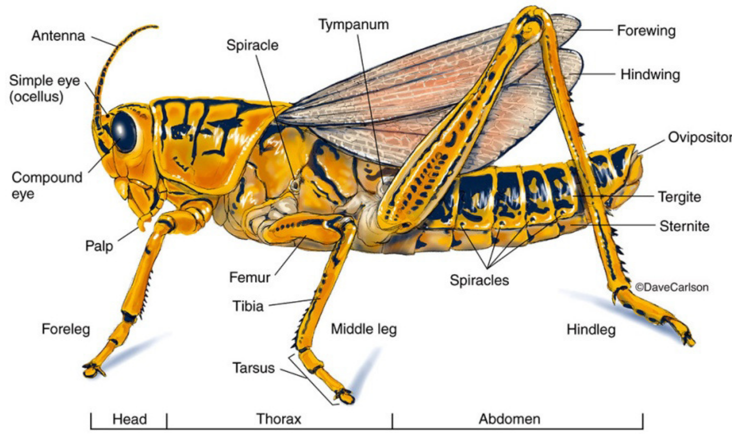
B.Sc. Ag II Sem

Fundamentals of Entomology

Credit - 4(3+1)

As per ICAR
5TH Dean Syllabus

Fundamentals of Entomology I
(Insect Morphology and Taxonomy)



Reading Material for Undergraduate Students of Agricultural Sciences

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THEORY – LECTURE WISE OUTLINES

S.No	Topics and Details
1.	History of Entomology in India, Contributions of eminent entomologists, Locations and year of establishment of entomological institutions • Arthropoda – Mention of insects in scripts • Contributions of Aristotle, J.C. Fabricius, J.G. Koenig, Carolius Linnaeus, Cramer, Dury, Dr. Kerr, Rev Hope Rothney, Ronald Ross, L De Niceville, H.M Lefroy, T.B.Fletcher, E.P. Stebbing, T.V. Ramakrishna Ayyar, B.V. David, Y.Ramachandra Rao, M S Mani, S Pradhan, H.S. Pruthi, M.R.G.K. Nair and S. Pradhan; ML Roonwal, T.Kumara Swami, M R G K Nair,K.K. Nayar and N. Ananthakrishnan • Locations and year of establishment of Division of Entomology, IARI, Zoological Survey of India (ZSI), Directorate of Plant Protection, Quarantine and Storage (DPPQS), Indian Institute of Natural Resins and Gums (IINRG), National Bureau of Agricultural Insect Resources (NBAIR), 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 - Major structural characters, developmental characters and protective characters (Morphological, physiological, behavioural and construction of protected niches) of Insecta in Animal Kingdom.
3.	• Classification of Phylum Arthropoda up to Classes – • Different Classes of Arthropoda and comparison of characters of Class Insecta with Arachnida, Crustacea, Symphyla, Chilopoda, Diplopoda and Onychophora;
4.	• Structure and functions of body wall and moulting – Different layers, chemical composition, functions of body wall and cuticular appendages • Cuticular processes and cuticular invaginations – Chaetotaxy • Moulting – Apolysis, ecdysis and sclerotization.
5.	• Body segmentation of the insects • Head (Syncephalon) – Procephalon and gnathocephalon, types of head, sclerites and sutures of insect head • Thorax – Segments and appendages (wings and legs).
6.	• Abdomen – Segments, pre and post genital appendages (Furcula, cornicles, tracheal gills and pseudo ovipositor in Diptera - Propodeum, petiole and gaster in Hymenoptera) • Male and female genital organs - Epimorphic and anamorphic development in insects.
7.	• Antenna – Structure of typical antenna and its modifications in different insects with examples.
8.	• Mouthparts – Biting and chewing, sucking (Piercing and sucking, Rasping and sucking, Chewing and lapping, Sponging and Siphoning/ Simple sucking), mask and degenerate types with examples.

9.	• Legs – Structure of a typical insect leg and modifications of insect legs with examples
10.	• Wings – Venation, margins and angles • Types of wings and wing coupling organs with examples
11.	• Types of Metamorphosis and diapauses • Metamorphosis- Ametamorphosis- Incomplete Metamorphosis or Direct or Simple Metamorphosis- Intermediate metamorphosis - Complete Metamorphosis or Complex or Indirect Metamorphosis- Hypermetamorphosis with examples • Diapause- Obligate and facultative diapauses – Stage of occurrence of diapause with examples
12.	• Types of larva and pupa – Differences between nymph and larva - Larva- Protopod-Oligopod (Campodeiform and Scarabaeiform)- Polypod and Apodus with examples • Pupa- Obtect- Exarate- Coarctate- Chrysalis with examples
13.	• Digestive system – Alimentary canal – Structure of foregut, midgut and hindgut –histology, functions, filter chamber and peritrophic membrane • Process of digestion- Extra intestinal digestion.
14.	• Circulatory system – Open and closed types – Organs of circulatory system – Dorsal blood vessel (diaphragms, sinuses and accessory pulsatile organs) • Process of circulation - Types of haemocytes • Properties and functions of haemolymph
15.	• Excretory system – Structure, functions and modifications of malpighian tubules • Structure and functions of other organs of excretion
16.	• Respiratory system – Tracheal system – Structure of spiracle and trachea • Classification based on functional spiracles and other means of respiration
17.	• Nervous system – Neuron and its types (based on structure and function) – Synapse, ganglia, central nervous system, sympathetic nervous system and peripheral nervous system
18.	• Reproductive system – Structure of male and female reproductive systems – Structure and types of ovarioles and structure of follicle – Types - Special modes of reproduction in insects
19.	• Secretory (endocrine) system – Structure and functions of neurosecretory organs (neuro secretory cells of brain, corpora cardiaca, corpora allata, prothoracic glands and ring gland).
20.	• Sense organs – Compound eyes – Structure of ommatidium – Ocelli – Dorsal ocelli and lateral ocelli - Types of images and auditory organs (auditory hairs, tympanum, Jhonston's organ and pilifer organ) – Chemoreceptors

21.	• Taxonomy – Importance - History – Binomial nomenclature - Holotype, allotype and paratype – Suffixes of tribes, subfamily, family and superfamily – Law of priority – Synonyms and homonyms - Definitions of biotype - Subspecies - Species – Genus - Family and Order. Characters of Class Insecta - Economic classification of insects-Classification up to Orders – Subclasses - Apterygota and Pterygota– Names of Orders of Apterygota and Pterygota with examples - Orthopteroid, Hemipteroid and Panarpoid group of orders.
22.	• Orthoptera – General characters - Gryllidae, Acrididae, Tettigonidae and • Gryllotalpidae – Characters with examples
23.	• Dictyoptera – General characters – Blattidae and Mantidae– Characters with • examples - Odonata - General characters with examples
24.	• Isoptera – General characters –Termitidae –Characters with examples - Order – • Thysanoptera – General characters –Thripidae –Characters with examples
25.	• Hemiptera – General characters - Sub order Heteroptera – Characters - Cimicidae - • Miridae, Pentatomidae, Lygaeidae, Coreidae, Pyrrhocoridae - Characters with examples
26.	• Hemiptera - Suborder Homoptera – Characters – Delphacidae, Cicadellidae, Aleurodidae, Aphididae, Coccidae, Pseudococcidae, Lopophidae- Characters with • examples -Neuroptera – General characters - Chrysopidae- characters with examples
27.	• Lepidoptera-General characters - Differences between moths and butterflies - Noctuidae, Lymantriidae and Sphingidae and Pieridae- Characters with examples
28.	• Lepidoptera- General characters - Pyralidae, Crambidae, Gelechiidae, Lycaenidae, Arctiidae, Papilionidae, Saturniidae and Bombycidae - Characters with examples
29.	• Coleoptera - General characters – Scarabaeidae, Coccinellidae, Chrysomelidae, - Characters with examples
30.	• Coleoptera - General characters – Cerambycidae, Bruchidae, Apionidae and Curculionidae - Characters with examples
31.	• Hymenoptera - General characters – Tenthredinidae, Ichneumonidae, Braconidae, Chalcididae, Trichogrammatidae, and Apidae- Characters with examples
32.	• Diptera -General characters - Culicidae, Cecidomyiidae, Muscidae, Tachinidae, Agromyzidae and Tephritidae - Characters with examples

PRACTICALS – LECTURE WISE OUTLINES

S.No	Topics and Details
1.	Methods of collection and preservation of insects including immature stages
2.	External features of Grasshopper / Blister beetle
3.	Study of types of mouthparts – Biting and chewing, piercing and sucking, rasping and sucking, chewing and lapping, sponging and siphoning
4.	Study of different types of insect antennae and legs
5.	Study of wing venation, types of wings and wing coupling mechanisms
6.	Study of different types of insect larva and pupa
7.	Dissection of digestive system in insects (Grasshopper).
8.	Dissection of female and male reproductive systems in insects (Grasshopper).
9.	Study of characters of Orders - Orthoptera, Dictyoptera and their families and Odonata.
10.	Study of characters of Orders - Isoptera and Thysanoptera and their families.
11.	Study of characters of Orders -Hemiptera and its sub order Heteroptera and their families.
12.	Study of characters of Sub Order - Homoptera and its families
13.	Study of characters of Order- Neuroptera and Lepidoptera and their 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

1. *Insects: Structure and Function.* Chapman, R. F 2013 Ed by Simpson, S. J. and Douglas, A C. Cambridge Univ. Press, UK.
2. *Imm's General Text Book of Entomology* (Vol. I and II). Richards, O.W. and Davies, R.G 1977. Chapman and Hall, London.
3. *Insect Physiology*. Wigglesworth, V.B 2013. Springer (Originally published by Chapman and Hall, London, 1974).
4. *Insect Physiology and Anatomy*. Pant, N.C. and Ghai, S. 198. ICAR, New Delhi.
5. *Theory and Practice of Animal Taxonomy.* Kapoor, V. C 2008. Oxford and IBH Publishing, New Delhi.
6. Borror and De Long's *Introduction to the Study of Insects.* Charles A Triplehom and Norman F. 2005. Johnson Thomson Brooks/Cole Publishing. U.S.A.
7. *Principles of Insect Morphology.* Snodgrass, R.E. 2001. CBS Publishers & Distributors, Delhi.
8. *Modern Entomology,* Timbhare, D.B. 2015 Himalaya Publishing House.

LECTURE-01

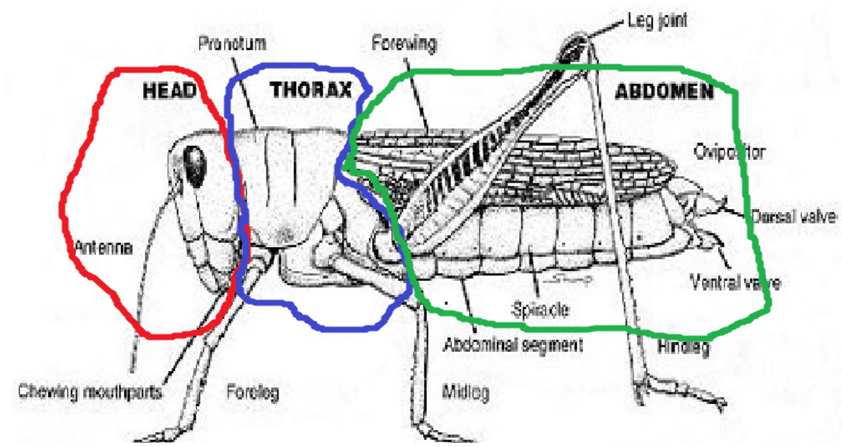
HISTORY OF ENTOMOLOGY *in India, Contributions of eminent entomologists, Locations and year of establishment of entomological institutions*
Arthropoda – Mention of insects in scripts
Contributions of Aristotle, J.C. Fabricius, J.G. Koenig, Carolius Linnaeus, Cramer, Dury, Dr. Kerr, Rev Hope Rothney, Ronald Ross, L De Niceville, H.M Lefroy, T.B.Fletcher, E.P. Stebbing, T.V. Ramakrishna Ayyar, B.V. David, Y.Ramachandra Rao, M S Mani, S Pradhan, H.S. Pruthi, M.R.G.K. Nair and S. Pradhan; ML Roonwal, T.Kumara Swami, M R G K Nair,K.K. Nayar and N. Ananthakrishnan
Locations and year of establishment of Division of Entomology, IARI, Zoological Survey of India (ZSI), Directorate of Plant Protection, Quarantine and Storage (DPPQS), Indian Institute of Natural Resins and Gums (IINRG), National Bureau of Agricultural Insect Resources (NBAIR), National Institute of Plant Health Management (NIPHM), National Centre for Integrated Pest Management (NCIPM) and Forest Research Institute (FRI).

- *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).
- *Insects account for more than two-thirds of all known organisms* date back some 400 million years (estimated between 250-500 million years ago), much earlier than appearance of humans, who only appeared 1 million years ago. There are about 1.3 million (=13 lakhs) described species.
- Insects belong to Phylum Arthropoda, which is the biggest phylum of Animal Kingdom.

Kingdom	:	*Animalia*
Phylum	:	*Arthropoda*
		(Invertebrates with Jointed Legs)
		(Largest Animal Phylum)
Class	:	*Insecta (also called as Hexapoda)*
		(Largest Class in Phylum Arthropoda)

- Insect is a small *invertebrate animal with hard, segmented bodies (Head, Thorax and Abdomen), three pairs of jointed legs, and, usually, two pairs of wings*; belong to *Arthropods* and are distributed throughout the world.
- *The head is the first segment of the body, and is the feeding and sensory centre*. It bears a pair of feelers / antennae (detects odours / smell and experience sense of touch), eyes (for vision), and mouthparts (for eating).
- *The thorax is the middle segment of the body, and is the locomotory centre.* Thorax is made up of three segments: the *pro-, meso, and metathorax*. It bears 3 pairs of legs (on all segments) (for walking or running) and 2 pairs of wings (in middle and last) (for flying).
- *The abdomen or end segment of the body, and is the metabolic and reproductory centre*. The food is digested, and excreted in this part, 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.
- Insects vary in size from 0.02 cm to 35 cm 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.



- Female adult lay eggs and small baby insects hatch out of eggs as larvae (an immature stage, usually in the form of a caterpillar, grub, or maggot) which after some time pass through 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 and 29 orders (as per old classification).
- The field of entomology may be divided in to two major aspects, as *Fundamental entomology or General entomology and applied entomology or Economic entomology.*
    1. *Fundamental entomology* deals with the basic or academic aspects of the science of entomology. It includes morphology, anatomy, physiology and taxonomy of the insects.
    2. *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 (grass hoppers), bharamara, shadpada (sixlegged), pipilika (ant), makshika (honey bees) umbakapalika (queen termite) 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 to recall the story of Mahabharata in which the boy Sage 'Mandavya' was himself impaled (pierce with a shapr instrument) on the point of a sharp crowbar for having collected and pinned insects.
- *Fabricius* Johann 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).
- *Ramakrishna Ayyar*, the pioneer entomologist of South India, had remarked this as a bit of the biography of the *first Indian insect collector*.

Early works on Indian Insects and Institutes in India

- In India scientific study of insects was undertaken only from the 18th century.
- *In the 10th edition of 'Systema Naturae' in 1758 Linnaeus had included only twelve Indian insects which form earliest record.* This is the beginning of modern Indian Entomology
- 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) during 1767-1779. 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.
- In 1840, Rev Hope published a paper on "*Entomology of the Himalayas and India*".
- 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. He made a breakthrough discovery during the dissection of a specific species of mosquito, the *Anopheles*, previously fed on a malaria patient. Malaria parasite was found in the mosquito salivary glands.
- The posting of *Lionel de Nicevelle* in 1901 as the *first Entomologist to the Government of India* marks the birth of professional entomology.

- Professor *Maxwell Lefroy*, an English Entomologist, a Professor in Imperial College, London. In 1903, he was appointed as second entomologist to the Government of India, succeeding Nicevelle. Prof. Lefroy was involved in creation of 'Imperial Agricultural research Institute' at Pusa (Bihar) in 1905 and was made the *first Imperial Entomologist*. Lefroy published "*Indian Insect Pests*" in 1906 and "*Indian Insect Life*" in 1909. 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.
- 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.
- *T.B. Fletcher, the Second Imperial Entomologist succeeding Maxwell Lefroy.* Published book "*Some South Indian Insects*" and "*Catalogue of Indian Insects*". 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.
- *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).
- *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. Distinguished Entomologists, HS Pruthi, and Y. Ramachandra Rao are the founders of the society, and Y. Ramachandra Rao is the Founding Editor of Indian Journal of Entiomology. (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 Agricultural Insect Resources (NBAIR)* 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.
- *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.
- *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.
- 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*.

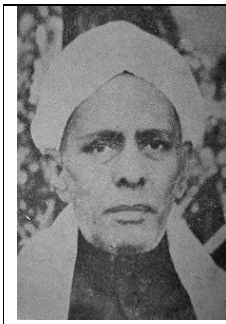
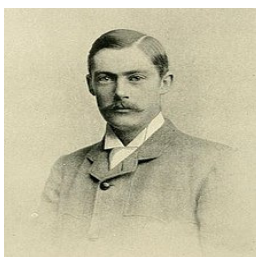
The Division of Entomology was established in 1905 as one of the five major Divisions of the then Agricultural Research Institute located at Pusa, Bihar. It was shifted to its present premises in 1936. Eminent entomologists like *H.M. Lefroy, T. B. Fletcher, H.S. Pruthi, S. Pradhan and K.N. Mehrotra* 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.
- *TNAU Insect Museum* – The *First Insect Museum in India*. Insects collected since 1900's are housed here. The Museum was commissioned in the year 2013, and completed by 2017. The museum showcases a rich diversity of insects from all over the country, and museum speaks realms about the magical world of Insects. It is located at Coimbatore.

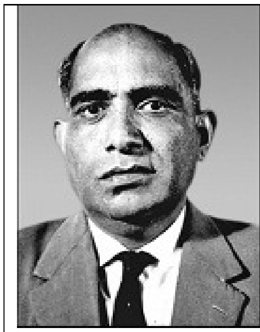
Important other braches of Entomology:

Forensic Entomology: Study and use of insects in crime investigations.
Veterinary Entomology: Study on insects related to live stock and veterinary animals.
Medical Entomology: Study of insects in relation to human beings.

DISTINGUISHED SCIENTISTS WORKED ON INSECTS IN INDIA:
(ADDITIONAL INFORMATION FOR REFERENCE PURPOSE ONLY)

	**T. V. Ramakrishna Ayyar** (20 July 1880 - 13 February 1952) • Pioneer Indian entomologist who worked in the agricultural department in British India. • He described numerous species of insects, especially the ***thrips***, catalogued Indian insect pests, taught, and • wrote a landmark textbook of entomology, the *Handbook of Economic Entomology for South India* (1940).
	**Sir Ronald Ross** (13 May 1857 – 16 Sept 1932) • British Medical Doctor, received Nobel Prize in Medicine, for Discovery of Malaria Parasite transmission through Mosquitoes. • Worked in Indian Medical Service for 25 years, and during his service that he made groundbreaking medical discovery.
	**Charles Lionel Augustus de Nicéville** (1852 in Bristol – 3 December 1901 in Calcutta from malaria) • Curator at Indian Museum in Kolkata • Studied Butterflies in Indian Subcontinent and wrote three volume monograph on butterflies of Subcontinent • The posting of Lionel de Nicevelle in 1901 as the *first Entomologist to the Government of India* marks the birth of professional entomology.
	**Harold Maxwell Lefroy** (20 January 1877 – 14 October 1925) • An English entomologist, Professor of Entomology at Imperial College London • In 1903, he was Posted as the *second Entomologist to Government of India* (succeeding Niceville) • In 1905, he was involved in the *creation of Imperial Agricultural Research Institute (IARI) at Pusa, Bihar*, and he was appointed at *First Imperial Entomologist*. • He worked on applied entomology and initiated experiments on the use of chemicals to control insects, founding the Rentokil company.

	**Thomas Bainbrigge Fletcher** (25 March 1878 – 30 April 1950) • An English entomologist. Although an amateur lepidopterist who worked in the Royal Navy, he became an expert on "*microlepidoptera*" and • was appointed as the *second Imperial Entomologist in India to succeed Harold Maxwell Lefroy*. • His work as head of entomological research in India was initially on identifying work that had already been done and that which was ongoing. By conducting meetings of researchers he ensured that duplication was avoided. • He produced a "*List of Publications on Indian Entomology*" and a *Catalogue of Indian Insects*. He also worked out the life-histories of many moth species in the families Gelechidae, Cosmopterygidae, Neopseutidae and Tortricidae and produced *A List of Generic Names used for Microlepidoptera* (1929). He also wrote several more general works on entomology including *Some South Indian Insects* (1914), *A Veterinary Entomology for India* and *Hints on collecting and Preserving Insects*.
	**Hem Singh Pruthi (HS Pruthi)** (23 February 1897 – 23 December 1969) • An Indian entomologist who served as *Imperial Entomologist*, being the first native Indian in that position, succeeding TB Fletcher in 1934. • He worked mainly on the Hemiptera. • In 1938 he *founded the Entomological Society of India*. • He was a *plant protection advisor to the Government of India* and helped establish a locust warning system. He retired in 1953. • In 1963 he published a *Textbook of Agricultural Entomology*.
	**Yelseti Ramachandra Rao** (11 Sept 1885 – 1 June 1972) • Pioneer in the study and management of the desert locust (*Schistocerca gregaria*). • Born in Yemmiganur, Adoni District. • He was trained at IARI under Maxwell Lefroy • Retired from Madras Government in 1941, but continued work in DPPQS • *Founded Entomological Society of India*, served as *Founding Editor for Indian Journal of Entomology* • He was given Rao Bahadur and Diwan Bahadur by British Government.

	**Dr. S. Pradhan** (1913-1973) • First Professor of Division of Entomology, IARI • Economic Entomology & Toxicology studies • Mode of action of Insecticides • Development of “Pusabin” • Periodicity of Locusts • He invented “biometer” and standardized techniques for population studies
	**Prof. KN Mehrotra** (1930-1999) • Professor of Entomology, IARI • He is the founder President of Society of Pesticide Science India (1987) • Pioneering research on Cholinergic system in different part of insect nervous system, sex pheromones, phagostimulants, deterrent is referred by insect physiologists.
	**B. R. Subba Rao** • Established a strong unit of biological control at IARI, with an emphasis on taxonomy of parasites and predators • Formerly Entomologist, Commonwealth Institute of Entomology, London, UK • Noted taxonomist of parasitic hymenoptera, especially Chalcidoidea. • Author of “*A History of Entomology in India*” in 1998. • Hymenopteran Egg Parasitoid *Dicopus longipes* (Subba Rao) was named in his honour.
	**Vasantharaj David Baliah** • Born on 17th Nov, 1935 in Myanmar • Published “*Elements of Economic Entomology*” • Chairman, Scientific and Academic Board, International Institute of Biotechnology & Toxicology

LECTURE-02

CONTRIBUTORY FACTORS FOR ABUNDANCE OF INSECTS

Major structural characters, developmental characters and protective characters (Morphological, physiological, behavioural and construction of protected niches) of Insecta in Animal Kingdom.

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.
- *Insects account for more than two-thirds (about 70%) of all known organisms* date back some 400 million years (*estimated between 250-500 million years ago*), much earlier than appearance of humans, who only appeared 1 million years ago. There are about 1.3 million (=13 lakhs) described species.
- Insects constitute the *most dominant class of the animal kingdom*. They also represent the culmination of evolutionary development in terrestrial arthropod.

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 *maintains the shape of the body* much more efficiently than the endoskeleton. 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 *turned in to appendages* used as *good tools for digging, preying, oviposition*, etc..
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* and is easier for smaller individuals to take shelter in *small niches* as well as against adverse abiotic and biotic environments. Smaller size *increases the chances of variability and mutation*. Smaller size leads to greater efficiency, and muscular strength is comparatively better in small animals.

Thus it is no wonder that a flea with a length of $^1/_{20}$ inch can jump a horizontal length of 13 inches and a height of 8 inches; 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.
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. 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. Functional wings enabled various species to undertake *international migration* as in the case of locusts and butterflies.

Mosquitoes, which, but for functional wings would not have been able to breed in small pools of water which dry in short time. 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. Fall army worm (a Maize pest) can fly upto 1000 kms, crossing oceans ans continents, spread across Africa and now (2018) entered inti India.

5. ***Hexapod locomotion:*** Jointed nature of legs and six legs is a characteristic feature in insects; represent the optimum number, as locomotion is cumbersome in millipedes which have many numbers of legs. In hexapods, during locomotion the body is always rests on a *tripod* while the other three legs move forward.
6. ***Compound eyes:*** These compound eyes are very complicated structures, and 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:*** The sense organs are distributed on diffent parts of body. Eyes, antenna and mouth parts on head, legs and wings on thorax, tympanum and cerci on abdomen possess various sense organs for various purposes, and scatteredness of sense organs on various parts of body prevents chance of being damaged.
8. ***Decentralized nervous system:*** This system is so decentralized that brainless insects, even if some parts of the body are removed, insects can be artificially stimulated to walk, fly or even feed and breed.
9. ***Direct respiration:*** The gases are taken in to and out 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. The presence of these tracheas allows free supply of oxygen to the insect and makes it to be an efficienct terrestrial or aerial arthropod.
10. ***Enteronephric excretion:*** The excretory function is performed by Malpighian tubules which open at the junction of midgut and hindgut, 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.

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, viz., mainly feeding stage larva and 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. ***Method of reproduction:*** Insects can reproduce both sexually and parthenogenitically.
3. ***Controlled reproduction:*** Insects have high degree of control number of females that can lay egss, based on the adverse conditions / social life requirements.
4. ***Quick rate of development / Short life cycle:*** Majority of insects, completes life cycle in less than a month, enable them to complete many generations in year.
5. ***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 of feeding of insect not only to different plant species or varieties but also to different parts of the same plant.
6. ***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.
7. **ZENITH (Peak) OF EVOLUTION:** The zenith of evolution depicted by social insects such as termites, ants and bees which shows the degree of specialization through development of various forms for various duties such as labour / worker forms, defence forms, sexual forms, asexual forms, polymorphism etc.

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 presence of *bristles, spines, hairs, scales* etc on body. Often *minute size of insects* affords protection against large predators. High degree of *protective colouration* and adaptation used for *camouflaging* (stick insects and leaf insects).
2. ***Physiological adaptations:*** Sap feeding (sucking insects) have special *filter chamber* in alimentary canal to protect the digestive enzymes from dilution. Some insects have special physiological mechanisms like *diapause* to escape/protect from adverse environmental conditions. Some insects produce and release *poisonous / unpleasant odour* through glands. Stink bugs have glands on thorax / abdomen, producing foul / bad smell chemicals (hydrocarbons). Larvae of swallow tail butter files have glands called *osmeteria* on just behind head, release repellent volatile chemicals whn disturbed. Blister beetles produce *cantharidin*, a strong irritant. Some possess *warning coloration by imitating certain distasteful insects*.
3. ***Behaviouristic adaptation:*** Some insects, for example *stinging hymenoptera* take up such an *offensive posture* when threatened that the predator is frightened. Some insects adopt dodging attitude as *feigning death*. Colorado potato beetle, when disturbed draw their legs beneath and drop to the ground and pretend as if dead. Some insects *eject some kind of offensive liquid*. Some insects *imitate with voice of dangerous insects / mimicry*.
4. ***Construction of protective structures:*** Insects developed protective adaptations through construction of protective structures such as *Termatoria by termites, honey comb by honey bees, and nests by ants*. The *hives of honey bees, wasp*, the *coccons of pupae* in so many species, the bag of clothes moth and other bag moths (cases / bags of case worms), 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.

LECTURE-03

CLASSIFICATION OF PHYLUM ARTHROPODA

Different Classes of Arthropoda and comparison of characters of Class Insecta with Arachnida, Crustacea, Symphyla, Chilopoda, Diplopoda ~~and Onychophora~~;

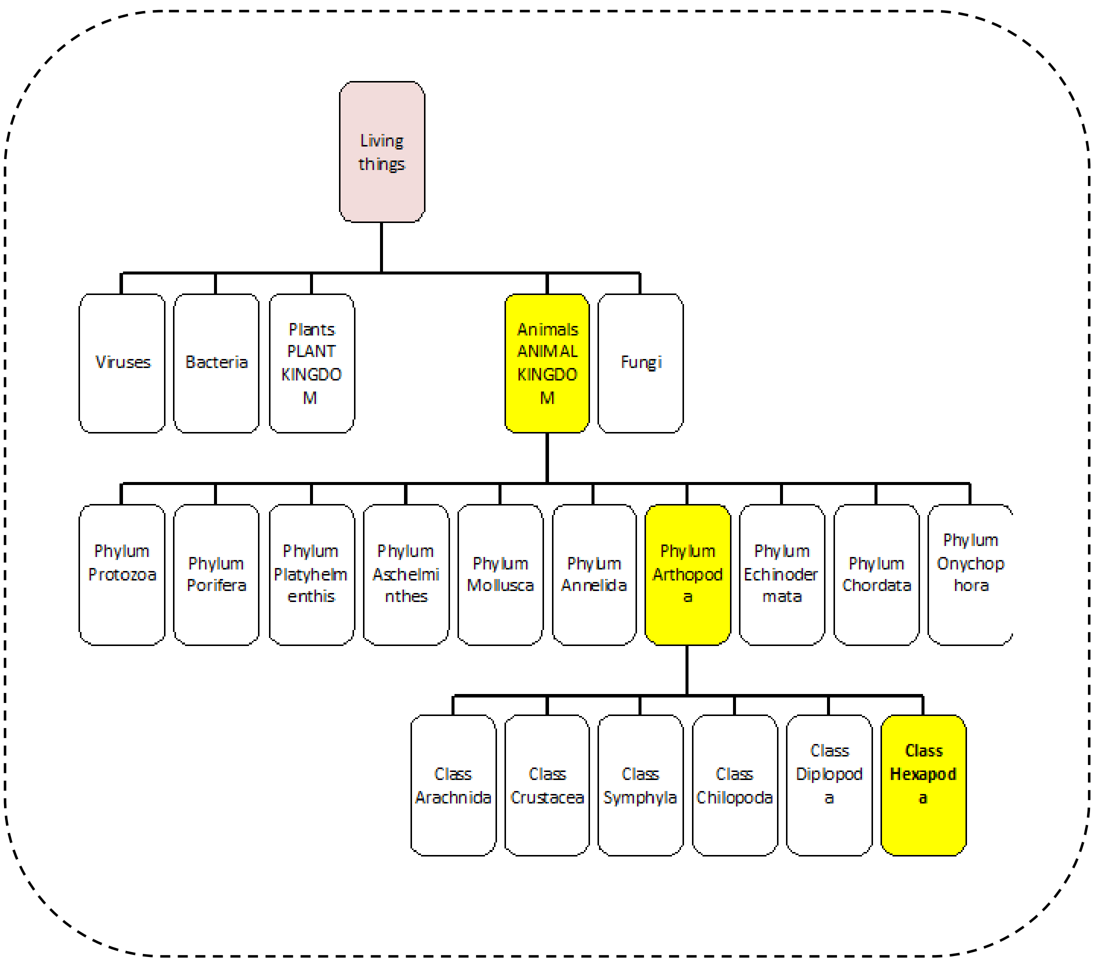
Classification: The sequence of classification categories can be remembered by memorizing this mnemonic phrase: **K**ing **P**hillip, **C**omes **O**ut **F**or **G**oodness **S**ake!

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 (Animalia)
- 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 (ARTHRO=JOINT, PODA=LEGS):

- The phylum Arthropoda contains the *hard shelled and jointed legged animals*.
- Phylum Arthropoda includes insects, spiders, lobsters, crabs, spiders, mites, ticks, scorpions and related animals.
- *Largest phylum in the animal kingdom* constitutes about 83% of all known animals on the earth.
- Arthropods were first studied by Aristotle, and Von Siebold coined the term Arthropoda.

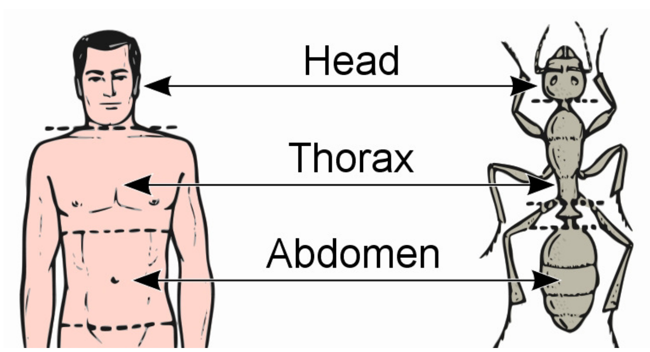
The following are the ***most typical characters*** of animals in Phylum Arthropoda:

1. *Segmented body:* Arthropods have *segmented bodies* with the segments grouped into two or three distinct sections (Head, Thorax & Abdomen).
2. *Paired jointed appendages (or) legs*
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*
7. *Ventral nervous system:* Nervous system comprised of a dorsal brain and ventral nerve cord
8. *Dorsal Heart with paired ostia (openings)*
9. *Striated muscles* in skeletal system
10. *Respiration by gills, tracheae or spiracles*

Classes of Phylum Arthropoda:

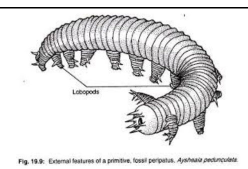
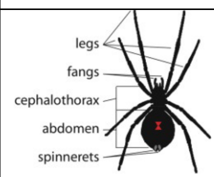
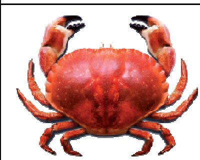
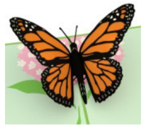
- Phylum Arthropoda is further divided into four smaller groups called *classes*.
- Phylum Arthropoda can be divided into *16 Classes (as per recent animal taxa),* excluding the extinct trilobites.

S.No	Class	Meaning	Examples
1.	Arachnida	Arachine-spider	Scorpion, spider, ticks, mites
2.	Crustacea	Crusta-shell	Prawns, crabs, wood louse
3.	Chilopoda	Chili-lip, poda-legs	Centipedes
4.	Symphyla	Sym-similar, kind	Centipede like
5.	Diplopoda	Diplo-two, poda-legs	Millipedes
6.	Hexapoda (or) Insects	Hexa-six, poda-legs In-internal, sect-cut	Insects



Comparison of characters of Class Insecta with Phylum Onychopohra, and other Classes of Phylum Arthropoda (AraCru, ChiSymDI)

S.No	Characters	PHYLUM Onychophora	Class Arachnida	Class Crustacea	Class Chilopoda	Class Symphyla	Class Diplopoda	Class Insecta / Hexapoda
1	Body	Head is continous with body	Body is divided into 2 parts, cephalothoram and abdomen		Body is divided into 2 parts; Head and trunk			Body is divided into 3 parts; Head, Thorax and Abdomen
2	Antenna	1 pair	NO	2 Pairs	1 Pair			
3	Mouth Parts	Jaws / Oral Papillae	Chelicerae and edipalpi	One pair of mandibles + 2 pairs of Maxillae with maxillary pads	One pair of Mandibles + 2 Pairs of Maxillae	Mandibles + Maxillae + Labium	One Pair of mandibles + 1 pair of Maxillae	Labrum + pair of mandibles + pair of Maxillae + Labium + Hypopharynx
4	Legs	Short, stumpy and one pair of legs per segment	2 or 4 pairs	5 pairs	1 pair per segment; first pair of legs is modified to from poison claws	1 pair per segment	2 pairs per segment	3 pairs in thorax region (@ one pair for each segment)
5	Respiratory organs	Cutaneous	Book lungs	Gills	Trachea			

S.No	**Characters**	**Phylum Onychophora**	**Class Arachnida**	**Class Crustacea**	**Class Chilopoda**	**Class Symphyla**	**Class Diplopoda**	**Class Insecta / Hexapoda**
6	Opening of reproductive organs	open at posterior or caudal segment	Open at the base of the abdomen anteriorly	Open anteriorly on 9th post oral segment	Open at penultimate segment of abdomen	Open after 4th cephalic segment	Open at behind the 2nd pair of legs	Opening at the anal end of the abdomen
7	Excretory organs	Coelomo ducts	Malpighian tubules	Coelomo ducts or green glands	Malpighian tubules			
8	Development	Direct	Direct except in mites and ticks	Indirect	Direct			Direct or indirect
9	Habitat	Terrestrial	Mostly terrestrial	Mostly aquatic in salt and fresh water	Terrestrial			Terrestrial or aquatic
10	Examples	Peripatus	Scorpions, mites, ticks, spiders	Crabs, shrimps, lobsters	Centipedes *(have poison glands behind head)*	Garden Centipedes	Millipedes	Insects
								

CLASS INSECTA / CLASS HEXAPODA (INSECTS)

Kingdom : Animalia
Phylum : Arthropoda
(Invertebrates with Jointed Legs)
(Largest Animal Phylum)
Class : Insecta (also called as Hexapoda)
(Largest Class in Phylum Arthropoda)

- *Insects account for more than two-thirds of all known organisms*
- It is estimated that Class of Insects originated on Earth about 480 million years ago, much earlier than appearance of humans, who only appeared 1 million years ago. There are about 1.3 million (=13 lakhs) described species.
- Insect is a small *invertebrate tracehate animal with hard, segmented bodies (Head, Thorax and Abdomen), three pairs of jointed legs, and usually two pairs of wings in thoracic region*; and genital organs at posterior end of the body (*abdomen*), with central nervous system, belong to *Arthropods* and are distributed throughout the world.
- Insects vary in size from 0.02 cm to 35 cm 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.
- *Only invertebrates with wings and only animals with true wings*
- Many feeding strategies
- Mostly terrestrial, some secondarily aquatic

Characteristic features of Class Insecta:

- *Chitinous Exoskeleton:* The skeleton of an insect is external and is composed of *chitin*. It is membranous at the joints, but elsewhere is hard. It plays an important role for survival of insects.
- *Segmented body:* The body is divided into 3 regions *viz.,* Head (1 segment), Thorax (3 segments) and Abdomen (8 to 10 segments)
- *The head is the first segment of the body, and is the feeding and sensory centre*. Head bears *a pair of feelers / antennae* (detects odours / smell and experience sense of touch), *eyes* (for vision), and *mouthparts* (for eating).
- *The thorax is the middle segment of the body, and is the locomotory centre.* Thorax is made up of three segments: the *pro-, meso, and metathorax*. It bears 3 pairs of legs (on all segments) (for walking or running) and 2 pairs of wings (in middle and last) (for flying).
- *The abdomen or end segment of the body, and is the metabolic and reproductory centre*. The food is digested, and excreted in this part, and where the reproductive organs are located and genital openings are at the posterior end of the body. (*Class Insecta*.).

- *Complete / incomplete metamorphosis* during development. Female adult lay eggs and small baby insects hatch out of eggs as larvae (an immature stage, usually in the form of a caterpillar, grub, or maggot) which after some time pass through 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.
- *Excretion is mainly by Malpighian tubules* helps in maintaining ionic balance in insects.
- *Decentralised Nervous System*

Classification of Class INSECTA: The classification of insects is largely based upon characteristics of the mouthparts, wings, and metamorphosis. Insects are divided into two subclasses and 29 orders (as per old classification).

- 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.
- Class Insecta is divided into *2 sub-classes: Apterygota and Pterygota*.

Sub-Class : Apterygota *Ametabola, Wingless*	**Sub-Class : Pterygota** *Metabola, Winged*
Small and primitive insects This subclass contains *primitive insects that do not fly*, and were *wingless throughout their evolutionary history*.	Developed insects The subclass Pterygota includes most of the world's insect species.
The name Apterygota is Greek in origin, and means "*without wings*."	Pterygota means "wings," and describes *insects that have wings, or once had wings in their evolutionary history*.
The wingless insects of this subclass *do not undergo metamorphosis*. Instead, *the larval forms are smaller versions of their adult parents*. (metamorphosis is simple / absent)	These insects also *undergo metamorphosis*. Metamorphosis is present and variable.
Apterygote insects *molt throughout their lives*, not just during the growth phase.	Pterygote insects *molt only during immature growth stages (nymphs and larvae)* and do not undergo molting in adult stages.
Adult moult several times	*Adults do not moult*

Their *mouthparts are retracted within the head. (Hidden in head)*	The *mouth parts are exposed and well developed*.
Mandibles articulate with head at single point *(monocondyle)*	Mandible articulate with head at 2 points (*dicondyle*)
Malpighian tubules absent / rudimentary	Malpighian tubules *present*
Adults have pre-genital abdomenal appendages.	Adults *without pre-genital appendages*.
Abdominal segments are more in number (11 or 12)	Abdominal segments are usually 8 to 10.
This sub-class is divided into 4 orders	The sub-class is further divided into two groups: *Super Order* Exopterygota (16 orders) and *Super Order* Endopterygota (9 orders).

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

Class : INSECTA (Hexapoda) Insect Orders (Imms Classification)			
Taxonomic Name ORDER NAME	Common Name & Examples	Wing character	Approx. No. of Species Worldwide **(ADDITIONAL INFORMATION)**
Sub-Class : APTERYGOTA (Wingless Primitive Insects with No True Metamorphosis) 4 orders			
Thysanura	Silver fish Bristle tails	Wings absent	55
Diplura	Pronged Bristletails Diplurans		600
Protura	Proturans Telson tails		10
Collembola	Springtails Snow fleas		3000
Sub-Class: PTERYGOTA (Winged Insects with Incomplete or Complete Metamorphosis) 25 orders			
Super-Order: Exopterygota (Hemimetabolous insects with incomplete metamorphosis) 16 orders			
Ephemeroptera	Mayflies	Can't fold wings over body	2000
Odonata	Dragonflies Damselflies	Can't fold wings over body	5000
Plecoptera	Stoneflies	Pleco-foldable	1700
Grylloblattodea	Ice bugs/Rock Crawlers	--	16
Orthoptera	Grasshoppers Locusts Crickets Mole Crickets	Ortho-straight	20000
Phasmida	Stick-Insects	--	3000
Dermaptera	Earwigs	Derma-skin like	1200
Embioptera	Web Spinners	Embio-lively	300
Dictyoptera	Cockroaches Mantids	Dictyo-netted	6000
Isoptera	Termites	Iso-same	1900

Zoraptera	--	Zor-pure, aptera-wingless	22
Psocoptera	Book lice Bark lice	Psokos-rubbed/gnawed (fractured wings)	2000
Mallophaga	Biting Lice	wingless	2800
Siphunculata	Sucking Lice	wingless	300
Hemiptera	True Bugs	Hemi-half	100000
Thysanoptera	Thrips	Thysano-fringed	500
Super Order: Endopterygota (Holometabolous insects with complete metamorphosis) 9 orders			
Neuroptera	Lacewings Ant lions	Neuro-nerved	4700
Mecoptera	Scorpionflies	Meco-long	400
Siphonaptera	Fleas	Siphon-tube/pipe, aptera-wingless (wingless)	1400
Coleoptera	Beetles	Coleo-sheath	370000
Strepsiptera	Stylops	Strepsi-twisted	370
Diptera	True Flies Mosquitoes	Di-two	100000
Lepidoptera	Butterflies Moths	Lepido-scaly	150000
Trichoptera	Caddisflies	Tricho-hairy	5000
Hymenoptera	Ants Bees 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.

