Ento-121

Fundamentals of ENTOMOLOGY

Edited by
Uma Shankar
Amit K. Singh

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Syllabus

Theory-Lecture Outlines

1. *History of Entomology in India*-Arthropoda-mention of insects in scripts-contributions of Fabricius, Linnaeus, Rothney, De Niceville, HM Lefroy, TB Fletcher, TV Ramakrishna Ayyar, B Vasantharaj David, Ronald Ross, HS Pruthi, MRGK Nair, and S Pradhan. Locations & year of establishment of Zoological Survey of India (ZSI), Directorate of Plant Protection, Quarantine & Storage (DPPQS), Indian Institute of Natural Resins & Gums (IINRG), National Bureau of Agriculturally Important Insects (NBAII), National Institute of Plant Health Management (NIPHM), National Centre for Integrated Pest Management (NCIPM) and Forest Research Institute (FRI).
2. *Contributory factors for abundance of Insects*- Structural characters, developmental characters and protective characters (morphological, physiological, behavioural and construction of protective niches)
3. *Classification of Phylum Arthropoda upto orders*-different classes of Arthrpoda and comparison of characters of Class Insecta with Aeachnida, Crustacea, Symphyla, Chilopoda, Diplopoda and Onychophora; Sub-Classes Apterygota and Pterygota-Names of Orders of Apterygota and Pterygota with examples and characters of Class Insecta-Economic classification of Insects.
4. *Structure & functions of Bodywall*-different layers, chemical composition, functions and cuticular appendages, cuticular processes and cuticular invaginations-chaetotaxy-moulting-apolysis-ecdysis and sclerotization.
5. *Body segmentation in insects*: Head-procephelon & gnathocephelon, types of head, sclerites, sutures of insect head; Thorax-segemnts & appendages (wings, legs); Abdomen-segments & appendages (furcula, cornicles, tracheal gills, pseudo-ovipositor in diptera, propodeum, petiole and gaster in hymenoptera); Epimorphic & Anamorphic development in insects.
6. *Antenna (Olfactory Organs)*-structure of typical antenna & its modifications in different insects with examples.
7. *Mouth Parts (Feeding Organs)*-biting & chewing, sucking (piercing & sucking, rasping & sucking, chewing & lapping, sponging, siphoning), mask & degenerate types with examples.
8. *Legs (locomotors Organs)*-structure of a typical insect leg & modifications of insect legs with examples.
9. *Wings (Flight Organs)*-venation, margins & angles-types of wings & wing coupling organs with examples.
10. *Sense organs:* Compound eyes-structure of ommatidium; Ocelli-dorsal and lateral ocelli; Types of images; Types of Auditory organs (tympanum & Johnston's organ)
11. *Metamorphosis and diapause in insects:* obligate & facultative diapause, stages of occurance of diapause with examples.
12. *Types of larvae and pupae:* Differences between nymph and larva.
13. *Digestive System:* Alimentary canal-structure of foregut, midgut & hindgut-histology, functions, filter chamber, peritrophic membrane, and process of digestion.
14. *Circulatory System*-open & closed types-organs of circulatory system-dorsal blood vessel (diaphrams, sinuses, aceessory pulsatile organs)-process of circulation-properties & functions of haemolymph.
15. *Excretory System*-structure, functions, modifications of malpighian tubules-structure & functions of other organs of excretion.
16. *Respiratory system*-tracheal respiration-structure of spiracle & trachea-classification of functional spiracles and other means of respiration.
17. *Nervous System*-neuron & its types (based on structure & functions)-synapse, ganglia, central nervous system, sympathetic nervous system & peripheral nervous system.
18. *Reproductive System*-structure of male & female reproductive systems-structure & types of ovarioles, structure of follicles, types of reproduction in insects.
19. *Secretory (endocrine) System*-structure & functions of neuro-secretory organs (neuro-secretory cells of brain, corpora cardiaca, corpora allata, pro-thoracic glands & ring glands).

20. *Taxonomy*: importance-history-binomial nomenclature-types: holotype, allotype, paratype-suffixes of tribe, subfamily, family, super family-law of priority-synonyms & homonyms-species, sub-species, genus, family, order et.
21. *Order Orthoptera*: General characters-family *Acrididae*, characters with examples.
22. *Order Dictyoptra:* General characters-family *Mantidae*, characters with examples.
23. *Order Isoptera:* General characters-family *Termitidae*, characters with examples; *Order Thysanoptera:* General characters-family *Thripidae*, characters with examples.
24. *Order Hemiptera:* General characters-suborder *Heteroptera*, characters with examples, families *Pentatomidae & Coreidae*, characters with examples.
25. *Order Hemiptera:* suborder *Hemoptera*, characters, families *Cicadellidae, Delphacidae, Aphididae, Pseudococcidae, Coccidae, Aleurodidae*, characters with examples.
26. *Order Lepidoptera:* General characters, differences between moths & butterflies, families *Noctuidae & Spingidae*, characters with examples.
27. *Order Lepidoptera:* families *Pyralidae, Gelechiidae, Arctiidae, Papilionidae*, characters with examples.
28. *Order Coleoptera:* General characters, families *Coccinellidae & Bruchidae*, characters with examples.
29. *Order Coleoptera:* families *Scarabaeidae, Chrysomelidae, Cerambycidae & Curculionidae,* characters with examples.
30. *Order Hymenoptera:* General characters, families *Tenthredinidae, Ichneumonidae, Braconidae & Trichigrammatidae*, characters with examples.
31. *Order Diptera:* General characters, families *Cecidomyiidae, Trypetidae, Agromyzidae & Muscidae*, characters with examples.

Practicals: Outlines

1. Methods of collection and preservation of insects including immature stages
2. External features of a grasshoppers/blister beetle
3. Types of insect mouth parts and study of biting and chewing (Orthopteran) and sucking (Hemipteran) mouth parts. Study of mouth parts of Diptera, Hymenoptera and Lepidoptera
4. Types of Insect Antennae
5. Wing venation, types of wings and wing coupling apparatus
6. Types of Legs
7. Types of insect larvae and pupa
8. Dissection of digestive system in insects
9. Dissection of male, female reproduction system
10. Study of characters of orders orthoptera and Dictyoptera and their families
11. Study of characters of orders Isoptera and Thysanoptera and their families
12. Study of characters of order Hemiptera and its families
13. Study of characters of order Lepidoptera and its families
14. Study of characters of order Coleoptera and its families
15. Study of characters of order Hymenoptera and its families
16. Study of characters of order Diptera and its families

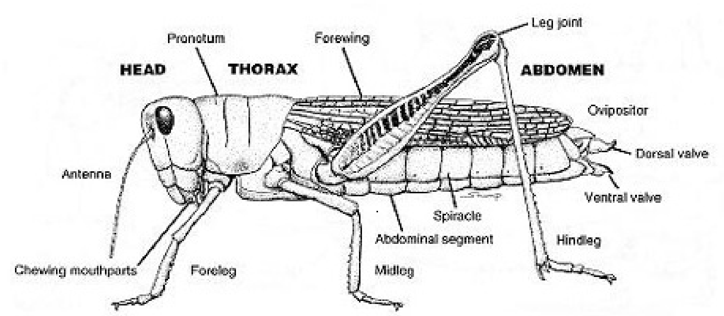
References:

No	*Name of the refence book*	*Authors*
1	General and Applied Entomology (1976)	Nayar KK, Ananthakrishnan TN and David BV
2	IMMS' General Text Book of Entomology (1977,1993) – Volume I and II	Richards OW and Davies RG
3	Insect Physiology and Anatomy (1981)	Pant NC and Swaraj Ghai
4	Insect: Structure and Function (1988)	Chapman RF
5	Principles of Insect Morphology (2001)	Snodgrass RE
6	Elements of Economic Entomology (2001)	Vasantharaj David B
7	Fundamentals of Insect Life (1990)	Metcalf CL and Flint WP
8	Hand Book of Economic Entomology for South India (1963)	Rama Krishna Ayyar TV
9	Text Book of Agricultural Entomology (1963)	Pruthi HS
10	General Entomology (1988)	Mani MS
11	Insect Physiology-Principles & Concepts	Gour TB & Sriramulu M

Lecture No: 1

History of Entomology in India-Arthropoda-mention of insects in scripts-contributions of Fabricius, Linnaeus, Rothney, De Niceville, HM Lefroy, TB Fletcher, TV Ramakrishna Ayyar, B Vasantharaj David, Ronald Ross, HS Pruthi, MRGK Nair, and S Pradhan. Locations & year of establishment of Zoological Survey of India (ZSI), Directorate of Plant Protection, Quarantine & Storage (DPPQS), Indian Institute of Natural Resins & Gums (IINRG), National Bureau of Agriculturally Important Insects (NBAII), National Institute of Plant Health Management (NIPHM), National Centre for Integrated Pest Management (NCIPM) and Forest Research Institute (FRI).

- An insect body has a hard exoskeleton protecting a soft interior; it is divided into three main parts (head, thorax and abdomen) each of which is in turn composed of several smaller segments.
- Insect is a small invertebrate animal with hard, segmented bodies, three pairs of jointed legs, and, usually, two pairs of wings; they belong to *Artropods* and are distributed throughout the world. An insect's body is divided into three segments: *head, thorax, and abdomen*. On the head is a pair of feelers, or antennae (for smell). The legs (for walking or running) and wings (for flying) are attached to the thorax, or middle segment of the body. The abdomen, or end segment of the body, is where food is digested and excreted and where the reproductive organs are located. (*Class Insecta*.)



- The skeleton of an insect is external and is composed of *chitin* It is membranous at the joints, but elsewhere is hard. *The head is the feeding and sensory centre*. It bears the antennae, eyes, and mouthparts. By means of the antennae, the insect detects odours and experiences the sense of touch. The eyes include compound eyes and simple eyes (ocelli). Compound eyes are formed of a large number of individual facets or lenses; there are about 4,000 lenses to each compound eye in the housefly. The mouthparts include a labrum, or upper lip; a pair of principal jaws, or mandibles; a pair of accessory jaws, or maxillae; and a labium, or lower lip. These mouthparts are modified in the various insect groups, depending on their diet.
- The *thorax is the locomotory centre*, and is made up of three segments: the pro-, meso, and metathorax. Each bears a pair of legs, and, in flying insects, the second and third of these segments also each bear a pair of wings. The wings are composed of an upper and a lower membrane, and between these two layers they are strengthened by a framework of chitinous tubes known as veins.
- The *abdomen is the metabolic and reproductive centre*, where digestion, excretion, and the sexual functions take place. In the female, there is very commonly an egg-laying instrument, or ovipositor, and many insects have a pair of tail feelers, or cerci. Most insects breathe by means of fine airtubes called tracheae, which open to the exterior by a pair of breathing pores, or spiracles. Reproduction is by diverse means. In most insects, mating occurs once only, and death soon follows.

- Insects vary in size from 0.02 cm/0.007 in to 35 cm/13.5 in in length. The world's smallest insect is believed to be a 'fairy fly' wasp in the family Mymaridae, with a wingspan of 0.2 mm/0.008 in.
- Many insects hatch out of their eggs as larvae (an immature stage, usually in the form of a caterpillar, grub, or maggot) and have to pass through further major physical changes (*metamorphosis*) before reaching adulthood. An insect about to go through metamorphosis hides itself or makes a cocoon in which to hide, then rests while the changes take place; at this stage the insect is called a pupa or a chrysalis if it is a butterfly or moth. When the changes are complete, the adult insect emerges.
- The classification of insects is largely based upon characteristics of the mouthparts, wings, and metamorphosis. Insects are divided into two subclasses (one with two divisions) and 29 orders. More than 1 million species are known, and several thousand new ones are discovered each year.
- *The study of insects / scientific study of insects is called Entomology*, a branch of Arthropodology. (from greek, *entomos*, "that which is cut in pieces or engraved/segmented", hence "insect"; and *-logia* is the scientific study).
- At some 1.3 million described species, *insects account for more than two-thirds of all known organisms* date back some 400 million years.
- Entomology includes a cross-section of topics as diverse as molecular genetics, behavior, biomechanics, biochemistry, systematics, physiology, developmental biology, ecology, morphology, paleontology, anthropology, robotics, agriculture, nutrition, forensic science and more.
- The field of entomology may be divided in to two major aspects, as *Fundamental entomology or General entomology and applied entomology or Economic entomology.*
- *Fundamental entomology* deals with the basic or academic aspects of the science of entomology. It includes morphology, anatomy, physiology and taxonomy of the insects.
- *Applied entomology* deals with the usefulness of the science of entomology for the benefit of mankind.

Ancient references on Insects:

- In the ancient times, study of entomology and other related branches of zoology did not receive proper recognition and serious attention of the biologists in our country. However, they had a fairly good acquaintance with some general facts of life and bionomics of many higher animals as may be seen from numerous references in our epics *Ramayana* & *Mahabharata.* Though there were no noteworthy contributions on Indian insects and literature with names of Indian entomologists, one should not come to the conclusion that our ancient people were completely ignorant of insects. The fact that our people were aware of the insects and their ways is evident from the terms such as *pathanga, bharamara, shadpada, pipilika, makshika, etc.* that have appeared in the ancient Sanskrit writings. Similarly, reference to different insects like flies, beetles, bees, hornets, moths, ants and glow worms is found in a verse of seven lines in the well known dictionary of Sanskrit synonyms *Amarakosa.* It is also interesting that the physician "Susrutha" even classified ants (*pipilika)* in to six groups and gave details of the structure and habits of these insects.
- There are also evidences in the past to show that our ancient people were quite conscious of the usefulness of insects which provide honey, lac and silk. They were familiar with the bees *(madhu makshika)* and the gathering of honey and wax from their hives. Reference to the lac *(laksha)* and dye found in ancient Sanskrit works like

Chanakya sutra, Arthasastra and *Sakuntala,* show that the people were aware of the usefulness of lac. Records also show that an ancient Indian King sent some silken stuff to a Persian ruler, as early as in 3870 B.C. It may be interesting and instructive to recall the story of Mahabharata in which the boy Sage 'Mandavya' was himself impaled on the point of a sharp crowbar for having collected and pinned insects.

- *Ramakrishna Ayyar*, the pioneer entomologist of South India, had remarked this as a bit of the biography of the *first Indian insect collector*.

Entomology in India

- In India scientific study of insects was undertaken only from the 18th century.
- *Fabricius* Johan Christian (1745-1808) born in Denmark, one of the most distinguished entomologists of earlier times. Fabricius' work was concentrated in the field of *descriptive systematics* (taxonomy).
- *In the tenth edition of 'Systema Naturae' in 1758 Linnaeus had included only twelve Indian insects which form earliest record.*
- However, the *first regular work on Indian insects* on scientific lines appears to have been initiated in South India by *Dr. J.G. Koenig* (official Naturalist of Nawab of Arcot). He supplied insect specimens collected at Coromandel Coast to systematists like Linnaeus, Fabricius, Cramer and Drury. In 1779 he published a special account of the *Termites of Thanjavur district*.
- In 1782 an account of lac insect was published by Dr. Kerr.
- In 1785 the 'Asiatic Society of Bengal was started in Calcutta.
- In 1790 a detailed account of *lac insect* was published in the Asiatic Researches by the botanist *Roxburgh*.
- A *monograph on the cochineal scale insects* was issued in 1791 by *Dr.J.Anderson*.
- In 1800 Buchnan wrote on the cultivation of lac and sericulture.
- In 1800 *Denovan* published '*Natural History of Insects'*, the first contribution on the insects of Asia and this was revised in 1842 by Westwood.
- With the foundation of the '*Indian Museum'* at Calcutta in 1875 and the '*Bombay Natural History Society*' in 1883 scientific studies received greater attention and impetus in India.
- *Moths of India* (4 volumes) (1892) by *Hampson.*
- In 1893 *G A James Rothney* published '*Indian Ants'* in which he described the control of white ants by red ants. This was the *first report of biological control of an insect pest in India*. The information on Indian insects in a consolidated form was made available by the Government of India in the publication of "Fauna of British India" series. Further information on the importance of applied aspect of entomology, was published in the "The Indian Museum Notes" in five volumes between 1889 to 1903. These are the monumental contributions in the field of Economic Entomology.
- *August 20 is World Mosquito Day*. On August 20, *1897*, *Sir Ronald Ross* discovered the link between malaria transmission and mosquitoes. Ross was awarded the Nobel Prize for medicine in 1902, the second person to receive it. Sir Ronald Ross was a British physician born in Almora, India. He had the breakthrough discovery during the dissection of a specific species of mosquito, the Anopheles, previously fed on a malaria patient. Malaria parasite was found on the mosquito and on its salivary glands.
- The posting of *Lionel de Nicevelle* in 1901 as the *first Entomoogist to the Government of India for agricultural entomology* marks the birth of professional entomology.
- Professor *Maxwell Lefroy* succeeded Nicevelle in 1903. He was attached to the 'Imperial Agricultural research Institute' which was established at Pusa (Bihar) in

1905 and was made the *first Imperial Entomologist*. This institute was subsequently shifted to New Delhi and the post was re-designated as the Head of the Division of Entomology, Indian Agricultural Research Institute. Lefroy published "*Indian Insect Pests*" in 1906 and "*Indian Insect Life*" in 1909.

- At the same time the state Governments also took up entomological investigations and *Punjab was the first to initiate work on agricultural entomology* in 1905 followed by Madras in 1906.
- *Indian Agricultural Research Institute (IARI):* Originally established in *1905 at Pusa (Bihar)* with the financial assistance of an American Philanthropist, Mr. Henry Phipps, the Indian Agricultural Research Institute (IARI) started functioning from New Delhi since 1936 when it was shifted to its present site after a major earthquake damaged the Institute's building at Pusa (Bihar). The Institute's popular name 'Pusa Institute' traces its origin to the establishment of the Institute at Pusa. During the late forties and fifties, the section of entomology at IARI was raised to the status of Division of Entomology and reorganized in to sections viz., Insect Ecology, Insect Physiology, Insect Toxicology, Insect Parasitology, Systematic Entomology and Insect Genetics.
- *Forest Research Institute (FRI)* established as Imperial Forest Research Institute in 1906, at *Dehradun*, is a premier institution under the Indian Council of Forestry Research and Education (ICFRE).
- *T.B. Fletcher, the first Government Entomologist of Madras State*, published book "*Some South Indian Insects*" in 1914. Since 1921 publication of the "Catalogues of Indian Insects" was taken up and more than 30 catalogues of various insect groups were published till date.
- *Stebbing* in *1914* published book "*Indian Forest Insects of Economic importance: Coleoptera*.
- In *1916*, *Zoological Survey of India (ZSI)* was established at *Kolkata*. The Zoological Survey of India, the only taxonomic organization in the country involved in the study of all kinds of animals from Protozoa to Mammalia, occurring in all possible habitats from deepest depth of the ocean to the peaks of Himalaya, was established on 1st July, 1916 to promote survey, exploration and research leading to the advancement in our knowledge of the various aspects of the exceptionally rich animal life "
- In *1925* the "*Indian Lac Research Institute (ILRI)*" started functioning, established at *Ranchi, earstwhile Bihar (now in Jharkhand)*. The name has been changed as *Indian Institute of Natural Resins and Gums (IINRG)* (formerly Indian Lac Research Institute (ILRI)) on *Sept 20, 2007*, which is a nodal Institute at national level for research and development on all aspects of lac and other natural gums & resins (excluding production) such as harvesting / tapping, processing, product development, training, information repository, technology dissemination and national/international cooperation.
- *A Text Book of Medical Entomology* (1931) by *Patton and Craigg.*
- *The Entomological Society of India* was inaugurated on the 1st January, 1937 at Culcutta and it took up publication of *Indian Journal of Entomology* from 1939. (1964- silver jubilee commemorative publication *Entomology in India* was published)
- *All India Beekepers Association*, Pune (Indian Bee Journal) formed in 1939.
- *Locust Warning Organization (LWO) established in 1939*, to monitor, forewarn and control of Desert Locust (an international pest) headquarters at Jodhpur, and later it was amalgamated with the Directorate of Plant-Protection, Quarantine and Storage in 1946.

- In *1946* the Government of India started the "*Directorate of Plant Protection, Quarantine and Storage (DPPQ&S) at Faridabad, UP*. By 1957 the Plant Protection Directorate established 14 Central Plant Protection Stations in Different regions of the country. Plant Protection Advisor (PPA) will be heading the Directorate.
- *National Plant Protection Training Institute (NPPTI)* (formerly known as Central Plant Protection Training Institute) was established on 28th August, 1966 at Hyderabad, Andhra Pradesh., as a training wing of Central Directorate of Plant Protection under the Department of Agriculture & Co-operation, Ministry of Agriculture, GOI. During XI Plan (2009) it was renamed with new mandate as *National Institute of Plant Health Management (NIPHM)* with a mandate for Human Resource Development in Plant Protection by way of generating Master Trainers/Subject Matter Specialists in the field of Plant Protection for various States/Union territories.

- The establishment of the Indian Station (1957) of the *Commonwealth Institute of Biological Control (CIBC)* at *Bangalore*. Then the Institute was renamed as *Project Directorate of Biological Control (PDBC),* Bangalore, in 1993, is the nodal agency in the country that organizes biological control research at the national level with 16 centres spread across the country for carrying out field studies on biosuppression of pests of crops and weeds. The National Biodiversity Authority (NBA) recognized PDBC as one of the Designated National Repositories (DNR) for various kinds of biological specimens, both dead and live. During XI plan *(2009), PDBC was upgraded as National Bureau of Agriculturally Important Insects (NBAII)* in order to exploit the agricultural insect resources from various agroclimatic zones, and To act as a nodal agency for collection, characterization, documentation, conservation, exchange and utilization of agriculturally important insect resources (including mites and spiders) for sustainable agriculture.
- National malaria control programme (1953) changed to "*National Malaria Eradication Programme (NMEP)*" in 1958.
- *National Centre for Integrated Pest Management (NCIPM)*, a national research centre of Indian Council of Agricultural Research (ICAR), India was established in February, *1988* at New delhi (IARI campus) to cater to the emerging plant protection needs of different agro-ecological zones of the country. The activities of the centre extend across and beyond different disciplines and agencies to establish partnerships with SAU's, Government Agencies, Industries, NGOs and Farmers. NCIPM plans and conducts eco-friendly IPM research and development programmes, essentially required for sustainable agriculture. The Mandate is to develop and promote IPM technologies for major crops so as to sustain higher crop yields with minimum ecological implications, to develop information base on all aspects of pest management and to advice on related national priorities and pest management policies, to establish linkages and collaborative programmes with other national and international institutes in the area of IPM and to extend technical consultancies.
- *Grain Storage Research and Training Centre (GSRTI)* was established at *Hapur in 1958* which was later expanded into *Indian Grain Storage Institute (IGSI)* with two field stations at Ludhiana and Bapatla (later shifted to Hyderabad) with the financial assistance from UNDP in 1968. Three field stations at Jabalpur, Jorhat and Udaipur were subsequently established in 1981. In *1996*, the IGSI was renamed as *Indian Grain Storage Management and Research Institute (IGMRI).* IGMRI, Hapur operates in the States of Uttar Pradesh, Bihar, Haryana, Madhya Pradesh, Jharkhand, Chattisgarh, Rajasthan, Delhi, Gujarat, Daman & Diu and Dadra & Nagar Haveili.

- In 1940 "*Economic Entomology for South India*" by *T.V.Ramakrishna Ayyar* was published and the book was revised in 1963.
- *The Desert Locust in India* (1960) by *Rao Bahadur Y Ramachandra Rao.*
- *Bulletin of Entomology* (1960) publication started from Madras, later takenover by Entomological Society of India.
- *Text book of Agricultural Entomology* by *H.S.Pruthi*(1963)
- *General Entomology* by *M.S.Mani* (1968)
- *A Monograph on Thysanoptera* (1969) by *TN Ananthakrishnan.*
- *Elements of Economic Entomology* (1975) by *B Vasantharaj David and T Kumaraswami*.
- *Insects and Mites of Crops in India (1975)* by *MRGK Nair* (Published by ICAR).
- *Insect Pests of Crops* (1969), *Agricultural Entomology and Pest Control* (1983) by *S Pradhan* (Published by ICAR)
- *General and Applied Entomology* (1986) by *KK Nair, TN Ananthakrishnan and B Vasantharaj David*.

The Division of Entomology was established in 1905 as one of the five major Divisions of the then Agricultural Research Institute located at Pusa, Bihar. It was shifted to its present premises in 1936. Eminent entomologists like *H.M. Lefroy, T. B. Fletcher, H.S. Pruthi, S. Pradhan and K.N. Mehrotra* laid strong foundation for basic and applied research in insect science. Their pioneering contributions resulted in the publication of a monumental reference work viz., *Indian Insect Life in 1906 by Lefroy* and *Text Book of Agricultural Entomology by Pruthi*. Faunistic surveys led to the establishment of the *National Pusa Collection (NPC), one of the largest collections of its kind in the world*. Now this Insect collection houses more than half a million specimens of which 0.1 million are authentically identified, comprising about 20,000 species. Over the last 50 years, 1500 new species of insects have been described from NPC. In the early sixties and seventies, studies on economic entomology and insecticide toxicology were carried out by *Pradhan* that led to more of basic research in understanding mode of action of insecticides and fate of insecticides in the environment. *Pradhan's contribution to identification of the insecticidal principles of neem, the concept of Integrated Pest Management (IPM), periodicity of locust swarms, mode of action of DDT and development of grain storage structure 'Pusa Bin' to prevent losses due to stored insect pests stand out prominently in the annals of entomological research of our country.* The biology and bionomics of major insect pests laid the foundation for adoption of eco-friendly IPM approaches. Significant contributions were made to understand the biology and host plant resistance of major insect pests viz., sorghum stem borer, sorghum shoot fly, American bollworm, pink bollworm, mustard aphid, cotton whitefly and white grubs. N.C. Pant studied nutritional requirements of insects and the role of symbionts. E.S. Narayanan and B.R. Subba Rao established a strong unit of biological control, with an emphasis on taxonomy of parasites and predators. The discovery of nucleopolyhedrovirus (NPV) of the tobacco caterpillar by N. Ramakrishnan led to development of NPV based bioinsecticides for the control of tobacco caterpillar.

- During the course of all these years enormous *collections of insects* have been made, re-classified and rearranged from time to time. The collections at the *IARI (National Pusa Collection-NPC), New Delhi, ZSI-Culcutta, the FRI-Dehradun and Agricultural College and research Institute, Coimbatore* forms the basic material for identification of insects.

Lesson No: 2

Contributory factors for abundance of Insects- Structural characters, developmental characters and protective characters (morphological, physiological, behavioural and construction of protective niches)

- Insect came on the scene of existence according to various estimates from 250 to 500 million years ago. Human being has come on the existence only one million years ago.
- Insects constitute the most dominant class of the animal kingdom. They also represent the culmination of evolutionary development in terrestrial arthropod.

Contributory factors for abundance of Insects:

- Insects constitute the largest class not only of the animal kingdom but of the living world as a whole including both the animal and the plant kingdom.
- According to the estimate of Metcalf (1940) the knowledge about animals has been growing during the last two hundred years as follows: In 1758 when Linnaeus established Binomial nomenclature he described only 312 genera and 4,203 species of animals of all classes. Out of this number 74 genera were of insects with 2,102 species. Counting the number of new species every 10 years published in these records it was estimated that a total of 9,48,780 species of insects were described between 1850 and 1940 and a total of 6,52,770 species of animals other than insects.

The various characteristic features which contribute to the insects' dominance as a class are

I. Structural Characters
II. Developmental Characters
III. Protective Characters

Structural Characters

1. ***Exoskeleton:*** The exoskeleton not only *provides a much larger area for the attachment of muscles* but also *protects the muscles from mechanical injury*. It affords excellent mechanism to *protect insects against desiccation*. Also, the exoskeleton has *turned appendages* in to *good tools for digging, preying, oviposition*, etc. The exoskeleton *maintains the shape of the body* much more efficiently than the endoskeleton.
2. ***Small size:*** The evolutionary course followed by insects has led to the development of a *large number of smaller individuals than a smaller number of large individuals*. Undoubtedly this step immensely *increases the chances of survival* of the species. It is easier for smaller individuals to sustain on *small quantities of food* available to individuals and easier it is for smaller individuals to take refuge in *small niches* against inclemency's of weather as well as against adverse biotic environments. Smaller size *increases the chances of variability and mutation*. Lastly smaller size leads to greater efficiency. Muscular strength is comparatively better in small animals. Thus it is no wonder that a flea with a length of 1 / 20" can jump a horizontal length of 13" and a height of 8"; if a man were to do similar feat he should jump 700 ft. and a high jump of 450 ft. This gives an idea of the relative efficiency of insect's small size.
3. ***Quicker speciation:*** As a result of exoskeleton and small size there has been quicker speciation. The possession of chitinous exoskeleton and the aerial mode of life has probably been the largest contributor to so much speciation in insects. Due to mechanical rigidity of chitinous exoskeleton comparatively minute variations in the

external genitalia obviously lead to reproductive isolation and consequent fixation of the species.

4. ***Functional wings:*** This feature, the insects do not share with their other Arthropod allies and which gives insects a definite superiority. The *power of flight greatly increased* the statistical chances of survival and dispersal except on wind swept islands, where reverse adaptation in losing the functional wings has taken place. It increased the feeding and breeding range and provided a new means of *eluding enemies*, of attacking a fast moving host (running or flying) and of finding a mate. Mosquitoes, which, but for functional wings would not have been able to breed in small pools of water which dry in short time. Functional wings enabled various species to undertake *international migration* as in the case of locusts and butterflies. Honeybee can fly at the rate of 5.7 miles per hour, a hover fly 7-8 miles per hour, a hawk moth about 11 miles per hour and a butterfly even 57 miles per hour.
5. ***Hexapod locomotion:*** Jointed nature of legs is a characteristic in insects. Six legs of insects (Hexapoda) represent the optimum number. Larger number of legs in millipedes, the locomotion is cumbersome. In hexapods, during locomotion the body is always rests on a *tripod* while the other three legs move forward.
6. ***Compound eyes:*** Insects share this characteristic only with crustaceans. These are of very complicated structure which is not met with in other groups of animals. It is obvious that the *insects will not lose the power of vision completely if a few of their ommatidia are injured*.
7. ***Scattered sense organs:*** Except the eyes none of the other sense organs are invariably concentrated on the head.
8. ***Decentralized nervous system:*** This system, despite the highly evolved stage of insects as a class, is so decentralized that brainless insects can be artificially stimulated to walk, fly or even feed and breed.
9. ***Direct respiration:*** These gases are taken to and from every minute part of the system directly through air tubes called trachea and tracheoles which have several openings called spiracles rather than a pair of nostrils.
10. ***Enteronephric excretion:*** The excretory function is performed by Malpighian tubules which open in to the front part of hind intestine instead of opening directly to the exterior. Also the excretory products are semisolid rather than liquid urine. Obviously this system is also very well suited for *water conservation* as it makes the excretory function very much independent of water supply as water is not wasted in this function.

Thus despite the very minute size the whole of the internal organization of the insect system is highly complex.

Developmental characters

- Full life history of the individual consists of four well defined stages *viz.,* the egg, larva, pupa and adult. Two of these stages, namely, mainly feeding stage larva and mainly reproductive stage adult are so different not only in structural details but also in their requirements of both food and habitat that their internal competition between the parent and the offspring for both food and shelter gets completely eliminated.

1. ***High fecundity:*** *High fecundity* as well as *quick rate of development* gives insect prolific power of reproduction. It has been calculated that the progeny of a single moth can cover the entire dry surface of the earth to a depth of 80 feet within a period of one year in case all the progeny is allowed to live their normal life.
2. ***Quick rate of development / Short life cycle:*** Majority of insects, completes entire life cycle in less than a month, and enables them to complete many generations per year.

3. ***Specificity of food:*** Insects show *great diversity of food habits*, preferring one kind of food or other. Locusts and army worms avoid interspecific competition by resorting to Polyphagy, another type like termites feed on foods like cellulose. Extreme degree of specificity not only to different plant species or varieties but also to different parts of the same plant.
4. ***Specificity in habitat:*** Insects show great specificity in habitat requirements, and within the same insect, different stages prefer different habitats, so as to reduce the competition within the species. Similarly, due to their varied requirements in habitat, the exclusiveness, and the reduced competitions for food and shelter, makes them to survive successfully and proliferate.

Protective characters:

- Insects as a class have developed a variety of very ingenious ways for ensuring protection. These can be grouped in to several categories, viz.,
  morphological adaptations
  physiological adaptations
  behaviouristic adaptations
  construction of protective structures and
  selection of safety niches

1. ***Morphological adaptations:*** The protective morphological basis (exoskeleton) has been supplemented in many cases by *bristles, spines, hairs, scales* etc. Often minute size of insects affords protection against large predators. High degree of *protective colouration* and adaptation used for *camouflaging*.
2. ***Physiological adaptations:*** Sap feeding (sucking insects) have special *filter chamber* in alimentary canal to protect the digestive enzymes. Some insects have special physiological mechanisms like *diapause* to escape/protect from adverse environmental conditions.
3. ***Behaviouristic adaptation:*** Some insects, for example *stinging hymenoptera* take up such an offensive posture when threatened that the predator is frightened. Others adopt such dodging attitude as *feigning death*. Still others eject some kind of offensive liquid.
4. ***Construction of protective structures:*** To this category belong the *termites* or white ants. The *hive s of honey bees, wasp*, the *coccons of pupae* in so many species, the bag of clothes moth and other bag moths, the underground nests of ants, the nests of so many solitary wasps all come in this category.
5. **Selection of safety niches:** So many insects use their jumping or flying capacity to escape danger.

ZENITH OF EVOLUTION

Finally the zenith of evolution depicted by such social insects as termites, ants and bees shows the degree of specialization to which the insects have reached.

Lecture No: 3

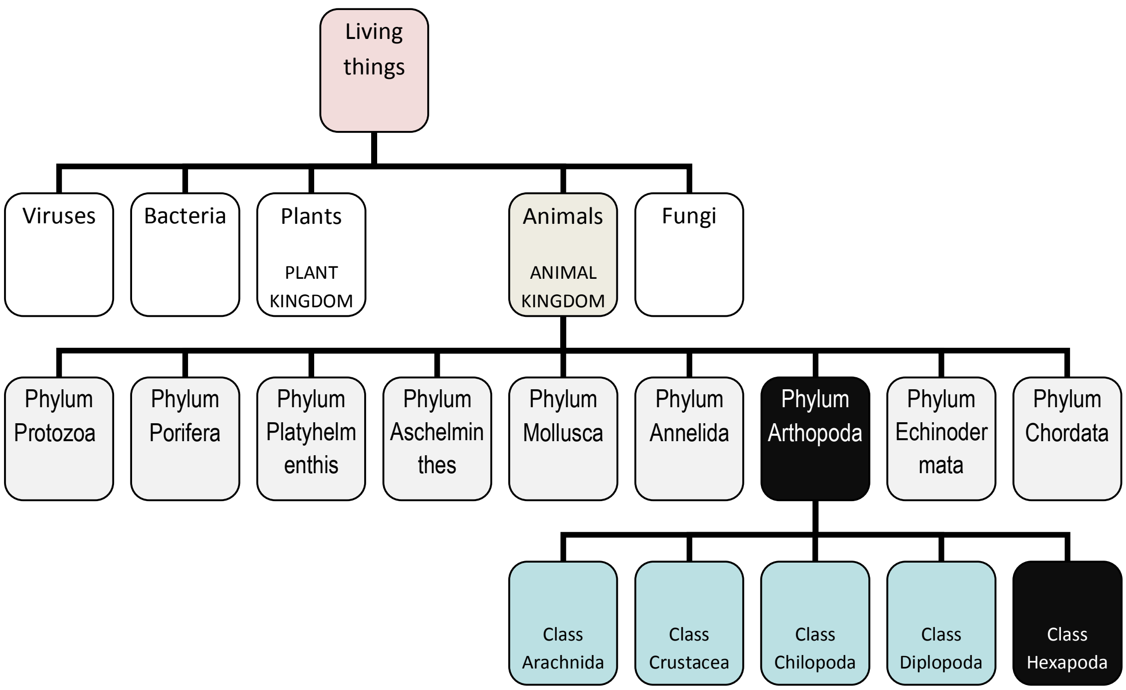
Classification of Phylum Arthropoda upto orders-different classes of Arthrpoda and comparison of characters of Class Insecta with Aeachnida, Crustacea, Symphyla, Chilopoda, Diplopoda and Onychophora; Sub-Classes Apterygota and Pterygota-Names of Orders of Apterygota and Pterygota with examples and characters of Class Insecta-Economic classification of Insects.

Classification: The sequence of classification categories can be remembered by memorizing this mnemonic phrase: **K**ing **P**hillip, **C**omes **O**ut **F**or **G**oodness **S**ake!

Kingdom: All the living things are divided into a series of sets and subsets depending on *how closely related they are*. For instance all living things are divided into *5 kingdoms*.

- Plants
- Animals
- Fungi
- very small things called Protoctista (virus)
- even smaller things called Bacteria

These last two are so small you can't see them without a microscope.



Phylum: The living members of the kingdom Animalia are divided into smaller groups called *phyla* singular *phylum*. *There are more than 38 phyla in the Animal Kingdom*. *Major Phyla are:*

- Protozoa
- Porifera (sponges)
- Platyhelminthes (flatworms)
- Aschelminthes (roundworms)
- Mollusca (snails)
- Annelida (earthworms)
- Arthropoda (crabs, mites, insects)
- Echinodermata (starfish)
- Chordata (fishes, reptiles, birds, mammals).

Phylum: Arthropoda: One of which, the Arthropoda is of particular interest to us. The phylum Arthropoda contains the *hard shelled, jointed legged animals*. Phylum Arthropoda includes insects, spiders, lobsters, and related animals.

1. *Segmented body plan:* Arthropods have *segmented bodies* with the segments grouped into two or three distinct sections.
2. *Paired jointed appendages on variable number of segments*
3. *Chitinous exoskeleton:* They have hard *chitinous external skeletons*, or exoskeletons, that are shed and regenerated as the animals grow.
4. *Bilateral symmetry*
5. Hemocoelic body cavity (*open circulatory system*)
6. *Tubular Alimentary canal* with mouth and anus
7. *Ventral nervous system:* Nervous system comprised of a dorsal brain and ventral nerve chord
8. *Dorsal Heart with paired ostia (openings)*
9. *Striated muscles* in skeletal system
10. *Respiration by gills, tracheae or spiracles*

Classes: Phylum Arthropoda is further divided into four smaller groups called *classes.* Phylum Arthropoda can be divided into *18 Classes (5 major classes),* excluding the extinct trilobites.

Class: Arachnida (scorpions, spiders, mites, ticks, daddy longlegs, etc.)

- *Two body regions* (cephalothorax and abdomen)
- Cephalothorax with 6 pairs of appendages (chelicerae, pedipalps and 4 pairs of walking legs)
- Abdomen with up to 3 pair of appendages (spinnerets)
- Mostly terrestrial and predatory, some secondarily aquatic and sap-sucking.

Class: Crustacea (crabs, lobsters, shrimp, isopods, water fleas, copepods, etc.)

- Primarily aquatic with most species being marine, some terrestrial representatives
- Body divided into *2 regions* (cephalothorax and abdomen)
- Cephalothorax with *2 pairs of antennae, 3 pairs of mouthparts* and at least *5 pairs of legs*
- Appendages biramous (forked segmentation)
- Most species scavengers or predatory

Class: Diplopoda (millipedes)

- Primarily herbivorous, all terrestrial
- *2 body regions* (head and trunk)
- Head with *one pair of antennae* and often a *pair of compound eyes*
- Diplosegmentation (two fused segments), segments usually cylindrical – advanced trait since
- Some segments still retain one pair of legs.
- *Typically two pairs or legs per body segment, due to diplosegmentation.*

Class: Chilopoda (centipedes)

- Terrestrial predators
- *2 body regions* (head and trunk)
- Dorso-ventrally (top-bottom) flattened with one pair of appendages per segment
- Head with *one pair of antennae* and *simple eyes*
- First pair of trunk appendages modified into poison claws
- Typically *one pair of legs per body segment*

Class Insecta = Hexapoda (insects)

- Many feeding strategies
- Mostly terrestrial, some secondarily aquatic
- *Body with 3 distinct regions* (head, thorax, abdomen)
- *Head with 5 pairs of appendages* (a pair of antennae-olfactory & tactile organ, a fused labrum, a pair of mandibles, a pair of maxillae, and a fused labium), many orders with mouthparts modified and lost.
- *Thorax with 3 pair of legs and usually two pair of wings* (primitive forms wingless others with wings secondarily lost). These are called pro-thorax, meso-thorax and meta-thorax. Each segment has one pair of legs, and meso-and meta-thoracic segments bear a pair of wings.
- Abdomen with up to one pair of appendages (cerci)
- *Only invertebrates with wings and only animals with true wings*

The Class Insecta Classification: The insects being such a large class of organisms their taxonomy and hence their classification can, and in fact does, get extremely complicated, with a large number of people discussing the merits of various taxonomic schemes. The one we usually follow throughout these pages is from Imms 1984 and is a basically functional if not extremely up to date system.

- Class Insecta is the *largest of class of animal kingdom*.
- The *29 insect orders* are numbered in an approximate series of *evolutionary complexity with the oldest and most primitive groups being listed first*. They are further gathered together into a number of groups depending on their degree of relatedness. The numbers to the right of the order name are estimates of the number of species known from that order in the world.
- Class Insecta is divided into *2 sub-classes: Apterygota and Pterygota*.

Sub-Class : Apterygota	**Sub-Class : Pterygota**
• The name Apterygota is Greek in origin, and means "*without wings*." • This subclass contains *primitive insects that do not fly*, and were *wingless throughout their evolutionary history*. • The wingless insects of this subclass *do not undergo metamorphosis*. Instead, *the larval forms are smaller versions of their adult parents*. • Apterygote insects *molt throughout their lives*, not just during the growth phase. • Their *mouthparts are retracted within the head.* • This sub-class is divided into 4 orders	• The subclass Pterygota includes most of the world's insect species. • Pterygota means "wings," and describes *insects that have wings, or once had wings in their evolutionary history*. • These insects also *undergo metamorphosis*. • Pterygote insects *molt only during immature growth stages* (*nymphs and larvae)* and do not undergo molting in adult stages. • The *mouth parts are well developed*. • The subclass is further divided into two groups: the *Super Order* Exopterygota (16 orders) and the *Super Order* Endopterygota (9 orders).

Super Order : Exopterygota	Super Order : Endopterygota
• Insects whose wings develop outside their body, and thus have externally visible wings buds in the late nymphal instars. • Insects in this group undergo a *simple or incomplete metamorphosis*. • The life cycle includes just *three stages:* egg, nymph, and adult. • No pupal stage • During the nymph stage, gradual change occurs until the nymph resembles the adult. • The growth stage *nymph* resembles mature adults stage, without developed wings. The late nymphal stages already show the development of wing pads. • But only in the last molt functional wings are developed. • The nymphs usually have the same feeding habits as the adults.	• Insects whose wings develop inside their body, and thus are not visible untile after metamorophosis, wings develop inside pupal stage. • These insects undergo a *complete metamorphosis*. • The life cycle includes *four stages*: egg, larva, pupa, and adult. • All four stages looks different in morphology, behavior, habits and habitats. • Growth stage, larva is active feeding stage which undergoes molting for gradual growth. • The development of wings is not visible during the larval stages. • The pupal stage is inactive (a rest period). • When the adult emerges from the pupal stage, it has functional wings.

Insect Orders

Taxonomic Name	Common Name & Examples	Wing character	No. of Species Worldwide
Sub-Class : APTERYGOTA (Wingless Insects with No True Metamorphosis)			
1. Thysanura	Silver fish	--	55
2. Diplura	Pronged Bristletails	--	600
3. Protura	Proturans	--	10
4. Collembola	Springtails	--	3000
Sub-Class: PTERYGOTA (Winged Insects with Incomplete or Complete Metamorphosis)			
Super-Order: The Exopterygota (Hemimetabolous insects with incomplete metamorphosis)			
5. Ephemeroptera	May-flies	Can't fold wings over body	2000
6. Odonata	Dragons and Damsels	Can't fold wings over body	5000
7. Plecoptera	Stone-flies	Pleco-foldable	1700
8. Grylloblattodea	Ice bugs/Rock Crawlers	--	16
9. Orthoptera	Grasshoppers	Ortho-straight	20000
10. Phasmida	Stick-Insects	--	3000
11. Dermaptera	Earwigs	Derma-skin like	1200
12. Embioptera	Web Spinners	Embio-lively	300
13. Dictyoptera	Cockroaches&Mantids	Dictyo-netted	6000
14. Isoptera	Termites	Iso-same	1900
15. Zoraptera		Zor-pure, aptera-wingless	22
16. Psocoptera	Book and Bark Lice	Psokos-rubbed/gnawed (fractured wings)	2000

17. Mallophaga	Biting Lice	wingless	2800
18. Siphunculata	Sucking Lice	wingless	300
19. Hemiptera	True Bugs	Hemi-half	100000
20. Thysanoptera	Thrips	Thysano-fringed	500
Super Order: The Endopterygota (Holometabolous insects with complete metamorphosis)			
21. Neuroptera	Lacewings etc.	Neuro-nerved	4700
22. Mecoptera	Scorpion-flies	Meco-long	400
23. Siphonaptera	Fleas	Siphon-tube/pipe, aptera-wingless (wingless)	1400
24. Coleoptera	Beetles	Coleo-sheath	370000
25. Strepsiptera	Stylops	Strepsi-twisted	370
26. Diptera	True Flies	Di-two	100000
27. Lepidoptera	Butterflies and Moths	Lepido-scaly	150000
28. Trichoptera	Caddis-flies	Tricho-hairy	5000
29. Hymenoptera	Ants Bees and Wasps	Hymen-membrane	120000 +

- The *largest insect order is coleoptera* (beetles), followed by lepidoptera (moths & butterflies), hymenoptera (ants, bees, wasps) and Hemiptera (true bugs). Hemiptera is the largest order in Hemimetabolous insects.
- **New Insect Order:** For the first time in 87 years, researchers have discovered an insect that constitutes a new order of insects. Dubbed "the gladiator" (for the recent movie), it lives in the Brandberg Mountains of Namibia, on the west coast of Southern Africa. Entomologist Oliver Zompro of the Max Planck Institute of Limnology in Plön, Germany, who identified the creature as unique, said it resembles "a cross between a stick insect, a mantid, and a grasshopper." The discovery of the new insect order, which has been named *Mantophasmatodea*, increases the number of insect orders to 30. No new order of insects has been identified since 1915.

Economic classification of Insects:

A study of insect, which affects the interests of man in various ways, is referred to as "*Economic Entomology*". Insects can be classified into various groups as per their economic importance (*Economic Classification*), as given below:

Insects

Insects possessing economic Importance (Economic entomology)

Insects of no economic importance (Harmless insects)

Harmful insects (Injurious)

Insect pests

a. ***Pests of crop and plants*** *(Agricultural entomology and Forest entomology)*

Damage by feeding.

Direct (Borers, leaf feeders)

Indirect (vectors, whitefly, leaf hoppers)

Damage by Non feeding

By Egg laying (cow bugs)

Using plant parts for Constructing nests (red ants, leaf cutter bee)

b. ***Pests of stored products*** *(Storage Entomology)*

c. ***House hold pests***

Damage by feeding (pulse beetle, furniture beetle)

Contamination by excretion (cockroach)

Seeking protection / building nests/tunnels (termites, wasps, meal moth)

d. ***Insects inimical to man*** *(Medical entomology)*

Causing annoyance: (head louse, bed bugs, eye fly, ants, etc.)

Causing irritations on body (ants, wasps, mosquito)

Disseminating diseases (mosquito-malaria, rat flea-plaque, housefly-cholera, typhoid, dysentery, diarrhea)

Sucking blood (mosquito, horsefly, flea)

Beneficial insects

(a) Productive insects

Secretion of insects : Silk by silk worm, Lac by lac insects, Wax by honey bees

Bodies useful or contain Dye (Cochneal insect), Cantharidin (Blister beetle), Fish bait (stone fly nymphs)

Collect and store plant product : Honey (nectar collected by honey bees)

Products from plant galls caused by insects: Tannic acid, inks, dyes.

Insects as food for animals and human beings (Termites, white grubs, silk worms, pupae, grasshoppers)

(b) Helpful insects

Aids in pollination (Honey bees, butterflies, fig wasp)

Predators and parasitoids (Dragon fly, praying mantis, *Chrysoperla*, *Trichogramma sp*,*Bracon* sp)

Destroy weeds: (Mexican beetle, *Zygogramma bicolorata* feeding on *Parthenium*.

Improve soil fertility: (Ants, crickets, ground beetles, termites)

As scavengers: (Dung rollers, maggots, beetles)

Ideal material for scientific investigations: *Drosphila melanogaster*

Aesthetic value: (Butterflies, Jewel beetle, clear wing moth)

Lecture No: 4

Structure & functions of Bodywall-different layers, chemical composition, functions and cuticular appendages, cuticular processes and cuticular invaginations-chaetotaxy-moulting-apolysis-ecdysis and sclerotization.

