are apparently misled.
e.g. i. Viceroy butterfly : *Liminitis archippus* - Mimic
Monarch butterfly : *Danaus plexippus* - Model
ii. *Hypolimnas bolina* - Mimic
Euploea core - Model
iii. A fly mimicking wasp.

Mullerian mimicry: Both model and mimic are unpalatable and the ingestion of either by a predator results in the avoidance of both the species. This form of

mimicry is advantageous to both the mimic and model. e.g. *Danaus chrysippus*, *D. genetua*.

25. TAXONOMY, PRINCIPLES AND PROCEDURES

Taxonomy is the science of classification. It can be defined as placing biological organisms or forms in order. Simpson (1961)has defined taxonomy as the theoretical study of classification including basis, principles, procedures and rules. Taxonomy includes nomenclature and classification.

Systematics: The science of study of kind and diversity of organisms and any or all relations among them. Systematics includes taxonomy and evolution.

Stages of taxonomy: The taxonomy of any group passes through several stages.

(i) Alpha taxonomy (α) : It is concerned with naming and characterisation of species.
(ii) Beta taxonomy (β) : Concerned with classification
(iii) Gama taxonomy (γ) : Concerned with evolutionary relations and phylogeny.

Basis for classification: Classification is the ordering of a large group of organisms based on certain characters into small groups. Classification is mainly based on evolutionary relationship and not based on superficial resemblance. Points considered while classifying are (i) external structure, (ii) internal characters, (iii) developmental history, (iv) physiological data and (v) cytogenetic data.

The biological system of classification is called hierarchial concept of classification. This was introduced by Carl Von Linnaeus (1758). A large group of organism is successively subdivided into small group. These groups are called taxa (taxon-singular). Each group is at a particular level in this system. This level is called the rank. Groups of the same rank are grouped together and that constitutes the taxonomic category. e.g. Class. Certain taxonomic categories are obligate, while others are optional. For describing and classifying any organism the basic taxonomic category is species. The lowermost category for classifying an organism is subspecies.

Systematic position of Indian honey-bee
* 1. Kingdom: Animalia
* 2. Phylum: Arthropoda
* 3. Class: Insecta
  4. Sub class: Pterygota
* 5. Order: Hymenoptera

6. Suborder: Apocrita
7. Super family: Apioidea
* 8. Family: Apidae
9. Subfamily: Apinae
* 10. Genus: Apis
* 11. Species: indica
(* - Obligate, while others optional)

Sub species is the geographic variety or race. Species is the natural reproductive unit among animals. It is a group of individuals having similar structure, development and behaviour which interbreed to produce viable offsprings. (Biological species concept says that a species is a natural, interbreeding population which is reproductively isolated from the individuals of other species).

Functions of species
i. Reproductive community: The individuals of the species are able to recognise each other as potential mate and seek each other for the purpose of reproduction.
ii. An ecological unit: Irrespective of the number of individuals they act as a unit and interact with the individuals of other species with which they share the habitat.

iii. A genetic unit: it consists of a large number of inter-communicating gene pool in which the individual is a temporary reservoir holding a portion of genes for a short period.
Body text young one by parthenogenesis.
i. Larval paedogenesis - e.g. gall midges.

26. **Nomenclature and identification**

A name is required for identification of any organism. Generally two types of names are used (i) common name (ii) scientific name.

I. Common name

(i) They are **inaccurate** because it varies from region to region and country to country and there is **no uniformity** followed in naming the organisms.

e.g. Locust is a bug referring cicada in European countries and normally locusts also refer to short horned grasshoppers living in groups.

(ii) Common name is not available for all organisms

e.g. **Squash bugs** present in cucurbitaceous plants are represented by many species, but no common name is available for each species. It is available only for a large group like order and family.

(iii) Same common name is used for insects of different orders.

e.g. Flies. A true fly has only 2 wings, whereas other insects like mayfly, dragonfly, etc., are also mentioned as flies.

(iv) Homonym - Same name is used for describing two different type of insects.

e.g. Boll worm is a common term used for more than five species of boll feeding insects.

(v) Synonym - More than one name denoting a single insect.

e.g. Gram pod borer, American bollworm denotes *Helicoverpa armigera*

II. **Scientific name:** The system of naming organisms using two words is called **Binomial nomenclature (Trinomial nomenclature** if three words are used). This system of naming gives accurate information. It is universal and is accepted in all parts of the world. The rule regarding the naming of organisms is contained in **International code for zoological nomenclature.**

Normally there are two names, the first name is the generic name and the second name is the species name**.** The names that follow the generic name are called **Trivial names.** The trivial names may be either species or a subspecies name.

e.g. Head louse: *Pediculus humanus captis*

Body louse: *Pediculus humanus corporis*

The first letter of the generic name is in capital and the first letter of species and subspecies are in small letter. All the words are Latinized and written in italics or it should be written and underlined separately. The **authority** name is written after the species name. It starts with capital letter. The author name is put in bracket if the taxa has been reclassified and placed in another group. e.g. Moringa fruit fly *Gitona distigma* (Meigon)

IDENTIFICATION

All insects present in the world are not yet identified and described (about 25% of the insect species are unidentified). An already described species produce new **race** which requires further identification. Identification helps to understand about the organism and to take proper control measure. Insects can be identified through an expert, by comparing the available collections, using photographs and pictures and by using **taxonomic keys**. Key is a tabular statement presenting alternatives, describing about the features of an organism.

Most of the keys are **dichotomous** i.e., always dividing into two or they are always in the form of couplets and give a clear cut alternative. Keys can be constructed based on single character (**monothetic key**) or many characters (**polythetic key**). Polythetic key is more advantageous. Monothetic key has three disadvantages (i) the organism may be an exception for a particular character (ii) chances of erring is more (iii) if the particular body part is broken on which the key is made, then the key cannot be used. Key can be classified based on evolutionary principles also as **phylogenetic key** and **arbitrary key**

(i) Phylogenetic key: The key is based on the evolutionary relationship. The group appears only once in the phylogenetic key.

(ii) Arbitrary key : The taxa or group appears at several places in the key. It has more advantages.

27. Classification of insects

Insects are the six legged flying arthropods coming under the phylum Arthropoda and class Insecta. The widely accepted classification of insects was proposed the eminent insect taxonomist **A.D.Imms**.

Characters of class Insecta

1. Body is divided into three regions
2. In head a pair of antenna and a pair of compound eyes are usually present.
3. Thorax is the centre of locomotion with, 3 pairs of five jointed legs and two pairs of wings.
4. Excretion is mainly through malpighian tubules.
5. Tracheal system of respiration well developed.
6. Brain is divided into protocerebrum, deutocerebrum and tritocerebrum.

The class Insecta has **two subclasses** viz., Apterygota and Pterygota.

	Apterygota	Pterygota
1.	Primarily wingless-evolved from wingless ancestors.	Winged or secondarily wingless-evolved from winged ancestors e.g. Flea, head louse, bed bug.
2.	Metamorphosis is totally absent or slight.	Present.
3.	Mandibular articulation in head is monocondylic i.e. single	Dicondylic i.e., double.
4.	Pleural sulcus in thorax is absent.	Present.
5.	Pregenital abdominal appen-dages present.	Absent.