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CLASSIFICATION AS PER ROYAL ENTOMOLOGICAL SOCIETY
(LATEST CLASSIFICATION)
ADDITIONAL INFORMATION

Sub-Class	General Description	Order	Examples
APTERYGOTA	Windless Primitive Insects	1. Archaeognatha (or) Microcoryphia	Bristletails
		2. Zygentoma	Silverfish, firebrats
PALAEOPTERA	Insects lacking the ability to fold their wings over abdomen	3. Ephemeroptera	Mayflies / upwing flies
		4. Odonata	Dragonflies, Damselflies
POLYNEOPTERA	Have the ability to flex their wings so that they can be folded flat over the body	5. Dermaptera	Ear wigs
		6. Dictyoptera	Cockroaches Termites Mantids
		7. Embioptera	Webspinners
		8. Grylloblattaria	Rock crawlers
		9. Mantophasmatode a	Heel walkers
		10. Orthoptera	Grasshoppers, Crickets, Bush-Crickets
		11. Phasmida	Stick insects
		12. Plecoptera	Stone flies
		13. Zoraptera	Zorapterans
PARANEOPTERA	True bugs, lice and thrips	14. Hemiptera	True bugs
		15. Phthiraptera	Sucking and Biting Lice
		16. Psocoptera	Book lice Bark lice
		17. Thysanoptera	Thrips

ENDOPTERYGOTA	The larvae look very different to the adults, and undergo metamorphosis in a pupa where the wings develop internally.	1.	Coleoptera	Beetles
		2.	Diptera	True flies
		3.	Hymenoptera	Ants Bees, Wasps
		4.	Lepidoptera	Butterflies, Moths
		5.	Mecoptera	Scorpion flies
		6.	Megaloptera	Alder flies
		7.	Nueroptera	Lace wings Ant lions
		8.	Siphonaptera	Fleas
		9.	Raphidioptera	Snake flies
		10.	Strepsiptera	Stylops
		11.	Trichoptera	Caddis flies

CLASSIFICATION OF INSECTS BASED ON ECONOMIC IMPORTANCE

(*Economic Classification*)

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)

Beneficial insects

(a) Productive insects

- *Secretions 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. 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 (harmful) 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)

(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* weed.
- *Improve soil fertility*: (Ants, crickets, ground beetles, termites)
- *As scavengers*: (Dung rollers, maggots, beetles)
- *Ideal material for scientific investigations*: *Drosophila melanogaster*
- *Aesthetic value*: (Butterflies, Jewel beetle, clear wing moth)

LECTURE-04

STRUCTURE AND FUNCTIONS OF BODY WALL AND MOULTING

Different layers, chemical composition, functions of body wall and cuticular appendages; Cuticular processes and cuticular invaginations – Chaetotaxy
Moulting – Apolysis, ecdysis and sclerotization.

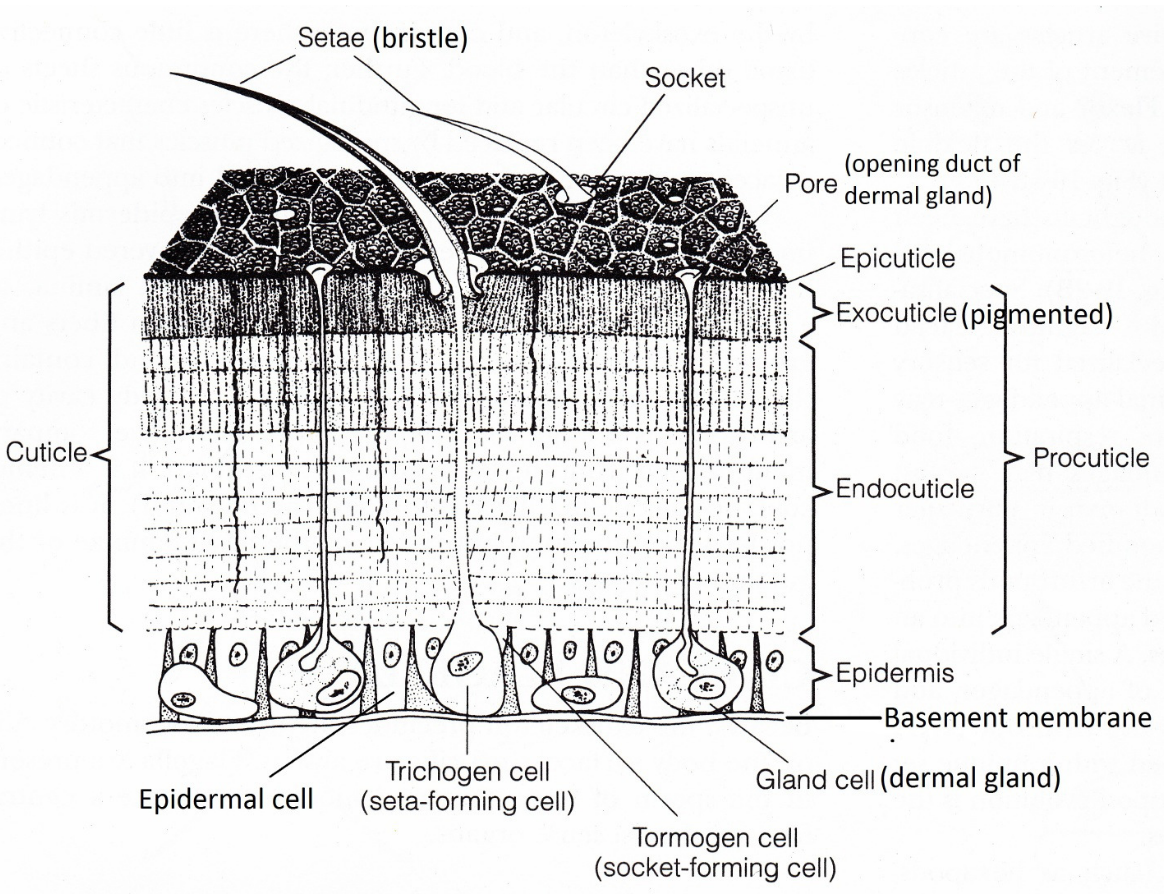
The integument (chitinous exoskeleton), which is a characteristic feature of the arthropods, forms the outer layer of the body, comprising the epidermis (hypodermis) and the cuticle. Integument of insects, besides functioning as an exoskeleton, and *holding the internal organs* together, acts as a *protective 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 INTEGUMENT / BODYWALL

- Acts as ***exoskeleton*** (like skin and bones in humans), *covering the insect completely* (as external armour), and *serving as supportive skeleton* (like bones in humans).
- ***Gives structure and form to Insect***: As Exoskeleton, it provides not only support to body and holding the internal organs, but also *gives shape to the body*. It also *provides space for muscle attachment*.
- ***Protective barrier***: The Protective covering over body protecting internal organs, protecting body from *physical abrasions*, create *barrier for water and ions loss from body*, and *prevent movement of pathogens, parasite, and dangerous chemicals into the body*. Various layers in Epi-cuticle such as cement layer (protect underlying wax layer from abrasions), wax layer (water proofing-imparts water conservation), polyphenol layer (highly resistance to acids and organic solvents) and other layers in Pro-cuticle protects the body. In some insects, the secretions over cuticular layer are bactericidal which protects from infection.
- ***Movement***: The rigidity that the exoskeleton exhibits makes it possible for muscle movements precisely, due to insertion of muscles to the integument wall tightly. Wing movement is possible only because of hard cuticular flight Sclerites in thoracic region.
- ***Sensory:*** The cuticle is modified into various structures that can receive stimuli.
- ***Behavior modulation***: The epidermal cells that secrete cuticle also secretes and deposits various chemicals such as *Pheromones and cuticlular pigments* within or on cuticle that are involved in behavioral sequences, mating and evading from enemies due to color changes / mimics.

GENERAL STRUCTURE OF INSECT 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. Basement membrane (inner layer)
  2. Epidermis (hypodermis) (middle layer)
  3. Cuticle (Exoskeleton) (outer layer)



BASEMENT MEMBRANE:

- Inner layer / basal part of the integument / body wall.
- It is formed from degenerated epidermal cells.
- Basement membrane appear as non-living amorphous (shapeless) granular neutral mucopolysaccharide layer.
- It is about 0.5 μ thick.
- Basement membrane forms a continuous sheet beneath epidermis, where muscles are attached, and become continuous with sarcolemma of muscles, similar to neural lamella.

EPIDERMIS (HYPODERMIS):

- *The single cellular (uni cellular) layer lying between the basement membrane and endocuticle*.
- These cells consists of well developed nucleus and other cytoplasmic contents.
- Adjacent cells are held together by means of certain cytoplasmic processes which are known as *desmosomes*.
- 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.

Different types of epidermal cells / modifications of epidermal cells:

- 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.
- Some of the epidermal cells are modified as *trichogen cells* producing hair like *setae or trichome*.
- Epidermal cells as *moulting glands* *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.
- *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 CUTICLE

- Outer most thick layer of integument. It *covers the whole body outside* as well as *lining of ectodermal invaginations such as foregut, hindgut and tracheae*.
- Cuticle is complex, *non-cellular*, *non-living* and is the *secretion of epidermis*. The epidermal cells secrete chemicals like chitin, protein and lipid, and these polymerize to form cuticle.
- *Cuticle comprises 50% of dry weight of insects*.
- The cuticle is primarily divided into two parts:
  1. Epicuticle : *non-chitinous*
  2. Procuticle : *chitin-protein complex*.

Epicuticle:

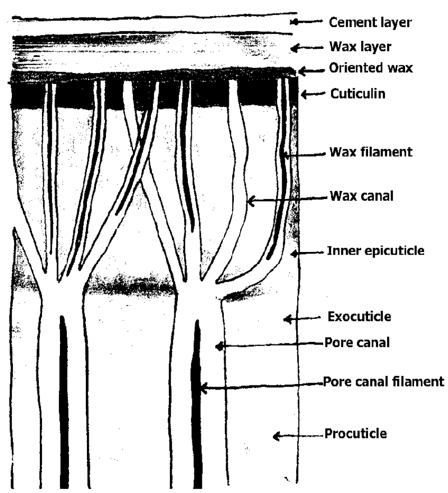
- *Epicuticle is non-chitinous.*
- It is *about 1 to 4 µm in thickness*, and in general, *covers the entire external surface of an insect*, except some chemoreceptive sensillae, midgut and ends of gland cells.
- *The main function of the epicuticle is to prevent water loss from the insect body*. It can 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 is *very stiff and inextensible*, and hence *restricts the dimensions of the exoskeleton*, forms the template for next stage / instar.
- Epicuticle is *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.*

(i) ***The outer most cement layer***:

- It is secreted by dermal glands and is *composed of lipoproteins*.
- The cement layer is *formed through secretions of specialized dermal glands* (Verson glands of the epidermal layer), and *consists of carbohydrates (lactose), proteins, long chain lipids and some polyphenolic substances*.
- It protects body from external damage, and *protect the underlying wax layer from abrasions*. It is also known as *tectocuticle* *protects wax layer*.
- *Act as a reservoir of mobile lipids, which leak out to replace lost waxes*.
- The thickness (not more than 0.1 µm) and distribution of cement layer may vary within an insect, or in different insects.
- *It may be totally absent as in honeybees*.

(ii) ***Wax layer***:

- It is a prominent layer, about 0.25 µm thickness *consisting of long chain hydrocarbons, esters of fatty acids and alcohols*.
- The wax layer usually lies below the cement layer and provides a kind of *waterproofing*. Also known as *lipoid layer imparts water conserving mechanism to insects*.
- The *epidermis secretes the lipids of the wax layer just before ecdysis*, 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.



Structure of Epicuticle

(iii) ***Polyphenol layer***

- *The outer epicuticle (referred to as cuticulin by Wigglesworth)*, is a *trilaminar layer*, 12-18 nm 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.

Procuticle:

- It is a comparatively *much thicker layer*
- *Consists of chitin-protein* and other substances.
- The *chief constituent of procuticle is chitin*, *forming 20-50 percent dry weight of cuticle*. *Chitin is a nitrogenous polysaccharide consisting of several N-acetylglucosamines interposed by molecules of glucosamine*.
- Besides chitins, *procuticle also contains non-chitinized substances (25-37%) such as several proteins (arthropodin, resilin, and other proteins) and other substances like lipids, pigments and salts* etc.
- The procuticle is distinguishable into Tanned / Colored Exocuticle (outer) and Untanned / colorless Endocuticle (inner).
- The much thicker endocuticle of procuticle (thickness ranges from 0.2 µm 200 µm) is in contact with epidermis (or hypodermis).

Outer exocuticle: *(tanned)*

- *Hard and dark in colour due to tanning* (*outer tanned or sclerotized exocuticle*), contained chitin and protein.
- 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.*
- It is *not tanned*.
- *The endocuticle is the largest section of the integument*, made up of fine horizontal lamellae and vertical lines called pore canals.

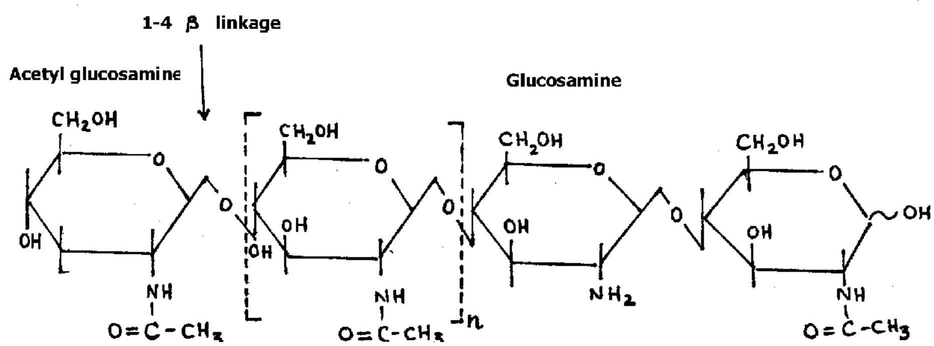
Important constituents of Cuticle:

- *Pro-cuticle is the main layer of cuticle, and is composed mainly of chitin and cuticular proteins.*
- Changes in the proportions 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:

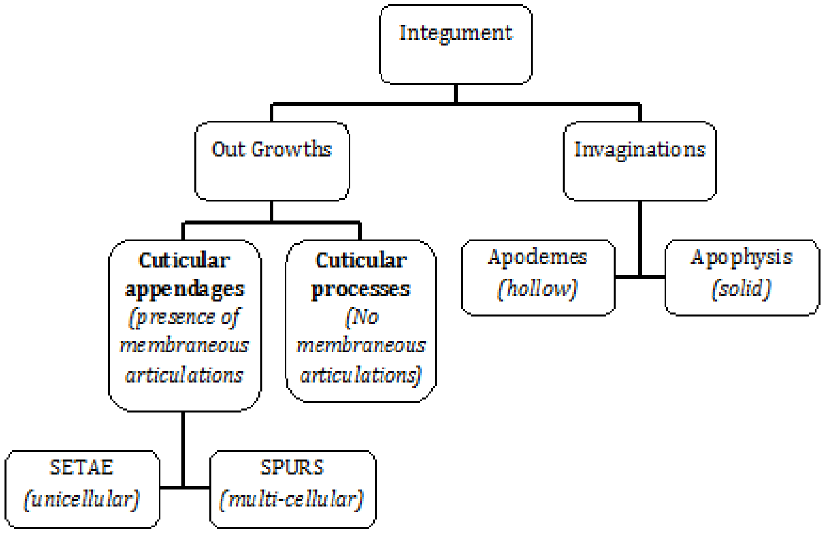
- *Chitin is a nitrogenous polysaccharide ($C_8H_{13}O_6N)_x$ in the form of a long chains consisting of several N-acetyl glucosamines interposed by molecules of glucosamine*. A polymer of anhydro N-acetyl glucosamine residues joined by β-glycosidic linkages (see fig below).
- It is embedded with proteins in the procuticle to from glycoproteins.
- It is *insoluble in water, alcohol, organic solvents*, dilute acids, concentrated alkalies, but *soluble only in concentrated mineral acids* and sodium hypochlorite.
- *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. Among the plants it is restricted to fungi.

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:

- Cuticle has mixture of several proteins.
- Important proteins are Arthropodin and Resilin.
- *Arthropodin* is *present in the upper layers of procuticle (exo-cuticle)*. It is *soft and 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". Sclerotin is a tanned protein which is usually amber colored and present only in exo-cuticle.*
- *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.



CUTICULAR APPENDAGES (OUT GROWTHS):

- 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 Macrotrichia:*** They are *uni-cellular hollow structures grown as an as extension of exocuticle.* Each setae (commonly known as *hairs or hair like projections*) arise from cup like pit i.e., 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 innervate 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)

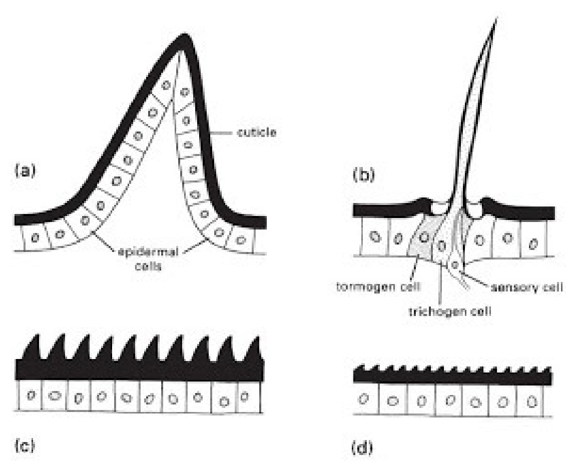
- These are outgrowths on the external surface of the cuticle *without membranous articulations / joints*.
- These are *non-cellular* processes rigidly connected with the cuticle.
- Fixed hair like structures found on the wings of certain Diptera, *Spines*-outgrowths of cuticle which is thorn like, immovable-hind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

Cuticular invaginations: The body wall / cuticle of the body wall invaginate internally and gow into definite structures:

Apodemes	Apophyses
Hallow cuticular invaginations	Soild invaginations
Provide area for muscle attachment	Provide mechanical support to various organs by forming distinct skeletal structures

Differences between Spurs and Spines	
Spurs	**Spines**
Cuticular appendages	Cuticular processes
Movable	Immovable
Multicellular structures and thick walled	Outgrowths of cuticle
Eg: present on tibia of plant hoppers and honey bees	Eg: Present on hind tibia of grasshoppers and leaf hoppers

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



(a) multi-cellular spine, (b) seta, (c) acanthae, (d) microtichia

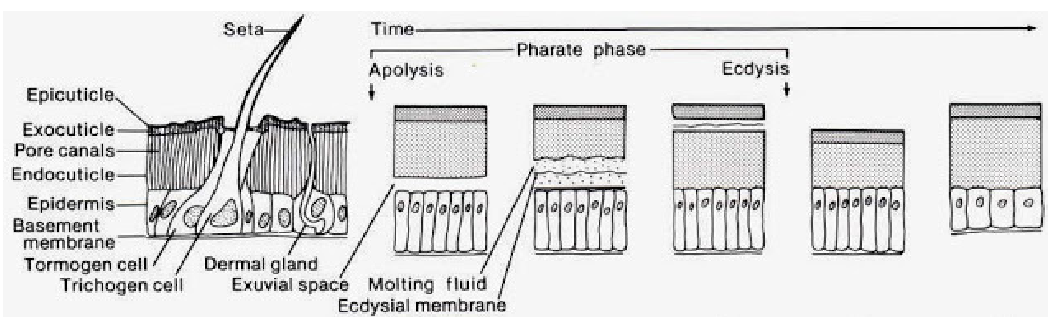
MOULTING, ECDYSIS, APOLYSIS AND SCLEROTIZATION

One of the general characteristics that defines the phylum Arthropoda (which includes insects, spiders, and crustaceans) is an external skeleton, also called an exoskeleton (or) Integument. The arthropod exoskeleton completely covers the outside of the body and the muscles inside adhere to it.

Insect cuticle is hard, and forms un-stretchable exoskeletons. *Because the exoskeleton is hard and rigid, an arthropod cannot grow unless it sheds its old exoskeleton and secretes a new one. The insect cuticle must be shed from time to time to allow insects to increase their size during growing period. Before old cuticle is shed, new cuticle will be formed underneath it. This process is called moulting*. *The stages between moultings are called instars*.

Pterygote (winged) insects cease moulting after attaining adulthood, but apterygote (wingless) insects (silverfish) undergo moulting even after attaining adulthood.

Moulting is complex process, which involve three steps; *1) apolysis, 2) ecdysis and 3) sclerotization.* 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.



APOLYSIS: (Apo=formation, lysis=dissolution)

- *Separation of epidermis from the cuticle* giving narrow space in between and this process is called apolysis, and can also be described as the dissolution of old cuticle and formation of new cuticle.
- Apolysis starts with repeated mitotic division of epidermal cells resulting in increase in size and number, which becomes columnar and densely packed.
- Because of this change, epidermal cells exert tension on cuticular surface and as a result get separated them from the cuticle.

- Epidermal cells fill the resulting gap with a secretion, inactive *moulting fluid* and then secrete a special *lipoprotein* (the *cuticulin layer*) that insulates and protects epidermal cells from the moulting 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.

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

- An insect that is actively constructing new exoskeleton is said to be in a *pharate* condition (*pharate instar*). During this process there may be very little evidence of change.
- When the new exoskeleton is ready, muscular contractions, intake of air and pumping of blood from abdomen to thorax, cause the insect's body to swell until the old exoskeleton splits open along *line of weakness (ecdysial suture in head).*
- The new instar comes out bringing its head followed by thorax, abdomen and appendages, and this process of ccdysis occurs quickly (in minutes to hours).
- This *process of shedding the old exoskeleton is termed as ecdysis*, and insect after shedding old skin continues to fully expand into new one.

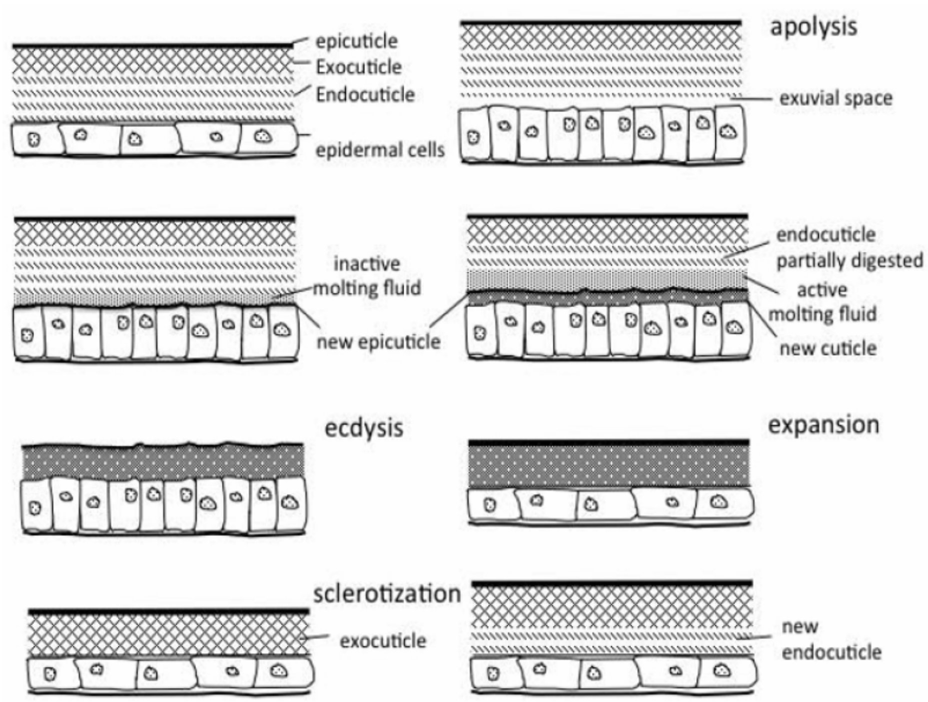
SCLEROTIZATION: The process by which the cuticle is hardened by substances other than chitin.

- After shedding the old cuticle, the fresh instar is very soft, milky white.
- Over the next few hours, the cuticle becomes hard (sclerotization) and changes to dark color (tanning), as sclerites *harden and darken due to formation of quinone cross-linkages in proteins within the exocuticle. This process called sclerotization or tanning, respectively,* gives the exoskeleton its final texture and appearance. The process by which cuticle is darkened is called tanning, and process may take one or two days.

The extent of an individual's growth between moults 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*. 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.

Juvenile Hormone (JH): produced from corpora allata of the brain. The hormone helps insect to be in the same stage (immature state) for some time (instar duration).
Moulting Hormone (MH): Produced from Pro-thoracic gland (PTG) of the brain. This hormone induces the process of moulting.
Eclosion Hormone (EH): Released from Neuro Secretary Cells (NSC) in the brain. This hormone helps in the process of ecdysis / eclosion.

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.



Process of Moulting

ADDITIONAL INFORMATION

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.

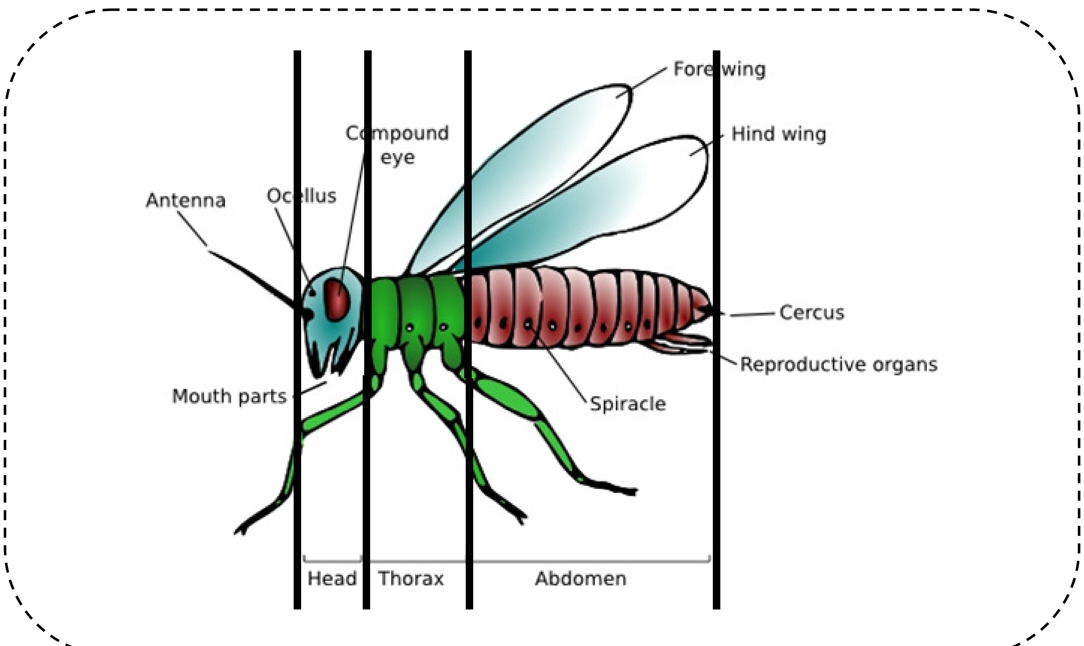
LECTURE-05

BODY SEGMENTATION OF THE INSECTS

Head (Syncephalon) – Procephalon and gnathocephalon, types of head, sclerites and sutures of insect head
Thorax – Segments and appendages (wings and legs).

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 Arthropods and are distributed throughout the world.
- In general, insect body is divided into series of segments, are referred as *somite or metamere* in primitive arthropods. During the evolution process, *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 (grouping of body segments) is called *tagmata* (for example, in insects each region such as head, thorax and abdomen is called tagmata, where head is the first tagmata in insects).
- The type of arrangement of body segments in embryonic stage is known as *primary segmentation*, while in adults it is known as *secondary segmentation* which differs primarily in having sclerotized membranous intersegmental region.
- The skeleton of an insect is external and is composed of *chitin*. It is membranous at the joints, but elsewhere is hard.



HEAD

- *The head is the feeding and sensory centre*.
- *Head consists of SIX fused segments*.
- It bears the pair of antennae, pair of eyes, and mouthparts.
- Insect detects *sense of touch and sense of smell* (olfaction) by antenna.
- The eyes include compound eyes and simple eyes (ocelli) which detectes *sense of vision*.
- 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. Various sensilla in different parts, especially maixillae and labial palps detect *sense of taste*.

THORAX

- The *thorax is the locomotory centre*.
- Thorax *is made up of THREE segments: the pro-, meso, and metathorax*.
- 3 pairs of legs: Each segment bears a pair of legs.
- 2 pairs of wings: In flying insects, the second and third (meso- and meta-thoracic) segments bear a pair of wings, and together termed as *ptero-thorax*.. 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.
- 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*).

ABDOMEN:

- 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*. Spiracles can be found in the conjunctive tissue between the terga and sterna of abdominal segments 1-8.
- Reproduction is by diverse means. In most insects, mating occurs once only, and death soon follows.
- The dorsal and ventral abdominal segments are termed terga (singular tergum) and sterna (singular sternum), respectively.

HEAD (Syncephalon)

- Foremost *tagmata* of the insect body.
- *The head is the feeding and sensory centre*.
- *Head consists of SIX fused segments.*
- The head is hard, and 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 contains *a pair of compound eyes, a pair of simple eyes (ocelli), mouth parts (mandibles, maxillae and labium)* and *a pair of antennae.*
- 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.
- Insects exhibit different types of antennae, some exhibiting a sexual dimorphism with regard to the type of antennae. Insect *detects odours (olfactory – sense of smell) and experiences the sense of touch* by antenna.
- 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 different appendages attach to the head capsule are, Antennae, Mandibles, Maxillae and Labium (lower lip).
- The insect segments can be divided into two regions: (1) *Procephelon:* The part of an insect's head that lies anteriorly to the segment in which the mandibles are located. (2) *Gnathocephelon:* The part of the insect head lying behind the protocephalon; bears the maxillae and mandibles.

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).

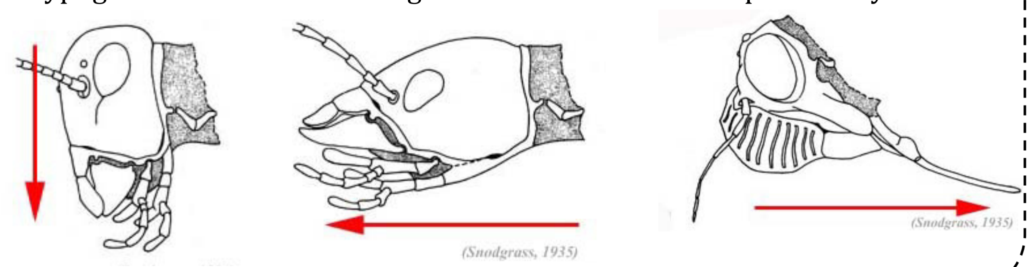
S.No	Segment Name	Region	Appendages
1	Pre-antennary (or) ocular (or) labral	Procephalon	No Appendages Bears pair of Compound eyes
2	Antennary		Pair of Antennae
3	Intercalary		No Appendages
4	Mandibular	Gnathocephalon	Pair of Mandibles
5	First Maxillary		Pair of Maxillae (1st Maxillae)
6	Second Maxillary (or) Labial		Labium (or) pair of 2nd Maxillae

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* (Hypo=below, Gnathous=Jaw); the *mouthparts are directed downward,* with the mouth parts in a continuous series with the legs, is a primitive type. This is also known as *orthopteroid* type. This orientation *mostly occurs in vegetarian species* living in open habitats. Eg: Grasshoppers, Cockroach.
- *prognathous* (Pro=infront, Gnathous=Jaw); the *mouthparts are directed forward*. This is also known as *coleopteroid* type. This is is *found in carnivores species* which actively pursue their prey, and in larvae, particularly of coleopteran, which use their mandible for burrowing**.** Eg. Beetles, Ants
- *opisthorhynchous* (Opistho=behind, gnathous=Jaw); the *elongated proboscis slopes backwards between the front legs*. This is also known as *hemipteroid / opisthorhynchous* type. Eg: Bugs, Mosquitoes.

Hypognathous Prognathous Ophisthorhynchous



SCLERITES OF INSECT HEAD CAPSULE:

The head capsule is formed by union of number of hardened sclerites (or) cuticular plates (or) areas, which are joined together by means of cuticular lines (or) ridges (or) sutures. These sutures provide mechanical support to the cranial wall. ***Occipital foramen*** connects the back of the head with the body. *There are 10 sclerites in the 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 a simple fused sclerite, often called the *upper lip*, and moves longitudinally. It is hinged to the clypeus.

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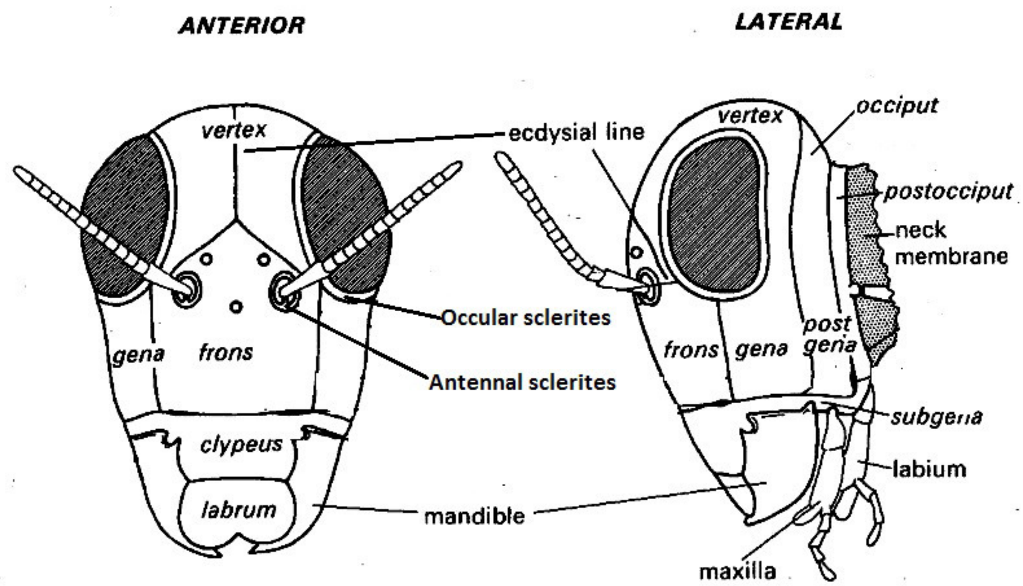
5. ***Gena*** (lateral sides)-It is the lower part of the head beneath the eyes and lies posterior to the frons. A general suture is present between frons and gena. The area directly posterior to the eyes is termed the post gena.
6. ***Post gena***-sclerites below the genae and above the mandibles.
7. ***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.



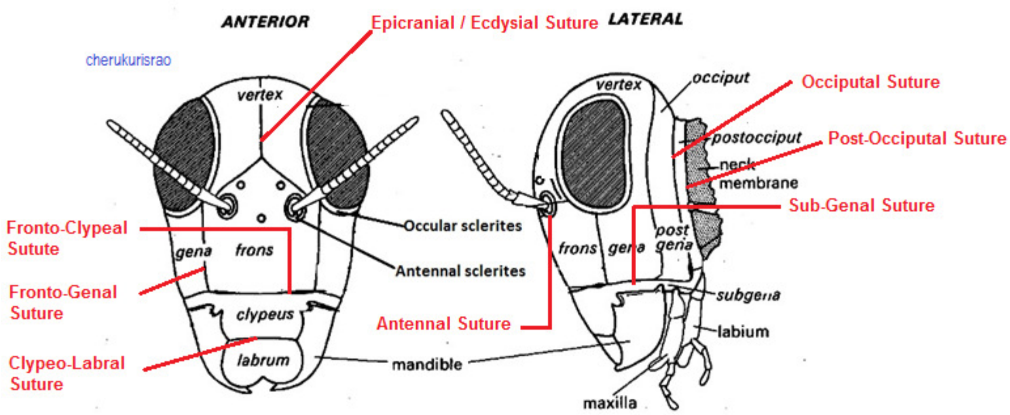
9. ***Occular sclerites:*** ring like structures around compound eye.
10. ***Antennal sclerites:*** these form basis for antennae and present around the scape which are well developed in plecoptera (stone flies).

SUTURES (LINES) OF INSECT HEAD:

The hard sclerites (segmental plates) 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 eight sutures in the head capsule.*

1. ***Epicranial suture*** (Ecdysial suture): It is an *inverted 'Y' shaped suture separating vertex and frons*. The epicranial suture also known as *line of weakness or ecdysial suture*, because the exuvial membrane spilts here along the suture during the process of moulting / ecdysis.
2. ***Fronto-clypeal suture*** (Epistomal suture): A line between frons and clypeus.
3. ***Clypeo-labral suture****:* A line between clypeus and labrum. It remains in the lower margin of clypeus from which the labrun hangs.
4. ***Fronto-Genal suture (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.

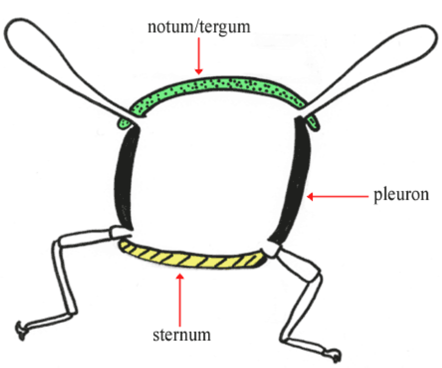
6. ***Occipital suture*:** A line between occiput and post occiput. It is 'U' shaped (or) horse shoe shaped.
7. ***Post-occipital suture***: of these, post-occipital suture is the *only real suture*, separating maxillary and labial segments. This suture separates head from the neck, hence named as real suture.
8. ***Antennal suture:*** It is a marginal depressed ring around the antennal socket.



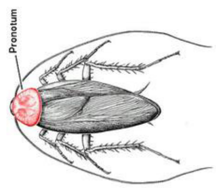
SUTURES OF INSECT HEAD

THORAX:

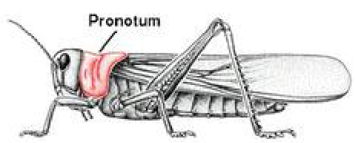
- *Locomotory Centre* of Insects.
- An insect thorax is *three segmented*, the *prothorax (pro=first), mesothorax (meso=middle), and metathorax (Meta=last).*
- Each segment consists of hardened plates, or sclerites. *Dorsal sclerites are called nota or terga* (singular notum), *lateral sclerites are 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.* Meso and Meta Pleuron is divided in to anterior *episternum* and posterior *epimeron* by pleural suture.



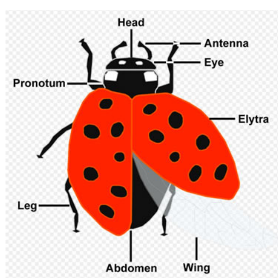
- Each thoracic segment contains one pair of legs, a total of 3 pairs of legs in thorax.
- Wings are found only on the meso- and metathoracic segments, and are together called as *pterothorax*. Prothorax never bears wings and varies in size. *Hence, the thorax is called as locomotory centre*.
- Two pairs of spiracles are present between pro and meso, and meso and meta thoracic segments.
- The *pronotum is the dorsal sclerite of the prothorax* and the pronotum of grasshopper; cockroaches, beetles and bugs are enlarged.



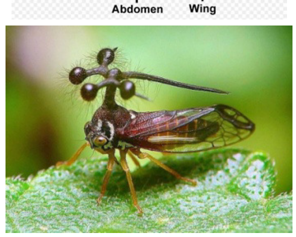
Cockroaches have *pronotums that extend forward over the head*.



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



Scarab beetles and other beetles may also have unusual pronotums.



Treehoppers have some of the most bizarre pronotums of all insects.

LECTURE-06

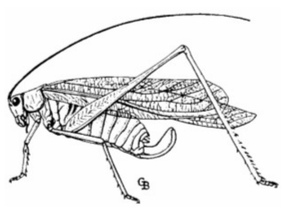
BODY SEGMENTATION OF THE INSECTS

Abdomen – Segments, pre and post genital appendages (Furcula, cornicles, tracheal gills and pseudo ovipositor in Diptera - Propodeum, petiole and gaster in Hymenoptera); Male and female genital organs - Epimorphic and anamorphic development in insects.

ABDOMEN:

- Abdomen is the *posterior part* of the body. *The abdomen or third tagmata of the body, and is the metabolic and reproductory centre*.
- Abdomen in embryo usually consists of 12 segments, but at later stages, the last segments degenerate and appear as 7-11 segments. In *Collembola, abdomen is six segmented.* Typically, abdomen consists of *eleven segments*. Abdomenal segments from 1 to 7 are called as *pre-genital segments,* 8th and 9th segments are termed as *genital segments* as they form genital appendages such as ovipositor in female from both 8th and 9th segments, and aedeagus or penis in male in 9th segment. The 10th and 11th segments are called as *Post-gential segments.*
- The food is digested, and excreted in this part, and where the reproductive organs are located. 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 *propodeum*. 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.



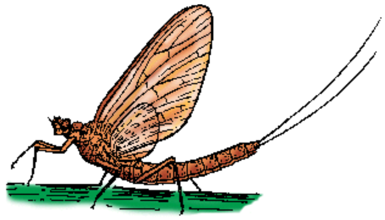
Blade-like ovipositor on katydid (order Orthoptera)

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

Needle-like ovipositor Orthoptera: Field cricket, female

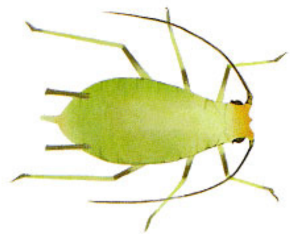
Abdominal appendages: (Either filaments or cerci).

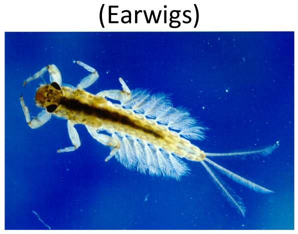
- Abdominal filaments are thread-like processes located at the end of abdomen.
- Abdomen bears *8 pairs of spiracles* from 1st to 8th segments on tergum margin.
- Pre-genital appendages are generally found in Apterygota and someimmature pterygots. In some pterygots, pre-Genital segments are represented by: *Styli* in Thysanura (Thrips), *Cornicles* (a pair of tubes on dorsal side-terga, of 5th and 6th segments) in Aphids.
- The most common appendages found in most insects are Anal Cerci, filament like extensiona. *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).*
- Immature stages forms of trichopterans, mayflies and mosquitoes 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.*

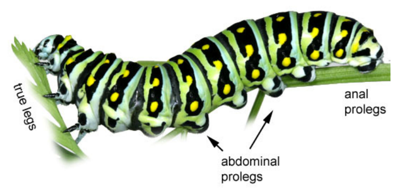

Long anal cerci in May flies


Anal cerci in Cockorach


Foreceps like anal cerci in Dermaptera (Earwigs)


Cornicles in 5th and 6th abdomenal segments in Aphids


Tracheal gills (abodmenal appendages) in larva



Abdomenal prologs in larval forms of holometabola


Pseudo-Ovipositor in Fruitflies

==*Anamorphic development*==: (*addition of body segments during post embryonic development in subsequent moults*) The young ones hatches with only 8 segments and telson, and the rest of the segments (3 segments) are added during post embryonic development in subsequent moults arisng behind the last abdominal segment. Such type of development is called anamorphic development. Eg. Protura.