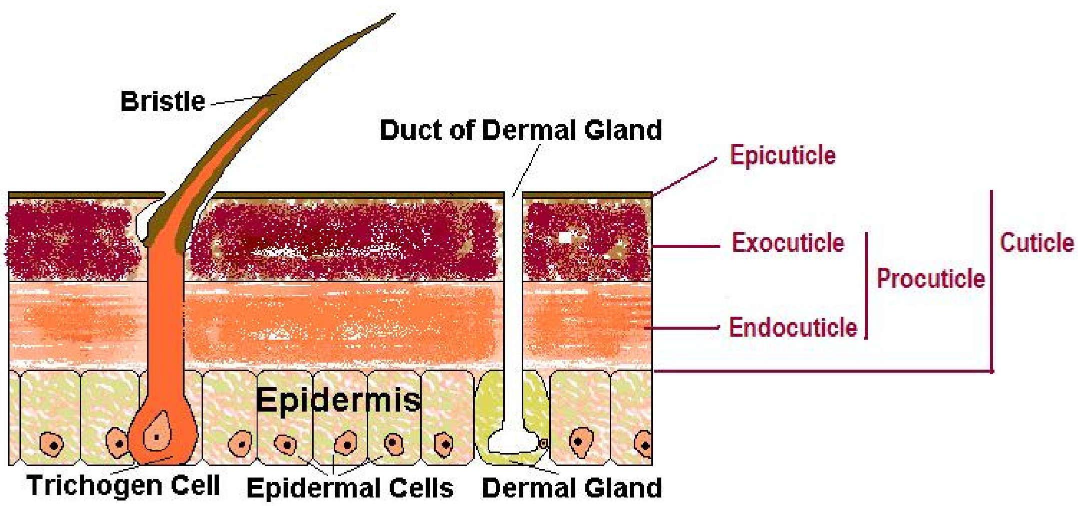
The integument, which is a characteristic feature of the arthropods, forms the outer layer of the body, *comprising the epidermis (hypodermis) and the cuticle*. Integument of insects, besides *functioning as an exoskeleton*, and *holding the internal organs together*, *acts as a protective barrier* between the insect and the environment. The integument *also provides external structures to the sensory receptors*, which perceive stimuli in various forms and is also *responsible to prevent the water loss* from the insect body. For these reasons, integument to a very large extent is considered *a major factor in the success of insects* as a terrestrial animal.

Functions of insect integument / bodywall:

- Insect integument or body wall *externally surrounds the insect body* & its appendages.
- Integument/body wall *function as exoskeleton of insects*.
- It is the *outer layer of insect*.
- It *provides shape and rigidity* to the animal body.
- It *supports muscles* attached to internal surface of body wall (helps in locomotion).
- It *holds internal organs together*.
- Acts as *protective barrier* *(from evaporation, entry of disease causing organisms, physical stress)*
- Provides *external structures/support for sensory organs* (sensory hairs, sensory areas)
- Prevents *water loss.*

Structure of bodywall / integument:

- All Arthropods have an exoskeleton made up of chitin and proteins.
- Arthropods grow their Exoskeleton outside the body (unlike internal in human body).
- Integument / body wall consist of three basic components / parts:
  1. Cuticle (Exoskeleton)
  2. Epidermis (hypodermis)
  3. Basement membrane



General structure of Insect Integument

The Cuticle

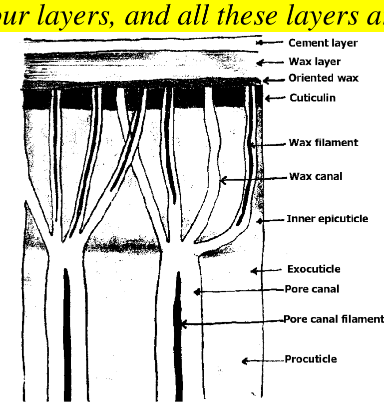
- Cuticle is complex, *non-cellular*, *non-living* and is the *secretion of epidermis*.
- It *covers the whole of outside of body* as well as lining of ectodermal invaginations such as foregut, hindgut and tracheae.
- *Cuticle comprises 50% of dry weight of insects*.
- The epidermal cells secrete chemicals like chitin, protein and lipid, and these polymerize to form cuticle.

The cuticle is primarily divided into two.

- Epicuticle : *non-chitinous*
- Procuticle : *chitin-protein complex*.

1. Epicuticle:

- *Epicuticle is non-chitinous.*
- Epicuticular layer of the insects is about 1-4μ in thickness, and in general, covers the entire external surface of an insect, except some chemoreceptive sensillae, midgut and ends of gland cells.
- *The main function of the epicuticle is to prevent water loss from the insect body*.
- It can maintain the water content in the body by uptake of water in terrestrial (e.g. flea, *Xenopsylla brasiliensis*) as well as aquatic (e.g. alderfly, *Sialis lutaria*) insects.
- The epicuticle *also restricts the dimensions of the exoskeleton* during intra-stadial growth of holometabolous larvae. It also dictates the extent of expansion of a newly ecdysed cuticle or distension of cuticle during the feeding activity of sap-sucking or blood-sucking insects.
- Epicuticle is also thought to be selectively permeable to the moulting fluid into the apolysial space, which is required for the digestion of the outer lying cuticle, and to the return of this partially digested exuvial cuticle into the body of the moulting insect.
- It probably *also acts as a reservoir for metabolic waste products*, defensive secretions and the juvenile hormone.
- *The epicuticle consists of four layers, and all these layers are secreted by epidermis.*



Structure of Epicuticle

(i) ***The outer most cement layer***: also known as *tectocuticle protects wax layer*. The cement layer is *formed through the combined secretions of specialized dermal glands* (Verson glands of the epidermal layer), and *consists of carbohydrates (lactose), proteins, long chain lipids and some polyphenolic substances*. The thickness (not more than 0.1μ) and distribution of cement layer may vary within an insect, or in different insects. *It may be totally absent as in honeybees*. The functions of cement layer are to protect the underlying wax layer from abrasions and to act as a reservoir of mobile lipids, which leak out to replace lost waxes.

(ii) ***Wax layer***: also known as *lipoid layer imparts water conserving mechanism to insects.* The wax layer usually lies below the cement layer and provides a kind of *waterproofing*. The *epidermis just before ecdysis secretes the lipids of the wax layer*, which is transported via pore canals, and the finer wax canals, and released to the surface. The wax canals are considered the route of entry into the insect for oil-soluble compounds. The composition of waxes varies not only between individuals of the same species, but also within the same individual at different times of development. In general, these waxes are composed of hydrocarbons of 12-31 carbon chain lengths, esters of even-numbered fatty acids and alcohols. The wax layer may exist (i) simply as a monolayer immediately above the outer epicuticle or (ii) may be combined with the cement layer or (iii) extend above the surface of the cement layer as wax blooms (e.g. in most homopterans, hemipterans and some coleopterans). Initially the wax layer is in a liquid form, but is later transformed into solid wax at ecdysis. The wax layer is composed of three layers: (1) oriented monolayer just above the cuticulin, (2) less ordered thick layer and (3) outer "bloom" layer. Oriented layer is instrumental in water balance. The thick layer is the majority of wax and is in with the cement layer.

(iii)***The outer epicuticle, referred to as cuticulin by Wigglesworth***, is a *trilaminar layer*, 12-18nm in thickness, *is present universally*, except over sensory endings, lines the trachea and serves as the insertion point for muscle tonofibrillae. *Consisting of protein and polyphenols, highly resistance to acids and organic solvents*. It is derived from the plasma membrane plaques. During its formation, they first appear as discrete plates above the membrane, which gradually form a continuous layer. Soon after its formation, there appear small pores (about 3nm dia.), and through these pores the apolysial droplets move out into apolysial space to partially digest the exuvial cuticle, and also the products formed after digestion are allowed back into the body of the instar undergoing moulting.

(iv)***The inner epicuticular*** layer consists of polymerized lipoproteins, stabilized by quinones. *It is produced by the secretions of epidermis*, and probably serves as a reservoir of the extracellular enzymes associated with repairing of the wounds.

While the outer and inner epicuticular layers are formed before apolysis, the cement and the wax layers are formed after apolysis.

2. **Procuticle:**

- It is a comparatively *much thicker layer*
- *Consists of chitin protein* and other substances.
- The *main component present in the procuticle is chitin*. *Chitin is the chief constituent forming 20-50 percent dry weight of cuticle*. It is a polysaccharide made up of N-acetyl glucosamine and glucosamine.
- Besides chitins, *procuticle also contains non-chitinized substances (25-37%) several proteins (arthropodin, resilin, and other proteins) and other substances like lipids, pigments and salts* etc.
- The much thicker procuticle (thickness ranges from 0.2μ–200μ), primary endocuticle is in contact with epidermis (or hypodermis).
- Procuticle is colourless in living insects.

The procuticle is distinguishable into two:

Outer exocuticle: *(tanned)*

- Hard and dark in colour due to tanning (*outer tanned or sclerotized exocuticle*)
- Has several rigid areas called sclerites.
- It contributes rigidity or toughness to the cuticle.
- Exocuticle is absent or reduced in the regions of the integument which are more flexible.

Inner endocuticle: (*untanned*)

- It is soft flexible and also contains chitin and protein fibers.
- It is not tanned.
- *The endocuticle is the largest section of the integument.*
- It is made up of fine horizontal lamellae and vertical lines called pore canals.

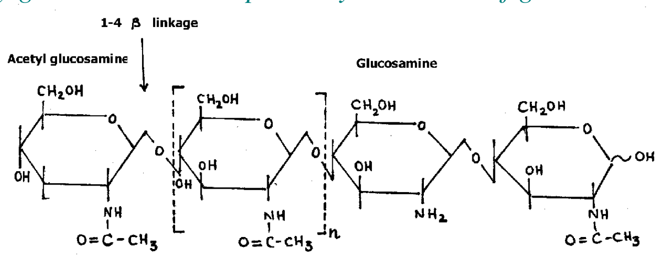
Though physically different, these layers are chemically similar, but differ quantitatively in the relative amount of chitin and protein, and in most insects appear to be intimately fused.

Important constituents of cuticle:

- *Cuticle is composed mainly of chitin and cuticular proteins.*
- Changes in the proportions of each of these components change the type of cuticle. For example, low levels of chitin form a highly elastic cuticle. In some insects elastic rubber like cuticle consisting of special protein called *"resilin"* is present in articulatary sites of wings and mouth parts, helping in movement of these organs.

Chitin:

- *Chitin is a nitrogenous polysaccharide in the form of a long chains consisting of several N-acetylglucosamines interposed by molecules of glucosamine.*



- *Chitin is the main constituent of Procuticle* and is chemically linked with protein, *arthropodin***.** This protein undergoes tanning process forming a hard, inflexible and dark *sclerotin.*
- *Chitin accounts 25-60 percent of the dry weight of various cuticles and the remainder is protein.*
- *It is absent in epicuticle, less in exocuticle and more in endocuticle.*
- It is widely distributed in invertebrates, but is unknown in protozoa and vertebrates. Among the plants it is restricted to fungi.
- It dissolves in conc. Mineral acids and insoluble in water, dilute acids, alkalies and organic solvents.
- Henri Beaconnot first described chitin in 1811, from mushrooms, and named it as "fungine". Odier in 1823 recorded it from insects and named it as "chitin", a Greek equivalent for a sort of a "belted coat" and "gown" or "envelop".

Protein:

- A mixture of several proteins is present, but the important ones are Anthropodin and Resilin.
- *Arthropodin* is present in the upper layers of procuticle. It is water soluble but becomes insoluble as a result of tanning reactions. The quinones (derived from tyrosine) tans arthropodin and tanned part becomes hard exocuticle. Such a *tanned arthropodin is called selerotin* and the process is known as "*scleretisation*" or "*tanning"*.
- *Resilin:* It is a *rubber like elastic protein present in movable joints* like wing joints and mouth parts. Resilin can be stretched under tension and returns immediately after its release.

Functions of Cuticle:

- Acts as exoskeleton
- Provides support to body
- Gives shape.
- Muscles attached to cuticle, facilitates various types of movement.
- At several places, cuticle is invaginated to provide internal support and muscle attachment.
- Wing movement is possible only because of hard cuticular flight Sclerites in thoracic region.
- Epicuticular wax layer provides a mechanism to conserve water.
- Secretions over cuticular layer in some insects are bactericidal, protects from infection.
- Various parts of cuticle modified to form sense organs to receive stimuli.

Epidermis (Hypodermis):

- *The single cellular layer lying between the basement membrane and endocuticle*.
- Between the moults, the epidermal cells are flattened and have no distinct boundaries. During and after a moult, the cells may develop long cytoplasmic processes on the outside extending into the pore glands. These processes are withdrawn when the cuticle matures.
- *Epidermal cells secrete the moulting fluid during apolysis.*
- *Epidermal cells secrete greater part of cuticle and also produce moulting fluid, which dissolves the old cuticle.*
- *It also absorbs the digestion products of old cuticle, repair wounds.*
- Some of the epidermal cells may become specialized to form sense organs (mechano- or chemoreceptors) or glands (dermal, peristigmatic etc.), neurons or glial cells.
- *During the cuticle formation the dermal glands (specialized epidermal cells) secrete and deposit the cement layer over the newly formed outer epicuticle*. Peristigmatic glands present in dipterous larvae around the spiracle continuously keep secreting a substance, which provides the hydrofuge properties to the cuticle surrounding the spiracle, and prevent the entry of water into the tracheal system.

Oenocytes: The oenocytes are large round or oval cells epidermal in origin and often lie in a group on either side of each abdominal segment, or between the bases of epidermal cells and basement membrane (as in Ephemeroptera, Odonata, Hemiptera) etc. In Homoptera, Hymenoptera and Diptera, the oenocytes are embedded in fat body, while in Lepidoptera and Orthoptera they form clusters in the body cavity. Oenocytes secrete the lipoprotein of the procuticle and the epicuticle, and probably are involved in the synthesis of wax.

Pore canals: Pore canals are the extracellular extensions of the cytoplasm that extend from the surface of the epidermal cell to the inner layer of epicuticle and may penetrate the outer epicuticle. Pore canals filled with the cuticular material are absent in the old endocuticle due to new layers being formed under the old. A filament is present in the pore canal for the maintenance of a hole in the new cuticle until the cuticle is permanent and for the transfer of materials into the cuticle. Pore canals become helical due to the compressive forces occurring during tanning. The number of pore canals per cell varies from species to species, cockroach having as many as 200 per cell (1,200,000/mm2), while *Sarcophaga* has 50-70 per cell.

Basement membrane:

- Basement membrane is an *amorphous granular neutral mucopolysaccharide layer*, up to 0.5µ thick and lies just below the epidermis forming a continuous sheet similar to neural lamella.

Cuticular appendages:

- These structures include *all outgrowths of the cuticle that are connected with it by means of membranous joint*.
- They arise from modified epidermal cells.
- *They are setae and spurs.*
- ***Setae or Macrotichia:*** They are *hollow structures grown as an as extension of exocuticle*. Each setae arises from cup like pit called as alveolus, are commonly known as *hairs or hair like projections* which arise from a special epidermal cell called *trichogen* (*sensillum forming cell*) which penetrates through another cell called *tormogen* (*socket forming cell*) which at the outside forms a membrane and articulate at this site. In some the setae like structure innervates the sense organ formed by epidermal cells which receive sensory nerve.

  The main kinds of setae are:

  Clothing hairs: invest general surface of the body or its appendages eg: plumose hairs in Apoidea bristles in Tachnidae

  Scales: Highly modified clothing hairs and are characteristic of lepidopteran wings.

  Glandular setae: those function as outlets for the secretion of epidermal glands. If they are rigid then they are termed as glandular bristles eg: certain lepidopteran larvae

  Sensory setae: Setae in certain appendages modified for sensory function and are connected with nervous system.
- ***Spurs:*** differ from setae in being multicellular origin. Occur on legs of insects Eg: End of tibia in orthoptera, Lateral claws in insect leg.

Cuticular processes (Microtrichia)

- These are outgrowths on the external surface of the cuticle *without membranous articulations / joints*.
- These are *non-cellular* processes rigidly connected with the cuticle.
  1. Fixed hair like structures found on the wings of certain Diptera.
  2. Spines-outgrowths of cuticle which is thorn like, immovable-hind tibia of Orthoptera.
  3. Nodules
  4. Tubercles
  5. Horns-males of Coleoptera

Chaetotaxy: *Arrangement of bristles on an exoskeleton of an insect* is called chaetotaxy. The chaetotaxy is being studied for taxonomic purposes.

Moulting, Ecdysis, Apolysis and Sclerotization

One of the general characteristics that defines the phylum Arthropoda (which includes insects, spiders, and crustaceans) is an external skeleton, also called an exoskeleton . The arthropod exoskeleton completely covers the outside of the body and the muscles inside adhere to it. Exoskeletons are hard and protect the body. *Because the exoskeleton is hard and rigid, an arthropod cannot grow unless it sheds its old exoskeleton and secretes a new one. This process is called molting*. Arthropod growth is limited to molting, so growth happens in steps rather than continuously. *The stages between moltings are called instars*. The extent of an individual's growth between molts and the length of time between molts are related to the temperature as well as to the amount of food and water an individual gets. The whole of the life history of the insect is geared to the moulting cycle and co-ordination of various aspects of moulting involves a number of hormones.

Moulting **:** Series of changes, which developmental stages undergo for the formation of new cuticle and structures associated with it. Periodically outgrow and replace its exoskeleton.

Ecdysis **:** The process of shedding the cuticle is called ecdysis.

Apolysis **:** Separation of epidermis from the cuticle giving narrow space in between and this process is called apolysis.

Sclerotization: The process by which the cuticle is hardened by substances other than chitin.

Tanning: The process by which the cuticle is darkened.

The cuticle is hard and forms unstretchable exoskeleton in insect, and it must be shed from time to time to permit insect to grow and increase size. Before the old cuticle is shed, the new one has to form underneath it. *The process of shedding the cuticle is called ecdysis*. Moulting includes the series of changes, which developmental stages undergo for the formation of new cuticle and structures associated with it. The process of moulting ends by the accomplishment of ecdysis when the old cuticle splits to liberate the new instar of the insect. *Pterygote (winged) insects cease moulting after attaining adulthood, but apterygote (wingless) insects (silverfish) undergo moulting even after attaining adulthood*.

The molting process is triggered by hormones released when an insect's growth reaches the physical limits of its exoskeleton. *Each molt represents the end of one growth stage (instar)* and the beginning of another. In some insect species the number of instars is constant (typically from 3 to 15), but in others it may vary in response to temperature, food availability, or other environmental factors. An insect is known as an imago (adult) when it becomes sexually mature. At this point, molting stops and energy for growth is channeled into production of eggs or sperm.

An insect cannot survive without the support and protection of its exoskeleton, so a new, larger replacement must be constructed inside the old one -- much like putting an overcoat under a sweater! The molting process begins when epidermal cells respond to hormonal changes by increasing their rate of protein synthesis. This quickly leads to *apolysis-physical separation of the epidermis from the old endocuticle.* Epidermal cells fill the resulting gap with an inactive molting fluid and then secrete a special lipoprotein (the cuticulin layer) that insulates and protects them from the molting fluid's digestive action. This cuticulin layer becomes part of the new exoskeleton's epicuticle.

After formation of the cuticulin layer, molting fluid becomes activated and chemically "digests" the endocuticle of the old exoskeleton. Break-down products (amino acids and chitin microfibrils) pass through the cuticulin layer where they are recycled by the epidermal cells and secreted under the cuticulin layer as new procuticle (soft and wrinkled). Pore canals within the procuticle allow movement of lipids and proteins toward the new epicuticle where wax and cement layers form.

When the new exoskeleton is ready, muscular contractions and intake of air cause the insect's body to swell until the old exoskeleton splits open along lines of weakness (ecdysial sutures). *The insect sheds its old exoskeleton (ecdysis)* and continues to fully expand the new one. Over the next few hours, *sclerites will harden and darken as quinone cross-linkages form within the exocuticle. This process (called sclerotization or tanning)* gives the exoskeleton its final texture and appearance.

An insect that is actively constructing new exoskeleton is said to be in a *pharate* condition. During the days or weeks of this process there may be very little evidence of change. Ecdysis, however, occurs quickly (in minutes to hours). A newly molted insect is soft and largely unpigmented (white or ivory). It is said to be in a teneral condition until the process of tanning is completed (usually a day or two).

Process of Molting (formation of new cuticle layers):

Step 1:
- *Triggering of moulting is under hormonal control*.
- Ecdysone is secreted from glands (pro-thoracic glands) behind the brain.
- Once it is released the molting process begins.

Step 2:
- *Apolysis*-separation of old exoskeleton from epidermis
- The *epidermis now separates from the cuticle* giving rise to a narrow space in between the epidermis and cuticle. This process of separation of epidermis is called *apolysis.*

Step 3:
- *Secretion of moulting fluid by epidermis*.
- This space is filled with *moulting fluid (contains enzymes) secreted by epidermis*.
- The fluid contains certain enzymes, chiefly a proteinase and a chitinase which *digest the entire endocuticle but does not attack the epicuticle*.

Step 4:
- The *first layer secreted* over the surface of separated epidermis in the formation of the new cuticle, *is protein epicuticle or cuticulin*.
- Production of cuticulin layer (outer epicuticle-consisting of protein and polyphenols, highly resistance to acids and organic solvents) for new exoskeleton.
- Premolt-new cuticle is secreted underneath (inside) old cuticle

Step 5:
- *Activation of moulting fluid*.
- The enzymes in the moulting fluid are activated only after the completion of the epicuticular layer.
- The moulting fluid due to presence of some unknown phenomenon has no effect on exocuticle, nerve and muscle connections to the old cuticle and a very thin portion of endocuticle.
- The latter forms the ecdysial membrane.

Step 6:
- *Digestion and absorption of old endocuticle*.
- After digestion of old cuticle and re-absorption of moulting fluid, the wax layer is laid on the surface of the cuticle.

Step 7:
- *Epidermis secretes new procuticle*
- Beneath epicuticle, procuticle is formed, which after the tanning process, gets differentiated into exo- and endo-cuticle.

Step 8:
- A *waxy material is produced* by the epidermal cells and is transported by pore canals through procuticle and deposited over the protein epicuticle in the form of lipid-epicuticle.

Step 9:
- *Ecdysis*-shedding the old exo- and epicuticle
- The insect shows active muscular activity to apply pressure on the old exocuticle which splits at ecdysial line of weakness.
- The muscular movements are supplemented by swallowing of air or water.
- In *some dipteran pupa* special organ called *ptilinum* is present *on the head*.
- Once the old cuticle splits, the new insect wriggles out. Head and thorax come out first followed by abdomen, legs and wings.
- The *volume of insect also increases* as the cuticle is not yet hard and is expandable.
- At this stage *cement layer is laid over the wax layer*.
- Thus, it can be seen that in the formation of epicuticular layers substance of inner most layer is secreted first and the materials of the outer layers are carried through pore canals and superimposed as successive layers described above.

Step 10:
- *Tanning / Sclerotization / Hardening of new exocuticle* (in procuticle-outer enxocuticle)
- In due course of time, during the formation of new cuticle and sepration from old cuticle, cuticular parts are characteristically tanned and become hard.
- When insect undergoes ecdysis the cuticle is soft and can expand to permit increase in the size of the animal.
- Soon procuticle consisting chiefly of protein and chitin undergoes chemical changes.
- The cuticular protein, arthropodin is water soluble. It becomes water insoluble as a result of tanning reactions.
- The tanned exocuticle becomes hard and brittle, it loses considerable amount of water and arthropodin changes in to sclerotin, and hence the process is called as *sclerotization.*

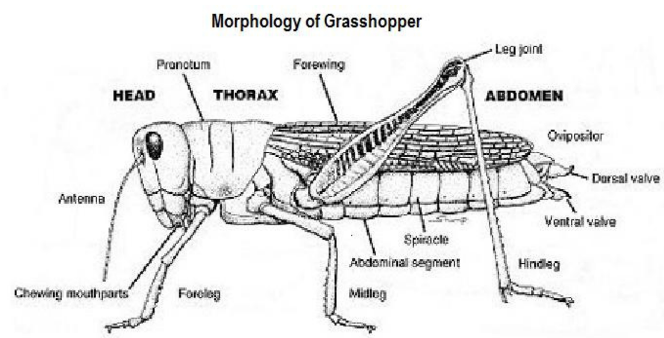
- The insects which moult several times e.g., some holometabolous larvae, the cuticle contains little exocuticle with the result that most of the cuticle is digested and absorbed.
- Some insects like Collembola eat their exuviae which is another method of conservation of cuticular material.

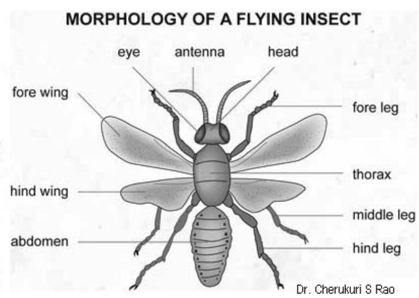
Lecture No: 5

Body segmentation in insects: Head-procephelon & gnathocephelon, types of head, sclerites, sutures of insect head; Thorax-segemnts & appendages (wings, legs); Abdomen-segments & appendages (furcula, cornicles, tracheal gills, pseudo-ovipositor in diptera, propodeum, petiole and gaster in hymenoptera); Epimorphic & Anamorphic development in insects.

Body Segmentation in Insects

- Insect is a small invertebrate animal with hard exoskeleton protecting soft interiors, and the body is segmented in to head, thorax and abdomen, each of which is inturn composed of several small segments, three pairs of jointed legs, and, usually, two pairs of wings; they belong to Artropods and are distributed throughout the world.
- An insect's body is divided into three segments: head, thorax, and abdomen. On the head is a pair of feelers, or antennae (for smell). The legs (for walking or running) and wings (for flying) are attached to the thorax, or middle segment of the body. The abdomen, or end segment of the body, is where food is digested and excreted and where the reproductive organs are located.
- Each segment in Insecta is referred as *somite or metamere*.
- In all adult arthropoda *some of the segments are more or less united in to groups forming distinct trunk sections or tagmata*. This type of grouping of segments in to body regions is called *tagmosis* and each region is called *tagmata*.

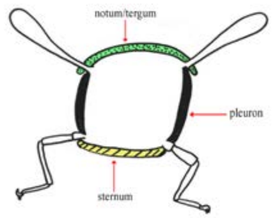




- The skeleton of an insect is external and is composed of *chitin*. It is membranous at the joints, but elsewhere is hard.
- *The head is the feeding and sensory centre. Head consists of SIX fused segments.* It bears the antennae, eyes, and mouthparts. By means of the antennae, the insect detects odours and experiences the sense of touch. The eyes include compound eyes and simple eyes (ocelli). Compound eyes are formed of a large number of individual facets or lenses (ommatidia); there are about 4,000 lenses to each compound eye in the housefly. The mouthparts include a labrum, or upper lip; a pair of principal jaws, or mandibles; a pair of accessory jaws, or maxillae; and a labium, or lower lip. These mouthparts are modified in the various insect groups, depending on their diet.
- The *thorax is the locomotory centre, and is made up of three segments*: *the pro-, meso, and metathorax*. Each bears a pair of legs, and, in flying insects, the second and third of these segments also each bear a pair of wings. The wings are composed of an upper and a lower membrane, and between these two layers they are strengthened by a framework of chitinous tubes known as veins.
- The *abdomen is the metabolic and reproductive centre*, where digestion, excretion, and the sexual functions take place. *Generally, abdomen consists of 11 segments*. In the female, there is very commonly an egg-laying instrument, or *ovipositor*, and many

insects have a pair of *tail feelers, or cerci*. Most insects breathe by means of fine airtubes called tracheae, which open to the exterior by a pair of breathing pores, or spiracles. Reproduction is by diverse means. In most insects, mating occurs once only, and death soon follows.

- Each body segment is formed into a ring like structure by the fusion of *dorsal tergum, ventral sternum and lateral pleuron*. (*Picture below is Transverse section of Insect Thorax*).



Head Appendages	:	Mouth Parts (feeding), Antenna (olfactory), Ocelli and Compound Eyes (vision)
Thoracic Appendages	:	Legs (locomotory) and Wings (flying)
Abdomenal Appendages	:	Ovipositor, cerci (furca), tympanal (auditory) organs, cornicles etc.

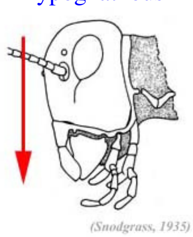
HEAD

- The head is almost a completely sclerotized capsule formed due to fusion of six segments.
- It is composed of mainly rigid sclerites or sclerotized segments.
  The insect head is a capsule that contains *a pair of compound eyes, a pair of simple eyes (ocelli), mouth parts* and *a pair of antennae.* Insects exhibit different types of antennae, some exhibiting a sexual dimorphism with regard to the type of antennae.
- The different appendages attach to the head capsule are, Antenna, Mandible, Maxillae and Labium.
- *Procephelon:* The part of an insect's head that lies anteriorly to the segment in which the mandibles are located.
- *Gnathocephelon:* The part of the insect head lying behind the protocephalon; bears the maxillae and mandibles.

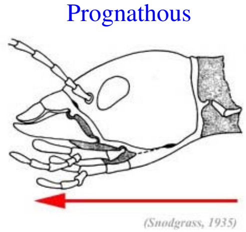
Orientation of Head: The orientation of head with respect to the rest of the body varies. Insects have three basic types of head viz.,

- *hypognathous* (the mouthparts are directed downward, with the mouth parts in a continous series with the legs, is a primitive type. This orientation mostly occurs in vegetarian speciaes living in open habitats.
- *prognathous* (the mouthparts are directed forward and this is found in carnivores species which actively pursue their prey, and in larvae, particularly of coleopteran, which use their mandible for burrowing)
- *ophisthorhynchous* (the elongated proboscis slopes backwards between the front legs, e.g. Hemiptera and Homoptera)

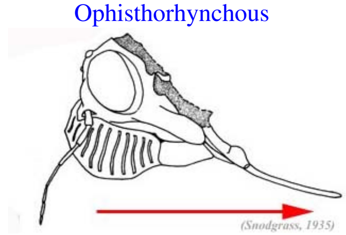
Hypognathous



Prognathous

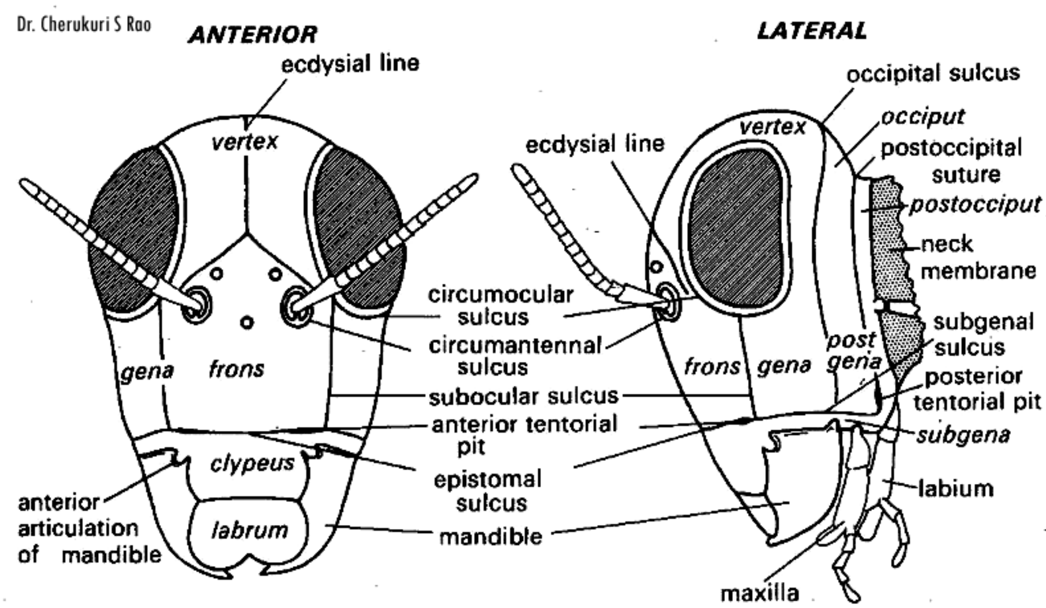


Ophisthorhynchous



Segments of Head Capsule: The head is almost a completely sclerotized capsule formed due to fusion of six segments. It is composed of mainly rigid sclerites (hardened body parts) or sclerotized segments.

1st segment	:	pre antennary	bears compound eyes and no other appendages
2nd segment	:	antennary	a pair of antennae is present.
3rd segment	:	Intercalary	segment inserts in between without any appendages.
4th segment	:	Mandibular	a pair of mandibles is present.
5th segment	:	Maxillary	a pair of maxillae is present (with 1st maxilla).
6th segment	:	Labial	a pair of second maxillae or labium is present.



Sclerites of Insect Head Capsule:

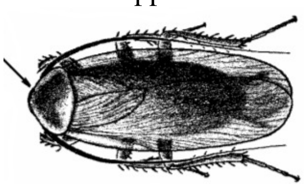
1. ***Vertex*** (Epicranium)-the top or *dorsal side of the head* is known as vertex. It is situated in *between the eyes* at the back of frons. *Ocelli and antennae* are present on vertex.
2. ***Frons***-It is present on the anterior face which lies between or below the epicranial arms. The *median ocellus is located on it*. It is bounded by the frontoclypeal suture ventrally.
3. ***Clypeus***-It is a tip like structure located between frontoclypeal suture and labrum. It is attached with the frons. The labrum hangs below it or articulate be means of membranous connection between them.
4. ***Labrum***-It is lower lip
5. ***Gena*** (lateral sides)-It is the lower part of the head beneath the eyes and lies posterior to the frons. A general suture is present between frons and gena. The area directly posterior to the eyes is termed the post gena.
6. ***Post gena***-sclerites below the genae and above the mandibles.
7. ***Occiput***-It is the area comprising most of the back of the head. The occipital suture divides it from the vertex and genae.
8. ***Post-occiput***-It forms the margin of the occipital foramen and narrow ring like in shape. The post-occipital suture divides it from occiput.

- Occipital foramen connects the back of the head with the body.
- These Sclerites (segments) are clearly separated by different lines or grooves called *sutures or sulci*.
- The areas of the head enclosed between sutures are called sclerites.
- *There are seven sutures in the head capsule.*

1. ***Epicranial suture*** (Ecdysial suture): It is an *inverted 'Y' shaped suture separating vertex and frons*. The stem is coronal suture and the arms are frontal sutures. Frontal sutures come in few of grasshoppers.
2. ***Fronto-clypeal suture*** (Epistomal suture): A line between frons and clypeus.
3. ***Clypeo-labral suture****:* A line between clypeus and labrum.
4. ***Genal suture***: Lies on either side of the head below the compound eyes separating facial part from gena.
5. ***Sub-genal suture***: A line below the gena on either side of the head.
6. ***Occipital suture*****:** A line between occiput and post occiput.
7. ***Post-occipital suture***: of these, post-occipital suture is the *only real suture*, separating maxillary and labial segments, as other sutures, do not represent real sutu

THORAX:

- An insect thorax is divided into three parts: the *prothorax (pro=first), mesothorax (meso=middle), and metathorax (Meta=last).*
- Each segment consists of hardened plates, or sclerites. *Dorsal sclerites are called nota* (singular notum), *lateral sclerites are called pleura* (singular pleuron), and *ventral sclerites are called sterna* (singular sternum).
- The terga of thoracic segments are called *notum*.
- The dorsal sclerites of pro-, meso- and meta-thoracic segments are called as *pronotum, mesonotum and metanotum.*
- Each thoracic segment contains one pair of legs.
- Wings are found only on the meso- and metathoracic segments, and are together called as *pterothorax*. Prothorax never bears wings and varies in size.
- The *pronotum is the dorsal sclerite of the prothorax* and the pronotum of grasshopper; cockroaches, beetles and bugs are enlarged.
- *Cockroaches* have *pronotums that extend forward over the head.*
- Scarab beetles and other beetles may also have unusual pronotums.
- Treehoppers have some of the most bizarre pronotums of all insects.

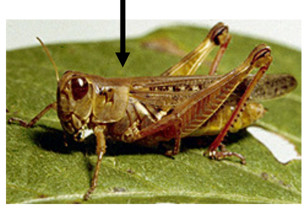

Cockroach


Hercules Beetle


Bocydium Spp.


Oaktree Hopper

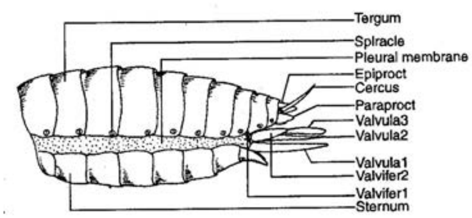
- In grasshopper the pronotum, is *saddle shaped* and consists of four sub-divisions or sclerites, namely, *prescutum, scutum, scutellum* and *post scutellum*.



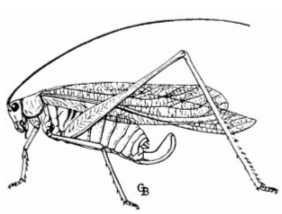
- In winged insects the meso and Meta thoracic segments which bears wings known as *pterothorax*.
- Meso and Meta Pleuron is divided in to anterior *episternum* and posterior *epimeron* by pleural suture.
- Two pairs of spiracles are present between pro and meso, and meso and meta thoracic segments.

ABDOMEN:

- In typical insect, abdomen consists of *eleven segments*.
- The abdomen contains the reproductive organs and the majority of the organ systems.
- The dorsal and ventral abdominal segments are termed terga (singular tergum) and sterna (singular sternum), respectively.
- Spiracles usually can be found in the conjunctive tissue between the terga and sterna of abdominal segments 1-8.
- In Hymenoptera (wasps, bees, ants), the *first abdominal segment* is transferred to thorax and closely attached/fused to metathorax to form mesosoma, hence the thorax looks like four segmented. The 1st abdominal segment thus transferred is referred as *propodaeum*. The 2nd abdominal segment is long called *petiole or pedicel*, where as the other abodmenal segments are enlarged, collectively called *gastor*.
- Reproductive structures are located on the *9th segment in males* (including the aedeagus, or penis, and often a pair of claspers) and on the *8th and 9th abdominal segments in females* (female external genitalia copulatory openings and ovipositor).



- *The ovipositor* is the egg-laying device found only in female insects. In some insects, the ovipositor is highly modified and conspicuous. In others, the apparatus may be needle or blade-like. *Parasitic wasps* (order Hymenoptera) use their ovipositors to insert eggs or small larvae into or onto a host. The stingers of bees and many wasps are modified ovipositors that have lost the egg-laying ability. *Crickets and katydids* (order Orthoptera) have needle-like and blade-like ovipositors, respectively.



Blade-like ovipositor on katydid (order Orthoptera)

Needle-like ovipositor on parasitic ichneumonid Order, wasp (order Hymenoptera)

Needle-like ovipositor Orthoptera: Field cricket, female, *Gryllus pennsylvanicus*

- In *Collembola*, *abdomen is six segmented*.
- Abdominal segments are divided in to three categories.

01-07 segments	pre genital segments
08-09 segments	genital segments
10-11 segments	post genital segments

Abdominal appendages: Either filaments or cerci.

- Abdominal filaments are thread-like processes located at the end of the abdomen.
- Pre-genital appendages are present in Apterygota and absent in all other insects.
- Abdomen bears *8 pairs of spiracles* from 1st to 8th segments on the margin of the tergite.
- *Cerci* are shorter, usually scleritized appendages of the *last segment of the abdomen*. *Anal cerci are the post-genital appendages attach to 11th segment*.
- In *dermoptera (Earwigs) the cerci are transformed in to forceps-like structures (Furca).*
- In Ephemeroptera (May flies) the immature stages possess *tracheal gills* on abdomen.
- Caterpillars of Lepidoptera and saw flies possess *abdominal prolegs*.
- In *Diptera* (house flies) *the terminal segments of the abdomen are telescoped in to one another and segments come out at the time of oviposition, thus act as ovipositor. Hence it is called pseudo-ovipositor.*
- In Homoptera (aphids) a pair of tubes called "*cornicles*" on the *5th and 6th* abdominal terga.

Epimorphic development: The young one after hatching from the egg consists of definite number of segments and the same number is maintained throughout. Such type of development is called Epimorphic development. Eg. Majority of insects.

Anamorphic development: The young ones hatches with only 8 segments and the rest of the segments are added during post embryonic development, such type of development is called anamorphic development. Eg. Protura.

Notes:

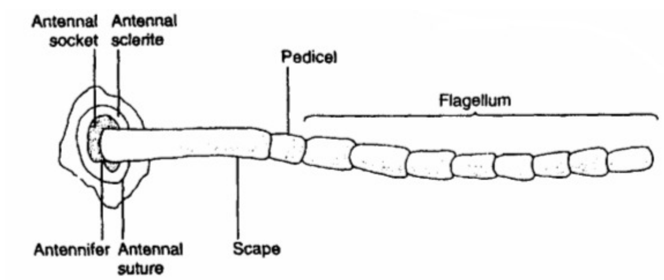
Lecture No: 6

Antenna (Olfactory Organs)-structure of typical antenna & its modifications in different insects with examples.

Antennae of Insects: Olfactory organs

- Antennae are *mobile sensory segmented appendages* of the head.
- They articulate with head in front or between the eyes.
- Antennae arise from antennal socket.
- They are the first pair of appendages of head.
- In certain larvae and in adults they arise from the base of mandibles.
- The size and shape of antennae varies in different insects.
- They are usually *larger in males* (sexual dimorphism) & the character can be used for identification of sex of some insects.
- They are well developed in almost all adults and nymphs.
- Antennae are *absent in Protura* and reduced in endopterygota larva.
- Antennal characters are used for taxonomic purposes.
- Antennae function almost exclusively in *sensory perception*.
- Some of the information that can be detected by insect antennae includes: motion and orientation, odor, sound, humidity, and a variety of chemical cues.
- In some insects, they may be useful for respiration, for holding the food or make and for communication.
- Sensilla on antenna acts as *tactile, olfaction, carbon dioxide, temperature, wind, humidity, and sound receptors.*

Structure of Antenna: Antennae consist of three parts: a) scape, b) pedicel and c) flagellum. Segments 1 and 2 are termed the scape and pedicel, respectively. The remaining antennal segments (flagellomeres) are jointly called the flagellum.

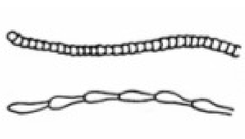
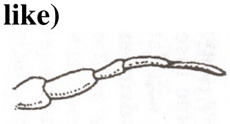
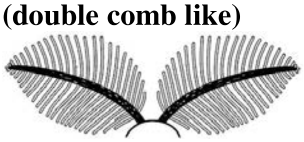


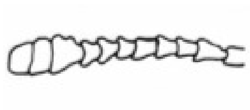
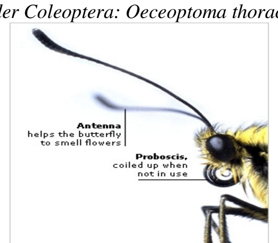
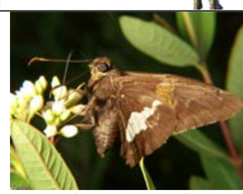
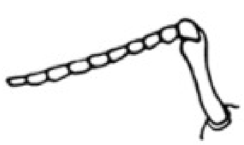
A).Scape:It is first basal segment of antenna by which the antennae is attached to the head. It is *often distinctly larger than the other succeeding joints*. It articulates with the antennal ridge.

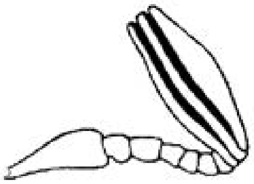
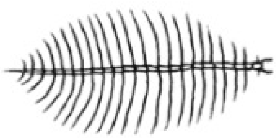
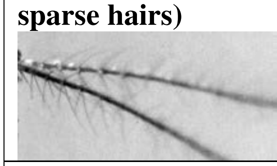
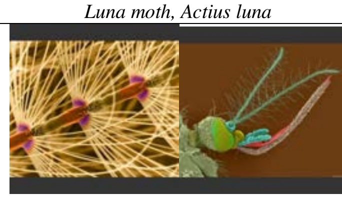
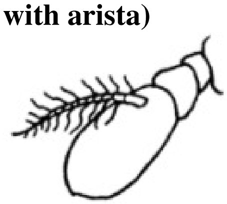
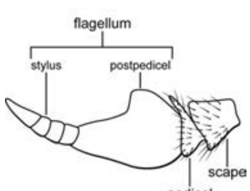
B).Pedicel:The joint immediately followed the scape is pedicel. It is usually small and *contains a special sensory structure known as Johnston's organ*, which is absent in Diplura, Collembola.

C).Flagellum: It is also known as clavola, and is the remaining part of the antenna. Flagellum segments (flagellomeres) increase in number in certain insects. It is modified according to the surroundings and habits of the insects. Flagellum is subdivided into ring segments, funicle and club.

Types of antennae: Antennae are of many shapes and sizes. Various types can be noticed in insects.

Type of antenna	***Examples***	***Modifications***
Filiform (Thread like) 	 *Asian Long Horned Beetle*  *Grasshopper*	Segments are more or less uniform throughout, from base to apex and never ends with bristle. *Filiform* antennae have a thread-like shape. *Examples: Grasshopper, Ground and longhorned beetles (order Coleoptera.*
Setaceous (Whip like or bristle like) 	 *American Cockroach*  *Dragon fly*	Segments gradually decreases from base to apex presenting a whip or bristle like structure. *Examples: Cockroach, Dragonflies and damselflies (order Odonata).*
Moniliform (like string of beads) 	 *Termites (Isoptera)*	Segments are round or oval with well developed constrictions between segments, appearing like a string of beads. *Example: Termites*
Pectinate (comb like) 	 Fire fly (Coleoptera)	Segments possess lateral processes on the side giving double comb like appearance. *Example: Female arctiid moth, Fire-colored beetles and fireflies (order Coleoptera).*
Bipectinate (double comb like) 	 *Mulbery Silk Moth*	Segments bear lateral processes on either side, giving double comb like appearance. *Example: Male Lymantriidd moth, Mulberry silk moth*

Type of antenna	*Examples*	*Modifications*
Serrate (saw like) 	 *Clik Beetle (Coleoptera)*	Segments of flagellum are triangular with projecting points on one side giving saw like appearance. *Example: Pulse beetle, Jewel beetle (Coleoptera)*
Clavate (clubbed): 	 *Order Coleoptera: Oeceoptoma thoracica*  	Segments gradually increase in diameter from base to tip ending in a club like apical part. *Clavate* antennae are gradually clubbed at the end. *Examples: Carrion beetles (order Coleoptera). Adult carrion beetles feed on decaying animal matter or maggots, Butterflies.*
Clavate with hook (clubbed antennae with hook)	 *Skipper Butterfly*	Segments gradually increase in diameter from base to tip and the last one ends with a small hook like structure. *Examples: Skipper butterflies.*
Capitate (clubbed with knob) 	 *Speckled wood butterfly*  *Red-banded hairstreak*	Segments gradually increase in diameter from base to apex and the terminal 3 to 5 segments suddenly enlarge to form a knob like structure. *Capitate* antennae are abruptly clubbed at the end. *Examples: Red flour beetle, Blister beetles. Butterflies (order Lepidoptera).*
Geniculate (elbowed) 	 *Order Hymenoptera: Carpenter ant*	The first segment (scape) is greatly elongated and flagellum always makes an angle with it. *Example: Ants, honey bees (order Hymenoptera).*

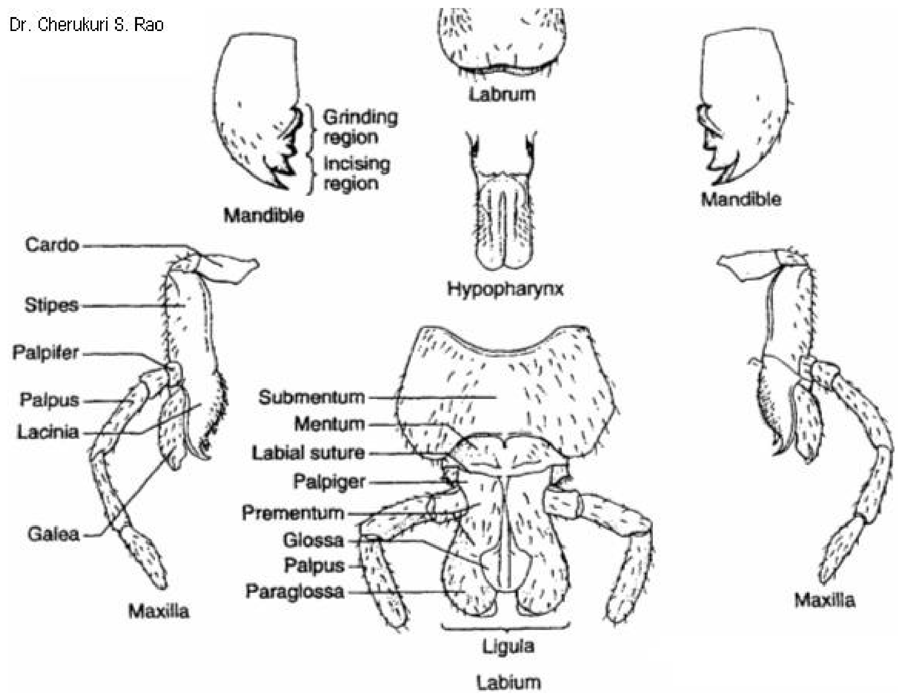
Type of antenna	*Examples*	*Modifications*
Lamellate 	 *Order Coleoptera: Japanese beetle*  *Order Coleoptera: Conifer scarab*	The terminal segments expand to one side into lateral oval lobes and appear as leaf like. *Lamellate* or clubbed antennae end in nested plates. *Examples: Rhinoceros beetle, Dung rollers, Chaffer beetle (order Coleoptera).*
Flabellate (Plate like) 		The terminal segments expand on one side into lateral lobes. The sides of the lobes are parallel. *Examples: Stylopids.*
Plumose (brush like with dense hairs) 	 *Mosquito male, Culex*  *Luna moth, Actius luna*	Whorls of hairs arise from each joint of the segment. Each whorl contains a number of hairs. *Plumose* antennae have a feather-like shape. *Examples: Moths (order Lepidoptera) and mosquitoes (order Diptera).*
Pilose (brush like with sparse hairs) 		Looks like plumose but each whorl contains less number hairs. *Examples: Female mosquito.*
Aristate (antennae with arista) 	 *House fly, Musca domestica*	Antennae are small, microscopic, three segmented. Third segment enlarged and bears a bristle called arista on its dorsal side. *Examples: House and shore flies (order Diptera).*
Stylate (antennae with style) 	 *Robber fly*	Antennae small 3 to 4 segmented. Terminal segment elongate in to bristle like structure called style. *Example: Robberfly.*

Functions of Antennae:

- The antenna functions primarily as *sense organs* and they bear very large number of sensilla. Usually there are several types of sensillum on antenna, usually most of these found in the middle of flagellum.
- The various types of sensilla function as *tactile and ordour receptors, contact chemoreceptors, Hygroreceptors and temperature receptors*.
- Olfactory receptors (odour receptors) on antenna useful for to bind to odour molecules, particlularly in males very useful for pheromones.
- The antenna as a whole involved in *perception of sound by male mosquitoes* and some other insects, and with the measurement of air speed. In these cases, movements of flagellum are monitored by *Johnston's organ, in the pedicel* of insects.
- In fleas and collembolan, the antennae are used in mating. Male fleas use the antenna to clasp the female.