The subclass Apterygota has 4 orders namely

1. Thysanura - Silverfish (Thysan-fringed, Ura-tail)
2. Collembola- Springtail or snowflea (coll-glue; embol-peg)
3. Protura - Proturans or Telsontail (Pro-first, Ura-tail)
4. Diplura - Diplurans or Japygids (Di-two; Ura-tail)

The sub class Pterygota has **two divisions**, namely **exopterygota** and **endopterygota** based on the wing development.

Character	Exopterygota	Endopterygota
1 .Wing development	External	Internal
2 .Metamorphosis (Holometabola)	Incomplete (Hemimetabola) or gradual (Paurametabola)	Complete
3. Pupal stage	Absent	Present
4. Immature stage	Naiad or Nymph	Larva
5. No. of orders	9	16

The class Insecta is divided in to 29 orders (4 in Apterygota and 25 in Pterygota).

EXOPTERYGOTA		**GROUPS**
01.	Ephemeroptera - Mayflies	I. **Paleopteran orders** (1,2)
02.	Odonata-Dragonfly, Damselfly	
03.	Plecoptera - Stonefly	II. **Orthopteroid orders**(3-11)
04.	Grlloblatodia - Rock crawlers	
05.	Orthoptera-Grasshopper, locust, cricket, mole cricket	
06.	Phasmida-stick insect, leaf insect	
07.	Dermaptera-Earwigs	
08.	Embioptera-Webspinners/Embids	

09. Dictyoptera-cockroach, preying mantis
10. Isoptera - Termites
11. Zoraptera - Zorapterans
12. Psocoptera - Book lice III. **Hemipteroid orders**(12-16)
13. Mallophaga - Bird lice
14. Siphonculata - Head and body louse
15. Hemiptera - Bugs
16. Thysanoptera - Thrips

ENDOPTERYGOTA

01. Neuroptera- Antilions, aphidlion, owl flies, mantispid flies.
02. Mecoptera - Scorpionflies.
03. Lepidoptera - Butterflies and moths.
04. Trichoptera - Caddisfly.
05. Diptera - True fly. **Group IV. Panorpoid complex (1-6)**
06. Siphonaptera - Fleas.
07. Hymenoptera - Bees, wasps, ants.
08. Coleoptera - Beetles and weevils.
09. Strepsiptera - Stylopids.

Paleopteran insects cannot flex the wings over the abdomen, i.e., wing flexing mechanism is absent. The characters of insects belonging to Orthopteroid group include mandibulate mouth parts, anal area of hind wing well developed, abdomen is always with cerci, many number of malpighian tubules and the ganglia of the ventral nerve cord are not fused. Hemipteroid insects have the haustellate mouth parts and mainly they feed on liquid food like plant sap. Panarpoid insects are holometabolous and they have larval and pupal stage.

Study of insect orders

1. Thysanura

Synonyms	:	Ectognatha, Ectotrophi
Etymology	:	Thysan - fringe; ura – tail.
Common names	:	Silverfish, Fire brat, Bristle tail

Characters: Body is elongate and flattened. Body is glistening and clothed with scales. Compound eyes are present or absent. Antennae is long, filiform and multisegmented. Mouthparts are ecotognathous, biting type. They are primarily wingless insects. Abdomen is 11 segmented. Varying number of bilateral styli are present on abdominal sternites. Styli are belived to be reduced abdominal legs. Female has elongate jointed ovipositor. Abdomen at its tip carries a pair of elongate many segmented cerci and a median caudal filament. Insemination is indirect. Metamorphosis is absent. Moulting continues even after attaining sexual maturity.

Importance: It is often a pest in home and libraries. *Ctenolepisma* sp. is the common household silverfish. It feeds and destroys paper, book bindings and starched clothing. It can be collected from amongst old books, behind calendar, photo frames, etc.

2. COLLEMBOLA

Synonyms	:	Oligentoma, Oligoentomata
Etymology	:	coll-glue; embol - wedge or peg.
Common names	:	Spring tail, Snow flea

Characters: They are minute insects. Body is globose or tubular. Compound eyes are absent. One to several pairs of lateral ocelli form an eye patch. Antenna is four segmented. Mouthparts are entognathous biting type and found within a pouch. Tibia is fused with tarsus to form tibio-tarsus. They are primarily wingless. Abdomen is six segmented with there medially situated pregenital appendages.

* **Ventral tube** or **Collophore** or **Glue peg**: It is a bilobed adhesive organ found on the first abdominal sternite. It is beleived to be associated with respiration, adhesion and water absorption.

* **Hamula** or **Tenaculum** or **Retinaculum**: It is present on the third abdominal sternite. It consists of a fused basal piece, corpus and free distal part called rami. It holds the furcula.

* **Furcula** or **Springing organ**: It consists of a basal manubrium, paried dens and distal claws called mucro. It is held under tension beneath the abdomen by retinaculum when at rest.

Malpighian tubules, tracheal system and metamorphosis usually absent.

Importance: *Sminthurus viridis* is a pest on alfalfa. It can be collected from moist places in soil. They are also found in mushroom houses as a pest.

3. Ephemeroptera

Synonyms	:	Ephemerida, Plectoptera
Etymology	:	Ephemero-living for a day; ptera-wing
Common names	:	Mayflies, Shadflies, Dayflies

Characters: Small to medium sized soft bodied insects. Compound eyes are large. There are three ocelli. Antenna is short and setaceous. Mouthparts in adults are atrophied. Forewings are large and triangular. Hind wings are small and absent in some species. Numerous cross and intercalary veins are present. Wings are held vertically over the abdomen. Wing flexing mechanism is absent. Abdomen is slender with a pair of long cerci. Median caudal filament may be present or absent. Metamorphosis is incomplete with three stages viz., egg, naiad and adult. Naiad is aquatic with biting mouthparts. It breaths through bilateral abdominal gills. At tip of the abdomen a pair of long cerci and a median caudal filament are usually present. Immediately after the adult emergence body of the insect is covered with closely set fine hairs called pellicle and this stage is called as subimago. It is dull in colour with opaque wings and legs and cerci are not well developed. In imago wings are transparent. Legs and cerci are well developed. Body is shiny and not covered with pellicle. Adults are found near lakes and ponds and are also attracted by light.

Importance: Naiads are important fish food. Adults are short lived and hence the name dayfly. When they emerge in large numbers the pose nuisance problem

4. Odonata

Etymology : Odon - tooth

Common names : Dragonflies and damselflies

Characters: Medium to large sized insects. They are attractively coloured. Head is globular and constricted behind into a petiolate neck. Compound eyes are large. Three ocelli are present. Mouthparts are adapted for biting. Mandibles are strongly toothed Lacinia and galea are fused to form mala which is also toothed.