==*Epimorphic development*==: In pterygotes, the young one after hatching from the egg consists of definite number of segments and the same number is maintained throughout. The differentiation of segments takes place in embryo itself. Such type of development is called Epimorphic development. Eg. Majority of insects.

LECTURE-07

ANTENNA

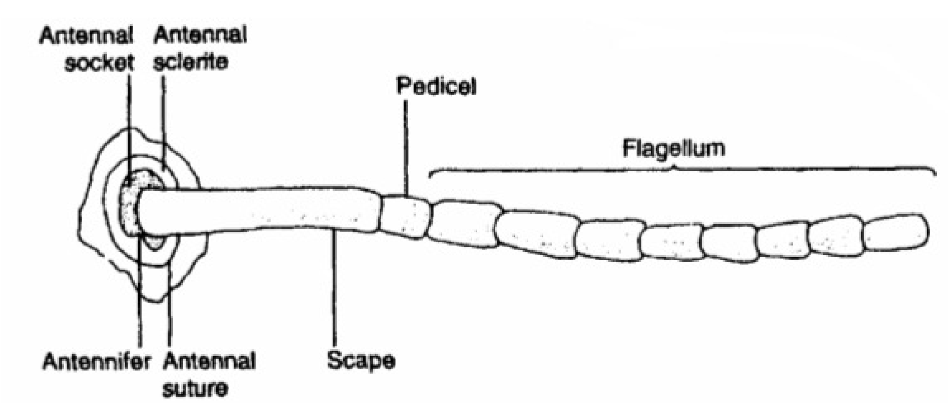
Structure of typical antenna and its modifications in different insects with examples.

ANTENNAE OF INSECTS: OLFACTORY ORGANS

- Antennae (*singular antenna*) are *uniramous (unbranched), mobile, sensory, segmented appendages* of the head, articulate in front or between the eyes.
- Antennae arise from antennal socket (antennifer) provided with an antennal suture. The base of the socket is connected to the edge of the socket by an articulatory membrane, which permits the movement of antenna.
- Antennae are the pre-oral, and first pair of appendages of head arisng from 2nd (or) antennary segment of head with nerve connections from deutocerebrum of the brain. 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 *well developed in almost all adults and nymphs*, and poorly developed in endopterygote larvae. Antennae are *absent in Protura.* They are usually *larger in males* (sexual dimorphism) and the character can be used for identification of sex of some insects. Under Arthropoda, 2 pairs of antenna are present in Class Crustacea. 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:

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



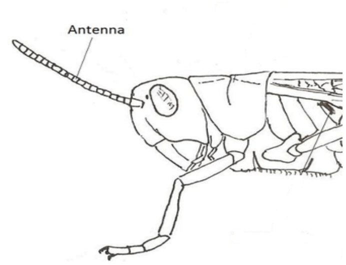
A).Scape: First basal segment of antenna by which the antenna is attached to the head. It is *often distinctly larger than the other succeeding joints*. It articulates with the antennal ridge.

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*, (*detects motion of flagellum*) which is absent in Diplura, Collembola.

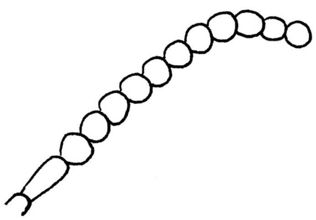
C).Flagellum: It is also known as clavola, and is the remaining part of the antenna. Flagellum segments (flagellomeres) increase in number in certain insects. It is modified according to the surroundings and habits of the insects. In chalcidoidea, flagellar segments are subdivided into basal ring segments, funicle and terminal club. In genreal, there are no muscles in the flagellum, and hence antenna is called as *annulated type.* In collembolan and diplura, the flagellar segments are muscular in nature and regarded as true segments, and the antenna is known as segmented type.

TYPES OF ANTENNA:

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

Type of antenna	Modifications	Examples
Filiform *(Thread like)* 	Segments are more or less uniform from base to apex, thread-like shape. Last segment never ends with bristle.	 *Grasshopper*
Setaceous *(Whip like or bristle like)* 	Segments gradually decrease in size from base to apex (towards tip)	 *American Cockroach* *Dragon fly*

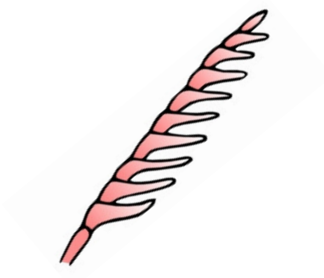
Moniliform
(like string of beads)



Segments are round or oval with well developed constrictions between segments, *appearing like a string of beads*.

Termites (Isoptera)

Pectinate
(comb like)



Segments possess lateral processes on one side giving comb like appearance.

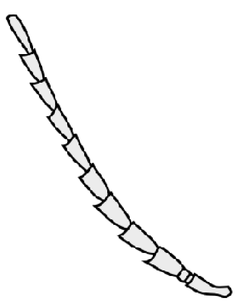
Female arctiid moth
Fire fly (Coleoptera)

Bipectinate
(double comb like)

Segments bear lateral processes on either side, giving double comb like appearance.

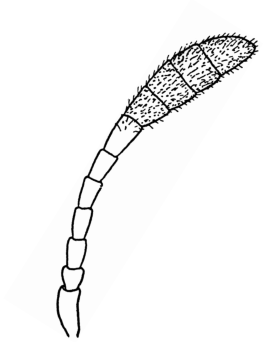
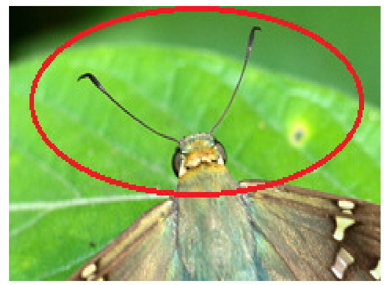
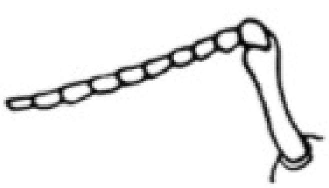
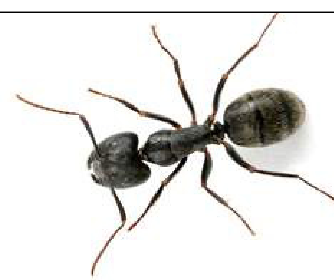
Mulbery Silk Moth
Male Lymantriidd moth

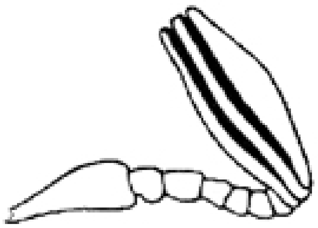
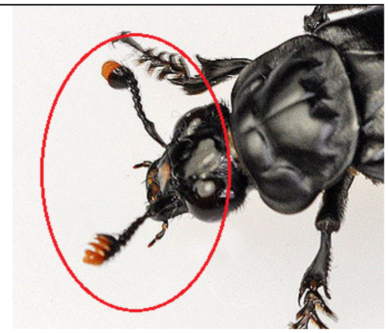
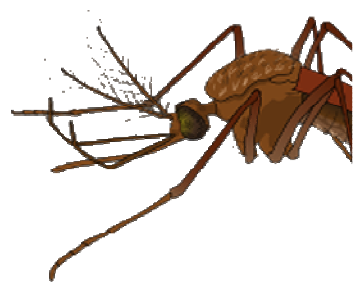
Serrate
(saw like)



Segments of flagellum are triangular with projecting points on one side giving saw like appearance.

Pulse beetle, Jewel beetle (Coleoptera)

Clavate *(clubbed)* 	Segments gradually increase in diameter from base to tip ending in a club like apical part.	 *Butterflies.*
Clavate with hook *(clubbed antennae with hook)* 	Segments gradually increase in diameter from base to tip ending in a club like apical part, and the last one ends with a small hook like structure.	 *Skipper Butterfly*
Capitate *(clubbed with knob)* 	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.	 *Red flour beetle*
Geniculate *(elbowed)* 	The first segment (scape) is greatly elongated and flagellum always makes an angle with it.	 *Ants, honey bees (order Hymenoptera).*

Lamellate *(plate like)* 	The *terminal segments expand to one side and form broad plate or leaf like structure*.	 *Rhinoceros beetle, Dung rollers, Chaffer beetle (order Coleoptera).*
Flabellate *(Plate like)* 	The terminal segments expand on one side and form a feather like structure *flabella*	 *Stylopids.*
Plumose *(brush like with dense hairs)* 	Whorls of hairs arise from each joint of the segment. Each whorl contains a number of hairs. *Plumose* antennae have a feather-like shape.	 Male Mosquito
Pilose *(brush like with sparse hairs)* 	Looks like plumose but each whorl contains less number of hairs	 Female Mosquito

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Aristate

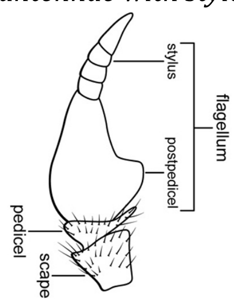
(antennae with arista)

Antennae are small, microscopic, three segmented.
Third segment enlarged and bears a bristle called arista on its dorsal side.

House fly

Stylate

(antennae with style)



Antennae small 3 to 4 segmented.
Terminal segment elongate in to bristle like structure called style.

Robber fly

Functions of Antennae:

- The antenna functions primarily as *sense organs* and they bear very large number of *sensilla*, usually *most of these found in the middle of flagellum*.
- The various types of sensilla function as *tactile receptors (touch), ordour receptors (odour), contact chemoreceptors (smell), Hygroreceptors (humidity) and temperature receptors*.
- Olfactory receptors (odour receptors) on antenna useful for to bind to odour molecules, particlularly in *males very useful for pheromones*. Hence, *male insects have bigger antenna than females* (sexual dimorphism).
- 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 (sound receptor / auditory organ), in the pedicel* of insects. This also helps in measurement of air currents.
- In fleas and collembolan, the antennae are used in mating. *Male fleas use the antenna to clasp the female* during copulation.
- Helps mandibles for holding prey and for mastication of food material.
- Aid in respiration by forming an air funnel in aquatic insects.

LECTURE-08

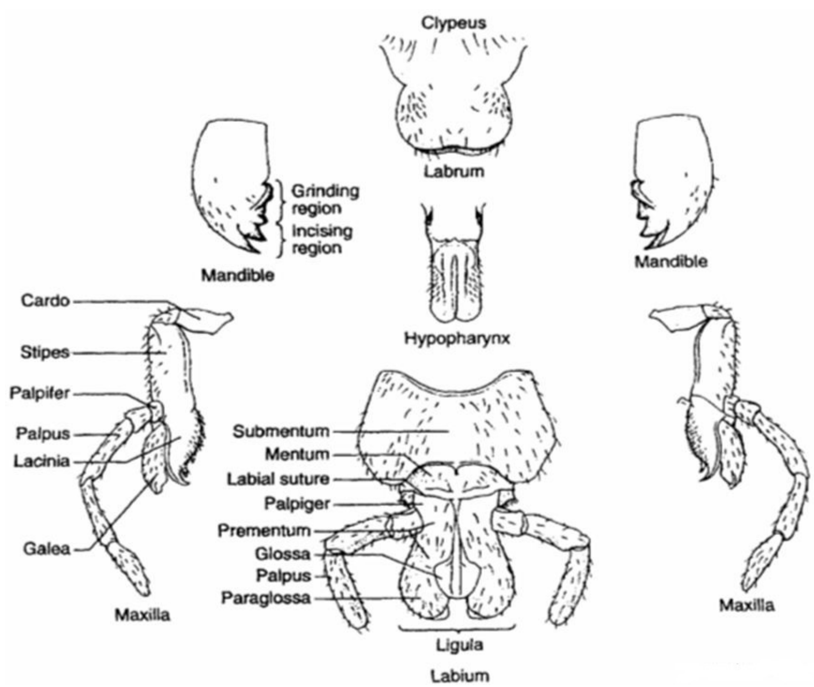
MOUTHPARTS (FEEDING ORGANS)

Biting and chewing, sucking (Piercing and sucking, Rasping and sucking, Chewing and lapping, Sponging and Siphoning/ Simple sucking), mask and degenerate types with examples.

MOUTH PARTS: FEEDING ORGANS

These are organs concerned with uptake of food and 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*

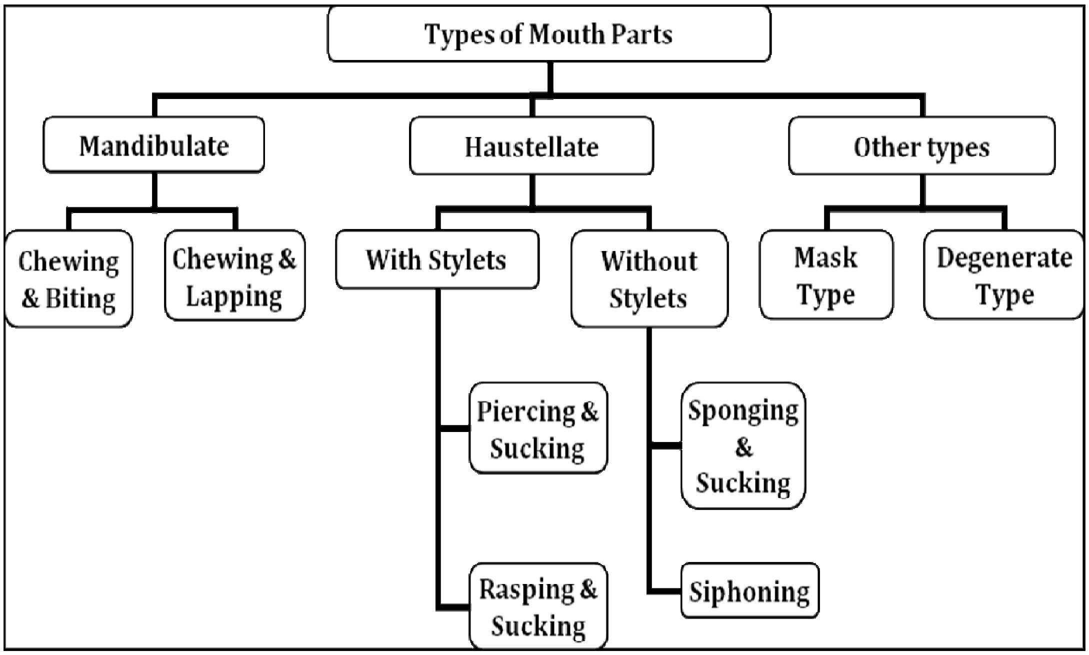


- *The labrum* is a simple fused sclerite, often called the *upper lip,* and moves longitudinally. It is hinged to the clypeus.
- *The mandibles*, or anterior jaws, are highly sclerotized paired structures that move at right angles to the body. They are used for biting, chewing and severing/cutting food.
- *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

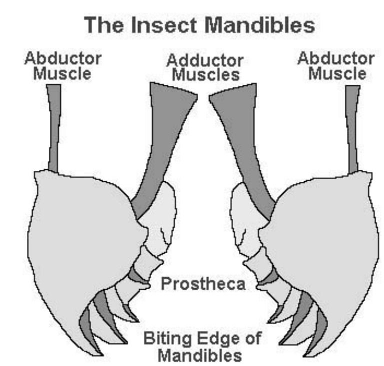
CHEWING & BITING TYPE:

The generalized biting type of mouth parts are *present in nymphs and adults of grasshoppers, cockroaches, termites and beetles and caterpillars*. 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, small sclerite*, and *forms upper lip of mouth cavity*.
- It is situated below the clypeus, anterior side of the head.
- It *overlaps the bases of mandibles*. It protects mandibles and helps in closing of the mouth cavity and guide food into mouth.
- Its *inner surface is usually provided with chemoreceptors* and is produced into small lobe-like *epipharynx in Hymenoptera*.
- Labrum hangs down from clypeus through clypeo-labral suture.

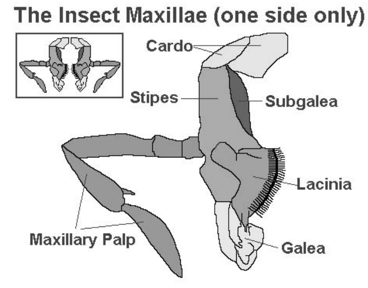
Mandibles:



- *Paired, heavily sclerotized, strongest, 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. So, the mandibles are adopted *for cutting or crushing the food*.
- The mandibles are frequently *used for defense also*.
- Each mandible is moved by powerful abductor and adductor muscles.

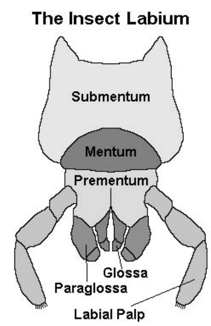
Maxillae:

- The paired homologous 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 (olfactory and gustatory senses)* and *function as sense organs*.



- The basal segment (triangular in shape) of the maxilla is the *cardo* and the second (middle) segment is the *stipes*.
- The lateral segment is *palipfer* borne on lobe of stipes, bearing *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:



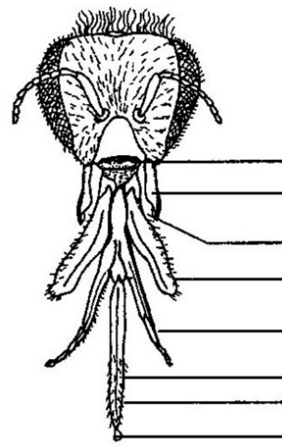
- Lower lip lies behind the maxillae, also called as secondary maxillae.
- It closes the mouth cavity from below.
- It is divided by a transverse suture (labial suture) into two portions a basal *post-mentum* and a distal *pre-mentum*.
- Post mentum usually divides into basal *sub-mentum* and distal *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* *(gustatory)*.

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 base of 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.
- Labrum and Mandibles are biting type.
- Maxillae, labium and hypopharynx combine together to form a *sucking proboscis*.
- Below the labrum is fleshly epipharynx which is an organ of taste.
- Mandibles are dumbbell shaped, 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.
- *Elongated central organ of the proboscis is the glossa of labium* and at the base of the glossae, there are two small concealed lobes are paraglossae. 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.*
- Maxillary palpi are reduced / small.
- The maxillae and labial palps form a tube enclosing the glossa which moves ups and down to collect nectar.
- At rest, mouth parts are folded beneath the head agiant stipes and mentum. During feeding, they are straightened with labial palpi closely appled to glossa and partially embraced by the ensheathing of galea and lacinia.
- Glossa is very active while food is being imbibed retracting and protruding from the base of mentum.
- The liquid food (nector) ascends by means of capillary action in the central channel of glossae and enters into the space between paraglossae and in the mouth cavity.

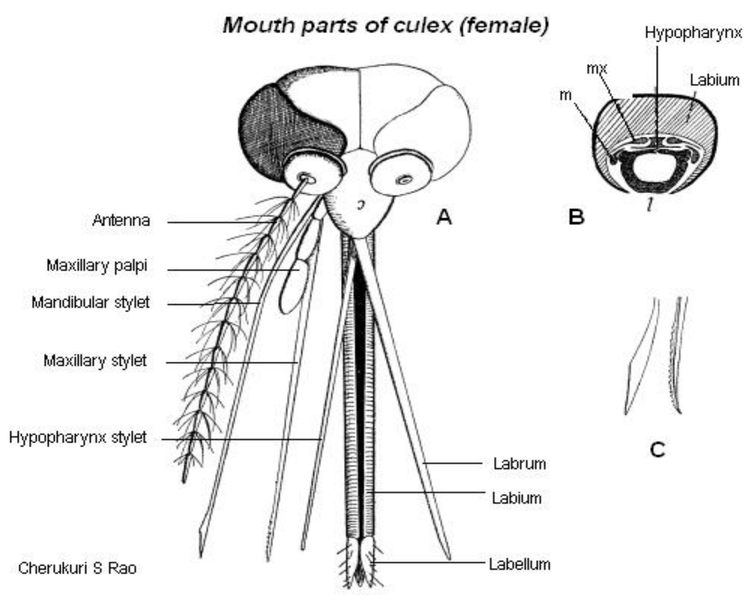
HAUSTELLATE TYPE:

- *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: plant bugs (order Hemiptera), sucking lice, and mosquitoes (order Diptera).

These mouth parts are *adopted for piercing the tissues and sucking either plant sap or nector or blood from host*.

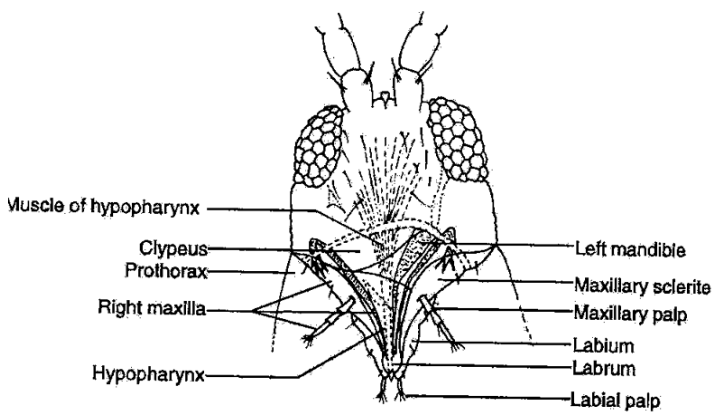


- Mouth parts are represented by *rostrum / beak which is modification of labium*. It *acts as pouch for protecting the mandibular and maxillary stylets*.
- *The mandible and maxillae are modified to form slender bristle like stylets which rest in the grooved labium*.

- 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 maxillary stylets froms posterior or inner pair of stylets. Each *maxillary stylets tapers to a fine point* and is grooved along its inner aspect the groove is divided in to two parallel channels (food channel - upper cibarium, and lower salivarium) by means of a longitudinal ridge which traverses the length of stylet. Cibarium used for sucking the sap, and salivarium used for releasing the saliva.
- *Labrum forms the cover* over the grooved labium.
- The hypopharynx is highly specialized and reduced to form pharyngeal pump, at the tip of the food channel.
- The stylets are pierced inside the plant tissues and generally they *suck plant sap from phloem vessels*.
- Insects with these type of mouth parts pierce the tissues with the mandibular stylets, and suck contents (sap / blood / nector) through cibarium with the action of pharyngeal and cibarial muscles.

RASPING & SUCKING / LACERATING & SUCKING TYPE:

Example: Thrips

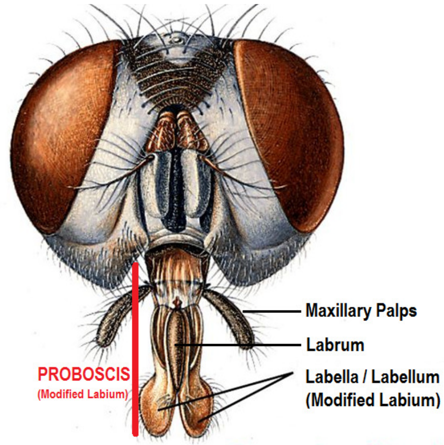


- These are between biting-chewing and piericing-sucking type mouth parts.
- The mouth parts are represented by *mouth cone*. The *labrum, labium, bases of maxillae are modified to a form* a small tubular cone called *mouth cone*.
- *The right mandible is absent / rudimentary (hence these mouth parts are called as Asymmetrical type) and the left mandible is modified as stylet*.
- *The maxillae are modified into stylets*.
- 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

Examples: Housefly (Diptera)

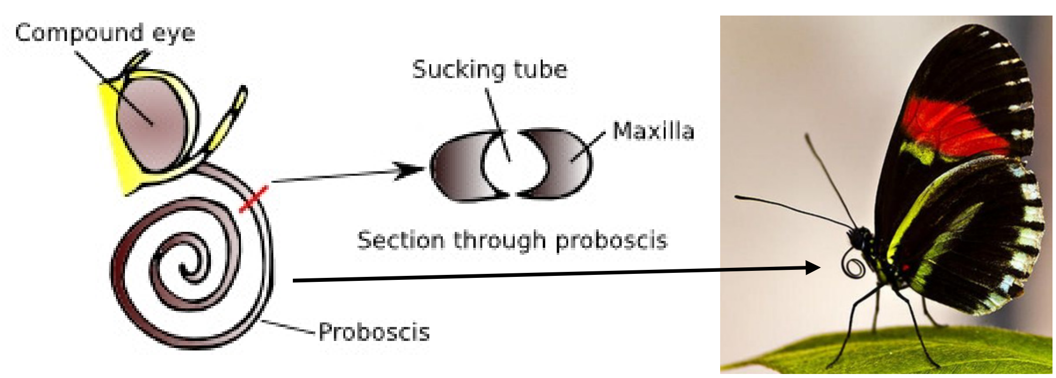
- The mouth parts are of sponging and sucking the liquid food material.
- The mouth parts comprise *a fleshy and retractile proboscis (modified labium)*, which lies under the head. The proboscis is formed of three parts
  1. Basal Rostrum-*modified labium*
  2. Middle Haustellum-*modified labium*
  3. Distal-a pair of labella



- *Rostrum* (*modified labium*) is cone shaped and has a clypeus in front. It bears a pair of *maxillary palps*.
- The *labellum is sponge-like structure*, transeversed by number of narrow transverse channels called *pseudo-trachea*. The food enters from this point into food channel, which is formed by labrum-epipharynx-hypopharynx.
- *The mandibles and maxillae are absent*. Maxillary palpi are 1-3 segmented.
- 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.

SIPHONING TYPE

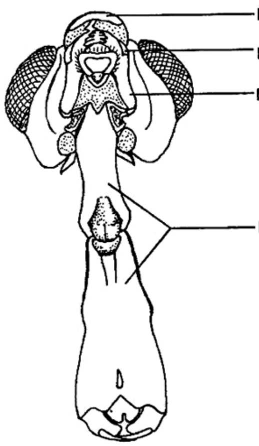
Examples: Butter flies and moths for simple sucking.



- Specially modified mouth parts for taking nector from flowers.
- *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



- Mainly used for catching the prey.
- *Labium is modified into a mask*. Prementum and postmentum forms an elongated structure with a joint.
- Labial palps help in catching the prey.
- All other parts remain rudimentary (reduced)
- 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 it is called masking type.

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-09

LEGS (LOCOMOTORY ORGANS)

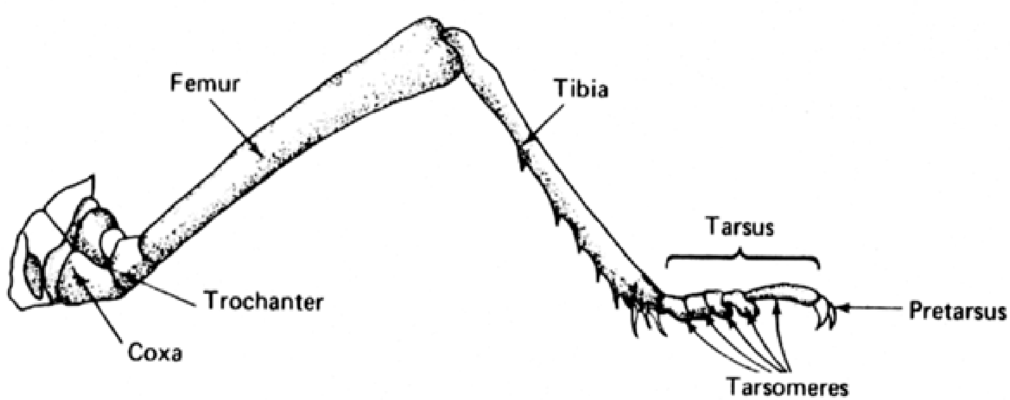
Structure of a typical insect leg and modifications of insect legs with examples

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 due to their high degree of mobility arising from the power of flight, but more local movements by walking or swimming etc also important.

All the three thoracic segments of an insect possess a pair of legs, a total of three pairs of legs, as locomotory organs, hence the class insecta also named as class hexapoda. The fore-legs are located on the prothorax, the mid-legs on the mesothorax, and the hind legs on the metathorax.

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. Definite impressed lines or internal ridges between sclerites are known as sutures.

A TYPICAL LEG OF AN INSECT CONSISTS THE FOLLOWING PARTS



In primitive insects, a small sclerite, known as sub-coxa occur before coxa, which from the basal segment. In the process of evolution, this sub-coxa is reduced / modified.

***Coxa*:**
The basal thick short segment fixed to thorax. It articulates with the body of the insect between pleura and sterna. This is the functional base of the leg.

Trochanter:

It is the second segment of the leg, small and 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 / jumping* (grasshopper).

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:

This is the last segment of the leg. This is usually divided into *five sub-segments (tarsomeres).* The numbers of tarsomeres vary in different insects. The first segment is large, big or broad in size known as *basitarsus.*

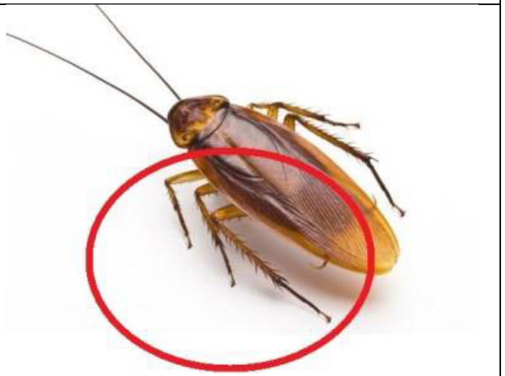
- Tarsus with single joint (2 segments)– Human louse
- Tarsus with two joints (3 segments)–Aphid
- Tarsus with three joints (4 segments)–Mole cricket, grass hopper
- Tarsus with four joints (5 segments)– Tettigonidae (grasshopper), Leaf beetle.

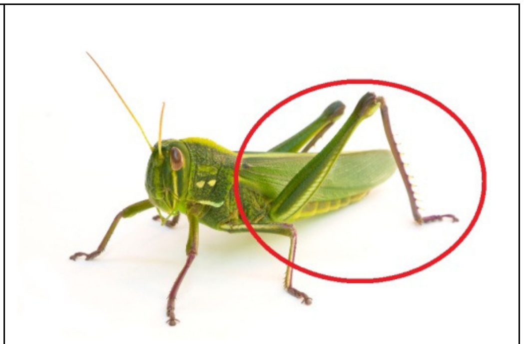
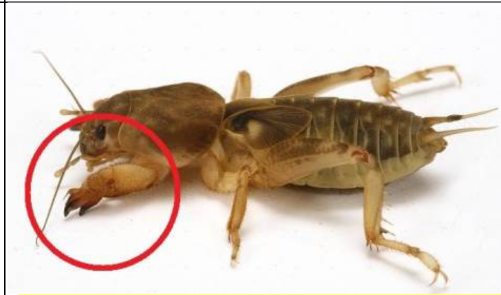
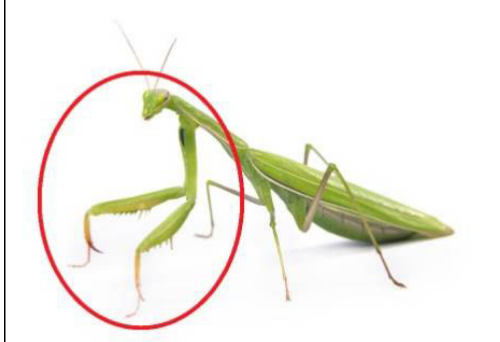
At the apex of the tarsus, a group of small structures called *pre-tarsus* are present. The pre-tarsus,

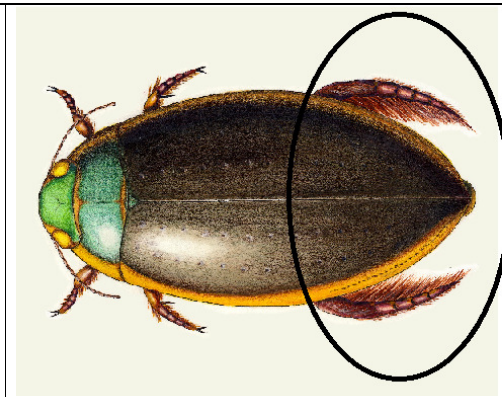
- In simplest form it is prolonged into a single claw- *Eg, Collembola, Protura*.
- In some insects claws are paired. In between the claws on the ventral side *pretarsus expand into a medium lobe or "Arolium". Eg. Housefly*.
- Among Diptera there are two lobes or "*Pulvilli*" lying below the claws often with an Arolium between them. *Eg. Housefly*.
- In place of arolium, pretarsus is sometimes prolonged into a medium bristle called "*Empodium*".

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*.

TYPES / MODIFICATIONS OF LEGS

Type of legs	***Purpose***	***Modification***	***Examples***	***Examples***
Ambulatory *(Ambulate-to walk)*	*Walking type*	*All the legs* are normal, uniformly well developed without any special modification.	Bugs Beetles Wasps	
Cursorial type *(cursor-a runner)*	*Running type*	*All the legs* are normal. Cursorial legs are modified for running, with long, thin leg segments. Coxa widely separated	Cockroaches Ground and tiger beetles	

Saltatorial type *(saltere-to jump)*	*Jumping type*	Saltatorial *hind legs* adapted for jumping. These legs are *characterized by an elongated femur and tibia*.	Grasshoppers & Crickets	
Fossorial type *(fossore-to dig)*	*Digging type*	*Front legs* are modified for digging. *The tibia and tarsus are short and broad with teeth like or rake like projections*. Beneath the tarsus, presents a slit like oar.	Ground dwelling insects Mole crickets Rhinoceros beetle.	
Raptorial type *(raptore-to seize)*	*Praying (or) Grasping ype*	*Fore legs* modified for grasping (catching prey). *Coxa very long and femur spiny*, possesses a central longitudinal groove. *Tibia narrow and blade like*, spinose and fits into groove of the femur.	Mantids	

Natatorial type *(nature-to swim)*	*Swimming type*	Natorial legs are modified for swimming. *Hind legs are modified as pad like as Coxa flattens out on the body wall. Tibia and tarsus short and broad (flat) and are provided with dense long marginal hairs.*	Water beetles water bugs	
Scansorial type *(scansum-to climb)*	*Clinging type*	*All legs* are modified. *Tibia possess tibial thumb. Tarsus single segmented without a joint, and pre-tarsus with a single long curved claw*. Useful for catching the hairs or clinging hairs.	Head louse.	

Prehensile or *(prehensum-to seize)*	*Basket forming legs / catching prey*	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.	Dragonfly	

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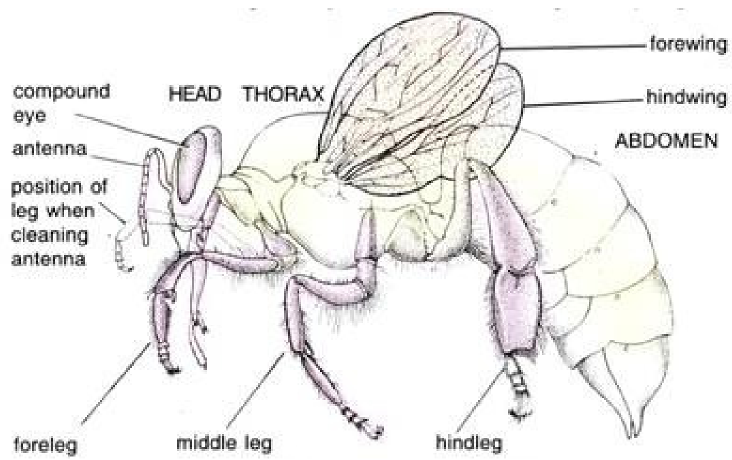
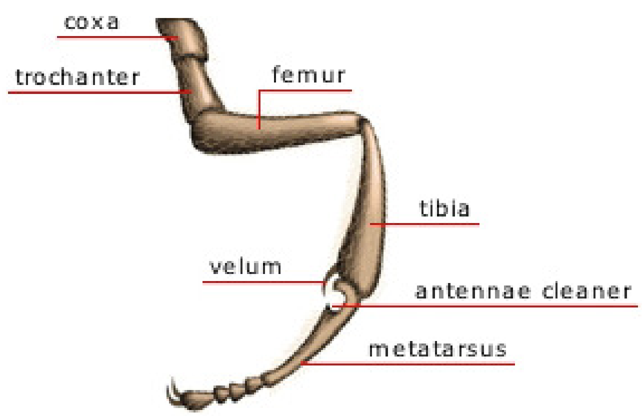
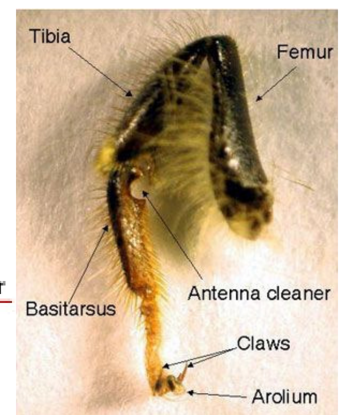
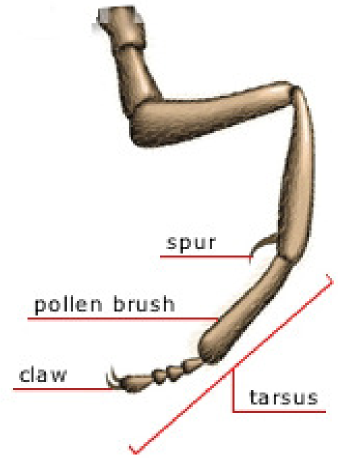
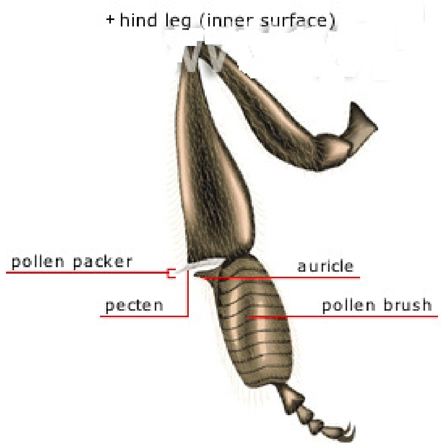
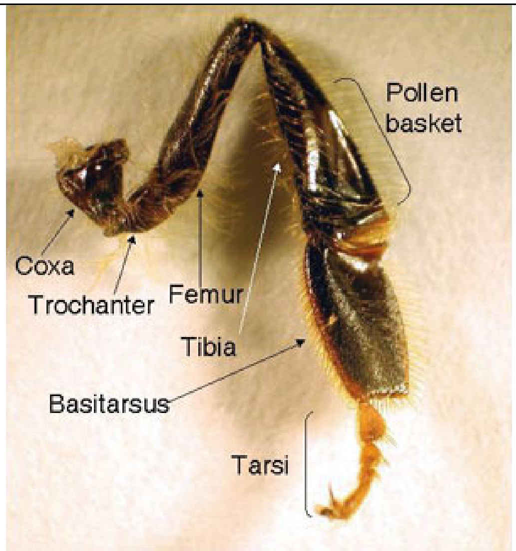
Honey bee Leg Modifications



Antennal cleaning	*First pair legs of honeybee*	 	*Tibia possesses a movable spine (velum), and 1st tarsal segment of fore-legs possesses a semicircular notch*. Velum 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 Honeybee*		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 ventral side of the abdomen.* Hence the *tibial spine is called wax pick*.
Pollen collecting type *Hind legs of Honey bees*	*Third pair of legs in honeybee*	 	Each *meta-thoracic leg has a large tibia with a cavity / groove with bristles forming a pollen basket* or corbicula used for temporary storage of pollen grains. First tarsal segment enlarged and possess short stiff hairs 'pectin' all over the surface called 'pollen brush'.

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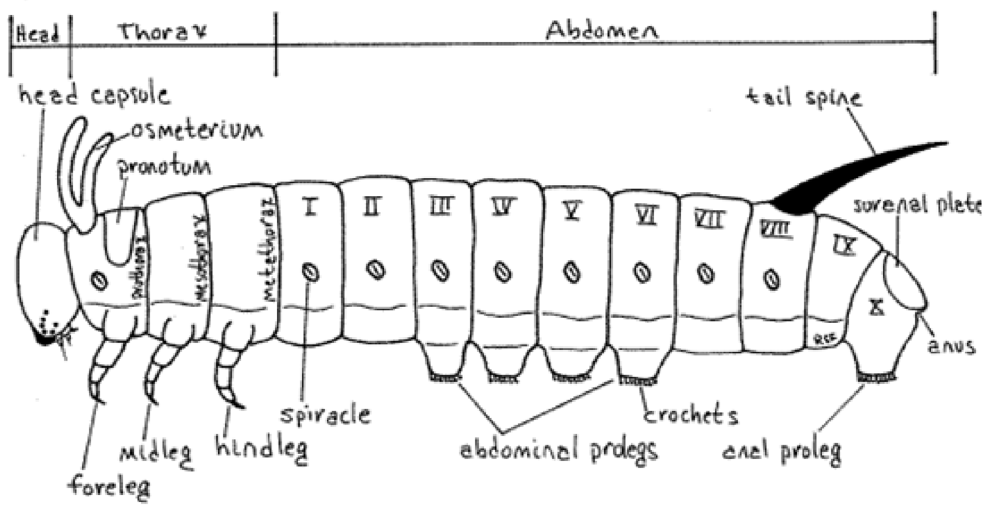
LEGS OF IMMATURE STAGES



- Immature stages of exopterygotes i.e nymph consists only thoracic legs like its adult stages.
- Immature stages of endopterygotes i.e. 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, prolegs on 3rd and 4th abomenal segments absent, and hence while movement, it looks like semi-loop, in some, looppers, prolegs 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 pro-legs. These are *unjointed, short, fleshy* with a flat surface at the bottom called planta.
- Several 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 prolegs in abdomen*. This is the unique feature of sawfly larva, but these prolegs do not bear crochets, unlike lepidopteran larva.

LECTURE-10

WINGS (LOCOMOTORY ORGANS-FLIGHT ORGANS)

Venation, margins and angles
Types of wings and wing coupling organs with examples

INSECT WINGS – GENERAL INFORMATION

One of the major reasons for success of the insects as terrestrial animals is due to their ability to fly. *Insects are the only invertebrates that can fly*.

Wings, their modifications and the characters of wings are the *primary tools for insect taxonomic studies*, and for the identification of insects. Silver fish and spring tails do not have wings (Apterygota), and some insects have only one pair of functional wings (Diptera). 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 Ephemeroptera are exceptional in having two fully winged nymphal instars.

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*.

Wings consisting of flattended lobes of the integument supported by hallow veins. Termites and certain insects break off or tear off their wings after a single nuptial flight and before beginning their life in soil, while fleas, lice and certain aphids and ants have degenerate wings.

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 which 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).