Mouth parts: Feeding organs

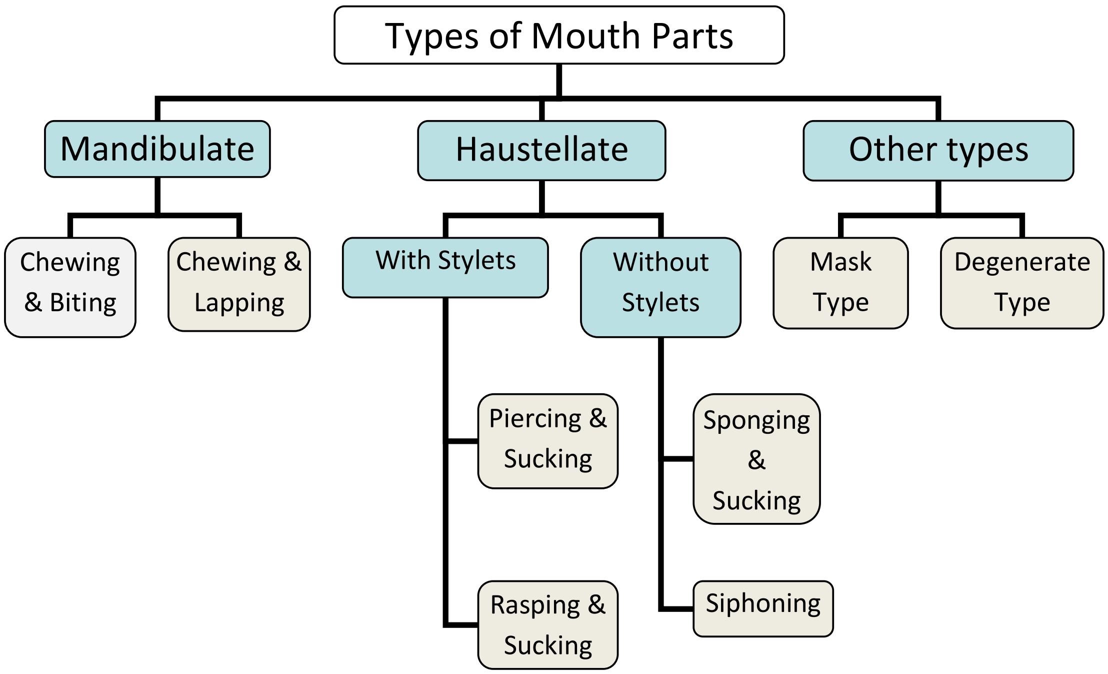
- These are organs concerned with feeding.
- The 5 main parts of typical insect mouth are
    1. Upper Lip or *labrum*
    2. Anterior Jaws or *mandibles*
    3. Accessory Jaws or *maxillae (plural maxilla) and*
    4. Lowe Lip or *labium.*
    5. Tongue like structure or *Hypopharynx*



- *The labrum* is a simple fused sclerite, often called the *upper lip*, and moves longitudinally. It is hinged to the clypeus.
- *The mandibles*, or anterior jaws, are highly sclerotized paired structures that move at right angles to the body. They are used for biting, chewing and severing/cutting food.
- *The maxillae* or accessory jaws are paired structures that can move at right angles to the body and possess segmented palps. They are used for holding and sending food into mouth.
- *The labium* (often called the *lower lip*), is a fused structure that moves longitudinally and possesses a pair of segmented palps.

Mouthparts vary greatly among insects of different orders, but basically the mouth parts may be divided into two groups:

- Chewing and Biting type (considered as primitive) (*mandibulate)*
- Sucking type (*haustellate)*



Chewing and Biting Type	Grasshoppers, Cockroaches
Chewing and Lapping Type	Honey Bee
Piercing and Sucking Type	Aphids, Bugs, Mosquitoes, Lice
Rasping and Sucking Type or Lacerating and Sucking Type	Thrips
Sponging or Lapping and Sucking Type	House fly
Siphoning Type	Butter Flies, Moths
Mask Type	Young ones (Naiads) of Dragon Fly
Degenerate Type	Maggots

CHEWING & BITING TYPE:

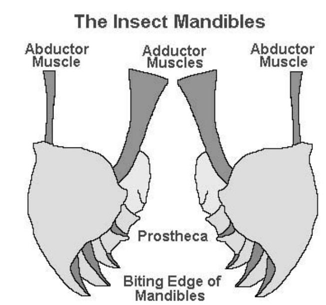
- The generalized biting type of mouth parts are as follows and are present in nymphs and adults of grasshoppers, cockroaches, termites and beetles.
- Examples: Dragonflies and damselflies (order Odonata), termites (order Isoptera), adult lacewings (order Neuroptera), beetles (order Coleoptera), ants (order Hymenoptera), cockroaches (order Blattaria), grasshoppers, crickets and katydids (order Orthoptera), and caterpillars (order Lepidoptera).

Labrum:

- Is a simple plate like structure situated below the clypeus, anterior side of the head.
- It overlaps the bases of mandibles.
- Its inner surface is usually provided with chemoreceptors and is produced into small lobe-like *epipharynx in Hymenoptera*.

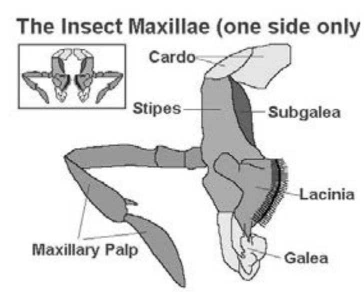
Mandibles:

- Paired heavily sclerotized, un-segmented jaws lying immediately behind the labrum.
- They articulate with the head capsule by means of two joints *ginglymus* and *condyle*. The ginglymus is a groove or cavity which articulates with a convex process on the clypeus and the condyle is a rounded head adopted to fit into the socket placed at the lower end of the gena or postgena.
- Mandibles possess two types of teeth: *Incisors and molars*. Incisors are useful for cutting and molars are useful for grinding.
- The mandibles are adopted for cutting or crushing the food.
- The mandibles are frequently used for defence also.



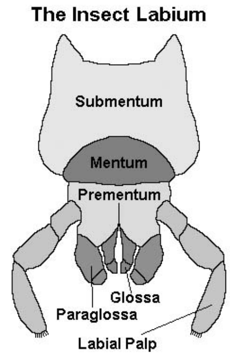
Maxillae:

- The paired structures lying behind the mandibles.
- They are segmented and each maxilla bears a feeler like organ, the palpus which are *useful to know the quality and taste of food*.
- The basal segment of the maxilla is the *cardo* and the second segment in the *stipes*. The palpus is borne on the lobe of stipes is called the palpifer (*maxillary palpi*).
- The stipes bears at its apex *two lobe like structures* the *lacinia*, an elongate jaw like structure and the *galea*, a lobe like structure.
- *Lacinia* is spined or toothed on its inner border. In some insects the *stipes bears a single lobe called male*. Functionally the maxillae are a pair of accessory jaws, their *lacinia aiding the mandibles in holding the food* when the later are extended as well as *assisting in mastication*.



Labium:

- Lower lip lies behind the maxillae.
- It is divided by a transverse suture (labial suture) into two portions a basal *post-mentum* and a distal *pre-mentum*.
- Post mentum usually divides into basal *sub-mentum* and distal *mentum*.
- The prementum bears a pair of palpi and a group of apical lobes which constitute the ligula. The *labial palpi* are borne on lateral lobes of the prementum, called palpiger.
- The ligula consists of a pair of small lobes in the middle, the *glossae* and one pair of larger lobes laterally, the *paraglossae*.
- Labial palpi functions as *sense organs*.



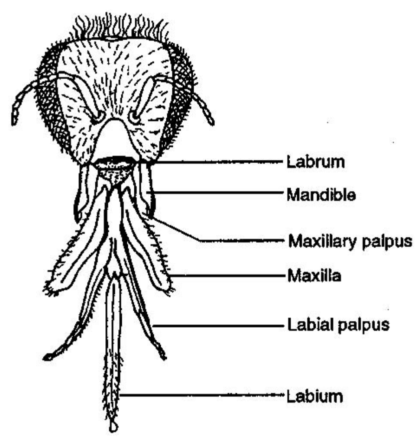
Hypopharynx:

- It is a short tongue like structure located above the labium and between the maxillae.
- In most insects the ducts from the salivary glands open on or near the hypopharynx.

CHEWING & LAPPING TYPE:

Example: Honey bees

- Mouth parts are modified *for collecting the nectar and the pollen*.
- Mouth parts consist of labrum, mandibles, maxillae, labium and epiphanyx.
- Below the labrum is fleshly epipharynx which is an organ of taste.
- Mandibles are smooth and are situated on either side of the labrum.
- *Mandibles are used in moulding wax and making the honey comb*.
- The labium has sub–mentum, mentum, paraglossa and glossa or tongue, with a long labial palp on each side. The glossa is long and at its tips is a small "*Flabellum or labellum*". The *glossa is used for gathering honey*. It is an organ of taste and smell.
- The maxillae and labial palps form a tube enclosing the glossa which moves ups and down to collect nectar.
- Labrum and mandiables are of biting type whereas maxillae, labium and hypopharynx combine together to form a sucking proboscis.

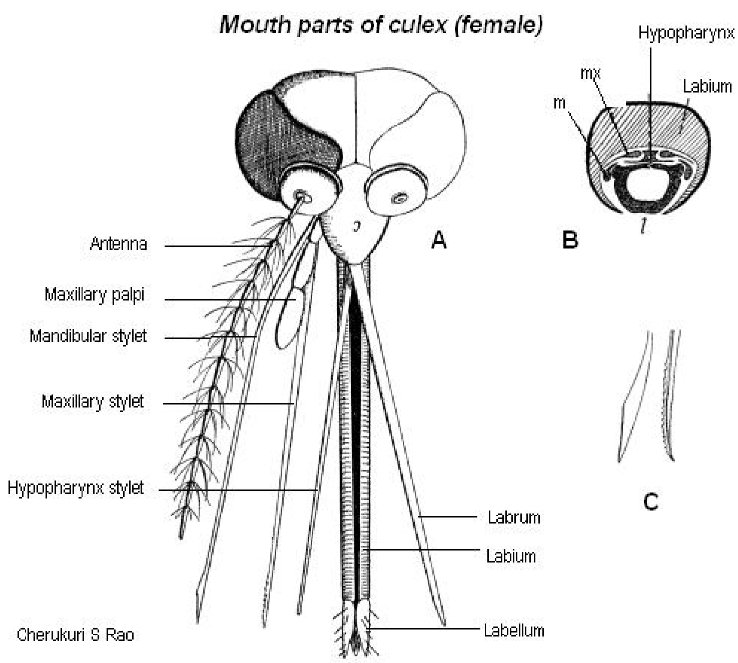


HAUSTELLATE TYPE:

- *Haustellate* mouthparts are *primarily used for sucking liquids* and can be broken down into two subgroups: those that possess stylets and those that does not.
- *Stylets* are needle-like projections used to penetrate plant and animal tissue.
- The modified mandibles, maxilla, and hypopharynx form the stylets and the feeding tube.
- After piercing solid tissue, insects use the modified mouthparts to suck liquids from the host.
- Some haustellate mouthparts lack stylets. Unable to pierce tissues, these insects must rely on easily accessible food sources such as nectar at the base of a flower. One example of non-stylate mouthparts are the long siphoning proboscis of butterflies and moths (Lepidoptera).
- Although the method of liquid transport differs from that of the Lepidopteran proboscis, the rasping-sucking rostrum of some flies is also considered to be haustellate without stylets.

PIERCING & SUCKING TYPE:

Example: Cicadas, aphids, and other plant bugs (order Hemiptera), sucking lice (order Phthiraptera-Anoplura), stable flies and mosquitoes (order Diptera).



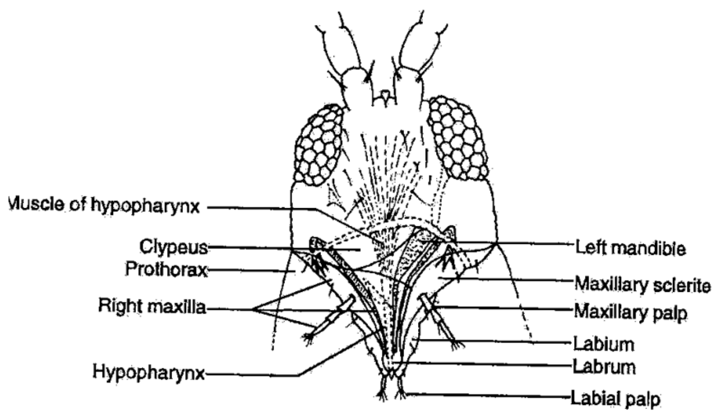
- *The mandible and maxillae are modified to form slender bristle like stylets which rest in the grooved labium*.
- Both pairs of stylets are hallowing sets–like structures capable of limited protrusion and retraction by means of muscular action.
- The *mandibular stylets* form the anterior or outer pair. They are *usually serrated with axe type edge, useful for piercing the skin*.
- The posterior or inner pair of stylets constitutes the maxillae. Maxillary palps absent. Each *maxillary stylets tapers to a fine point* and is grooved along its inner aspect the

groove is divided in to two parallel channels by means of a longitudinal ridge which traverses the length of stylet.

- *When both the maxillary stylets come close together, they enclose two extremely fine tubes. 'Saliva' may be pumped down one of the tubes. This saliva makes the food into a liquid. The liquified food is sucked up the other tube*.
- The stylets themselves are enclosed in a *sheath formed almost entirely by the labium* which is dorsally grooved for their reception. At its base however the labial groove is wanting and in this region the sheath is roofed over the labrum. Usually labium is four segmented. Labial palps are wanting.
- *Labrum forms the cover* over the grooved labium.
- The hypopharynx is highly specialized and reduced either to form the floor of the cibarial sucking pump or to form mandibular plates.
- The stylets are pierced inside the plant tissues and generally they *suck plant sap from phloem vessels*.

RASPING & SUCKING / LACERATING & SUCKING TYPE:

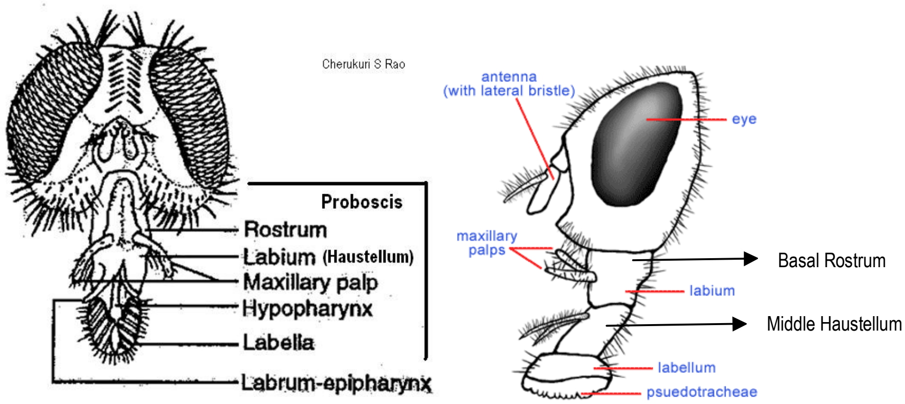
Example: Thrips



- The labrum, labium, bases of maxillae are modified to a form a small tubular cone called *mouth cone*.
- *The maxillae are modified into stylets*.
- *The right mandible is absent and the left mandible is modified as stylet*.
- All these three stylets are repeatedly inserted into the plant tissues and the oozing out cell sap is sucked by applying mouth cone.
- Hypopharynx is reduced and small.

SPONGING / LAPPING & SUCKING TYPE

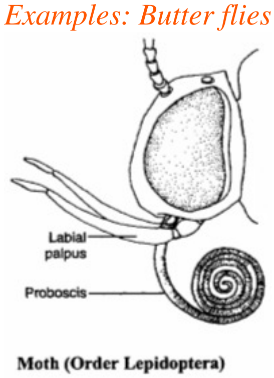
- Sponging mouthparts are used to sponge and suck liquids.
- The mouth parts are of sponging and sucking the liquid food material.
- *Examples: House flies and blow flies (order Diptera).*
- The mouth parts comprise *a fleshy and retractile proboscis (modified labium)*, which lies under the head. The proboscis is formed of three parts
  1. Basal Rostrum-*modified labium*
  2. Middle Haustellum-*modified labium*
  3. Distal-a pair of labella

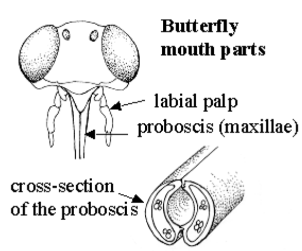


- *Rostrum* (*modified labium*) is cone shaped and has a clypeus in front. It bears a pair of *maxillary palps*. Inside the Rostrum is a chitinous Fulcrum which enclosed the pharynx.
- Hinged to the Fulcrum is *Haustellum* is formed by *highly modified labium* and it possesses two triangular plates *labrum epipharynx and hypopharynx*. The posterior part of haustellum bears chitinous mentum. The front side of Haustellum has a deep oral groove, enclosing a labrum–epipharynx, hypopharynx has a salivary duct. The labrum–epiphanyx is grooved. The groove is closed by the hypopharynx, to form food canal.
- *The mandibles and maxillae are absent*. The outer surface of labella has a series of channels called pseudotrachea, which open externally. Near the mouth are very small prestomal teeth which are used for rasping the solid food.
- During feeding the proboscis (modified labium) is lowered and salivary secretions are pumped onto the food. The dissolved or suspended food then moves by capillary action into the pseudotracheae (sponge) and is ingested. There may be sharp teeth on the pseudotracheae to rasp flesh and draw up blood. The labella are the fleshy distal end of the labium that functions as a sponge-like organ to sop up liquids.

SIPHONING TYPE

Examples: Butter flies and moths for simple sucking.

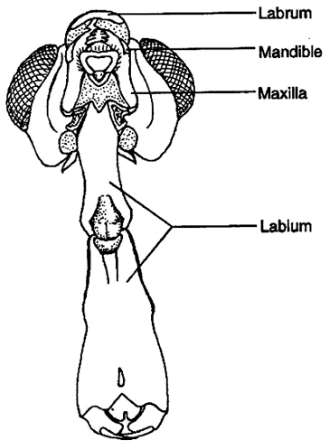




- In these Siphoning types of mouth parts, *mandibles are totally absent*.
- All mouth organs are highly reduced except the *galea of maxillae*.
- *Each galea is elongated into a hallow structure and semicircular.*
- When both galea come close together they enclose, a sucking proboscis. Thus both the galea together forms the sucking proboscis coiled and kept below the head during non-feeding.

MASK TYPE:

Examples: Young one (Naiad) of Dragonfly



- These moth parts are modified for biting and chewing type.
- *Labium is modified into a mask*. Prementum and postmentum and the suture between them form a hinge. Labial palps and help in catching the prey.
- When prey is sighted it is stretched with great rapidity. When at rest the mask is kept in a position the labium covers a portion of the head hence.

DEGENERATE TYPE:

Example: Maggots

- In maggots a definite head is always absent and the mouth parts are highly reduced and are represented by one or two mouth hooks.

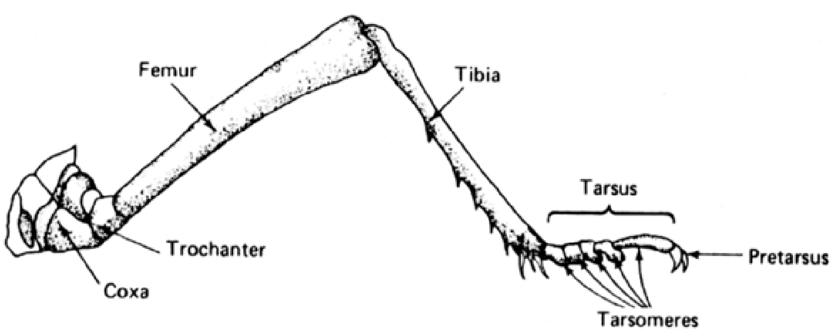
Lecture No: 8

Legs (locomotors Organs)-structure of a typical insect leg & modifications of insect legs with examples.

- Mobility at some stage of the life history is a characteristic of all animals.
- They must move inorder to find food, dispersal, mate etc.
- The success of insects as terrestrial animals is in part due to their high degree of mobility arising from the power of flight, but more local movements by walking or swimming etc also important.

INSECT LEGS

- The fore-legs are located on the prothorax, the mid-legs on the mesothorax, and the hind legs on the metathorax.
- Each leg has six major components, from proximal to distal: coxa (plural coxae), trochanter, femur (plural femora), tibia (plural tibiae), tarsus (plural tarsi), pretarsus.
- The tarsus appears to be divided into one to five "pseudosegments" called *tarsomeres*.
- Like the mouthparts and antennae, insect legs are highly modified for different functions, depending on the environment and lifestyle of an insect.
- In the leg of an insect, the cuticle may contain *unicellular hair–like outgrowth* known as *Setae*, which *represent sensory organs* of various types and may also take the form of pegs, hooks or scales.
- The femur and tibia may be modified with spines (multi-cellular outgrowths).
- *Multi-cellular outgrowths* are of two types. If they are *immovable* they are called *spines*, if they are *movable and articulated* they are referred as *spurs*.
- Definite impressed lines or internal ridges between sclerites are known as sutures. Flexible in folding of the body wall are called conjunctivae and definite joints as between segments of legs are called articulation.
- The flexible portion of the cuticle, connecting the hard ring like portions of any two segments is called conjuctive and articular membrane.

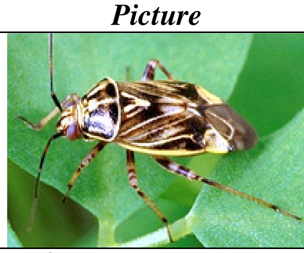
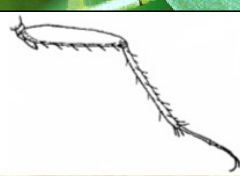
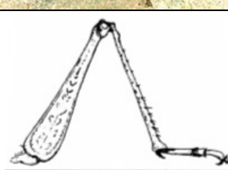


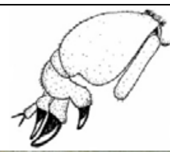
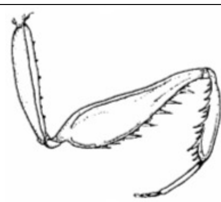
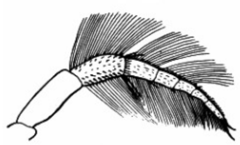
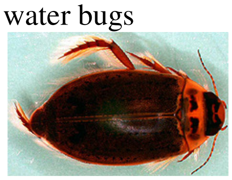
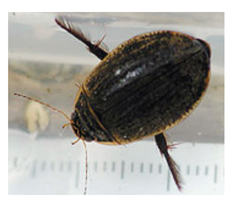
A typical leg of an insect consists of the following parts:

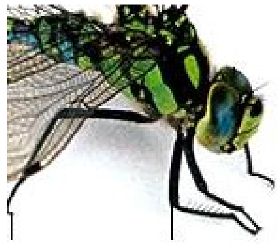
- ***Coxa*: **The basal thick short segment is coax. This is the functional base of the leg. It articulates with the body of the insect between pleura and sterna.
- ***Trochanter***: It is the second segment of the leg, triangular structure. It articulates with the coxa but rigidity fixed to the Femur. In *Odonata and parasitic Hymenoptera*, it is divided into sub segments (*trochanter two segmented*).

- ***Femur:*** It usually forms the *largest and strongest part* of the leg and especially conspicuous in most insect *which have power of leaping*.
- ***Tibia:*** This is the 4th segment of the leg and is almost always slender and *frequently equal or exceeds the femur in length*. Near its distal (Terminal) extremity it carries one or more tibial spurs.
- ***Tarsus:*** The last segment of the leg is Tarsus, usually divided into *five sub-segments* (*tarsomeres).* In some insects it bears 2, or 3 or 4 or one segment.
  Tarsus with single joint – Ex. Human louse
  Tarsus with two joints – Ex. Aphid
  Tarsus with three joints – Ex. Mole cricket, Gryllidae (grass hopper)
  Tarsus with four joints – Ex. Tettigonidae (grasshopper), Leaf beetle.
- At the apex of the tarsus, a group of small structures called *pre-tarsus* are present. Which are…
  a) In simplest form it is prolonged into a single claw- *Eg, Collembola, Protura*.
  b) In some insects claws are paired. In between the claws on the ventral side *pretarsus expand into a medium lobe or "Arolium". Eg. Housefly*.
  c) Among Diptera there are two lobes or **"***Pulvilli***"** lying below the claws often with an Arolium between them. *Eg. Housefly*.
  d) In place of arolium, pretarsus is sometimes prolonged into a medium bristle called "*Empodium***"**.

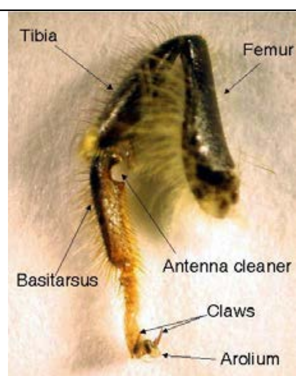
TYPES OF LEGS

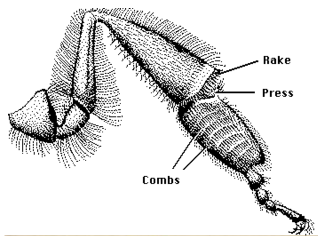
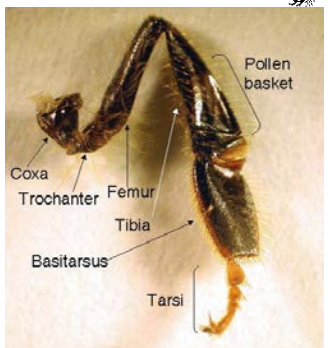
Type of legs	***Picture***	***Example***	***Modification***
Ambulatory or *Walking type (Ambulate-to walk)*		Bugs (order Hemiptera), leaf beetles beetles (Order Coleoptera).	*All the legs* are normal. Ambulatory legs are used for walking. The structure is similar to cursorial (running) legs
Cursorial type or *Running type (cursor-a runner)*	 	Cockroaches (order Blattaria), ground and tiger beetles (order Coleoptera), Wasp	*All the legs* are normal. Cursorial legs are modified for running. Note the long, thin leg segments.
Saltatorial type or *Jumping type (saltere-to jump)*	 	Hind legs of Grasshopper, crickets and katydids (order Orthoptera).	Saltatorial *hind legs* adapted for jumping. These legs are *characterized by an elongated femur and tibia*. Femur and tibia are elongated and are useful for leaping and jumping.

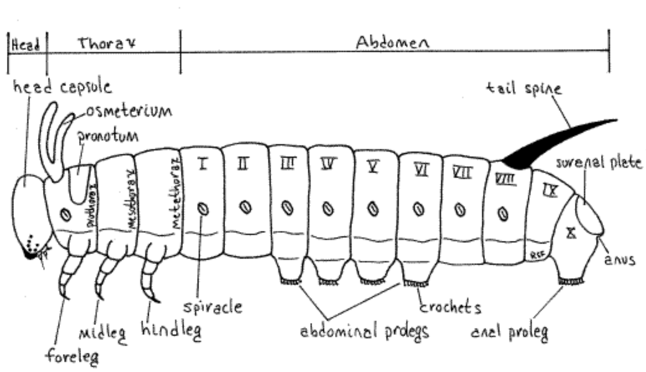
Type of legs	***Picture***	***Examples***	***Modification***
Fossorial type or *Digging type (fossore-to dig)*	 	Ground dwelling insects (Dung rollers), mole crickets (order Orthoptera) and cicada nymphs (order Hemiptera). Rhinoceros beetle.	*Front legs* are modified for digging. *The tibia and tarsus are modified and bear teeth like or rake like projections*. Useful for digging out tender roots of plants. Beneath the tarsus, presents a slit like oar.
Raptorial type or *Grasping type (raptore-to seize)*	 	Mantids (order Mantodea), ambush bugs, giant water bugs and water scorpions (order Hemiptera).	Raptorial *fore legs* modified for grasping (catching prey). Front legs are modified. *Coxa very long and femur spiny*, possesses a central longitudinal groove. *Tibia narrow and blade like*, spinose and fits into groove of the femur.
Natatorial type or *Swimming type (nature-to swim)*	 	Water beetles, water bugs  	Natorial legs are modified for swimming. These legs *have long setae on the tarsi*. *Hind legs are modified.* *Tibia and tarsus short and broad and are provided with dense long marginal hairs.* Coxa flattens out on the body wall. Tibia and tarsus are flat.
Scansorial type or *Clinging type (scansum-to climb)*		Head louse.	*All legs* are modified. *Tarsus without a joint, and with a single curved claw* only. Useful for catching the hairs or clinging hairs.

Prehensile or *Basket forming legs (prehensum- to seize)*		Dragon flies	In Dragon flies the *thoracic segments are obliquely arranged*. Tergal plates pushed backward, whereas sternal plates pulled forward. As a result all the legs which are attached to sternal plates came forwards and are seen below the head – *All the legs together form a basket like structure* useful for catching the prey.

Honey bee Leg Modifications

Antennal cleaning *First pair legs of honey bee*		Tibia possesses a process and the *1st tarsal segment of fore-legs possesses a semicircular notch*. Each thoracic leg has a row of stiff bristle on tibia forming an eye brush for cleaning the compound eyes. At the distal end of tibia there is a movable spine the yelum which can close over a notch on the tarsus, to form an antenna comb, through which the antenna is drawn for cleaning.
Wax picking type *Second pair of legs in Honey bees*		*Long bristles on the meso-thoracic leg tarsus form a pollen brush* for removing pollen from the front part of the body. Each mesothoracic leg has a pollen brush on the tarsus; the end of the tibia has a spur like spine for removing pollen from the pollen basket and wax from abdomen. Hence the *tibial spine is called wax pick*.

Pollen collecting type *Hind legs of Honey bees*	  	Each *meta-thoracic leg has a large tibia with a cavity with bristles forming a pollen basket* or corbicula used for storing pollen during collection, at the distal end the tibia has a row of stiff bristles call pectin below which is a flat plate, the auricle. The pectin and auricle form a wax pincher for removing wax from the abdomen of workers. The outer surface of the tarsus has a pollen brush and the lane surface has a pollen comb, having row of stiff spines. The pollen comb removes pollen from the body and fillsit in the pollen basket.

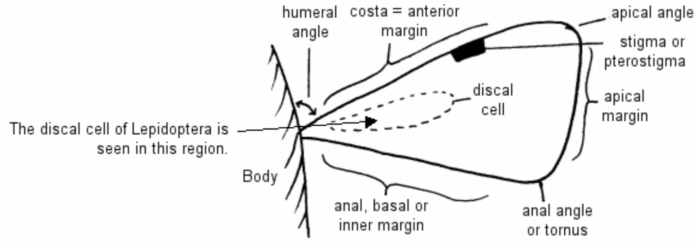


- Caterpillars' posses' *three pairs of thoracic legs (true-legs) and five pairs of abdominal legs (pro-legs) on 3rd, 4th, 5th, 6th, and last abdomenal segments. In some, semi-loopers larvae, prologs on 3rd and 4th abomenal segments absent, and hence while movement, it looks like semi-loop, in some, looppers, prologs present only on 6th and last abdomenal segments, and hence while movement, it looks like loop.*
- Thoracic legs are also called the true legs, which are *typically jointed and sclerotized*.
- Abdominal legs are called prolegs. These are *unjointed, short, fleshy* with a flat surface at the bottom called planta.
- A number of hooks like structures called crochets are seen arranged in circular or semi cuticular form on the surface of the plants.
- In *sawflies of Hymenoptera*, the larvae have 3 pairs of true legs in thorax, and *6 or >6 pairs of prologs in abdomen*. This is the unique feature of sawfly larva, but these prologs do not bear crochets, unlike lepidopteran larva.

INSECT WINGS (*Flight organs)*

- The success of the insects as terrestrial animals is atleast partly due to their ability to fly.
- Wings, their modifications and the characters of wings are the *primary tools for insect taxonomic studies*, and for the identification of insects.
- Typically, adult insects *have two pairs of wings* articulating with the thorax and consisting of flattended lobes of the integument supported by hallow veins.
- Most insects have two pairs of wings-one pair on the mesothorax and one pair on the metathorax (never on the prothorax). The wing-bearing thoracic segments (meso-& meta-thorax) together called as *pterothorax*.
- Silver fish and spring tails do not have wings (Apterygota)
- Some insects have only one pair of functional wings (Diptera)
- Termites and certain insects break off or tear off their wings after a single nuptial flight and before beginning their life in soil.
- Fleas, lice and certain aphids and ants have degenerate wings
- *Insects are the only invertebrates that can fly*.
- Their *wings develop as evaginations of the exoskeleton* during morphogenesis but they become fully functional only during the adult stage of an insect's life cycle.
- The wings may be membranous, parchment-like, heavily sclerotized, fringed with long hairs, or covered with scales.
- The base of the wing connects with the body by a membranous hinge and membranous hinge bears a group of small sclerites called *axillary sclerites*. Axillary sclerites articulate with the edge of the notum.
- Wings serve not only as organs of flight, but also may be adapted variously as *protective covers* (Coleoptera and Dermaptera), *thermal collectors* (Lepidoptera), *gyroscopic stabilizers* (Diptera), *sound producers* (Orthoptera), or *visual cues* for species recognition and sexual contact (Lepidoptera).
- Fully developed and functional wings occur only in adult insects, although the developing wings may be present in the larvae. In hemi-metabolous nymphs, they are visible as external pads (exo-pterygota), but they develop internally in holometabolous forms (endo-pterygota). The Epimeroptera are exceptional in having two fully winged nymphal instars.
- In most cases, a characteristic network of veins (wing venation) runs throughout the wing tissue.
- These *veins are extensions of the body's circulatory system*. They are filled with hemolymph and contain a tracheal tube and a nerve.
- In membranous wings, the veins provide strength and reinforcement during flight.
- *Wing venation is a commonly used taxonomic character, especially at the family and species level. Wing shape, texture, and venation are quite distinctive among the insect taxa and therefore highly useful as aides for identification*.
- Two orders of winged insects, the *Ephemeroptera and Odonata, have not evolved wing-flexing mechanism (folding wings over body during rest)*, and their axillary sclerites are arranged in a pattern different from that of the Neoptera; these two orders (together with a number of extinct orders) form the Paleoptera.

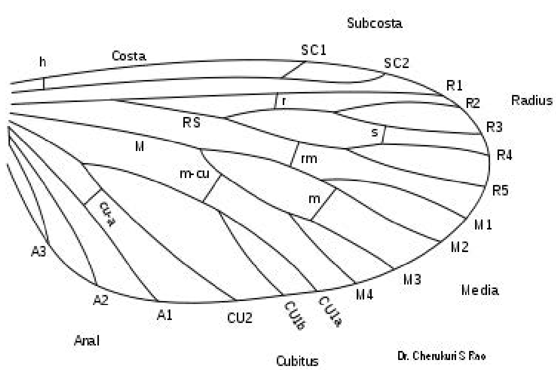
Insect Wing Structure:



- In outline the wings are often somewhat triangular shape.
- The front or anterior side of the triangle is known as *Remegium or costal margin*.
- The outer side is the *apical margin*
- The inner side is called *Anal margin*
- The three angles of the wings are *Humeral angle, Apical angle and Anal angle or Tornus*
- The areas of various shapes enclosed between the veins are called "*Cells*". Cells are of two types: *Open cells and closed cells*. If the area is entirely surrounded by veins–"closed cells" and if the area extends to the wing margin without intervening veins–"Open cell".
- Generally the veins are heavier or closely placed towards the costal margin, due to greatest stress during flight.
- Supporting fibres are of two types-Veins and Cross veins. The fibres which run from the base of the wing towards the apex are called "Veins" and those which run crosswise of the wing and connect veins are called cross veins.

Wing Venation:

- The pattern of veins and cross veins is termed "Venation".
- The *archedictyon* is the name given to a hypothetical scheme of wing venation proposed for the very first winged insect such as fossil insects. Since all winged insects are believed to have evolved from a common ancestor, the *archediction* represents the "template" that has been modified (and streamlined) by natural selection for 200 million years. According to current dogma, the archedictyon contained 6-8 longitudinal veins. These veins (and their branches) are named according to a system devised by *John Comstock and George Needham*-the Comstock-Needham System.
- The *Comstock-Needham system* is a naming system for Insect Wing Veins, devised by *John Comstock* and *George Needham* in *1898.* It was an important step in showing the *homology* of all *insect wings.* This system was based on Needham's *pretracheation theory* that was later discredited by *Frederic Charles Fraser* in 1938.



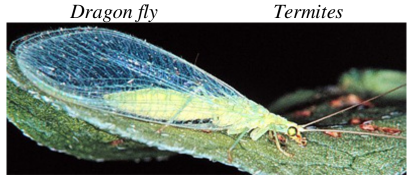
Longitunal Veins and Cross Veins
Insect wing venation, showing the names after the Comstock-Needham system

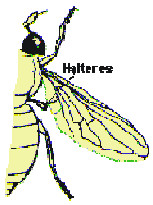
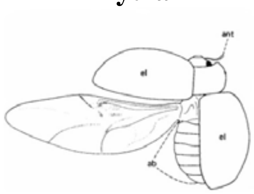
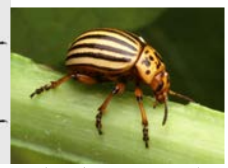
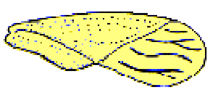
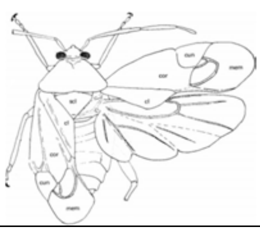
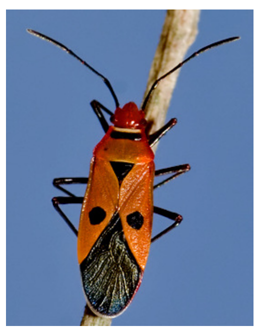
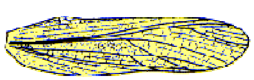
The Comstock and Needham system attributes different names to the veins on an insect's wing. From the anterior (leading) edge of the wing towards the posterior (rear), the major longitudinal veins are named (*Standard abbreviations are used to indicate different veins are*):

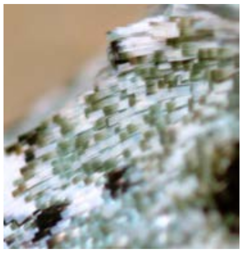
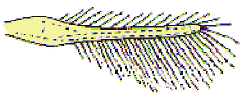
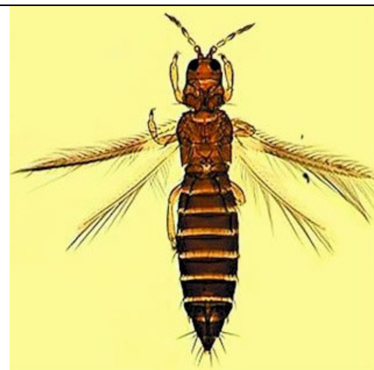
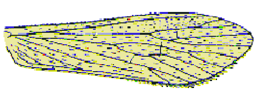
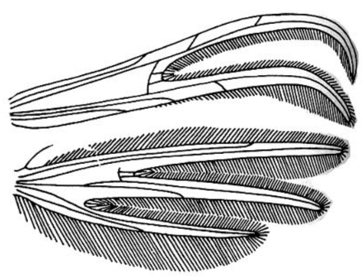
- Costa-“C” (*meaning Rib*) usually forms the thickened anterior margin of the wing-*it is always unbranched*.
- Sub Costa-“Sc” (*meaning below the Rib*) runs immediately below costa, always in the bottom of a trough between Costa and Radius. Sc is divided into two branches-SC_1 and SC_2.
- Radius-“R” (*analogy with abone in the forearm*) is the next main vein. It is a stout one and connects at the base with the second axillary sclerite. The radius typically branches once near the base, producing anteriorly the $\mathbf{R_1}$ and posteriorly the *radial sector* **Rs**. The radial sector may fork twice into four main branches-R_2, R_3, R_4, R_5.
- Media-“M” (*meaning Middle*) is one of the two veins, articulating with some of the small medium sclerites. Media is divided typically into four branches *viz.,* M_1.M_2,M_3,M_4. (*The Media (M) can be divided into MA (anterior media) and MP (posterior media) which again, divides, but infact these two can not be distinguished all the time, and hence M1, M2, M3 and M4 names are given).*
- Cubitus-“Cu” (*meaning Elbow*) also articulates with the median axillary sclerite. According to the Comstock-Needham system, the cubitus forks once, producing the Cu_1 and Cu_2. According to some other authorities, Cu_1 may fork again, producing the Cu_{1a} and $Cu_{1b.}$ (*the Cu 1a and Cu1b of Comstock-Neetham system can named as CuA (anterior cubitus) and CuP (posterior cubitus).*
- Anal Vein-“A” (*reference to its posterior location*) form a set, which are united or close together at the base and closely associated with the 3^{rd} axillary sclerites. As there are several anal veins, they are called $\mathbf{A_1}$, $\mathbf{A_2}$, and so on.

Cross Veins: Crossveins link the longitudinal veins, and are named accordingly (for example, the medio-cubital crossvein is termed **m-cu**). Some crossveins have their own name, like the humeral crossvein **h** and the sectoral crossvein **s.**

Wing Adaptations and Modifications:

Wing Type	***Photos***	***Modifications and Examples***
Membranous 	 *Damsel Fly (Odonata)*   *Dragon fly* *Termites*  *Green lacewing*	• Membranous wings are *thin & more or less transparent*, but some are darkened. • These wings are with *highly developed venation*. • They are *useful for flight*. *Examples: Hind wings of Grasshopper, Dragonfiles and damselflies (order Odonata), lacewings (order Neuroptera), flies (order Diptera), bees and wasps (order Hymenoptera), termites (order Isoptera)*

Halteres  	 *Crane fly*  *Bees*	• Halteres are an extreme modification among the order Diptera (true flies), in which the *hind wings are reduced to mere nubs*. • *Used for balance and direction during flight (gyroscopic stabilizers).* • It is divided into three regions-scabellum, pedicel and capitalum. *Examples: All flies (Diptera).*
Elytra 	 *Lady Bird Beetles*  *Colorado Potato Beetle*	• Elytra (singular elytron) are the *hardened, heavily sclerotized forewings of beetles* (horny sheet without venation). • *Modified to protect the hind wings when at rest.* • *Examples: All beetles (order Coleoptera).*
Hemi Elytra  	 *Red Cotton Bug*	• A variation of the elytra is the hemelytra. • The forewings of Hemipterans are said to be hemelytrous because they are *hardened throughout the proximal two-thirds, while the distal portion is membranous*. • Unlike elytra, hemelytra function primarily as *flight wings*. • *Examples: Bugs(Hemiptera)*
Tegmina 	 *Cockroach*  *Grasshopper*	• Tegmina (singular tegmen) are the *leathery forewings* of insects in the orders Orthoptera, Dictyoptera • Like the elytra on beetles the tegmina help *protect the delicate hind wings*, and also used for flight sometimes. • *Examples: Grasshoppers, crickets and katydids (Orthoptera), Cockroaches, Mantids (Dictyoptera).*

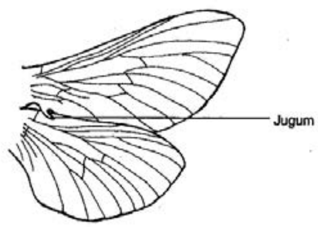
Scaly Wings 	 *Io Moth (Forest Moth)*  *Monarch Butter fly*	• Scaly wings-thin and *membranous front and hind wings covered over surface with flattened unicellular setae (scales)*. • The scales make the wings colorful and used for taxonomic studies. • They are *useful for flight*. • Examples: Butterflies, moths and skippers (order Lepidoptera), caddisflies (order Trichoptera).
Fringed Wings 	 *Thrips*	• Fringed wings-slender front and hind wings with long *fringes of marginal hairs*, giving a feather like appearance. • The wings are highly reduced with *reduced venation*. • They are *useful for flight*. • *Example: Thrips (Thysanoptera)*
Hairy Wings 		• Hairy wings-front and hind *wings clothed with setae*. • They are *useful for flight* • *Example : Trichoptera*
Clefted Wings (Fissured Wings)		• *Front wing* is longitudinally divided forming a *fork-like* structure. • The *hind wing* is divided twice, forming two forks *with three arms*. • All forks possess small marginal hairs. • They are *useful for flight*. • *Example: Both wings of Plume Moth*

Wing Coupling Apparatus and Mechanism:

- During flight, both the wings of insects are kept together by different inter-locking small structures. These inter-locking structures are called wing coupling apparatus. They are of different types: Jugum type, Frenulum & Retinaculum type, Amplexiform & Humuli type

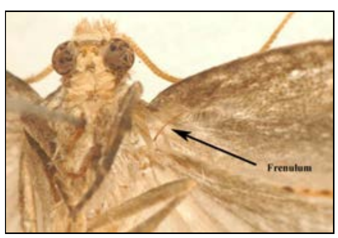
Jugum:

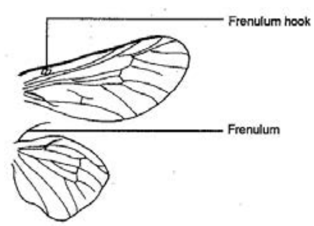
- *Examples: Primitive Lepidopterous Insects.*
- The *anal margin of the forewing possesses a small lobe* (jugum lobe or jugum) at its base called fibula-, projects behind hind-wings, which rests upon the surface of the hind wing.
- Sometimes a *spine is present on costal surface of hindwings*. In this manner the wings become inter locked.



Frenulum & Retinaculum type:

- *Examples: Moths.*
- The *hind wing* possesses a *bristle like structure* called *frenumlum at its humeral angle*- and the *fore wing* possesses *a hook-like structure called "retinaculum", on the anal side*.
- During flight the Frenulum passes beneath the retinaculum and thus both the wings are kept together.



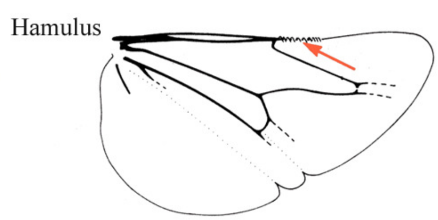


Amplexiform type:

- *Examples: Butter flies.*
- In this type the anal margin of the front wing and costal margin of the hind wing enlarge to overlap each other.
- Due to this over lapping both the wings are kept together.

Hamuli type:

- *Examples: Wasps and Bees.*
- In this type the *costal margin of hind wings posses a row of hooks called Humuli*.
- The Humuli catch the upward fold of front wings and thus both the wings are kept together.



Lecture No: 10

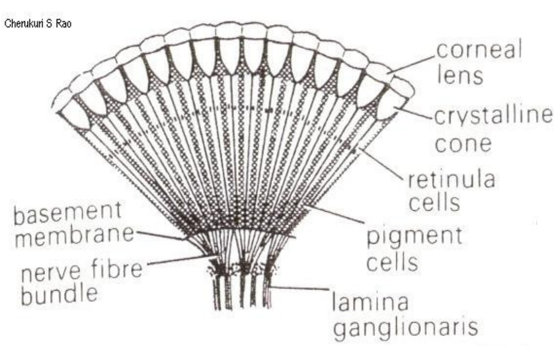
Sense organs: Compound eyes-structure of ommatidium; Ocelli-dorsal and lateral ocelli; Types of images; Types of Auditory organs (tympanum & Johnston's organ)

VISUAL ORGANS (Photoreceptors-perception to electromagnetic stimuli):

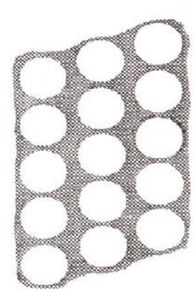
Light is perceived by insects through a number of different sense organs and these are the organs that react with light and useful for vision. These are of different types, but most important are the compound eyes.