Wings are either equal or sub equal, membraneous; venation is net work like with many cross veins. Wings have a dark pterostigma towards the costal apex. Sub costa ends in nodus. Wing flexing mechanism is absent.

Legs are anteroventrally placed. They are suited for grasping, holding and conveying the prey to the mouth. Spinous femora and tibiae are useful for holding the prey. Forward shift of leg attachments allow easy transfer of prey items to mouth in flight. Legs are held in such a way that a basket is formed into which the food is scooped.

Abdomen is long and slender. In male gonopore is present on ninth abdominal segment. But the functional copulatory organ is present on the second abdominal sternite. Before mating sperms are transferred to the functional penis. Cercus is one segmented.

Metamorphosis is incomplete with three life stages. The naiad is aquatic. Labium is greatly elongated, jointed and bears two hooks at apex. It is called mask. It is useful to capture the prey.

Importance: Adults are aerial predators. They are able to catch, hold and devour the prey in flight. Naiads are aquatic predators. Dragonflies and damselflies can be collected with an aerial net near streams and ponds especially on a sunny day. Naiads can be collected from shallow fresh water ponds and rice fields.

Classification: There are two sub-orders. Dragonflies are classified under **Anisoptera** and damselflies are grouped under **Zygoptera.**

5. Orthoptera

Synonyms : Saltatoria, Saltatoptera

Etymology : Ortno - straight; ptera-wings.

Common names : Grasshoppers, Locust, Katydid, Cricket, Mole cricket

Characters : They are medium to large sized insects. Antenna is filiform. Mouthparts are mandibulate. Prothorax is large. Pronotum is curved, ventrally covering the pleural region. Hind legs are saltatorial. Forewings are leathery, thickened and known as tegmina. They are capable of bending without breaking. Hindwings are membranous with large anal area. They are folded by longitudinal pleats between veins and kept beneath the tegmina.

Cerci are short and unsegmented. Ovipositor is well developed in female. Metamorphosis is gradual. In many Orthopterans the newly hatched frist instar nymphs are covered by loose cuticle and are called pronymphs. Wing pads of nymphs undergo reversal during development. Specialized stridulatory (sound-producing) and auditory (hearing) organs are present.

Classification

This order is sub divided into two suborders, viz., **Caelifera** and **Ensifera**.

	Caelifera	Ensifera
1.	Antenna is short with less than 30 segments.	Antenna is long with more than 30 segments.
2.	Tympanum is found on the lateral side of the first abdominal segment.	Tympanum is fund on the foretibia.
3.	Vision and hearing acute	Tactile respones is well developed.

4.	Mandibles are specialized for consuming monocot foliage.	Feed on dicot plants
5.	Diurnal	Nocturnal
6.	Rely on jumping to escape from predators	Rely on crypsis
7.	Eggs are laid in groups in soil inside shallow burrows.	Eggs are singly inserted into plant tissue or soil.

I. Sub order : Caelifera

Family: Acrididae : Short horned grasshoppers and locusts.

II. Sub order: Ensifera

Families:1. Tettigonidae: Long horned grasshoppers, Katydids and bush crickets.

2. Gryllidae: Crickets. **3. Gryllotalpidae :** Mole crickets.

6. Phasmida

Synonyms : Phasmodea, Phasmatodea

Etymology : Phasma - an apparition

Common names : Stick insects, Leaf insects

Characters : Body is stick - like or leaf – like. Head is prognathous. Mouthparts are chewing type. Prothorax is short. Meso and metathorax are long. Metathorax is closely associated with the first abdominal segment. Legs are widely separted. They are long and slender resembling twigs in stick insect. Tibia and femur shows lamellate expansion in leaf insects. A line of weakness is found between the tro-chanter andrest of the leg. The legs get broken easily at this region and such legs get regenerated subsequetly. Tarsus is five segmented. Wings may be present or absent. Forewings when present are small and modified into tegmina. In leaf insects the wing venation mimics leaf venation. Cerci are short and unsegmented. They show protective resemblance. They are herbivorous.

Classification : There are two families. Stick insects are grouped under **Phasmidae** and leaf insects are classified under **Phyllidae.**.

7. Dermaptera

Synonyms : Euplexoptera, Euplecoptera

Etymology : Derma - skin; ptera - wing

Common names : Earwigs

Characters: They are generally elongate insects. Head is with a distinct `Y' shaped epicranial suture. They have chewing mouthparts. Prothorax is large, well developed and mobile. Meso and Metathorax are fused with the first abdominal segment. Forewings are short, leathery and veinless. Both the wings meet along a mid dorsal line. They are called tegmina or elytra. They are protective in function and are not used for flight. Hindwings are large, membranous, semicircular and ear like. The anal area of the wings is large with a number of branches of anal veins which are radially arranged. They are folded fan like, longitudinally and twice transversely and kept beneath the forewings at rest. Wings do not cover the abdomen fully. Cerci are found at the end of the abdomen. They are unsegmented enlarged, highly sclerotised and forceps like. They are large and bowed in male and nearly straight in female. They are useful in defence, folding and unfolding of wings, prey capture and copulation. Parental care is shown by female earwigs. It literally, roost on the eggs until hatching occurs and also cares for the nymphs.

Importance: *Euborellia annulipes* bores into groundnut pods and feeds on the kernel.

8. Embioptera

Synonyms : Embiodea, Embiidina

Etymology : Embia-lively; ptera-wings

Common names : Embiids, Webspinners

Characters: They are small elongate soft bodied insects. Antenna is filiform. Mouthparts are chewing type. Basitarsus of the foreleg is greatly enlarged. Silk glands and spinnerets are found in the basitarsus. Hind femur is enlarged and helps in backward running. Male has well developed wings; while female is apterous. Wings are elongate, nearly equal, smoky brown with reduced wing venation. Radial vein is thick. Cerci are asymmetrical; left cercus is one segmented and it serves as clasper. Cerci are equal and two segmented in female. Embiids are gregarious and live inside tubular silken tunnels beneath stones, logs and bark of trees. Silken tunnels give protection against predators, prevent excessive water loss from the body and provide a humid atmosphere. Females show strong parental care and they nurse the eggs and nymphs. They feed on decaying plant matter.

9. Dictyoptera

Synonyms	:	Oothecaria, Blattiformia
Etymology	:	Dictyon - net work; ptera - wings
Common names	:	Cockroaches and preying mantids.

Characters: Head is hypognathous. Antenna is filiform. Mouthparts are chewing type. Tarsus is five segmented. Forewings are more on less thickened, leathery with a marginal costal vein. They are called tegmina. Hindwings are large, membranous and folded fanlike and kept beneath the forewings. Cerci are short and many segmented. Eggs are contained in an ootheca.