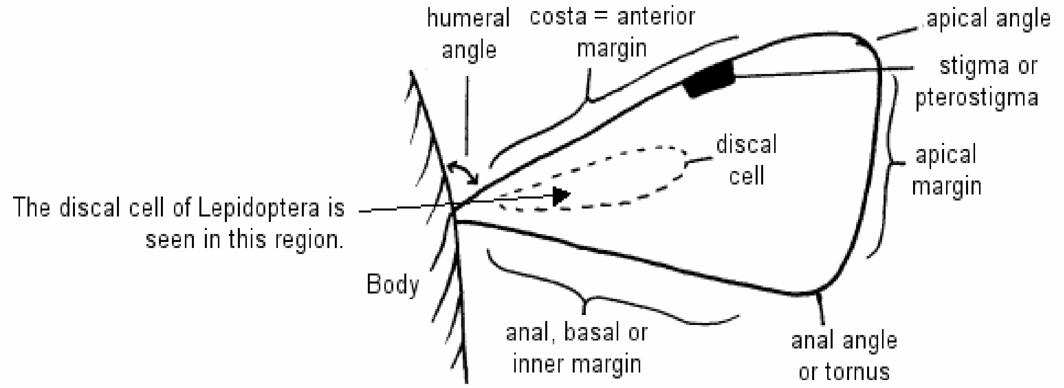
In most cases, a characteristic network of veins (wing venation) runs throughout the wing tissue. These *veins are extensions of the body's circulatory system*. They are filled with hemolymph and contain a tracheal tube and a nerve. In membranous wings, the veins provide strength and reinforcement during 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)*. Based on the degree of development of wings, the insects may be classified into *apterous, brachypterous and macropterous*.

INSECT WING STRUCTURE:

Margins and Angles:

- 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 surface area of typical wing is divided into two portions *viz*., *remigium and vannal area*. The anterior part of the wing towards coastal margin where a greater number of longitudinal veins present is remigium. The posterior part of the wing where veins are sparsely distributed in known as vannal area, which is called clavus in forewings and vanus in hindwings. *Jugum* is the inner most portion of the wing that is cutoff from the main wing by jugal fold.



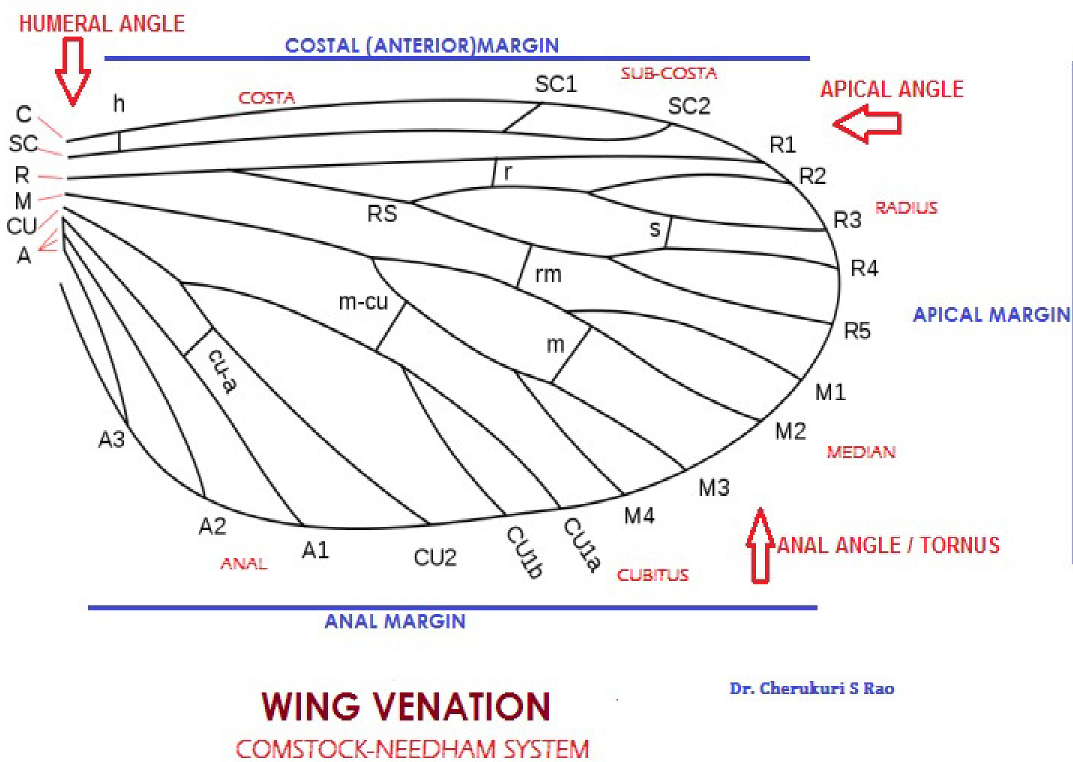
Wing Venation:

- Wings are thin, broad, leaf like structures, segmented by several hollow, narrow, tubular supporting fibres (or) structures called veins.
- The fibres / veins which run from the base of the wing towards the apex are called "*longitudinal veins*" and the shape may be conclave or convex, while those which run crosswise of the wing and connect veins are called '*cross veins'*.
- Generally, the veins are heavier or closely placed towards the costal margin, due to greatest stress during flight.
- The pattern (or) arrangement of veins and cross veins on wing surface is termed "*Wing Venation*".
- 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 surrounded by veins, is called "closed cells" and if the area extends to the wing margin without intervening veins is called "Open cell".
- In some insects, the wings sometimes possess some pigmented spot near coastal margin, known as *pterostigma* or *stigma*. |Eg. Dragon flies and damsel flies (Order Odonata).

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.

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 (*Standard abbreviations are used to indicate different veins*):



1. **Costa-"C"** (*meaning Rib*): Usually forms the *thickened anterior margin of the wing,* and *is always unbranched and convex in shape*.
2. **Sub Costa-"Sc"** (*meaning below the Rib*) runs immediately below costa, always in the bottom of a trough between Costa and Radius. It is forked distally, and is divided into two branches-SC_1 and SC_2.
3. **Radius-"R"** (*analogy with a bone 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.
4. **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).*
5. **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).*

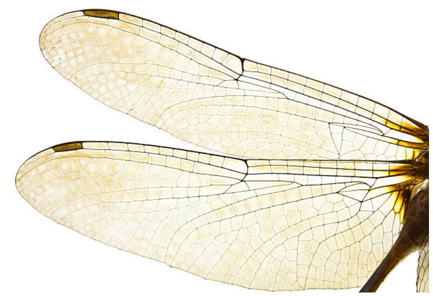
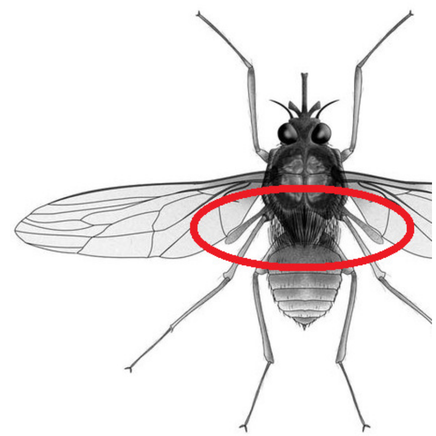
6. **Anal Vein-"A"** (*reference to its posterior location*) form a set, which are united or close together at the base and closely associated with the 3rd axillary sclerites. As there are several anal veins, they are called $\mathbf{A_1}$, $\mathbf{A_2}$, and so on.

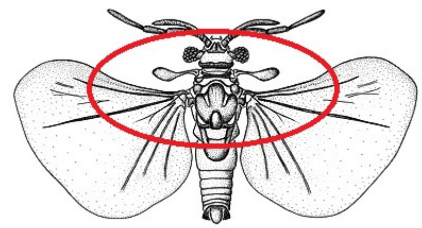
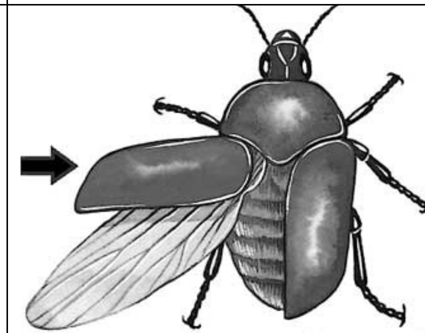
Cross Veins:

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.**

1. Humeral cross vein (h) – between costa and sub-costa.
2. Radial cross vein (r) – between radius and radial sector.
3. Sectional cross vein (s) – between sub branches of radial sector.
4. Radio median cross vein (r-m) – between radius and media.
5. Medio cross veins (m) – between branches of media.
6. Medio-cubital veins (m-cu) – between media and cubitus.

WING ADAPTATIONS AND MODIFICATIONS:

WING TYPE	MODIFICATIONS AND EXAMPLES	EXAMPLES	PICTURES
MEMBRANOUS	• Membranous wings are *thin & more or less transparent*, but some are darkened. • These wings are with *highly developed venation*. • They are *useful for flight*.	Both wings of dragonflies, damsel flies (Odonata), bees & wasps (Hymenoptera), lace wings (Neuroptera), termites (Isoptera) Hind wings of Grasshopper (Orthoptera), beetles (Coleoptera). Forewings of flies (Diptera)	
HALTERES	• Halteres are an extreme modification among the order Diptera (true flies), in which the *hind wings are reduced to mere microscopic nubs* called halteres. • *Used for balance and direction during flight (gyroscopic stabilizers)*. • It is divided into three regions-scabellum, pedicel and capitalum.	Hind wings of flies (Diptera)	

PSEUDO-HALTERES	• Wings are short and modified into pseudo-halteres which are *dumbell shaped*	Fore wings of Strepsiptera	
ELYTRA	• Elytra (singular elytron) are the *hardened, heavily sclerotized forewings of beetles* • horny sheet *without clear venation* • *Modified to protect the hind wings when at rest.* • Protect abdomen.	Forewings of beetles (Coleoptera)	
HEMI ELYTRA	• A variation of the elytra is the hemelytra. • The forewings are *hardened throughout the proximal two-thirds (thick like elytra), while the distal portion is membranous*. • The thick portion is divided into corium, clavus cuneus and embolium. • Unlike elytra, hemelytra function primarily as flight wings, in addition to protection.	Fore wings of bugs (Hemiptera)	

TEGMINA	• 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 used for flight sometimes.	Fore wings of Grasshoppers, crickets and katydids (Orthoptera), Cockroaches (Dictyoptera), Mantids (Mantodea)	
SCALY WINGS	• Scaly wings *are 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*.	Both wings of Butterflies, moths and skippers (Lepidoptera), caddisflies (Trichoptera).	

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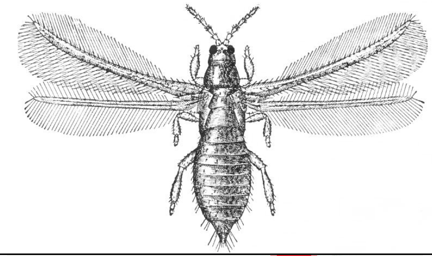
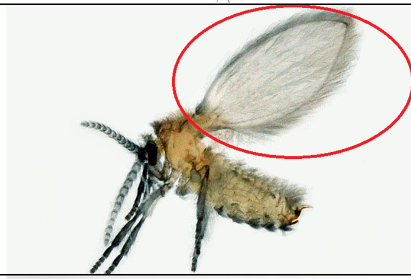
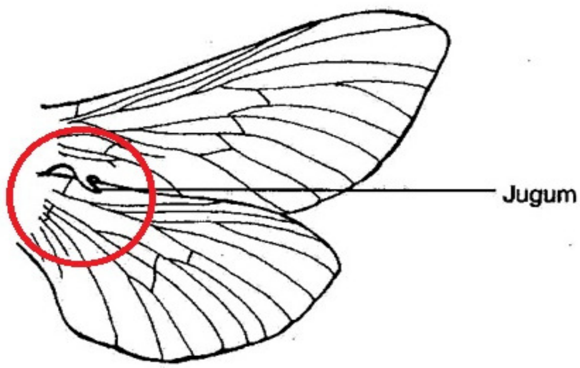
FRINGED WINGS	• The wings are slender, highly reduced with *reduced venation*. • Front and hind wings with long *fringes of marginal hairs*, giving a feather like appearance. • They are *useful for flight*.	Both wings of Thrips (Thysanoptera)	
HAIRY WINGS	• Hairy wings-front and hind *wings clothed with setae*. • They are *useful for flight*	Trichopteran wings	
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*.	Both wings of plume moth	

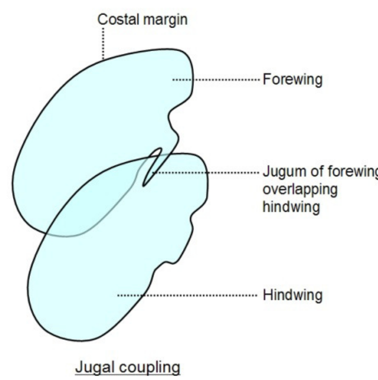
Wing Coupling Apparatus and Mechanism:

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 type / Jugate type

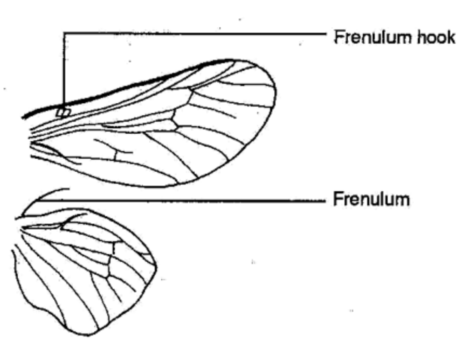
- *Examples: Primitive Lepidopterous Insects*.
- The *anal margin of the forewing possesses a small lobe* (jugum lobe or jugum) at its base called fibula-, projects behind hind-wings, which rests upon the surface of the hind wing.
- Sometimes a *spine is present on costal surface of hindwings*. In this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

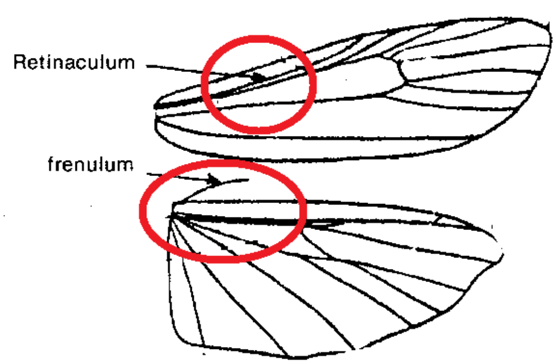




Frenulum & Retinaculum type:

- *Examples: Moths*.
- The *hind wing* possesses a *bristle / spine 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.



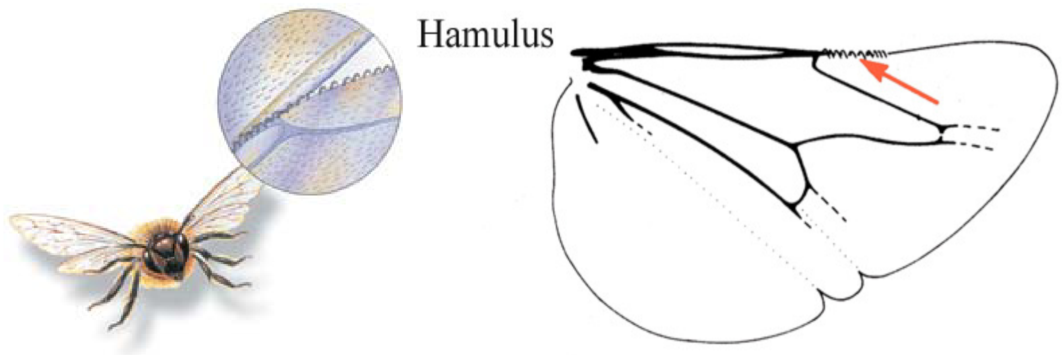


Amplexiform type:

- *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-11

TYPES OF METAMORPHOSIS AND DIAPAUSES

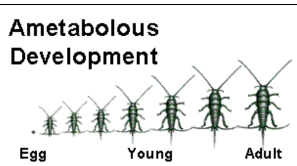
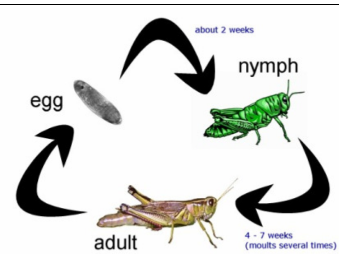
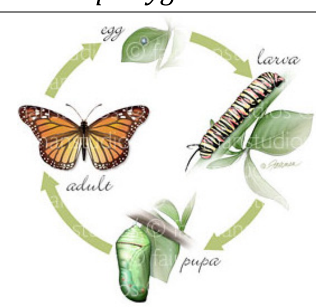
Metamorphosis- Ametamorphosis- Incomplete Metamorphosis or Direct or Simple Metamorphosis- Intermediate metamorphosis - Complete Metamorphosis or Complex or Indirect Metamorphosis-Hypermetamorphosis with examples
Diapause- Obligate and facultative diapauses – Stage of occurrence of diapause with examples

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 post-embryonic changes that involve growth and moulting in larval stages, differentiation in pupal stages, maturation and reproduction in adult stages from egg stage to adult stage are known as *morphogenesis*. Metamorphosis is derived from Greek word 'meta' means 'change', 'morph' means 'form' or 'structure'.

Majority of insects pass through profound metamorphosis. Presence of hard exo-skeleton prevents growth of immature stages *viz.,* larva and Numph. The growth of an immature insect is accompanied by a series of molts or ecdysis, in which the cuticle is shed off and renewed. These series of events allow insect to grow their body size. 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 silver fish and all apterygotes 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.

No metamorphosis	***Incomplete metamorphosis***	***Complete metamorphosis***
A-metamorphosis Undergo slight or no metamorphosis	***Hemi-metamorphosis*** Undergo incomplete metamorphosis	***Holo-Metamorphosis*** Undergo complete metamorphosis
Life cycle includes 3 developmental stages: *egg, larva and adult*	Life cycle includes 3 developmental stages: *egg, nymph and adult*	Life cycle includes 4 developmental stages: *egg, larva, pupa and adult*

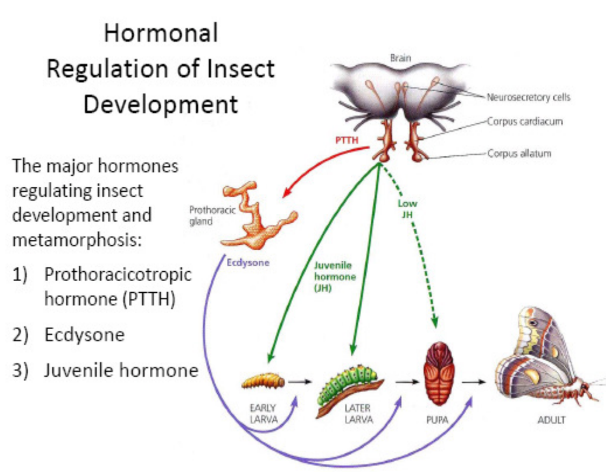
Direct Development The development is direct (young one to adult)	***Direct Development*** The development is direct (young one to adult)	***Indirect Development*** The development is indirect (youngone to pupa, then to adult)
Eggs laid with no coverings	*Eggs are often covered by an egg case,* and holds them together	*Eggs are sometimes covered by hairs/scales*
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, usually wormlike and differs from adult both in morphological characters & feeding habits.
Young one may be called as larva / nymph	Young one (immature stage) is called nymph.	Young one (immature stage) is called as larvae.
Immature and Mature have same food hbilts	Numphs and Aduts have same food habits	Larval and Adult food habits are totally different
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*
Wingless Adults	Wings develop during growth of young one (nymph)	Wings develop during growth of adult inside pupae
All *Apterygote insects*	Characteristics of lower insect orders : *Exopterygote insects*	Characteristic of higher orders : *Endopterygote insects*
		
About <0.1% insects undergo No Metamorphosis	About 12% of all insects undergo Imcomplete Metamorphosis	About 88% of all insects undergo Complete Metamorphosis

Hyper-metamorphosis:

It is Complete / Holo Metamorphosis in which at least one of the larval instar are distinctly different from other, functionally or morphologically, represent two or more different forms of larva or switch in food habits.

- Blister Beetles (Meloidae-Coleptera) – the mobile first instar (*is also generally called as Planidium*) morphology is campodeiform lives an active life on plants (*planidium in Meloidae is also called as triungulin*). In its second instar it turns into a less triungulin-like form, and feeds again. Then it turns into the less active scaraboid form for two or more instars, depending on species, and then it adopts pre-pupal forms, pupate and finally emerge as an adult beetle. One specific example is the campodiform larva of the Oil Beetle (Meloidae) lives an active life on plants until it attaches itself to a bee, which carries it to the hive, where it feeds on her eggs. After casting the skin it becomes a short-legged grub, and feeds on the honey. Another change of skin leads to a third stage, in which no food is taken, the jaws being immovable, and the legs reduced to tubercles. A third moult is succeeded by the fourth and final larval condition; the Oil Beetle grub being now a maggot resembling in appearance those of the bees, living and feeding on honey (Jardine).
- Early instars of many papilionidae (Lepidoptera) are of a colour, shape and texture suggest bird droppings, later instras that are larger and would simply standout in such camouflage, typillay become leaf-green.

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 period of arrested / suspended growth and development in the life cycle of insects that can occur at the embryonic, larval, pupal, or adult stage, depending on the species*. During this period, the physiological processes such as differentiation and reproduction are suspended.

Diapause is a *physiological state of dormancy (sleep-time) with very specific triggering & releasing conditions, a neurohormonally mediated, dynamic state of low metabolic activity.* During the period in addition to low rate of metabolism, other characters such as low O_2 consumption, low body weight, low body water content and vitamin deficiency in the blood are reported. Animals do not grow during this time.

Diapause is the delay in development in response to regularly and recurring periods of *adverse environmental conditions*. Diapause is a mechanism used as a *means to survive in predictable and unfavourable environmental conditions*, such as temperature extremes, drought or reduced food availability.

Stages of occurance of Diapause:

In some, 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:*

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

Facultative and obligatory diapauses:

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 *obligatory diapause* is the stage of the suspended activity of the insect, *is usually heriditory character controlled by genes, and is species specific* (eg. Egss of silkworm), while *facultative diapause* is the stage of the suspended activity of the insect *mainly due to unfavourable conditions*, and with the onset of favourable conditions, the insect regains its original activity (eg. Cotton pink bollworm). The unfavourable conditions may be biotic (natural enemies, population density, etc.) or abiotic (temperature, rainfall, humidity, photoperiod, type of food materials etc.).

Diapause and Photoperiod:

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*. In simple terms, *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 and Temperatures:

Diapause is brought about by token stimuli due to change in the environment, and diapause begins before the actual severe conditions arise. *Diapause during summer is called aestivation,* and these insects are active in rainy season and *sleep (dormant)* during *drought/summer. Diapause during winter is called hibernation,* and these insects are 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.

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 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.

LECTURE-12

TYPES OF LARVA AND PUPA

Differences between nymph and larva - Larva- Protopod-Oligopod (Campodeiform and Scarabaeiform)- Polypod and Apodus with examples
Pupa- Obtect- Exarate- Coarctate- Chrysalis with examples

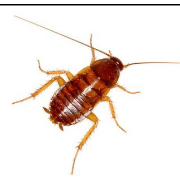
In metamorphosis, immature stages (*active feeding stages viz.,* nymph in hemi-metabolous, larva in holo-metabolous) and pupae (*non-feeding resting stage*) are most important stages in metamorphosis between egg to mature stage.

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

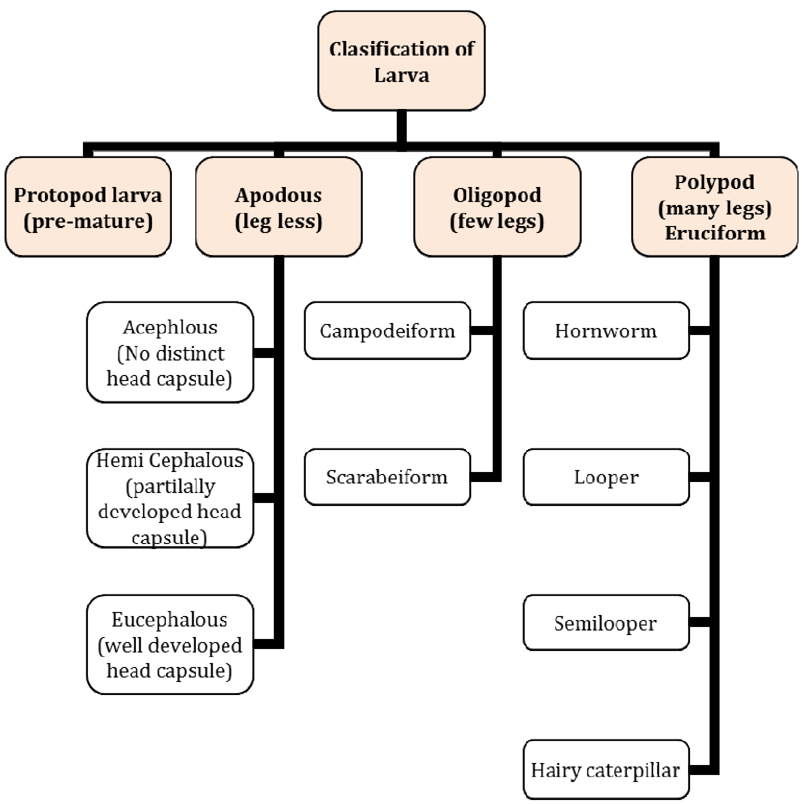
The nymph, an immature form of insects, looks exactly like adults in most aspects except in development of wings externally, and reproductory organs internally, and undergoing gradual metamorphosis before reaching to adult stage. In all insects of hemi-metabolous type, the nymphs just like adults, and only one type is present. *Nymphs of aquatic insects*, as in the orders Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), and Plecoptera (stoneflies) *are also called naiads*, In Odonata (Ephemeroptera and Plecoptera as well) *nymphs differs from adults in possessing adaptive organs like the tracheal gills, modified labium.*

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	Larva
Young one of exopterygote insects	Young one of endopterygote insects
Undergoes hemi-metamorphosis	Undergoes holo-metamorphosis
Growth to adult is unaccompanied by the pupal stage	Growth to adult is accompanied by the pupal stage
Resemble adults and *differs from the adult about the wings and genitalia*-that are present in an incompletely developed condition.	Differs from adults in appearance. *Body in vermiform*.
Food habits of nymph is same as adult	Food habits of larva is totally different from its adult
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.

Antenna generally well developed and visible	Antenna highly reduced to 1-3 segments, always microscopic and not visible
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. Wings are totally absent.
Nymph have 3 pairs of thoracic legs as in adults	*Legs are present in both thorax and abdomen.* Number of legs in larva are variable from 0-11 pairs invarious orders.
Mouthparts are like those of adults	Mouth parts are different from adults in most cases
Genital organs are under-developed	Genital organs are totally absent
Bugs, Cockroach, Grasshopper	Housefly, Butterfly, Moths
 	

THE CLASSIFICATION OF LARVA IS MAINLY BASED ON NUMBER OF LEGS.



PROTOPOD LARVA: (PRE-MATURE 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*

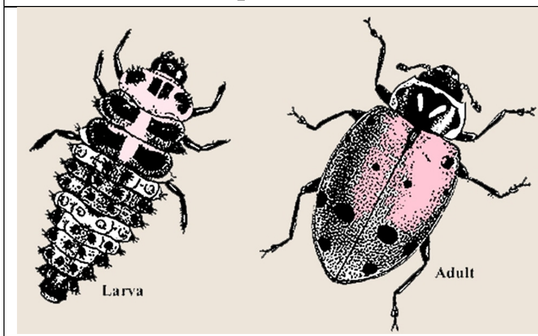
APODOUS LARVA: (LEG LESS LARVA):

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 degree of development of head capsule and its appendages.

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

OLIGOPOD LARVA: (FEW LEGGED LARVA) :

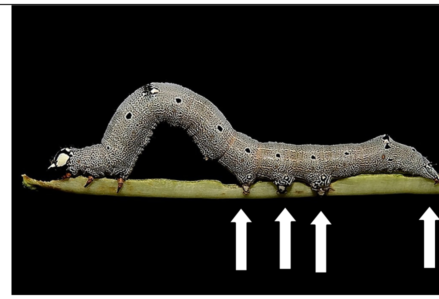
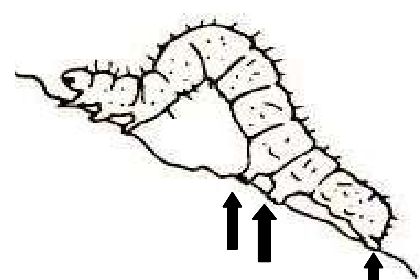
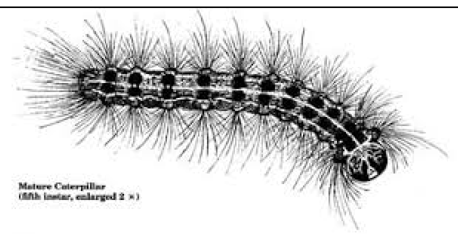
Oligopod larva bears well developed thoracic legs, and head capsule and its appendages. This larva bears *no abdominal appendages* (abdominal legs absent). Oligopod larvae are classified in to 2 types based on the shape and other characters.

Campodeiform	**Scarabaeiform**
	
Long and straight body (*Allegator like*)	**C** shaped body
Body is flat 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 terminal 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) (MANY LEGGED LARVA) :

These larvae have *well developed segmentation in thorax and abdomen* with *both thoracic and abdominal legs.* The appendages of head and abdomen are well developed. Antenna present, but very small in size or rudimentary. Peripneustic respiration is common. These larvae are comparatively inactive, living close to their food or host plant, and generally Phytophagous. *Examples: Some Lepidoptera and Sawflies of Hymenoptera*

Polypod larvae can be classified into 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*.	 Sphinx moth (death head moth)- *Acherontia spp.*
Semi Looper	*First two pairs of prolegs (3rd and 4th abdominal seg) are reduced*. Due to reduction of size of first prolegs, during locomotion the body form a loop shape, and hence these are called *semiloopers.*	 Castor Semilooper *Achaea janata*
Lopper	*Generally, only two pairs of prolegs (6th and last abdominal seg) are present and other prolegs 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*

A PUPA (for doll) is the inactive, non-feeding, resting life stage of holo metabolous insects. 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. 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 feed and move about),* except in some cases, where they crawl (Aphid lion-Nueroptera), can swim (eg. Mosquitoes).

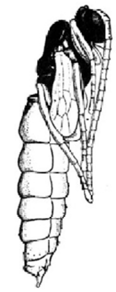
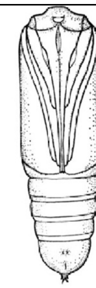
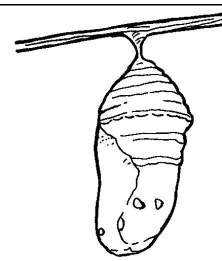
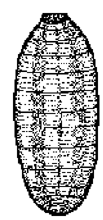
They have a hard-protective coating and often use camouflage to evade potential predators. Pupation may be brief, for example 2 weeks as in monarch butterflies, or the *pupa may enter dormancy or diapause* until the appropriate season for the adult insect (in temperate climate pupae usually stay dormant 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	Adecticous Pupa
Posesses relatively *powerful sclerotized articulated mandibles used to escape the adult from cocoon or cell* or to break the cocoon.	Having non-articulated often *reduced mandibles* that in most species are *not used for escape from the pupal cocoon*.
They are primitive type and *always exarate (free appendages, not adhering to rest of body).*	They are developed type, and different 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.*	
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

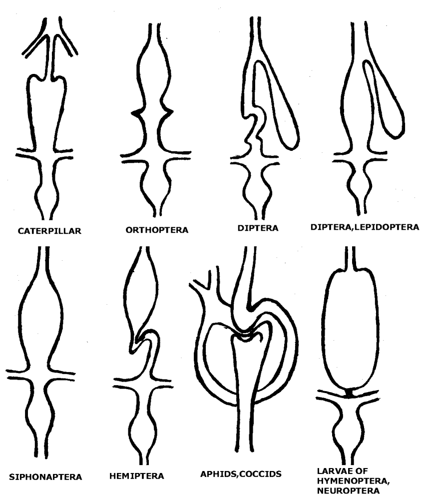
DIGESTIVE SYSTEM

Alimentary canal – Structure of foregut, midgut and hindgut –histology, functions, filter chamber and peritrophic membrane
Process of digestion- Extra intestinal digestion.

General Introduction

Insects may be phytophagous, entomophagous, wood borers, wool feeders, saprophytic, mainly feeding on solid materials. Some insects also feed on plant sap or nector or blood, a liquid food. As the food of various insects varies greatly, the digestive system modifies accordingly to suit to the type of food materials, for digestion into primary energy materials such as carbohydrates, proteins (amino acids) and fatty acids.

Insects feeding on solid materials possess chewing and biting mouth parts, while insects feeding on liquid materials possess haustellate (sucking / lapping) type of mouth parts. *Soild feeders have well developed gizzard, while sap suckers possess a filter chamber.* Compared to carnivoures or sap suckers, solid feeders have long alimentary canal.



Various types/shapes of digestive tracts in different insects

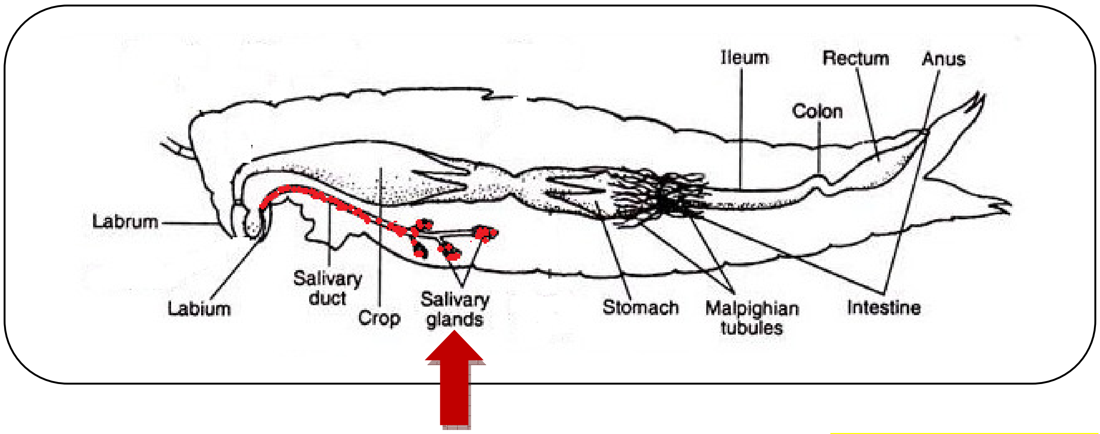
The insect digestive system is a closed system, with one long enclosed tube (alimentary canal) running lengthwise through the body. The alimentary canal is a one way street - food enters the mouth and gets processed as it travels toward the anus.

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.

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. 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.

The three sections of the alimentary canal perform a different process of digestion. 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 oesophagus, 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 Malpighian tubules to form *faecal pellets*. The *rectum absorbs most of the water in this waste matter*, and the dry pellet is then eliminated through the anus.

SALIVARY GLANDS



Salivary Glands are not part of digestive system, but the *saliva helps for the lubrication of the food* when enters into pre-oral food cavity. Immediately behind the mouth are the Salivary Glands, are *paired glands*, which *secrete saliva* into pre-oral food cavity where it mixes with food. Salivary gland tubes opens in hypopharynx between labrum and labium. Their ducts unite to form a common duct opening at the base of the hypopharynx is the *salivarium*. Functionally, labial glands are the salivary glands in most insects. In most species these glands secrete saliva, generally a watery fluid that *lubricates the food and contains a few enzymes (amylases, lipases, proteases, but never cellulases)* 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 lepidopteran and caddis fly larva, the labial glands are modified as *silk glands*, take up the function of silk secretion (contain two proteins, fibroin and sericin), while *mandibular glands produce saliva*. Similarly in Queen Honeybee, mandibular glands secrete saliva and hormones.

In blood suckers like mosquitoes, these salivary glands produce *anti-coagulants* (*Glossina moristans* saliva has antithrombin, similar to hirudin, while in *Glossina 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.

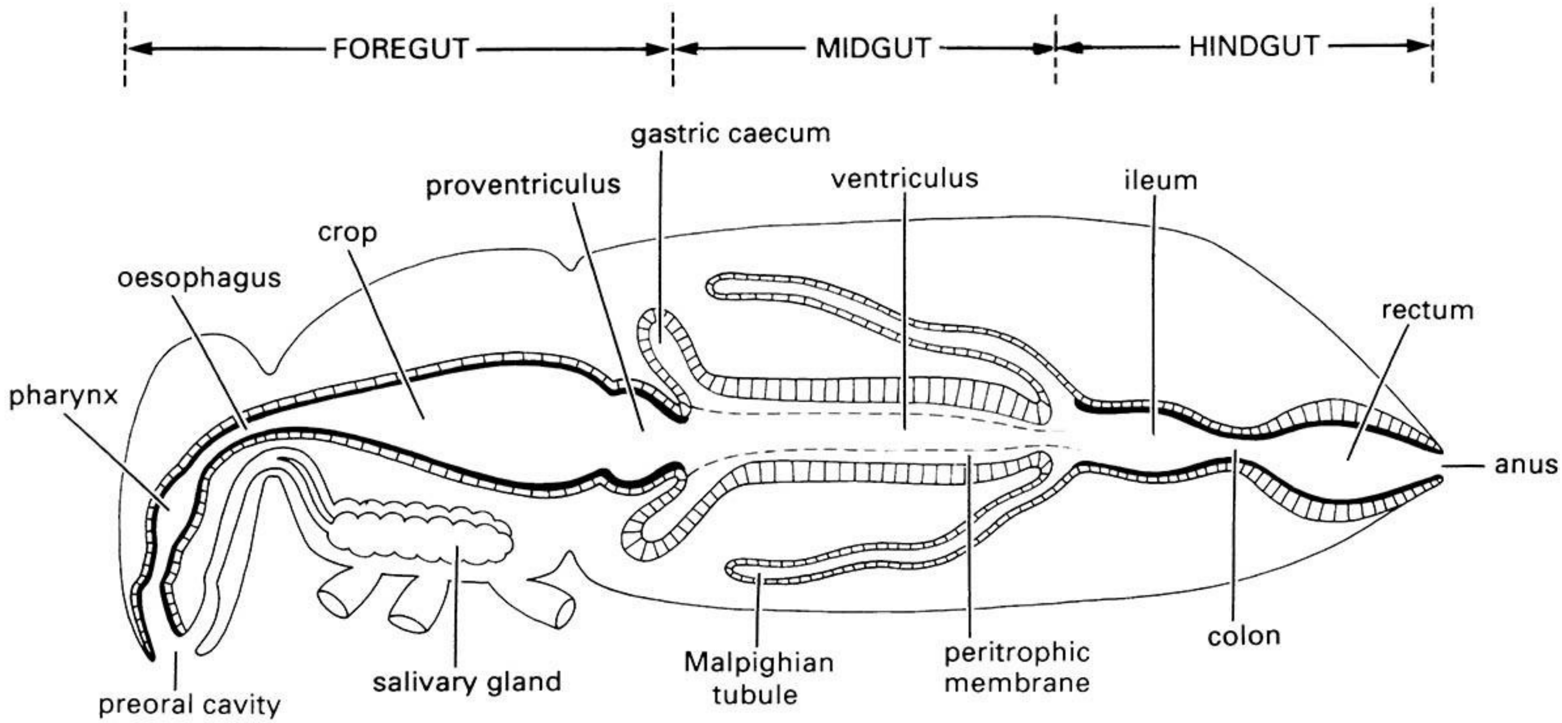
PRE-ORAL CAVITY AND BUCCAL CAVITY

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. In insects with mandibulate mouthparts, this space is divided by the hypopharynx in to an dorsal *cibarium* and 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 / Mouth Cavity is the oral part of the foregut. It is not structurally differentiated from the pharynx. The mouth cavity is formed by labrum as upper lip, and labium as lower lip, with mandibles and maxillae laterally for catching and inserting the food into mouth cavity, and hypopharyx at the centre. At the base of the hypopharynx, salivary glands open into mouth cavity.

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*.


FOREGUT
MIDGUT
HINDGUT
gastric caecum
proventriculus
ventriculus
ileum
crop
oesophagus
rectum
pharynx
anus
preoral cavity
salivary gland
Malpighian tubule
peritrophic membrane
colon

FOREGUT (*Stomodaeum)*

Foregut arises as an ectodermal invagination. *Foregut is lined on its inside with the cuticular intima, produced by a single layer of epithelial cells*. *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 (*Stomodaeum)* is generally considered to consist of four sections: The Pharynx, The Oesophagus, The Crop and The Proventriculus.

1. **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*.
2. **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.*
3. **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.
4. **The Gizzard (Proventriculus)** is the last section of the foregut. It is small constricted, *muscular extension of the crop*. This consists of *cuticular intima layer modified into teeth like denticles that help the grinding of food materials*. In 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*. 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 *honey 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* (*honey stopper*) and retains the nectar in the crop. Nectar is retained in the crop, regurgitated and is processed to form honey.

Internally foregut consist the following layers viz.,

1. innermost intima layer,
2. epithelial cells,
3. basement membrane,

4. circular muscles
5. longitudinal muscles.

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 Mesenteron***)**:**

The fore gut and the mid gut are separated by the *'stomodeal or cardiac valve'*. The foregut opens into midgut through these valves or sphincters which regulate the forward movement of the solid particles from the midgut into the foregut.

In many insects the surface area of the stomach is increased by the development of sac like *gastric cacae*. These organs are usually situated at the anterior end of the mesenteron; serve to increase the surface area of the midgut, thus increasing its ability to secrete digestive enzymes and its ability to extract useful products from the partially digested food.

Structurally midgut consists of

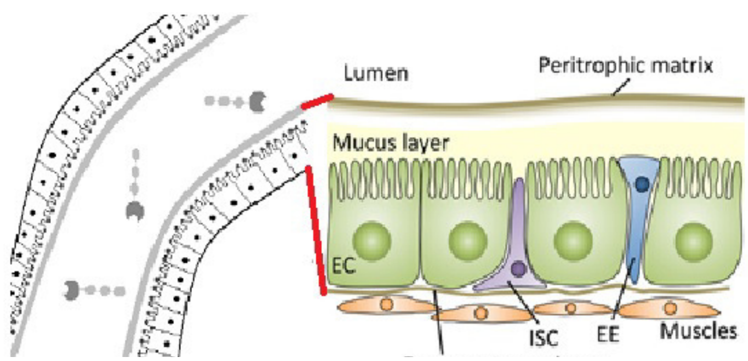
1. Inner peritrophic membrane
2. A layer of epithelial cells
3. Basement membrane
4. Circular muscles
5. Longitudinal muscles

Midgut (*Mesenteron*) *performs the function of digestion and absorption*.