Compound eyes:

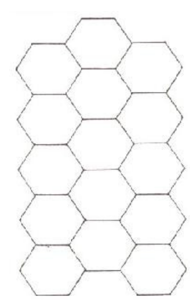
- Most insect adults have *a pair of compound eyes*, one on either side of the head, which bulgeout to a greater or lesser extent, so they give a wide field of vision in all directions.
- *Compound eyes are absent in Protura & Diplura*.
- Compound eyes are absent in larval forms of holometabolous insects, but have simple *stemmata* on each sides of the head, and the vision is by ocelli.
- The *compound eyes are strongly reduced or absent in parasitic groups* such as Siphunculata and Siphonoptera, and in female coccids.
- Compound eyes occur on the side of the head and are quite separate from each other in majority of insects (*dioptic eyes*), but in some insects, the compound eyes are very close to each other (*holoptic eyes*). An insect with completely separated compound eyes is the bee (Hymenoptera), while the insect with very closer compound eyes is dipteran flies.
- Each compound eye is an aggregation of similar units known as *ommatidia*, the number of which varies from one (in worker ant of *Ponera*) to >10,000 (*dragon flies*).
- When only few ommatidia are present, the facets which they present to outside be separated from each other by narrow areas of cuticle; more usually, with larger numbers, the facets are packed close together and assume a hexagonal form.
- If the number of ommatidia is more, these are closely packed and are *Hexagonal* in shape.
- If number is less, these are loosely packed and are *Circular* in shape.
- Ommatidia vary in size from insect to insect.
- These develop embryonically in exopterygotes however post-embryonically in endopterygotes.



Section through part of an eye showing arrangement of ommatidia



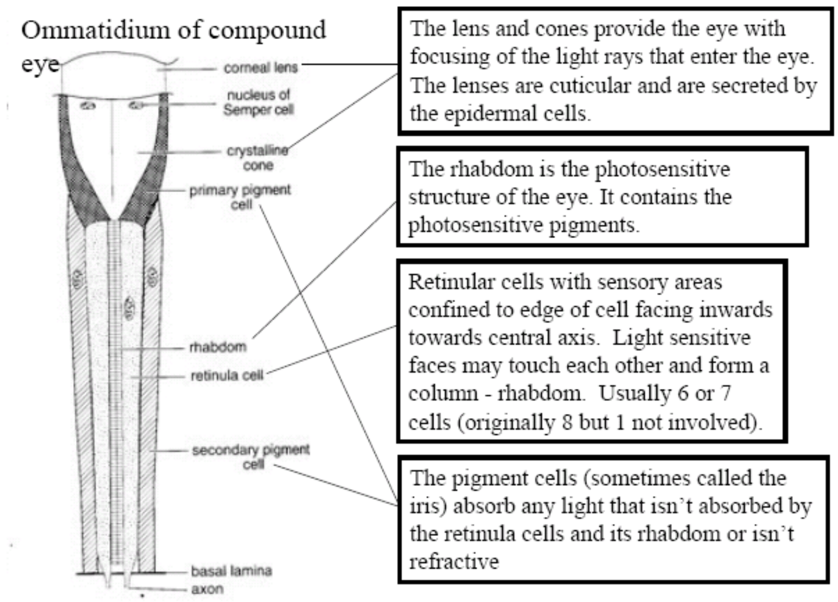
Surface view of part of the eye of an aphid, which consists of small number of ommatidia



Surface view of part of the eye of a syrphid, which consists of a large number of ommatidia with the facets crowded together

Structure of ommatidium:

- Each ommatidium consists essentially of an *(1) optical, light gathering part* and a *(2) sensory part, perceiving the radiation and transmitting it into electrical energy.*
- *The optical part* of the system usually consists of two elements, *a cuticular lens (corneal lens)* and a *crystalline cone.*



The cornea (The Lens):

- This is the outermost transparent colorless layer of cuticle forming the external facet and *acting as a lens*.
- It is *biconvex.*
- Like the rest of the cuticle, it is *secreted by epidermal cells*, each lens being produced by two cells, the *corneagen cells*, which later become withdrawn to the sides of the ommatidium and *form the primary pigment cells*.

Crystalline cone:

- Beneath cornea are four cells, the *simper cells*, which, in most insects, *produce the crystalline cone* (which is comprised of four cells called 'Semper cells' after the man who first described them).
- Normally this functions as a *secondary lens*.
- This is hard, clear intracellular structure bordered laterally by the primary pigment cells.
- Eyes in which the crystalline cone is present are called *eucone eyes*. (In some eg. Elatridae and Lampyridae, the simper cells do not form the crystalline cone, but they extend to the retinula cells as slender refracile strands, and this is known as exocone eyes condition.)

Primary pigment cells (Primary skin cells):

- These are densely pigmented, commonly two in number present around the crystalline cone.
- These are primarily *corneagen cells* and after formation of cornea, they become primary pigment cells withdrawing to the sides of ommatidia, surrounding crystalline cone.

Retinular cells (nerve cells):

- Immediately behind the crystalline cone in eucone eyes are the *sensory elements*.
- They are elongate nerve cells known as retinula cells.
- The *receptive parts of an insect's eye are the 'retinula cells'*.
- The cytoplasm of the retinula cells contains pigment granules, which are especially concentrated at the edge of the rhabdomere, but those granules do not contain the visual pigment.
- Each ommatidium normally has *eight retinula cells* arranged to leave a central core space in the centre of the ommatidium, into which each retinula cell projects a series of microvilli (like very small fingers).
- The *microvilli from each retinula cells are the actual light detecting part of the cells and are collectively referred to as the rhabdomere* (think cornea).
- The rhabdomeres are the microvilli emanating from retinula cells into central gap between all eight retinular cells.
- The eight (or occasionally 7 or 9) rhabdomeres (sets of microvilli) form a rhabdom.
- The retinula cells are connected to axons at the base of the eye, it is these which carry the information collected by the lenses and converted into electrical impulses by the rhabdom to the brain, thus allowing the insect to see.
- The corneal lens is supported by '*primary pigment cells'*.
- The retinula cells and associated rhabdoms are supported by '*secondary pigment cells'*.

Variation in the lens system:

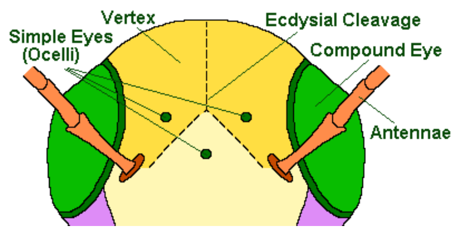
- Eyes in which the crystalline cone (produced by 4 semper cells beneath cornea) is present are called *eucone eyes*.
- In some eg. Elatridae and Lampyridae, the simper cells do not form the crystalline cone, but they extend to the retinula cells as slender refracile strands, and this is known as *exocone condition*.

Variation in the retinula cells:

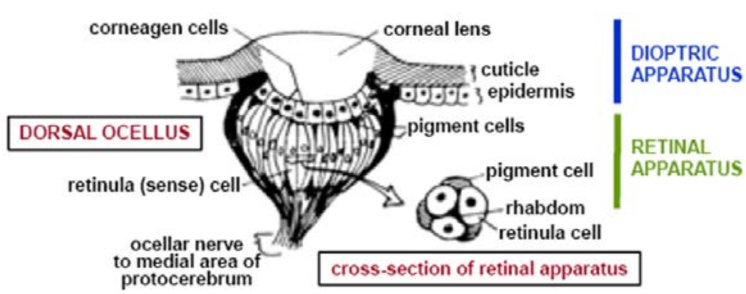
- The arrangement of the retinula cells falls broadly in two classes. (1) those in which the rhabdom extends to the crystalline cone, and (2) those in which there is a clear zone between the cone and rhabdom.
- Eyes in which there is clear zone between cone and rhabdome are called as *clear-zone eyes*; they were previously known as *superposition eyes*, on the basis of their functioning. These eyes are found in *crepuscular and nocturnal insects*.
- Eyes in which rhabdom reaches the crystalline cone are called as *apposition eyes*.These are found in *diurnal insects*.
- *Superposition eyes can achieve greater sensitivity than apposition eyes, so are better suited to dark-dwelling creatures*.

Simple Eyes (Ocelli):

- Simple eyes or Ocelli are present in most insects to some degree.
- Two different forms of ocelli have been described for insects, *dorsal ocelli* and *lateral ocelli*.
- *Dorsal ocelli* are found in adult insects and the larvae of hemimetabolous insects. Typically there are three, forming an inverted triangle antero-dorsally on the head. Dorsal ocelli occur mostly in adult insects and are situated on the front of the insects face in the area of the 'frons' and or the 'epicranium'.
- Lateral ocelli generally occur on the sides of the insect head and are the form of eye most common in larval forms.
- Ocelli very *sensitive to low light levels*.
- Ocelli have role in circadian rhythm (day light responses eg. In diapause)

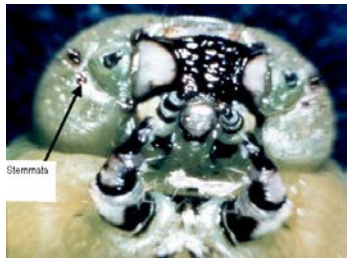


Dorsal ocelli:
- Generally *present in all adult insects and nymphs of hemi-metabola*.
- Usually *number is three* though some times reduced to two, *arranged in triangle on vertex and frons*.
- These are *highly reduced and represent by fenestree in cockroaches*.
- Ocelli absent in Apterygota forms and present in winged insects.
- Typical ocelli have a single thickened cuticlular lens, but in other cases the cuticle is transparent, but not thickened. The space beneath the cuticle being occupied but with transparent cells. Though the lens is optically capable of forming an image, it does so at a level far below the retina. Blackening of the dorsal ocelli reduce the speed with which some insects respond to stimulation of the compound eye by light. They are therefore regarded as *stimulatory organs*.
- Dorsal ocelli develop embryonically or post-embryonically.
- All parts derived from Ectoderm (*ectodermal in origin*).



Lateral ocelli or stemmata:

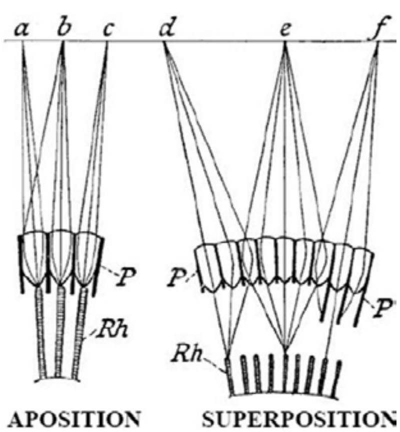
- *Lateral ocelli are only the eyes present in insect larvae of holometabola and in apterygote adults*.
- Ocelli have very *poor resolution power*.
- Caterpillars behaviorally scan from side to side using these visual organs. Similar to structure and function to ocelli. These are present on either side of the head in the position corresponding with those of the compound eyes. The number may vary from 1-7 or more on each side. Probably not image forming but sensitive to direction of light.



- These are innervated from the optic lobes of the brain.
- Stemmata can form an inverted image irrespective of the distance of the object.
- Each stemmata can form image of only one visual field of object thus forming a very coarse mosaic of intensities. By moving the head from side to side it can examine a larger field and is at least capable of orientating it self towards the boundary between light and dark parts of the environment.
- Caterpillar behavior for food and pupation suggest that they have color vision.
- Start development during embryonic stage but the process may only be completed during post embryonic life.
- All parts derived from Ectoderm (*ectodermal in origin*).

Types of Image formation:

Iris cell pigments absorb light that is not refracted. Their structure differentiates the superposition eyes from appositions eyes.



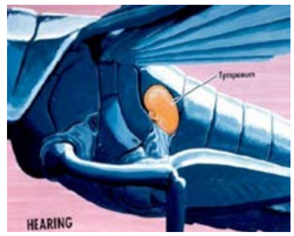
- *Aposition eyes* have *ommatidia optically isolated, rhabdom extends/reaches to crystalline cone* and function best under *bright light conditions***.** *These eyes are found in diurnal insects.*
- In *superposition eyes*, the secondary iris cells have mobile pigments which can isolate or expose retinular layer of ommatidium to light from adjacent ommatidia (*optically not-isolated*). In these eyes, there is a clear zone between the cone and rhabdom (clear-zone eyes). These are found in *crepuscular and nocturnal insects.* These eyes are adopted for dim light conditions.
- Eyes adopted for bright light conditions are apposition eyes, and eyes adopted for dim light conditions are superposition eyes

AUDITORY ORGANS (Sound sensing):

- Sounds are produced by many insects (Orthoptera) using variey of mechanisms. Some sounds, such as that resulting from vibration of the wings in flight. Many but not all insects can hear sounds; some even hear sounds that we can't hear ourselves. Insects hear through one of four different ways, the most common of which is the *tympanum*.

Tympanal organs:

- Always occur as paired organs.
- They are composed of a thin cuticular membrane (the tympanum) stretched across an air space of some sort and some form of connection to the nervous system. *Scoplopodium* form the tympanal organ of the locust.



- In the Orthoptera (Grasshoppers and Crickets) tympanum are common, though situated in different places in different species, i.e. on the *first abdominal segment* in Grasshoppers and on the front legs (*base of fore tibia*) in the Crickets.
- Tympanal organs also occur in the Cicada (Cicadidae, Hemiptera) and some families of the Lepidoptera, (i.e. Noctuidae, Geometridae, and Pyralididae).

Johnston's Organ:

- The second segement of antenna, *pedicle,* usually *contains a special sensory structure, auditory organ, known as Johnston's organ*, which is absent in Diplura, Collembola.
- It detects the motion in the flagellum (third segment)
- The Johnston's organ in male mosquito is extremely important in mating. The male detects the wing beat frequency of female and is attracted to her.
- This can also sense wind.

Auditory Hairs these occur on some Lepidopteran larvae as well as on some Orthoptera.

The Pilifer; this is a *unique auditory organ found only in the head of certain species of Hawk Moths* of the subfamily Choerocampinae its optimum frequency is between 30 and 70 kHz which would allow it *to hear the echolocation calls of many of the larger insectivorous bats.*

Other sense organs for detection various stimuli:

Hygroreceptors: Sensilla that response to changes in the humidity and are extremely important to insects that need to conserve water loss. Sense cells responsive to temperature and humidity are present in the same sensillum. All insects have this on antenna.

Osmoreceptors: The ability to respond the changes in *osmotic pressure* of the fluid. Osmoreceptors have not been studied in insects in detail. Literature suggests the presence of these receptors in horsefly.

Thermoreceptors: Heat reception is used by hematophagous insects (blood sucking) to induce biting. *Two hairs on the tarsi of foreleg of Glossina mosquitoes, on tarsi of Periplanata Americana, found in heat seeking Melanophila beetles.*

Chemoreceptors: Gustation or contact reception. Detection of chemicals by contact, can be located anywhere on the body, but usually found on labrum, maxillae, labium, antenna, tarsi, ovipositor etc.

Chemoreceptors: Olfaction. The sense of smell or response to volatile chemicals, i.e detection of chemicals by smell, can be located anywhere antenna, palps and genetalia. Pheromone binding protein is produced by the trichogen and tormogen cells on antenna.

Proprioreceptors: In desert locust, they have specialized hairs with swollen bulbs at the tip of cerci. *Centre of Grivity* is presumed to be inside the bulb.

So, hair sensilla are very important for various senses, spread all over the body in various forms for smell, touch, gravity, pressure, taste, pheromones etc. *Sense of touch* sensilla found on allover the body, antenna, cerci, ovipositor, mouth parts etc., *sense of air movement* sensilla found on antenna, cerci.

Lecture 11

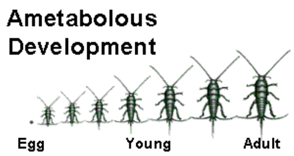
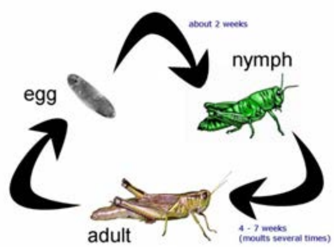
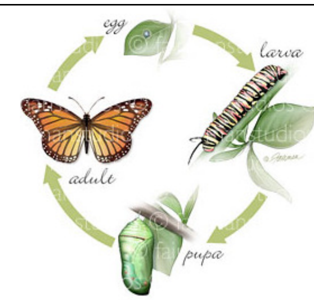
Metamorphosis and types of diapause-obligate and facultative diapauses-stages of occurance of diapauses with examples.

Once an insect hatches from the egg it is usually able to survive on its own, but it is small, wingless, and sexually immature. Its primary role in life is to eat and grow. If it survives, it will periodically outgrow and replace its exoskeleton (a process known as *molting*). In many species, there are other physical changes that also occur as the insect gets older (growth of wings and development of external genitalia, for example). Collectively, all changes that involve growth, molting, and maturation are known as *morphogenesis*.

Metamorphosis:

- *Metamorphosis actually means change.*
- *The changes in the development from egg to adult, collectively called Metamorphosis (life cycle).*
- *Post-embryonic changes in form are collectively called as metamorphosis.*
- *Metamorphosis refers to the way that insects develop, grow, and change form.*
- Majority of insects pass through profound metamorphosis. The growth of an immature insect is accompanied by a series of molts or ecdysis, in which the cuticle is shed off and renewed. The number of molts varies in most insects from 4-8. However some undergo as many as 20 or more molts. *A few insects like Bristle tail Thysanura silver fish (apterygota) may continue molting even after reaching the adult stage*. But most of the insects neither molt nor increase in size once then adult stage is reached. *The intervals between the ecdysis are called Stadia. The term instar is applied to form of an insect during stadium.* In numbering the instar, the form assumed by the insect between hatching from the egg and the first post embryonic molt is termed "First Instar".
- Depending on the presence or absence of metamorphosis and depending upon the degree metamorphosis the insects are grouped into 3 types.

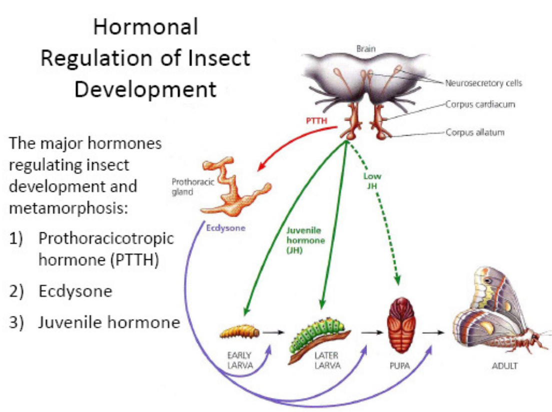
Ametabola	***Hemimetabola***	***Holometabola***
No metamorphosis	***Incomplete metamorphosis***	***Complete metamorphosis***
Wingless	Wings develop during growth of young one (nymph)	Wings develop during growth of adult inside pupae
Undergo slight or no metamorphosis	Undergo incomplete metamorphosis	Undergo complete metamorphosis
Life cycle includes 3 developmental stages: egg, larva (many) and adult	Life cycle includes 3 developmental stages: egg, nymph and adult	Life cycle includes 4 developmental stages: egg, larva, pupa and adult
Eggs laid with no coverings	*Eggs are often covered by an egg case*	*Eggs are sometimes covered by hairs/scales*
No changes take place during development	*Young one (immature stage) is called nymph.*	*Young one (immature stage) is called as larvae.*
The development is direct (young one to adult)	The development is direct (young one to adult)	The development is indirect (youngone to pupa, then to adult)
Young (immature) looks like the adult in all characters, only it may be missing sexual organs	Young one (nymph) resembles the adult in all characters except in wings	Young one (larva) does not resemble and differs from adult both in morphological characters & feeding habits.

Larva/Nymph directly becomes adult	Nymph directly becomes adult	Young one undergo pupal stage before adult stage
No pupal stages	*Pupal stage absent*	*Pupal stage present*
All *Apterygote insects*	Characteristics of lower insect orders : *Exopterygote insects*	Characteristic of higher orders : *Endopterygote insects*
		

Incomplete Metamorphosis: About 12% of all insects go through incomplete metamorphosis. It has 3 stages. *Eggs* are often covered by an *egg case* which protects eggs, and holds them together. Eggs hatch into *nymphs,* which looks like small adults, but usually donot have wings. Insect nymphs eat the same food adult eats. Nymphs shed or molts their exoskeleton (outer casings made up of chitin) and replace them with larger ones several times as they grow. Most nymphs molt 4-8 times. *Adult* stop molting when reach their adult stage. By this time, they have also grown wings.

Complete Metamorphosis: About 88% of all insects go through incomplete metamorphosis. It has 4 stages. *Eggs* are sometimes covered by hairs/scales. *Larva* hatch from eggs and do not look like adult, in any case. They usually have worm-like shape (caterpillars, maggots, grubs). Larva molts several times, and grows larger. Larva makes cocoons around themselves, and larva do not eat while inside cocoons. Their bodies develop in to adult with wings, legs, internal organs etc. This change takes place anywhere from 4 days to many months. Inside the cocoons, the larva change in to adult. After a period of time, the adult breaks out of cocoon.

The metamorphosis is regulated by endocrine system, releasing various types of hormones *viz*, Brain Hormone or PTTH from Corpora Cardiaca, Juvenile Hormone from Corpora Allata and Ecdysone from Pro-Thoracic Glands. The production, storage, release and function of all these growth regulating / promoting hormones are basically regulated by neurosecretary cells in brain of an insect.



DIAPAUSE

- Many species of insects have evolved a strategy called diapause.
- *Diapause is a suspension of development that can occur at the embryonic, larval, pupal, or adult stage, depending on the species*.
- *Diapause is a physiological state of dormancy (sleep-time) with very specific triggering & releasing conditions, a neurohormonally mediated, dynamic state of low metabolic activity. Diapause is the delay in development in response to regularly and recurring periods of adverse environmental conditions.*
- *Animals do not grow during this time*.
- Diapause is a mechanism used as a *means to survive predictable, unfavourable environmental conditions*, such as temperature extremes, drought or reduced food availability.
- In some species, diapause is *facultative* and occurs only when *induced by environmental conditions*; in other species the diapause period has become an *obligatory part of the life cycle*.
- The latter (*obligate diapause*) is often seen in *temperate-zone insects*, where diapause is *induced by changes in the photoperiod* (the relative lengths of day and night).
- The day length when 50% of the population has entered diapause is called the critical day length, and it is usually quite sudden.
- Insects entering diapause when the day length falls below this threshold are called *long day insects*.
- Those insects that develop normally when there are only a few hours of sunlight and that enter diapause when exposed to longer days are called *short-day insects*.
- The critical day length is a genetically determined property (Danilevskii 1965; Tauber et al. 1986). *Long-day insects* are the ones that *go into diapause because the days get shorter*. *Short-day insects go into diapause when there are longer days*.
- *Diapause* is brought about by token stimuli due to change in the environment.
- Diapause begins before the actual severe conditions arise.
- *Diapause during summer is called aestivation*. Be active in rainy season and *sleep (dormant)* during *drought/summer.Diapause during winter is called hybernation*. Be active in summer season, and *sleep (dormant)* during *winter.*
- The difference between *hibernation* and *estivation* is that hibernations is when animals sleep during winter and live off of fat and food energy that they store for when they go into a deep sleep and estivation is when animals go into a deep sleep when is too warm
- Diapause is especially important in temperate zone insects that overwinter.
- After a few warning-signal days, the female will lay '*diapausing' eggs*. These eggs will have their cycle from egg to adult stopped somewhere. *Some examples of these 'sleepers' are:*

Common Name	***Scientific Name***	***Diapause Stage***
Silk worm	*Bombyx mori*	Early-Embryonic Stage (egg diapause)
Locust	*Schistocerca gregaria*	Mid-embryonic stage (egg diapause)
Gypsy Moth	*Lymantria dispar*	Post-Embryonic Stage (egg diapause)
Bamboo borer	*Omphisa fuscidentalis*	Larval diapause
Rice stem borer	*Scirpophaga incertulas*	Larval diapause
Mosquito	*Aedes spp*	Larval diapause
Cabbage White	*Pieris brassicae*	Pupal diapause
Colorado potato beetle	*Leptinotarsa decemlineata*	Adult diapause

- *Diapause is not only induced in an organism by specific stimuli, but once it is initiated, only certain other stimuli are capable of releasing the organism from this state.* The latter is essential in distinguishing diapause as a different phenomenon from other forms of *dormancy* such as *hibernation.*
- The insects get warning signals a few times before they actually do anything about it. These warning signs might be: *Day length, Temperature, Food etc.*

Regulation of Diapause: Diapause in insects is regulated at several levels Environmental stimuli interact with genetic pre-programming to affect the neuronal signaling, endocrine pathways and eventually metabolic and enzymatic changes.

Environmental*:* Environmental regulators of diapause generally display a characteristic seasonal pattern. ***In*** *temperate regions, photoperiod is one of the most reliable cues of seasonal change*. Depending on the season in which diapause occurs, *either short or long days can act as token stimuli*. Insects may also respond to *changing day length as well as relative day length. Temperature may also act as a regulating factor*, either by inducing diapause or, more commonly, by modifying the response of the insect to photoperiod. Insects may respond to *thermoperiod*, the *daily fluctuations of warm and cold* that correspond with night and day, as well as to *absolute or cumulative temperature*. *Food availability and quality* may also help regulate diapause. In the desert locust, *Schistocerca gregaria*, a plant hormone called giberellin stimulates reproductive development. During the dry season, when their food plants are in senescence and lacking giberellin, the locusts remain immature and reproductive tracts do not develop.

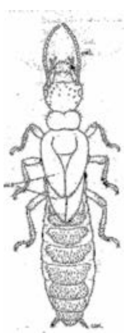
Neuroendocrine: Neuroendocrine system of insects consists primarily of neurosecretory cells in the brain, the corpora cardiaca, corpora allata and the prothoracic glands. There are several key hormones involved in the regulation of diapause: juvenile hormone (JH), diapause hormone (DH), and prothoracicotropic hormone. Prothoraciotropic hormone stimulates the prothoracic glands to produce ecdysteroids that are required to promote development. Larval and pupal diapauses are often regulated by an interruption of this connection, either by preventing release of prothoracicotropic hormone from the brain or by failure of the prothoracic glands to respond to prothoracicotropic hormone. The corpora allata is responsible for the production of juvenile hormone. In the bean bug, *Riptortus pedestris*, clusters of neurons on the protocerebrum called the pars lateralis maintain reproductive diapause by inhibiting JH production by the corpora allata. Adult diapause is often associated with the absence of JH, while larval diapause is often associated with its presence. In adults, absence of JH causes degeneration of flight muscles, atrophy or cessation of development of reproductive tissues, and halts mating behaviour. The presence of JH in larvae may prevent moulting to the next larval instar, though successive stationary moults may still occur. In the corn borer, *Diatraea gradiosella*, JH is required for the accumulation by the fat body of a storage protein that is associated with diapause. Diapause hormone regulates embryonic diapause in the eggs of the silkworm moth, *Bombyx mori*. DH is released from the subesophogeal ganglion of the mother and triggers trehalase production by the ovaries. This generates high levels of glycogen in the eggs, which is converted into the polyhydric alcohols glycerol and sorbitol. Sorbitol directly inhibits the development of the embryos. Glycerol and sorbitol are reconverted into glycogen at the termination of diapause.

Tropical Diapause*:* Diapause in the tropics is often in response to biotic rather than abiotic factors. For example, food in the form of vertebrate carcasses may be more abundant following dry seasons, or oviposition sites in the form of fallen trees may be more available following rainy seasons. Also, diapause may serve to synchronize mating seasons or reduce competition, rather than to avoid unfavourable climatic conditions. Diapause in the tropics poses several challenges to insects that are not faced in temperate zones. Insects must reduce their metabolism without the aid of cold temperatures and may be faced with increased water loss due to high temperatures. While cold temperatures inhibit the growth of fungi and bacteria, diapausing tropical insects still have to deal with these pathogens. Also, predators and parasites may still be abundant during the diapause period. Aggregations are common among diapausing tropical insects, especially in the orders Coleoptera, Lepidoptera and Hemiptera. Aggregations may be used as protection against predation, since aggregating species are frequently toxic and predators quickly learn to avoid them. They can also serve to reduce water loss, as seen in the fungus beetle, *Stenotarsus rotundus*, which forms aggregations of up to 70,000 individuals, which may be eight beetles deep. Relative humidity is increased within the aggregations and beetles experience less water loss, probably due to decreased surface area to volume ratios reducing evaporative water loss.

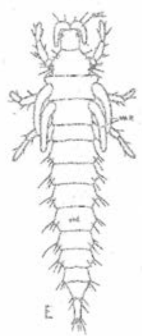
Lecture 12

Types of Larvae and pupae; Differences between nymph and larva

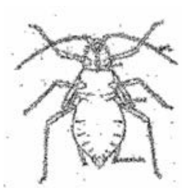
In metamorphosis, immature stages (*active feeding stages viz.,* nymph in hemi-metabolous, larva in holo-metabolous) and pupae (*non-feeding resting stage*) are most important stages in metamorphosis between egg to mature stage. The nymph looks exactly like adults in most aspects except in development of wings externally, and reproductory organs internally. In all insects of hemi-metabolous type, the nymphs just like adults, and only one type is present. But, incase of holo-metabolous insects, the immature stages i.e. larva looks totally different, and larvae of various insects are typically different from others. There are several types of larvae in nature depending up on number of legs, size, shape, locomotion etc. Similarly, pupae of different group of insects look totally different from others.



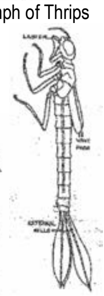
Nymph of Termite



Nymph of Thrips



Aphid nymph



Naiad

In biology, a *nymph* is the immature form of some invertebrates, particularly insects, which undergoes in gradual metamorphosis (hemimetabolism) before reaching its adult stage. Unlike a typical larva, a nymph's overall form already resembles that of the adult. In addition, while a nymph moults it never enters a pupal stage. Instead, the final moult results in an adult insect.

This is the case, for example, in Orthoptera (crickets and grasshoppers), Hemiptera (cicadas, shield bugs, etc.), mayflies, termites, cockroaches, mantids, and Odonata (dragonflies and damselflies). Some arachnids (e.g., mites and ticks) also have nymphs.

Nymphs of aquatic insects, as in the orders Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), and Plecoptera (stoneflies) *are also called **naiads***, which is an Ancient Greek name for mythological water nymphs, which would lure men to their deaths with their cold black hearts. In older literature, these were sometimes referred to as the heterometabolous insects, as their adult and immature stages live in different environments (terrestrial vs. aquatic). In Odonata (Ephemeroptera and Plecoptera as well) *nymphs differs from adults in possessing adaptive organs like the tracheal gills, modified labium.*

The Young ones of Insects: The young ones of exopterygots (hemi-metabolous) called Nymphs and endopterygots (holo-metabolous) called larva.

Nymph	***Larva***
Young one of exopterygote insects	Young one of endopterygote insects
Resemble adults and *differs from the adult with regard to the wings and genitalia*-that are present in an incompletely developed condition.	Differs from adults in appearance.
Food habits of nymph is same as adult	Food habits of larva is totally different from its adult
Wing rudiments may not be discernible in the first instar, but later become visible as wing-pads that increase in size with each instar.	No wing rudiments
Mouthparts are similar to those of adults	Mouth parts are different from adults in most cases

Compound eyes in nymphs are normal in form and function	Compound eyes are *absent* in larva and *stemmata* are present in place of compound eyes.
Growth to adult is unaccompanied by the pupal stage	Growth to adult is accompanied by the pupal stage
Nymph have 3 pairs of thoracic legs as in adults	Number of legs in larva are variable from 0-11 pairs invarious orders, and legs are present in both thorax and abdomen
Wings and genital organs are under-developed	Wings and genital organs are totally absent
Antenna generally well developed and visible	Antenna highly reduced to 1-3 segments, always microscopic and not visible

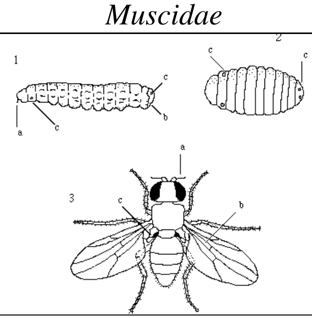
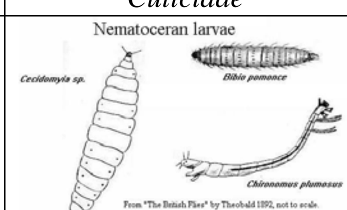
The classification of larva is mainly based on number of legs.
The following are the types of larva: Protopod, Apodous, Oligopod & Polypod

Protopod Larva:

- Larva is *pre-maturely hatched embryo* (*egg contains small quantity of yolk and hence larva hatches from egg before completing its embryonic development*).
- Segmentation in abdomen is absent
- Rudimentary cephalic and abdominal appendages (appendages of head and abdomen are small and undeveloped).
- Nervous and respiratory systems are undeveloped.
- Cannot lead free life, and *always internally parasitic on other insects*.
- *Examples: Parasitic Hymenoptera*

Apodous Larva:

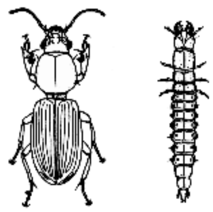
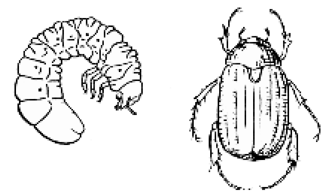
- *Trunk appendages or legs are completely absent*. In place of thoracic legs, 3 pairs of sensory papillas are present. Apodous larvae are classified in to 3 types based on the development of head capsule.

Acephalous	***Hemicephalous***	***Eucephalous***
No distinct Head Capsule. Mouth parts represented by Mouth hook and are usually called as *Maggots*	Appreciable reduction of the head capsule (head capsule partially developed) and its appendages, accompanied by marked retraction of the head into thorax.	Head capsule more or less well developed (well sclerotized head capsule) with relatively little reduction of the cephalic appendages.
Cyclorrhapha (Diptera)- House flies of family Muscidae	*Brachycera (Diptera)- Robberflies of family Asilidae*	*Nematocera (Diptera)- Mosquito of family Culicidae*
		

Oligopod Larva:

- *More or less developed thoracic legs*
- Well developed head capsule and its appendages
- *No abdominal appendages* (abdominal legs absent)

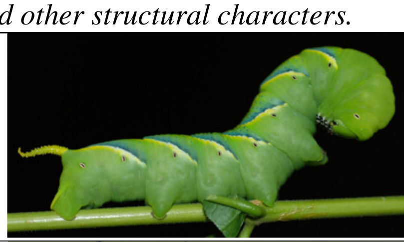
Oligopod larvae are classified in to 2 types based on the shape and other characters.

Campodeiform	***Scarabaeiform***
 campodeiform Larva-Ground Beetle	 Scarabaeiform larva-Scarab Beetle
Straight body (Allegator like)	C shaped body
Body is falt dorso-ventrally compressed	Body is cylindrical or sub-cylindrical
Body wall sclerotized	Body wall soft & fleshy
Head-Prognathous	Head-Hypognathous
Thoracic legs relatively well developed and long (body looks like thrips)	Thoracic legs relatively reduced, short
Pair of anal cerci or styles may be present	Anal cerci absent
Usually active	Inactive
Mostly predators	Mostly phytophagous
Neuroptera, Trichoptera, Coccinellid beetles, Ground beetles	*Scarabaeidae family of Coleoptera (dung rollers, root grubs, rhinoceros beetles)*

Polypod Larva (Eruciform larva)

- Well developed segmentation in thorax and abdomen
- *Both thoracic and abdominal legs are present* (appendages of head and abdomen are well developed)
- Peripneustic respiration is common
- Antenna present but very small in size or rudimentary
- Comparatively inactive, living close to their food or host plant
- Generally Phytophagous
- *Examples: Some Lepidoptera and Sawflies of Hymenoptera*

Polypod larvae can be classified in to various types based on the number of legs, locomotion and other structural characters.

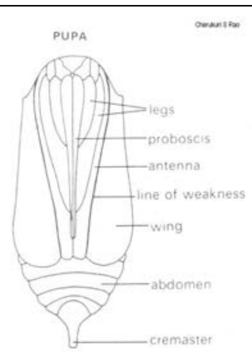
Sphingid Larva (Horn worm)		Posses well developed *hook like structure on the dorsal surface of 8th abdominal segment*, in addition to all polypod characters. Hence these known as *Hornworms*. Example: Sphinx moth (death head moth)-*Acherontia spp.*
Semi Looper		*First two pairs of prologs (3rd and 4th abdominal seg) are reduced*. Due to reduction of size of first prologs, during locomotion the body form a loop shape, and hence these are called *semiloopers*. Castor Semilooper *Achaea janata*

Lopper		*Generally only two pairs of prologs (6^{th} and last abdominal seg) are present and other prologs are absent*, and hence during the locomotion, the larva gives complete loop like shape, and hence these are called *loopers*. Cabbage Looper, *Trichoplusia ni*
Hairy Caterpillar		*Having hairs over the entire body*, hence are called Hairy Caterpillars Bihar Hairy caterpillar *Spilosoma obliqua,* Red Hairy Caterpillar *Amsacta albistriga,* Castor Hairy Caterpillar *Euproctis lunata, E. similis*

- The larvae of *lepidoptera* (butterflies and moths) are called *caterpillars*
- The larvae of *coleopteran and hymenoptera* are called *grubs*
- The larvae of *diptera* are called *maggots*

PUPA:

- **A pupa** (for doll) is the life stage of some insects undergoing transformation.
- The *pupal stage is found only in holometabolous insects*, those that undergo a complete metamorphosis, going through four life stages; embryo, larva, pupa and imago. (For a list of such insects see Holometabolism. pupae of different groups of insects have different names such as *chrysalis in the Lepidoptera* and *tumbler in mosquitoes*).
- *Pupae may further be enclosed in other structures such as cocoons, nests or shells*.
- In the life of an insect the pupal stage follows the larval stage and precedes adulthood (*imago*).
- It is during the time of pupation that the adult structures of the insect are formed whilst the larval structures are broken down.
- *Pupae are inactive and usually sessile (not able to move about).*
- *They have a hard protective coating and often use camouflage to evade potential predators.*
- Pupation may be brief, for example 2 weeks as in monarch butterflies, or the *pupa may enter dormancy or diapause* until the appropriate season for the adult insect (in temperate climate pupae usually stay dormant during winter, in the tropics pupae usually do so during the dry season). Pupation may last weeks, months or even years. Anise Swallowtails sometimes emerge after years as a chrysalis.

	Insects emerge (**eclose**) from pupae by splitting the pupal case, and the whole process of pupation is controlled by the insect's hormones. Most butterflies emerge in the morning. In mosquitoes the emergence is in the evening or night. In fleas the process is triggered by vibrations that indicate the possible presence of a suitable host. Prior to emergence, the adult inside the pupal exoskeleton is termed "***pharate***". Once the pharate adult has eclosed from the pupa, the empty pupal exoskeleton is called an "***exuvium***" (or **exuvia**); in most hymenopterans (ants, bees and wasps) the exuvium is so thin and membranous that it becomes "crumpled" as it is shed.

Pupae are mainly 2 types:

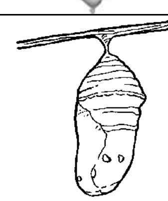
Decticous pupa:

- Posses relatively *powerful sclerotized articulated mandibles used to escape the adult from cocoon or cell*.
- They are primitive type and *always exarate* (*free appendages, not adhering to rest of body).*
- *Examples: Neuroptera, Mecoptera, Trichoptera.*

Adecticous pupa:

- Having non-articulated often *reduced mandibles* that in most species are *not used for escape from the pupal cocoon*.
- Examples: Lepidoptera and Diptera.
- Based on the shape and attachment of appendages, adecticous pupae are classified into 4 types:

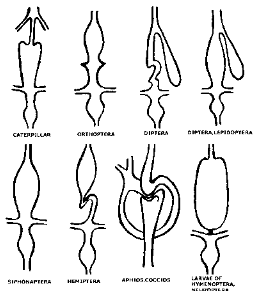
Based on the shape and attachment of appendages, adecticous pupae are classified into 4 types:

Adecticous Exarate	The pupa has *free appendages, not adhering to the rest of the body*. All wings, legs, antenna, mouth parts are independent, not attached except at their point of origin. *Examples: Most of Coleoptera, Diptera, Hymenoptera, Primitive Lepidoptera.*	 Exarate-Coleoptera  Exarate-Diptera
Adecticous Obtect	The *appendages of pupa are firmly attached against the body*. The pupal cooon is highly chitinized. *Examples: All the moths belong to Lepidoptera*	
Adecticous Obtect - Chrysalis	It is an *obtect type of pupa*, which has *prominent stalk and coloration*. *Examples: All butterflies belong to lepidoptera*	
Adecticous Exarate - Coarctate	The *adecticous exarate pupa remain closed in a puparium* which is formed from the preceeding larval cast skin and pupa looks like a capsule or a barrel. *Examples: House flies (Diptera), Suborder Cyclorrapha*	

Lecture 13

Digestive System:

Alimentary canal-structure of foregut, midgut & hindgut-histology, functions, filter chamber, peritrophic membrane, and process of digestion.



Various types/shapes of digestive tracts in different insects

- *The insect digestive system is a closed system, with one long enclosed tube (alimentary canal) running lengthwise through the body.*
- *The alimentary canal is a one way street-food enters the mouth and gets processed as it travels toward the anus.*
- *Each of the three sections of the alimentary canal performs a different process of digestion.*
- *The salivary glands produce saliva, which travels through salivary tubes into the mouth.*
- *Saliva mixes with food and begins the process of breaking it down.*

- *Digestion* is the process by which the food is broken down hydrolytically into simpler components, which can be absorbed or assimilated by the animal.
- The process of digestion is brought about in a digestive tract or alimentary canal in insect.

Salivary glands:

- Immediately behind the mouth are the Salivary Glands, are paired glands, which secrete saliva into pre-oral food cavity where it mixes with food.
- Their ducts unite to form a common duct opening at the base of the hypopharynx is the salivarium.
- In most species these secrete saliva, generally a watery fluid that *lubricates the food and contains a few enzymes* to begin the processes of digestion. However, in insects that ingest liquid food, it may be involved in dissolving solid particles or for diluting viscous liquids.
- In some carnivorous insects, the saliva is composed entirely of digestive enzymes; this applies particularly to those with external digestion of the food.
- In other insects the salivary glands have become modified for purposes that have nothing to do with digestion. *In Lepidopteran caterpillars and Caddisfly larvae they have been converted to the production of silk*, while in the *Queen Honey Bee they are called the mandibular glands and secrete hormones*.
- Salivary gland tubes opens in hypopharynx between labrum and labium.
- They are not part of digestive system, but the saliva helps for the lubrication of the food when enters into pre-oral food cavity.
- *Functionally, labial glands are the salivary glands in most insects*. *However, in some lepidopteran larvae labial glands take up the function of silk secretion, while mandibular glands produce saliva.*
- *Glossina moristans* in its saliva has antithrombin, similar to hirudin.
- *G. papalis* in addition to an anticoagulant has an apyrase which functions to prevent platelets from aggregating and forming plugs.
- Anticoagulants have also been reported in tabanids, blackflies and mosquitoes.
- The first section of the alimentary canal is the foregut or stomodaeum. *In the foregut, initial breakdown of large food particles occurs, mostly by saliva*. The foregut includes the buccal cavity, the esophagus, and the crop, which stores food before it passes to the midgut.

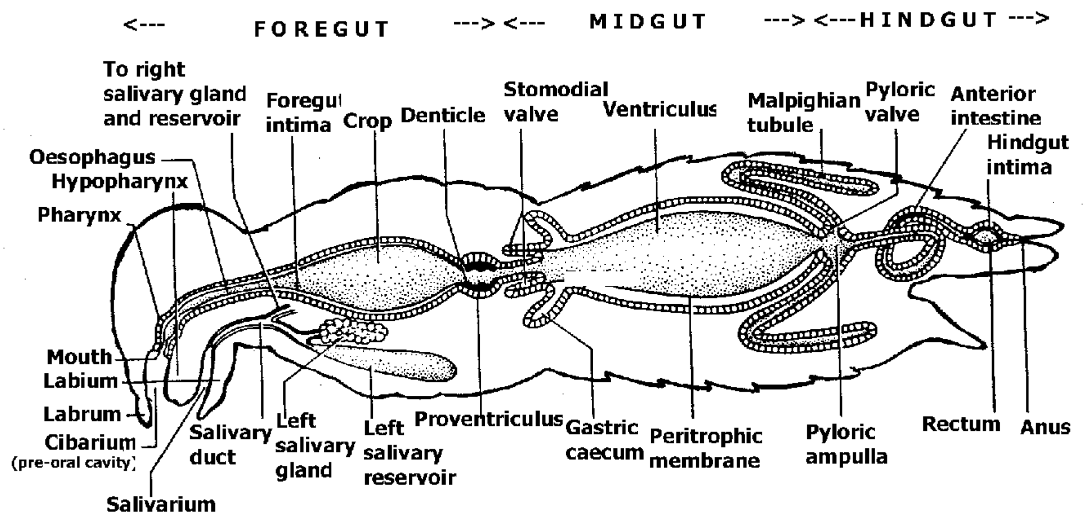
- Once food leaves the crop, it passes to the midgut or mesenteron. *The midgut is where digestion really happens, through enzymatic action*. Microscopic projections from the midgut wall, called microvilli, increase surface area and allow for maximum *absorption of nutrients*.
- In the hindgut or proctodaeum, *undigested food particles* join uric acid from Malphigian tubules to form *fecal pellets*. The *rectum absorbs most of the water in this waste matter*, and the dry pellet is then eliminated through the anus.

Functions of digestive system:

- Intake of raw food material
- Digestion and absorption of nutrient substances from the raw food material
- Ejection of the unused / undigested food material
- Distribution of absorbed products among cellular tissues

General structure of alimentary canal: In insects the alimentary canal is divided into three main parts: Foregut (*Stomodeum),* Midgut (*Mesenteron*). and Hindgut (*Proctodeum)*

- *Stomodeum (foregut) and proctodeum (hindgut) are ectodermal in origin, while mesenteron (midgut) is endodermal in origin*.
- Insects show diverse morphologies of the digestive system because of their diverse diets. Generally, the higher the protein content, the shorter the intestine, and lower the protein content the longer is the intestine.



The areas proceeding to foregut are *pre-oral food cavity* and *buccal cavity*. These parts are not the part of gut, but are important to understand.

- **The Pre-oral food cavity:** *is the space lying between the mouth parts and the labrum and is not a part of the gut.* In insects with mandibulate mouthparts this space is divided by the hypopharynx in to an anterior or dorsal *cibarium* and a posterior or ventral *salivarium*. Cibarium is a small pouch for the temporary storage of food or modified into sucking pump in hemiptera. Salivarium also undergo modification to form the salivary syringe of the hemiptera and silk regulator in the lepidoptera larvae.
- **Buccal cavity:** *is the oral part of the stomodaeum (foregut). It is not structurally differentiated from the pharynx.*

FOREGUT (*Stomodaeum*):

Foregut arises as an anterior ectodermal invagination. *Foregut is lined on its inside with the cuticular intima, produced by a single layer of epithelialcells*, which are flattened and unspecialized and with distinct boundaries. *The function of foregut is to receive the food from the mouthparts and to pass it to the midgut. The pharynx and the oesophagous achieve these activities*. In the foregut, initial breakdown of large food particles occurs, mostly by saliva. The fore gut (*It is also known as the Stomodaeum)* is generally considered to consist of four sections: The Pharynx, The Oesophagus, The Crop and The Proventriculus.

- **The pharynx:** is the *first part of the fore gut* and apart from being a tube that connects the interior of the mouth area (sometimes known as the 'Buccal Cavity) with the more inward parts of the gut it *sometimes serves as a pump to suck up the liquefied food of those insects which feed by means external digestion*.
- **The Oesophagus** is basically a tube leading to the mid gut via the crop and the proventriculus or gizzard. *Oesophagous is useful for passage of food from pharynx to crop*.
- **The crop (Ingluvies):** *The primary function of the crop is storage though a part of digestion starts in the crop*. Crop is an enlargement of the foregut, where ingested food is stored temporarily, before its passage into midgut. In acridids, caterpillars and honeybees, the crop is largely expanded. In adult Diptera and Lepidoptera, it forms a lateral diverticulum. The volume of the crop greatly enlarges when it is filled with the food.
- **The Gizzard (Proventriculus)** is *a muscular extension of the crop*. In those insects which feed on solid foods it is *used to grind the food up into smaller particles*, it can *also serve as a filter to keep oversized particles out of the main digestive tract* and as a valve *controlling the flow of food into the midgut*. The gizzard (proventriculus) is the last section of the foregut. In some insects (orthopterans) it is developed into a grinding organ. In cockroaches, crickets and termites the longitudinal folds of the intima of proventriculus form strong plates, teeth or spines. Fleas have spine-like structures which rupture the RBCs in the blood meal ingested by them. In bees, the anterior part of proventriculus invaginates into the crop and forms four mobile lips, each having a number of spines. Here, the proventriculus not only, regulates the movement of food into the midgut, but also removes pollen from the nectar suspension and retains the nectar in the crop. Nectar is retained in the crop, regurgitated and is processed to form honey.
- The fore gut and the mid gut are separated by the ***'stomodeal or cardiac valve'***. *Valves or sphincters regulate the forward movement of the solid particles from the midgut into the foregut.*
- While most internal digestion takes place in midgut, *in some insects, due to regurgitation of midgut juices, it may take place even in crop, e.g. in Schistocerca, α glucosidase activity occurs in lumen of foregut.*

MIDGUT (*Mid-Intestine or Stomach or Ventriculus or Mesenteren Mesenteron*):

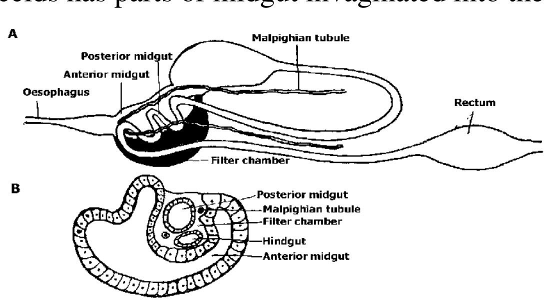
- Midgut is tubular or elongate sac of approximately uniform diameter.
- In some insects (fluid feeding insects) it is divided into 2 to 4 separate parts. In many insects the surface area of the stomach is increased by the development of sac like diverticula the enteric or gastric cacae. These organs are usually situated at the anterior end of the mesenteron.
- Midgut (*Mesenteron*) *performs the function of digestion and absorption*.
- *In insects, midgut is lined with a delicate* ***peritrophic membrane*** *secreted from special glands located at the junction of fore and midgut. Peritrophic membrane is considered to have a protective function, protecting epithelial cells of midgut from abrasions by*

the food and as a barrier to bacteria. Peritrophic membrane is absent in many fluid feeding hemipterans and homopterans. Peritropic membrane is permeable to enzymes and digestive products. Presence of peritrophic membrane in some fluid feeding insects or nectar feeding adults of several lepidopterans remains a mystery as it is expected to have no function to perform.