Classification: Dictyoptera is divided into two suborders viz., **Blattaria** (cock-roaches) and **Mantodea** (preying mantids). The important families are **Blattidae** and **Mantidae.**

10. Isoptera

Synonyms	:	Termitina, Termitida,Socialia
Etymology	:	Iso - equal; ptera - wing.
Common names	:	Termites, White ants

Characters: They are small greyish white, soft bodied insects. The body is pale yellow in colour because of weak sclerotization. Compound eyes are present in alate forms and usually absent in apterous forms. Antennae are short and moniliform. Mouthparts are adapted for biting and chewing. Two pairs of wings are present which are identical in size form and venation. Wings are membranous and semitransparent. Venation is not distinct. Veins near the costal and anal margin alone are distinct. Anterior veins are more sclerotised. Wings are flexed over the abdomen at rest. They are extended beyond the abdomen. Wings are present only in sexually mature forms during swarming season. Wing shedding takes place along the basal or humeral suture, after swarming. The remanant or the stump remaining behind is called **`scale'.** Abdomen is broadly jointed to the thorax without constriction. External genital organs are lacking in both the sexes. Cerci are short.

Specialities: They are ancient polymorphic, social insects living in colonies.

Internal characters: Salivary glands are well developed. Rectum is distended forming rectal pouch to accommodate large number of intestinal symbionts. Fat body development is extensive in male and female reproductives. Soil inhabiting termites construct earthern mounds called **termitaria**. They have evolved complex relationships with other organisms like bacteria, protozoa and fungi which help them in the digestion of wood. Incessant food sharing (**trophallaxis**) occurs between the members of the commounity by mouth-to-mouth and anus-to-mouth food transfer.

Importance: Termites are nature's scavengers. They convert logs, stumps, branches etc, to humus. Many are injurious to crops, furniture and wood works of buildings.

11. Psocoptera

Synonyms	:	Corrodentia, Copeognatha
Etymology	:	Psoco-rub small; ptera – wings ;Psochos-dust like.
Common names	:	Book lice, Bark lice, Dust lice.

Characters: They are minute and soft bodied insects. Head has a distinct `Y' shaped epicranial suture. Clypeus is swollen. Mouthparts are biting and chewing type. Mandibles are with well developed molar and incisor areas. Lacinia is rodlike (`**pick**') which is partially sunken into the head capsule. Legs are slender. Wings may be present or absent. Forewings are larger than hind wings. Wings are held roof like over the abdomen. Cerci are absent. Psocids are frequently gregarious. Some psocids have the ability to spin silk. Dorsal pair of labial glands are modified into silk glands.

Imporance: The common book louse is *Liposcelis* sp. They feed on paper paste of book binding, fragments of animal and vegetable matter and stored products. They are also damage dry preserve insects and herbarium specimens.

12. Mallophaga

Synonyms	:	Phthirapters
Etymology	:	Mall-wool; phaga-eat.
Common names	:	Chewing lice, Biting lice, Bird lice.

Characters: They are minute insects. Body is dorsoventrally flattened. Head is large triangular and broder than thorax. Compound eyes are reduced. Mouthparts are biting type with large dentate mandibles. Mandibles are useful to clip off the host's skin debris or feather and cling to the host. Prothorax is invariably free and not fused with pterothorax. Meso and metathorax may be free or fused. Legs terminate in a pair of claws usually which are adapted for clinging to feathers. The tarsus is either unsegmented or two segmented. Wings are absent and are secondarily wingless. Eggs are called nits and are cemented to the feathers.

Importance: They are obligate parasites on birds and less frequently on mammals. They severely infest the poultry bird. Affected birds will become restless and peck at one another continuously, leading to loss of plumage. Louse infestation results in reduced body weight and decline in productivity. Bird lice feed on feathers, hairs,

skin scales, scabs and possible blood clots around wounds. They cause irritation while feeding and crawling. In order to obtain relief, birds have dust bath.

e.g. *Menopon pallidum* and *M. gallinae* are the two common lice assoicated with poultry.

13. Siphunculata

Synonyms : Anoplura

Etymology : Siphunculus - a little tube

Common names : Sucking lice

Characters: They are minute insects. Body is dorsoventraly flattened. Head is small, conical and narrower than thorax. Mouth is surrounded by a row of hooks which are anchored in the host skin while feeding. Mouthparts are piercing and sucking type. There are three slender stylets which are withdrawn into a pouch in the head capsule at rest. This pouch is variously called stylet sac, buccal sac and trophic sac. Legs are **scansorial**, inwardly bent and adapted for clinging to mammalian hair. Tarsus is one segmented and ends in a single large claw which folds back on a thumb like projection of tibia forming an efficient organ of clinging. Wings are absent. They are secondarily wingless. Thoracic spiracles are dorsally located. Abdominal pleurites are highly sclerotised. Eggs are called nits and are strongly glued to the base of the hairs.

Importance: They are obligate blood sucking ecotoparasites on mammals. The prescence of lice lesions on the skin is known as **pediculosis**. Louse infestation causes itching and anaemia. The following lice are associated with man.

1. Head louse: *Pediculus humanus captis*. Eggs are glued to hairs. It is also called cootie.

2. Body louse: *Pediculus humanus corporis*. It infests neck, armpits and crotch. It transmits epidemic typhus, relapsing fever and trench fever, which are serious and often fatal diseases to humans. Eggs are attached to clothing.

3. Crab louse: *Pthirus pubis*. It infests armpits, pubic and perianal regions. **Pthiriasis** causes intense itching.

14. Hemiptera

Synonym : Rhynchota

Etymology : Hemi - half; ptera - wing

Common name : True bugs

General characters: Head is opisthognathous. Mouthparts are piercing and sucking type. Two pairs of bristle like stylets which are the modified mandibles and maxillae are present. Stylets rest in the grooved labium or rostrum. Both labial palps and maxillary palps are atrophied. Mesothorax is represented dorsally by scutellum. Forewings are either uniformly thickened throughout or basally coriaceous and distally membranous. Cerci are always absent. Metamorphosis usually gradual; rarely complete. Alimentary canal is suitably modified (**filter chamber)** to handle liquid food. Salivary glands are universally present. Extra-oral digestion is apparently widespread. Abdominal ganglia fused with thoracic ganglia.

Classification: There are two suboders *viz*., Heteroptera and Homoptera.

	Heteroptera (Hetero-different; ptera-wing)	**Homoptera** (Homo-uniform; ptera-wing)
1.	Head is porrect or horizontal	Head is deflexed
2.	Bases of the forelegs do not touch the head	Bases of the forelegs touch the head
3.	Beak arises from the anterior part of the head	Beak arises from the posterior part of the head
4.	Gular region of the head (midventral sclerotised part between labium and foramen magnum) well defined.	Gular region not clearly defined
5.	Pronotum usually greatly small	Pronotum is almost alway

	enlarged.	and collar-like.
6.	Scutellum (triangular plate found between the wing bases) well developed	Scutellum not well developed.
7.	Forewings heavily sclerotized at the base and the apical half is membranous (Hemelytra)	Forewings are of uniform texture. They are frequently harder than hind pair.
8.	Wings are held flat over the the back at rest and the left and right side overlap on the abdomen.	Wings are held roof-like over theback and wings do not over lap.
9.	Honey dew secretion uncommon	Honey dew secretion common
10.	Repungnatorial or odori-ferous or scent glands present.	Wax glands usually present.
11.	Both terrestrial and aquatic	Terrestrial.
12.	Herbivorous, predaceous or blood sucking.	Herbivorous.