Peritrophic Membrane: In insects, midgut is lined with a *delicate peritrophic membrane* secreted from epithelial cells located at the junction of foregut 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*. Peritropic membrane is *permeable to enzymes and digestive products*. Peritrophic membrane is absent in many fluid feeding hemipterans and homopterans. However, 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.

Midgut Epithelium: The epithelium of the midgut contains three main types of cells: *Columnar cells (Cylinder cells), Regenerative cells and Calciform cells (goblet cells).*

1. *The columnar cells* are columnar in shape; vary in size, actively *involved in the secretion of enzymes through a series of microvilli arranged in brush border (or) honey comb, and absorption of the products of digestion*.
2. *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 through production / formation of new cells to replace the whole columnar cells involved in holocrine secretion of enzymes.
3. In a number of insects, the midgut cells i.e *Calciform Cells or Goblet Cells may accumulate spherules*, which involve in *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.



HINDGUT: (*Proctodaeum*)

The food passes from midgut to hindgut. The indgut is lined inside by intima, and more permeable than foregut. 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).

Ileum is a small intestine (or) tube like structure and appears as pouch in scarabid beetles. Colon may or may not present, and if present, it leads to rectum. 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. The epithelial cells of rectum may sometimes get differentiated into *rectal palpi* (or) pads which vary in number from 3 to 6. These are involved in *reabsorption of water, salts from the fecal matter*.

Anterior end of hindgut can be marked by presence of *Malpighian tubules* (named after Malpighi who discovered them) which 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 (haemolymph) and excrete them into the intestines which are the first part of the hind gut. The anterior end of hind gut also have *pyloric valve.*

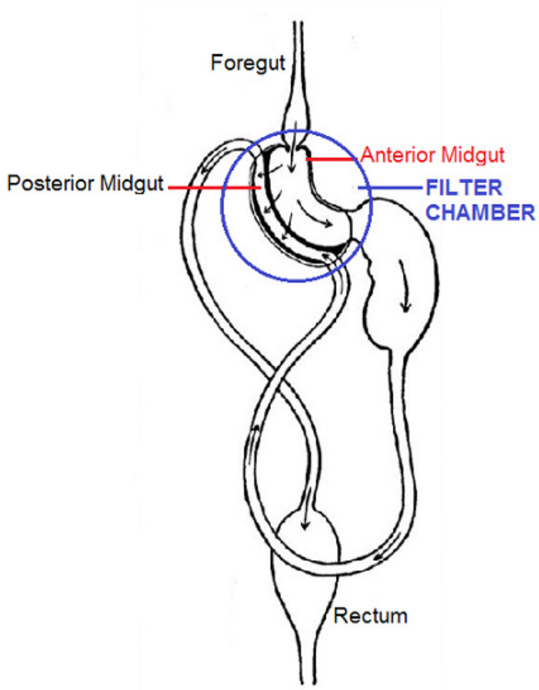
Though insects possess a large number of digestive enzymes, they are often helped by the presence of symbiotic micro-organisms, such as *protozoa in the case of the termites and some primitive cockroaches which feed on wood*, and *bacteria in the wax moth Galleria mellonella which feeds on the wax* that honey bees *Apis mellifera* uses to make the combs in its hives.

Filter Chamber:

A number of fluid feeders such as aphids, plant hoppers, *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. This filter chamber *enables the excess fluids including sugar in the food to pass directly from the anterior part of the midgut to the hind gut without passing through the middle portion of the midgut* thus preventing excessive dilution of haemolymph, enzymes, and facilitate better enzyme activity.

In aphids, the *honey dew* (rich in sugars) is the substance that is being excreted after passing through the filter chamber.

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.



FUNCTIONS OF DIGESTIVE SYSTEM:

- Intake of raw food material
- Digestion of raw food materials into nutrient substances
- Absorption of nutrient substances from digestive system through midgut epithelium
- Transport of nutrient substances from digestive system to circulatory system through midgut epithelium
- Ejection of the unused / undigested food material
- Distribution of absorbed products among cellular tissues

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 re-absorption* is another important function carried out by the gut.

PROCESS OF DIGESTION:

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. The food ingested by the insects through the mouth parts and mouth cavity enters into the alimentary canal (or) digestive tract, the food is broken down into smaller micro molecules which can be absorbed by the epithelial cells of midgut and hindgut, and undigested waste material is excreted as fecal matter through anus.

The process of digestions takes place in 5 steps:

1. **Ingestion:** The food is partially digested in the oral cavity with the help of enzymes produced by salivary glands. In fluid feeders or sucking insects such as carnivorous hemiptera, blowfly larva etc., the digestion occurs outside the intestine through extra-intestinal or extra-oral digestion.
2. **Transportation:** The food material entered into the oesophagous (of foregut) is transported to the crop by muscular activity (peristaltic movement). Food moves continuously from oesophagous to the crop, where it is stored. Then food moves to gizzard, where the food materials of broken into small pieces with the help of denticles or cuticular teeth of Gizzard.
3. **Digestion:** 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*. *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. 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*. This process of breaking of larger molecules into smaller absorbable micro molecules is done by enzymes produced by epithelial cells of modgut. The proteases breaks proteins into amino acids, carbohydrases break carbohydrates into mono and disaccharides, and lipases break lipids into fatty acids and glycerol. In termites, the digestion takes place in colon of hindgut where *mycetomes (group of cells harboring the micro organisms like protozoa)* secrete the cellulase anzyme, which can digest the wood materials containing cellulose. In case of scarabid beetle larva, *bacteria* are involved in digestion. In wood feeders, *keratin* digestion is facilitated by *alkaline p^H of midgut.* In *Tineola* (cloths moth), *keratinase* is secrested by protozoans.

4. **Absorption:** *Absoption occurs in midgut through epithelial cells. Absorption of micro-molecules is either through either active or passive process, through peritropic membrane and midgut epithelial cells finally into haemolymph*. The malpighian tubules maintain ionic balance by absorption of Na and K salts from blood. The cells of midgut epithelium also involved in the re-absorption of water, salts and other metabolies from faecal matter.
5. **Egestion:** Egestion is the discharge of waste food material from alimentary canal through anus as fecal matter by the action of anal muscles.

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 and closed types – Organs of circulatory system – Dorsal blood vessel (diaphragms, sinuses and accessory pulsatile organs)
Process of circulation - Types of haemocytes
Properties and functions of haemolymph

There are two types of circulatory systems in the animal kingdom. 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*. In some animals, the blood moves / travels without aid of vessels. In Insects, the blood travels through *body cavity (haemocoel)* irrigating various tissues & organs, and hence is known as *open 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*.

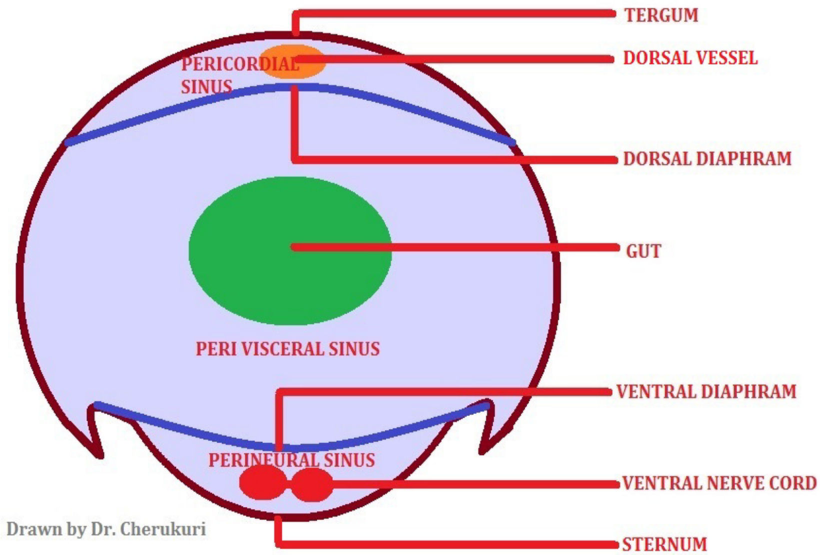
In Insects, the body cavity through which the blood travels is called *Haemocoele.* The nutritive fluid or blood that is present in haemocoele is called *Haemolymph.* Insect blood is only about 10% hemocytes (blood cells); most of the hemolymph is watery plasma. *The insect circulation system does not 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.

HAEMOCOEL

To facilitate circulation of hemolymph, the *body cavity (Haemocoel) is divided into three compartments (called blood sinuses) by two thin sheets of muscle and/or membranes (dorsal and ventral diaphragms)*.



The diaphrams and sinuses:

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 area lying between tergum and dorsal diaphram is called *dorsal / pericardial sinus*. This contains heart.

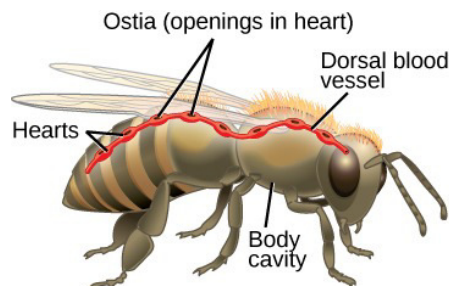
The *ventral diaphragm* usually covers the nerve cord; it separates the perivisceral sinus from the perineural (ventral) sinus. The ventral diaphragm is a continuous layer, lying just above the nerve cord and divides the abdomen into two sinuses, viz., *perineural and perivisceral sinus*. The area between dorsal and ventral disphrams is called perivisceral / visceral sinus, and the area lying between sternum and ventral diaphragm is called perineural / ventral sinus. The ventral sinus contains nerve cord. Between the dorsal and ventral sinuses is the large visceral sinus containing principal internal parts such as alimentary canal, gonads, and alary muscles.

The ventral diaphragm is usually absent in thorax of most insect larvae (except in some Hymenoptera), and most adult insects.

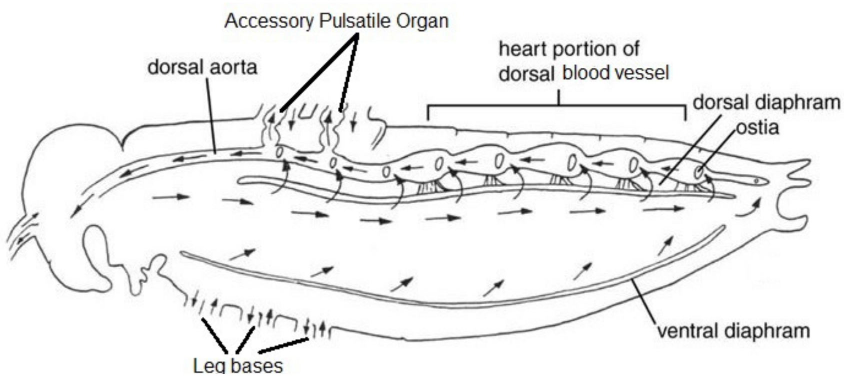
The *heart is maintained in position by* filaments known as *alary muscles.*

DORSAL BLOOD VESSEL:

A *dorsal blood vessel* is the major structural component of an insect's circulatory system. It *works like a heart*, a long tubular, 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*. The dorsal vessel is the *principle blood conducting and pulsatory organ* in insects *pumping the blood through ostia with the movement of alary muscles.* It is *closed at the posterior end and opens anteriorly into the head*.



Haemolymph in insect *body circulates mechanically* in a posterior to anterior direction by the action of a *pulsatile organ*, the dorsal vessel. *Dorsal vessel can be divided into anterior aorta (in thoracic region) and posterior heart (in abdominal region) extending throughout the length of the body.*



Aorta **:** The anterior part of dorsal vessel (often referred as aorta) is a *simple unperforated tube*, *present in thoracic regions* and *may end in a frontal sac, or open simply in head near brain*, or its anterior part may be modified to divide into vessels supplying haemolymph to the antennae (cephalic arteries). Functions as principal artery, *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 **:** The posterior part of dorsal blood vessel in the abdomen is called as the heart. Heart is divided segmentally into chambers that are separated by valves (ostia) to ensure one-way flow (only inflow) of hemolymph from pericardial sinus of body cavity into heart.

A pair of alary muscles is attached laterally to the walls of each chamber to make sure that the position of heart is not changed. The alary muscles *appear like fan like* laterally over the heart. 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 walls of heart also consists muscles, and heart mainly function as *pumping organ* into aorta.

The *number of ostia depends upon number of heart chambers*, usually 9. 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 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. Various tubes, septa, valves, sac like structures and pumps, which are collectively termed as accessory pulsatile organs, bring the unidirectional movement of blood. 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.

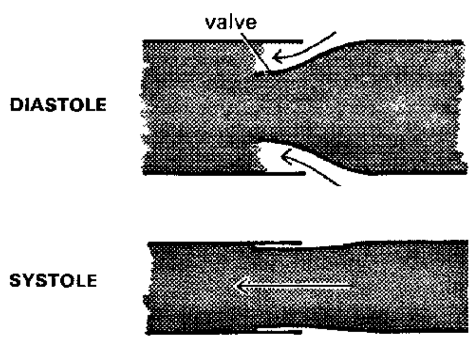
Alary Muscles: Alary muscles are largely composed of *connective tissue with elastic properties* rather than muscle cells. Alary muscles arise, usually, from a restricted origin on the tergum and fan out, in such a way that those of opposite sides meet into a broad zone at the midline, over the surface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

CIRCULATION OF HAEMOLYMPH:

The heart is the principal pulsatory organ and rhythmical contractions (expansion and contraction) of heart which are brought about by the muscle fibrillae of its walls leads to blood circulation. Contraction of the heart takes the form of a wave of peristalsis which runs forward from posterior end (anti-clock wise). 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).

Systole (contraction phase of heart): 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. This creates pressure on the blood within the heart leading to forward movement into the aorta, and from aorta the blood enters into head and flows back bathing the visceral organs in the visceral sinus and nueral cord in the pernueral sinus.

Diastole (expansion phase of heart): Then at *diastole (relaxation phase)*, results from the relaxation (contraction) of the fan like *alary muscles*, resulting in increase in volume of the heart, and decrease in the area of pericardial sinus, and this result in forcing the the *blood to enter into the heart* through incurrent ostia. These incurrent ostia allow only the entry of blood from the sinus into the heart, and prevent its backflow from the heart to the sinus.



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.

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*.

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.

PROPERTIES AND FUNCTIONS OF HAEMOLYMPH: Insect Haemolymph consist *liquid plasma and blood cells* or haemocytes.

Plasma: The blood *doesn't contain Haemoglobin*, and hence it is usually *colorless* or green, or yellowish in color with about 90% plasma. The green color is due to chlorophyll dissolved in plasma, and red color in chironomus midges and mosquitoes is due to harmoglobin in haemolymph. The insect blood constitutes about 5-40% of insect body weight, and may vary with sex, stage, age of insect. Plasma contains 85% water, *slightly acidic* and includes inorganic ions, amino acids, proteins, fats, sugars, organic acids and other substances. Potassium Chloride and Sodium Chloride are the major inorganic substances present in blood. 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. The pH of the blood varies from 6-7, and the specific garivty varies from 1.01 to 1.06. Insect blood *doesnot contain vitamin K*. The principal blood sugar is insect blood is *trehalose*.

Haemocytes: Haemolymph have 90% plasma, and 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. 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 unlike in humans.

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 blood:

1. ***Storage and transport of minerals and food materials:*** The blood plasma is the principal part for food storage, and aids in transportation of food materials and hormones.
2. ***Blood stores water:*** Insect blood plasma water is used during desiccation by insect.
3. ***Helps during moulting:*** Blood helps in the process of moulting for splitting up of old cuticle.
4. ***Phagocytosis**:* The most common function of haemocytes is phagocytosis of foreign particles, micro organisms and tissue debris. Mainly the plasmocytes perform this function.
5. ***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 dies through lack of oxygen.
6. ***Secretion and metabolism***: Some of the haemocytes are useful for the formation basement membrane, formation of fat body, activation of prothoracic gland (which produces moulting harmone, ecdysone). In some instances the cells themselves break down to provide nutriment for other tissues.
7. ***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.
8. ***Connective tissue formation***: Blood provides lipoproteins that are necessary for formation of connective tissues.
9. ***Immunity***: Blood provides immunity through production of antibodies to restrict further infections.
10. ***Reflex bleeding***: The plasma also used for *defensive mechanism* in some insects, for example reflex bleeding in some insects when they are disturbed through pores, slits and articulations of the cuticle.
11. ***Detoxification***: Haemocytes are capable of detoxifying the chemicals, and hence insects get ability to sustain from toxic chemicals.

LECTURE: 15

EXCRETORY SYSTEM

Structure, functions and modifications of malpighian tubules
Structure and 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. Excretion is an essential process in all forms of life.

Excretion is the process of eliminating waste products of metabolism and other non-useful materials. The waste products may be solid, semisolid, liquid or gaseous form. *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.

The principle excretory product in the gaseous form is CO_2, liquid is honey dew, solid form is urea / uric acid and semi solid form is allantoin. 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. Various organs of insects that are involved in the process of excretion are malpighian tubules (principal organs), rectum of hind gut, integument / body wall, tracheal system, nephrocytes, urate cells, oenocytes, labial glands and chloride cells.

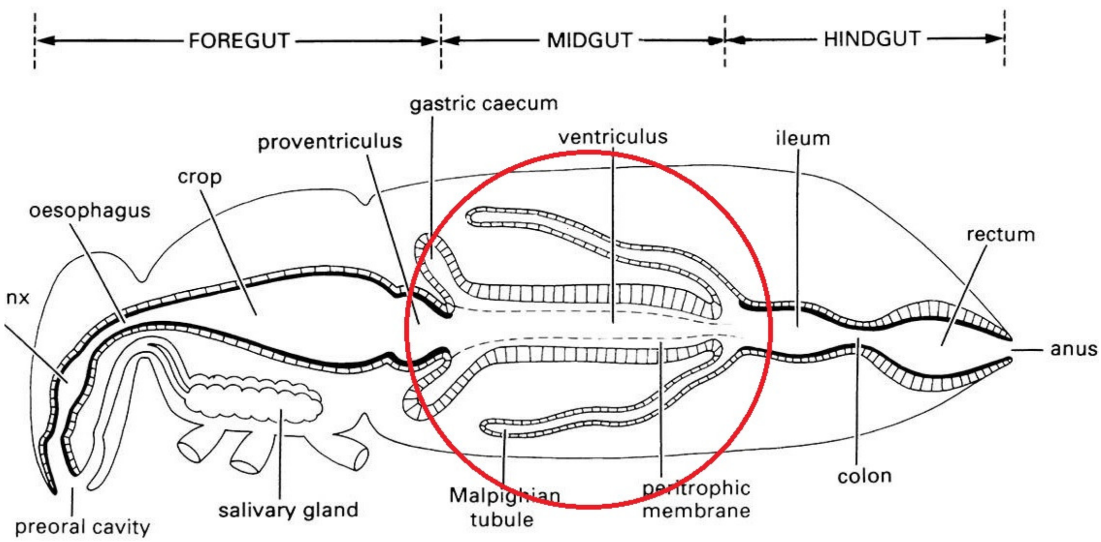
Excretory Products:

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.

MALPIGHIAN TUBULE SYSTEM:

Malpighian tubule system is a type of excretory and osmoregulatory system found in Insects and Myriapoda, arachnids and tardigrades. Marcello Malpighi, an anatomist, 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 Heckel termed these as Malpighian tubes in 1820.

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 / floating freely in the body cavity / haemolymph*, 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*). They may *open independently into the gut* or may join in groups at an ampula.



The Malpighian tubules *absorb salts, water, and wastes from the surrounding hemolymph, by diffusion*, and are then converted into Uric Acid, and this *organ empties Uric acid directly into the alimentary canal*, as it connects at the junction between the midgut and hindgut. The semi-solidified waste empties into the hindgut, and becomes part of the fecal pellet, which is then out of the body through anus.

Numbers, Shape and Size:

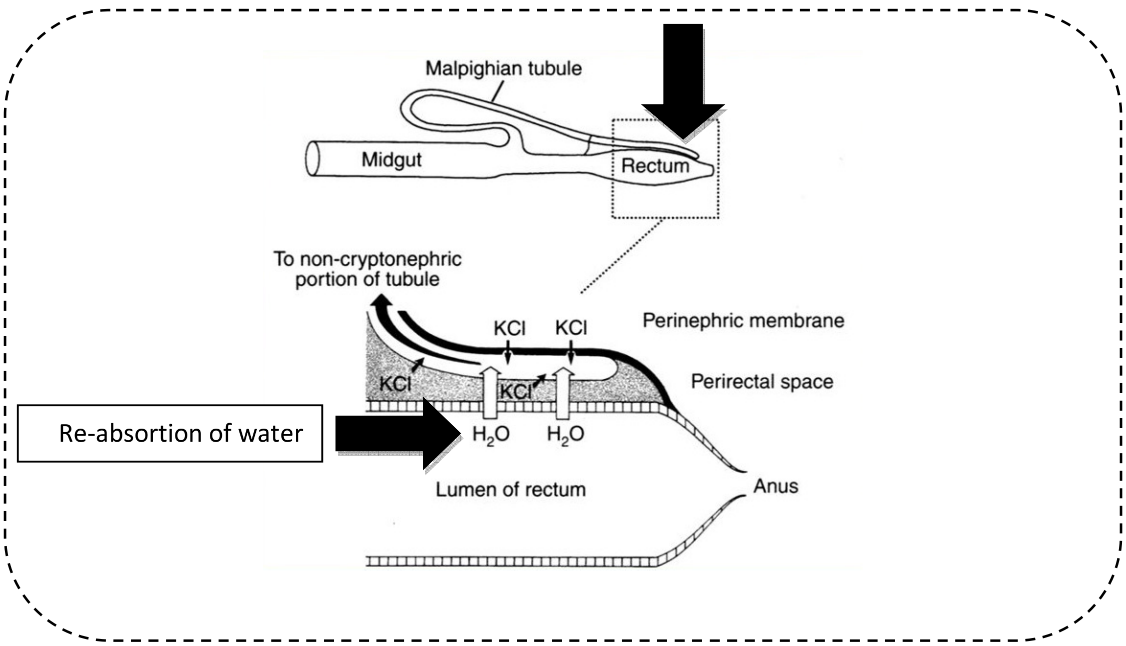
Numbers: The number of Malpighian tubules in insects may vary (2 in coccids, 250 in locusts), from species to species. *Malpighian tubules are absent in Collembola, Thysanura. Their primitive number is six (three pairs)*, but in coccids their number is reduced to only two. *More than 20 present in members of family aphididae (Aphids).*

Shape: The shape of the tubules may be sac like, papillae like or branched. In Diptera, Protura and Strepsiptera these are represented by papillae. They may be simple or sometimes branched.
Size: The tubules vary from 2-100 mm in length and 30-100 µm in diameter.

Like arms of an octopus, the Malpighian tubules extend throughout the insect's body. 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. Generally the distal ends of tubes are freel floating in the Haemocoel / body cavity.

Cryptonephridial condition:

In Coleoptera (beetles), larvae of Lepidoptera, and a dipteran (flies), *the blind / distal ends of Malpighian tubules, are not free in haemocoel; instead lie closely parallel to the external wall of the rectum, by 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.

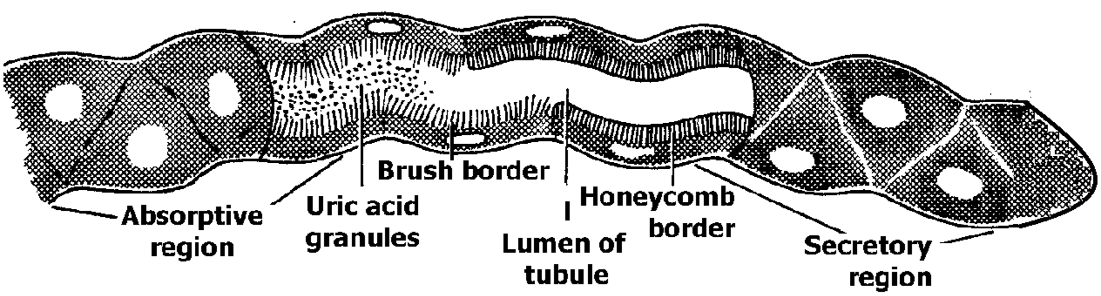


This kind of arrangement forms a mat over rectum, covering by single epithelial cell layer. It is *highly developed in insects feeding on dry matter* (*Tenebrio molitor* and *Dermestes*). This condition is best developed in terrestrial insects, *to conserve water (re-absorption of water from rectum).*

STRUCTURE OF MALPIGHIAN TUBULES:

Malpighian tube is *made up of single-celled thick wall*, with 2-5 cells. The tubes are *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 *provides structural support*.



----------------proximal end--------------   ---------------------- distal end ----------------------

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 of epithelial cells 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 *absorptive region* are more widely spaced, forming a typical "*brush border*", comprising the cytoplasmic filaments. In the remaining *two-third distal (upper) secretory region*, parallel and closely spaced microvilli 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:

1. primary cells which have basal infolds and large microvilli with mitochondria
2. *leptophragma cells, a* smaller and thinner, found at intervals along the tubule.

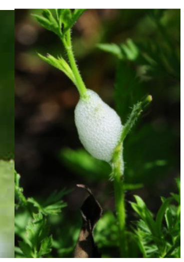
The cells of Malpighian tubules also produce various enzymes, acid and alkaline phosphatases, dehydrogenases, lipases, vitamins like thiamine, ascorbic acid etc.

Functions and Modifications of Malpighian tubules:

1. Helps in process of excretion (or) removal of waste materials / products in order to regulate the internal environment of body.
2. Helps in keeping ionic balance.
3. Helps in keeping Water balance.
4. In some insects, helps in storage of Calcium, which is necessary for hardening of puparium.
5. In some insects, MTs produce light energy. Distal ends of Malpighian tubules produce light in Glow Worms.
6. In some Insects, MTs produce secreations for stalked eggs. Eg. Chrosoperla (Aphid lions).
7. In some insects, MTs secrete foam like liquid which form around immature nymphs. Eg. Spittlebugs

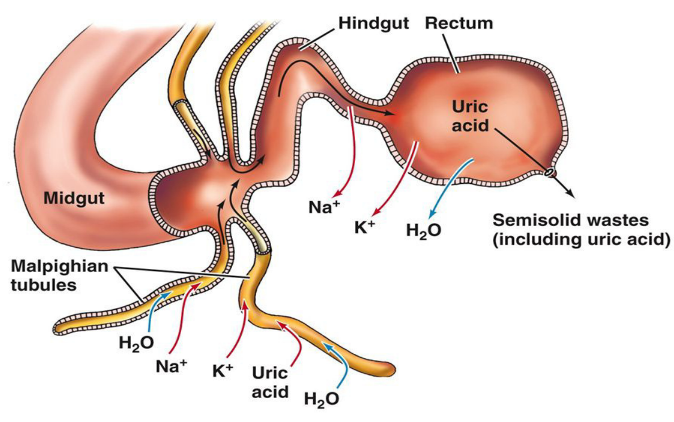
Glowworms

stalked eggs of Chrysoperla



foam – spittlebugs

Physiology of excretion: 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.



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. Some respiration also take place through the integument (cutaneous respiration), and hence *ectoderm may also be considered as an excretory organ for elimination of CO_2 and water from the body*.

Tracheal System:
Technically speaking even *tracheal system is also excretory system* as it eliminate CO_2 through spiracles.

Alimentary canal:
The gut of the insects also plays a major role in excretion by removing unwanted materials, dead cells formed during enzyme secretion (holocrine) and intima layer during moulting. Epithelial cells of the gut, which contain excretory products, are also shed along with exuviae at each moulting. The midgut of *Bombyx* is capable of excreting some acid dyes. Rectum plays very important role in excretion by reabsorption of water from faeces.

Labial glands:
Labial glands present in the head of Collembola, are probably excretory in function.

***Nephrocytes and Pericardial cells*:**
Nephrocytes are ensheathed in basement membrane and suspended in haemocoel, freely bathed in haemolymph. These nephrocytes regulate haemolymph composition by filtration followed by *endocytosis* and processing sequesters secondary toxic metabolites (foreign chemicals of relatively high molecular weight) which the Malpighian tubules may be incapable of dealing with. *Nephrocytes are 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". In *Calliphora*, the nephrocytes produce, store and release the enzyme, lysozyme.

Oenocytes:
These are large cells and are usually *present near the abdominal spiracles*. They arise from the ectoderm or hypodermis. These cells are thought to secrete cuticulin layer of epicuticle and in cockroach, surface grease which covers the integument is believed to be involved in excretion.

Urate cells:
Some of the *fat body cells which store urea or uric acid* in the form of granules are known as urate cells. Preserved uric acid can be utilized subsequently. These are present in insects' lack of Malpighian tubules. In cockroach, the waste material in the

form of uric acid is stored throughout its life in the fat bodies without any harmful effects. This phenomenon of storage of urea / uric acid in fat body cells is called *Storage Excretion*, which is useful for supply of Nitrogen, when insect feeds on nitrogen deficient food.

Chloride Cells:

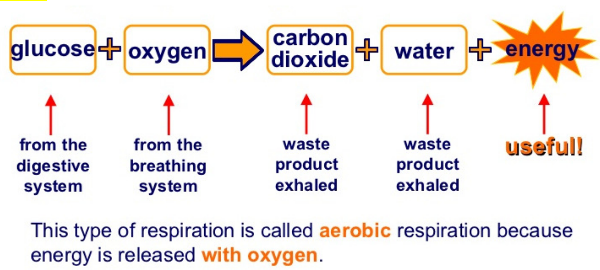
The cells are distributed on the body of *aquatic insects* such as larva of mayfly or stonefly. These cells *absorb ions from salt water* (body) and then excrete into the surrounding medium to compensate the changes in the ionic concentrations of haemolymph.

LECTURE: 16

RESPIRATORY SYSTEM

Tracheal system – Structure of spiracle and trachea
Classification based on functional spiracles and other means of respiration

All insects are aerobic organisms, and they must obtain oxygen (O_2) from their environment in order to survive. All body cells engage in cellular respiration. They use oxygen and glucose, and convert them to ATP (adenosine triphosphate), or cellular energy, and carbon dioxide. Insects 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. In Humans the oxygen is taken through nostrils, which is purified by lungs, and from where the oxygen is transported to all cells through blood, as the blood containing haemoglobin. Insect blood (haemolymph) is not the carrier of gas (oxygen, CO_2), and gases are transported directly from environment to cells (direct respiration) through system of tubes i.e. tracheal system containing trachea and tracheoles.

TRACHEAL SYSTEM

The tracheal system in insects is a *complex network of tubes* distributed throughout the body, which delivers oxygen-containing air to every cell of the body. The tracheal system is one of the characteristic physiological features of insects, and is a *light-weight respiratory system which allows insects to achieve the highest mass-specific metabolic rates*. *Most collembola have no tracheae at all*. Thus *oxygen is carried directly to its sites of utilization.*

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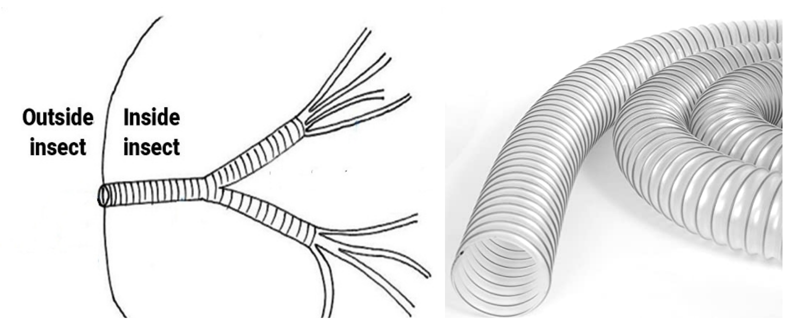
TRACHEA & TRACHEOLES

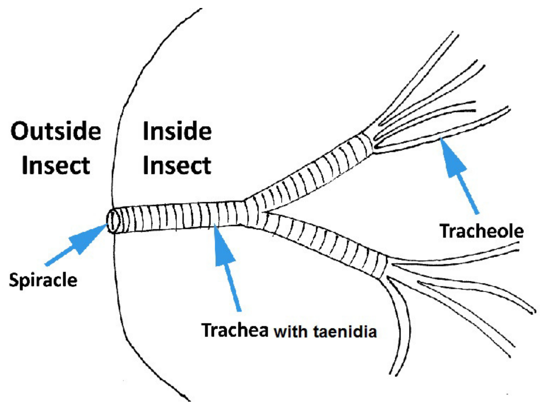
The tracheal tube develops as an *invagination of the ectoderm* during embryonic development. The structure consists of *cuticle, epidermis, basement membrane* just like body wall structure, but arranged in reverse manner i.e. basement membrane forms the outermost layer and *inner cuticular linings* forms the intima inside. The cuticular lining (intima) *appear as a spiral thickening* throughout the length of the tracheal tube, called as '*taenidia*'. 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. This means giving *support to treachea without being collapsed when there is no air*. This consists of chitin, resilin in protein-chitin matrix. The trachea gives a *silvery appearance* when filled with air. The trachea is elastic.

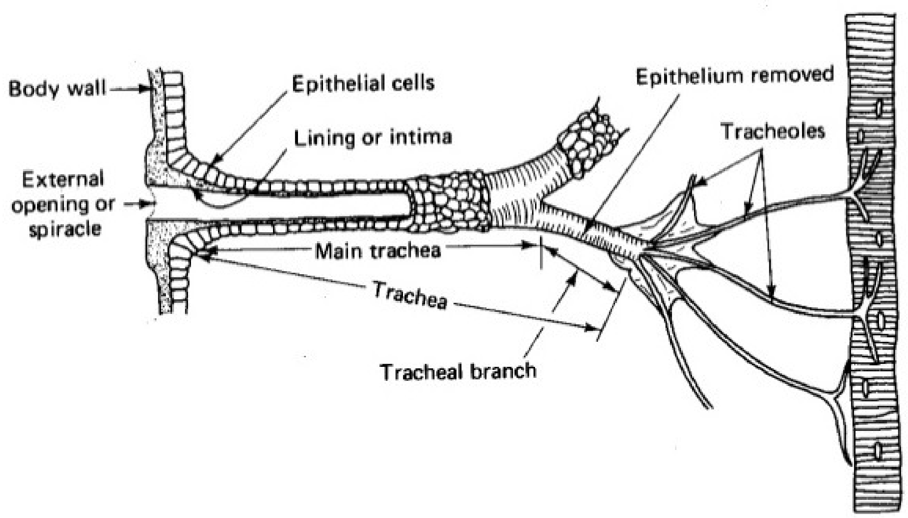


The *absence of taenidia in certain parts of the tracheal system allows the formation of collapsible air sacs, balloon-like structures that may store a reserve of air*. In dry terrestrial environments, this temporary air supply allows an insect *to conserve water* by closing its spiracles during periods of high evaporative stress. Aquatic insects consume the stored air while under water or use it to regulate buoyancy.

The tracheae are open to the outside (in the exoskeleton) through segmental pores, the *spiracles*, which generally *have some closing mechanism* (valve like) which permit minimum water loss. The *spiracles are located laterally* (Pleural surfaces) along thorax and abdomen of most insects; usually one in each side of the segment. The air enters into body through these spiracles. 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.

The trachea is usually breaking into very fine branches called *tracheoles*, which ramify through the organs of entire body and appendages, supplying oxygen to body tissues. Tracheoles form a network over the visceral organs including the alimentary canal as well as gonads (overies, testis) and penetrate into tissues of these organs, and become intra-cellular and supply oxygen directly to the tissues and cells. These tracheoles are formed into cells called *tracheoblast* or tracheloar end cell, which are derived from epidermal cells of trachea. *These cells provide a thin, moist interface for the exchange of gasses between atmospheric air and a living cell.*





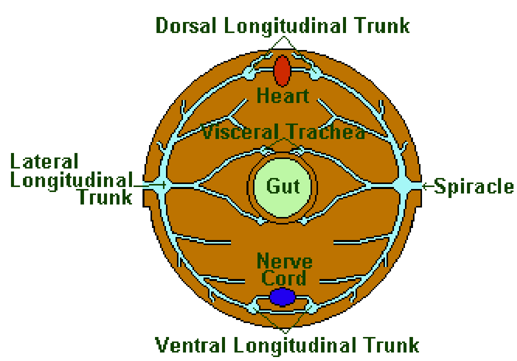
Structure of Trachea

DIFFERENCES BETWEEN TRACHEA AND TRACHEOLES	
Trachea	Tracheoles
Large tubes running from spiracles, opening outside body of insect	Fine tubes arising from trachea, and ending on tissues
Never become intra-cellular	Intra-cellular
Taenidia present	Taenidia absent
Intima layer is shed during moulting	Intima layer is retained, unchanged during moutling
Intima layer consists of protein-chitin matrix with resilin protein	Resilin absent

Tracheal trunks:

In most insects the tracheae from spiracles throughout body are all linked through a series of longitudinal pipes called *tracheal trunks* and many smaller connections. Similarly, all the tracheal trunks (dorsal, ventral and lateral trunks) are also connected through transverse commisures and longitudinal commisures. The *dorsal longitudinal trunk* is at near the top of the insect's body; *lateral longitudinal trunk* is running along the side's just in from the spiracles; and *ventral longitudinal trunk* running along the belly of the insect. Transverse, dorsal or ventral commissures connect the systems of each side.

The dorsal longitudinal trunk through branches and tracheoles supplies oxygen to proximal part of the body, heart and dorsal muscles. The head and mouth parts are supplied with branches derived from anterior spiracle (spiracle I) and dorsal longitudinal trunks. The ventral longitudinal trunk supply oxygen to the central nervous system, and the two lateral longitudinal trunks supply oxygen to alimentary canal, legs, gonads and wings.



Spiracles:

The spiracles are the *external openings* of the tracheal system. They are *positioned laterally*, usually on the pleura. Generally *10 pairs of spiracles* are seen (two pairs in thorax and eight pairs in abdomen). Except in Diplura, in all orders, spiracls are absent in pro-thorax and distributed in meso- and meta-thorax. The air generally enters the trachea through spiracles, through *gaseous exchange process* but is also a major site of water loss. Sometimes the spiracles are closed or absent, and respiration in such cases is cutaneous.

The spiracles consist of a *small ring like sclerite* at opening called '*peritreme*' leading to cavity known as '*atrium*'. The closing and opening of spiracles is aided by atrial valves, and form so called *filter chamber*, which reduces water loss in the absence of

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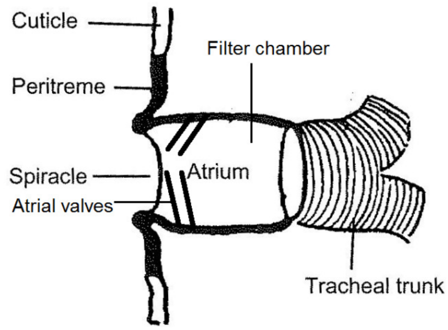
closing mechanism. In some insects (dipterans, coleopterans, lepidopterans), spiracles consists of *sieve plate* containing large number of small apertures through which gas exchange takes place. This modification is present to prevent entry of water, especially in aquatic insects.



In most of the terrestrial insects, water loss through spiracles is controlled by the closing mechanism which consists of one or two valves or constriction of trachea through muscular activity. The *hydrophobic nature of spiracles* is also due to the presence of *modified epidermal glands known as peristigmatic glands which secrete a hydrophobic materials preventing wetting of these organs*.

Air movement and supply:

As the head do not contain spiracles, air is supplied through the first pair of spircales by means of two branches of the dorsal longitudinal trunk, where one branch supply O_2 to eyes, antenna, brain, and other branch supply air to mouth parts and muscles of the head.

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.

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. 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.

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*. Small insects rely almost exclusively on *passive diffusion* and physical activity for the movement of gasses within the tracheal system.

In large, active insects, *diffusion alone doesnot bring the sufficient oxygen to the tissues to meet their requirements*. It is supplemented through active *ventilation* of the tracheal system (changes in volume of the tracheal system) especially when active or under heat stress. This is accomplished by opening some spiracles and closing others while using abdominal muscles to alternately expand and contract body volume.

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.

CLASSIFICATION OF TRACHEAL SYSTEM BASED ON NUMBER AND ARRANGEMENT OF FUNCTIONAL SPIRACLES:

The largest number of spiracles found in insects is ten pairs, two thoracic and eight abdominal. Except in Diplura, in all orders, spiracls are absent in pro-thorax and distributed in meso- and meta-thorax. In numerous insects, the first spiracle is on the pro-thorax region, but is meso-thoracic in origin. 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 :** These are primitive type, with 10 pairs of functional spiracles (1+1+8)	1 mesothoracic, 1 metathoracic, 8 abdomenal (1-8 abdomenal segments)	Dragon flies Grasshoppers Cockroaches
	Peripneustic : 9 functional spiracles (1+0+8) Meta-thoracic spiracles are closed.	1 mesothoracic, 8 abdomenal	Larvae of Neuroptera Lepidoptera Hymenoptera Coleoptera
	Hemipneustic : 8 functional spiracles (1+0+7) Meta-thoracic and one abdominal spiracles are closed	1 mesothoracic, 7 abdomenal	Mycetophilid larvae

OLIGOPNEUSTIC: *1 or 2 functional spiracles on each side*	**Amphipneustic** : 2 functional spiracles (1+0+1)	1 mesothoracic, 1 post-abdomenal	Larva of cyclorrhaphan diptera. Psychodid larvae
	Metapneustic : 1 functional spiracle (0+0+1)	1 post-abdomenal	Larvae of culicidae (Mosquito) and tipulidae
	Propneustic : 1 functional spiracle (1+0+0)	1 mesothoracic	Dipteran (Mosquito) pupae
APNEUSTIC *No functional spiracles*	Apneustic does not imply 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. These non-functional spiracles open at ecdysis and permit the cast intima to be shed.		Aquatic insects (Numph of Odonata-Dragon flies, and Mayfly larva) and endoparasites Chironomid larvae
HYPOPNEUSTIC *Some spiracles disapeared*	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*.		Mallophaga, Siphunculata.
HYPERPNUESTIC	More than 10 pairs of spircles present		Japyx spp (Dipluran)

OTHER MEANS OF RESPIRATION IN INSECTS

1. ***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 i.e. body wall.* 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.*

2. ***Gills or Branchial Respiration:***
   a) ***Tracheal gills:*** These are present in majority of *aquatic larvae*, and gills are *usually borne on the abdomen*, and hence also called as *abdominal gills*. These *are filiform or lamellate shape out growths of trachea*, located on lateral side of the body. These gills are well supplied with tracheae

and tracheoles. The gaseous exchange takes place through these structures, and in many cases these are only organs of respiration but in others these are accessory in function and co-exist with open spiracles. Examples: Larva of Trichoptera, Numphs of Ephemeroptera.

b) ***Spiracular gills:*** These occur in *pupae of some beetles and dipteran families, living in water bodies (aquatic).* 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*.

c) ***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, *present at the anal end of body* ranging from 4-6 in larae of trichoptera, while 2 pairs are present in penultimate segment in chironomid larva. These derive their name from the fact that these *contain blood*. Insects with this kind of gills, may not have tracheae, but tracheoles may be present occassionally. These structures *help in the absorption of water and inorganic ions rather than respiration*.

d) ***Rectal gills:*** The *rectum modify into barrel like chamber* where rectal wall forms into basal thick pads and distal gill filaments supplied with tracheoles. These gills help in respiration. Eg: Nymphs (Naids) of Dragonfly.