- The epithelium of the midgut contains three main types of cells: *Columnar cells (Cylinder cells), Regenerative cells and Calciform cells (goblet cells).*
  - *The columnar cells* are actively *involved in the secretion of enzymes and absorption of the products of digestion*.
  - *The regenerative cells* are present in most of the insects either single or in *groups (Nidi)* in midgut. Their function is *to renew the other epithetical cells* when these are destroyed.
  - In a number of insects, the midgut cells i.e *Calciform Cells or Goblet Cells may accumulate spherules*, which contain accumulation of various elements like calcium, copper and iron. They may disappear either as a consequence of their utilization after a temporary storage or may be released into the midgut. Globlet cells in *Tineola* (Lepidoptera) accumulate metals and dyes in the cytoplasm or globlet cavity of the cell. These substances are discharged at the following moult when the whole of the epithelium is removed. This process is called as the *storage excretion*. Globlet cells in the midgut of Lepidoptera and Ephemeroptera secrete K+ from the haemolymph into the lumen of the intestine making it alkaline. They are of special importance in lepidopteran larvae because both the toxins of *Bacillus thuringiensis* and baculovirus are active in the alimentary canal of the lepidopteran larvae due to the alkalinity (pH 10) of the midgut.

Filter Chamber:

- A number of cicadids and cercopids *suck sap* from xylem, which contains amino acids in very dilute solution and relatively higher concentration of salts.
- This solution has to be concentrated before absorption so as to avoid excessive dilution of haemolymph.
- In these insects *removal of excessive water is done with the help of "the filter chamber*".
- *The filter chamber consists of an expanded thin walled bladder-like anterior midgut, which lies in close association with (or surrounds) the posterior midgut (interior) and proximal ends of the Malpighian tubules (interior) or anterior part of the hindgut.*
- The chamber formed within the folds of the anterior gut is called the filter chamber. It is suggested that the Malpighian tubules produce a hypertonic fluid, which is rich in K+. This establishes an osmotic gradient from the anterior midgut to the filter chamber then to the Malpighian tubules, so that water passes almost directly to the hindgut and absorption of nutrients takes place in the more central region of the midgut. Filter chamber of the coccids has parts of midgut invaginated into the rectum.



A. Diagram of the alimentary canal showing filter chamber. B.Transverse section of filter chamber

- A number of insects (members of diaspididae, larvae of Neuroptera, most Hymenoptera and some Diptera) have a *discontinuity in the gut*, usually separating the midgut from the hindgut. This discontinuity in some insects is lost at the final moult.
- The isolation of the midgut probably is for the conservation of symbiotic bacteria present in this part or for rapid elimination of excess water.

HINDGUT: (*Proctodaeum*)

- From the mid gut, food passes to the hind gut.
- In most insects the hindgut can be divided into three regions:
  - *Small intestine or Ileum*,
  - *Large intestine or Colon* (both put together known as anterior intestine) and
  - *Rectum* (posterior intestine).
- The *'rectum' which compresses the undigested food and waste products, extracts more water* from this if necessary before it is passed out through the 'anus' as faeces.
- Arising from and the foremost part of the hind gut are the *Malpighian tubules* (named after Malpighi who discovered them) are *not really to do with digestion at all but with elimination (excretion).* They act like our kidneys and extract metabolic waste products (mostly nitrogenous ones such as urea, and uric acid) from the circulating body fluid called the haemolymph and excrete them into the intestines which are the first part of the hind gut.
- Though insects possess a large number of digestive enzymes, they are often helped by the presence of symbiotic micro-organisms, such as *protozoa in the case of the termites and some primitive cockroaches which feed on wood*, and *bacteria in the wax moth Galleria mellonella which feeds on the wax* that honey bees *Apis mellifera* uses to make the combs in its hives.

Special functions of the gut:

Apart from the main functions of digestion and absorption, the gut is also

- Responsible for *swallowing of air for cuticle expansion at the time of moulting*.
- In Odonata nymphs, the *rectal glands are assigned the function of respiration*. In addition, the gut is involved in propulsion in Odonata nymphs.
- It also *acts as a reservoir for symbionts in several insects* e.g. bacteria and protozoa in termites.
- Apart from excreting the undigested food material the gut is responsible for *storage excretion* during metamorphosis and as an organ for food storage.
- *Water retention via reabsorption* is another important function carried out by the gut.

DIGESTION & ABSORPTION:

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

- All insects have a complete digestive system. This means that food processing occurs within a tube-like enclosure, the alimentary canal, running lengthwise through the body from mouth to anus. Ingested food usually travels in only one direction.
- Before the food can be absorbed by midgut, the food has to broken down into simpler soluble substances, and this is done by digestive enzymes, secreted by salivary glands and midgut epithelium.
- *Digestion occurs in crop and midgut*
- *Absoption occurs in midgut. Absorption of micro-molecules is through either active or passive process, through peritropic membrane and midgut epithelial cells finally into haemolymph.*

Main groups of enzymes found in insects are:

- Carbohydrases responsible for break down of carbohydrates
- Lipases are concerned with breakdown of fats
- Proteases are useful for digestion of proteins.

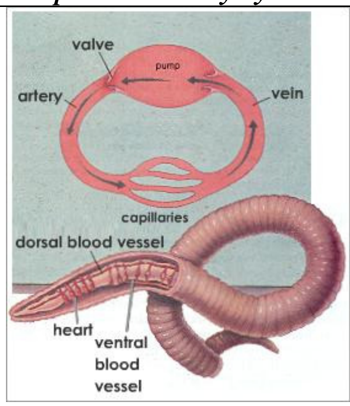
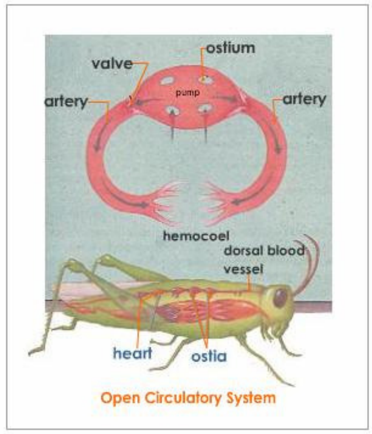
***Digestion in Termites**:* In *termites cellulose is the main content of the food material*. The enzyme that can digest cellulose (cellulase) is not produced in midgut. *The colon of the hind gut in termites is often enlarged called as rectal pouch, where some symbiotic protozoans present*. These *protozoa produce enzyme cellulases* that can digest cellulose. Hence, in termites digestion takes place in hind gut.

Notes:

Lecture 14

Circulatory System

Open & closed types-organs of circulatory system-dorsal blood vessel (diaphrams, sinuses, aceessory pulsatile organs)-process of circulation-properties & functions of haemolymph.

Open Circulatory System	*Closed Circulatory System*
	
In many animals (Humans, Vertebrates), the blood travels through special vessels such as arteries, capillaries, and veins, and hence is known as Closed Circulatory System	When the blood moves / travels without aid of vessels, the organism has a Closed Circulatory System. In Insects, the blood travels through body cavity irrigating various tissues & organs, and hence is known as Closed Circulatory System. In open system, the blood / haemolymph spends much of its time flowing freely within the body cavity where it makes direct contact with all internal tissues and organs.

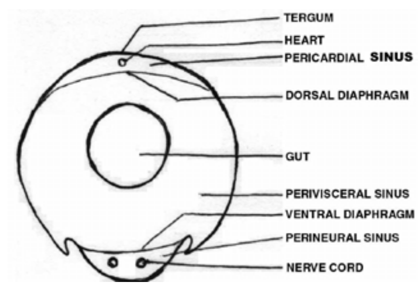
- In Insects, the body cavity through which the blood travels is called *Haemocoele.*
- The nutritive fluid or blood that is present in haemocoele is called *Haemolymph.*
- Insect blood is only about 10% hemocytes (blood cells); most of the hemolymph is watery plasma.
- *The insect circulation system does not carry oxygen*, so the blood does not contain red blood cells as ours does.
- *Hemolymph is usually green or yellow in color.*

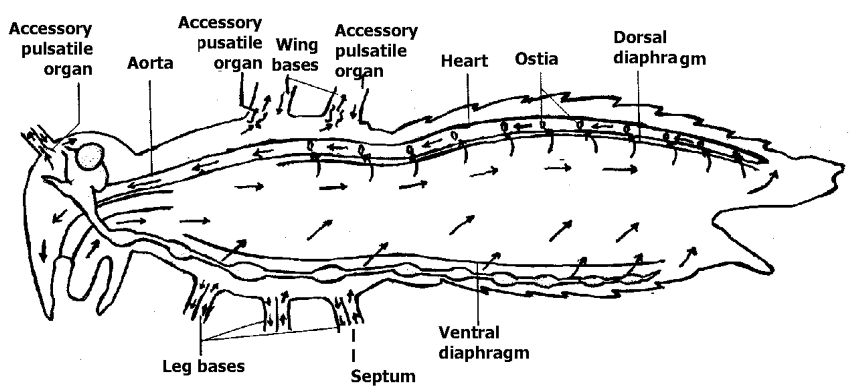
Functions of Insect Circulatory System:

- The circulatory system is responsible for *movement of nutrients*
- For *movement of salts*
- For *movement of hormones*
- For *movement of metabolic wastes* throughout the insect's body.
- In addition, it plays several *critical roles in defense*: it *seals off wounds* through a clotting reaction, it *encapsulates and destroys internal parasites or other invaders*, and in some species, it produces (or sequesters) distasteful compounds that provide a degree of protection against predators.
- The hydraulic (liquid) properties of blood are important as well. *Hydrostatic pressure generated internally by muscle contraction is used to facilitate hatching, molting, expansion of body and wings after molting, physical movements* (especially in soft-bodied larvae), reproduction (e.g. insemination and oviposition), and evagination of certain types of exocrine glands.
- In some insects, the *blood aids in thermoregulation*: it can help cool the body by conducting excess heat away from active flight muscles or it can warm the body by collecting and circulating heat absorbed while basking in the sun.

The diaphragms and sinuses:

- To facilitate circulation of hemolymph, the *body cavity (Haemocoele) is divided into three compartments (called blood sinuses) by two thin sheets of muscle and/or membranes (dorsal and ventral diaphragms)*.
- The *dorsal diaphragm* is formed by alary muscles of the heart and related structures; it separates the pericardial (dorsal) sinus from the perivisceral sinus.
- The *ventral diaphragm* usually covers the nerve cord; it separates the perivisceral sinus from the perineural (ventral) sinus. The ventral diaphragm is a continuous layer, lying just above the nerve cord and divides the abdomen into two sinuses, viz., perineural and perivisceral sinus. The ventral diaphragm is usually absent in thorax of most insect larvae (except in some Hymenoptera), and most adult insects.
- Between the dorsal and ventral sinuses is the large visceral sinus containing principal internal pairs of alary muscles composed of striated fibres and tissues resembling elastic connective fibres, arise from the terga and spreadocet fanwise over the surface of the dorsal diaphragm.
- The *heart is maintained in position by* these sedpusary filaments known as *alary muscles.*





Dorsal Vessel:

- A *dorsal vessel* is the major structural component of an insect's circulatory system.
- *This tube runs longitudinally through the thorax and abdomen, along the inside of the dorsal body wall.*
- In most insects, it is a fragile, membranous structure that *collects hemolymph in the abdomen and conducts it forward to the head*.
- Haemolymph in insect body circulates mechanically in a posterior to anterior direction by the action of a *pulsatile organ*, the dorsal vessel. Hence, the *dorsal vessel is the principle pulsatile organ.*
- *Dorsal vessel can be divided into Aorta and Heart*

Aorta:

- The anterior dorsal vessel (often referred as aorta) is a *simple unperforated tube*, which may end in a frontal sac, or open simply, or its anterior part may be modified to divide into vessels supplying haemolymph to the antennae.
- *The aorta lacks valves or musculature*.
- Hemolymph bathes the organs and muscles of the head as it emerges from the aorta, and then haphazardly percolates back over the alimentary canal and through the body until it reaches the abdomen and re-enters the heart.

Heart:

- *In the abdomen, the dorsal vessel is called the heart*.
- *Heart is divided segmentally into chambers that are separated by valves (ostia) to ensure one-way flow of hemolymph*.
- *A pair of alary muscles is attached laterally to the walls of each chamber*.
- Peristaltic contractions of the muscles force the hemolymph forward from chamber to chamber. During each diastolic phase (relaxation*), the ostia open to allow inflow of hemolymph from the body cavity*.
- The heart's contraction rate varies considerably from species to species-typically in the range of 30-200 beats per minute. The rate tends to fall as ambient temperature drops and rise as temperature (or the insect's level of activity) increases.
- The primitive (maximum) number of ostia appears to be 12 pairs (in Blattodea), one in each of the thoracic segments and nine in the abdominal part of the dorsal vessel. In Archaeognatha and *Bombyx mori*, prothoracic pair is absent while in *Dytiscus* only eight pairs have been recorded. In most Lepidoptera there are 7-8 pairs of ostia, 5-6 in Collembola and only four in *Musca*. *Extreme loss of ostia occurs in some Hemiptera*.

***Accessory Pulsatile organs*:**

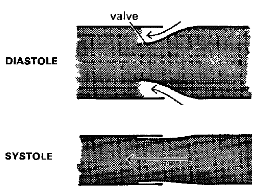
- *The principle pulsatory organ in insect circulatory system is the dorsal vessel pumpimg the blood through ostia with the movement of alary muscles.*
- Circulation of haemolymph is unidirectional in appendages, and various tubes, septa, valves, and pumps, which are collectively termed as accessory pulsatile organs, bring this about. In some insects, *accessory pulsatile organs* (pumps) are located near the base of the wings or legs. These are sac-like structures situated in various regions or the body and pulsate independently of the heart, ensuring adequate ciruclation of blood through the appendages. These muscular "pumps" do not usually contract on a regular basis, but they act in conjunction with certain body movements to force hemolymph out into the extremities. Haemolymph circulation in legs of *Triatoma phyllosoma pallidipennis* (Hemiptera) is assisted by a septum and a pulsatile organ. The organs responsible for circulation in antennae consist of an ampulla (sac), which gathers blood from the blood space at the anterior end of the aorta. Antennal pulsatile organs are located in *Melolontha* at the base of each antenna.

Alary Muscles:

- Alary muscles are largely composed of connective tissue with elastic properties rather than muscle cells.
- Alary muscles arise, usually, from a restricted origin on the tergum and fan out, in such a way that those of opposite sides meet into a broad zone at the midline, over the surface of the dorsal diaphragm, beneath the dorsal vessel.

Circulation of Haemolymph:

- The heart is the principal pulsatory organ and undergoes rhythmical contractions which are brought about by the muscle fibrillae of its walls.
- Contraction of the heart takes the form of a wave of peristalsis which runs forward from posterior end.
- The process of blood circulation in the system (in and out of heart, sinuses for blood supply) can be explained in three stages viz., systole (heart contration phase to send the blood out), diastole (expansion of heart for sending blood in), diastatis (in some).
- In normal circulation of blood, at *systole (contraction phase*), *the blood from the posterior is pumped anteriorly in the dorsal vessel in the form of a peristaltic wave*.
- The heart wall muscles (alary muscles) bring about the rhythmical contractions of the heart. Haemolymph flows out through the excurrent ostia at which time the incurrent ostia close to prevent the escape of the blood. Blood pressure in the perivisceral sinus increases and the blood tends to pass backwards along the pressure gradient. Movements of the ventral diaphragm force the percolated blood in the perineural sinus, producing a backward flow and eventually supplying blood to the nervous system. The dorsal diaphragm, which normally is convex above, tends to flatten by the contractions of alary muscles. The *flattening of the dorsal diaphragm increases the volume of the pericardial sinus at the expense of the perivisceral sinus so that the blood moves up into the pericardial sinus*.
- Then at *diastole (relaxation phase)*, results from the relaxation of the heart muscles and in some insects it is by the *contraction of the alary muscles*, the blood enters the heart by the incurrent ostia which may exclude some or all haemocytes. On contraction the expanded lips of these ostia acts as valves so that the blood is prevented from returning through these to the pericardial sinus and is propelled forward.



The blood is drawn into the heart through the incurrent ostia, as a result of the relaxation of the elastic muscles of the heart and in some insects it is facilitated by the contraction of alary muscles or elastic tension of their fibres.

- In its forward passage, some blood leaves the heart by the excurrent ostia and lateral segmental vessels (when these are present); the remainder enters the cephalic haemocoele from which a part is pumped into the antennae by accessory pulsatile organs. Pulsatile organs help in the circulation of blood into wings, legs and other appendages.
- From the head and thorax the blood flows backwards in the haemocoel and is probably assisted in this direction by undulatory movements of the ventral diaphragm.
- After diastole, there is a third phase in heart cycle, *Diastatis***,** in which the *heart rests in expanded state (diastole state).* Increses in the frequency of the heart beat results from reductions in period of diastatis.
- The accessory pulsatile organs located near or within the appendages may also assist haemolymph circulation in appendages.
- The rate of heart beat (systole-contraction phase) is greatly affected by the temperature, physiological state of the insect. In some larvae there are 14 beats per minute and in some 150 beats per minute were also recorded.

Process and Functions of Haemolymph: Insect Haemolymph consist *liquid plasma and blood cells* or haemocytes.

Plasma:

- About 90% of insect hemolymph is plasma.
- Plasma contains 85% water, slightly acidic and includes inorganic ions, amino- acids, proteins, fats, sugars, organic acids and other substances.
- Plasma is a watery fluid-usually clear, but sometimes greenish or yellowish in color.
- Potassium Chloride and Sodium Chloride are the major inorganic substances. Sodium predominates in carnivorous insects where as the Potassium predominates in the phytophagous insects. Magnesium, Calcium and Phosphorous are also present.
- *Amino acids are present in high concentrations* compared to vertebrate blood.
- Generally plasma of insect blood contains relatively high concentrations of free amino acids, proteins, sugars, and inorganic ions.
- Overwintering insects often sequester enough ribulose, trehalose, or glycerol in the plasma to prevent it from freezing during the coldest winters.
- Insect blood *doesnot contain vitamin K*.

✓ Storage of water which can be used during desiccation.
✓ Principal part is food storage.
✓ Transportation of food materials and hormones
✓ Mechanical function in ever sion of protrusible structures (proboscis, wings, penis)
✓ Reflex bleeding in some insects when they are disturbed through pores, slits and articulations of the cuticle – acts as a protective function
✓ Aids in splitting of the old cuticle during moulting Haemocytes.

Haemocytes:

- The remaining 10% of hemolymph volume is made up of various cell types (collectively known as hemocytes).
- They are involved in the clotting reaction, phagocytosis, and/or encapsulation of foreign bodies.
- Haemocytes may occur commonly as leucocytes, plasmatocytes, oenocytoides, cystocytes etc.
- The density of insect hemocytes can fluctuate from less than 25,000 to more than 100,000 per cubic millimeter.
- With the exception of a few aquatic midges, insect *hemolymph doesnot contain hemoglobin* (or red blood cells). Oxygen is delivered by the tracheal system, not the circulatory system.

Types of haemocytes: The haemocytes have been distinguished into

1. Prohaemocytes (small rounded cells with large nuclei, divide frequently to give rise other type of cells).
2. Plasmatocytes (most abundant, phagocytic)
3. Granular haemocytes (phagocytic)
4. Cystocytes (coagulants, specialized granular haemocytes, often possess phenoloxidaes)
5. In addition to most common above, few other types such as *oenocytoids, spherule cells, adipohaemocytes* may be present in some insects.

The main functions of haemocytes are:

- *Phagocytosis:* The most common function of haemocytes is phagocytosis of foreign particles, micro organisms and tissue debris. Mainly the plasmocytes perform this function. Plasmatocytes perform this function. Phagocytosis tissue debris may be associated with metamorphosis. Phagocytosed material may be digested in the cell or may be encapsulated by other Phagocytes.

- *Encapsulation*: Particles such as metazoan parasites which are too large to Phagocytose are encapsulated. The haemocytes congregate round the parasite and became flattened and thereby kills the parasite and remove from the metabolic food material. The parasite deis through lack of oxygen.
- *Secretion and metabolism*: Some of the haemocytes are useful for the formation basement membrane, formation of fat body, activation of prothocacic gland (which produces moulting harmone, ecdysene). In some instances the cells themselves break down to provide nutriment for other tissues.
- *Wound healing and coagulation*: The plasmocyte extend their thread like processes which join with those of other cells to form a cellular network. The plasma coagulates in this network and the wound is effectively plugged until epidermis regenerates.

In insects the blood does not coagulate readily. Coagulation might result either from agglutination of the haemocytes or from the coagulation of plasma. *Vitamin K is absent in insect blood* unlike other animals. ***Two types of coagulation occur.*** When the blood is exposed the cystocytes stop moving and their cytoplasm expands rapidly and becomes vacuolated. Round each cystocyte, a thin fog of particles appears in the plasma progressively increasing in amount and density. This material coagulates so the cystocytes are surrounded by areas of coagulation in which other types of haemocyte may be trapped. In the second type the cystocytes send out straight, thread like pseudopodia which stick to interfaces and foreign particles forming a meshwork of threads. Slowly the fluid contained within the mesh becomes jelly like abd coagulates. Other types of haemocytes may stick to the pseudopodia or become trapped during coagulation.

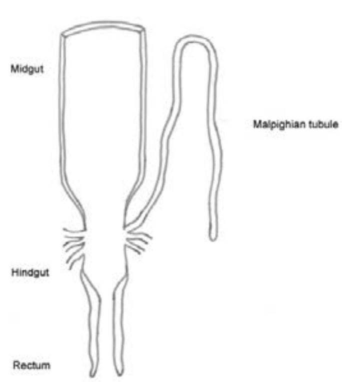
Lecture No: 15

Excretory System

Structure, functions, modifications of malpighian tubules Structure & functions of other organs of excretion.

- The activities of the cells are carried out most efficiently within a narrow range of conditions. It is therefore important that the environment within the cell and in the animal in general should be kept as nearly uniform as possible. This involves the *maintenance of constant level of salts and osmotic pressure in the haemolymph and the elimination of toxic nitrogenous waste derived from the protein and purine metabolism* and of other toxic compounds which may be absorbed from the food. In these activities excretion plays an essential part.
- So, the *Excretion is the process of eliminating waste products of metabolism and other non-useful materials*.
- Excretion is an essential process in all forms of life.
- In most insects, the Malpighian tubules and the rectum are concerned in excretion and salt and water regulation. Water and salts and excretory products pass into the Malpighian tubules from the haemolymph and controlled resorption takes place in the rectum. Waste nitrogen is usually excreted as uric acid since this is relatively non-toxic and insoluble. It can be therefore be excreted with a minimum of water and the terrestrial insect is thus able to conserve the water.
- *Malpighian tubule system is a type of excretory and osmoregulatory system* found in Insects and Myriapoda, arachnids and tardigrades.
- The system consists of branching tubules extending from the alimentary canal that absorbs solutes, water, and wastes from the surrounding hemolymph. The wastes then are released from the organism in the form of solid nitrogenous compounds.
- The system is named after Marcello Malpighi, a seventeenth century anatomist.
- The *Malpighian tubules work with the insect hindgut to excrete nitrogenous waste products*.
- This *organ empties directly into the alimentary canal*, and connects at the junction between the midgut and hindgut.
- The tubules themselves vary in number, from just two in some insects to over 100 in others.
- Like arms of an octopus, the Malpighian tubules extend throughout the insect's body.
- Waste products from the hemolymph diffuse into the Malpighian tubules, and are then converted to uric acid. The semi-solidified waste empties into the hindgut, and becomes part of the fecal pellet. The hindgut also plays a role in excretion. The insect rectum retains 90% of the water present in the fecal pellet, and reabsorbs it back into the body. This function allows insects to survive and thrive in even the most arid climates.

Malpighian tubules

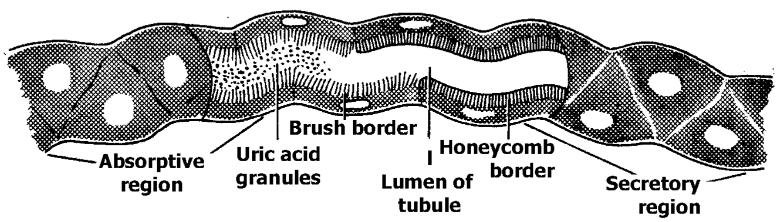


- Malpighian tubules of insects are *long tubular epithelium, closed at one end, arise from the gut near the junction of mid- and hindgut, and lie freely in the body cavity*, in most insects. Sometimes the arising position of Malpighian tubules may vary e.g. in *Necrophorus* spp (Coleoptera), these arise from midgut, while in caterpillars, these arise from anterior hindgut, or rectum (in *Rhodnius*).
- Malpighian tubules are considered to be *evaginations of hindgut and hence are ectodermal in origin*.
- They contain actin for structural support and microvilli for propulsion of substances along the tubules.

- They may *open independently into the gut* or may join in groups at an ampula or a more tubular ureter which then enters the gut.
- Marcello Malpighi first described these in 1669, called them as '*Vasa varicosa*' and thought that these have a biliary function. Herold (in 1816) observed their excretory function and Meckel termed these as Malpighian tubes in 1820.
- The number of Malpighian tubules in insects may vary, from species to species.
- *Malpighian tubules are absent in Collembola, Thysanura and members of family aphididae*, there may be more than 200 in different insect species. *Their primitive number is six (three pairs)*, but in coccids their number is reduced to only two. In Diptera, Protura and Strepsiptera these are represented by papillae. The tubules vary from 2-100mm in length and 30-100μm in diameter.

Structure of Malpighian Tubules:

- Basic Malpighian tube is *made up of single-celled thick wall*, with 2-5 cells.
- Comprising the circumference, *richly supplied by trachea, indicating a high metabolic activity of the cells*. In some insects (e.g. Orthoptera), the Malpighian tubules possess external longitudinal muscles, which allow them wavy movements.
- The *outermost layer* of Malpighian tubules is composed of *a non-cellular, fibrous matrix* called *basal lamella / basement membrane,* and tracheoles lying outside of this layer. The basal lamella, besides *providing structural support*.



- On the inner side of the basal lamella lies *a layer of one-cell thick, simple epithelial cells*. Generally two to five cells are seen in a cross-section of a tubule.
- The *basal plasma membrane is highly folded* forming somewhat deep slits perpendicular to the basal lamella. *These folds provide a highly increased surface area so as to facilitate increased quantity of transport proteins and maximize solute-water coupling during fluid transport*.
- Malpighian tubule can be differentiated into two regions, based on their histology and functions. The microvilli in the lower (proximal) one-third *resorptive region* are more widely spaced, forming a typical "*brush border*", comprising the cytoplasmic filaments of varying lengths (7-40μ long). In the remaining *two-third distal (upper) secretory region*, parallel and closely spaced microvilli (3-10μ) form a striated "*honey comb" border*. The cells of distal part contain more mitochondria and actively discharge materials into the lumen of the tube either by merocrine or holocrine secretory process. In the lower region uric acid granules are present.
- ***The Malpighian tubules are composed of two types of cells***: i) primary cells which have basal infolds and large microvilli with mitochondria and ii) the *leptophragma cells* which are much thinner and smaller are found at intervals along the tubule. *Potassium chloride is actively pumped into the distal parts of the Malpighian tubules creating an osmotic gradient along which water is drawn from the rectum, facilitating in the production of dry excreta.*

Cryptonephridial condition:

- In the cryptonephridial system of *Coleoptera, larvae of Lepidoptera, and a dipteran*, *the blind ends of Malpighian tubules, are not free in haemocoel; instead lie closely parallel to the external wall of the rectum*.
- It is *highly developed in insects feeding on dry matter* (*Tenebrio molitor* and *Dermestes*).
- This condition is best developed in terrestrial insects, *to conserve water.*
- Such arrangement though seen in many phytophagous and carnivorous species, is absent in aquatic Lepidoptera.
- The *distal ends of the six Malpighian tubules lie close to the rectum, and form a highly convoluted mat over it*. The entire complex is covered by a perinephric membrane, which consists of an outer sheath composed of a single epithelial layer, an underlying layer of tracheal cells and an inner sheath comprising of several layers of flattened cells. The perinephric membrane (outer sheath) is relatively impermeable.

Other organs of excretion:

Integument: *Moulting in insects is considered to be a process of excretion*, since during each moulting insect loses a considerable amount of nitrogen in the form of exuviae. Also, since some respiration may take place through the integument, *ectoderm may also be considered as an excretory organ for elimination of CO_2 and water from the body*, and technically speaking even *tracheal system is also excretory system* in the same way.

Alimentary canal:

- In some insects, the cells of midgut are known to have a role in regulation of the haemolymph content, both inorganic ions and organic molecules.
- In Collembola and aphids, Malpighian tubules are absent. Epithelial cells, which contain excretory products, are also shed along with exuviae at each moulting.
- Midgut of the termite, *Reticulitermis falvipes* harbour bacteria, which have an ability to recycle uric acid nitrogen, representing a scavenging mechanism designed to recover which would otherwise be lost by the excretion of uric acid. Evidence also exists in support of fat body recycling of urate nitrogen in *Periplaneta americana*.
- The midgut of *Bombyx* is capable of excreting some acid dyes.

Labial glands: These are tubular structures present in the head of Collembola, open above the base of the labrum through a common duct. These consist of an upper saccule followed by a coiled labyrinth and have a gland, which opens into the outlet duct. These glands are probably excretory in function.

Nephrocytes and Pericardial cells: ***Nephrocytes*** are cells which takeup from haemocoel foreign chemicals of relatively high molecular weight which the Malpighian tubules may be incapable of dealing with. They are ensheathed in basement membrane, suspended in the haemocoel by connective tissues and occur either singly or in groups in various parts of insect body. *Nephrocytes are probably present in all insects*. The *dorsal pericardial nephrocytes* are arranged along the head and aorta and have often been termed as "pericardial cells", "diaphragm cells" or "paracardial cells". The *ventral nephrocytes* lie suspended beneath the oesophagous and have been referred as "garland cells", "wreath cells", and "circumoesophageal" or sub-oesophageal cells". Scattered nephrocytes in fat body cells are termed "disseminated nephrocytes". Nephrocytes are considered to be involved in endocytosis. In *Calliphora*, the nephrocytes produce, store and release the enzyme, lysozyme.

Excretory Products: *In insects, principle excretory product is Uric Acid*. Ammonia is the primary end product of the nitrogen metabolism, but it is highly toxic except in extreme dilutions. Consequently ammonia is only excreted in any quantity by insects with an ample supply of water. But, for most terrestrial insects water conservation is essential and the loss by excreation must be reduced to a minimum. Hence, it is necessary to produce a less toxic substance than ammonia so that the less water is required for its safe elimination. The substance produced is uric acid, which is relatively harmless, and is also highly insoluble. As a result it tends to crystalline out of solution and can be retained as a soild, non-toxic waste substance for long periods. Further, uric acid contains less nitrogen. Most insect excrete 80-90% of their nitrogen as uric acid.

Excretion from Malpighian tubules: The products of nitrogen excretion are, in most insects, eliminated from the haemolymph via the Malpighian tubules. *The movement into the tubules is probably passive*, the rate depending on the sixe of the molecule and the rate of fluid secreation. As a consequence urea passes into tubules more rapidly than uric acid. Subsequently, in the more proximal parts of the system, water and salts are resorbed to a grater or lesser extent and uric acid or urate may precipitate out. The continous flow of the water down the Malpighian tubules to the rectum carries the uric acid with it, so that ultimately the nitrogenous waste is excreted with the faeces via the anus.

Storage excretion: *The products of metabolism, instead of being excreted out are retained in the body in a harmless form. This is known as storage excretion*. In a large number of insect species the Malpighian tubule cells contain various types of intercellular crystals. These crystals serve as a form of storage excretion. These crystals are associated with a specific cell type e.g. the upper tubule cell of *Rhodnius* or the primary cell of *Aedes* and *Periplaneta americana*. In some moths and butterflies, purines and Pteridine are stored away from the metabolic pool in the general body cuticle and in wing scales. Similarly, in *Dysdercus* uric acid is stored in epidermal cells and it contributes to the colour pattern of the insect. In earlier literature, occurrence of uric acid in fat body of some insects (especially *Periplaneta*) was recognized as a process of storage excretion. It was later argued that the fat body is metabolically an extremely active tissue, and that urate deposits are not permanent in fat body. Hence, it is assumed that the urates in cockroaches and termites form a mobile reserve.

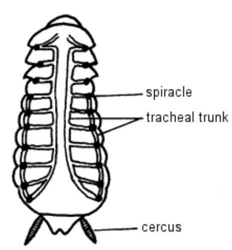
Notes:

All insects are aerobic organisms-they must obtain oxygen (O_2) from their environment in order to survive. They use the same metabolic reactions as other animals (glycolysis, Kreb's cycle, and the electron transport system) to convert nutrients (e.g. sugars) into the chemical bond energy of ATP. During the final step of this process, oxygen atoms react with hydrogen ions to produce water, releasing energy that is captured in a phosphate bond of ATP. The respiratory system is responsible for delivering sufficient oxygen to all cells of the body and for removing carbon dioxide (CO_2) that is produced as a waste product of cellular respiration. The respiratory system of insects (and many other arthropods) is separate from the circulatory system.

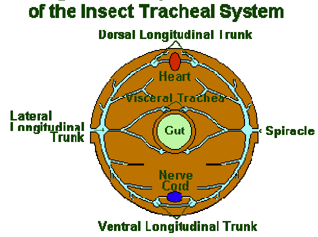
- *Gaseous exchange in insects is carried on through a system of internal tubes, the tracheae, the finer branches of which extends to all parts of the body and may become functionally intracellular in muscle fibres. Thus oxygen is carried directly to its sites of utilization and the blood id not concerned with gas transport. The tracheae open to the outside through segmental pores, the spiracles, which generally have some closing mechanism which permit minimum water loss.*
- *The spiracles open in response to low concentration of oxygen or high concentratrion of carbon dioxide. Diffusion alone can account for the gaseous requirements of tissues of most insects at rest, but in larger insects or during activity demands on oxygen are greater, and to meet the requirements, the insect pumps air in and out of tracheal system by expanding and collapsing air-sacs, which are enlarged parts of the tracheae whose volume can be changed by movements of the body. These movements are controlled by endogenous rhythms within the central nervous system.*

Tracheal System:

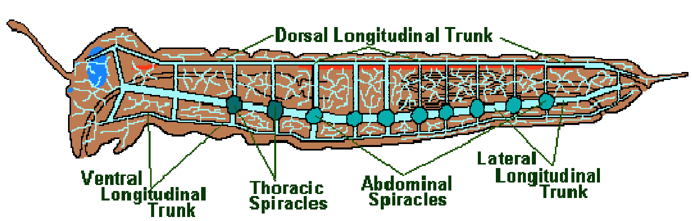
- It is a *complex network of tubes* (called a *tracheal system*) that delivers oxygen-containing air to every cell of the body.
- *Air enters the insect's body through valve-like openings in the exoskeleton*. These openings (called *spiracles*) are located laterally along the thorax and abdomen of most insects-usually one pair of spiracles per body segment.
- Air flow is regulated by small muscles that operate one or two flap-like valves within each spiracle-contracting to close the spiracle, or relaxing to open it.



Diagramatic Representation In TS of the Insect Tracheal System



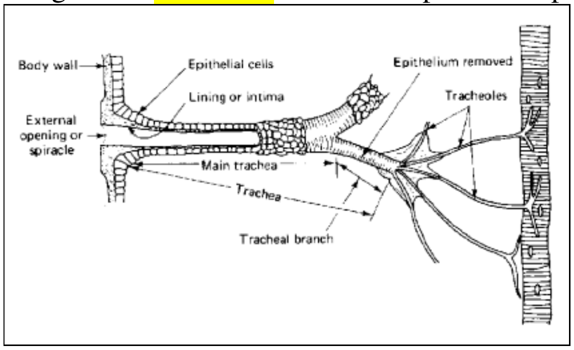
Diagramatic Representation of the Insect Tracheal System

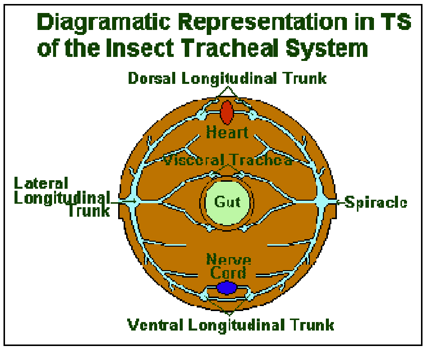


- After passing through a spiracle, air enters a *longitudinal tracheal trunk*, eventually diffusing throughout a complex, branching network of *tracheal tubes* that subdivides into smaller and smaller diameters and reaches every part of the body.
- At the end of each tracheal branch, a *special cell (the tracheole)* provides a thin, moist interface for the exchange of gasses between atmospheric air and a living cell.
- *Oxygen in the tracheal tube first dissolves in the liquid of the tracheole and then diffuses into the cytoplasm of an adjacent cell*. At the same time, carbon dioxide, produced as a waste product of cellular respiration, diffuses out of the cell and, eventually, out of the body through the tracheal system.
- Each *tracheal tube develops as an invagination of the ectoderm* during embryonic development.
- To prevent its collapse under pressure, a thin, reinforcing "wire" of cuticle *(the taenidia*) winds spirally through the membranous wall. This design (similar in structure to a heater hose on an automobile or an exhaust duct on a clothes dryer) gives tracheal tubes the ability to flex and stretch without developing kinks that might restrict air flow.
- *The absence of taenidia in certain parts of the tracheal system allows the formation of collapsible* ***air sacs***, balloon-like structures that may store a reserve of air. In dry terrestrial environments, this temporary air supply allows an insect to conserve water by closing its spiracles during periods of high evaporative stress.
- Aquatic insects consume the stored air while under water or use it to regulate buoyancy.
- During a molt, air sacs fill and enlarge as the insect breaks free of the old exoskeleton and expands a new one. Between molts, the air sacs provide room for new growth-shrinking in volume as they are compressed by expansion of internal organs.
- Small insects rely almost exclusively on *passive diffusion* and physical activity for the movement of gasses within the tracheal system. However, larger insects may require active *ventilation* of the tracheal system (especially when active or under heat stress). They accomplish this by opening some spiracles and closing others while using abdominal muscles to alternately expand and contract body volume.

Trachea:

- The Tracheae are the *larger tubes of the tracheal system*, running inwards from the spiracles and usually breaking up into finer branches, which ramify through the organs of the entire body and appendages.
- *The fine branches of trachea are called as Tracheoles*.
- These are the *ectodermal invaginations* of the body wall and so are *lined by a cuticular intima* which is continous with the rest of the cuticle.
- A *spiral thickening of the cuticular intima* runs along each tube, each ring of the spiral being called *taenidium*, that are helpful to keep the trachea distended.

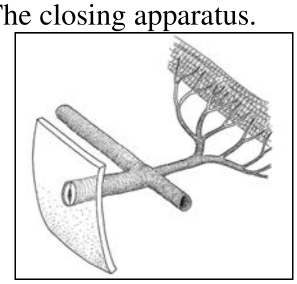
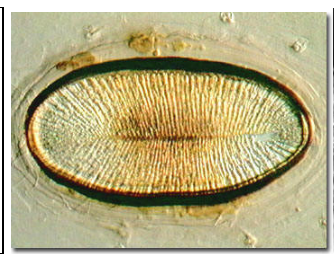
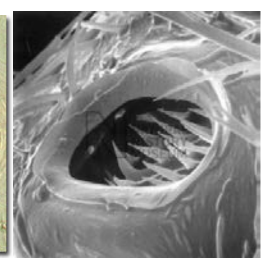




- They are elastic tubes and when filled with air present a *silvery appearance*.
- In most insects the tracheae are all linked through a series of *longitudinal pipes called tracheal trunks* and many smaller connections. See the diagram above. *Dorsal Longitudinal Trunk* near the top, or back, of the insect's body; *Lateral Longitudinal Trunk* running along the sides just in from the spiracles; *Ventral Longitudinal Trunk* running along the belly of the insect. Transverse, dorsal or ventral *commissures connect the systems of each side*.
- The arrangement of tracheal system varies between different insects, but in general,
  - ✓ Heart and dorsal muscles are supplied by branches from *dorsal trunks*
  - ✓ Alimentary canal, gonads, legs and wings are supllied by *lateral trunks*
  - ✓ Central Nervous System supplied by *ventral trunks*
  - ✓ The head and mouth parts are supplied with branches derived from anterior spiracle (spiracle I) and dorsal longitudinal trunks
- *Most collembola have no tracheae at all*.

Spiracles:

- The spiracles are the *external openings* of the tracheal system.
- They are *lateral in position*, usually on the pleura.
- Generally *10 pairs of spiracles* are seen (two pairs in thorax and eight pairs in abdomen).
- The air generally enters the trachea through spiracles.
- Sometimes the spiracles are closed or wanting. Respiration in such cases is cutaneous.
- *Spiracles permit gaseous exchange but are also a major site of water loss*.
- Typical functional spiracle includes.
  - ✓ The external opening or spiracular openings
  - ✓ The annular sclerite or peritreme surroundings the opening.
  - ✓ The *artrium* – the chamber in which the external opening leads.
  - ✓ The closing apparatus.

Classification of Insects based on Number of Functional Spiracles:

- The respiratory system is classified depending upon the number and arrangement of functional spiracles.
- The largest number of spiracles found in insects is ten pairs, two thoracic and eight abdominal, and the respiratory system may be classified on the basis of the number and distribution of the functional spiracles (keilin, 1944).

Polypneustic : *Atleast 8 functional spiracles on each side*	*Holopneustic : 10 spiracles* 1 mesothoracic, 1 metathoracic, 8 abdomenal (1-8 abdomenal segments)	*Hymenoptera* Bibionid larvae
	Peripneustic : 9 spiracles 1 mesothoracic, 8 abdomenal	Larvae of Neuroptera & Lepidoptera
	Hemipneustic : 8 spiracles 1 mesothoracic, 7 abdomenal	Mycetophilid larvae

Oligopneustic: *1 or 2 functional spiracles on each side*	*Amphipneustic : 2 spiracles* 1 mesothoracic, 1 post-abdomenal	Larva of diptera Psychodid larvae
	Metapneustic : 1 spiracle 1 post-abdomenal	Larvae of culicidae and tipulidae
	Propneustic : 1 spiracle, 1 mesothoracic	Dipteran pupae
Apneustic: *No functional spiracles* *Aquatic insects and endoparasites Chironomid larvae* Apneustic doesnot implay that the insect has no tracheal system, but that the tracheae do not open to the outside. Air enters the closed tracheal system by diffusion through the general body surface or specialized extensions of the body known as gills brachide. These non-functional spiracles open at ecdysis and permit the cast intima to be shed.		
Hypopneustic: In all the above types of respiratory systems the total of functional and non-functional spiracles are equal to 10 pairs. In contrast to them the term ***hypopneustic*** is used to denote system *in which more pairs of spiracles have disappeared completely*. Eg: Mallophaga, Siphunculata.		

- *In numerous insects, the first spiracle is on the pro-thorax, but is meso-thoracic in origin.*
- Spiracles are normally open for the shortest time necessary for the efficient respiration in order to keep water loss from the tracheal system to a minimum. Spiracle closure results from the sustained contraction of the closer muscle, while opening commonly results from the elasticity of the surrounding cuticle when closer muscle is relaxed.
- From the spiracles oxygen passes through the tracheal system to the tissues and ultimately must reach the mitochondria in order to play a part in oxidative processes. Carbon dioxide follows the reverse path. There are thus two distinct phases in the transport of gases, one through tracheal system, known as *air-tube diffusion*, and other through the tissues in solution in the cytoplasm, known as *tissue diffusion*.
- In large, active insects, diffusion alone doesnot bring the sufficient oxygen to the tissues to meet their requirements and it is supplemented by convection produced by chnges in the volume of the tracheal system, and this process is known as *ventilation*.

Other means of respiration in insects

- ***Integumental (cutaneous) respiration:*** In insects that do not have tracheae or that have an imperfect or a secondarily closed tracheal system and are not provided with other devices for respiration, the exchange or gases takes place directly through the integument. The best known examples of insects having this type of respiration are *majority of collembola, protura, aquatic chironemidae and parasitic insect larvae* which live entirely submerged in the liquids or tissues of the hosts.
- ***Gills or Branchial Respiration: Tracheal gills:*** These are present in majority of *aquatic larvae* are usually borne *on the abdomen*. These are filiform or more or less lamellate organs which are well supplied with tracheae and tracheoles. In general good deal of gaseous exchange takes place through these structures. In many cases these are only organs of respiration but in others these are accessory in function and co-exist with open spiracles.
- ***Spiracular gills:*** These occur in *pupae of some beetles and dipteran* families. These are extensions of spiracles or the cuticle immediately surrounding them to form long, partly hollow processes. One or more pairs of spiracles usually form spiracular gills. These structures are adopted both for aquatic and aerial respiration.

- ***Blood gills:*** These are found in *larval trichoptera and diptera* and are well developed in larvae of chironemus. These are tubular and some times eversible. These derive their name from the fact that these contain blood but not as a rule tracheae, although occasional tracheoles may be present. These structures help in the absorption of water and inorganic ions rather than respiration.
- ***Gaseous plastron:*** In some aquatic form of the family Denacinae and some of the Hemiptera, there is a *permanent thin layer of gas known as gaseous plastron held by various means around the body surface*. These insects never visit the surface throughout their life history, because the volume of *plastron (air film)* remains constant and is maintained in its position by various hydrofuge devices like hairs which are spaced so closely together that water under normal pressure cannot enter these. The *spiracles are situated just below the plastron layer* but the air itself does not enter the trachea. The *plastron acts as a physical gill through which the dissolved oxygen from the water enters the plastron and then diffuses into insect system. Plastron type of respiration is found in many insect eggs and pupae or aquatic insects*.

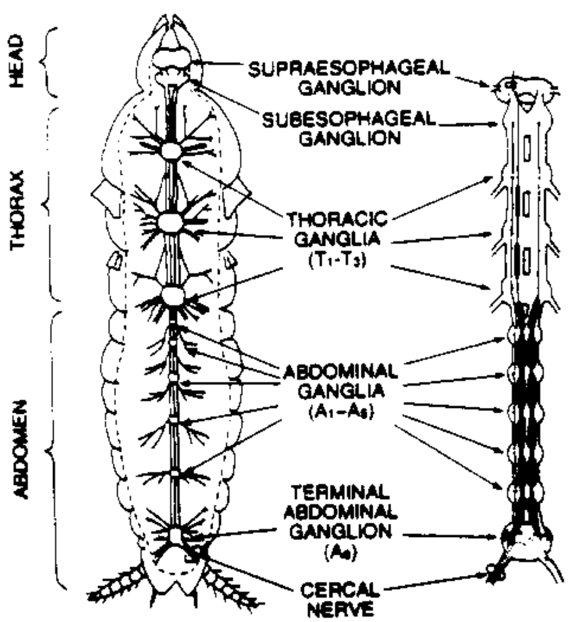
Notes

Lecture 17

Nervous System

Neuron & its types (based on structure & functions)-synapse, ganglia, central nervous system, sympathetic nervous system & peripheral nervous system.

- The nervous system is a conducting system ensuring rapid functioning and co-ordination of effectors, modifying their responces according to the input of the peripheral sense organs.
- The nervous system *coordinates the reception, integration and modification of the stimuli*, and the reaction in response to these stimuli. Input-information is received from the environment (external or internal) and the output is the form of a behavioural response to the information received.
- The information, frequently referred to as stimulus, may be chemical (gustatory or olfactory), light, pressure, heat, magnetism, etc. The information received and transmitted is in the form of chemical or electrical signals.
- The *basic elements in the nervous system are nerve cells* which are produced into long processes, or axons, along which the nerve impulses are conducted.
- Conduction along a nerve axon is an *electrochemical process* which is influenced by the composition of fliud bathing the axons.
- The *bodies of the nerve cells are aggregated to form ganglia* while *bundles of axons form nerves*.
- The insect nervous system primarily can be divided into 1) Central Nervous System and 2) Stomatogastric (stomodaeal) nervous system.
- *Central Nervous System* (CNS) consists of a *brain* situated dorsally in the head and *ventral nerve cord* (chain of segmented ganglia, runs ventrally through thorax and abdomen) from which nervers run to the peripheral sense organs and muscle systems.
- *Stomatogastric (Stomadaeal) nervous system* containing nuber of small ganglia connected to the brain and their associated nerves controls the movements of alimentary canal.