Important families of heteroptera

1. Gerridae: (Jesus bugs, Water striders, or Pond skater)

2. Reduviidae: (Assassin bugs, Kissing bugs or cone nose bugs)

3. Cimicidae: (Bed bugs)

4. Tingidae: (Lacewing bugs)

5. Miridae: (Plant bugs or Leaf bugs)

6. Lygaeidae: (Seed bugs or Chinch bugs)

7. Pyrrhocoridae: (Red bugs or Stainers)

8. Coreidae: (Squash bugs or leaf footed bugs)

9. Pentatomidae: (Stink bugs or Shield bugs)

10. Nepidae: (Water scorpions)

11. Belostomatidae: (Giant water bugs or electric light bugs)

Important families of homoptera

1. Cicadidae: (Cicadas)

2. Membracidae: (Tree hoppers or Cowbugs)

3. Cicadellidae: (Leaf hoppers or Jassids)

4. Cercopidae: (Spittle bug or Cuckoo-spilt or Frog hopper)

5. Delphacidae : (Plant hoppers)

6. Lophopidae: (Aeroplane bugs)

7. Psyllidae: (Jumping plant lice)

8. Aleyrodidae: (Whiteflies)

9. Aphididae: (Aphids or Plant lice or Greenflies)

10. Coccidae: (Scale insects or Soft scales)

11. Diaspididae: (Armoured scale)

12. Kerridae: (Lac insect)

13. Pseudococcidae: (Mealy bugs)

15. Thysanoptera

Synonyms : Physopoda

Etymology : Thysano - fringe; ptera - wings

Common name : Thrips.

Characters: They are minute, slender, soft bodied insects. Mouthparts are rasping and sucking. Mouth cone is formed by the labrum and labium together with basal segments of maxillae. There are three stylets derived from two maxillae and left mandibles. Right mandible is absent. Hence mouthparts are asymmetrical. Wings are either absent or long, narrow and fringed with hairs which increase the surface area. They are weak fliers and passive flight in wind is common. Tarsus is with one or two segments. At the apex of each tarsus a protrusible vesicle is present. Abdomen is often pointed. An appendicular ovipositor may be present or absent. Nymphal stage is followed by prepupal and pupal stages which are analogous to the pupae of endopterygote insects.

This order is subdivided into two suborders.

1. Terebrantia: Female with an appendicular ovipositor. Abdomen end is not tube like.

Wing venation is present. Important family is **Thripidae**

2. Tubulifera: Ovipositor is absent. The abdomen end is tubular.

Wing venation is absent.

Importance: Most of the thrips species belong to the family Thripidae and are phytophagous. They suck the plant sap. Some are vectors of plant diseases. Few are predators. e.g. Rice thrips: *Stenchaetothrips biformis* is a pest in rice nursery.

16. Neuroptera

Etymology : Neuro-nerve; ptera - wings.

Common names : Lace wings, Ant lions, Mantispidflies, Owlflies.

Characters: They are soft bodied insects. Antenna is filiform, with or without a terminal club. Mouthparts are chewing type in adults. Wings are equal, membranous with many cross veins. They are held in a roof-like manner over the abdomen. They are weak fliers Larva is campodeiform with mandibulosuctorial mouthparts. Pupa is exarate. Pupation takes place in a silken cocoon. Six out of eight Malpighian tubules are modified as silk glands. They spin the cocoons through anal spinnerets.

Classification: This order is subdivided into two suborders viz., Megaloptera and Planipennia.

Sub order : Planipennia:

1. Chrysopidae: (Green lacewings, Goldeneyes, Stinkflies, Aphid lions)

2. Mantispidae: (Mantispidflies).

3. Myrmeleontidae: (Ant lions)

4. Ascalaphidae: (Owlflies)

17. Diptera

Etymology : Di-two; ptera-wing

Common names : True flies, Mosquitoes, Gnats, Midges,

Characters: They are small to medium sized, soft bodied insects. The body regions are distinct. Head is often hemispherical and attached to the thorax by a slender neck. Mouthparts are of sucking type, but may be modified. All thoracic segments are fused together. The thoracic mass is largely made up of mesothorax. A small lobe of the mesonotum (scutellum) overhangs the base of the abdomen. They have a single pair of wings. Forewings are larger, membranous and used for flight. Hind wings are highly reduced, knobbed at the end and are called **haltere**. They are rapidly vibrated during flight. They function as organs of equilibrium. Flies are the swiftest among all insects. Metamorphosis is complete. Larvae of

more common forms are known as maggots. They are **apodous** and **acephalous**. Mouthparts are represented as mouth hooks which are attached to internal sclerites. Pupa is generally with free appendages, often enclosed in the hardened last larval skin called **puparium**. Pupa belongs to the coarctate type.

Classification This order is sub divided in to three suborders.

Nematocera (Thread-horn) Antenna is long and many segmented in adult. Larval head is well developed. Larval mandibles act horizontally. Pupa is weakly obtect. Adult emergence is through a straight split in the thoracic region.

Brachycera (Short-horn) Antenna is short and few segmented in adult. Larval head is retractile into the thorax. Larval mandibles act vertically. Pupa is exarate. Adult emergence is through a straight split in the thoracic region.

Cyclorrhapha: (Circular-crack) Antenna is aristate in adult. Larval head is vestigial with mouth hooks. Larval mouth hooks act vertically. Pupa is coarctate. The coarctate pupa has a circular line of weakness along which the pupal case splits during the emergence of adult. The split results due to the pressure applied by an eversible bladder **ptilinum** in the head.

i. Nematocera

1) Culicidae: (Mosquitoes)

2. Cecidomyiidae : (Gall midges)

ii. Brachycera

3. Asilidae: (Robber flies)

4. Tabanidae: (Horse flies)

iii. Cyclorrhapha

5. Syrphidae: (Hover flies, Flower flies)

6. Tephritidae: (Fruit flies)

7. Drosophilidae: (Vinegar gnats, Pomace flies)

8. Tachinidae: (Tachinid flies)

9. Muscidae: (House fly)

10. Hippoboscidae: (Dog fly)

18. Coleoptera

Synonym : Elytroptera

Etymology : Coleo - Sheath ; ptera-wing

Common names : Beetles, Weevils

Characters: They are minute to large sized insects. Antenna is usualy 11 segmented. Mouthparts are chewing type. Mandibles are short with blunt teeth at the mesal face in phytophagous group. In predators the mandibles are long, sharply pointed with blade like inner ridge. In pollen feeders teeth are absent and the mandibles are covered with stiff hairs. Prothorax is large, distinct and mobile. Mesothorax and metathorax are fused with the first abdominal segment.