3. ***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.

4. ***Air sacks***: The *trachea gets dilated at some points to form thin wall air sacks which do not contain the taenidia*. These look like glistering sac like structures, function as storage structures of air which change their volume with respiratory movement.

LECTURE: 17

NERVOUS SYSTEM

Neuron and its types (based on structure and function)
Synapse, ganglia, central nervous system, sympathetic nervous system and peripheral nervous system

The nervous system is a *conducting system* ensuring rapid functioning and co-ordination of effectors (muscles, glands etc.), modifying their responses according to the input from sense organs. The nervous system *coordinates the reception, integration and modification of the stimuli, and sending output in the form of behavioural reaction / response in response to the information received*. The received information, frequently referred to as *stimulus*, may be chemical (gustatory or olfactory), light, pressure, heat, magnetism, etc. The stimulus is received through sense organs which include various sensilla that respond to different kinds of stimuli. The information received and transmitted is in the form of chemical or electrical signals. Hence, we can simply say this system is a *link between sense organs and effector organs* (muscles, glands etc.).

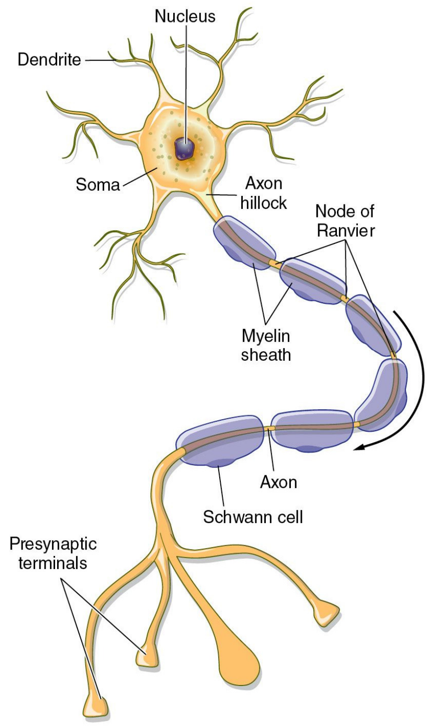
The insect nervous system primarily can be divided into

1. *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.
2. Visceral (or) Stomatogastric (stomodaeal) (or) Sympathetic nervous system: *Stomatogastric (Stomadaeal) nervous system* containing number of small ganglia connected to the brain and their associated nerves controls the movements of alimentary canal.
3. Peripheral Nervous System

THE NERVE CELL - NEURON

The *basic elements in the nervous system are nerve cells (neurons) and glial cells*. The neurons are produced into long processes, or axons, along which the nerve impulses are conducted. Conduction along a nerve axon is an *electrochemical process*. The *bodies of the nerve cells are aggregated to form ganglia* while *bundles of axons form nerves*.

A nerve cell consists of a *cell body (soma or perikaryon)* containing the nucleus and the *long cytoplasmic projections (axons)* which extend to make contact with other neurons. Frequently, the *axon has cytoplasmic projections (or) branches, collaterals*, and ends in terminal arborisation.



Besides the large nucleus, nerve cell body has

(i) rough endoplasmic reticulum (RER),
(ii) Golgi complexes
(iii) lysosomes
(iv) multi vesicular bodies and
(v) mitochondria

Axons lack Golgi but contain some mitochondria and neurotubules that transfer materials from the perikaryon to the axon terminal.

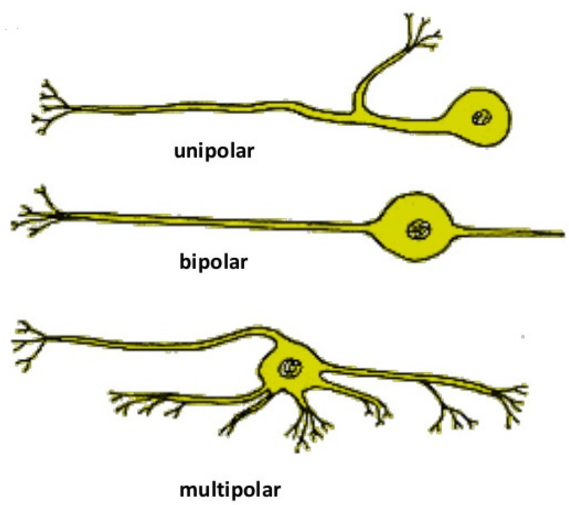
Each neurone is almost wholly invested by one or more *glial cells (Schwann cells),* which form an *insulating protective sheath around it*. These cells *serve to insulate axons* from each other and *synapse occurs where glial folds are absent*. The glial cells *pass nutrient materials to neurone*; this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

The *neurons do not occur singly*, and the cell bodies of interneurons and motor neurons are aggregated to form nerve centers called '*ganglia*'.

TYPES OF NEURONS:

Based on number of Projections / structure:

1. Most insect neurons are *monopolar or unipolar in insects*. The cell body having only a *single short projection* i.e *neurite*, which subsequently may ramify into branches (axonal arbor, dendrites). The cell bodies of these neurons are located on the periphery of the ganglion and are electrically inactive.

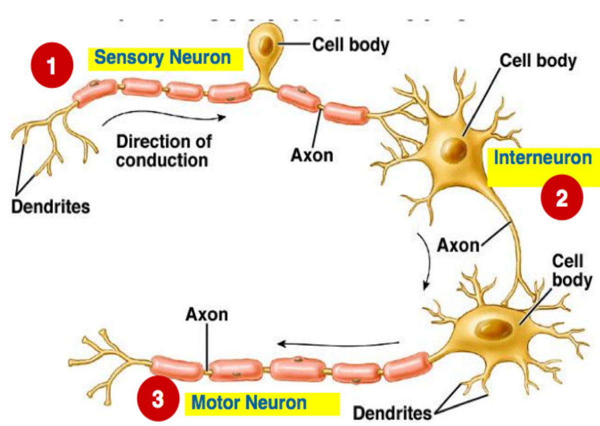


2. *Bipolar:* Bipolar neuron has *one dendrite and one axon extending from Soma*. The *peripheral sensory cells are bipolar* with short distal dendrite receiving stimuli from environment and a proximal axon extending to the central ganglia (passing CNS without synapse).
3. *Multipolar neurons*: Multipolar neuron has *one axon and multiple dendrites*. Some *multipolar cells* occur in hypocerebral and frontal ganglia, are associated with *stretch receptors (mechano receptors – organs and muscles).*

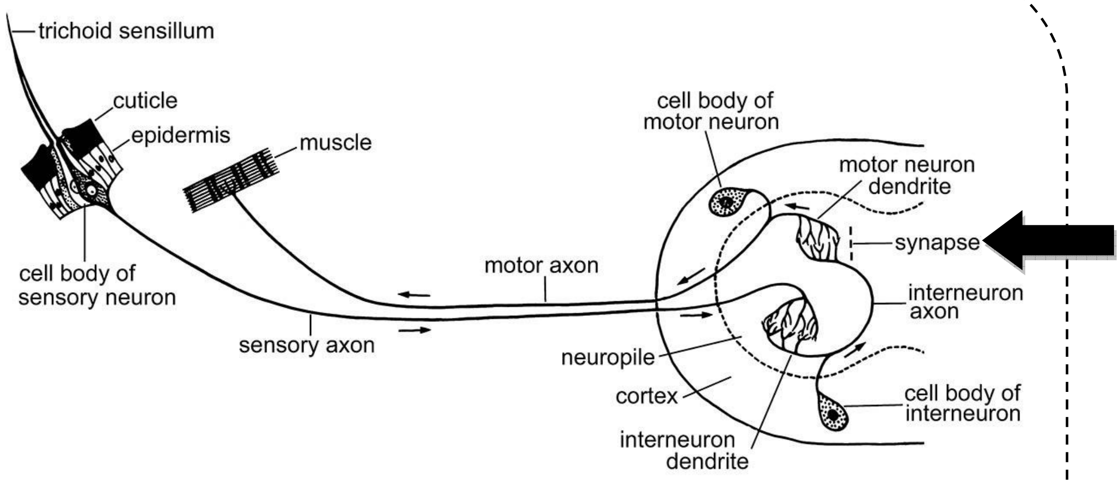
Based on function:

The neurons are classified into three kinds based on the function viz., afferent (sensory) neurons, efferent (motor) neurons, and internuntial / associate neurons.

1. ***Afferent neuron***: These are also called as ***sensory neurons*** (or) ***receptor neurons***. They present just beneath the integument and associate with sense organs. Dendrite process of these neurons extends to cuticle, communicate with specialized interneurons. These neurons carry nerve impulses from sensory organs or receptors to Central Nervous System.
2. ***Association / internuntial neuron***: Associated in between sensory and motor neurons, most commonly present in ganglia consists of axons of sensory neurons and soma of motor neurons. The best known of these are in the brain, in the optic lobes and corpora pedunculata.
3. ***Efferent neuron***: These are also called as ***motor*** neurons. Always monopolar / unipolar carrying nerve impulses from CNS to effectors such as muscles or glands. They are involved in muscular control, and axons of these neurons forms neuro-muscular junctions with effectors.



The neurons get connected with each other by having a link between dendrites of the soma of one neuron with terminal arborizations of the axon of another neuron, through a *synapse*. The dendrite is specialized for reception of stimuli which initiates conduction in the axon. The *neuronal junction* at which the message from one neuron is transferred to another neuron is called as synapse, which is a physical gap between two neuronal connections, is approximately 100^{0}A. The Synapse can be the site of transmission of impulses between two nerve cells (neurons) or between a neuron and a gland or muscle cell (effector). A synaptic connection between a neuron and a muscle cell is called a *neuromuscular* junction. Neurotransmitters are released from one neuron and get attached to another neuron for transferring the impulse / message from one to another neuron. *Acetyl Choline* is an important neuro-transmitter.



Neuro-Transmitters

Acetylcholine (Ach)		Excitatory	Neuro-Neural
Biogenic Amines	Dopamine	Excitatory / Inhibitory	CNS
	Serotonin	Generally Inhibotory	CNS
	Norepinephrine	Excitatory / Inhibitory	CNS
Amino Acids	GABA	Inhibitory	Neuro-Neural
	L-Glutamate	Excitatory	Neuro-Muscular

THE INSECT NERVOUS SYSTEM CAN BE DIVIDED PRIMARILY INTO

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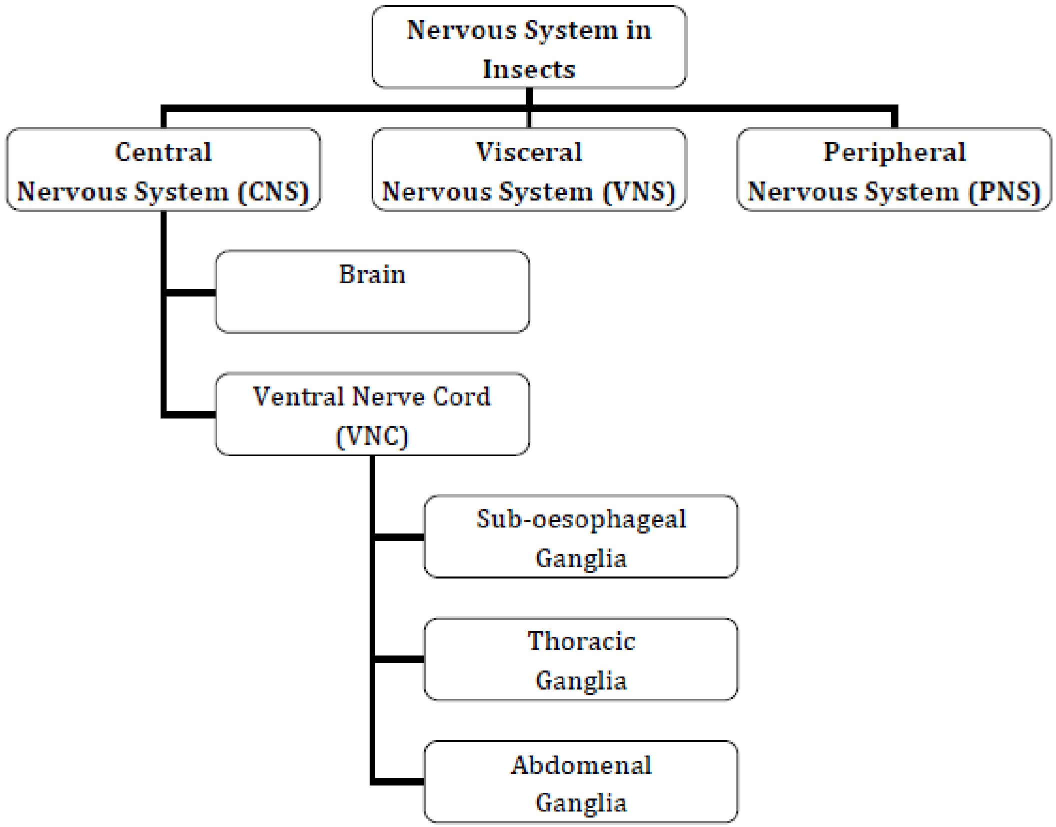
3. ***Peripheral Nervous System***



CENTRAL NERVOUS SYSTEM (CNS)

The CNS in mammals comprises of brain and spinal cord, while in insects, Central nerous system comprises *brain and ventral nerve cord (VNC)*, which consists of a chain of *segmentally arranged ganglia* joined together by paired interganglionic connectives. *Aggregation of neurons is called ganglia*. The perikarya of internuerons and motor neurons are aggregated to fom ganglia. Embriologically there are 20 ganglia (*3 in the brain, 3 sub-oesophageal, 3 thoracic and 11 abdominal*) in insect. The *most anterior ganglion is the brain or cerebral ganglion lying dorsal to the oesophagus in the head*. The ventral nerve cord (VNC) consists of a chain of ganglia *viz.*, *the sub-oesophageal, thoracic and abdominal ganglia*.

BRAIN:

The brain is the *principal association centre* of the body, *receiving sensory input from all sensory organs of the head*. It is a *fusion of three pairs of ganglia* of first 3 segments, each supplying nerves for specific functions. Insect brain is divided into protocerebrum, deutocerebrum and tritocerebrum.

Protocerebrum:

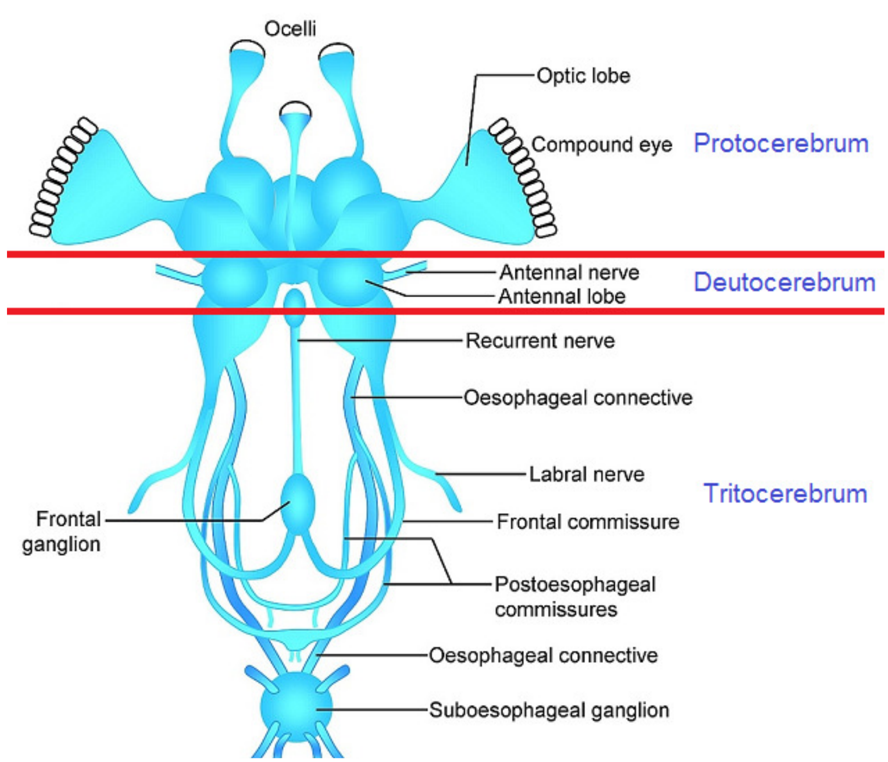
It is formed by union of the *ganglia of pre-antennary segment* and forms greater part of the brain. It connects to the *compound eyes and the ocelli* and *controls vision*.

Duetocerebrum:

It is formed from *ganglia of antennary segment* and innervates the *antennae*. Deutocerebrum has *antennal lobes*, the dorsal parts have sensory and the ventral have motor nerves.

Tritocerebrum:

It is formed by the union of the ganglia of the third segment, and is relatively small. It 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.

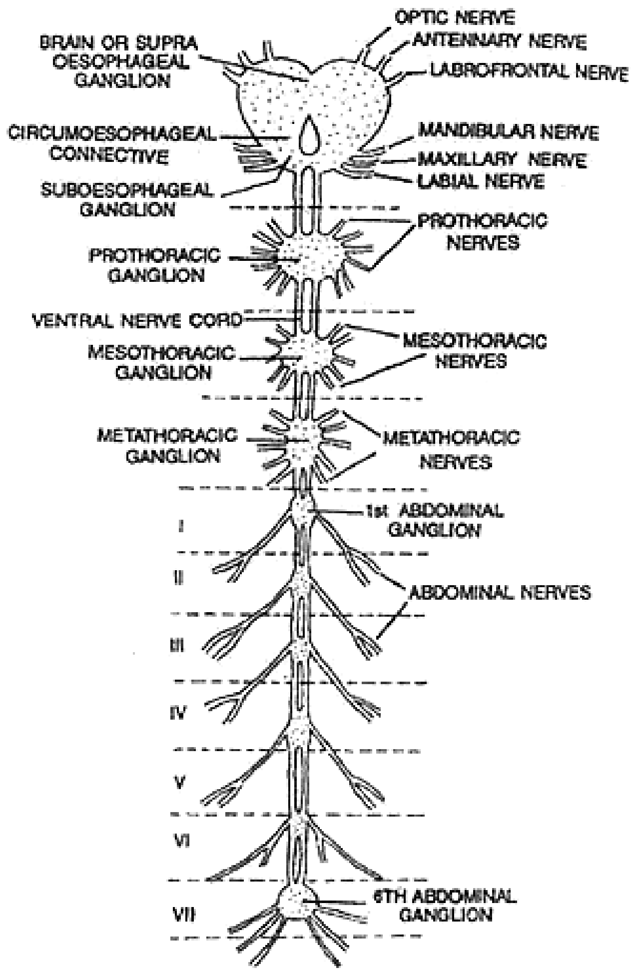


VENTRAL NERVE CORD (VNC):

The ventral nerve cord consists of a chain of ganglia *viz.*, *the sub-oesophageal, thoracic and abdominal ganglia* connected by means of longitudinal connectives and transverse commissures.

Sub-oesopghageal ganglia:

Below the brain, *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. Nerves from this ganglion control most of the *mouthparts, the salivary glands, neck muscles and corpora allata*.



Thoracic ganglia:

Typically, an insect have *three thoracic ganglia*, innervating muscles and sensilla of the thorax and its appendages (legs, wings and muscles). *Musca (House fly)*, *Syrphys* and *Tabanus* etc., have only one thoracic ganglion, *Melolantha*, *Apis*, *Culex* etc., have two thoracic ganglia.

Abdominal 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 composite ganglion. The degree of fusion varies from species to species. In *Musca* all the ventral ganglia are fused to form a single mass. The *abdominal ganglia are smaller* than those of thorax; in general, fewer peripheral nerves arise from each of them than arise from the thoracic ganglia. The abdominal ganglia give off nerves to muscles of its segments, and the last ganglia passes nerves to anal cerci and ovipositor.

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.

a. The *stomatogastric nervous system (oesophageal sympathetic nervous system-autonomus system)* consists of a number of small ganglia and their associated nerves. It is directly connected to brain which supplies nerves for the *anterior part of the alimentary canal (foregut, midgut), heart and certain other parts*.
b. The *ventral visceral nervous system* is in close contact with the ventral nerve cord and consists of unpaired ventral longitudinal nerves that are connected to each ganglia of VNC. They innervate the *tracheal system, muscles of spiracles and some somatic muscles*.
c. The *caudal visceral nervous* system arises from the compound abdominal ganglion and innervates the *reproductive system and hind gut*.

PERIPHERAL NERVOUS SYSTEM

It includes all nerves coming from the ganglia of CNS and that of visceral nervous system.

LECTURE: 18

REPRODUCTIVE SYSTEM

Structure of male and female reproductive systems
Structure and types of ovarioles and structure of follicle – Types
Special modes 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 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.

MALE REPRODUCTIVE ORGANS

Internal Genitalia: The male reproductive *internal genitalia* typically consist of

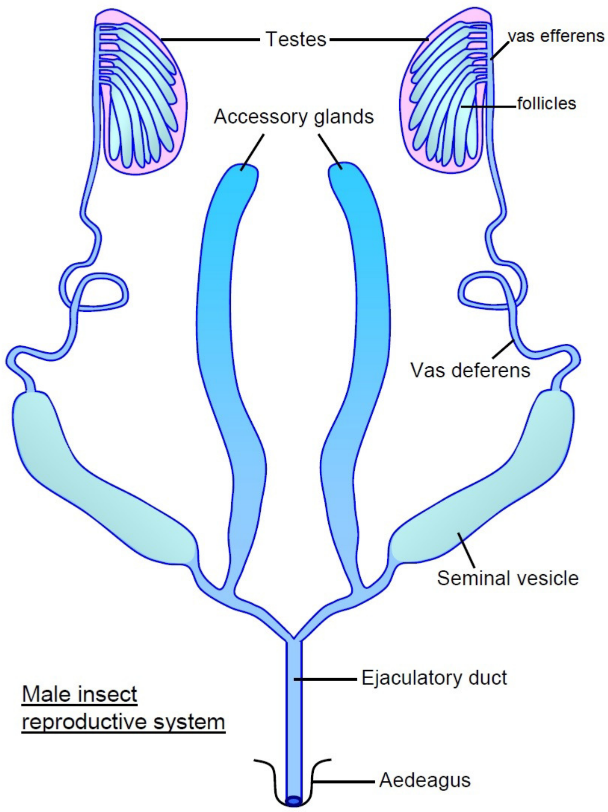
a. *a pair of testis* connecting with
b. *vasa differentia,* and a
c. *median ejaculatory duct*.
d. In most insects there are also a number of *accessory glands* which open into the vasa deferentia or the ejaculatory duct.

External Genitalia: The male reproductive *external genitalia* typically consist of

a. aedeagus
b. Clasping structures (in some)

Testis:

The testis lies in visceral cavity, above or below the gut in the abdomen and often close to the midline. The testes are connected to the body wall through translucent ducts, and well supplied with trachea and fat body tissues. Usually each testis consists of a number of oval shaped *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. The size of the testis is of same size of ovaries in apterygota, and very much smaller in pterygota.



Vas deferens

The testes discharge spermatozoa into the lateral ducts i.e, *vas deferens* which is *paired canals* (partly or wholly mesodermal in orgin). From each testis follicle, a fine, short, *vas efferens* connects with the vas deferens, 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 unite posteriorly to form a *common ejaculatory duct*. The terminal section of ejaculatory duct is enclosed in a finger like evagination of body wall (ectodermal in origin lined with cuticle, with part of the wall is muscular), i.e *aedeagus or penis or male copulatory organ.* Ephemeroptera have no ejaculatory duct and vasa deferentia lead directly to the paired genital openings.

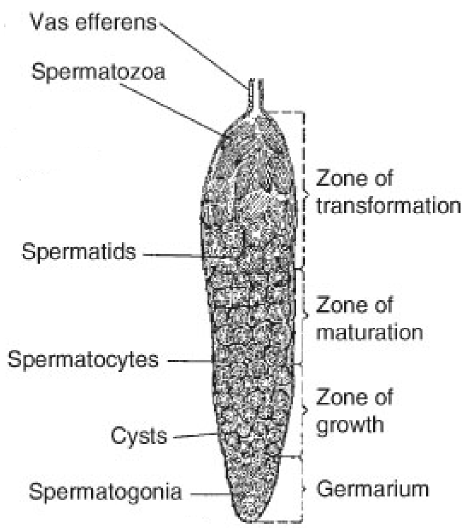
Accessory glands

One to three pairs of accessory glands are usually present, and open into ejaculatory ducts. These are called *mushroom glands* in cockroach and mantids because of their shape. In most cases, their secretion mix with spermatozoa. A primary function of these secretions is to facilitate

- *spermatophore formation,*
- *sperm maintenance and activation,*
- *sperm nourishment and*
- *sperm transfer from male to female*.

In some cases, the secretions may have some nutritional value for the female or they may accelerate oocyte maturation. In most insects, the secretory activity of male accessory glands (MAGs) is regulated by JH (Juvenile Hormone), which specifically controls the production of proteins in secretion. However, the production of some proteins appers not to be influenced by JH, but their synthesis is regulated by Ecdysteroids. During sexual maturation, JH and Ecdysteroids seem to interact to bring about a specified temporal sequence of protein synthesis in the MAGs.

Structure of follicle and Spermatogensis



Each testis is composed of a group of *testicular follicles*. The testicular follicles are *lined with a layer of epithelium*. Each testicular follicle leads into a small duct the *vas efferens* which in turn opens into *vas deferens.*

Each follicle is *divided into a series of zones* characterized by the presence of sex cells in different stages of development.

At the distal end of each follicle is the *germarium*, is the region (also called as zone of spermatogonia) 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* (also called as zone of spermatocytes) is where the spermatogonia increase in size, undergo repeated mitosis and develop into spermatocytes. The *zone of division / maturation* is where the spermatocytes undergo meiosis and give a rise to spermatids. The *zone of transformation* (also called as zone of spermatids) is where the spermatid becomes transformed into spermatozoa.

External Genitalia:

The primary function of the male genitalia in insects is insemination of the female. Process of achieving insemination include *clasping and holding the female*, retaining the connection with the female gonopore, the construction of spermatophores, and the deposition of spermatophores or semen into the female genital tract; in some insects the injection of semen takes place directly into the female body (traumatic insemination of some Hemiptera). Other functions of the male genitalia include excretion and various sensory functions. The genitalia of male insects exhibit such an enormous variety of shapes and constituent parts. The male external genitalia are derived from the *ninth abdominal coxites*.

FEMALE REPRODUCTIVE ORGANS:

The female reproductive *internal genitalia* consists of

a. A *pair of ovaries (gonads)*, which connects to
b. A *pair of lateral oviducts (gonoducts)*. These join to form
c. A *median oviduct (oviduct common)* opening posterior into
d. *Genital chamber*
e. *Spermatheca* (*recepteculum semin*) for storage of sperm.
f. *a pair of accessory glands*.

The female reproductive *external genitalia* consists of

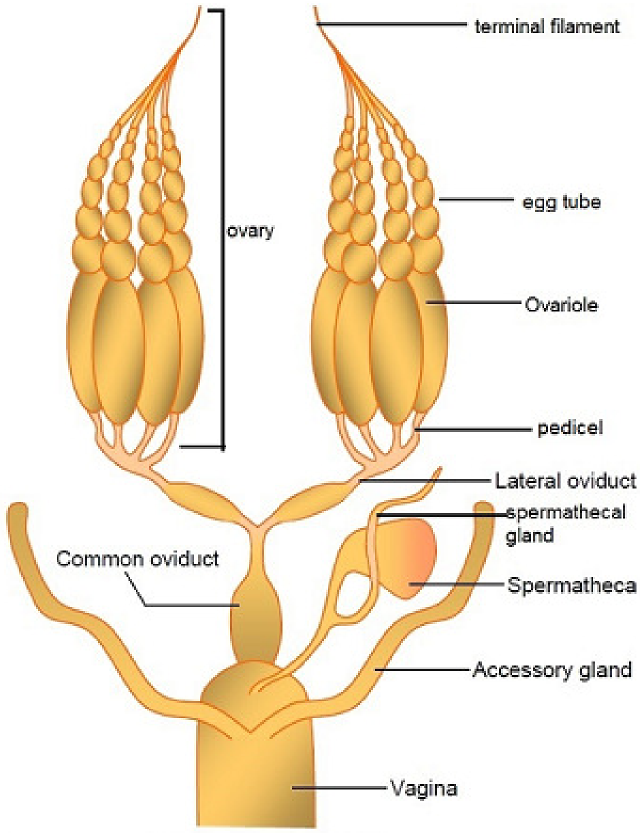
a. Sometimes, genital chamber forms a tube*, the vagina* (opens behind the 8^{th} or 9^{th} abdominal sternum), and this is often developed to form
b. *a bursa copulatrix* (*copulatory pouch*) for reception of the penis.

Ovary

The ovaries lie in the abdomen above or lateral (either side) to the gut. Each ovary consists of a number of *egg-tubes, or ovaries*, comparable with the testis follicles in male. The ovaries get connected with the body wall by means of thread like suspendary ligaments. The development of the oocytes takes place in ovaries. The number of ovaries is roughly constant within species. Usually, 4 to 8. In isopteran they may reach more than 2000.

Ovariole

Each ovariole is enveloped by a double layered cellular wall, and the outer wall is called ovarial sheath which is richly supplied with trachea. 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. This ligament is attached to the body wall or dorsal diaphragm, helps to remain suspended at proper place. Proximally the ovariole narrows to a fine duct, the pedicle, which connects with the oviduct. The eggs are discharged into the lateral oviducts.



Lateral Oviduct

Proximal end of ovarioles of each ovary join to form a lateral oviducts on each side. The oviducts tube walls are with single layer of columnar cells.

Median Oviduct

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 is sac like structure consisting of spermathecal gland and opens into vagina through spermathecal duct. This serves for the *storage of sperm* until the eggs are fertilized. This also produces some fluids responsible for longevity of cells for several hours. 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. These glands *produce a substance for attaching the eggs to the substratum* during the oviposition and hence they are often called as *collateral glands*. In Cockroach, the collateral glands produce an *ootheca* consisting of a tanned, cuticle-like substance. The *frothy secretions which form the eggpods of grasshoppers* and gelatinous sheath of

Chironomous (Diptera) eggs are also produced by accessory glands. These glands produce *poisonous substances* in hymenoptera.

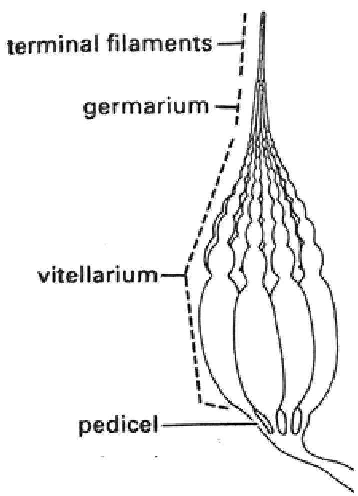
Vagina

In most of the insects' median oviduct doesnot open diretly to outside, and it opens into a tubular chamber or vagina. This is formed by invagination of bodywall from 8th segment. The vagina opens outside and the opening is called vulva. The vulva serves in receiving the sperm and discharge of eggs.

Bursa copulatrix

In some insects, the genital chamber or vagina develops a separate pouch called bursa copulatrix, into which insects have two reproductive openings viz., one is vulva open on 8th segment sternum for receiving sperms, and another one is ovipore or gonopore open on 9th segment for discharging eggs.

Structure of ovariole and Oogenesis:



Each ovariole is enveloped by a *double layered cellular wall,* and the outer wall is called ovarial sheath which is richly supplied with trachea. The inner layer is called tunica propria, which is elastic in nature. 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. This ligament is attached to the body wall or dorsal diaphragm, helps to remain suspended at proper place.

Proximally the ovariole narrows to a fine duct, the pedicle, which connects with the oviduct. The eggs are discharged into the lateral oviducts. 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 forms 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.

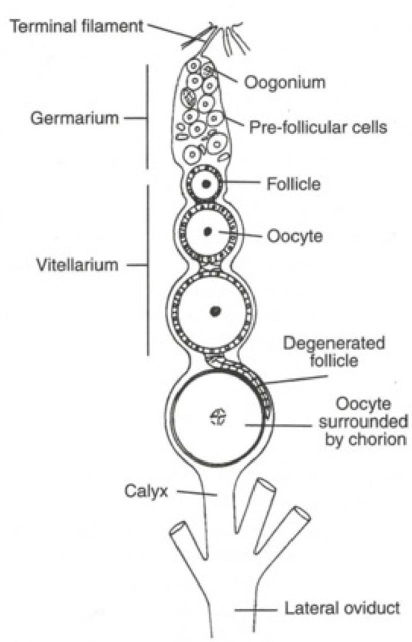
The egg tube is divided into two parts.

a. ***Germarium***: also called as egg chamber, which contain primordial (or) undifferentiated germ cells. These cells are seen in an active stage or division and differentiation giving *3 types of cells*; germ cells developing into oogonia and finally oocytes, nutritive cells or nurse cells or trophocytes, and follicle cells.

b. ***Zone of growth or vitellarium***-The *egg cells grow and attain their mature stage* in this zone, and it consists of longitudinal series of developing egg. It occupies major part of ovariole. As they grow by deposition of yolk, the eggs distend the ovariole. In the anterior region of vitellarium, the nurse cells and oocytes remain mixup and assume central position while follicle cells take peripheral position. *Each egg is enclosed in a layer of follicular epithelium which secrets chorion or egg shell*. The nurse cells absorb nutrients from haemolymph through follicular cells and transmit nutrients (yolk) to oocytes. In some cases, follicle cells provide nutrients where nurse cells absent. The principal function of the trophic tissue of meriostic ovarioles is *to supply yolk and RNA to the oocyte in large quantities* for its subsequent rapid growth.

Vitellogenesis: The deposition of yolk in oocyte is called vitellogenesis which occurs in the more proximal parts of the ovariole resulting in a very rapid increase in size. The yolk (produced by trophocytes / nurse cells) may be *protein-carbohydrate complex yolk* and *lipid yolk*.

The passage of oocytes into oviduct is known as *ovulation*.

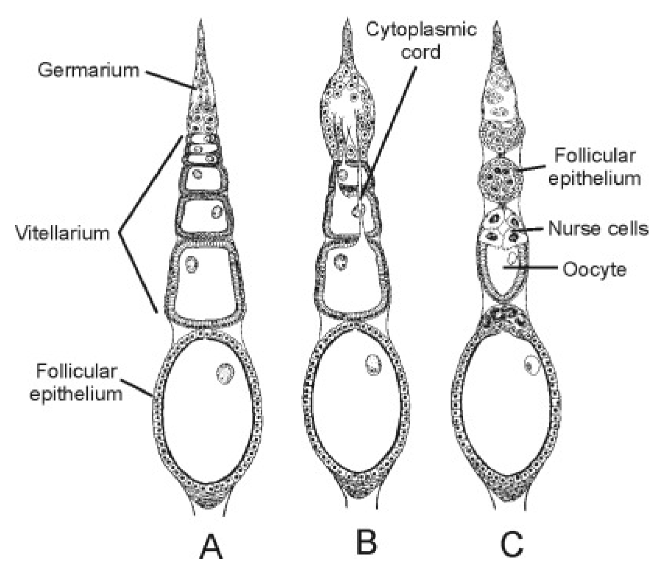


Oocytes arise from oogonium in germarium and descend into vitellarium surrounded by follicular cells. The follicle cells produce chorion around the oocyte and then degenerate

Types of ovarioles:

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

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



A : Panoistic Ovariole – Nurse Cells Absent - nourishment for the oocyte comes only from the follicular epithelia
B : Telotropihc Meriostic Ovariole - Nurse Cells Present, but only at Terminal Part, and hence connects oocyte with cytoplasmic connections
C : Polytrophic Meriostic Ovariole –nurse cells accompany each oocyte within follicle

TYPES OF REPRODUCTION

Insects are bisexual, and they can undergo sexual reproduction for producing either the eggs (or) young ones. However, they also reproduce by other means of reproduction.

1. **Oviparous (female insects that lay eggs, and eggs complete incubation outside) :** Most insects are *oviparous,* i.e, they lay eggs which hatch into young ones after incubation. The *embryonic development starts after the eggs are laid*, and immature emerges after completion of incubation period. All the nourishment for the embryonic development is met by yolk present in the egg. The female may lay eggs singly or in groups. Eg: moths and butterflies.

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

2. **Viviparity: (development of embryo inside the body og the parent - female insects retain eggs inside and give birth to young ones).** The *fertilized eggs 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. Viviparous species commonly produce fewer off springs than oviparous, as these insects may have reduced number of ovarioles.

   There are four main types of viviparity.

   a) ***Ovoviviparity*****:** Insects retain the eggs in the genital tracts until the larvae are ready to hatch, giving birth to young ones. The *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. Examples: Mainly Diptera (Tachnidae), Dictyoptera (cockroaches), Homoptera, Thysanoptera, Coleoptera, Lepidoptera.

   b) ***Pseudoplacental viviparity:*** 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. Examples: 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 (internal parasitism) 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.

3. **Polyembryony: (eggs with 2 or more embryos):** Sometimes, *an egg instead of giving rise to single larva may produce two or more as the egg may have 2 or more embryos*, and this process being called polyembryony. Examples: Some endoparasitic insects such as *Platygaster* of Hymenoptera and Ichneumonidae insects which parasite the eggs and larva of Lepidoptera.

4. Parthenogenesis: (eggs without fertilization): Sometimes, *eggs develop without being fertilized* and this phenomenon is known as parthenogenesis. These females have ability to reproduce without fertilization (or) copulation with males. This occurs due to the genetic character, heredity, failure in finding male, hormonal changes within the body or environmental factors. Generally, parthenogenesis is commonly seen in hemi-metabolous insects (dragonfly, grasshoppers, locusts, stick insects, mantids, aphids, coccids, thrips etc) and in holo-metabola, coleopteran (beetles), hymenopterans (bees, wasps, ants), diptera (flies) follow parthenogenesis.

Types of Parthenogenesis based on occurance:

a. *Constant (obligatory) parthenogenesis*: occurs regularly. Eg: thrips, stick insect
b. *Occasional (facultative) parthenogenesis*; when a female individual can reproduce via both sexual and asexual reproduction. resulting from the failure of a female to find a mate, is probably widespread, while in others, normal means of parthenogenesis is regular. Eg: silkworm, bees
c. *Cyclic (sporadic) parthenogenesis*: It is nothing but alteration of sexual reproduction with parthenogenesis. Eg: Aphids

Parthenogenesis has been recorded in almost all insect orders except odonata, dermaptera, neuropteran and siphonoptera.

Types of Parthenogenesis based on sex of the off-spring:

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:

a. *Arrhenotoky: Only males are produced* (scale insect *Icerya purchasi,* onion thrips *Thrips tabaci,* bee)
b. *Thelytoky: Only females are produced* (eg. Unmated males of *Schistocerca*, and *Bombyx mori, aphids*)
c. *Amphitoky: Individuals of either sex may be produced* (eg: hymenopterans)

5. **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 alternation of generations with several parthenogenetic generations occurring during the summer, and sexual reproduction in winter.
6. **Paedogenesis:** Sometimes *immature insects mature precociously and are able to reproduce*, and 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.
7. **Hermaphroditism**: It is a type of reproduction where both male and female gonads present in the same individual. It may be functional (eg: *Icerya purchasi*) or non-functional (stone fly, *Perla marginata*).
8. **Castration**: It is a type of reproduction where the separation of the individuals occurs mainly due to the development of the reproductive organs. The insects with well developed ovaries develop into females (queens), insects with well developed testis develop in to males (drones), and insects with under developed ovaries develop into workers. Eg: Social insects such as Honey bees.

LECTURE: 19

SECRETORY (ENDOCRINE) SYSTEM

Structure and functions of neurosecretory organs (neuro secretory cells of brain, corpora cardiaca, corpora allata, prothoracic glands and ring gland).

The *endocrine organs* (neuro secretary cells and glands) and *hormones* (juvenile hormone, moulting hormone) 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.

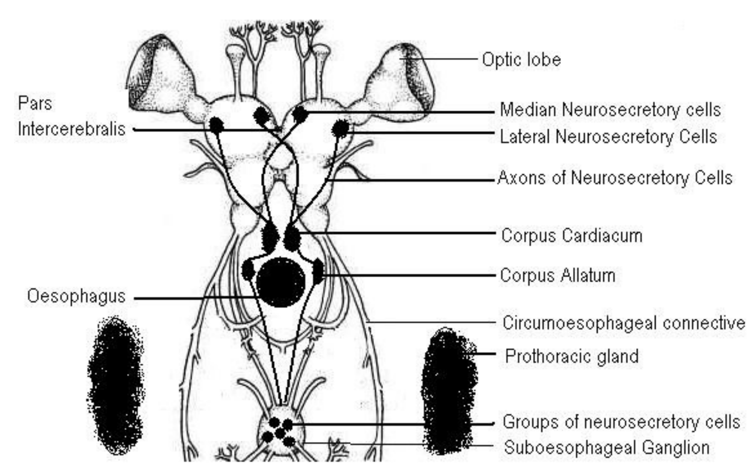
Functions of Endocrine Glands and Secretions:

1. Homeostatis
2. Regulation of Moulting, growth and development
3. Determination of form at Metamorphosis
4. Polymorphism
5. Regulation of Diapause
6. Involvement in Reproduction
7. Regulation of Metabolic activities and general body functions
8. Regulation and coordination of behavious
9. Regulation of programmed cell death

ENDOCRINE ORGANS OF INSECT:

The endocrine organs of insects are of two types; *Secretory cells* mainly Neuro Secretory Cells within the central nervous system and the *specialized endocrine glands* such as corpora cardiac (CC), corpora allata (CA) and prothoracic glands(PTGs). 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.

1) **Neuro Secretory Cells (NSCs):** *The neurosecretary cells are modified motorneurons*, and 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 secretion of NSCs is granular, synthesized in cell bodies and pass down to axons. The neuro secretary 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. The visible secretion of NSCs is sometimes 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.
   a) **Neurosecretory cells of the Brain:** The neurosecretory cells are *found in clusters, both medially (median neuro secretary cells) and laterally (lateral neuro secretary cells) in the insect's brain*. One group of NSCs is in the pars intercerebralis, near the midline, are called *median neurosecretary cells*. The second group of cells (*lateral neurosecretory cells*) is variable in position, but usually between the optic lobe and corpora pedunculata. The axons of NSCs lead out to corpora cardiaca (CC). The products of the neurosecretory cells of the brain (*Brain Hormone*) pass along the axons, usually to the corpora cardiaca or allata. The brain hormone may be stored for some time in Corpora Cardiaca or released. The secretions of the median neurosecretory cells promote the functioning of the prothoracic glands (PTG), stimulate protein synthesis and possibly control water loss, oocyte development and activity.
   b) **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. 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*.