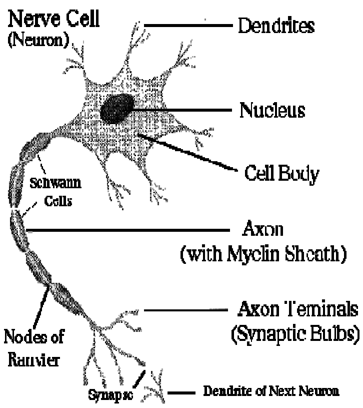
Structure of Insect Nervous System:

The principle structure of insect nervous system can be described with following sub-heads:

- Nerve Cell
- Central Nervous System (brain and ventral nerve cord)
- Stomatogastric nervous system

Nerve Cell:

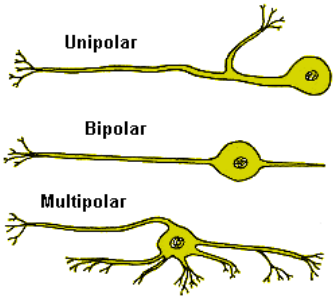
- *The basic elements of the nervous system of insects are the nerve cells (neurones) and glial cells.*
- A nerve cell consists of a *cell body (soma or perikaryon)* containing the nucleus and the *long cytoplasmic projections (axons)* which exptend to make contact with other neurons.



- Frequently, the *axon has branches, collaterals*, and ends in terminal arborisation.
- Nerve impulse conducucted from one cell to next along axons.
- Part of each neurone is specialized for the *reception of the stimuli* which initite conduction in the axon. This part is known as *dendrite*, which may arise directly from the cell body / perkaryon or reprenst the distal end of an axon in which there is no anatomical differentiation between axon and dendrite.
- The site at which neurons are closely apposed so that the activity of one nuerone can be paased on to other nuerone is called *synapse (physical gap between nerve cells*).
- The *neurons do not occur singly*, but are aggregated to form nervous system comprising the central nervous systems, with its peripheral nerves and stomatogastric nervous system.
- The nerve cells that are ectodermal in origin are anatomically and physiologically polarized.
- Besides the large nucleus, the nerve cell body of insects has (i) rough endoplasmic reticulum (RER), (ii) Golgi complexes distributed throughout the cytoplasm, (iii) lysosomes, (iv) multivesicular bodies and (v) mitochondria.
- *Axons are cytoplasmic projections* that arise from the axon-cone, frequently a narrow, morphologically distinct region at the junction of soma and axon. The threshold for the generation of action potential is lower at the axon cone than elsewhere. *Axons lack Golgi* but contain some mitochondria and neurotubules that transfer materials from the perikaryon to the axon terminal.
- Insect axons are tunicated, and not myelinated as the vertebrate axons.
- The axon of insect neuron is almost *entirely enveloped* (wrapped), except in synaptic regions, *by several loose layers of glial (Schwann) cells* (but do not tighten down as in case of myelination).

Types of Neurons:

Based on number of Projections:



- Most insect neurons are *monopolar or unipolar*, having only a *single projection from the perikaryon*. This projection, or nuerite, subsequently branches to form the axon and dendtrite. They are lying on the periphery of the ganglion.
- *Bipolar:* The peripheral sensory cells are bipolar with short distal dendrite receiving stimuli from environment and a proximal axox entending to the central ganglia (passing CNS without synapse).
- Some *multipolar cells* occur in hypocerebral and frontal ganglia, are associated with *stretch receptors.*

Based on function:

Afferent Neurons	*Efferent Neurons*
Sensory Nuerons or Receptor Neurons	Motor Neurons
Carry nerve impulses from sensory organs or receptors to CNS	Carry nerve impulses away from CNS to effectors such as muscles or glands
Dendrite process extending to cuticle, communicate with specialized interneurons, axons conduct towards CNS	Involved in muscular control
Axons from most sensilla are believed to extend to ganglia of CNS without any synapses	Axon forms neuro-muscular junctions with effectors

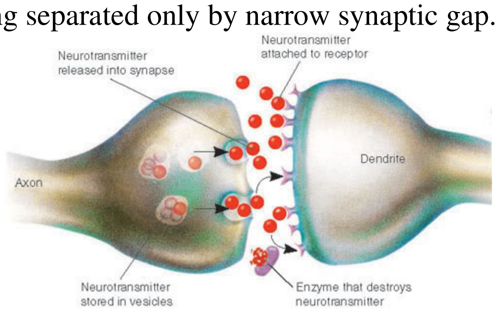
- Some direct contacts are known to occur between affrerent, sensory, fibres and motor neurons, but these monosynaptic pathaways are unlikely to occur commonly. But ingeneral, *interneurons* are interpolated between sensory and motornuerons, and in most of the neurons in the central nervous system are internuerons. Afferent *fibres* may synapse directly with *efferent fibres,* but more frequently one or more nuerones, known as *internuerons,* are interpolated between two. Many interneurons are confined to individual ganglia. The best known of these are in the brain, in the optic lobes and corpora pedunculata.

Glial Cells:

- Each neurone is almost wholly invested by one or more glial cells, which form an *insulating protective sheath around it*. These cells *serve to insulate axons* from each other and it is believed that synapse occur where glial folds are absent.
- The glial cells pass nutrient materials to neurone; this is facilitated by finger like pushings into the neurone.

Synapse:

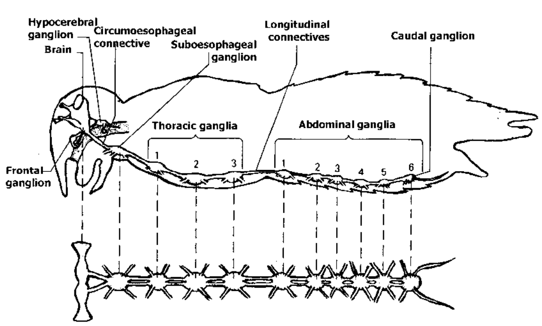
- A *gap between two neurons* that functions as the *site of information transfer* from one neuron to another.
- Synapse is the junction between two neurons (axon-to-dendrite) or between a neuron and a muscle*"nerve impulses cross a synapse through the action of neurotransmitters"*
- *Synapses occurs where glial cells are absent* and the axons lie very closed together, their membranes being separated only by narrow synaptic gap.

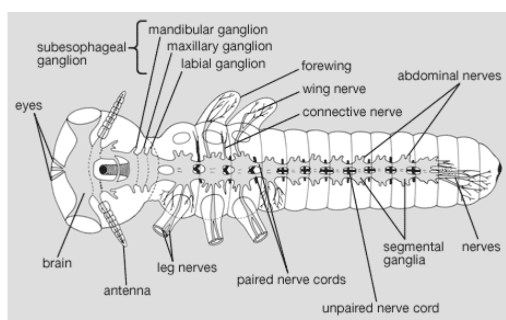


- Nerve impulses are essential for the propagation of signals.
- These signals are sent to and from the central nervous system via efferent and afferent neurons in order to coordinate smooth, skeletal and cardiac muscles, bodily secretions and organ functions critical for the long-term survival of multicellular vertebrate organisms such as mammals.
- Neurons form networks through which nerve impulses travel. The impulse travels through nerve axons and synapse by *electrochemical reactions.*
- Each neuron receives as many as 15,000 connections from other neurons.
- Neurons do not touch each other; they have contact points called synapses.
- A neuron transports its information by way of a *nerve impulse*. The impulse travels through nerve axons (before it reaches to synapse) by *electrochemical reaction through creation and transfer of action potential.*
- When a nerve impulse arrives at the synapse, it releases *neurotransmitters (Acetyl choline)*, which influence another cell, either in an inhibitory way or in an excitatory way-*Chemical Nuerotransmission*.
- The next neuron may be connected to many more neurons, and if the total of excitatory influences is more than the inhibitory influences, it will also "fire", that is, it will create a new action potential at its axon hillock, in this way passing on the information to yet another next neuron, or resulting in an experience or an action.

CENTRAL NERVOUS SYSTEM (CNS)

- The central nervous system (CNS) arises from the ectoderm on either side of the ventral midline.
- Central nerous system consists of *brain and ventral nerve cord (VNC).*
- It consists of a chain of *segmentally arranged ganglia* joined together by paired interganglionic connectives. The prikarya of internuerons and motor neurons are aggregated to fom ganglia.
- In many embryonic insects there is a paired ganglion in each segment of the body, but these always show some degree of confusion be fore the insect emerges from the egg.
- The *most anterior ganglion is the brain or cerebral ganglion lying dorsal to the oesophagus in the head.*
- The CNS in mammals comprises of brain and spinal cord, while in insects it is made up of brain and central nerve cord.





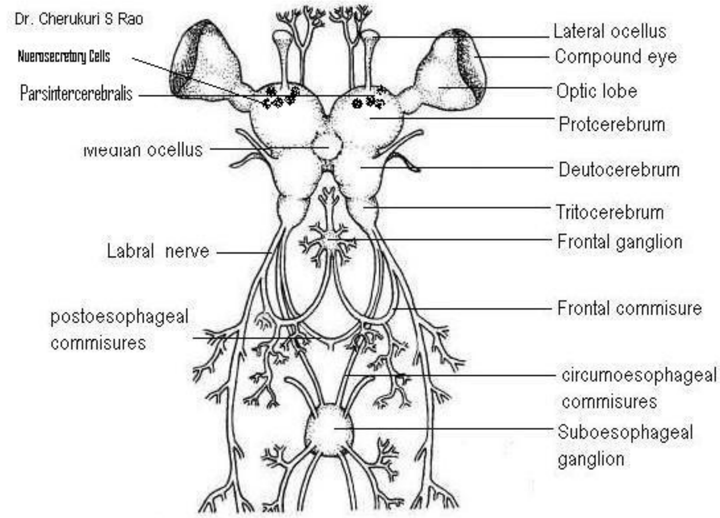
Insect Nervous System - Ventral View

Dr. Cherukuri S Rao

Brain:

- The brain is the *principal association centre* of the body, receiving sensory input from the sense organs of the head and via, ascending interneurons from the more posterior ganglia.
- The insect brain is a *centre for receiving sensory stimuli from all sensory organs located on the head and the posterior ganglia.*

- Motor nerves from the brain innervate antennal muscles and other posterior ganglia. Brain to some extent controls the activities of the rest of the nervous system and also governs the behavior and learning process.



Insect Brain - Anterior View

- The insect brain is a *fusion of three pairs of ganglia*, each supplying nerves for specific functions.

Protocerebrum:

- The first pair, called the *protocerebrum*, connects to the *compound eyes and the ocelli* and controls vision.
- The protocerebrum is a *bilobed structure* and is continuous laterally with the optic lobes.
- It is the *most complex part* of the brain.
- On either side of the midline, lying anterodorsally is a mass of cells called *Pars intercerebralis*, anterior cells of which provide fibres to ocellar nerves. *The neurosecretory cells lying in pars intercerebralis extend axons to the corpora cardiaca*.
- At the sides of the parsintercerebralis are the *corpora pedunculata,* which has two lobes (α & β). The corpora pedunculata have an important role in visual integration in social Hymenoptera, but in other insects they are relatively unimportant.
- *Optic lobes* are the lateral extensions of the protocerebrum to the compound eyes, each lobe consists three neropile masses.

Duetocerebrum:

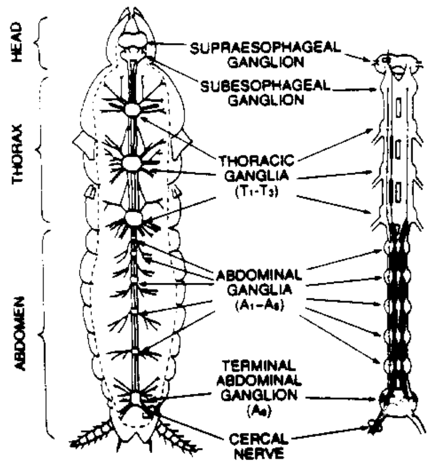
- The *deutocerebrum* innervates the *antennae*.
- Deutocerebrum has *antennal lobes*, the dorsal parts have sensory and the ventral have motor nerves.

Tritocerebrum:

- The third pair, the *tritocerebrum*, controls the *labrum (upper lip)*, and also connects the brain to the rest of the nervous system.
- Tritocerebrum lobes lie beneath the deutocerebrum and are connected with the sub-oesophageal ganglion.
- Anteriorly, the sensory and motor nerves connect with frontal ganglia and the labrum.
- The tritocerebrum is composed of fibres and synapses between the frontal ganglion connectives and the supra- and sub-oesophageal ganglia.

Ventral Nerve Cord (VNC):

- Embriologically, in the insect CNS, there are totally 20 ganglia: *3 in the brain, 3 sub-oesophageal, 3 thoracic and 11 abdominal.*
- The ventral nerve cord consists of a chain of ganglia *viz., the sub-oesophageal, thoracic and abdominal ganglia*.



Sub-oesopghageal ganglia:

- Below the brain, another set of fused ganglia forms the *subesophageal ganglion*. Nerves from this ganglion control most of the *mouthparts, the salivary glands, and the neck muscles*.
- Suboesophageal ganglia are absent in *Hydrometra* and *Stylops*.
- The *sub-oesophageal ganglion* is considered to be formed by the *fusion of ganglia of mandibular, maxillar and labial segments*, since it innervates these segments. In addition it also innervates to some extent the neck and the salivary glands.

Thoracic ganglia:

- Typically, an insect should have *three thoracic ganglia*, innervating muscles and sensilla of the thorax and its appendages. *Musca*, *Syrphys* and *Tabanus* etc., have only one thoracic ganglion, *Melolantha*, *Apis*, *Culex* etc., have two and *Blatta*, *Sirex* etc., have three thoracic ganglia.

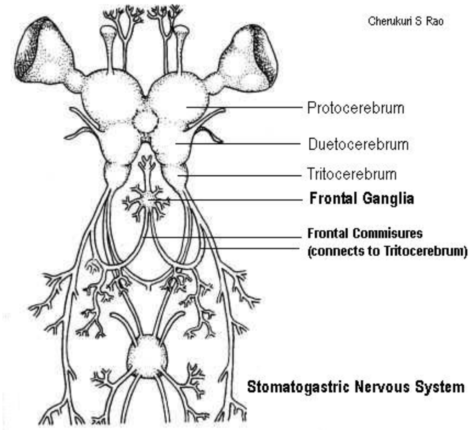
Abdomenal ganglia:

- The *abdominal ganglia are maximum eight in Thysanura*, while in most insects the posterior four ganglia are fused together to form a single last ganglion. The degree of fusion varies from species to species. In *Musca* all the ventral ganglia are fused to form a single mass. In general, the adults show more consolidation than the immature stages of the same insect.
- The *abodmenal ganglia are smaller* than those of thorax; in general, fewer peripheral nerves arise from each of them than arise from the thoracic ganglia.

VISCERAL NERVOUS SYSTEM

- This can be divided into *stomatogastric nervous system, ventral visceral nervous system, and caudal visceral nervous system* for the convenience, but in general, only *stomatogrstric nervous system* is studied in insects in detail as a system perse.
- The *stomatogastric nervous system (sympathetic nervous system-autonomus system)* consists of a number of small ganglia and their associated nerves. Above the oesophagus, in front of the brain, is the small *frontal ganglion,* which is connected by

a nerve (*frontal commisure*) to *tritocerebral lobe* on each side. Sometimes a median frontal nerve extends forwads from the ganglion to the wall of the pharynx and posteriorly a median recurrent nerve runs along oesophagus beneath brain, joining hycerebral ganglion just benind brain.



- The frontal ganglion contains the endings of axons from the brain and from the recurrent nerve, and sends motor axons ot the muscles of the gutwall. Thus it acts as a motor realy centre, co-ordinating local sensory input with premotor excitation from the barin.
- The frontal ganglion may control *swallowing movements,* but most of the movements of the foregut and midgut are directly controlled by the *ingluvial ganglion*.

- The *ventral visceral nervous system* is in close contact with the ventral nerve cord and consists of unpaired ventral longitudinal nerves (Leydig's nerves) originating in the median commissural area of each ventral ganglion. These run caudally and each nerve gives off a pair of branches between the ganglia. They innervate the tracheal system, muscles of spiracles and some somatic muscles.
- The *caudal visceral nervous* system arises from the compound abdominal ganglion and innervates the reproductive system and proctodeum.

▪ The peripheral nervous system present in mammals is divided into somatic nervous system (SNS) and the autonomous nervous system (ANS)-the latter does not exist in insects. Somatic system includes the sensory receptors and the motor nerves responsible for the muscle response.

Notes:

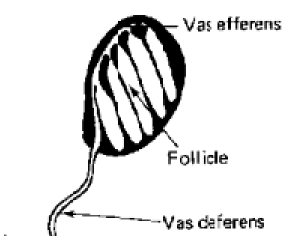
Lecture 18

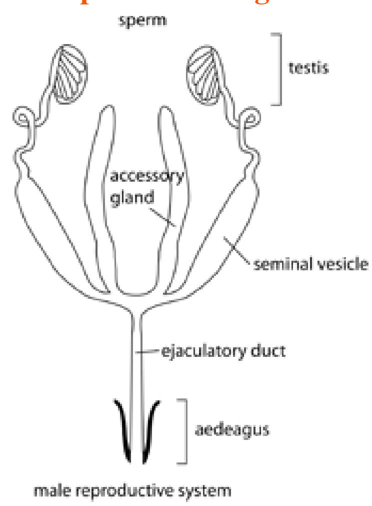
Reproductive System

Structure of male & female reproductive systems-structure & types of ovarioles, structure of follicles, types of reproduction in insects.

- Insects are not always sexually mature when they have completed the final molt to adult stage, and in species with an adult diapause, there may be considerable delay before mature sex cells are produced. Hence it is necessary to distinguish between becoming adult and becoming sexually mature.
- The reproductive organs do not contribute primarily, to the welfare of the individual, as other organs but their chief concern lies with the succeeding generation. This system is divided into two parts *internal genitalia and external genitalia*. *The internal genitalia facilitate the development of germ cells. The external genitalia accomplish the union between the sexes and enable the female to deposit the eggs.*
- The male and female reproductive systems *generally consist of paired gonads connected to median duct leading to the gonopore*.
- *Accessory glands are often present which in the male are usually concerned with spermatophore formation and sperm maintenance and in the female provide glue for sticking the eggs to the substratum or provide the substance for a complex egg-case*.
- The female has, in addition, a *spermatheca for storing sperm after copulation*.

Anatomy of MALE internal reproductive organs:





The male reproductive *internal genetalia* typically consist of
- *a pair of testes* connecting with
- *vasa differentia,* and a
- *median ejaculatory duct*.
- In most insects there are also a number of *accessory glands* which open into the vasa deferentia or the ejaculatory duct.

The male reproductive *external genetalia* typically consist of
- aedeagus
- Clasping structures (in some)

Testis:
- The testis lies above or below the gut in the abdomen and often close to the midline.
- Usually each testis consists of a number of *testis tubes or follicles*.

- The walls of follicles consist of a *thin epithelium* standing on a basement membrane, and the follicles bound together by peritoneal sheath. Testis as a whole is enclosed in a common coat known as scrotum.

Vasa deferens

- The testes discharge spermatozoa into the lateral ducts, *vasa differentia* which is *paired canals* (partly or wholly mesodermal in orgin).
- From each testis follicle a fine, short, *vas efferens* connects with the vas differens, which is a tube with fairly thick bounding epithelium.
- The vas deferens runs backwards to lead into distal end of the ejaculatory duct
- A portion of the vas deferens is often *enlarged to form the seminal vesicle, which stores the sperm before they are discharged into the female*. The seminal vesicles have glandular linings that secrete nutrients for nourishment and maintenance of the sperm.

Ejaculatory duct

- Each vas deferens becomes enlarged posteriorly to form a *common ejaculatory duct*.
- This *leads to the aedeagus*, is ectodermal in origin and is lines with cuticle. Often at least a part of the wall is muscular. Ephemeroptera have no ejaculatory duct and vasa deferentia lead directly to the paired genital openings.
- The terminal section of ejaculatory duct is enclosed in a finger like invagination of the ventral body wall, *male copulatory organ or aedegus*.

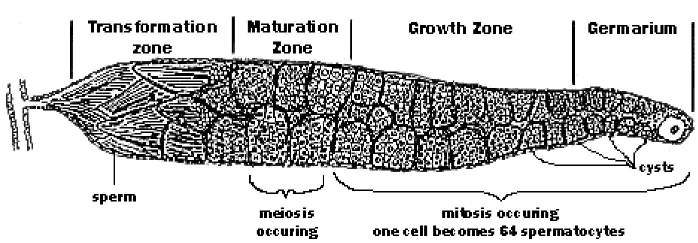
Accessory glands

- One to 3 pairs of accessory glands are usually present associated with genital ducts (Mushroom shaped gland is cockroach).
- The male accessory glands *open into the vasa deferentia* or the distal end of the ejaculatory duct.
- They may be exctodermal in origin, when ther are known as *ectodernia*, and in this case they may open into ejaculatory duct. Ectodernia occur in coleoptera. Glands of *mesodermal origin, mesodenia,* are found in orthoptera. Where large number of glands occur they probably produce a variety of secreations.
- *A primary function of these secretions is to facilitate spermatophore formation, sperm maintenance, sperm nourishment and sperm transfer.*
- In some cases, the secretions may have some nutritional value for the female or they may accelerate oocyte maturation.

Spermatogensis (Structure of follicle)

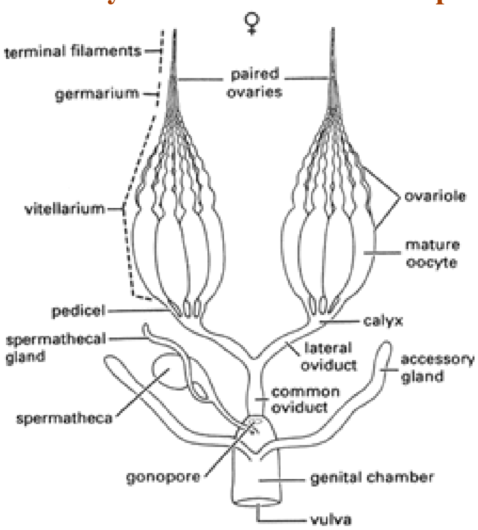
- Each testis is composed of a group of *testicular follicles*.
- The testicular follicles are *lined with a layer of epithelium.*
- Each follicle is *divided into a series of zones* characterized by the presence of sex cells in different stages of development.
- Each testicular follicle leads into a small duct the *vas efferens* which in turn opens into *vas deferens*

Testis Follicle Showing Spermatogenesis



- At the distal end of each follicle is the *germarium*, in which the germ cells divide to produce *spermatogonia*. The germarium is the region containing the *primordial germ cells or spermatogonia* which undergo multiplication. As more spermatogonia are produced, they push those which have developed earlier down the follicle.
- Three zones of development are commonly recognized below the germarium.
- The *zone of growth* is where the spermatogonia increase in size, undergo repeated mitosis and develop into spermatocytes.
- The *zone of division* and reduction where the spermatocytes undergo meiosis and give a rise to spermatids.
- The *zone of transformation* where the spermatide become transformed into spermatozoa.

Anatomy of FEMALE internal reproductive organs:



The female reproductive *internal gentalia* consists of

- A *pair of ovaries (gonads)*, which connects to
- A *pair of lateral oviducts (gonoducts)*. These join to form
- A *median oviduct (oviduct common)* opening posterior into
- *Genital chamber*.
- Opening from the genital chamber or vagina, is a *spermatheca* (*recepteculum semin*) for storage of sperm.
- Frequently *a pair of accessory glands* is present.

The female reproductive *external gentalia* consists of

- Sometimes, genital chamber forms a tube*, the vagina* (opens behind the 8^{th} or 9^{th} abdominal sternum), and this is often developed to form *a bursa copulatrix* (*copulatory pouch*) for reception of the penis.

Ovary:

- The ovaries lie in the abdomen above or lateral to the gut.
- Each consists of a number of *egg-tubes, or ovaries*, comparable with the testis follicles in male.
- Development of the oocytes takes place in ovaries.
- The number of ovaries is roughly constant within species. Usually, 4 to 8. In isoptera it is said to reach more than 2000.

- A typical ovariole consists of three parts namely: *Terminal filament, Egg tube and Supporting stalk or pedicel*. Distally each ovariole is produced into a long terminal filament. The terminal filaments of all ovarioles of one side unite distally with one another in a suspensory ligament. Proximally the ovariole narrows to a fine duct, the pedicle, which connects with the oviduct.

Oviduct:

- The oviducts tubes with walls of single layer of columnar cells.
- Usually, two lateral oviducts join a median oviduct which is ectodermal in origin and hence is lines with cuticle.
- The median oviduct is usually more muscular than the lateral oviduct.

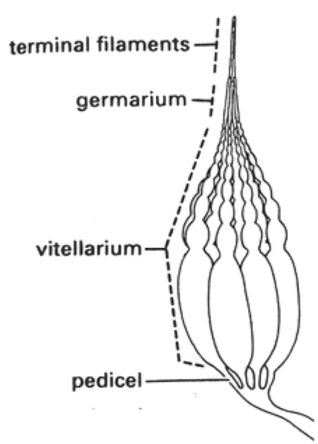
Spermatheca:

- This serves for the *storage of sperm* from the time female is impregnated until the eggs are fertilized.
- This is present in most female insects.
- Spermatheca opens into genital chamber independently of the oviduct.
- This is ectodermal in origin, and is lined with cuticle.

Accessory Glands

- Female accessory glands often arise from the genital chamber or the vagina.
- Often these glands *produce a substance for attaching the eggs to the substratum* during the oviposition and hence they are often called as *collateral glands*, but there are frequent instances of specialized functions which have been fully investigated in cockroach, *Periplanata*. In this insect the eggs are laid in an *ootheca* consisting of a tanned, cuticle-like substance, which is produced by the accessory glands. The cuticle is produced by epidermal cells.
- The frothy secretions which form the eggpods of grasshoppers and gelatinous sheath of *Chironomous* (Diptera) eggs are also produced by accessory glands.

***Oogenesis*:**



- Each ovariole consists of a *distal germarium* in which oocytes are produced from oogonia, and a more *proximal vitellarium* in which the oocytes grow as *yolk is deposited* in them.
- The vitellarium in a mature insect froms by far the greater part of the ovariole.
- Typically each ovariole contains a linear series of oocytes in successive stages of development with the most advanced in the most proximal position at the greatest distance from the germarium.

The egg tube is divided into two parts.

- End chamber of *germarium*-germ cell are seen in an active stage or division and differentiation.
- *Zone of growth or vitellarium*-The egg cells grow and attain their mature stage. Consists of longitudinal series of developing egg. As they grow by deposition of yolk the eggs distend the ovariole. Each egg is enclosed in a layer of follicular epithelium which secrets chorion or egg shell.

There are two types of ovarioles: There are two broad categories of ovarioles, based on the presence or absence of special nurse cells (trophocytes).

<table>
<tr><th>Panoistic ovariole</th><th colspan="2">Meriostic ovariole</th></tr>
<tr><td rowspan="2">These ovarioles have no special nurse cells</td><td colspan="2">These ovarioles have special nurse cells, trophocytes (which are responsible for producing yolh of the egg)</td></tr>
<tr><td>Telotrophic (Acrotrophic) ovariole</td><td>Polytrophic ovariole</td></tr>
<tr><td>The developing egg cell receives its yolk from the undifferentiated follicular epithelium.</td><td rowspan="2">All the trophocytes are terminal in the germarium, and are connected with the developing oocytes by cytoplasmic strands.</td><td rowspan="2">Trophocytes accompany each oocyte and are enclosed within follicle</td></tr>
<tr><td>Found in primitive orders (Apterygota, thysanura, odonata, plecoptera, orthoptera, Isoptera)</td></tr>
<tr><td>Among the holometabolous insects, only siphonoptera have ovarioles of this type</td><td>Hemiptera, Coleoptera</td><td>Endopterygota</td></tr>
</table>

- The principal function of the trophic tissue of meriostic ovarioles is to supply RNA to the oocyte in large quantities for its subsequent rapid growth.
- *Vitellogenesis:* The dopsition of yolk in oocyte is called vitellogenesis occurs in the more proximal parts of the ovariole and it results in a vaery rapid increase in size. The yolk (produced by trophocytes) may be *protein-carbohydrate complex yolk* and *lipid yolk*.
- The *egg shell* of the eggs is formed largely, and in many cases wholly, *by the follicle cells*. Apart from this, follicle cells also secrete *chorion*, part of egg shell.
- The passage of oocytes into oviduct, a process known as *ovulation*.

Types of Reproduction: Oviparous

- Most insects are *oviparous*, i.e, they lay eggs which hatch after deposition.
- The *embryonic development starts after the eggs are laid*, and after completion of incubation period the immature emerges.
- All the nourishment for the embryonic development is met by yolk present in the egg.

Exceptions to these generalizations are: Viviparity, Polyembryony, Parthenogenesis, Alternation of generations, Paedogenesis.

***Viviparity*:**

- The *fertilized eggs and are retained within the body of female for some time before being laid*.
- The embryonic development is completed within the body of the female parent and which therefore produce larvae or nymphs instead of laying eggs are said to be viviparous.
- Viviparous species commonly produce fewer off springs than oviparous.
- These may have reduced number of ovarioles.
- There are four main types of viviparity.

***(a) Ovoviviparity*:**

- Many species retain the eggs in the genital tracts until the larvae are ready to hatch, *hatching occurring just before or as the eggs are laid*.

- All the nourishment for the embryo is present in the egg and no special nutritional structures are developed.
- Ovoviviparity differs from normal oviparity only in the retention of eggs.
- Mainly Diptera (Tachnidae), Dictyoptera (cockroaches), Homoptera, Thysanoptera, Coleoptera, Lepidoptera.

(b) Pseudoplacental viviparity:

- In this the insects produce *eggs containing little or no yolk*, which are retained by the female.
- The *eggs receive nourishment via embryonic or material structure called pseudoplacenta*.
- Viviparous development continues upto the time of hatching.
- Eg. Aphids, Dermoptera (Earwigs), Heteroptera, Psocoptera (Book lice).

(c) Adenotrophic vivipatiry:

- Fully developed eggs with chorions are produced and passed to the uterus where they are retained.
- Embryonic development follows as in ovoviviparity, but when the *larva hatches it remains in the uterus and is nourished by maternal glands*.
- The larva feeds on the uterus on the secretion of the specialized glands, known as *milk glands*; this milk contains proteins, aminoacids and lipids. The nutrient in the milk is derived from the blood meals taken by the parent fly.
- This type of viviparity only occurs in *Glossina* and the Pupipara.

***(d) Haemocoelus viviparity*:**

- *The development occurs in the haemocoel of the parent female*.
- This type of development occurs throughout *strepsiptera* and in some larval cecidomyidae which reproduce paedogenetically.
- Female strepsiptera have 2 or 3 ovarial strands on either side of the midgut, and mature oocytes are released into haemocoel by the rupture of the ovarian walls.

Polyembryony:

- Sometimes, *an egg instead of giving rise to single larva may produce two or more* and this process being called polyembryony.
- It occurs occasionally in Acridoidea, but in some endoparasitic insects as regular phenomenon (*Platygaster* of Hymenoptera, Ichneumonidae insects which parasite the eggs and larva of Lepidoptera).

Parthernogenesis:

- Sometimes, *eggs develop without being fertilized* and this phenomenon is known as parthenogenesis.
- Occasional parthenogenesis, resulting from the failure of a female to find a mate, is probably widespread, while in others, normal means of parthenogenesis is regular.
- It has been recorded in almost all insect orders except odonata, dermaptera, neuropteran and siphonoptera.
- The sex of the off-spring developing from an unfertilized egg is depending on the sex-determining mechanism of an insect.
- An alternative classification based on the sex of the offspring produced as a result of parthenogenesis is as follows:

Arrhenotoky	*Only males are produced* (eg.the coccid, Icerya purchasi)
Thelytoky	*Only females are produced* (eg. Unmated males of Schistocerca, and Bombyx mori)
Amphitoky	*Individuals of either sex may be produced*

Alternation of generations:

- A number of insects combine the advantages of parthenogenesis with the advantages of bisexual reproduction by an alternation of generations. This occurs, for instance, in the cynipidae, which are commonly bivoltine, a generation of parthenogenetic females alternating with bisexual generation.
- ***Aphids*** have more complex laternation of generations with several parthenogenetic generations occurring during the summer. Aphids reproduce rapidly, combining the advantages of parthenogenesis with viviparity and paedogenesis, so that the successive generations are extensively telescoped.

Paedogenesis:

- Sometimes *immature insects mature precociously and are able to reproduce*, this phenomenon is called paedogenesis.
- It arises from an unusual hormonal balance and most insects reproducing paedogentically are also parthenogenetic and viviparous.
- In *Miastor* and *Micromalthus* the larva gives birth to other larvae, occasionally lay eggs. In some, nymphs give birth to nymphs.

Notes:

Lecture 19

Secretory (endocrine) System-structure & functions of neuro-secretory organs (neuro-secretory cells of brain, corpora cardiaca, corpora allata, pro-thoracic glands & ring glands).

- The endocrine organs and hormones together referred as endocrine system in insects.
- The endocrine organs produce *hormones* which travel usually in blood to various organs of the body coordinating their activities.
- The endocrine system is thus complimentary to the nervous system.
- *Endocrine system* helps to maintain homeostasis, coordinate behavior, and regulate growth, development, and other physiological activities.
- A *hormone* is a chemical signal sent from cells in one part of an organism to cells in another part (or parts) of the same individual. Hormones are often regarded as *chemical messengers*. Although typically *produced in very small quantities*, hormones may cause profound changes in their target cells. Their effect may be stimulatory or inhibitory. In some cases, a single hormone may have multiple targets and cause different effects in each target.

Endocrine organs are of two types:

- *Neurosecretory cells* in the central nervous system, and *specialized endocrine glands*. *The neurosecretary cells are modified motorneurons*.
- Both types of organs produce hormones which are generally released directly or indirectly via storage organs (*neurohaemal organs*), into blood, but in some instances the hormones produced by neurosecretaory cells are conveyed to the target organs along the axons of the cells.
- Nervous stmuli commonly lead to the release of the hormones.

Endocrine Organs in insects:

- The endocrine organs of insects are of two types; *neurosecretary cells* (mainly within the central nervous system) and the *specialized endocrine glands* (such as corpora cardiac, corpora allata and prothoracic glands).

Neurosecretory Cells:

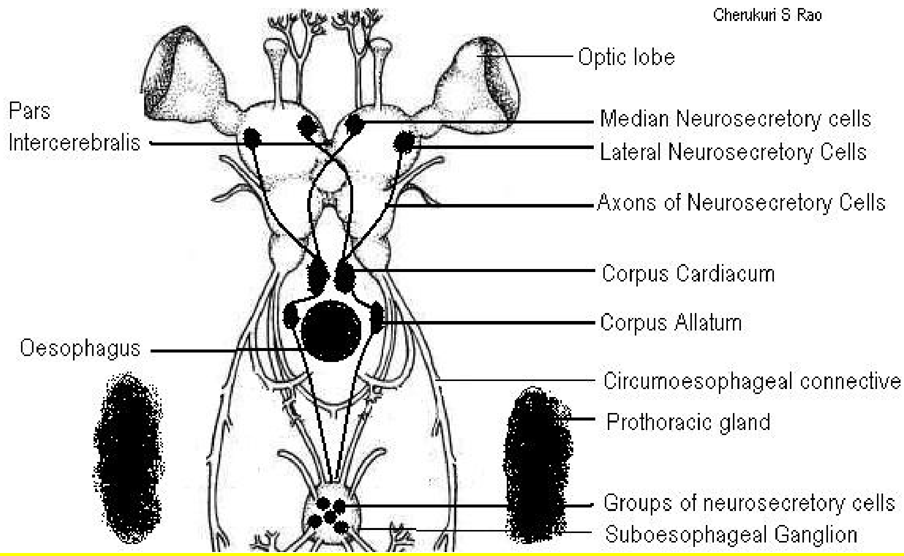
- The neurosecretary cells normally occur in the ganglia of the CNS.
- They generally resemble typical bipolar nerve cells, but are characterized by showing cytological evidence of secretion.
- *The neurosecretary cels are modified motorneurons*.
- The secretion is granular, synthesized in cell bodies and pass down to axons.
- It is possible that the visible secretion is only a carrier (possibly a lage protein), to which the smaller hormone molecule is attached.
- When hormone is finally released it becomes separated from the carrier (protein) and is then free into blood.
- The endocrine activity of neurosecretary cells may take one of two forms: the cells may either produce hormones which act directly on effector organs, or they may act on other endocrine organs, which in turn, are stimulated to produce hormones.

Neurosecretory cells of the Brain:

- The neurosecretory cells are *found in clusters, both medially and laterally in the insect's brain*.
- Axons from these cells can be traced along tiny nerves that run to the corpora cardiaca and corpora allata.
- Typically there are two groups of neurosecretory cells on each side of the brain.
- One group is in the pars intercerebralis, near the midline, are called *median neurosecretary cells*. The axons from these cells pass backwards through the brain and

some or all of them cross over to the opposite side, emerging from the brain as a nerve which runs back to the corpus cardiacum. Most of the fibres end here, but few pass through the corpus cardiacum to the corpus allatum, and in the locust, to the foregut and ingluvial ganglion.

- The second group of cells (*lateral neurosecretory cells*) is variable in position, but usually between the optic lobe and corpora pedunculata. From these cells, a second axon also extends to the corpus allatum.



- The products of the neurosecretory cells of the brain (*Brain Hormone*) pass along the axons, usually to the corpora cardiac or allata. Here they may be stored or released.
- The secretions of the neurosecretory cells in the pars intercerebralis (median NS cells) promote the functioning of the prothoracic glands (PTG), stimulate protein synthesis and possibly control water loss, oocyte development and activity.

Neurosecretory cells of other ganglia:

- Large number of neurosecretory cells occurs in the ventral ganglia of the nerve cord.
- In *bombyx* there is more number of NS cells in the ventral ganglia than brain.
- Different cell types are widely distributed in different ganglia.
- The secretory products are liberated into blood via neurohaemal organs on the peripheral nerves.
- *The functions of these cells in general are not known*, but in some cases they are known to be concerned with water regulation.

Corpora Cardiaca:

- The corpora cardiaca are a pair of organs often closely associated with aorta.
- These are absent in collembolan.
- Each organ contains endings of axons from NS cells in the brain and other axons passing through to the corpora allata.
- The corpora cardiac *store and release hormones from NS cells of the brain*, to which they are connected by one or two pairs of nerves.
- In addition, the intrinsic secretory cells produce hormones which are concerned with the regulation of the heartbeat and have other physiological effects.

Corpora Allata

- The *corpora allata are glandular bodies, usually one on either side of oesophagus*.
- They are fused to a single organ in diptera.

- Each is *connected with corpus cardiacum* of the same side by a nerve which carries fibres from NS cells of the Brian.
- In addition, a fine nerve connects each corpus allatum with suboesophageal ganglion.
- The corpora allata produce *Juvenile Hormone* (JH) which regulate metamorphosis and yolk deposition in eggs. Changes in the volume of corpora allata or in the sizes of the cells within gland are not necessarily correlated with JH activity in the haemolymph.

Prothoracic Glands (PTG)

- The prothoracic, or thoracic, glands are *a pair of diffuse glands at the back of the head or in the thorax*.
- Each gland has a rich tracheal supply and often nerve supply.
- The glands show cycles of development associated with secretion. At rest, the nuclei are small and oval, but in active gland, they become enlarged and lobulated and the cell has more extensive and deeply staining cytoplasm. During active phase, the number of mitochondria increase and endoplasmic reticulum becomes more extensive. This reflects the production of enzumes engaged in synthesis of *ecdysone*.
- The prothoracic glands produce *moulting hormone, ecdysone*, and except in thysanura, which moult as adults, the prothoracic glands breakdown soon after the final moult to adult.

Ring Gland

- In the larvae of cyclorrhaphous Diptera, the *ring gland surrounds the aorta just above the brain*.
- *It is formed from corpora allata, corpora cardiac and prothoracic glands, all fused together*.
- The ring gland is connected to the brain by a pair of nerves.

Disposal of Hormones

- Hormones produced in the NS cells pass along the axons of these cels as a result of the intra-axonal flow of cytoplasm or possibly along the minute tubes which run the length of the axon. In this way hormone may pass directly to their target organs or they may ultimately be released into the blood.
- Direct transfer of neurosecretion to specific target organ is widespread. Where the hormones are released into blood, specialized *neurohaemal organs* are involved. For instance, the *corpora cardiac* serve for the storage and release of the brain hormone (released from NSC of brain), and othe position of these organs adjacent to aorta, may facilitate dispersal of the hormone. Other nuerohaemal organs are present in thorax and abdomen, and nerves of peripheral nervous system. Fat body is always absent in neurohaemal organs and hence haemolymph can circulate freely over them.
- JH is lipophilic and is distributed in the haemolymph bound to a specific water-soluble lipoprotein.
- Ecdysone is water soluble and is released directly into haemolymph.

Role and function of Hormones:

- When an immature insect has grown sufficiently to require a larger exoskeleton, sensory input from the body activates certain neurosecretory cells in the brain.
- These neurons respond by secreting *brain hormone which triggers the corpora cardiaca to release their store of prothoracicotropic hormone* (PTTH) into the circulatory system.
- This sudden "pulse" of *PTTH stimulates the prothoracic glands to secrete molting hormone* (ecdysteroids). Molting hormone affects many cells throughout the body, but its principle function is to stimulate a series of physiological events (collectively known as apolysis) that lead to synthesis of a new exoskeleton.

- During this process (apolysis), the new exoskeleton forms as a soft, wrinkled layer *underneath* the hard parts (exocuticle plus epicuticle) of the old exoskeleton. The duration of apolysis ranges from days to weeks, depending on the species and its characteristic growth rate. Once new exoskeleton has formed, the insect is ready to shed what's left of its old exoskeleton. At this stage, the insect is said to be pharate, meaning that the body is covered by two layers of exoskeleton.
- As long as ecdysteroid levels remain above a critical threshold in the hemolymph, other endocrine structures remain inactive (inhibited). But toward the end of apolysis, ecdysteroid concentration falls, and neurosecretory cells in the *ventral ganglia begin secreting eclosion hormone*. This hormone triggers ecdysis, the physical process of *shedding the old exoskeleton*. In addition, a rising concentration of eclosion hormone stimulates other neurosecretory cells in the *ventral ganglia to secrete bursicon*, a hormone that causes *hardening and darkening of the integument* (tanning) due to the formation of quinone cross-linkages in the exocuticle (sclerotization).
- In immature insects, *juvenile hormone is secreted by the corpora allata* prior to each molt. This hormone inhibits the genes that promote development of adult characteristics (e.g. wings, reproductive organs, and external genitalia), causing the insect to remain "immature" (nymph or larva). The corpora allata become atrophied (shrink) during the last larval or nymphal instar and stop producing juvenile hormone. This releases inhibition on development of adult structures and causes the insect to molt into an adult (hemimetabolous) or a pupa (holometabolous).
- At the approach of sexual maturity in the adult stage, brain neurosecretory cells release a brain hormone that "reactivates" the corpora allata, stimulating renewed production of juvenile hormone. *In adult females, juvenile hormone stimulates production of yolk for the eggs. In adult males, it stimulates the accessory glands to produce proteins needed for seminal fluid* and the case of the spermatophore. In the absence of normal juvenile hormone production, the adult remains sexually sterile.
- Although the role of hormones in the physiology of molting was first described by V. B. Wigglesworth in the 1930's, there is still much about the process that we do not fully understand. Insect endocrinology is currently an active area of research because it offers the potential for disrupting the life cycle of a pest without harm to the environment.

Lecture 20

Taxonomy: importance-history-binomial nomenclature-types: holotype, allotype, paratype-suffixes of tribe, subfamily, family, super family-law of priority-synonyms & homonyms-species, sub-species, genus, family, order et.

- Insects came into existence 300-500 million years ago, constitutes 70% of animal kingdom.
- Every year >2000 new speices are being added, and to deal with such large number, to refer, to make use of study such as morphology, biology, physiology, ecology, toxicology etc., systematic classification is essential.

"Wisdom begins by calling things by their right names,"

History:

- ***Aristotle (384-322 BC):*** A good beginning of taxonomy was made by Aristotle. He erected *entomon*. He could distinguish mandibulates and haustellates; winged and wingless forms. The insect orders like coleopteran, dipteral, psyche (Lepidoptera) were created by him. Hence, he was called as *Father of Biological Classification*.
- ***Linnaeus (1707-1778):*** *Father of Taxonomy. Father of Binomial Nomenclature. He coined the term Insecta*. He used the term *Systematics*. His greatest contribution is *Systema Naturae*.
- Brawer (1885): Laid foundations for modern system of classification and responsible to divide class Insecta into Apterygota and Pterygota.
- Michael Anderson (1727-1806): Contemporary and rival of Linnaeus. Introduced *Numerical Taxonomy* and hence is called *Father of Numerical Taxonomy.*

Generally three terms *viz., taxonomy, systematics and classification* are in use.

Taxonomy:

- The word finds its roots in the Greek *τάξις*, *taxis* (meaning 'order', '*arrangement'*) and *νόμος*, *nomos* ('law' or 'science'). Taxonomy uses taxonomic units, known as *taxa* (singular taxon). It was coined by *A P De Candolle*, a professor of Montpellier University in France.
- *Taxonomy is the theory and practice of classifying organisms into categories based on similarities or differences, and describing of these systematically. Taxonomy* is the science of naming organisms.
- *Taxonomy* is the practice and science of classification.
- *Taxonomy* is the study of the principles of scientific classification.

Systematics:

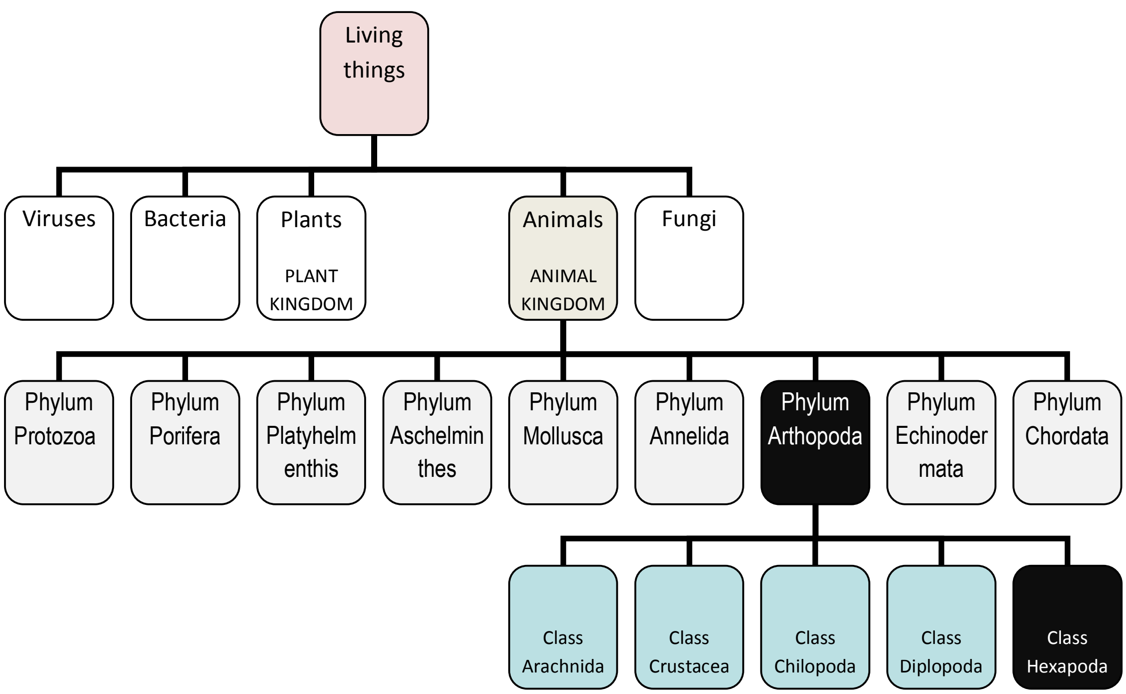
- Systematics is the area of biology devoted to the *classification of organisms*.
- Originally introduced by Carl Linnaeus (1707-1778), who based his classification system on physical traits, systematics now includes the similarities of DNA, RNA, and proteins across species as criteria for classification.
- *Systematics* is the science of study of kinds of organisms, and of any and all relationships among them, or *science of diversity of organisms.*
- *Systematics* is the study of the classification of organisms, and their historical relationships, also known as phylogenetics.

Classification: It is the scheme of arranging organisms into different groups of systematic study. *Classification* is the arrangement of organisms in to groups on the basis of their relationships.

Taxonomy is properly the describing, identifying, classifying, and naming of organisms, while "classification" is focused on placing organisms within groups that show their relationships to other organisms.