Forewings are heavily sclerotised, veinless and hardened. They are called elytra. Forewings do not overlap and meet mid-dorsally to form a mid-dorsal line. It is not used for flight. They serve as a pair of convex shields to cover the hind wings and delicate tergites of abdomen. Hind wings are membranous with few veins and are useful in flight. At rest they are folded transversely and kept beneath the elytra. In some weevils and ground beetles the forewings are fused and hind wings are atrophied. A small part of the mesothorax known as scutellum remains exposed as a little triangle between the bases of elytra. Cerci and a distinct ovipositor are absent. Metamorphosis is complete. Larvae are often called grubs. Pupae are usually exarate and rarely found in cocoons.

Importance:

It is the largest order. It includes predators, scavengers and many crop pests. They also damage stored products.

Classification:

This order is divided into two suborders, viz., **Adephaga** (devourers) and **Polyphaga** (eaters of many things). Adephaga includes Cicindelidae, Carabidae and Dytiscidae. Other families listed out below come under Polyphaga.

Families of predators

1. Cicindelidae: (Tiger beetles)

2. Carabidae: (Ground beetles)

3. Dytiscidae: (True water beetles, Predaceous diving beetles)

4. Gyrinidae: (Whirligig beetles)

5. Coccinellidae: (Lady bird beetles)

6. Lampyridae: (Fireflies, Glow worms)

Families of scavengers

1. Scarabaeidae: (Scarabs, Dung beetles)

2. Hydrophilidae: (Water scavenger beetles)

Families of stored product pests

1. Anobiidae: (Wood worms, Wood borers)

2.Bostrychidae: (Grain borers)

3) Bruchidae: (Pulse beetles, Seed beetles)

4. Tenebrionidae: (Meal worms)

Families of crop pests

1. Apionidae: (Ant like weevils)

2. Buprestidae: (Jewel beetles, Metallic wood borers)

3. Cassididae: (Tortoise beetles)

4. Cerambycidae: (Longicorn beetles)

5. Curculionidae: (Weevils, snout beetles)

6. Dynastidae: (Unicorn beetles, Rhinoceros beetles)

7. Elateridae: (Click beetles, Wire worms)

8. Galerucidae: (Pumpkin beetles)

9. Meloidae: (Blister beetles, Oil beetles)

10. Melolonthidae: (Chafer beetles, June beetles, White grubs)

19. Hymenoptera

Etymology : Hymen - membrane; ptera - wings.
Hymeno - god of marriage; ptera - wings,
(Marriage / union of fore and hind wings by hamuli)

Common names : Ichneumonflies, Ants, Bees, Wasps, Parasitoids.

Characters : Mouthparts are primarily adapted for chewing. Mandibles are very well developed. In bees both labium and maxillae are integrated to form the **lapping tongue**. Thorax is modified for efficient flight. Pronotum is collar like. Mesothorax is enlarged. Metathorax is small. Both prothorax and metathorax are fused with mesothorax. Wings are stiff and membranous. Forewings are larger than hindwings. Wing venation is reduced. Both forwings and hindwings are coupled by a row of hooklets (**hamuli**) present on the leading edge of the hindwing.

Abdomen is basally constricted. The first abdominal segment is called **propodeum**. It is fused with metathorax. The first pair of abdominal spiracles is located in the propodeum. The second segment is known as **pedicel** which connects the thorax and abdomen. Abdomen beyond the pedicel is called **gaster** or **metasoma**. Ovipositor is always present in females. It is variously modified for oviposition or stinging or sawing or piercing plant tissue.

Metamorphois is complete. Often the grub is apodous and eucephalous. Larva is rarely eruciform. Pupa is exarate and frequently enclosed in a silken cocoon secreted from labial glands. Sex is determined by the fertilization of the eggs. Fertilized eggs develop into females and males are produced from unfertilized eggs. Males are haploid and females diploid.

Classification: This order is subdivided into two suborders.

	Symphyta	**Apocrita**
1.	Abdomen is broadly joined to the thorax.	Abdomen is petiolated.
2.	Larva is a caterpillar and belongs to eruciform type	Larva is a grub and it belongs to apodous eucephalous type
3.	Stemmata are present	Stemmata are absent.
4.	Both thoracic and abdominal legs are present	Legs are absent

5.	Ovipositor is saw like and suited for piercing the plant tissue	Ovipositor is not saw like and is suited for piercing in para-sitic groups or for stinging in other groups.
6.	Behavioural sophistication is less	Behavioural sophistication is more.
7.	They are phytophagous	They are generally parasitic

Suborder : Symphyta

1. Tenthredinidae : (Sawflies)

II. Suborder: Apocrita

1. Ichneumonidae: (Ichneumonflies)

2. Braconidae : (Braconid wasps)

4. Bethylidae: (Bethylid wasps)

5. Chalcididae: (Chalcid wasps)

6. Eulophidae: (Pupal parasitoids)

7. Trichogrammatidae: (Egg parasitoids)

8. Evaniidae: (Ensign wasps)

9. Agaonidae: (Fig wasps)

10. Vespidae: (Yellow jackets, Hornets)

11. Sphecidae: (Thread waisted wasp, Digger wasp, Mud dauber)

12. Formicidae: (Ants)

13. Apidae : (Honey bees**)**

14) Megachilidae: (Leaf cutter bees)

15. Xylocopidae: (Carpenter bees)

20. Lepidoptera

Synonym : Glossata

Etymology : Lepido - scale; ptera - wings.

Common names : Moths, Butterflies, Skippers

Characters: 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. Mouthparts in adults are of **siphoning** type. Mandibles are absent. The galeae of maxillae are greatly elongated and are held together by interlocking hooks and spines. The suctorial proboscis is coiled up like a watch spring and kept beneath the head when not in use.

Wings are membranous and are covered with overlapping pigmented scales. Forewings are larger than hind wings. Cross veins are few. Wings are coupled by either **frenate** or **amplexiform** type of wing coupling.

Larvae are **polypod-eruciform** type. Mouthparts are adapted for chewing with strong mandibles. A group of lateral ocelli is found on either side of the head. The antenna is short and three segmented. There are three pairs of five segmented thoracic legs ending in claws. Two to five pairs of fleshy unsegmented **prolegs** are found in the abdomen. At the bottom of the proleg, **crochets** are present. Pupa is generally **obtect**. It is either naked or enclosed in a cocoon made out of soil, frass, silk or larval hairs.

Classification: Majority of Lepidopteran insects (97%) are grouped under the suborder **Ditrysia** in which the female insects have two pores. The copulatory pore is located in eighth abdominal sternite and the egg pore in ninth abdominal sternite. Ramaining insects are grouped under the suborder **Monotrysia** in which the female insects have one pore.