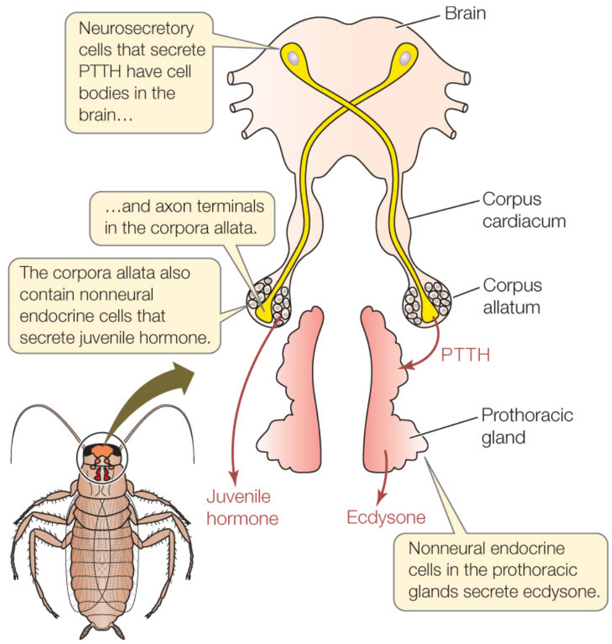
2) Secretary Glands (SGs): In insects, three kinds of glands are commonly present, which produce different types of hormones, and some helps in storing the hormone for some time. The glands that store hormones are called as *neurohemal organs*. In insects, the largest gland is prothoracic gland, which is situated in prothocic region. The other neuro secretary glands are corpora allata and corpora cardiaca.

a) Corpora Cardiaca (CC): 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 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. Corpora Cardiaca also called as *neurohemal organs (storage organ)* as they store brain hormone released from NSCs. In addition, the *intrinsic secretory cells produce hormones which are concerned with the regulation of the heartbeat and have other physiological effects.*

b) Corpora Allata (CA): 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), also called as *Neotenin* under the influence of Brain Hormone. The JH regulates 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. The JH helps to keep the insect in young stage only.

c) ***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 prothoracic glands produce *moulting hormone, called ecdysone*, and the prothoracic glands breakdown soon after the final moult to adult, except in thysanura (which moult as adults) and solitary locusts. *These glands are seen only in immature, not in adults in almost all insects*. 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 enzymes engaged in synthesis of *ecdysone*.

d) ***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 Neuro Secretory cells pass along the axons of these cells. 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* (corpora cardiaca) are involved. For instance, the *corpora cardiac* serve for the storage and release of the brain hormone (released from NSC of brain), and the 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.

Insect Hormones via-a-vis Pest Management:

Compounds based on insect hormones are classified as:

1. Molting hormone analogs (MHAs): Biscylhydrazines (tebufenozide)
2. Anti-molting hormone analogs (AMHAs)
3. Juvenile hormone analogs (JHAs): Fenoxycarb, Pyriproxyfen
4. Anti-juvenile hormone analogs (AJHAs) : Fluomevalonate, Compactin (a fungal metabolite); Imidazoles, ETB – ethyl-4-benzoate; piperonyl butoxide, precocenes)

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LECTURE: 20

SENSE ORGANS

Compound eyes – Structure of ommatidium – Ocelli – Dorsal ocelli and lateral ocelli - Types of images and auditory organs (auditory hairs, tympanum, Jhonston's organ and pilifer organ); Chemoreceptors

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Like humans, Insects are responsive to many stimuli in their surroundings, such as light, heat, touch, chemicals, and vibrations. All insects have sense organs that allow them to see, smell, taste, hear, and touch their environment.

All sense organs (*receptors*) convert light / chemical / mechanical energy from environment into electrical energy of nerve impulses in sensory neurons. These signals travel to the brain or ventral nerve cord, where they stimulate appropriate behavioural responces (finding food or mate, avoiding danger, reacting to changes in the environment).

The sense organs can be classified as

1. Visual organs / visual receptors / photo receptors (organs of vision)
2. Auditory organs (organs of hearing)
3. Chemo receptors (organs of smell)
4. Tactile receptors (organs of touch)
5. Gustatory receptors (organs of taste)

ORGANS OF VISION / VISUAL ORGANS / PHOTO RECEPTORS:
(*Perception to electromagnetic stimuli*):

Light is perceived by insects through a number of different sense organs and these organs 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 bulge out to a greater or lesser extent, so they give a wide field of vision in all directions. These organs possess the ability to perceive light energy and able to produce nerve impulse.

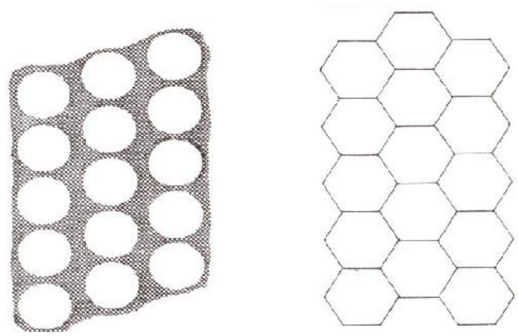
Compound eyes are absent in Protura & Diplura. *Compound eyes are absent in larval forms of holometabolous insects, but have simple* *stemmata* on each sides of the head, and the vision is by ocelli. The *compound eyes are strongly reduced or absent in parasitic groups* such as Hymenoptera, Siphunculata 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 (*dichoptic 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. In tabanid flies, male eyes are holoptic, and female insects have dichoptic eyes (*sexual dimorphism*).

Dichoptic Eyes

Holoptic Eyes

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) will be separated from each other by narrow areas of cuticle; while insects with larger numbers of ommatidia, 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. *The Ommatidia develop embryonically in exopterygotes however post-embryonically in endopterygotes*.

STRUCTURE OF OMMATIDIUM

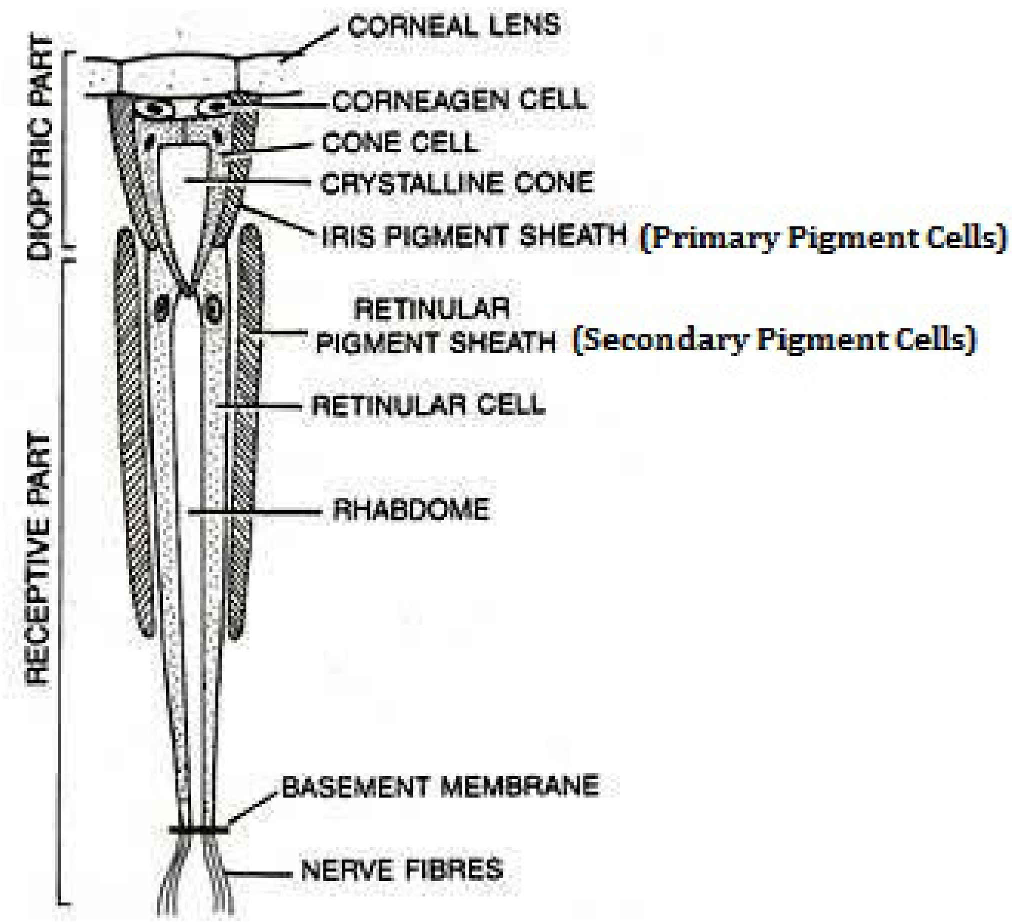
Each ommatidium consists essentially of an

1. **Dioptric apparatus** *(optical, light gathering part)* and a
2. **Sensory part** *(perceive the radiation and transmitting it into electrical energy)*

OPTICAL PART *(dioptric part)* of the system usually consists of two elements, *a cuticular lens (corneal lens)* and a *crystalline cone.*

a. ***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*.

b. ***Crystalline cone:*** Beneath cornea are four cells, which, in most insects, *produce the crystalline cone* (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*, and in some insects for example, Elatridae and Lampyridae, the semper cells do not form the crystalline cone, but they extend to the retinula cells as slender refractile strands, and this is known as *exocone eyes* condition.



c. ***Primary pigment cells (Primary skin cells) (Iris pigment 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.

SENSORY PART, *perceive the radiation and transmitting it into electrical energy.*

a. ***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, which are the *receptive parts of an insect's eye.* 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 called as rhabdomere, which are the actual light detecting part of the cells. All rhabodmeres collectively form a rod like structure referred as rhabdome*. The cytoplasm of the retinula cells contains *pigment granules (contain light absorbing pigment called rhodopsin).* 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.

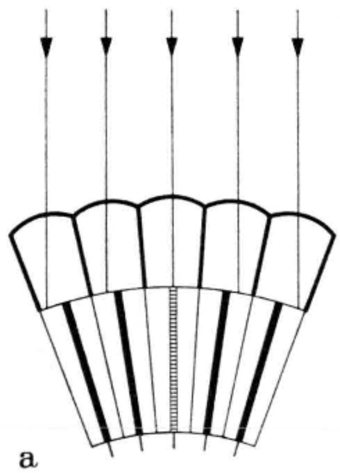
b. ***Secondary pigment cells:*** The retinal cells and associated rhabdoms are supported by '*secondary pigment cells'*. These cells separate ommatodia, surrounding retinular and primary pigment cells. These are numerous in number.

IMAGE FORMATION:

The light perceived by cornea, will be transferred to crystalline cone to retinular cells. The cytoplasm of the retinula cells contains *pigment granules (contain light abosorbing pigment called rhodopsin).* The retinular cells carry the information collected by the lenses and Rhabdom convert the stimuli into electrical impulses and will be passed on to axons at the base of the eye, then to the brain, thus allowing the insect to see.

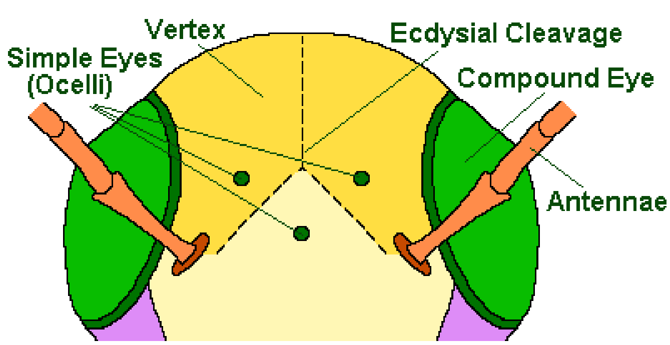
The image formation is generally two types in insects, and hence eyes are termed as Apposition and Superposition Eyes. The following are the differences:

Apposition Eyes (Photopic Eyes)	**Superposition Eyes** (Scotopic Eyes)
The eyes of most *day-active* (diurnal) insects such as bees have apposition eyes, and *adopted for bright light condition.*	The eyes of most *night-active* (Nocturnal and crepuscular) insects are apposition eyes, *adopted for dim light condition*.
The rhabdome reach crystalline cone, and hence there is *no gap between cone and rhabdome*	There is a clear zone (pigment free) between Crystalline cone and Rhabdome, and hence these eyes also called as *clear-zone eyes*
Each ommatidia is optically isolated	Each ommatidia is optically not isolated
The photoreceptors of each ommatidium receive light exclusively from the single facet lens of their own ommatidium. *Light received from each facet pass through central portion and forms the image on the rhabdom of the same ommatidium*	The light received by many ommatidia (or) the neighboring ommatidia forms a image on a single rhabdom.

This is because each ommatidium is sleeved (or) surrounded by layer of light absorbing pigment cells that prevent light arriving from other ommatidium	This is because the *pigment cells lack pigment,* and constructed in such a way that they *allow passing the light to rhabdom from neighboring ommatidia*. The lenses allow light from many hundreds of facet lenses to be focused onto single photoreceptors in the retina, thus dramatically increasing light capture.
Image formed is distinct	Noctuirnal insects evolved remarkable visual capabilities, produce *sharp image*, can distinguish colors at night, though the image is not clear only general features of objects are formed.
Butterflies and bees	Moths and Beetles
	

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*. Ocelli are very *sensitive to low light levels*, and play a *role in circadian rhythm* (day light responses eg. in diapause).



a. ***Dorsal ocelli*** are found in all adult insects and the larvae of hemimetabolous insects, and absent in apterygota. *Typically there are three*, forming an inverted triangle antero-dorsally on the head, between compound eyes. These are *highly reduced and represent by fenestrae in cockroaches*. Typical ocelli have a single thickened cuticlular lens (carnea), but in other cases the cuticle is transparent, but not thickened. 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*).

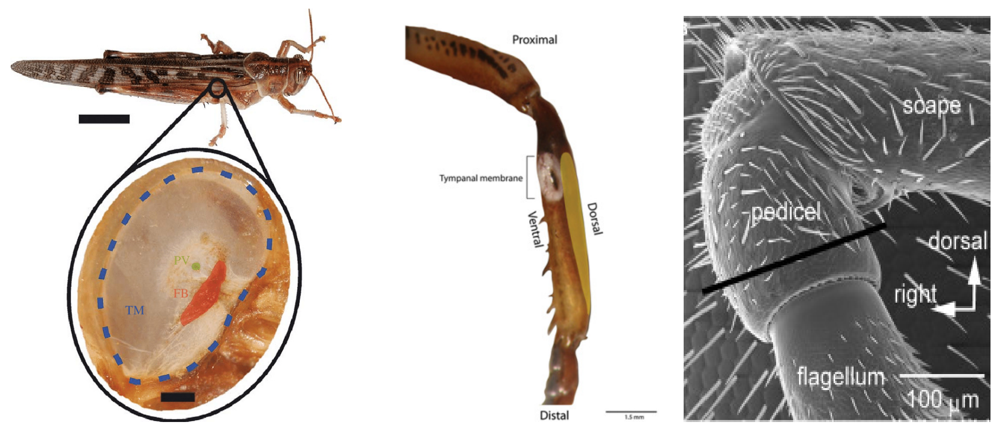
b. ***Lateral ocelli or stemmata:*** *Lateral ocelli are only the eyes present in insect larvae of holometabola and in apterygote adults*. Ocelli have very *poor resolution power*. Caterpillars behaviorally scan from side to side using these visual organs. Similar to structure and function to ocelli. 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. These are innervated from the optic lobes of the brain. *Probably not image forming but sensitive to direction of light, perception of moving objects, color, form, distance*.

ORGANS OF HEARING / AUDITORY ORGANS / MECHANO RECEPTORS (Sound sensing):

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*.

a. **Tympanal organs:** Always occur as paired organs. They are composed of a *thin cuticular membrane* (the tympanum) which internally consists of a '*mullers organ*', with some form of connection to the nervous system. 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 first abdomenal segments in Cicadas (Cicadidae, Hemiptera) and some families of the Lepidoptera, (i.e. Noctuidae, Geometridae, and Pyralididae) at the base of the abdomen. *Scoplopodium* form the tympanal organ of the locust.

b. ***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.



Left : Auditory Organ - Tympanum in first abdomenal segment in Grasshoppers
Middle : Auditory Organ - Tympanum in base of fore tibia of legs in Crickets
Right : Auditory Organ - Johnstons organ in pedicel of antenna of all insects

c. ***Auditory Hairs*** these occur on some Lepidopteran larvae as well as on some Orthoptera. They respond to sounds of air or water currents mediated by hair sensillae.

d. ***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.*

ORGANS OF SMELL / CHEMO RECEPTORS / OLFACTORY RECEPTORS (Smell sensing)

Insect olfaction refers to the function of chemical receptors that enable insects to detect and identify *volatile compounds* for foraging, predator avoidance, finding mating partners (via pheromones) and locating oviposition habitats. The sense of smell allows insects to detect, discriminate and react to a broad range of different chemicals, even with similar molecular structure, found in the environment. Thus, it is the most important sensation for insects, as olfactory sense detects plethora of behaviourally relevant odor chemcials. The olfactory receptors can be located anywhere on antenna, palps and genetalia.

ORGANS OF TOUCH / TACTILE RECEPTORS (Touch sensing)

Insects are far more sensitive to touch than people are and have touch receptors on hairs located all over their bodies, including their antennae, feet, wings and even their eyes. Some insects, like migratory locusts, have touch-sensitive hairs on their heads that react to air pressure and create a stimulus to keep their wings beating.

ORGANS OF TASTE / GUSTATORY RECEPTORS (Taste sensing)

Insects don't have taste buds, but their *hairs with chemoreceptors* that are similar. These receptors can be located anywhere on the body, but usually found on labrum, maxillae, labium, antenna, tarsi (legs), ovipositor etc. Bees and beetles can distinguish sweet, sour, salty and bitter tastes, just as people can.

OTHER SENSE ORGANS

- **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.*
- **Proprioreceptors*:*** In desert locust, they have specialized hairs with swollen bulbs at the tip of cerci. *Centre of Gravity* 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: 21

TAXONOMY

Importance - History – Binomial nomenclature - Holotype, allotype and paratype – Suffixes of tribes, subfamily, family and superfamily – Law of priority – Synonyms and homonyms - Definitions of biotype - Subspecies - Species – Genus - Family and Order. Characters of Class Insecta - Economic classification of insects-Classification up to Orders – Subclasses - Apterygota and Pterygota– Names of Orders of Apterygota and Pterygota with examples - Orthopteroid, Hemipteroid and Panarpoid group of orders.

It is estimated that Class of Insects originated on Earth about 480 million years ago, much earlier than appearance of humans, who only appeared 1 million years ago. There are about 1.3 million (=13 lakhs) described species, 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,"

Aristotle (384-322 BC): A good beginning of taxonomy was made by Aristotle. 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): *He coined the term Insecta*. He used the term *Systematics*. His greatest contribution is *Systema Naturae*. In his 10th edition of Systema Naturae published in 1758, he *used **binomial system of nomenclature** for the first time for both plants and animals.* He is also fondly called as *Father of Taxonomy, and Father of Binomial Nomenclature*. This double naming in latin; one for genus and other for species has been universally accepted and adopted subsequently. But before adopting binomial nomenclature, several scientists / taxonomists used different kinds of nomenclature.

Johan Christian Fabricius (1745-1808) was a Danish zoologist specializing in "Insecta". He was a *student of Carl Linnaeus*, and is considered one of the most important entomologists of the 18th century, having named nearly 10,000 species of animals, and established the basis for the modern insect classification.

Michael Anderson (1727-1806): Contemporary and rival of Linnaeus. Introduced *Numerical Taxonomy* and hence is called Father of Numerical Taxonomy.

Brawer (1885): Laid foundations for modern system of classification and responsible to divide class Insecta into Apterygota and Pterygota.

In 1872, ***Strickland*** published a code of *nomenclature in English*, called Strickland code. Another code '*dal code*' was published by Americans in 1877. Similarly, some more codes of nomenclature was evolved in animals, such as an International code of zoological nomenclature was evolved in 1901 at Berlin and was approved by 16th session of International congress of zoology, and being revised and published in 1964.

Using three words for a name is called *Trinomial system of Nomenclature*. It was given by **Lamarck**, it consists of three words i.e., genus, species, sub-species (in zoological literature) or variety (in botanical literature).

Binomial Name : *Apis cerana*

Trinomial Name : *Apis cerana indica* (Fabricius, 1798)

TAXONOMY:

Taxonomy is the science and practice of describing, identification, naming, and classifying organs into groups of biological organisms on the basis of shared characteristics.

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.

SYSTEMATICS:

Systematics is the study of the biological diversity and evolutionary relationships among the organisms, both extinct and modern.

(Taxonomy+Phylogeny = Systematics)

Phylogenetics is the study of evolutionary relationships among biological entities - often species, individuals or genes (which may be referred to as taxa).

Systematics originally introduced by Carl Linnaeus, who based his classification system on physical traits, and now systematics includes the similarities of DNA, RNA, and proteins across species as criteria for classification.

CLASSIFICATION:

Classification is the arrangement of organisms in to groups on the basis of their relationships.

Taxonomy is properly the describing, identifying, naming and classifying organisms into groups, 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 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! (Kingdom…. Phylum… Class…. Order…. Family…. Genus….Species). The following is the example of Hierarchy for Indian 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	*cerana*	--
Sub Species	*indica*	--
Binomial Name	: *Apis cerana*	
Trinomial Name	: *Apis cerana indica* (Fabricius, 1798)	

The ICZN (International Code of Zoological Nomenclature) name biological organisms, and ICZN ecretariat is housed in the Department of Palaeontology at the Natural History Museum, London. ICZN publishes International Code of Zoological Nomenclature and the Bulletin of Zoological Nomenclature. According to ICZN, the descriptions of unrecorded species should be based on a single specimen whether it is a male or female, and the specimen is referred as '*holotype*'. Holotype is a single type specimen upon which the description and name of a new species is based. The opposite sex specimen which is described along with the holotype is termed as '*allotype*'. The other specimens of the species kept along with the holotype and allotype as called as '*paratypes*'.

The underlying principle of ICZN is *Law of Priority* i.e. the first published name remains in official records while all the subsequently published names go as *synonyms*. If the same name is given by different scientists to the different organisms, it is called *Homonymy*. All such cases are refered to International Commission on Zoological Nomenclature which settles such cases.

Species concept: A good working definition 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*.

General Rules:

- The scientific names are to given in Latin
- The names are to written in Italics if printed (*Apis cerena indica* Fabricius) or Undelined (Apis cerena indica Fabricius) if hand written.
- The genus name is always starts with capital letter and species name with small letter (*Apis cerena indica* Fabricius)
- Name of the authors in full should be written at the end of the species name without any punctuation (*Apis cerena indica* Fabricius)
- The supraspecific categories like tribe, sub family, family and super family are denoted by endings –ni, -inae, -idea, and –oides, respectively.

Biotype: The population within a species which can survive on and destroy varieties that have genes of resistance. It is the ability of the insects to overcome selection pressure.

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.

LECTURE : 22

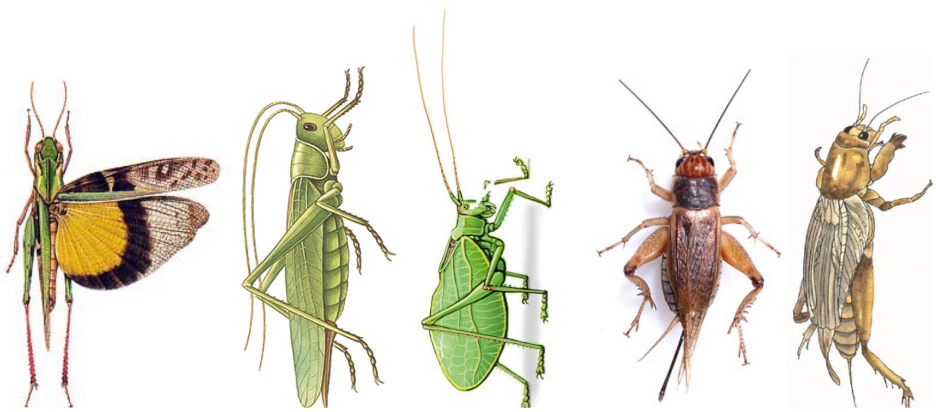
ORDER ORTHOPTERA

General characters; Families - Gryllidae, Acrididae, Tettigonidae and Gryllotalpidae – 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.*



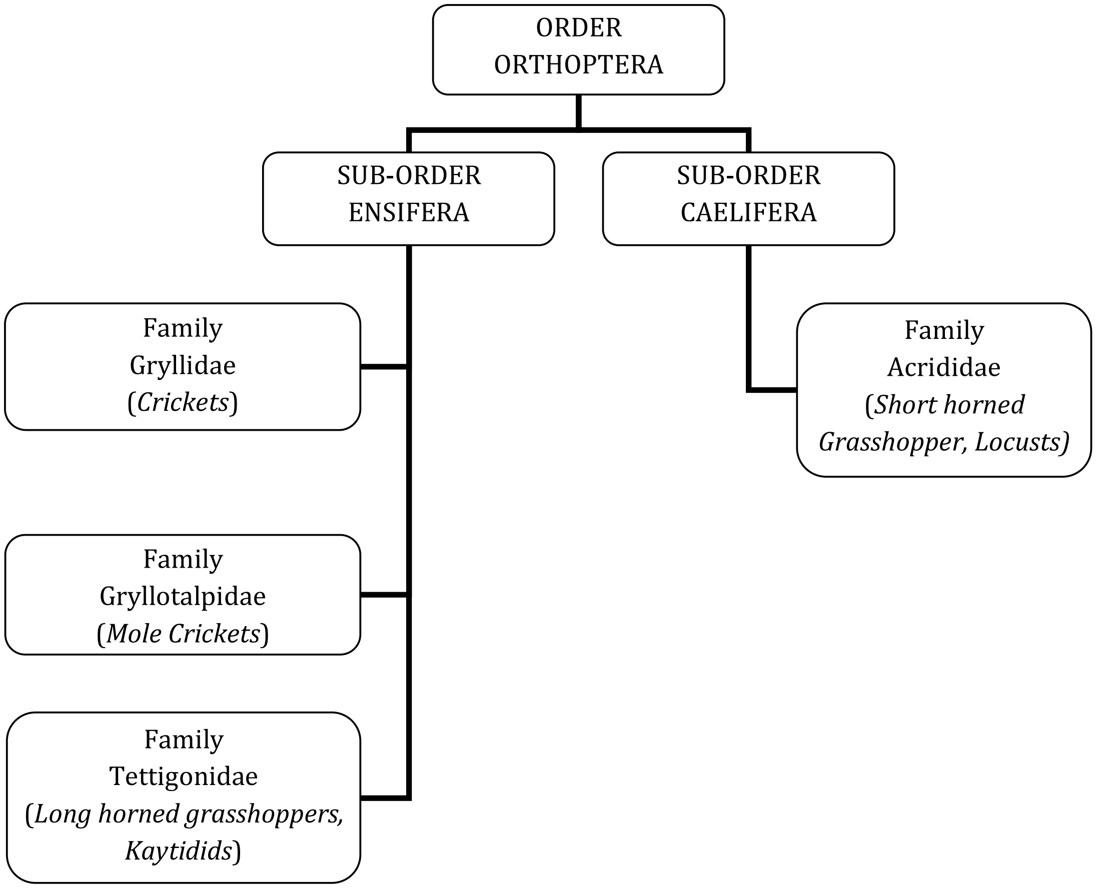
Habitat	Mostly terrestrial, tropical. The Orthoptera can be found in most habitats, the Desert Locust *Schistocerca gregaria* lives in Desert and Semi-Desert, while the Mole-cricket (*Gryllotalpa gryllotalpa*) lives under ground.
Food Habit	*Highly polyphagous.* Grasshoppers, Groundhoppers and a few rare Bush-crickets are predominantly herbivorous (eat only plant material), while most of the rest are *omnivorous* (eating both plants and animals) eating whatever comes their 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*. *Fore wings are long, narrow, toughened and strengthened to form tegmina*. *Hind wings are broad, many 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	*Stridulation (sound producing) is the characterstic feature of Orthoptera insects, and are renowned for singing (sound producing) males for attracting females.* They produce their songs in a variety of different ways; most of the *Ensifera sub-order insects (Gryllidae-Crickets, Tettigonidae-Kaytidids) rubs one forewing (tegmina) against the other (alary type: rubbing fore wings against each other)* while Caelifera *sub-order insects (Acridicae-Locusts) rubs one or both hind femora over their tegmina (femoro-alary type: rubbing forewings with hind legs)*.

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. 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).

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 sub-order insects (Gryllidae-Crickets, Tettigonidae-Kaytidids) all have ears (tympanal organs) on fore tibia (front legs) The Caelifera sub-order insects (Acrididae-Locusts) have their ears on either side of the first segment of their abdomen*.
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* Crickets Needle like in Crickets; Sword like in long-horned grasshoppers; Blade like in Katydids
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.



FAMILY : GRYLLIDAE (CRICKETS)

Common cricket : *Gryllus personatus*

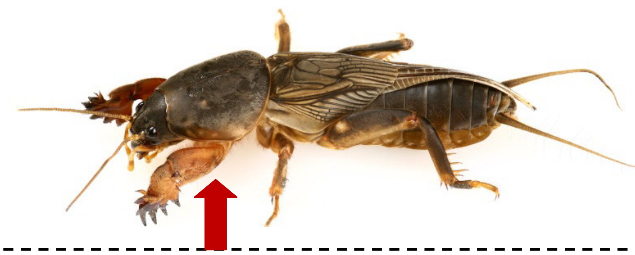
Crickets (చిమటలు)

- *Forewings are abruptly bend down to cover the sides of the body, and hindwings are acuminate (tapering to a point)*
- Saltatorial (Jumping) Hind Legs
- Tarsus 4 segmented
- Ovipositor is slender and *needle like*
- Cerci are long and unsegmented

- *Males stridulate during night, producing shrill chirping sounds; Alary type (fore wings rubbing each other)*
- Auditory organs (tympanum) on fore tibia

FAMILY : GRYLLOTALPIDAE (MOLE CRICKETS)

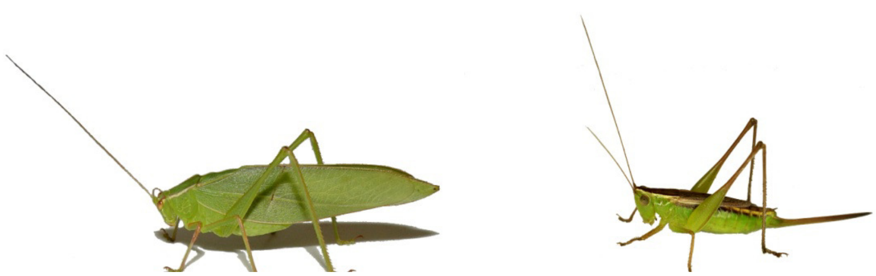
Oriental Mole Cricket : *Gryllotalpa orientalis*



- Brown colored insects *found in burrows.*
- Eyes are reduced
- *Pronotum elongated, ovate and rounded posteriorly*
- *Fore legs fossorial (for burrowing)*
- Hindwings are expanded beyond the tegmina as a pair of processes
- Special *stridulatory structures are absent*, but a humming sound is produced by rubbing forewings
- A pair of auditory organs (tympanum) is found on the under side of the tibiae
- Ovipositor vestigial
- *Anal cerci long*
- They act as soil builders

FAMILY : TETTIGONIDAE
(Long-Horned Grasshoppers, Kaytidids)

Surface grasshopper : *Conocephalus indicus*

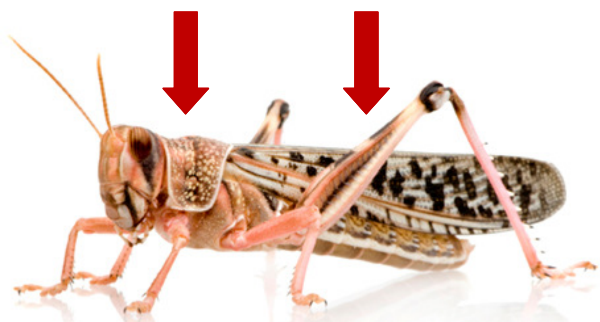


- Cryptic coloration.
- *Antenna as long as or longer than body*
- Tarsus 4 segmented

- *Alary type stridulation*
- Ovipositor : Very long, Sword like
- Mainly herbivores, but some carnivores.

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*



Schistocerca gregaria (ఎడారి మిడత)

Hieroglyphus banian

- *Short horned grasshoppers and locusts*
- They are polyphagous and often destructive
- *Antennae filiform*, shorter than the body with less than 30 segments
- *Saddle shaped pronotum.*
- *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*
- Legs : 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

LIVE MINT

Locusts attack Jaipur, FAO warns of higher risks along India-Pakistan border

1 min read. Updated: ***26 May 2020***, 12:14 PM ISTDhirendra Tripathi

The desert locust is considered the most destructive migratory pest in the world and a single swarm covering 1 square kilometre can contain up to 80 million locusts.

NEW DELHI: Swarms of desert locusts swept Jaipur on Monday as the insect onslaught spread wider to parts of Rajasthan, Madhya Pradesh and Uttar Pradesh. Locusts can destroy standing crops and devastate livelihoods of people. Scientists are blaming the higher frequency of cyclones originating in the Indian ocean in 2019 for the increased incidents of locust attacks this year.

Gujarat and Punjab have warned their farmers of locust attacks.

This is the second round of locust attack in India, the first one having occurred during December-February. Today is the fourth consecutive day of attacks on the Indian side in the current cycle. The desert locust is considered the most destructive migratory pest in the world and a single swarm covering 1 square kilometre can contain up to 80 million locusts

The Food and Agriculture Organization of the United Nations (FAO) had on Friday said there was an increased risk along both sides of the India-Pakistan border.

Locust attacks in 12 countries, including Pakistan, Iran and ten nations in Africa, have damaged crops over millions of hectares.

Countries in Africa and West Asia have been battling swarms of locusts since December. Sindh, Balochistan and Punjab in Pakistan have been severely affected by the attacks.

“Despite control operations, recent heavy rains have created ideal conditions for the pest's reproduction in several countries. Young juveniles will become voracious adults in June just as farmers begin to harvest, compounding an already bleak food security situation," FAO warned in its Friday release.

The World Bank has set up a $500 million programme to help countries in Africa and the Middle East combat the impact of locusts.

LECTURE: 23

DICTYOPTERA & ODONATA

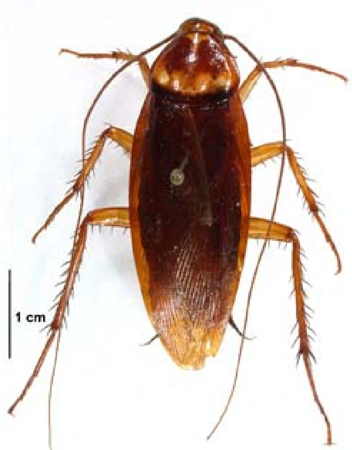
General characters – Blattidae and Mantidae– Characters with examples
Odonata - General characters with examples

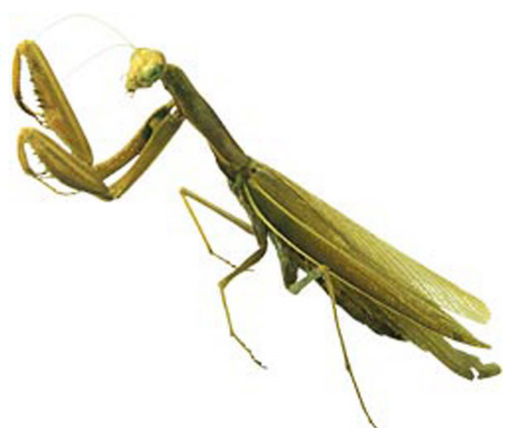
ORDER : DICTYOPTERA

Dictyo: Net, Ptera: Wings, Netted winged Insects

Examples : Cockroach and Praying Mantis

- 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
- 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.





Habitat	Terrestrial, tropical and subtropical insects.
Food Habit	Cockroaches are *omnivorous*, while Mantis is *predacious* on other insects and small animals
Size	Variable, Large to Medium sized
Shape	*Dorso-ventrally flattened*, depressed, oval shape in cockroaches or very long bodied, stick like in some mantis.

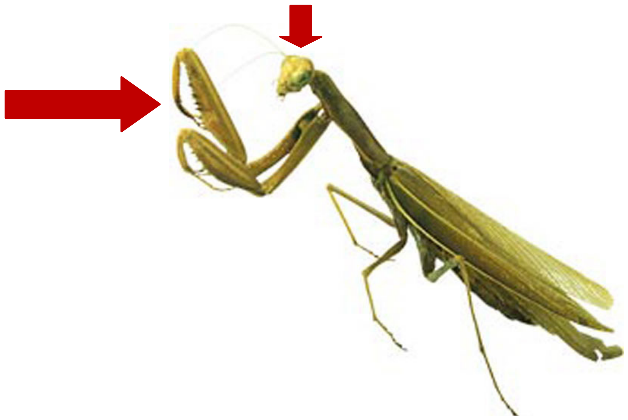
Taxonomic characters:

Head	Usually *Hypognathous*
Antennae	Long, may be longer than the body. Filiform (Mantis) 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.
Legs	*Cursorial (running in cockroach) or Raptorial forelegs (Mantis) with 5 tarsal segments.* All three pairs are similar in Blattidae (cockroaches) useful for running, while in Mantidae (praying mantis), 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 Mantis.
Anal cerci	A pair of many segmented anal cerci is present, they are visible, and *hairs on anal cerci in cockroach are very sensitive to air movements, and hence it is very difficult to catch them*.
Genetalia	Genetalia of both sexes reduced, concealed behind 7th abdominal segment in female, and behind 9th 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.

FAMILY : MANTIDAE
(MANTIS & STICK INSECTS) (గొల్లభామలు)

Greenhouse mantis : *Mantis religiosa*
Common Indian mantis : *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.
- Long body, abdomen flattened.
- *Head is triangular deflected*.



- Three ocelli present.
- Antenna: filiform, long, many segmented.
- *Prothorax greatly elongated*, meso- and meta-thoracic segments are short.
- Characterized by *raptorial type of front legs, with long coxa, tibia and femur bearing prominent spines.*
- 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) (బొద్దింకలు)

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

- Nocturnal, Omni vorous (feed on food stuff, clothes, paper etc.). Impart foul smell to food by contaminating with excreta.
- Body dorsoventrally flattened, depressed and oval shaped
- Body heavily pigmented body
- Head is not mobile in all directions, and *head is hidden by pronotum*
- *Pronotum large plate like / shield like* covering the head
- *Degenerated Ocelli (sensitive to light) called fenestrae*
- Antennae setaceous (whip like), long with many segments.
- Legs: All thre pairs similar, *cursorial (running) type*.

Blatta orientalis

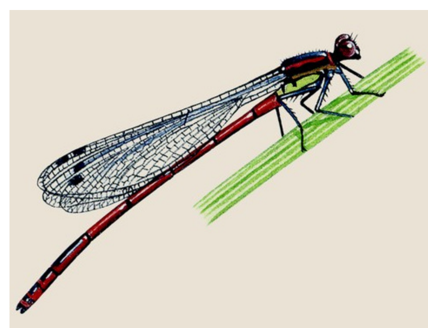
Periplanata americana

- 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)

ORDER : ODONATA
(DRAGON FLIES AND DAMSEL FLIES)

Most ancient and beautiful insects that ever roamed earth, as well as some of the largest flying invertebrates ever to have lived belong to Odonata.

Dragon fly (□□□□□)



Damsel fly

- Medium and large sized insects
- Attractively colored
- *Head is Globular*, and constrictd behind into a petiole neck
- Large compound eyes
- Three ocelli present
- Mandibles are strongly toothed; In young ones (*Naids-aquatic*), labium is modified into a prehensile labial mask that is used for capturing potentially fast moving organisms up to predator's own size. It is called Mask. (*Mask type of mouth parts*)

- Wings are either equal or sub equal. Membranous wings with network like venation with many cross veins. Wings have dark pigment spot (*pterostigma*) towards the coastal apex.
- *Wing flexing mechanism is absent*.
- Legs are used for grasping, holding and conveying the prey into mouth. Spinous femora used for holing the prey, and legs are held in such a way that a basket is formed (*prehensile – basket forming legs*) into which the food is scooped.
- Abdomen is long and slender
- Male gonopore is present on 9th abdomenal segment, but the functional copulatory organ is present on the second abdomenal sternite.

There are two sub-orders in order Odonata; Anisoptera and Zygoptera

Anisoptera	**Zygoptera**
Dragon flies	Damsel flies
Trong fliers	Weak fliers
Wings are unequal Hind wings are broader than forewings	Both wings are equal
Wings are broadly attached to abdomen	Wings are narrowly attached to abdomen
Wing venation is not similar in both wings	Wing venation is similar in both wings
Wings spread laterally at rest	Wings are held at an angle above the abdomen
Compound eyes are large and meet mid dorsally	Compound eyes are small, botton like, and wide apart (dioptic)
Oviposition exophytic	Oviposition Endophytic
Male has three abdomenal appendages	Four terminal abdomenal appendages are present
Young ones are called Naiads	

LECTURE 24

ISOPTERA

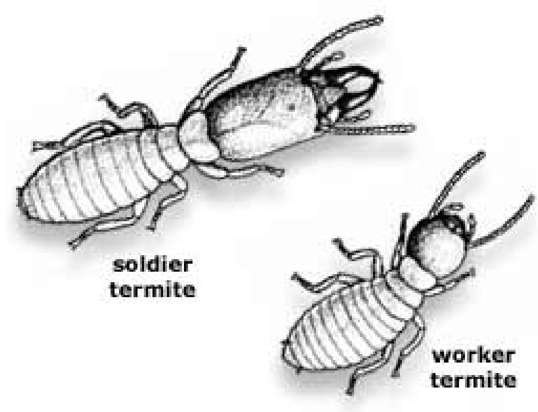
General characters –Termitidae –Characters with examples
Thysanoptera – General characters –Thripidae –Characters with examples

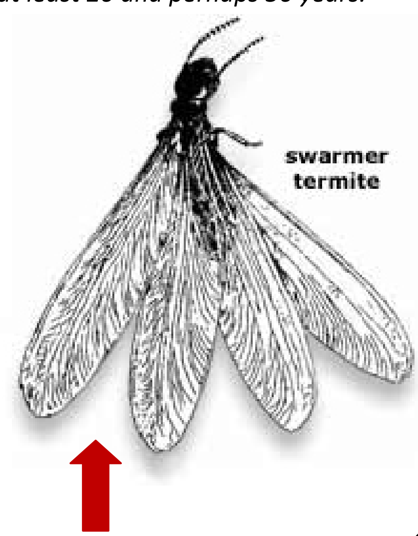
ORDER : ISOPTERA

Iso : equal, Ptera : Wings, Equal winged Insects

(TERMITES OR WHITE ANTS) (చెదపురుగులు / చెదలు)

- *They are often called as '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.*
- *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, and hence are economically significant as pests.*
- *Famous for their construction of huge mounds or 'termitarium' 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.*
- *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 (ఉసిళ్లు in telugu)*
- *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.*





Habitat	Common in tropics
Habit	Detritivores; obtaining nutrients from dead plants Highly Polyphagous, Economically very important
Types	Highly Polymorphic, well developed caste system; social insects
Size	Small to medium sized; soft-bodied

Taxonomic characters:

Head	*Head is movably articulated*, Prognathous
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*.
Antennae	*Moniliform* *(bead like),* appearing as if composed of a series of beads, comprising 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 and median ocelli wanting
Thorax	Pro-thorax is freely movable, narrower than head. Meso- and meta-thorax wider than head
Wings	Three forms of adult termites based on development of wings: 1. *Apterous (sterile adults-workers & soldiers; major population of the colony),* 2. *Brachypterous (supplementary reproductives – very less in numbers) and* 3. *Winged (sexually mature primary reproductives)* *Wings are present only in sexually mature adult 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.
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 (of adults) that are usually seen in termite colony:

1) Reproductives or Primary Reproductives (Fertile King and Queen) (Winged adults / Alates / swarmers)

The primary function of *termites with wings, or swarmers*, is to reproduce and generate new colonies. They have two wing pairs, and the presence of these insects indoors signifies that a building is likely infested. Flying termites can commonly be found swarming around window sills or exterior lighting because light attracts them. These winged termites also called as *alates*.