Hierarchy of biological classification: A *hierarchy* is an arrangement of items (objects, names, values, categories, etc.) in which the items are represented as being "above," "below," or "at the same level as" one another and with only one "neighbor" above and below each level.

- *The biological unit in the process of classification is the individual organism*.
- Closely related similar individuals are grouped into species, closely related species into genus, genera into family, families into order, orders into class, classes into phylum and phyla into kingdom.
- Sometimes there are certain intermediary categories like sub-class, sub-order, super-family, sub-family, tribe etc.
- The sequence of classification categories with hierarchy can be remembered by memorizing this mnemonic phrase: **K**ing **P**hillip, **C**omes **O**ut **F**or **G**oodness **S**ake!



Insect Orders			
Taxonomic Name	**Common Name & Examples**	**Wing character**	**No. of Species Worldwide**
Sub-Class : APTERYGOTA (Wingless Insects with No True Metamorphosis)			
1. Thysanura	Silver fish	--	55
2. Diplura	Pronged Bristletails	--	600
3. Protura	Proturans	--	10
4. Collembola	Springtails	--	3000

Sub-Class: PTERYGOTA (Winged Insects with Incomplete or Complete Metamorphosis)			
Super-Order: The Exopterygota (Hemimetabolous insects with incomplete metamorphosis)			
5. Ephemeroptera	May-flies	Can't fold wings over body	2000
6. Odonata	Dragons and Damsels	Can't fold wings over body	5000
7. Plecoptera	Stone-flies	Pleco-foldable	1700
8. Grylloblattodea	Ice bugs/Rock Crawlers	--	16
9. Orthoptera	Grasshoppers	Ortho-straight	20000
10. Phasmida	Stick-Insects	--	3000
11. Dermaptera	Earwigs	Derma-skin like	1200
12. Embioptera	Web Spinners	Embio-lively	300
13. Dictyoptera	Cockroaches&Mantids	Dictyo-netted	6000
14. Isoptera	Termites	Iso-same	1900
15. Zoraptera		Zor-pure, aptera-wingless	22
16. Psocoptera	Book and Bark Lice	Psokos-rubbed/gnawed (fractured wings)	2000
17. Mallophaga	Biting Lice	wingless	2800
18. Siphunculata	Sucking Lice	wingless	300
19. Hemiptera	True Bugs	Hemi-half	100000
20. Thysanoptera	Thrips	Thysano-fringed	500
Super Order: The Endopterygota (Holometabolous insects with complete metamorphosis)			
21. Neuroptera	Lacewings etc.	Neuro-nerved	4700
22. Mecoptera	Scorpion-flies	Meco-long	400
23. Siphonaptera	Fleas	Siphon-tube/pipe, aptera-wingless (wingless)	1400
24. Coleoptera	Beetles	Coleo-sheath	370000
25. Strepsiptera	Stylops	Strepsi-twisted	370
26. Diptera	True Flies	Di-two	100000
27. Lepidoptera	Butterflies and Moths	Lepido-scaly	150000
28. Trichoptera	Caddis-flies	Tricho-hairy	5000
29. Hymenoptera	Ants Bees and Wasps	Hymen-membrane	120000 +

The following is the example of Hierarchy for Honey Bee:
(Also note ***suffixes for various taxa***)

Taxa	***Name of the Taxa***	***Suffix for Taxa***
Kingdom	Animilia	--
Phylum	Arthropoda	--
Class	Insecta (Hexapoda)	--
Subclass	Pterygota	--
Order	Hymenoptera	ptera
Superfamily	Apoidae	oidae
Family	Apidae	idae
Subfamily	Apinae	inae
Genus	Apis	--
Species	dorsata	--

Species concept: A good working definition for this class is… "the smallest grouping capable of reproduction and the production of fertile offspring." The name of a species is called a *scientific binomen*. It's a two part Latin name the first of which is the *genus* and the second is the *species***,** which is always *italicized***.** Examples: *Heliothis armigera* Hubner, *Bemisia argentifolii* Bellows and Perring, *Ceratitis capitata* (Weidemann).

- ***Species:*** It is *group of individuals which are similar in structure capable of interbreeding and producing fertile offsprings* but at the same time reproductively isolated from other such groups.
- ***Sibling Species:*** Morphologically similar but reproductively isolated.
- ***Sub-Species:*** It is an aggregate of phenotypically similar populations of a species, inhabiting a geographic subdivision of the range of species and differing taxonomically from other populations of the same species (biotype/race/strain).
- ***Genus:*** A group of species having some definite similar characters or relations.
- ***Sub-Family:*** Is a group of allied genera.
- ***Family:*** A taxonomic category containing a single or group of genera of common phylogenic origin which is separated from related families by a decided gap.
- ***Order:*** Families showing similar characters from order.

Scientific Nomenclature:

- Scientific nomenclature was started with Linnaeus.
- He used *binomial system of nomenclature* for the first time for plants and animals in his 10th edition of for the first time for plants and animals in his 10th edition of *system nature* (1758).
- *Carl Linnaeus*, also known as Carolus Linnaeus (1707-1778), is often called the *Father of Taxonomy*.
- His system for naming, ranking, and classifying organisms is still in wide use today (with many changes).
- For Linnaeus, ***species*** of organisms were real entities, which could be grouped into higher categories called ***genera*** (singular, **genus**).

Binomial Nomenclature:

- It is the *double name of an organism* for genus and species in latin, followed by the author name in full without punctuation between them.
- If the sub-species name is also given, it is *trinomial*. The scientific name is printed in *italics (eg. Apis dorsata).* If it is written, it should be underlined (eg. Apis dorsata) separately. The genus name is always starts with capital letter and species name with small letter.
- The value of the binomial nomenclature system derives primarily from its economy, its widespread use, and the stability of names it generally favors.
- *The same name can be used all over the world, in all languages, avoiding difficulties of translation.*

International Code of Zoological Nomenclature (ICZN):

- The International Commission on Zoological Nomenclature is dedicated to achieving stability and sense in the scientific naming of animals, and also publishes *International Code of Zoological Nomenclature* and the *Bulletin of Zoological Nomenclature* containing applications to, and rulings by, the Commission. ICZN will distribute this information as widely as possible, working towards the provision of a free service.
- The ICZN Secretariat is housed in the Department of Palaeontology at the Natural History Museum, London, SW7 5BD U.K.

Law of Priority:

- *The underlying principle in ICZN is the law of priority*. It may so happen that *different names* are given by different scientists to the same organism. In such cases the *first published will be accepted as the correct name* provided the author has followed the rules and all the other names go as ***synonyms***. Conversely, the same name may be given by different scientists to different organisms. In such cases, the first published will be accepted as the correct name and the remaining go as ***homonyms*** and they have to be renamed.
- You should note that most animals and plants are known only by their **genus** and **species** names, i.e. *Heliothis armigera*, note also that while the **genus name is spelt with a capital letter the species name is normally spelt with a small letter, and that in printed text the pair are normally written in *italics*** the rest usually remains unsaid.
- You should also note that though an animal will generally share its genus, family, order and class names etc. with other animals its combination genus/species name will be unique to it.
- In some books you may find a persons name or part of a persons name written after the animals name i.e.*Euclida glyphica* (Linnaeus, 1758) this mean that Linnaeus was the first person to name this moth and that he did so in a work published in 1758, the brackets around his name mean that the species has since been moved to another genus. Linnaeus, being the first person to use this system widely, put a lot of moths in one genus, such as *Noctua*, and later taxonomists realized that some of them belonged to different genera and moved them, like putting them in a different box. This means that the species was named and described by Linnaeus, but the genus was described later be a different taxonomist. This process is called taxonomic revision.
- Also you will occasionally see some species written in a shortened for *Formica exsecta* Nyl., Nyl stands for Nylander, Finally you should know that scientist are still arguing about some of the family, class and order names so these may be different in different books. Note also that identifying, describing and naming things, i.e. assigning them to particular groups is ***taxonomy***, while arranging those groups in a coherent order which reflects their evolution and relatedness is ***classification***. Another word is ***Systematics*** which may be defined as the study of the diversity of organisms and the way they relate to each other, ***modern Systematics is called Phylogenetic Cladistics*** and has a whole set of special rules telling you how to do it properly.

Analytical Key:

- *It is a devise used to identify all sorts of organisms. Keys work by a process of elimination, gradually narrowing down the number of possibilities.*
- It is important to understand that a key is much more trustworthy in proving that your insect is not A, than in proving that it is B. It might, for instance, actually be C, a species not mentioned in the key. A key does not prove anything positive, it only suggests possibilities. People used to be faddy about the sort of key they liked, but these days the arrangement that has the greatest acceptability for simplicity and directness is the dichotomous key, so-called because at each step it asks you to choose between two alternatives. The following is the example:

1a. Insect with wings..2
1b. Insect without wings..27
2a. Insects with four wings (two pairs)...3
2b. Insects with only two wings (one pair)..25
3a. Wings covered with scales...........................Butterflies and Moths **Lepidoptera**
3b. Wings not covered with scales, though they may be hairy...4
4a. Fore-wings partly or entirely horny or leathery and used as covers for hind-wings often much narrower than hindwings..5
4b. Both pairs of wings entirley membranous (flexible) and used for flying....................................12
5a. Mouth-parts tube-like, adapted for piercing and sucking.. True Bugs **Hemiptera**
5b. Mouth-parts adapted for biting and chewing..6
6a. Fore-wings and hind-wings with veins, hind-wings stiffer and harder than and serving as covers for hind-wings..7
6b. Fore-wings without veins, and modified into hard, horny cases for hind-wings………..……..10
7a. Body dorsoventrally flattened...................Cockroaches **Dictyoptera; Blattodea**
7b. Body rounded or quadrate in section...8
8a. Forelegs raptorial, adapted for grasping and holding..........Preying Mantids ....**Dictyoptera; Mantodea**

8b. Forelegs not raptorial...9

9a. Prothorax as large as or larger than meso and meta thorax, hind legs generally enlarged and adapted for jumping........Grasshoppers and Crickets **Orthoptera**

9b. Prothorax smaller than meso and meta thorax, legs normally similar in thickness, if hind legs enlarged then not used for jumping.............Stick-Insects **Phasmida**

10a. Fore-wings short...11

10b. Fore-wings as long as, or nearly as long as abdomen the 2 wings may be joined where they meet along the animals back and hence never used for flying..Beetles ....**Coleoptera**

Typification of Species: According to ICZN, the author while describing a new species or group has to designate a type.

Type	is a zoological object on which the original published description of a name is based
Holotype:	The single specimen selected by the author of a species as its type, or the only specimen known at the time of description; a true type
Allotype:	It is a specimen of the opposite sex to the type.
Paratype:	A specimen cited in the original description other than the holotype.
Cotype :	Any one of all specimens present before the describer at the time the description is drawn (not including type and allotype)
Neotype:	If holotype is damaged irreparably or lost, the specimen selected by the authority in group to replace is called neoype.\
Homeotype:	The specimen compared by the authority with holotype and sent out for comparative study.
Genotype:	The species which is designated as the type species of a genus, up on which it is based.
Isotype:	A duplicate of the type.
Topotype:	A specimen collected in the exact locality from where the original type was obtained.

Lecture 21

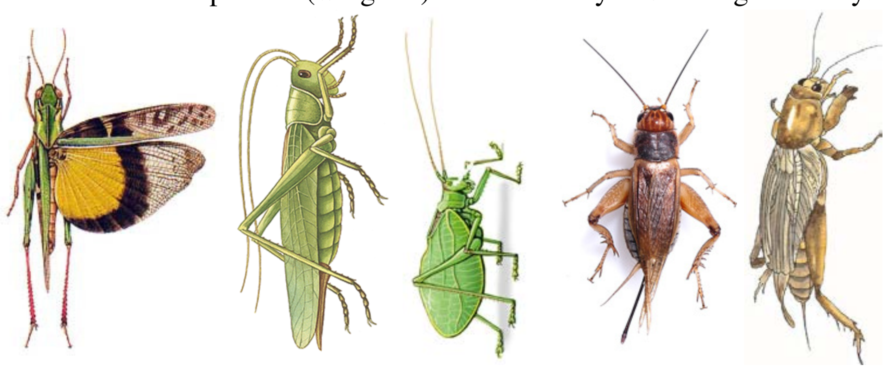
Order Orthoptera: General characters-family *Acrididae*, characters with examples

ORDER : **ORTHOPTERA** *(Ortho: straight, Ptera: Wings, Straight winged Insects)*

Examples : **Grasshoppers, Crickets, Locusts**

- It is considered by most scientists that the Orthoptera arose in the late Upper Carboniferous more than 300 million years ago.
- The Orthoptera are a group of large and easily recognised insects which includes the Grasshoppers, Locusts, Groundhoppers, Crickets, Bush-crickets (called Katydids in America), Mole-crickets and Camel-crickets as well as some lesser groups.
- There are about 20,000 known species distributed around the world, some species are very wide spread and a couple occurs in both the old world and the new world.

- *Habitat* — *Mostly terrestrial, tropical.* The Orthoptera can be found in most habitats, the Desert Locust *Schistocerca gregaria* lives in Desert and Semi-Desert, while the Mole-cricket (*Gryllotalpa gryllotalpa*) lives under ground.
- *Food Habit* — *Highly polyphagous.* Most of the Orthoptera will eat vegetable matter of some sort. Only Grasshoppers, Groundhoppers and a few rare Bush-crickets are are predominantly *herbivorous* (eat only plant material) most of the rest are *omnivorous* (eating both plants and animals) eating whatever comes there way. *Some are predacious.*
- *Size* — Medium or large insects that are usually winged as adults but may be apterous (wingless) in some. They have elongated body.



Taxonomic characters

- *Head* — Hypognathous or Proganthous
- *Compound eyes* — Normally *have large well developed compound eyes as well as three ocelli*.
- *Antennae* — Filiform with more than 12 segments.
  The Grasshoppers, Locusts and Groundhoppers (sub-order: caelifera) all have *short antennae with less than 30 segments*. The various crickets, long-horned grasshoppers (sub order: ensifera) have *long antennae* that at least reach their abdomens and normally reach beyond them, with large number of segments; the Mole-crickets have the shortest antennae in this group though they are still longer than the Grasshoppers.

- *Mouthparts* Mandibulate
  (Chewing and biting type with well developed mandibles)
- *Prothorax* They *have a large pronotum* (the plate covering the first thoracic segment or prothorax). *Saddle shape pronotum in Grasshoppers*. Meso- and Meta-thorax closely associated to form pterothorax and its notum is divided into *prescutum, scutum and scutellum*.
- *Wings* Winged or Wingless. If winged, the *wings are straight to the body, hence are called Orthoptera*. In the winged forms the the *fore wings are long, narrow, toughened and strengthened to form tegmina*, the *hind wings are broad, namy veined, and membraneous* and folded fan like. When at rest, the hind wings folded fanwise beneath the forewings. Well developed anal lobe is present in hind wings, useful for flight.
- *Legs* *Have enlarged (often greatly so) hind femur* which are *used for jumping*. Hind legs are saltatorial (jumping) in grasshoppers
  Fore legs modified for digging (fossorial) in crickets
  Tarsi 3-4 segmented
- *Stridulatory* *Orthoptera are renowned for the songs (sound producing males: Stridulatory organs in males)*. Most species, particularly crickets use 3 different sorts of song 1) calling songs (species-specific to "call" females from far away), 2) courtship songs (mostly only used if male and female have antennal contact), and 3) aggressive songs ("battle" calls, male to male, this is one male telling all the other males to stay away). They produce their songs in a variety of different ways; most of the *Ensifera-Gryllidae, Tettigonidae (crickets) rubs one forewing (tegmina) against the other (alary type). Caelifera-Acridicae (Grasshoppers) rubs one or both hind femora over their tegmina (femoro-alary type)*, there is a special toothed area on the inside of the femora which causes the tegmina to vibrate, in Locusts there are no teeth on the inside of the femora instead they have a specially raised 'intercalary vein' on the tegmina which has teeth on it.
- *Tympanal organs* *Auditory or Tympanal organs or ears or sound perceiving or sound receiving or sound sensing organs* are also well developed, and are located on either side of the first abdominal segment (Acrididae) or at the base of fore tibia (Gryllidae). The *Ensifera-Acrididae (Grasshoppers, Locusts and Groundhoppers) all have ears (tympanal organs) on either side of the first segment of their abdomen. The Caelifera-Gryllidae, Tettigonidae (Crickets) differ in that they have their ears on their fore tibia (front legs)*.
- *Male genetalia* Male genetalia concealed by the boat shaped 9th abdominal sternum.
- *Ovipositor* *Females usually have well developed sword shaped / blade like / needle like ovipositor*; this is more obvious in the Crickets (needle like), long-horned grasshoppers (sword like), Katydids (blade like). With well developed ovipositor with 3 pairs of valves which are not concealed, and are useful for inserting eggs inside the soil.
- *Anal cerci* *Cerci are normally well developed, short* and one segmented / unsegmented.

- *11th abdominal* — Segment is highly reduced, its tergum is reduced and called *epiproct* and sternum is represented by a pair of *paraprocts.*
- *Metamorphosis* — They are described as *hemimetabolous* (having nymphs that look like small adults and no pupa), having three stages of development; egg, nymph and adult.

Major families in the order Orthoptera:

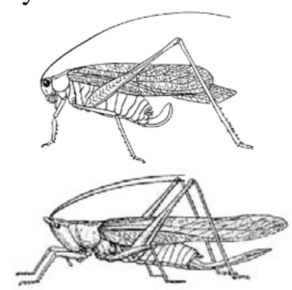
Suborder: Ensifera (crickets, katydids, long-horned grasshoppers)

Ensifera is a suborder of the order Orthoptera, comprising insects commonly known as crockets, katydids and bush crickets. "Ensifer" means "*sword bearer*" in Latin, and refers to the *typically elongated and blade-like ovipositor of the females*.

Family	Gryllidae	True or field crickets
Family	Gryllotalpidae	Mole crickets
Family	Tettigoniidae	Long-horned grasshoppers and katydids

Gryllidae

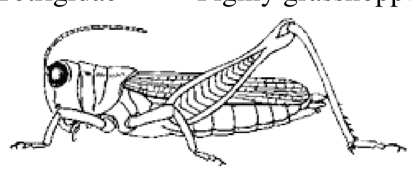
Gryllotalpidae



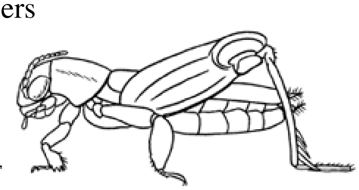
Tettigonidae

Suborder: Caelifera (short-horned grasshoppers, locusts)

Family	Acrididae	Short-horned grass hoppers (includes locusts)
Family	Tetrigidae	Pigmy grasshoppers



Acrididae

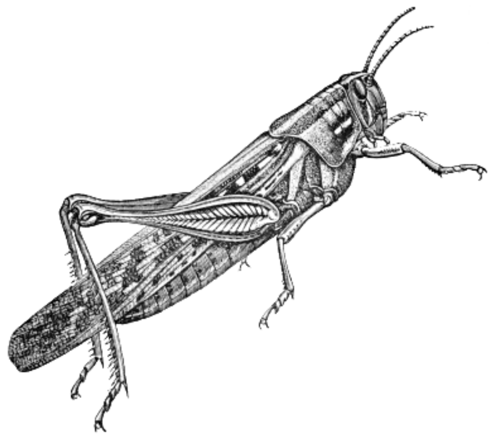


Tetrigidae

Family	**: ACRIDIDAE (Short-Horned Grasshoppers & Locusts)**
Rice grasshopper	: *Hieroglyphus banian*
Rice small grasshopper	: *Oxya nitidula*
Calotropis grasshopper	: *Poikilocerus pictus*
Cotton grasshopper	: *Cyrtacanthacris ranacia*
Desert Locust	: *Schistocerca gregaria*
African migratory locust	: *Locusta migratoria*

- Short horned grasshoppers and locusts
- They are polyphagous and often destructive
- *Antennae filiform*, shorter than the body with less than 30 segments
- *Stridulation: femoro-alary type*. The ridge on the inner side of the hind femur with peg like projections (acting as file) is rubbed againt the hardened radial vein of tegmina.
- *Auditory or tympanal organs situated on either side of the first abdominal segment*

- Hind Femur is greatly enlarged, and *hind legs modified for jumping (saltatorial),* tarsi 3 segmented.
- *Fore wings tegmina*, hind wings membranous.
- Ovipositor short and well developed. Its valves are short and curved



Schistocerca gregaria

Hieroglyphus banian

Lecture 22

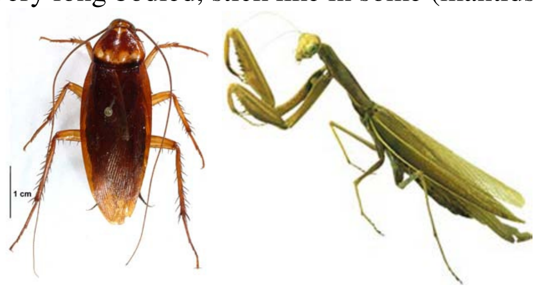
Order Dictyoptra: General characters-family *Mantidae*, characters with examples.

ORDER : **DICTYOPTERA** *(Dictyo: Net, Ptera: Wings, Netted winged Insects)*

Examples : **Cockroaches and Praying Mantids**

- Dictyoptera means "*network wings*," referring to the visible network of veins present in the wings of this order.
- The order Dictyoptera includes two suborders of insects related by evolution and features: *Blattaria*, the cockroaches, and *Mantodea*, the mantids.
- The Dictyoptera are one of the Orthopteroid orders and are thus closely related to the Orthoptera (Crickets and Grasshoppers) themselves, as well as to the Phasmida (Stick-Insects), the Isoptera (Termites), the Grylloblattodea and perhaps more distantly to the Dermaptera (Earwigs).
- Blattids (cockroaches) are the oldest living insects, have been in existence for over 350 million years

- *Habitat* — Terrestrial, tropical and subtropical insects. The order Dictyoptera contains nearly 6,000 species, distributed worldwide. With very few exceptions, mantids and cockroaches require terrestrial habitats. Most species live in tropical regions.
- *Food Habit* — Cockroaches are *omnivorous*, while Mantids are *predacious* on other insects, small animals
- *Size* — Variable, Large to Medium sized
- *Shape* — Dorso-ventrally flattened, depressed, oval shape (cockroaches) or very long bodied, stick like in some (mantids)



Taxonomic characters:

- *Head* — Usually *Hypognathous*
- *Antennae* — Long, may be longer than the body. Filiform (Mantids) or Setaceous (Cockroaches), usually long, thin, composed of many segments
- *Mouthparts* — Mandibulate (Chewing and biting type)
- *Wings* — Have two pairs of wings, held flat over the body (roof shaped) when at rest. *Fore wings modified into leathery tegmina* with marginal costal vein. *Hind wings are membranous* with a large anal lobe folded in a fan like fashion, often fan like.
- *Legs* — *Ambulatory (running in cockroach) or Raptorial forelegs (Mantids) with 5 tarsal segments*. All three pairs are similar in Blattidae (cockroaches) useful for running (ambulatory), while in Mantidae (praying mantids), forelegs are modified for grasping the prey (Raptorial), and middle and hind legs are normal used for running.

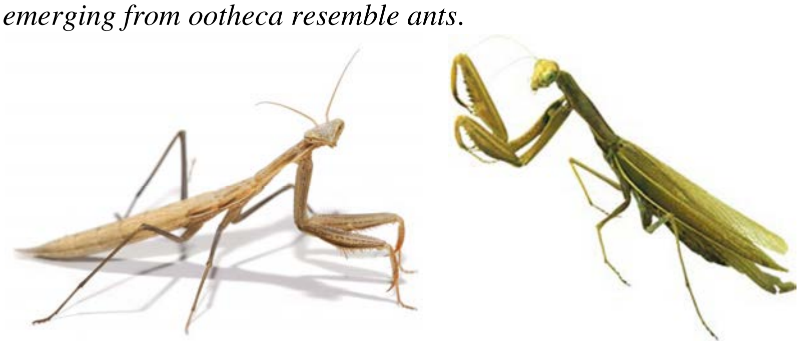
		In Mantids, fore legs coxa is very long, femur is spiny. A tarsus is 5 segmented in both Blattids, and Mantids.
•	*Anal cerci*	A pair of many segmented anal cerci is present, they are visible, and hairs on circus are very sensitive to air movements in cockroaches, and hence it is very difficult to catch them.
•	*Genetalia*	Genetalia of both sexes reduced, concealed behind 7^{th} abdominal segment in female, and behind 9^{th} abdomenal segment in males.
•	*Eggs*	*laid in ootheca*. The female lays eggs in groups, and then encases them in foam (polystyrene-secreted by female accessory glands) which hardens into a protective capsule, or ootheca.
•	*Metamorphosis*	Members of this order undergo *incomplete or simple metamorphosis (hemimetabolous)* with three stages of development: egg, nymph, and adult.

Major families in the order Dictyoptera:

Suborder	Blattodea	Family Blattidae	Cockroaches
Suborder	Mantodea	Family Mantidae	Preying Mantids

Family : **MANTIDAE (*Mantids*)**
Greenhouse mantid : *Mantis religiosa*
Common Indian mantid : *Gongylus gongyloides*

- Most are tropical, sub-tropical.
- Mostly predacious. Nymphs and adults are predators on other insects, small animals.
- They usually exhibit cryptic colorations, simulating with the background (mimicry). Uniformly coloured insects.
- *Head is triangular deflected.*
- *Prothorax greatly elongated*, meso- and meta-thoracic segments are short.
- Three ocelli present.
- Antenna: filiform, long, many segmented.
- Well characterized by *raptorial type of front legs*, *with long coxa, tibia and femur bearing prominent spines*.
- Long body, abdomen flattened.
- Anal cerci short and segmented.
- No specialised stridulatory organs are present though *some Mantids do have a single ear on the metathorax* which allows them to hear the sonar of bats.
- Eggs are laid in a water tight *egg case/ootheca which is fixed to plants*. The case is formed from a frothy gum (polystyrene) secreted by collateral glands of females. After exposure to air, the case hardens.
- *Nymphs emerging from ootheca resemble ants*.

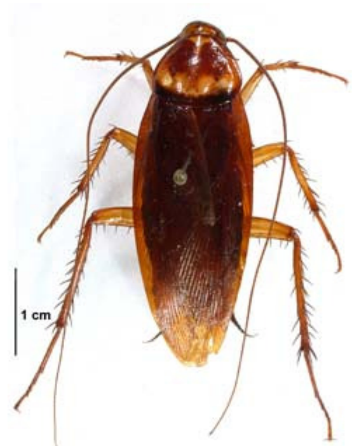


Family **: BLATTIDAE (*Cockroaches*)**

- There are over 4000 species world wide.
- They are *omnivorous scavengers and will eat almost anything* (sometimes even cannibalistic), and *active mainly at night*.
- They are considered *pests of stored produce* because, although they eat only a little, they *contaminate large quantities* which take on a characteristic smell and have to be thrown away. Also they can be carriers of diseases spread by viruses and bacteria.
- They can be up tp 60 mm long, and their flattened bodies allow them to squeeze through cracks and hide in crevices.

American cockroach : *Periplanata Americana*
Oriental cockroach : *Blatta orientalis*
(Common cockroach)

- *Body dorsoventrally flattened, depressed and oval shaped*, *Heavily pigmented body*
- ***Ocelli called fenestrae***
- *Antennae setaceous (whip like), long with many segments.*
- *Pronotum large plate like* covering the head
- Legs: All thre pairs similar, *ambulatory (running) type*.
- Wings: Two pairs of wings, both are functional, used for flying. *Forewings modified as tegmina*, *hind wings membranous* with large anal area.
- Eggs : arranged in double row and are enclosed in sac called ***ootheca*** which is formed by the secretions (polystyrene) of collateral glands (modified accessory glands of females)

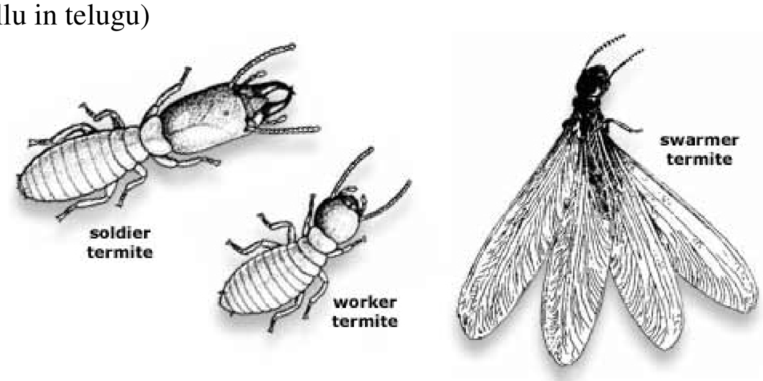


Lecture 23

Order Isoptera: General characters-family *Termitidae*, characters with examples
Order Thysanoptera: General characters-family *Thripidae*, characters with examples

ORDER : ISOPTERA
(Iso : equal, Ptera : Wings, Equal winged Insects)
Examples : Termites or White ants

- Highly polyphagous, are well known both for their *destruction of human property and cause damage to crops. Feed on dead plant materials,* generally in the form of dead wood, leaf litter etc.
- *Economically significant* as pests that can cause serious structural damage to buildings, crops or plantation forests.
- Famous for their construction of huge mounds or *'termitaria'* which allow them to have a great degree of control over the temperature and humidity of the environment they live in.
- They are *common in the tropics and occur in most warm habitats as well.*
- They are often called *'white ants'* because the majority of them are white and small and live in large colonies much like ants. They are not actually closely related to the ants at all but are closely related to the Cockroaches.
- Some of the most advanced species are the Macrotermitidae which grow fungi for food (Termitomyces) inside their nests on piles of faecal pellets. The sterile workers live for 2-4 years while primary sexuals live for at least 20 and perhaps 50 years.
- *Polymorphic* (having more than one form) with *well developed caste system.*
- *Social insects*.
- Usually small to medium sized *soft bodied insects*, and are being served as delicious food (usillu in telugu)



Taxonomic characters:

- *Head* — *Head is movably articulated*, Prognathous
- *Antennae* — *Moniliform*-*bead like*-appearing as if composed of a series of beads, compraising 9-30 segments (sometimes filiform also)
- *Mouthparts* — Mandibulate (chewing and biting type with well developed powerful mandibles)
- *Compound eyes* — Present in winged (alate forms), while sterile workers & secondary reproductives have no / greatly reduced compound eyes. median ocelli wanting
- *Thorax* — Pro-thorax is freely movable, narrower than head. Meso- and meta-thorax wider than head

- *Wings* — Three types: *Apterous, Brachypterous and Winged*. *Wings are present only in sexually mature forms during swarming season.* In winged forms, the *front and hind wings are similar in size, shape and venation*, *hence is called Isoptera*
  When at rest, *wings are held flat over the body and extend beyond the tip of the abdomen*. Wings are membranous with somewhat reduced venation and shed by means of basal fractures along basal suture leaving wing scale/stub.
- *Frontal gland* — *Frontal gland is a characteristic termite organ, which is greatly developed in soldiers for defense function*. It is formed by the hypodermal cells in the head, is sac like gland opens in a shallow depression on the surface of the head where the cuticle is pale, is known as *fontonelle*.
- *Legs* — Short and stout, *Tarsi usually 4 segmented*
- *Anal cerci* — short or very short
- *Metamorphosis* — Simple or incomplete (Hemimetabolous), with three stages; egg, nymph and adult.
- *Caste system* — Well developed, with 3 types of castes.

The following are the three different castes that are usually seen in termite colony:

1) Reproductives or Primary Reproductives (Fertile King and Queen):

- They are darker in colour, than other castes
- These are highly developed individuals sexually.
- They *have fully developed wings and compound eyes* and are usually heavily pigmented.
- The males are often small.
- Queen sometimes live for several years.
- The kings and queens are usually produced in large numbers at certain seasons.
- They *leave the colony in swarm; mate and individual pairs establish colonies* (swarming termites)
- *Wings are shed after mating*, *leaving the remnants called wing stub/scales*.
- *The queen attains enormous size after mating and the obesity is known as* ***physogastry***. The increase in size is affected only in abdomen.

2) Supplementary Reproductives:

- They are *brachypterous* and less pigmented (sclerotized), usually have smaller eyes.
- They sometimes carry on extensive reproduction in the colony and may supplement the queen in building the colony.

3) Sterile Castes: They form the bulk of the colony. They include workers and soldiers.

a) Workers:

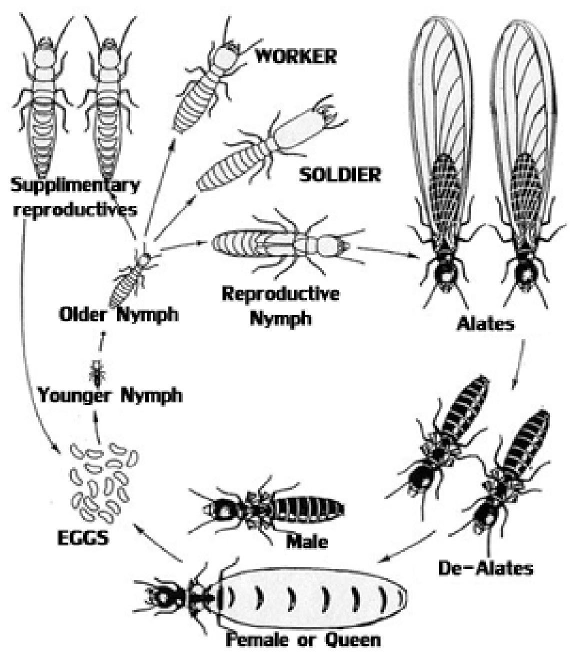
- These are *sterile wingless adults*.
- They are pale in color, *lack compound eyes*.
- Mandible relatively small.
- They collect food and feed queens, soldiers and newly hatched young ones.
- They build up nests, passageways, tunnels and galleries.
- They may be dimorphic including major and minor forms.
- They form the bulk of the colony (>90%).

b) Soldiers:

- They are also *sterile wingless adults* with *greatly enlarged heads and mandibles*, with *well developed frontal system*.
- Slightly larger than workers, may or may not have compound eyes.
- They *protect the colony*.
- They are two types *(1) Mandibulate type*: have well developed mandibles, defensive in function *(2) Nasute type*: Have the head prolonged anteriorly into a narrow snout through which a sticky secretion is excluded or squirted on the intruder. They have well developed frontal gland. Mandibles are reduced.

Family **: TERMITIDAE**
Termites : *Odontotermis obesus*
Microtermis obesi

- Ground dwelling with wide range of food habits
- Well developed caste system
- Mouth parts : biting types, well developed mandibles
- *Frontenelle present*
- Antenna : Moniliform
- Pronotum of workers is naroow with a raised lobe, saddle shaped
- The scales/stub of the front wing is shorter than pronotum
- Wing margin is more or less hairy. Radial sector (Rs) is reduced or absent
- Anal cerci 1 or 2 segmented
- *Apterous, Brachypterous and Winged* forms present



ORDER **: THYSANOPTERA**

(Thysano: fringed, Ptera: Wings, Fringed-winged Insects)

Examples **: Thrips**

- Thrips are small, thin, slender bodied insects
- Yellow-brown or black insects
- Commonly found on flowers in summer
- Terrestrial insects
- These are *important pets of food plants and horticultural crops*
- *Vectors of some diseases*
- They have habit of hiding in flowers and flower buds
- Minute to small size, elongate with transversely constricted body
- *Thrips are the only members of the 'Exopterygote' to have developed a true pupal stage*. They are described as holometabolous (having a complete metamorphosis even though the nymphs look like small wingless adults) insects with 2 or 3 inactive pupa-like instars

Taxonomic characters:

- *Antennae* — 6-10 segmented with *sensorial (cone like structure) on 3^{rd} or 4^{th} segment*
- *Compound eyes* — Conspicuous with 3-4 ommatidium in apterous forms, up to 150 in winged forms. 3 ocelli in winged forms.
- *Mouth parts* — *Asymmetrical mouth parts. Right mandible is absent*.
  Lacerating or Rasping and sucking type with three stylets.
  Mouth cone is formed by labrum, labium and the maxillae and extends ventrally, between the fore coxae
- *Wings* — Winged/wingless. Flight-capable thrips have *two similar, strap-like, pairs of wings with a ciliated fringe*, from which the order derives its name. Wings when fully developed are long and narrow with highly reduced venation (with 1-2 veins). The wings are fringed with long hairs on the margins.
- *Legs* — Legs usually end in *two tarsal segments* with a bladder-like structure known as an arolium at the pretarsus.
- *Abdomen* — Elongate with 10-11 segments, usually tapering posteriorly.
- *Anal cerci* — Absent
- *Metamorphosis* — *Intermediate between simple and complex*, in which 1^{st} and 2^{nd} instar larvae are active, resemble adults (called nymphs) where as *3^{rd} and 4^{th} instar consists of inactive pre-pupal and pupal like stages*.
- *Parthenogenesis* — This type of reproduction is very common, and in many species males are rarely seen.

Family : **THRIPIDAE**
Chilli thrips : *Scirtothrips dorsalis*
Onion thrips : *Thrips tabaci*
Grapevine thrips : *Rhapiphorothrips cruentatus*

- The Thripidae are the most speciose family of thrips, with over 290 genera representing just over two thousand species.
- Largest, most important and *most injurious family* in thysanoptera.
- Antennae 6-9 segmented, *3rd and 4th antennal segments are conical with sense cones or sensorial*, antennae with 1-2 segmented apical style, 4th segment is usually enlarged
- Winged or wingless forms. If winged, *wings are narrow, pointed at the tip and fringed with hairs on the margins*
- They can be distinguished from other thrips by a *saw-like ovipositor curving downwards*
- 1st and 2nd segments of tarsi consists of claw like appendage

Lecture 24 & 25

Order *Hemiptera:* General characters

Sub order *Heteroptera*, characters with examples, families *Pentatomidae & Coreidae*, characters with examples.

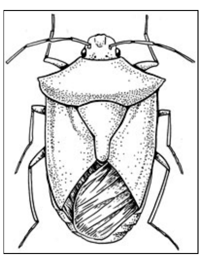
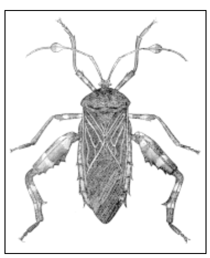
Suborder *Hemoptera*, characters, families *Cicadellidae, Delphacidae, Aphididae, Pseudococcidae, Coccidae, Aleurodidae*, characters with examples.

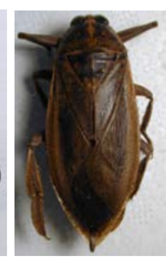
ORDER : HEMIPTERA

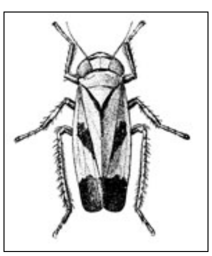
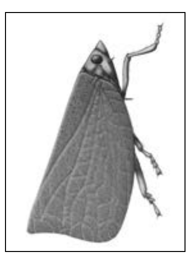
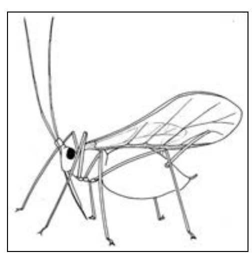
(Hemi: half thickened or basally thickened, Ptera: Wings,
(Half thickened or basally thickened winged Insects)

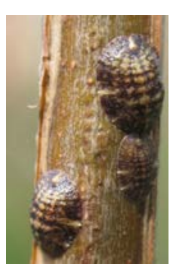
Examples : True bugs/plant bugs/bugs/jassids/aphids/whiteflies/mealy bugs etc.

- The Hemiptera is the largest and by far the *most sucessful of the hemimetabolic insects* (having young that look like wingless adults and a sort of metamorphosis that does not involve a pupa).
- There are at least 80,000 named species
- Hemiptera insects most often known as the *true bugs* comprising *cicadas, aphids, planthoppers, leafhoppers, shield bugs, mealy bugs and others*.
- Traditionally they are divided into two groups; *Heteroptera and Homoptera*, based basically on wing structure.
- *All the Homopterans and many of the Heteropterans feed on plant juices*, though many of the *Heteroptera are predatory* and some are useful as controllers of plant pests.
- Some can *transmit the plant diseases*.
- Size range from 1 mm to 11 cm in length.
- The Hemiptera or *true bugs are most easily recognized by the form of their mouth parts, adopted for piercing and sucking*, and this habit is prevalent throughout the life *except in male coccids, where adult mouth parts are atrophied*.


Taxonomic characters:

- *Head* — Porrect (straight) in Heteroptera, deflected (downward) in Homoptera.
- *Antennae* — fairly long with 4-5 segments
- *Compound eyes* — well developed, 2 ocelli may be present/absent
- *Mouth parts* — *piercing and sucking type of mouth parts*: Slender segmented beak (rostrum) that arises from front part of the head usually extends back along ventral side of the body. Segmented portion of the beak is labium. *Mandibles and maxillae are modified to form slender bristle like stylets which rest in grooved labium*. The maxillary stylets together form 2 channels (food channel and salivary channel). Maxillary palpi are absent, labial palpi wanting. The hypopharynx is highly specialized.
- *Wings* — Two pairs of wings. In *Heteroptera,* there is marked difference between both pairs of wings. *Forewings of Heteroptera are termed as Hemielytra* and their proximal area is well sclerotized resembling elytra, with only small distal portion remaining membranous. The *hindwings are always membranous* and are folded beneath the hemielytra at rest. In *Homoptera, the forewings are uniform texture entirely scleretized with no membranous tip*.
- *Wing orientation* — The wings of the *Heteropterans are usually held flat over the body*, while *Homopterans usually hold their wings over the body like a tent*.
- *Legs* — First pair of legs raptorial in predacious forms
  2-3 tarsal segments with a pair of claws, supported by an empodium but without arolium. Pulvilli are present one under each claw.
- *Scent Glands* — Scent glands (*odoriferous glands*) are present, *opens near hind coxae*, give off characteristic odour in Heteroptera
- *Wax glands* — Wax glands are present in Homoptera.
- *Abdomen* — 11 segments, first 2 segments are modified for sound production (especially in cicadidae)
- *Anal cerci* — Absent
- *Ovipositor* — with 3 pairs of valves, absent in aphidoidea and coccoidea
- *Spiracles* — 10 pairs present in Heteroptera
- *Sub-Orders* — Heteroptera and Homoptera

Character	**Sub-Order**	
	Heteroptera	**Homoptera**
Examples	Bugs	Jassids, Leaf hoppers, Aphids, whiteflies, Scales, Mealybugs
Basic Character	Hetero : Different wings Hemi-Elytra	Homo : Same/uniform/alike Uniform wings
Size	Comparatively large	Comparatively small
Head	Proganthous (Porrected)	Deflected (Downwards)
Antenna	4-5 segmented	3-10 segmented
Rostrum	*Rostrum arises from front part of the head* and head base does not touch anterior coxa	*Rostrum arises from posterior part of the head* and head base extends between anterior coxa

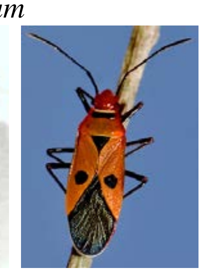
Pronotum	*Pronotum Large*, while meso- and meta-notum are relatively small	*Pro-notum Small*, collar-like, large meso-notum, and small meta-noum
Forewings	*Hemi-elytra* Forewings which are hard and stiff almost like beetle elytra have the end part soft and membranous; therefore Heteropteran forewings are referred to as 'hemi-elytra'.	*Uniform in consistence* The forewings are entirely sclerotised with no membraneuos tip
Wings position	*Wings held flat over the body at rest*	*Wings are held roof like / tent like over the body at rest*
Tarsi	3 segmented	1-3 segmented
Glands	*Odoriferous glands* (Scent Glands) present, opens at hind coxae, gives off characteristic odour	*Wax glands* present on the entire body
Life History	Parthenogenesis is present in some insects	In most species, the life history is very complex involving sexual and parthenogenetic generations, winged and wingless individuals
Important Families	*Pentatomidae* : Stink Bugs/Shield Bugs *Coridae:* Leaf-footed bugs	*Cicadellidae:* Leaf Hoppers, Jassids *Aphididae:* Aphids or Plant Lice *Coccidae:* Scales, Mealy Bugs *Aleurodidae:* Whiteflies
Others	Do not transmit diseases	*Most insects act as Vectors*
	Usually do not release Honeydew	*Most insects release Honeydew*

FAMILIES OF SUB-ORDER: HETEROPTERA

Family : PENTATOMIDAE (Stink Bugs / Shield Bugs)
Green Stink Bug : *Nezara viridula*
Red Cotton Bug : *Dysdercus cingulatus*
Cabbage Painted Bug : *Bagrada cruciferarum*


Nezara virudula

Halyomorpha halys

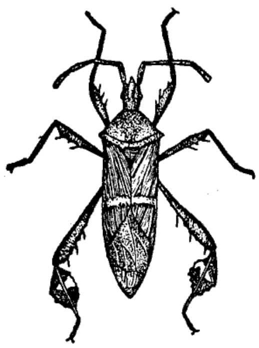

Dysdercus cingulatus


Bagrada bug

- Stink / Shield Bugs
- *Body medium sized, shield like and brightly coloured*
- They produce highly disagreeable odours. *4 pairs of odoriferous glands present on the dorsum of the abdomen of nymphs*
- The lateral margins of head conceals the bases of antenna
- *Antenna : 5 segmented*
- *Pronotum : Broad and Shield shaped*
- Forewings : Hemi-Elytra, corium large, membranous, with many longitudinal veins arising from a vein parallel to the apical margin of the corium
- Tarsi : 2-3 segmented, claws with pulvilli
- Eggs : usually barrel shaped with spines on the upper end.

Family : **COREIDAE (Leaf footed Bugs)**
Rice Gundhy Bug : *Leptocorisa vericornis*
Pulse pod bugs : *Clavigralla gibbosa*

- Leaf Footed Bugs
- Body medium sized to large shield
- *Long and narrow bugs*
- *Hemi-Elytra with richly branched veins*
- *Antenna : 4 segmented*
- Head : Narrower, shorter than pronotum
- In most of the species, either of both of the *hind femora and tibiae may have conspicuous enlargements or leaf like dilations*, and hence the name leaf footed bugs
- Tarsi : 3 segmented, pulvili present



Leaf-footed Bug

Coreidae

FAMILIES OF SUB-ORDER: HOMOPTERA

Family : **CICADELLIDAE (Leaf Hoppers / Jassids)**
Cotton Leaf Hopper : *Amrasca biguttula biguttula*
Paddy Leaf Hopper : *Nephotettix virescens*
Mango Leaf Hopper : *Idioscopus clypealis, Amritodus atkinsoni*
Bhendi Leaf Hopper : *Amrasca biguttula biguttula*

- Leaf Hoppers
- Economically very important family
- These are *vectors of important plant diseases*
- *Cause plant injury by injecting toxins*, causing hopper burns
- They are usually small in size
- Slender, usually *tapering posteriorly*
- *Wedge shaped* insects during rest
- They jump/ leap several feet when disturbed
- Both nymphs and adults have characteristic habit of *running sidewise or diagonally*
- Forewings are somewhat thickened, often brightly coloured
- Anal veins 1A and 2A do not unite to form Y shaped vein
- Antennae minute, bristle like, 3 segmented
- *1 or 2 rows of small spines are present on hind tibia*
- Ovipositor well developed and adopted for lacerating plant tissues for egg laying

- Many *excrete honey dew through anus*, over which sooty mould (black) develops and hampers photosynthesis ability of the plant



Amrasca biguttula biguttula *Nephotettix virescens* *Idioscopus clypealis*

Family : DELPHACIDAE (Plant Hoppers)
Brown Plant Hopper on Paddy : *Nilaparvata lugens*
White Backed Plant Hopper in Paddy : *Sogatella furcifera*
Maize shoot bug : *Perigrinus maidis*

- Plant Hoppers
- Economically very important family
- Small insects with reduced wings
- *Alary polymorphism* is present within the same species (Apterous, Brachypterous and Winged)
- *Large mobile apical spur on hind tibia*
- Anal vein 1A and 2A unite to form Y shaped vein




Nilaparvata lugens *Sogatella furcifera*

Family : APHIDIDAE (Aphids or Plant lice)
Cotton Aphid : *Aphis gossypii*
Maize Aphid/Tobacco Aphid : *Myzus persicae*
Bean Aphid/Groundnut Aphid : *Aphis craccivora*
Apple Aphid : *Eriosoma lanigerum*

- Plant Lice
- Economically very important family
- *Polyphagous*
- *Pear shaped*, small and soft bodied insects
- Rostrum usually long and well developed
- *A pair of cornicles on dorsal surface of 5th and 6th abdominal segments* (cornicles produce wax substance to protect from other insects)

- *Alary polymorphism* (winged / wingless forms, normally wingless forms are predominant. In winged forms, hind wings are much smaller with fewer veins)
- At rest, the wings are generally held vertically above the body
- *Tarsus 2 segmented* with pair of claws
- 9 pairs of spiracles
- *Excrete honeydew through anus* (honey dew consists of excess sap, excess sugars and waste materials), to which ants are attracted. The transportation of aphids through ants is called *poracy*.
- Aphids generally exhibit polymorphism in their development in different generations of the same species.
- The *reproduction can be through parthenogenesis, oviparity, viviparity*, in the occurance of generations the sexes are unequally developed, males often being rare.