Butterfly families

1. Nymphalidae: (Brush footed or four footed butterflies)

2. Lycaenidae: (Blues, Coppers, Hair streaks)

3. Papilionidae: (Swallow tails)

4. Pieridae: (whites and Sulphurs)

5. Satyridae: (Browns, Meadow - browns)

MOTH FAMILIES

6. Arctiida : (Tiger moths)

7. Bombycidae: (Silk worm moths)

8. Cochlididae: (Slug caterpillar)

9) Crambidae : (Grass moths)

10. Gelechiidae: (Paddymoth)

11) Geometridae: (Loopers)

12. Lymantridae: (Tussock moths)

13. Noctuidae: (Noctua moths)

15. Pyraustidae: (Grass borers)

16. Saturniidae: (Moon months, giant silk worm moths)

17. Sphingidae : (Hawk moths, Sphinx moths, Horn worms)

Skipper family

18. Hesperiidae (Skipper)

29.Collection and preservation of insects

I. Collection

1. Hand picking : This method is suitable for large insects like beetles and grasshoppers. It is a tedious method. It is unsuitable for insects Inflicting painful bites and stings.

2. Insect net: There are two types of insect nets.

i. **Aerial net**: (Butterfly net) It is light in weight. It is useful for catching active fliers like months, butterflies, dragonflies, flies, wasps, etc. The net consists of three parts viz., hoop, handle and porous cloth bag made out of mosquito netting material. It has a small hoop (30-40 cm dia.) and a long handle (100 cm). The diameter of the hoop and the depth of the bag should be in the proportion of 1:2. This net can be home made by using an old badminton racquet.

ii. **Sweep net**: This is heavier than the aerial net. It consists of a short handle, a large hoop and a muslin cloth bag. This is suitable for collecting leafhoppers, grasshoppers and other small insects. The net is swept over vegetation. The handle is turned by quick turn of the wrist to fold the cloth bag over the hoop in order to prevent the escape of trapped insects.

3. Aspirator (Pooter): Device useful to collect small insects into a vial with no damage to the specimens. It is also useful for collecting insects from the insect net or any other surface. Usually a long glass tube bent at one end and other end attached to a rubber tube, can be used as aspirator. To prevent entry of insects in to mouth a small cloth piece is kept in between the glass and rubber tube.

4. Traps: Traps can be used for collecting different types of insects.

Food lure trap	-	Flies
Sex lure trap	-	Moths
Water trap	-	Brown plant hopper
Light trap	-	Positively phototropic insects
Sticky trap	-	White flies
Suction trap	-	White flies

5. Berlese funnel: Soil dwelling insects can be collected by using Berlese funnel.

II. Killing : Killing should be done immediately after capture. Potassium cyanide, ethyl acetate, carbon tetra chloride (carbona) and chloroform are commonly used for killing insects. Potassium cyanide kills the insect quickly but rigor mortis sets in quickly. cyanide is a deadly poison and must be handled with extreme care. Ethyl acetate kills the insects more slowly and does not last long. But the dead insects remain in a relaxed condition for a longer time without becoming brittle.

Preparation of killing bottles

Killing bottle preparation should be done in a well ventilated room.

i. Cyanide killing bottle

Steps

1. Take a wide mouthed strong bottle or vial with a tight fitting lid.
2. Place a layer of potassium cyanide (1/4 inch thickness) at the bottom of the bottle.
3. Cover it with a layer of dry plaster of Pairs (1/2 inch thickness).
4. Mix plaster of Paris with enough water so that it will pour off from the end of a spoon (if it is too wet the cyanide will expand itself too soon; if too dry the surface will be rough and unsatisfactory).
5. Pour 1/2 inch layer of wet plaster of Pairs over the dry layer.
6. Tap the bottle lightly on the table to eliminate any bubbles in the plaster and to smoothen the top.
7. Leave the lid off for a day to let the plaster dry in a well ventilated room, completely away from direct sunlight.
8. Keep a circular piece of blotting paper on the top of the plaster and a few strips of blotting-paper or newspaper inside the bottle to keep it dry and avoid condensation of water droplets on the sides of the bottle.

ii. Ethyl acetate killing bottle

1. Pour 1/2 inch layer of wet plaster of Paris to the bottom of a bottle.
2. Allow it to dry thoroughly (The drying process may be quickened by keeping the bottle inside an oven)

3. Saturate the plaster of Paris layer with ethyl acetate

4. Recharge the bottle with the chemical again as and when it looses its effectiveness

Dos:

1. Tape the bottom of the bottle with a few strips of insulation tape to prevent the shattering of the bottle if it is accidentally dropped.
2. Affix a conspicuous `POISON' label both in English and in vernacular along with the skull and cross bone symbol.
3. Keep the bottle tightly closed to prevent gas leakage.
4. Remove the insects as and when they are dead.
5. Use a separate large killing bottle for moths and butterflies and another for beetles and grasshoppers.

6) Keep the killing bottle in a safe place away from those who are unaware of its deadlines.

7. Dispose the contents of old cyanide bottles preferably by burying it in a pit

Don'ts

1. Do not mix small insects with scaly insects.
2. Do not mix delicate and small insects with large insects like beetles and grasshoppers.

3. Do not allow the bottle to sweat

4. Never overload the bottle

iii. Pinching the thorax: A butterfly or moth can be immobilised and killed in an emergency by giving a sharp pinch on the thorax.

iv. Killing with alcohol: Many insects can be killed by dropping them directly into 70 to 90% ethyl or isopropyl alcohol.

III Preservation

i. Materials required

1. Paper folds (Paper envelopes): They are useful for temporary preservation and storage of large winged insects such as dragon files, butterflies or moths. These

triangular envelopes can be made from a sheet of note book or by using absorbent type of paper used in duplicating machines. Cut the paper into rectangles with their sides in the proportion of 3:5. Bring the diagonally opposite corners together to leave two projecting flaps. Write the data regarding collection on the outer side of a projecting flap. Keep the immobilised insect in between the two overlapping triangles. Fold the flaps to produce a triangular envelope.

2. Setting board (Spreading board): It is useful for spreading the wings of dead insects. It is a wooden board with a central groove in the middle. Flat cork strips are glued on either side of the groove and in the bottom of the groove to enable pinning. A thermocole sheet with a centrally cut groove can also be used as a substitute for the setting board.

3. Relaxing container: Setting or mounting an insect should be done within a day after killing. Otherwise the insect will become stiff and brittle. Stiffness in the dead insect can be removed by placing it in a relaxing container. High humidity inside the relaxing container permits water to be reintroduced into the specimens thus making them flexible.

Fill a container with sand to 1/4th of its capacity. Saturate the sand with water. Add a few drops of carbolic acid or formaldehyde to prevent mold growth. Keep the dried specimens in a small open box or in an uncovered Petri dish to avoid direct contact of the specimen with moist sand. Close the lid tightly and allow them to remain for a day or two until they become flexible.

4. Pins: Common pins are undesirable for pinning insects. They are usually too thick and too short. They usually rust or most commonly a green substance called **verdigris** forms where the pin comes into contact with the insect body. Pins used for pinning insects should be `slender, hard with a pointed tip and a small head. Pure nickel pins or nickel plated ones resist rusting. Commonly No.16 and 20 pins are used for pinning larger and smaller insects respectively.