Aphis gossypii

Family : **COCCIDAE (Scales)**
Sugarcane Scales : *Melanapsis glomerata*
Cottony Cushiony Scale/Citrus Scale : *Icerya purchase*
Mango Scale : *Aspidiotus destructor*
Guava Scale / Mealy Bug : *Pulvinaria psidi*
Black Scale on Crotons : *Saissetia nigora*
Coffee Scale : *Saissetia coffeae*
Citrus Scales : *Aonidiella citrina*

- Sexual dimorphism present

Sexual dimorphism	
Females	*Males*
Females very common	Males are rare
The females in this family are degenerated, flattened, elongate, oval insects with obscure segments. *Hard smooth exoskeleton or covered with wax or tough scales*	Males are active
Wingless	Front pair of wings highly developed, Hind pair reduced to halteres
Legs present or absent	Tarsus if present, 1 segmented with single claw
Antenna absent or much reduced	Antenna long and hairy
Mouth parts functional, well developed	*Moth parts vestigial* or absent
Adults feed on plant sap	Adults do not feed and short lived
	Caudal filament present at tip of the abdomen

- Anus covered by 2 dorsal plates
- Excrete honey dew through anus
- The metamorphosis is usually complex. The first instar nymphs have legs and antenna and are fairly active, and are called *crawlers*. They move at crawler stage. After first moult, the legs and antennae usually lost and they become sessile. *A waxy scale like*

covering is secreted. In males, the last instar proceeding to adult is quiescent and is often called *pupa*. Females have 1 instar less than males.

- Oviparous, ovoviviparous and viviparous forms.

Icerya purchase

Family : **PSEUDOCOCCIDAE (Mealy Bugs)**
Sugarcane Mealy Bug : *Saccharicoccus sacchari*
Grapevine Mealy Bug : *Mecanellicoccus hirsutus*
Brinjal Mealy Bug : *Centrococcus insolitus*
Planococcus insolitus
Tailed Mealy Bug on Fruit Tress&Pulses: *Ferrisia virgata*
Guava Mealy Bug / Scale : *Pulvinaria psidi*
Citrus Mealy Bug : *Planococcus citri*

- *Females elongate, oval*
- Distinct segmentation
- *Body covered with mealy or filamentous waxy secretion*.
- Antenna is present
- Legs well developed and females move freely.
- *Females wingless*
- Eggs laid on loose waxy material

Saccharicoccus sacchari

Family **ALEURODIDAE (Whiteflies and Blackflies)**
Cotton Whitefly : *Bemisia tabaci*
Citrus Whitefly : *Dialeurodes disperses*
Sugarcane Whitefly : *Aleurolobes barodensis*
Spiralling Whitefly : *Aleurodicus disperses*
Citrus Blackfly : *Aleurocanthus wooglumi*
Rose Blackfly : *Aleurocanthus spiniform*
Castor Whitefly : *Trialeurodes ricini*

- Minute insects
- 1-3mm, resemble tiny moths with opaque body
- Adults have two pairs of wings with reduced venation and *covered by a fine whitish dust or powdery wax giving white colour*
- Antenna fully developed, 7 segmented
- Reniform compound eyes, 2 ocelli
- Rostrum 3 segmented
- Tarsi nearly with two equal segments with paired claws and with empodium
- *Vasiform Orifice on dorsal surface of last abdominal segment* in both nymphs and adults, through *which honeydew excretes*. It is the characteristic feature of the family.
- Metamorphosis is complex. The 1st instar young ones are active (*crawlers*) but subsequent immature stages are sessile and look like scales. The scale like covering is a waxy secretion of the insect. The wings develop internally during metamorphosis and the early instars are called larvae. The next to the last instar is quiescent stage called pupa. The wings are given out at the moult of last larval instar.
- The *eggs are very characteristic being provided with pedicel which sometimes exceeds the length of the egg*.
- Sexual reproduction is common, but parthenogenesis is also seen.
- They are *Vectors of Plant Diseases* (Mosaic Viruses)

Bemisia tabaci

Lecture 26 & 27

Order Lepidoptera: General characters, differences between moths & butterflies

Families *Noctuidae, Spingidae*, *Pyralidae, Gelechiidae, Arctiidae, Papilionidae*, characters with examples.

ORDER : LEPIDOPTERA

(Lepido: Scales, Ptera : Wings, Scaly winged Insects)

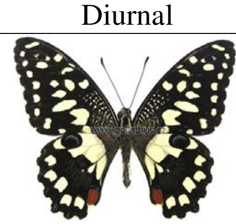
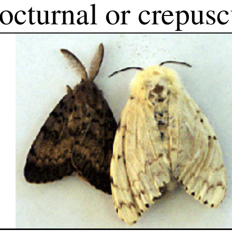
Examples : Butterflies and Moths

- The name Lepidoptera comes from the Greek *'Lepidos' a scale and 'Pteron' a wing*, they are called this because their wings are covered in small scales (these are modified hairs)
- The Butterflies and Moths are by far the *most popular group of insects* in both the mind of the general public and with Entomologists, there are more books on Lepidoptera, and more people collecting and working on Lepidoptera than any other insect order, *everybody loves Butterflies*.
- The Lepidoptera are one of the five great orders of insects and when all the counting has been finished will probably be fighting for 3^{rd} place with the Diptera behind the Hymenoptera and the Coleoptera, but ahead of the Hemiptera (especially in those taxonomic organisations that split the Hemiptera into 2 orders).
- There are about 1,50,000 named species most (more than 85 percent) of which are Moths.
- The insects belong to this order, has *great economic importance*. Most of its members are crop pests. Some are productive insects and are useful (silkworm). Some are pollinators and some are predators.
- *Small to large sized insects with overlapping scales and hairs on the body, wings and other appendages, giving beautiful colors to the insects*.

Taxonomic characters:

- *Head* — Relatively small, free with *small neck*
- *Antennae* — Many segmented, variable in size and type
- *Compound eyes* — Relatively large, ocelli two in numbers, present on either side close to compound eyes
- *Thorax* — *Prothorax reduced*, mesothorax large well developed and consists of a pir of triangular tigulae
- *Mouth parts* — *Siphoning type*, represented by *long coiled proboscis formed by the galea of maxilla*.
  Maxillary palpi small or lacking.
  Mandibles are absent except in the family, micropterygidae
- *Wings* — Usually *two pairs of membranous wings covered with scales giving beautiful color patterns*.
  Forewings are usually large.
  In *males of various insects*, *scales known as androconia occur on upper surface of the wings* and serve as the outlets of *odoriferous glands.*
  Forewings are fringed distally with each tip of the fringe finely divided. A large cell called *distal cell* is formed in the wing due to the absence of stems of R4, R5 and the main stem of the median vein.

- *Wing coupling* — *Frenulum and retinaculum or Amplexiform type*
- *Larva* — Larvae are called *caterpillars* usually *eruciform*. Caterpillar (means eating machine) grows very fast and become pupa.
  Mostly are phytophagous and are very serious pests of crops. Larvae have well developed head and cylindrical body consisting of 13 segments (3 thoracic+10abdomenal).
  Larvae head bears 6 ocelli on each side, and small bristle like antenna.
  Mouth parts are mandibulate type with well developed mandibles. *Labium with a spinneret*, median process for spinning silk.
  Each of the thoracic segments of larvae bears a pair of legs which end in a point. Abdomenal segments 3,4,5,6 and 10^{th} usually bear a pair of prologs which are fleshy and broad/bearing a number of tiny hooks known as *crochets*.
  Caterpillars have well developed silk glands and are usually *peripneustic*.
- *Pupa* — Pupae are usually *adecticus*, *obtect* and generally enclosed in cocoon in Moths. Butterflies do not make cocoons and their *pupa are called chrysalis*.
- *Adults* — *Harmless, except citrus fruit sucking moths, and castor semilooper*
- *Silk* — Natural silk the product of this order
- *Metamorphosis* — Complete metamorphosis

Character	*Butterflies*	*Moths*
Antenna	Have *thin slender filamentous* antenna, *have small balls or clubs at the tip of antenna*	*Lack club ends*, usually *comb like* or feathery antenna
Wing	Most have *bright colors* on their wings.	Moths have *dull colored* wings. Nocturnal moths on the other hand, are usually plain brown, grey white or black and often with obscuring patterns of ziz-zags or swirls which help camouflage them as they rest during the day. However many day flying moths are brightly colored, particularly if they are toxic.
Scales	*Have fine scales*	Have *larger scales*, makes them look more dense and fluffy.
Wing-coupling	Amplexiform	*Frenulum and retinaculum*
Pupa	Chrysalis	Cocoon
Body structure	Slender & smoother abdomen	Fat and furry bodies
Activity	Diurnal	Nocturnal or crepuscular
		

Family : **NOCTUIIDAE (Army Worms and Cut Worms)**

Gram Pod Borer : *Helicoverpa armigera*
Tomato or Chilli Fruit Borer : *Helicoverpa armigera*
Tobacco Cut Worm/Tobacco Caterpillar : *Spodoptera litura*
Castor Semi Looper : *Achaaea janata*
Bhendi Fruit and Shoot borer : *Earias vitella, Earias insulana*
Paddy Climbing Cutworm : *Mythimna separata*
Fruit Sucking Moths on Citrus : *Eudocima (Othreis) materna*
Eudocema (Othreis) ancilla
Eudocema (Othreis) fullonia

- Largest family of Order Lepidoptera
- *Antenna* : Filiform
- Maxillary palpi: Normally vestigial, labial palpi well developed
- Ocelli present
- *Fore Wings*: *Cryptic and dull coloured simulating with the surroundings*, M2 arises close to M3 than to M1. Cubitus appears four branched. In hind wings, Sc and R fuse for very short distance at the base of the discal cell.
- *Larvae*: Usually 5 pairs of prologs, but in some due to absence of prologs on 3rd and 4th abdominal segments, a part of larval body forms a loop when moving, hence they are called *semi loopers*. Most of them are highly polyphagous and noctuirnal. Majority feed on foliage and some are stem borers, and they are called *army worms* or *cut worms* by their habit.
- *Pupa*: Usually *pupate in earthen cell in soil* and the pupa is characterized by the presence of labial palpi and maxillae extending to the caudal margin of the wings.
- *Adults*: Have a pair of well developed tympanal organs at the base of the abdomen. Often adults are harmful, as fruit sucking moths, castor semilooper, *Achea janata*


Helicoverpa armigera


Spodoptera litura


Earias vitella


Achaea janata

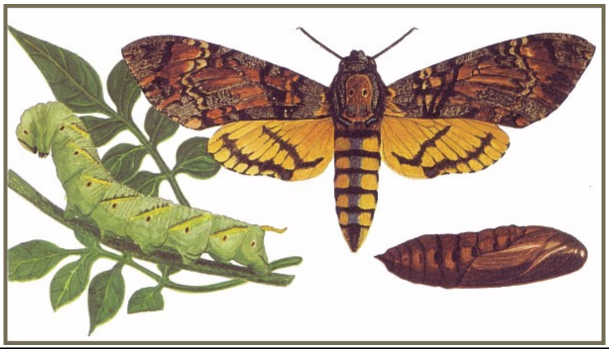

Eudocema (Othreis) fullonica


Mythimna separata

Family : **SPHINGIDAE (Sphinx or Hawk Moths, Horn Worms)**
Gingelly deaths head moth : *Acherontia styx*
Sweet Potato Sphinx : *Herse convolvuli*

- Medium to large sized, *heavily bodied, powerfully flying moths with spindle shaped body tapering and pointed both anteriorly and posteriorly*.

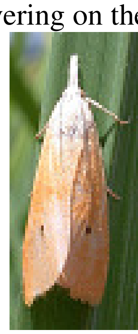
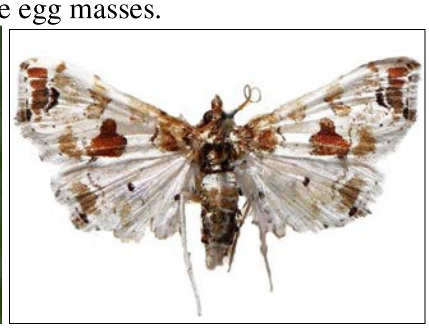
- *Antenna is thickened in the middle or towards the tip*. Usually *pointed or hooked at the tip*.
- *The proboscis is very long in most of the species*, and attains its greatest length in this family. Usually adults produce sound by forcing air through proboscis.
- The *fore wings are elongate with oblique outer margin*. Hind wings small and usually lightly coloured.
- Larvae of most of the species have a *conspicuous horn on the dorsal surface of 8th abdominal segment* with is relatively longer in 1st instar, hence the name *Horn Worms*.
- Pupation occurs freely in a cell in the ground or in a very loose cocoon on the surface among leaves.



Family : PYRALIDAE (Snout Moths)

Paddy Stem Borer	: *Scirpophaga incertulas*
Jowar Stem Borer	: *Chilo partellus*
Brinjal Shoot and Fruit Borer	: *Leucinodes orbonalis*
Mango Leaf Webber	: *Orthaga exvincea*
Brinjal Stem Borer	: *Euzophera perticella*
Cabbage Borer	: *Hellula undalis*
Crucifer leaf webber	: *Crocidolomia binotalis*
Sapota leaf webber	: *Nephopteryx eugraphylla*

- These are small, delicate, snout moths with well developed antennae and ocelli present
- *Labial palpi well developed and projected forward appearing as a snout* in front of the head, and hence are called *snout moths.*
- Forewings elongate or triangular. *Cubitus 4 branched*.
- Hind wings are usually broad with Sc and R usually fused or closely parallel for a short distance beyond distal cell.
- Larvae are naked, number of prologs variable but always present on 6th segment.
- *Generally internal feeders*
- Female moths are provided with a *tuft of anal hairs* at the caudal extremity which are deposited as a covering on the egg masses.

Family : **GELECHIIDAE (Grain Moths, Tuber Moths)**
Groundnut Leaf Minor : *Aproaerema modicella*
Potato Tuber Moth : *Phthormoea operculella*
Cotton Pink Boll Worm : *Pectinophora gossypiella*
Angomois grain moth : *Sitotroga cerealella*

- These are small to minute moths, usually cryptic coloured.
- *Labial palpi are long and **upcurved**, and the terminal segment is long and pointed.*
- *Forewings are narrower than hind wings and are **trapezoidal***. Forewing veins R4 and R5 are stalked at the base. Hind wings usually have the outer margin, curved and R5 and M1 are stalked.



Sitotroga cerealella *Pectinophoa gossypiella* *Aproaerema spp.*

Family : **PAPILIONIDAE (Swallow tails)**
Citrus Butter fly : *Papilio demoleus*
Curry leaf butter fly : *Papilio polytes*

- Medium to large sized butter flies.
- Most of them have a *tail like prolongation in the hind wings*.
- *Cubitus of the fore wings appears 4 branched*.
- Larva is smooth with a series of *fleshy dorsal tubereles* or occasionally a raised prominence on the 4th segment.
- Pupa is characteristic *Chrysalis* in having 2 lateral cephalic projections



Papilio demoleus *Papilio polytes* *Larvae of citrus butterfly*

Family : **ARCTIIDAE (Tiger Moths)**
Bihar Hairy Caterpillar : *Spilosoma obliqua*
Sunhemp Hairy Caterpillar : *Utetheisa pulchella, Argina astria*
Red Hairy Caterpillar : *Amsacta albistriga*
Black Hairy Caterpillar : *Amsacta lactinea*

- These are *stout bodied*, medium sized, *conspicuously and brightly spotted or banded moths*
- Noctuirnal moths
- Sc and Rs in hind wings are usually fused near or beyond the middle of the discal cell.

- *Caterpillars are usually densely hairy* and some are called *wooly bears* and they curl into a compact mass when disturbed
- Many species are capable of producing sound
- *Pupation in cocoon* and the cocoons are made of silk and larval body hairs.

Spilosoma oblique

Amsacta lactinea

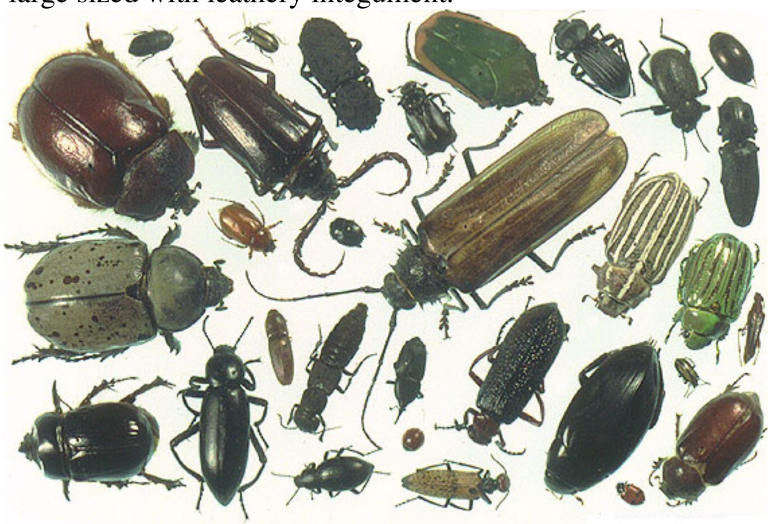
Argina astrea

Utetheisia pulchella

Lecture 28 & 29
Order *Coleoptera:* General characters, families
Families, *Coccinellidae & Bruchidae*, *Scarabaeidae, Chrysomelidae, Cerambycidae & Curculionidae,* characters with examples.

ORDER : COLEOPTERA
(Coleo: Sheath, Ptera : Wings, Sheathed winged Insects)
Examples : Beetles and Weevils

- This is the *single largest order in class Insecta* comprising 1/4 or 25% of the known insect species. >3,60,000 species are named.
- They occur in soil, humus, rotten wood and other decomposing organic matter, in timber, furniture and museum specimens.
- Some are aquatic, some littoral and others infest stored products.
- Some are predators.
- Some are phytophagous, some pollinators and some are subterranean.
- Minute to large sized with leathery integument.



Taxonomic characters:

• *Head*	*Highly sclerotized*, *free*, normal (beetles) or prolongated into snout (weevils)
• *Antennae*	Variable, usually *11 segmented*
• *Compound eyes*	Normal, ocelli absent
• *Mouth parts*	*Chewing type with well developed mandibles*. The mandibles attain their greatest size in males of stag beetles (Family Leucaenidae)
• *Thorax*	*Prothorax large and freely movable*. Mesothorax much reduced and fused with metathorax, and the tergum of these segments is divisible into prescutum, scutum and scutellum.
• Wings	Two pairs of wings present. *Forewings are horny and leathery known as elytra*, which almost always rest to form a straight mid dorsal suture. *Forewings are not used for flight*, but protect the hind wings and body. *Hind wings membranous*. Wings are highly reduced in few beetles.

- Legs — Well developed for walking or running. Tarsal segments are variable.
- Abdomen — Usually 10 segmented. First tergum is membranous and one or more of the sterna from the 1st to 3rd are aborted in many species. Terminal segments of female are retractile and tubular thus functioning as *ovipositor* (Family: Cerambycidae)
- Larva — *The larvae are known as grubs* and *generally thoracic legs are absent(apodous)*
- Pupa — Exarate, pale coloured and are invested by a thin soft cuticle
- Adults — Most of the adults possess stridulatory organs and these are variable
- Metamorphosis — Complete and complex

Family : COCCINELLIDAE
(Lady bird beetles / coccinellids / Hadda beetles)

A predator on Aphids : *Menochilus sexmaculata*
A predator on cottony cushiony scale: *Rodolia cardinalis*
Lady Bird Beetles on Brinjal : *Henosepilachna vigintioctopunctata*
: *Henosepilachna dodecastigma*

Lady birds are among the most familiar and best loved of the commonly identified insects, they are generally brightly coloured and are *symbols of good in many myths*. There are more than 5,200 species world wide. The name Ladybird arises from the vernacular name for the common 7-spot-ladybird (*Coccinella 7-punctata*) in Europe. Our Lady's Bird, the Lady in this case being 'The Virgin Mary' from Christian Mythology. The red base colour of the elytra is said to represent her cloak and the 7 black spots to represent the 'Virgins' 7 joys and 7 sorrows.

- Beetles of moderate size, ovate *convex dorsally and horizontal ventrally*
- *Brightly coloured or spotted*
- Head partly concealed from above the pronotum
- *Antennae usually clavate*, short and partly concealed
- *Legs are short and hidden under the body; tarsi 4 segmented*, but appear to be 3 segmented, since the 3rd segment is small. Tarsal formula is 4:4:4 and the tarsal claws are toothed at the base.
- *Grubs are usually covered with minute tubercles or spines*, known as *spinose* or *rugose* and are usually flattened
- *Elytra covers the abdomen completely*
- Both adults and grubs of most of the species are highly predacious feeding on aphids, coccids, mites, psyllids and other soft bodied insects. Genus *Henosepilachna* is phytophagous.


Coccinella septumpunctata


Rodolia cardinalis


Henosepichna vigintioctopunctata


Menochilus sexmaculatus

Family : **BRUCHIDAE (Seed beetles, Pulse Beetles)**
Pulse beetles : *Callosobruchus chinensis, C. maculatus*

- *Short, stout bodied beetles* with body narrowed anteriorly
- Head is produced anteriorly into a short and broad snout
- *Antenna : serrate or pectinate*
- Prothorax: prominent, somewhat triangular & its notum is greatly narrowed anteriorly
- *Elytra short, never cover the tip of the abdomen* and the abdominal tip of elytra is bluntly rounded
- Legs short, *tarsi formula 5-5-5*, *hind femur thickened and often toothed*
- Larva (Grubs) usually undergo *hypometamorphosis*, first instar with well developed legs and possess spine or toothed thoracic plates to aid in entering smooth and hard seeds.
- After 1st moult it becomes partially or wholly apodous

Family : **CURCULIONIDAE (Weevils or Snout Beetles)**
Coconut red palm weevil : *Rhynchophorus ferrugineus*
Rice weevil : *Sitophilus oryzae*
Sweet potato weevil : *Cylas formicarius*
Mango stone weevil : *Sternochetus mangiferae*
Banana rhizome weevil : *Cosmopolites sordidus*
Myllocerus weevil : *Myllocerus undecimpustulatus*

- They are *somber colored*
- When disturbed they draw in their legs, antennae & fall to ground, remain motionless.
- Minute to large insects, characterized by the *head prolonged to form a pronounced rostrum or snout* of variable size, shape and length, hence they are called *snout beetles*. In most species, they exhibit sexual dimorphism, being better developed and long in females than in the males. In females, it acts as a boring instrument for placing eggs.
- *Antenna : geniculate and clubbed (clavate) arising from the middle of the snout*
- *Mouth parts small, arranged at the tip of snout*. Labrum absent. Palpi reduced & rigid.
- Legs: short or very long. Tarsi 5 segmented, 4th one often small. *Trochanter elongated*.
- Wings : well developed, rudimentary or absent
- Abdomen with 5 visible sternites
- *Larva (grubs) : apodous* curved with well developed head
- Adults and grubs are phytophagous and stored grain pests.

Family : **SCARABAEIDAE**
(Chafer Beetles/Horn Beetles/Dung Rollers/Root Grubs)

Coconut Rhinoceros Beetle : *Oryctus rhinoceros*
Root Grub in Sugarcane : *Holotrichia serrata, H. consanguina*
Chafer beetle on orchards : *Anomala varians*

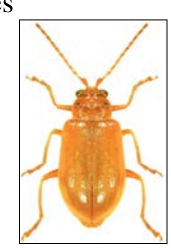
- They are *stout bodied, oval or elongate* usually convex beetles
- Head often with slender, recurved sometimes *toothed or bifurcated frontal horn*
- Antenna 8-11 segmented and *lamellate type*
- *Prothorax large, simple or horny structures (horn beetles)*
- *Elytra not usually cover the abdomen completely*. Abdomen has 6 visible sternites
- Tarsal formula 5-5-5, tarsi 5 segmented. The front femora more or less dialted with the outer edge toothed.
- Adults usually feed on foliage.
- *Grubs typically scaraboid "C" shaped* and feed on roots, known as *root grubs* which are serious pests of most of the crops while some feed on the organic matter in manure pits. The grubs are sluggish, stout and usually white in colour and called as *white grubs*

Family : **CHRYSOMELIDAE**
(Flea Beetles or Leaf Beetles, Tortoise Beetles)

Rice Hispa : *Dicladispa armigera*
Red Pumpkin Beetle : *Aulacophora foveicollis*
Grape flea beetle : *Sclerodonta strigicollis*
Sweet potato tortoise beetle : *Metriona circumdata*

- Usually small to medium, oval or sphere shaped beetles with the *upper surface of the bosy generally bare and shining, frequently with metabolic colouration*
- Antennae short or moderate length usually with 11 segments, except in this character, they usually resemble cerambycids
- *Legs short. Hind femora enlarged for jumping* in many forms. *Tarsi 5 segmented, but appear to be 4 segmented* since is small and concealed in the notch of the bilobed 3rd segment. Tarsal formula is 5-5-5. Usually tibial spurs absent.
- Abdomen short 5 visible sternites

Rice hispa



Red Pumpkin Beetle

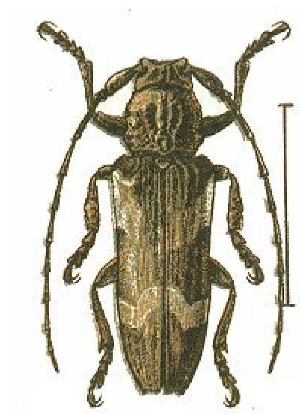
Grape flea beetle

Family : CERAMBYCIDAE (Lon horned wood boring Beetles)
Mango stem borer : *Batocera rufomaculata*
Cashew Tree Borer : *Plocaederus ferrugineus*
Grape stem borer : *Crelosterna scabrator*
Grapevine stem girdler : *Sthenias grisator*

- These are *elongate and cylindrical beetles*
- Have *very long filiform antennae at least 2/3rds as long as body*, capable of being flexed backwards.
- *Prothorax is narrow* or as wide as mesothorax, *usually spined* or tuberculate
- Elytra usually cover the body but some times may leave the posterior one or two segments exposed in few cases
- Legs well developed. Tarsi 5-segmented but appear to be 4 segmented. Tarsal formula 5-5-5

Mango stem borer

Cashew tree borer



Grape stem girdler

Lecture 30

Order Hymenoptera: General characters

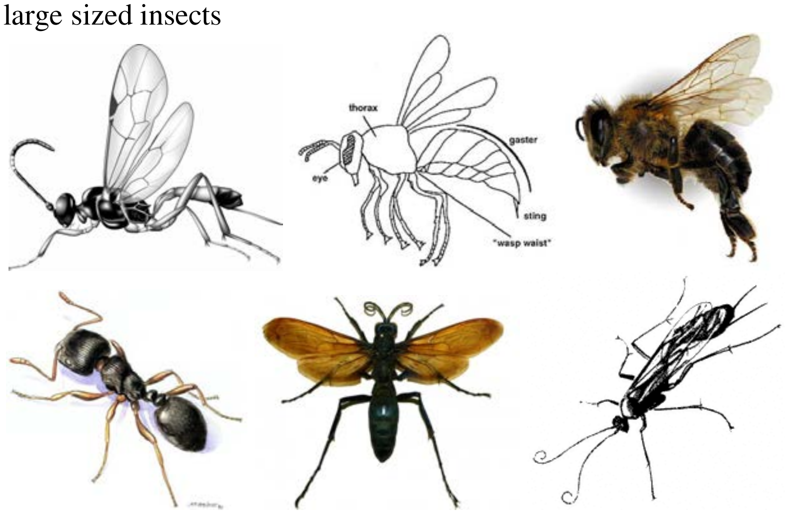
Families *Tenthredinidae, Ichneumonidae, Braconidae & Trichigrammatidae*, characters with examples.

ORDER : HYMENOPTERA

(Hymen: membrane, ptera: wings, membranous winged Insects)

Examples : Wasps, Ants, Bees, Sawflies

- This is the *most beneficial order* in class Insecta comprising parasites, predators and bees involved in pollination and honey production
- The name refers to the heavy wings of the insects, *hymen: membrane and pteron: wing.*
- The hindwings are connected to the forewings by a series of hooks called *hamuli*
- The Hymenoptera are *exceedingly important insects* from mans point of view for three main reasons, Firstly they include the Bees who as everybody knows make Honey and Wax, secondly because a lot of the parasites and the Ants are important enemies of crop pests, ants consume huge numbers of lepidopteran caterpillars as well as other pests and were first deliberately used to protect plants from pests in China 4000 years ago when species of *Oecophylla* were encouraged to live in fruit trees because their presence was known to improve fruit yeilds. Hymenopteran parasites are regularly used in biological pest control these days and are among the first creatures screened by scientists when they are searching for a control mechanism for insect and other invertebrate pests. Thirdly and perhaps most importantly many Hymenoptera, though not the Ants are pollinators of most of our crop plants, both those we eat ourselves and those we use to feed our livestock. Because they work for free it is impossible to estimate their economic importance but it easily amounts to Billions of pounds every year. It is humbling to realise that if all the Hymenopterans were too suddenly dissappear from this earth among the numerous changes would be the collapse of human society
- The Hymenoptera with over 1,30,000 named species are a contender for the *second largest order of insects* in the world, the Beetles (Coleoptera) boast a the greatest number of species
- *Parasitism is a common way of life* among a number of Hymenopterans
- Most of them are *social living*
- Small to large sized insects

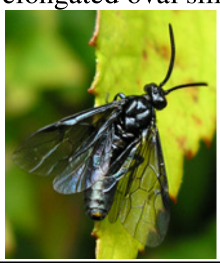


Taxonomic characters:

- *Head* — Varied in size and shape. *Head is free from thorax and often extremely mobile*.
- *Antennae* — Variable, usually exhibit *sexual dimorphism* being longer in males.
- *Compound eyes* — *Acuteness of vision is a characteristic feature of the order*. Compound eyes are almost always large. Ocelli 3 or absent.
- *Mouthparts* — Exhibit a wide range of differentiation from the generalized biting type to highly modified lapping and sucking type. Mandibles always present. Their mouthparts are created for *chewing, with well-developed mandibles*. Many species have further developed the mouthparts into a lengthy proboscis (*chewing & lapping*), with which they can drink liquids, such as nectar.
- *Wings* — Usually 2 pairs of *membranous wings with reduced venation*.
  Hind wings are smaller than fore wings
  Hind wings interlocked with fore wings by means of tiny hooks *(hamuli) present along the costal margin*. The hamuli catch on a fold along the posterior margin of the fore wing.
  Usually stigma is present in the fore wings along the costal margin near apex.
- *Legs* — Slender, *trochanter 1 or 2 segmented*.
  Honey bee legs are modified for various purposes (Antennal cleaning forelegs, wax picking midlegs, pollen collecting hindlegs)
- *Abdomen* — *Basally constricted abdomen*. The *first abdominal segment* is transferred to thorax & closely attached/fused to metathorax to form mesosoma, hence the *thorax looks like four segmented*. The 1st abdominal segment thus transferred is referred as *propodaeum*. The 2nd abdominal segment is long called *petiole or pedicel*, while the other abodmenal segments are enlarged, collectively called *gastor*.
- *Ovipositor* — Very well developed and modified for sawings, boring and piercing. It is *modified for piercing*, and, in some cases, is several times the length of the body. In some species, the ovipositor has become *modified as a stinger*, and the eggs are laid from the base of the structure, rather than from the tip, which is used only to inject venom. The stinger is typically used to immobilise prey, but in some wasps and bees may be used in defence.
- *Larva* — The larvae of majority of advanced hymenoptera, more closely *resemble maggots*, and are adapted to life in a protected environment. This may be the body of a host organism, or a cell in a nest, where the adults will care for the larva. *Such larvae have soft bodies with no limbs*. They are also unable to defecate until they reach adulthood due to having an incomplete digestive tract, presumably to avoid contaminating their environment. The larvae of the more *primitive hymenoptera resemble caterpillars* in appearance, and like them, typically feed on leaves. They have large chewing mandibles, *three thoracic limbs, and, in most cases, a number of abdominal prologs (sawfly)*.
- *Pupa* — Exarate and a cocoon is generally present.
- *Metamorphosis* — Complete

Family : **TENTHREDINIDAE (Saw Flies or wood wasps)**
Mustard saw fly : *Athalia lugens proxima*

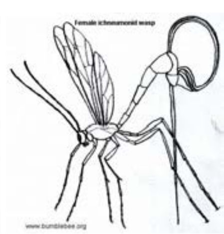
- Primitive hymenopteran family
- Only family with *phytophagous insects*, causing damage to various crops, due to caterpillar like active feeding larva
- These are *stout wasp like insects*, often brightly colored *without abdominal pedicel*
- Adults are frequent visitors of flowers and some are carnivorous praying upon small flies and beetles
- Antenna : 3 or 6 or 8-11 segmented, filiform or setaceous
- *Trochanter : 2 segmented, fore tibia with 2 apical spurs*
- Ovipositor is well developed, toothed or saw like with two pairs of flattened plates
- In many species, sexes are differently coloured
- Parthenogenesis is very common
- *The larvae often bear a close general resemblance to those of Lepidoptera*, and are exclusively phytophagous. *The larvae have 6 or morethan 6 pairs of prologs (while lepidopteran larvae will never have morethan 5 pairs of prologs/abdomenal legs).* Sawfly larvae also *do not have velcro-like grippers at the ends of the prolegs*. Sawfly larvae are *phytophagous*
- Pupation occurs in an elongated oval silken cocoon or in earthen cell




Family : **ICHNEUMONIDAE (Ichneumonids)**
Isotoma javensis : Larval parasitoid of sugarcane top shoot borer
Xanthopimpla stemmator : Pupal parasitoid of jowar stem borer

- Ichneumon wasps are *important parasitoids (endo-parasites) of other insects*.
- Common *hosts are larvae and pupae of Coleoptera, Hymenoptera, and Lepidoptera.*
- *Antenna*: large, filiform with *more than 16 segments*
- Legs : legs are provided with conspicuous *tibial spurs and strong claws*, *trochanter : 2 segmented, tarsi 4 segmented*
- Fore wings: the costal cell is wanting and have 2 recurrent veins
- Abdomen : long and slender, *petiole usually curved*
- Ovipositor : *very long often longer than the body arising anterior to the tip of abdomen* and permanently extruded






Family : **BRACONIDAE (Braconids)**

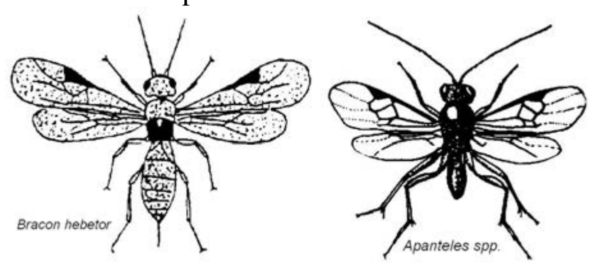
Bracon hebetor : Larval parasitoid of several species of pyralid moths, that attck stored products (Indian meal moth, *Plodia interpunctella*), nuts

Apanteles flavepis (=Cotesis flavepis) : Larval parasitoid of several cereal stems borers

Apanteles glomerata : Larval parasitoid of cabbage butterfly (*Pieris rapae*), cabbage looper (*Trichoplusis ni*), cabbage diamond backed moth (*Plutella xylostella*)

Apanteles africanus : Larval parasitoid of tobacco caterpillar *Spodoptera litura* & other lepidoptran larvae

- Family of *parasitoid wasps* & *one of the richest families of insects, with* 150,000 sps
- Most braconids are *primary parasitoids* (both external and internal) on other insects, especially upon the *larval stages of Coleoptera, Diptera, and Lepidoptera*, but also some *hemimetabolous insects like aphids*.
- Most sps kill their hosts, though *some cause the hosts to become sterile & less active*
- Closely related to ichneumonoids but smaller
- Minute to small, stout bodied parasitic insects
- Abdomen sessile, subsessile or petiolate
- Costal cell is wanting in forewings, with only one recurrent vein
- Ovipositor well developed
- Unlike Ichneumons, *pupate in silken cocoon on the outside of the host*
- Polyembryony occurs in a few species



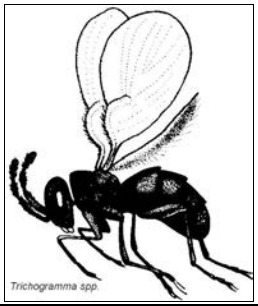
Family : **TRICHOGRAMMATIDAE (Trichogrammatids)**

Trichogramma chilonis : Egg parasitoid on lepidopterans
Trichogramma australicum

- *Tiny wasps* (smallest of all insects), with most species having adults <1 mm in length.
- Economically important family because these wasps are *strictly egg parasites* and have been reared from the holometabolus orders as well as Homoptera, Heteroptera, Orthoptera, and Thysanoptera. A few genera of Trichogrammatidae are of interest for use in biological control. *Trichogramma* has received the most attention from applied entomology because its members parasitize numerous pests of Lepidoptera and can be mass propagated and released with relative ease. *Trichogramma* has been the world's most widely used arthropod for augmentative biological control programs.
- They are *not strong fliers* and are generally moved through the air by the prevailing winds
- Their *forewings are typically somewhat stubby and paddle-shaped, with a long fringe of hinged setae around the outer margin* to increase the surface area during the

downstroke. Males of some species are wingless, and mate with their sisters inside the host egg in which they are born, dying without ever leaving the host egg

- Wing venation gratly reduced
- Head short and somewhat concave behind
- Abdomen constricted at base
- *Tarsi 3 segmented. This character differentiates from other families*.



Lecture 31

Order Diptera: General characters

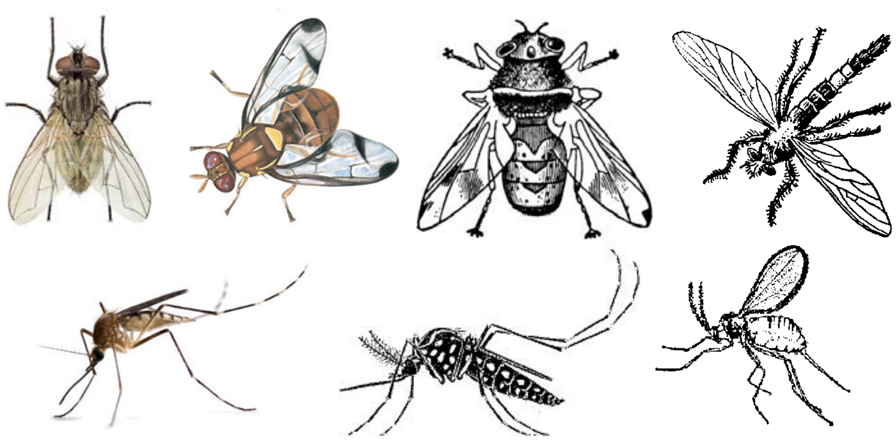
Families *Cecidomyiidae, Trypetidae, Agromyzidae & Muscidae*, characters with examples.

ORDER : **DIPTERA** *(di: two ptera: wings; two winged insects)*

Examples : **True flies, mosquitoes, midges etc**

House flies, Dung flies, Stable flies, Blow flies, Bots, Crane flies, Mosquitoes, Water midges, Robber flies, Horse flies, Bee flies, Fruit flies, Hover flies etc.

- Order Diptera is *economically very important* comprising of important crop pests, parasites, blood sucking mosquitoes acting as vectors of human disease, predators etc.
- Diptera is a large order, containing an estimated 2,40,000 species of mosquitoes, gnats, midges and others. They are an incredibly diverse group with a wide variety of fascinating life cycles and ecological adaptations; studying even one family of them is a life-time's work.
- The Diptera or *true flies* are an amazing order of insects which can be readily recognised in their adult forms because those which have wings, and most of them do, *have only two*, nearly all other flying insects have four wings; in the true flies the *hind wings have become modified into a pair of small balancing organs called halteres*. The only other insects with two wings are the Strepsiptera which are quite small and difficult to find and can be easily distinguished from true flies because they have the forewings reduced to balancing knobs and fly with their hindwings, the opposite arrangement to flies.
- The *common names of true flies are written as two words*, e.g., crane fly, robber fly, bee fly, moth fly, fruit fly. The common names of non-dipteran insects that have "fly" in their name are written as one word, e.g., butterfly, stonefly, dragonfly, scorpionfly, sawfly, caddisfly, whitefly.
- Small to medium sized flies.
- Widely distributed soft bodied insects



Taxonomic characters:

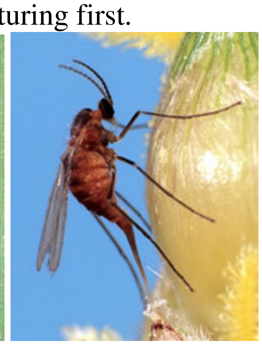
- *Head* Prominent and small neck
- *Eyes* *Large, usually larger in males*, holoptic (eyes continuously placed) or dioptic (eyes distinctly separated)
- *Antenna* Mostly short, 3 segmented; *aristate in flies, plumose & pilose in mosquitoes*

• *Ptilinum*	*Ptilinum or frontal sac* is characteristic feature of cyclorrhapha (sub-order), indicated by the ptilinal/frontal suture It is used to force off the end of the puparium in order for the fly to emerge, and after this inflation at emergence, the ptilinum collapses back inside the head, marked thereafter only by the ptilinal suture (which defines the aperture through which it everts)
• Mouth parts	*Sucking type* and form proboscis. In some like *mosquitoes-piercing and sucking type, Housefliues-sponging & lapping type* with labium expanded into a pair of fleshy lobes, called labella
• Mesothorax	*Mesothorax Large*. Pro- and Meta thoracic segments are small fused with mesothorax
• Wings	*Only front pair of wings present. Hind pair modified into halteres which act as balancers*
• Legs	Well developed. Tarsus usually 5 segmented, *pulvilli and an empodium usually present*
• Metamorphosis	Complete
• Larva	Eruciform, apodous, known as *maggots*, mostly amphipneustic
• Pupa	*Coarctate enclosed in puparium*

Family : CECIDOMYIIDAE (Gall Midges or Gall Flies)

Rice Gall Midge : *Orseolia oryzae*
Sorghum earhead midge : *Contarinia sorghicola*
Midge on Chilli : *Asphondylia capsici*
Sesamum Midge : *Asphondylia sesame*

- As the name implies, the *larvae of most gall midges feed within plant tissue, creating abnormal plant growths called galls*.
- These are very *fragile/delicate, small insects* usually only 2-3 mm in length and many are less than 1 mm long.
- Somewhat hairy with small head
- *Have long antenna,* unusal in the Order Diptera. Moniliform with prominent whorls of hairs.
- *Legs, long resembling mosquitoes, tibia without spurs*
- They are characterised by *hairy wings*, unusual in the Order Diptera. Wing broad with few longitudinal veins (3 to 5), most part unbranched with no obvious cross veins
- *Larva live in pants forming galls*, some occur under bark, in decaying vegetation and a few are predacious or parasitic on aphids, scales etc. The head is greatly reduced without mandibles. In the last larval instar, most of the prothorax used for jumping.
- Cecidomyiidae are also known for the strange phenomenon of *paedogenesis* in which the larval stage reproduces without maturing first.

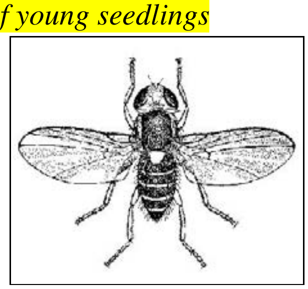


Family : **TEPHRITIDAE / TRYPETIDAE (Fruit Flies)**
Mango fruit fly : *Bactrocera dorsalis*
Cucurbit fruit fly : *Bactrocera cucurbitae*
Guava fruit fly : *Chaetodacus incises*
Ber fruit fly : *Carpomyia vesuviana*

- *Tephritidae* is referred to as "*fruit flies*." Tephritidae does not include the biological model organisms of the genus *Drosophila* (Drosophilidae), which is often called the "common fruit fly".
- There are nearly 5,000 described species of tephritid fruit fly, categorized in almost 500 genera.
- Tephritid fruit flies are of *major importance in agriculture*. Some have negative effects, some positive. Various species of fruit fly cause damage to fruit and other plant crops. The genus *Bactrocera (Dacus)* is of worldwide notoriety for its destructive impact on agriculture.
- Small to medium flies, lightly hairy or bristly
- Head large, broad with small neck
- *Wings large, mostly pictured with spots or bands*. Subcosta bends apically forward at almost right angle and then fades out without reaching the margin
- *Middle tarsi with spurs*
- Ovipositor very well developed horny and flattened and usually 3 segmented
- Adults are visitors of flowers, fruits and foliage
- Larvae phytophagous, Amphipnuestic

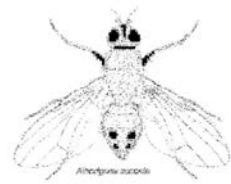

Family : **AGROMYZIDAE (Leaf miners)**
American serpentine leaf miner : *Liriomyza trifolli*
Pea stem fly : *Ophiomyia phaseoli (Melanagromyza phaseoli)*
Red gram pod fly : *Melanagromyza obtusa*

- Small blackish or yellowish flies
- Wings hyaline or pictured
- Femora of legs bristled
- Vibriosae are generally absent (a pair of stout bristles are on each side of the face just above the oral margin, longer than bristles on the vibrisal ridge)
- Most of the *larvae are phytophagous, mine into leaves producing characteristic blotches or mine into stems of young seedlings*


Family : **MUSCIDAE (Shoot flies)**
Jowar shoot fly : *Atherigona varia soccata*
Rice seedling fly : *Atherigona oryzae*

- Small to medium dark flies resembling houseflies
- Fine erect hairs are present on the under surface of scutellum. Possess more than one sternopleural bristles
- In the fore wing vein, Cu1 +1A is short and does not reach the wing margin
- Larvae are cylindrical and truncated posteriorly
- Mostly phytophagous, some are scavengers and a few are parasitic



Notes

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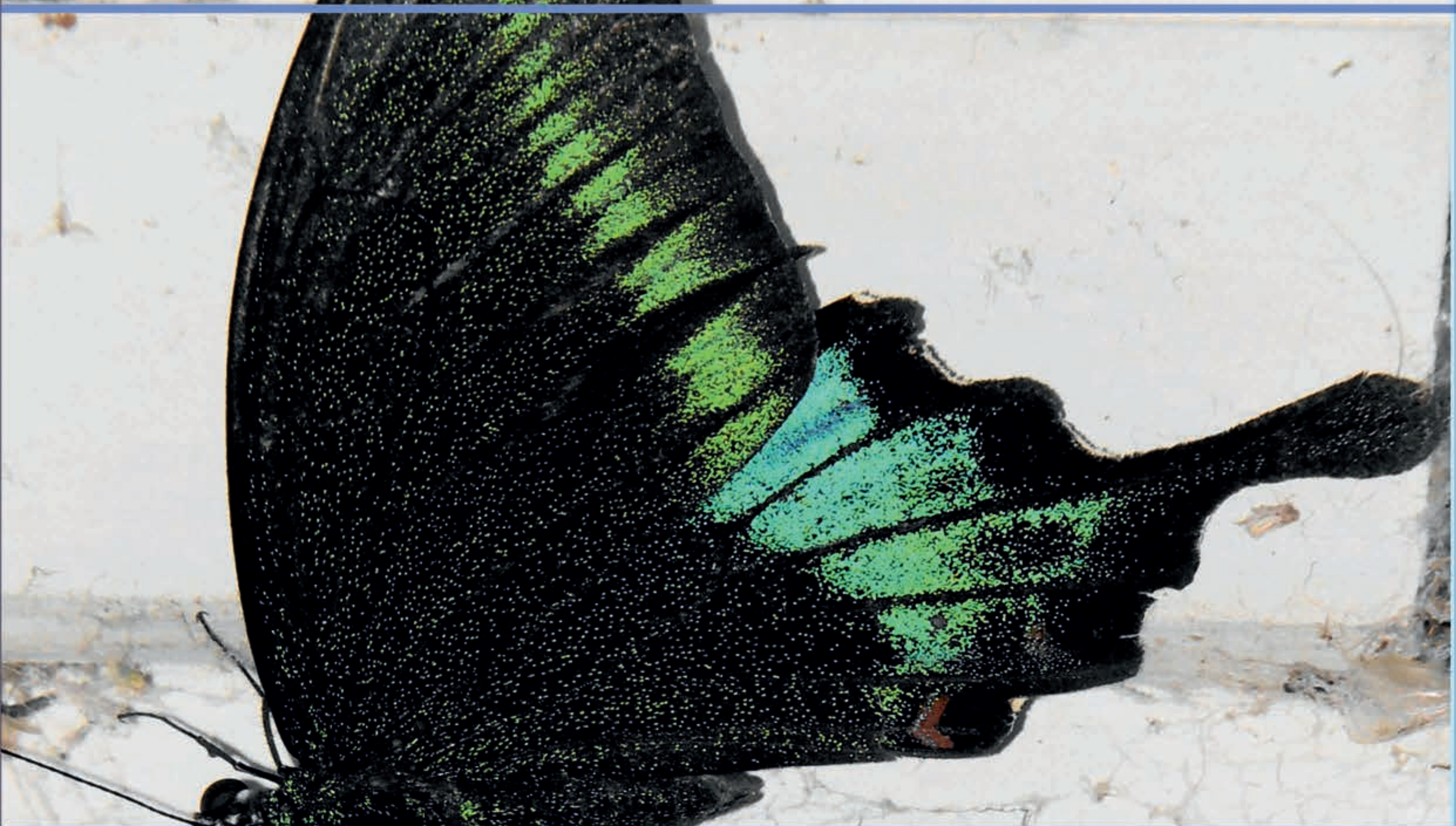

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