5. Micropins: For pinning very small insects micropins are used. They are very thin, slender, delicate and headless pins. They do not rust. They are also known as insect pins minuten pins or entomological pins.

ii. Methods of preservation

1. Pinning

It is the best and most common method to preserve hard bodied insects. They will dry and remain in perfect condition on the pins without requiring any further treatment. During drying the outer exoskeleton remains intact while the inner soft tissues dry up.

Insects can be pinned directly if they are big. They should be pinned in such a way that all important diagnostic characters can be viewed clearly. They are pinned vertically through their body. Depending upon the size of the insect the pin has to be selected. During pinning the insect is held between the thumb and forefinger of one hand and the pin is inserted into the insect with the other hand. While pinning 1/3rd length of the pin should be above the insect to permit a comfortable finger hold. Exact place of insertion of the pin varies among different groups of insects.

S.No.	Insect groups	Pinning region
1.	Grasshoppers, crickets, preying mantids and cockroaches	Pronotum
2.	Bugs	Scutellum
3.	Stick insects	Metanotum
4.	Beetles and weevils	Right elytron
5.	Earwings	Right tegmen
6.	Drgonfly, damselfly, antlion, green lacewingfly, moths, butterflies, bees, wasps, ants and true flies	Thorax

2. Double mounting

Pinning is troublesome in smaller insects. Very small insects cannot be pinned because most of the body parts of the insects will be lost during pinning. For such insects double mounting can be followed.

i. Staging: The stage is a narrow rectangular piece of pith or cork. The small insect is pinned correctly with a micropin to the stage. Later the stage is pinned in the insect store box with a bigger pin.

ii. Carding: A rectangular (5 x 8 mm or 5 x 12 mm) white card or celluloid bit may be used as stage. On the stage instead of pinning, the insect specimen is stuck on it by using transparent or stain free adhesive. A spot of good glue or white gum can also be used. The insect should not be embedded in the glue and only minimum quantity of the glue should be used. After mounting, the card is pinned to the insect storage box with a large pin.

iii. Pointing: The insect specimen is glued to a card or celluloid bit into a triangle of 10 mm height and 5 mm base. Bend down the tip of the card to form a small surface to which the insect is stuck. Apply a drop of glue or adhesive by touching the point to the glue and to the thorax of the insect to be mounted. Press the right side of the specimen against angled and glued card tip. A bigger pin is inserted at the midpoint near the base for pinning the card with the insect to insect store box.

3. Liquid preservation

Soft bodied forms (nymphs, larvae and many adults) shrivel when mounted dry. Such insects can be preserved in preservative fluids like ethyl alcohol (70%) and formalin (4%). All these preservatives are highly voltatile. Screw cap vials are satisfactory if the caps are tight fitting. Sealing the stopper with paraffin wax reduced the evaporation of preservative. Label is written with pencil and placed inside the vial along with the specimen. Careful examination of liquids preserved specimens once in a year is essential to replace the evaporated fluid.

4. Setting

Setting insects is essential to study the wing characters. It affords a better look to the preserved specimens. Wings of moths, butterflies, dragonflies and

damselflies are set on either side. In grasshoppers, wings on one side alone are set. Setting boards are used for setting insects. Setting should be done before the insects become stiff.

Setting a butterfly

1. Pin the dead butterfly through the thorax into the groove of the setting board.
2. Ensure that the body of the insect is well settled in the groove and the wing base is in level with the top of surface of the setting board.
3. Orient the antennae symmetrically
4. Position the legs with a pin
5. Support the abdomen with pins crossed beneath it to form a platform to prevent the abdomen from sagging while drying.
6. Position the wings with two narrow card board strips and pins.
7. Pull the forewing with a pin from near the base of the wing along the front margin until the hind margin is at right angle to the body.
8. Push the front edge of the hindwing under the rear edge of the forewing.
9. Use separate large card board strips for pressing the wings either side.
10. Protect the set insects against ants, lizards etc.
11. Keep the specimens on the settings board until the abdomen becomes stiff.

5. Blowing soft bodied larva

Blowing is the most popular method of preserving soft bodied larvae. This method consists of removing the internal contents of the larva and then inflating it like a baloon to its natural size and drying it in this position in a blowing apparaturs. For blowing small sized larva a disposable syringe with a hypodermic needle can be used.

Procedure

1. Drown the caterpillar in warm water which will aid easy removal of internal contents.
2. Place the caterpillar over a filter paper on a table.
3. Make a slit at the anal end using a sharp blade.
4. Roll over the body a cylindrical glass rod slowly, exerting gengle but firm pressure starting just behind the head to the abdominal tip.

5. Pull out the alimentary canal protruding out through the anus by using forceps and cut it off with a razor blade.
6. Insert the syringe needle or the nozzle of the blowing apparatus into the anal slit and fasten by wrapping a thread at the end without puncturing the body.
7. Inflate the exoskeleton gently by pressing the plunger of the syringe or the bulb of the blower until it reaches the normal size. (Avoid too much inflation as this makes the caterpiller grotesque).
8. Keep the inflated caterpillar inside a hot chamber for a few minutes.
9. Gently rotate the caterpiller so that all sides get uniformly heated and turn stiff.
10. Stick the blown up caterpillar to a match stick with gum or adhesive.
11. Pin it in the insect box through the match stick.

IV. Labelling: Labels are must for every collection. Any collection should have a locality label giving particulars about date and locality of its capture. An additional label is often used that usually has the name or initials of the collector and the habitat or host from which the specimen is collected. Labels should be small, (12 x 6 mm) neat and made of stiff paper. Labels may be printed or hand written with microtipped pen. They are inserted beneath the insects at 1/3rd height from the base. The long axis of the label should coincide with the long axis of the insect. If more than one label is used then the label should be parallel. All labels should be oriented so that they read from left side.

V. Display: Insect store boxes: Commonly wooden boxes of dimension 45 x 30 x 15 cm are used as insect store boxes for displaying preserved insects. The box should be light in weight, air tight and moisture proof with a well fitting hinged lid. A cell is provided inside to keep repellents. Cork sheets are glued to the inside of the top and bottom of the box to permit pinning. Glass topped boxes can be used for displaying insect collections but the colour of the preserved insects fades due to constant exposure to light.

Repellents and preservatives: Preserved specimens are commonly attacked by dermedstid beetles, red flour beetle and psocids. Naphthalene balls mounted on pins are pinned inside to repel museum insects. This is done by heating the head of a pin in flame and pressing it against a napthalene ball. The ball melts at the point

of contact. The pin head enters the ball and the melted napthalene solidiflies around the pin head. Napthalene flakes can also be kep in perforated envelopes and can be pinned in the boxs. In the place of napthalene, para-dichloro-benzene (PDB) crystals can be used which wil not only keep off museum insects but also check their infestation.

Riker mount: A Riker mount is a flat container having a glass or transparent cover containing cotton wool and is used for mounting a plant or insect specimen. The name Riker is given after an American botanist. It is useful for displaying various life stages (Blown up caterpillar, empty pupal case and adult of lepidopteran insects). Riker mounts can be used as excellent teaching aids.