Termites with wings (adults developed from nymph) depart from their nests and fly when the conditions are appropriate. These winged insects will turn into the queens and kings of new colonies. The males and females will swarm together in the air. After they land, the swarmers will shed their wings, mate, and start new colonies.

- They are darker in colour (heavily pigmented), than other castes
- These are highly developed individuals sexually.
- They *have fully developed wings and compound eyes*
- The males are often small.
- Queen sometimes live for several years.
- 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*. These adults are called as dealated reproductives.
- *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* (short, reduced wings) 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 (Apterous; wingless adults)*

They form the bulk of the colony. They include workers and soldiers.

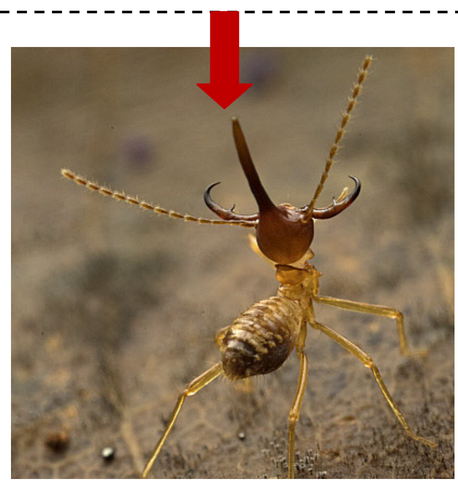
a) Workers:

- 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.

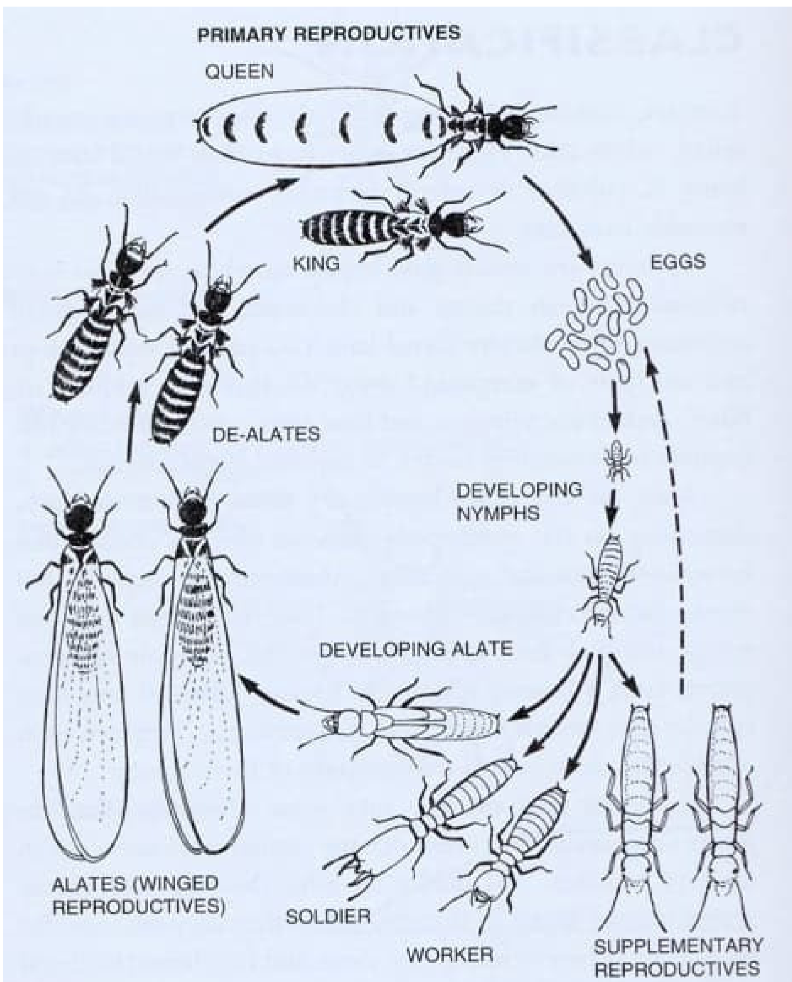

Mandibulate type sodier


Nasute type soldier

Family : TERMITIDAE

Termites : *Odontotermis obesus*
Microtermis obesi

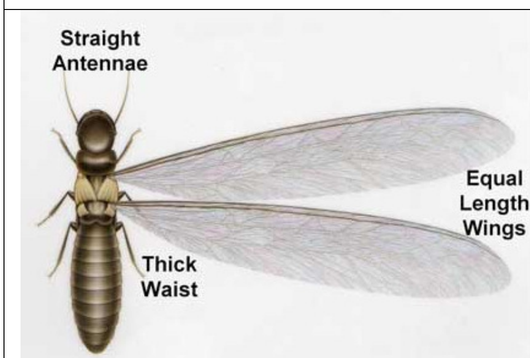
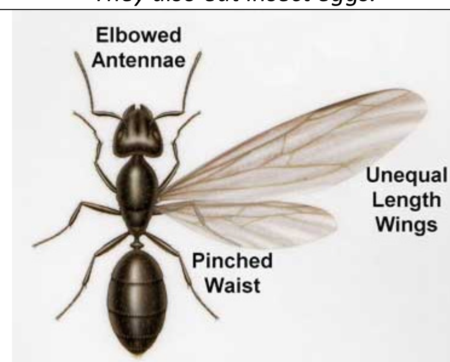
- It is the biggest family with 2/3rd of Isopterans.
- Ground dwelling with wide range of food habits
- Well developed caste system
- Mouth parts : biting types, well developed mandibles
- *Frontenelle present*
- Antenna : Moniliform
- Pronotum of workers is naroow with a raised lobe, saddle shaped
- 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



WHITE ANTS AND ANTS: Relationsship and Differences

Termites are often called as white ants because the majority of them are white and small and live in large colonies similar to ants.

They are not actually closely related to the ants. The differences are as follows:

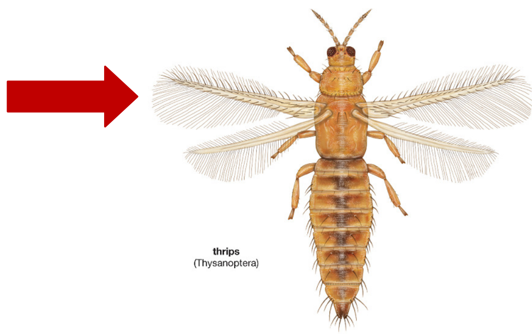
White Ants	Ants
White Ants are Detritivores (dead plants) Highly polyphagous;	**Ants** are omnivorous *they eat everything. In nature, they feed on the milk of aphids and other small Hemiptera, insects and small living or dead invertebrates, as well as the sap of plants and various fruits. They also eat insect eggs.*
 *Flying Adult Termite*	 *Flying Adult Ant*
Monilform (bead like) Antenna	Geniculate (Elbowed) Antenna
Both Pairs of Wings are equal	Fore wings are bigger in size
Thoracic and Abdomenal segements are bigger, thicker and joined like together	Constriction at the first abdomenal segment, which distinctly separate abdomen from thorax.
Wingless adults (Queen, soldier, worker) are very very smooth and soft (pale in color, less sclerotized body)	Wingless adults (Queen, soldier, worker) are Hard (highly sclerotised body)
Order : Isoptera Hemi-Metabola	Order : Hymenoptera Holo-Metabola

ORDER : THYSANOPTERA

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

Thrips are minute to small, thin, slender elongated with transversely constricted bodied insects. Terrestrial insects, commonly found on flowers in summer; they have habit of hiding in flowers and flower buds.

These are *important pets of food plants and horticultural crops, and also vectors of some diseases. Thrips are the only members of the 'Exopterygota' to have developed a true pupal stage.* They have unusual life cycle with with 2 or 3 inactive pupa-like instars.



Thrips (తామర పురుగులు)

Habitat	Terrestrial, commonly found in flowers
Habit	Phytophagous
Size	Minute to small, thin, slender elongated bodied insects

Taxonomic characters:

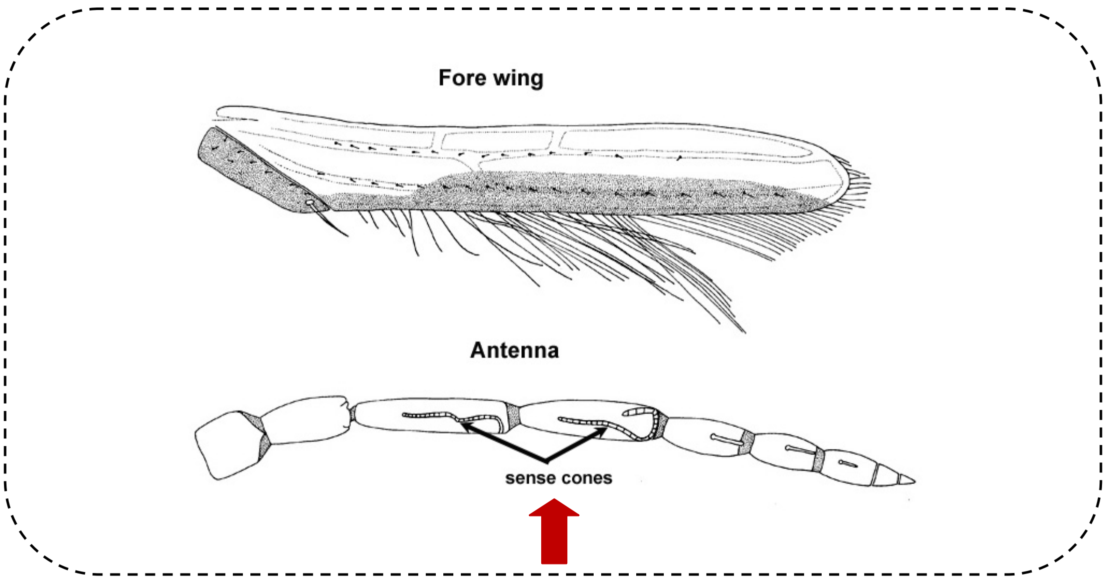
Antennae	6-10 segmented with *sensorial (cone like structure) on 3rd or 4th segment*
Compound eyes	Conspicuous with 3-4 ommatidia in apterous forms, up to 150 in winged forms. 3 ocelli in winged forms.
Mouth parts	*Asymmetrical mouth parts. Right mandible is absent.* *Lacerating or Rasping and sucking 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 pairs of similar, strap-like wings with a ciliated fringe on margins with long hairs*, from which the order derives its name. Wings when fully developed are long and narrow with highly reduced venation (with 1-2 veins).

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 1st and 2nd instar larvae are active, resemble adults (called nymphs) where as *3rd and 4th 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*

- Largest, most important and *most injurious family* in thysanoptera.
- Antennae 6-9 segmented, *3rd and 4th antennal segments are conical with sense cones or sensoria*, 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



LECTURES: 25 & 26

HEMIPTERA

General Characters
Sub order Heteroptera – Characters
Families – Cimicidae, Miridae, Pentatomidae, Lygaeidae, Coreidae, Pyrrhocoridae - Characters with examples
Hemiptera - Suborder Homoptera – Characters
Delphacidae, Cicadellidae, Aleurodidae, Aphididae, Coccidae, Pseudococcidae, Lopophidae- Characters with Examples

ORDER : HEMIPTERA

Hemi: half thickened or basally thickened, Ptera: Wings,
Half thickened or basally thickened winged Insects)
(TRUE BUGS / PLANT BUGS / LEAF HOPPERS / JASSIDS / APHIDS / WHITEFLIES / MEALYBUGS)

The Hemiptera is the largest and by far the *most successful of the hemimetabolic insects*. 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 few of Heteropterans *are predatory.* Some can *transmit the plant diseases*. The Hemipterans *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*. The size ranges from 1 mm to 11 cm in length.

Habitat	Terrestrial
Habit	Phytophagous; some are predacious; can transmit diseases
Size	Small; 1 mm to11 cm
Color	Varying

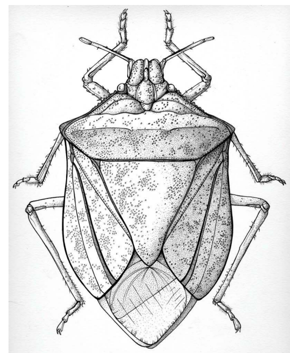
Taxonomic characters:

Head	Prognathous in Heteroptera, Hypognathous / opisthognathous 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*
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 *basal half is well sclerotized resembling elytra, with only small*

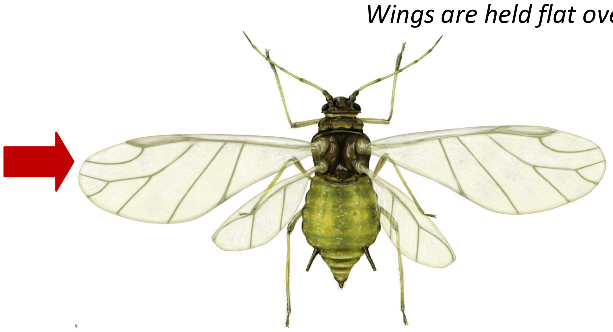
distal portion remaining membranous. The *hindwings are always membranous* and are folded beneath the hemielytra at rest.

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*.

Wings of Heteropterans (Bugs)
Forewings-Hemielytra, Hindwings-Membranous
Wings are held flat over the body




Wings of Homopterans
Forewings and Hindwings-Membranous
Wings are held over the body like 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)

Sound production Many hemipterans can produce sound for communication. The "song" of male cicadas, the loudest of any insect, is produced by *tymbal organs* on the underside of the abdomen, and is used to attract mates. The tymbals are drumlike disks of cuticle, which are clicked in and out repeatedly, making a sound in the same way as popping the metal lid of a jam jar in and out.

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	True 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	Hypognathous / Opisthognathous
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

Sound Productio	No sound producing organs	Many can produce sounds Sound production due to *tymbal organs* in first two abdomenal segments (Cicadas)
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	*Cimicidae:* Bed bugs *Pentatomidae* : Stink Bugs/Shield Bugs *Lygaeidae :* Seed bugs, Chinch Bugs *Miridae :* Mirid bugs *Pyrrhocoreidae :* Cotton bugs /cotton stainers *Coridae:* Leaf-footed bugs	*Cicadellidae:* Leaf Hoppers, Jassids *Delphacidae ;* Plant hoppers *Aphididae:* Aphids or Plant Lice *Pseudococcidae :* Mealy bugs *Coccidae:* Scale insects *Aleurodidae:* Whiteflies *Lophodidae :* Aeroplane bugs
Other Characters	Do not transmit diseases	*Most insects act as Vectors*
	Usually do not release Honeydew	*Most insects release Honeydew*

FAMILIES OF SUB-ORDER HETEROPTERA

FAMILY : CIMICIDAE
(BED BUGS)

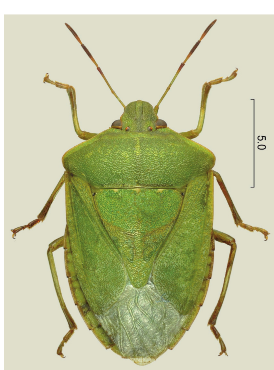
Bed bug : *Cimex lecturalis*

Bedbugs (నల్లులు)

- Body is dorsoventrally flattened, so that they can hide in cracks and crevices
- Thorax is deeply notched in front to receive the short head upto bulging eyes
- Hemielytra short and reduced to scale like pads
- Stink glands are located in the dorsal surface of the first three abdomenal segments, opens at hind coxae
- Male bed bugs pierce the integument of the female, and inject sperm into the haemocoel during copulation called *haemocoele / traumatic insemination*
- They are blood sucking ecto-parasites on birds and mammals

FAMILY : PENTATOMIDAE
(STINK BUGS / SHIELD BUGS)

Green Stink Bug : *Nezara viridula*
Red Pumpkin Bug : *Aspongopus (Coridius) janus*
Cabbage Painted Bug: *Bagrada cruciferarum*



Green Stink Bug

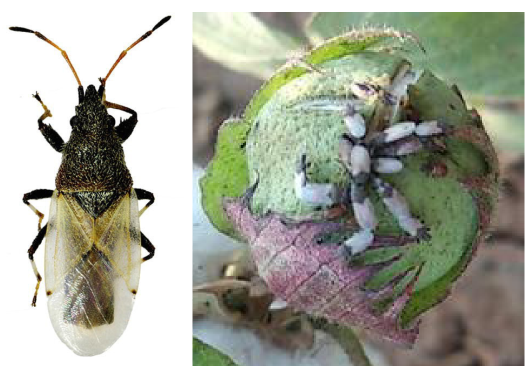
Red Pumpkin Bug

Cabbage Painted Bug

- Medium to large sized, broad shied like Stink / Shield Bugs
- *Body medium sized, shield like and brightly coloured*
- Ocelli present
- The lateral margins of head conceals the bases of antenna
- *Antenna : 5 segmented*
- *Pronotum: Broad and Shield shaped*, scutellum of mesonotum is large, triangular, sometimes extends posteriolry to the extent of covering wings entirely.
- 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
- They produce highly disagreeable odours. A pair of *odoriferous glands* opens at hind conxae, and in addition, *4 pairs of odoriferous glands present on the dorsum of the abdomen of nymphs*
- Eggs : usually barrel shaped with spines on the upper end.

FAMILY : LYGAEIDAE (SEED BUGS / CHINCHBUGS)

Dusky Cotton Bug : *Oxycarenus laetus*
Groundnut Pod Bug : *Elasmolomus (=Aphanus) sordidus*



Dusky cotton bug

- Hard bodied insects
- Antenna 4 segmented, inserted down on the sides of head. The apical (last) segment of antenna is large.
- Compound eyes and ocelli are well developed
- Fore wings Hemielytra with 4 to 5 un-branched simple veins in the membranous part. Cuneus is lacking, and clavus elongate
- Meta thoracic glands openings are present
- In some, the *front femora moderately swollen with 2 rows of teeth beneath coxa*, tarsi 3 segmented, pulvuli present.

FAMILY : MIRIDAE (=CAPSIDAE) (MIRID BUGS)

Paddy Mirid Bug : *Cyrtorhinus lividipennis* (Useful Insect – Predator)
Tea Mosquito Bug : *Helopeltis antonii*


Paddy Mirid Bug (Useful Insect)


Tea Mosquito Bug

- Small to medium, usually delicate insects
- Majority live on plant juices, some prey on arthropods
- Ocelli absent
- Rostrum 4 segmented
- Cuneus (triangular shaped region at the distal end of forewing) is present
- Indistinct Empodium (lobe or spine like structure in between two claws at the end of the tarsus)
- Tarsi 3 segmented

FAMILY : PYRRHOCOREIDAE (REDCOTTON BUGS/COTTON STAINERS)

Red Cotton Bug : *Dysdercus cingulatus*


Red Cotton Bug (Nymphs & Adults)

- They exhibit red and black colorations
- Ocelli absent
- More branched veins and cells present in Hemielytra
- *Coxa is rotator, and tarsi 3 segmented*

FAMILY : COREIDAE
(LEAF FOOTED BUGS)

Rice Gundhy Bug : *Leptocorisa vericornis*
Pulse pod bugs : *Clavigralla gibbosa*

Rice Gundhy Bug (వరి కంపునల్లి) *Pulse Pod Bug*

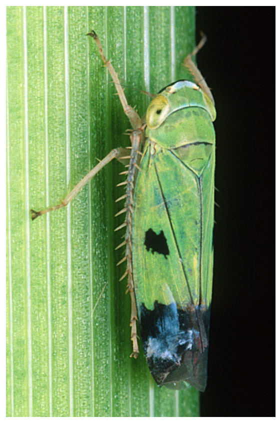
- Leaf Footed Bugs
- Medium to large sized, long and narrow bugs
- Head : Narrower, shorter than pronotum
- *Hemi-Elytra with richly branched veins*
- *Antenna : 4 segmented*, situated well upon the sides of the head above a line drawn from the eyes to the base of the beak.
- Ocelli present
- In most 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

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*

Amrasca biguttula biguttula
(దీపపు పచ్చదోమ)



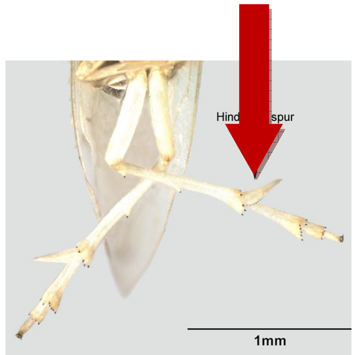
Nephotettix virescens
(వరి పచ్చదోమ)

Idioscopus clypealis
(మామిడి తేనెమంచు పురుగు)

- 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*
- Antennae minute, bristle like, 3 segmented
- Forewings are somewhat thickened, often brightly coloured
- Fore wing anal veins usually separate from base to anal margin (Anal veins 1A and 2A do not unite to form Y shaped vein)
- *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

FAMILY : DELPHACIDAE (PLANT HOPPERS)

Brown Plant Hopper on Paddy : *Nilaparvata lugens*
White Backed Plant Hopper in Paddy: *Sogatella furcifera*

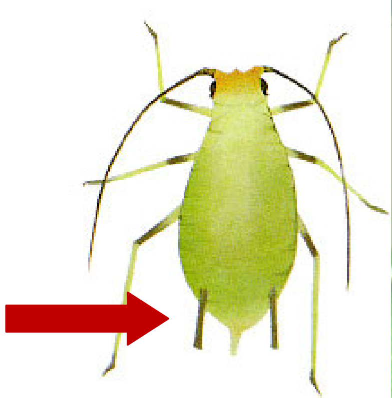
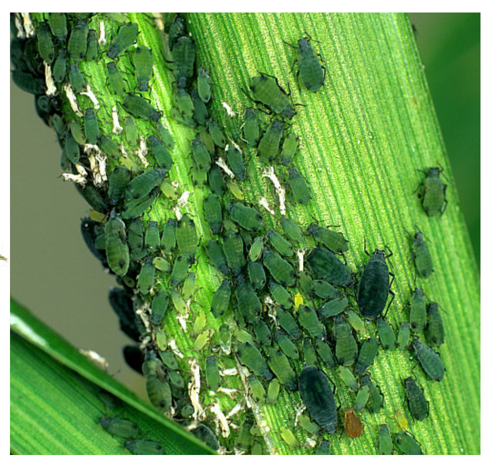



BPH in Paddy (వరి సుడిదోమ)

- 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 is the characteristic feature of this family.*
- Anal vein 1A and 2A unite to form Y shaped vein.

FAMILY : APHIDIDAE (APHIDS OR PLANT LICE) (పేను బంక)

Cotton Aphid : *Aphis gossypii*
Maize Aphid/Tobacco Aphid : *Myzus persicae*
Bean Aphid/Groundnut Aphid : *Aphis craccivora*
Apple Aphid : *Eriosoma lanigerum*

Aphids ( )

- Economically very important family; *Polyphagous*; Some act as *vectors of plant diseases*, and some even feed on roots.
- *Pear shaped*, small and soft bodied insects, usually found in large numbers / colonies, sucking as from various parts of plants.
- *Rostrum usually long* and well developed
- Antenna fairly long.
- *A pair of cornicles on dorsal surface of 5th and 6th abdominal segments* (cornicles produce wax substance to protect from other insects) is the characteristic feature of insects belongs to this family.
- *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 (like tent) above the body*
- *Tarsus 3 segmented with pair of claws*
- *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*.
- The *reproduction can be through parthenogenesis, oviparity, viviparity*, in the occurance of generations the sexes are unequally developed, males often being rare.

FAMILY : PSEUDOCOCCIDAE (MEALY BUGS) (పిండి నల్లి / పిండి పురుగు)

Sugarcane Mealy Bug	: *Saccharicoccus sacchari*
Grapevine Mealy Bug	: *Mecanellicoccus hirsutus*
Brinjal Mealy Bug	: *Centrococcus insolitus* *Planococcus insolitus*
Tailed Mealy Bug -Fruit Trees&Pulses	: *Ferrisia virgata*
Guava Mealy Bug / Scale	: *Pulvinaria psidi*
Citrus Mealy Bug	: *Planococcus citri*


Mealy bugs (పిండి నల్లి / పిండి పురుగు)

- *Females elongate, oval, wingless*, with distinct segmentation
- *Body covered with mealy or filamentous waxy secretion*.
- Antenna is present
- Legs well developed and *females move freely*.
- No instar is sessile / immovable. *All instars freely moving because of legs*.
- Eggs laid on loose waxy material

FAMILY : COCCIDAE
(SCALES) (పొలుసు పురుగు)

Sugarcane Scales : *Melanapsis glomerata*
Cottony Cushiony Scale/Citrus Scale : *Icerya purchase*
Mango Scale : *Aspidiotus destructor*
Guava Scale / Mealy Bug : *Pulvinaria psidi*
Coffee Scale : *Saissetia coffeae*
Citrus Scales : *Aonidiella citrine*

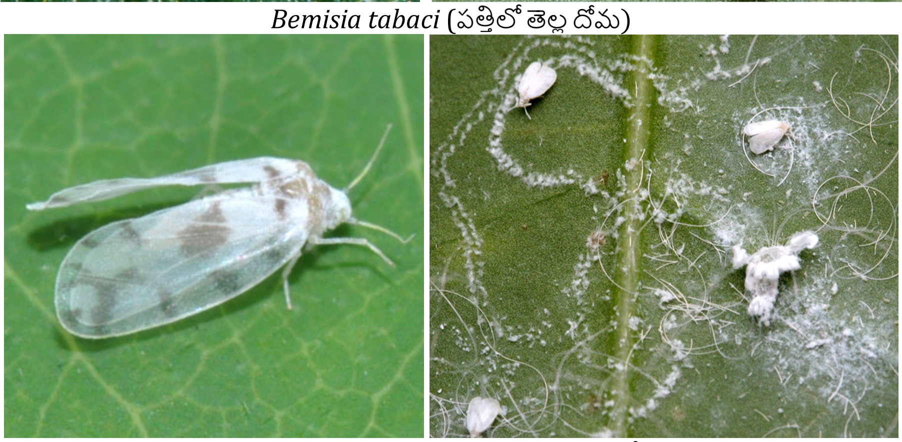
Sexual dimorphism	
Females	*Males*
Females very common	Males are rare
The females in this family are degenerated, flattened, elongate, oval insects with obscure segments. *Hard smooth exoskeleton or covered with wax or tough scales*	Males are active
Wingless	Front pair of wings highly developed, Hind 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.

FAMILY : ALEURODIDAE
(WHITEFLIES AND BLACKFLIES) (తెల్ల దోమ)

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*

Bemisia tabaci (పత్తిలో తెల్ల దోమ)



Spiralling whitefly (సర్పిలాకార తెల్ల దోమ)

- 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 (honey dew excreting organ) 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)

Family : LOPHOPIDAE (Aeroplane bugs)

Sugarcane Leafhopper : *Pyrilla perpusilla*

Sugarcane Pyrilla (చెరుకు దూదేకుల పురుగు)

- Head is produced into snout (or) rostrum
- *Hind trochanter is directed backward*
- Hind basitarsus is moderately long
- Both nymphs and adults sucksap, and reduce the quality and quantity of juice
- *Nymph has pair of anal filaments covered with whitish fluffy waxy material*

LECTURE 27 & 28

NEUROPTERA

General characters - Chrysopidae- characters with examples

LEPIDOPTERA

General characters

Differences between moths and butterflies

General characters of families: Noctuidae, Lymantriidae, Sphingidae, Pieridae- Characters with examples

General characters of families: Pyralidae, Crambidae, Gelechiidae, Lycaenidae, Arctiidae, Papilionidae, Saturniidae and Bombycidae - Characters with examples

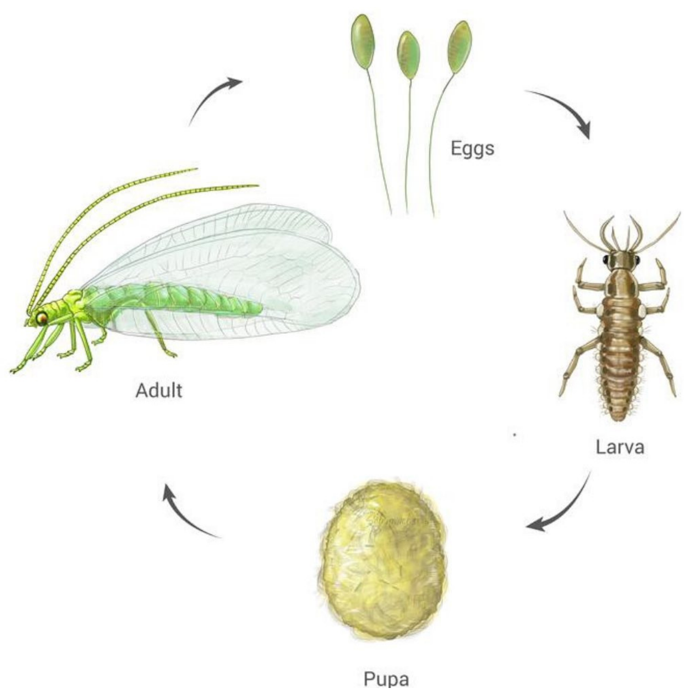
ORDER : NEUROPTERA

Neuro : Nerve, Ptera: Wings,
Wings with net like patterns of veins

LACEWINGS, APHID IONS, ANT LIONS, ALDER FLIES, SNAKE FLIES (అల్లిక రెక్కల పురుగు)

- Neuroptera have two pairs of similar size membranous wings with a complex, net-like pattern of veins.
- They are rather fragile insects and weak fliers
- Antennae filiform, with or without terminal club
- Adults and larva have chewing mouthparts; larva with very strong elongated mandibles, but some larval mouthparts is modified for piercing and sucking.
- Larva is compodiform and predaceous.

- Lacewings and their immature forms, known as *aphid lions*, are the most common insects in this order, and both adults and larvae feed on aphids. Immature *antlions* are called "doodlebugs." They form pits in dry, dusty soil.
- Adult green lacewings can be found throughout the year. They are considered beneficial because they feed on other insects.
- Six out of eight malpighian tubuls are modified as silk glands
- Larvae spin cocoons through anal spinneret, and pupation takes place in silken cocoon.



FAMILY : CHRYSOPIDAE
GREEN LACEWINGS, APHID LIONS, GOLDEN EYES
(అల్లిక రెక్కల పురుగు)

Common Green Lacewing : *Chrysoperla carnea*

- Body is pale green in color
- *Eggs are mounted on stalks* to avoid predation and cannibalism
- Larvae prey on soft bodied insects, especially aphids, often carry layer of debris on its body which provides camouflage
- They emit a stinking fluid when alarmed, from prothoracic stink glands
- They are mass multipled and released in field for control of aphids

ORDER : LEPIDOPTERA

Lepido: Scales, Ptera: Wings, Scaly winged Insects

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 are about 1,50,000 named species most (more than 85 percent) of which are Moths, may be in 3rd place with the Diptera behind the Hymenoptera and the Coleoptera.

The insects belong to this order, has *great economic importance,* as most of its members are crop pests, and some are productive insects, pollinators, predators and are useful (silkworm).

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
Mouth parts	*Siphoning type in Adults*, represented by *long coiled proboscis formed by the galea of maxilla*, Maxillary palpi small or lacking, *Mandibles are absent*. *Chewing and biting type in larva*.
Wings	*Two pairs of membranous wings covered with scales giving beautiful color patterns*. Forewings are usually large. *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. In *males of various insects, scales known as androconia occur on upper surface of the wings* and serve as the outlets of *odoriferous glands.*
Wing coupling	*Frenulum and retinaculum or Amplexiform type*
Larva	Larvae are called *caterpillars* (eating machine) usually *eruciform, are mostly phytophagous* and very serious pests of crops. Larvae have well developed head and cylindrical body consisting of 13 segments (3 thoracic+10 abdomenal). 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*, useful for spinning silk. Each of the thoracic segments of larvae bears a pair of segmented legs (true legs) which end in a point. Abdominal segments 3,4,5,6 and 10th usually bear a pair of non-segmented legs (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 is the product of this order
Metamorphosis	Complete metamorphosis

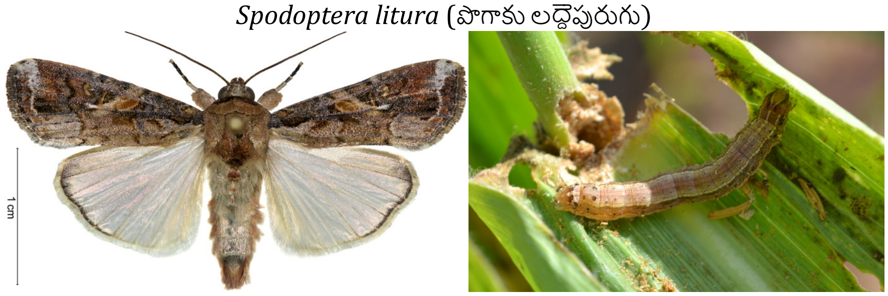
Character	***Butterflies***	***Moths***
Antenna	Have *thin slender filamentous* antenna, *have small balls or clubs at the tip of antenna*	*Lack club ends*, usually *comb like* or feathery antenna
Wing	Most have *bright colors* on their wings.	Moths have *dull colored* wings. However many day flying 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 : NOCTUIDAE (ARMY WORMS AND CUT WORMS)

Gram Pod Borer	: *Helicoverpa armigera*
Tomato or Chilli Fruit Borer	: *Helicoverpa armigera*
Tobacco Cut Worm/ Caterpillar	: *Spodoptera litura*
Fall Armyworm	: *Spodoptera frugiperda*
Paddy Swarming Cutoworm	: *Spodoptera mauritia*
Castor Semi Looper	: *Achaea 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*

Helicoverpa armigera (శెనగ పచ్చ పురుగు)

Spodoptera litura (పొగాకు లద్దెపురుగు)

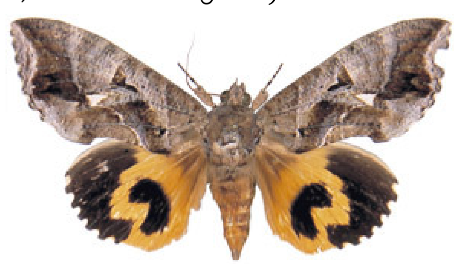


Spodoptera frugiperda (మొక్కజొన్న కత్తెర పురుగు)


Spodoptera mauritia (వరి కత్తెర పురుగు)


Achaea janata (ఆముదం దాసరి పురుగు / నామాల పురుగు)


Earias vitella (బెండ కాండం, కాయ తొలుచు పురుగు)

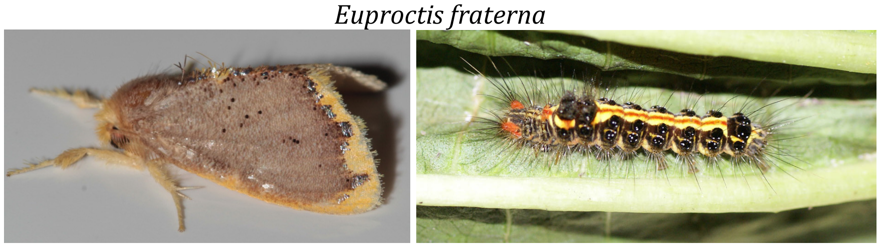
Othreia materna *Othreis fullonica*
(నిమ్మ, బత్తాయి పండ్లలో రసం పీల్చు రెక్కల పురుగు)

- *Largest family of Order Lepidoptera*; medium sized nocturnal moths (active at night) attracted to sugar mixture and light.
- *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 prolegs*, but in some due to absence of prolegs 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 nocturnal. 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*) and citrus fruit sucking moths (*Othreis materna, Othreis fullonica*)

FAMILY : LYMANTRIIDAE
(TUSSOCK MOTHS, GYPSY MOTHS)
(HAIRY CATERPILLARS) (బొచ్చు పురుగులు / గొంగళి పురుగులు)

Hairy caterpillar on fruit trees, pulses, castor	*Euproctis fraterna*
	Euproctis scintillans
Casuarina hairy caterpillar	*Lymantria incerta*
Gypsy Moth	*Lymantria dispar*
Paddy Yellow hairy caterpillar	*Psalis secures*


Euproctis fraterna


Euproctis scintillans

Gypsy Moth: Lymantria dispar
(Adult Female, Adult Male, Larva)

- "*Lymantria*" means "*Destroyer*", and larvae of several species are defoliators causing severe damage to field crops and forest species.
- Medium sized, dull colored, nocturnal moths, and *do not feed*, as the *Proboscis is atrophied (rudimentary)*.
- In some, female moths have only rudimentary wings.
- Males have tympanal organs
- Ocelli absent
- *Antenna bi-pectinate in males*; *Antenna pectinate or plumose in Females*, thus showing *sexual dimorphism*.
- Wing venation resembles Noctuidae. Sub costa (Sc) and Radius (R) fused to some extent and basal areole is larger in some species in hind wings.
- The caudal extremity of *females is often provided with the large tuft of anal hairs* which are deposited as a covering on egg masses.
- *Caterpillars are densely hairy*, often with thick compact dorsal tufts on certain segments. Some caterpillars have *urticating hairs which cause irritation* and painful reactions. *Osmeteria are frequently present on 6th and 7th abdominal segments*.
- Pupation takes place in a cocoon above ground, and characterized by evident setae.

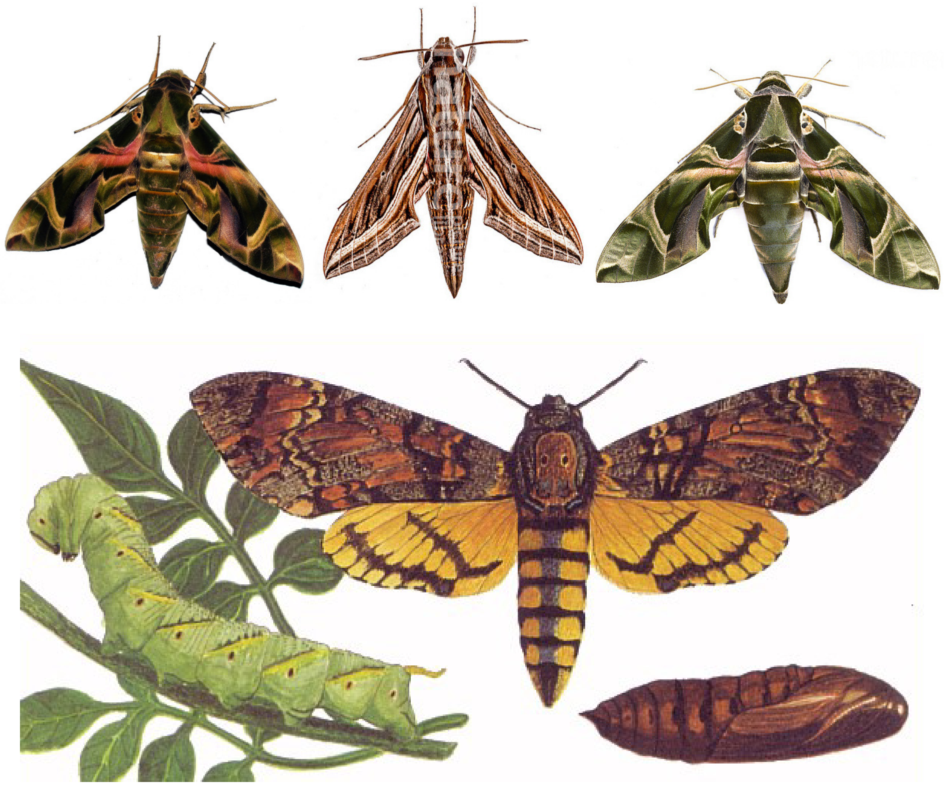
FAMILY : PIERIDAE (WHITES AND SULPHURS)

Dhaincha butterfly : *Eurema hecabe* (Common grass yellow)

- They are white or yellow or orange colored with black markings
- Larva is green, elongate, ringslike body segments, covered with fine hairs.

FAMILY : SPHINGIDAE
(SPHINX / HAWK MOTHS / DEATHS HEAD MOTHS)
(HORN WORMS) (దెయ్యం తల పురుగు / కొమ్ము పురుగు)

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 & Fruit Borer : *Leucinodes orbonalis*
Mango Leaf Webber : *Orthaga exvincea*
Sapota leaf webber : *Nephopteryx eugraphylla*

Paddy stem borer
(వరి కాండం తొలుచు పురుగు)

Jowar Stem borer
(జొన్న కాండం తొలుచు పురుగు)

Brinjal shoot and fruit borer (వంగ కాండం మరియు కాయ తొలుచు పురుగు)

- These are small, delicate, *snout moths* with well developed antennae.
- 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 broad with Sc and R usually fused or closely parallel for a short distance beyond distal cell.
- Larvae are naked, number of prolegs 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 : CRAMBIDAE (treated as sub-family of PYRALIDAE) (GRASS MOTHS)



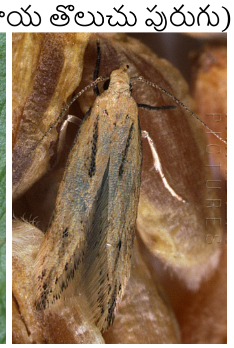
FAMILY : GELECHIIDAE (GRAIN MOTHS, TUBER MOTHS)

Groundnut Leaf Miner : *Aproaerema modicella*
Potato Tuber Moth : *Phthormoea operculella*
Cotton Pink Boll Worm : *Pectinophora gossypiella*
Angoumois grain moth : *Sitotroga cerealella*


Cotton Pink Bollworm (పత్తి గులాబీ మచ్చల కాయ తొలుచు పురుగు)

Groundnut leafminer

Potato tuber moth



Grain moth

- 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 curved and R5 and M1 are stalked.

FAMILY : LYCAENIDAE (COPPERS AND HAIR STREAKS)

Pomegranate fruit borer : *Virachola isocrates*
Redgram blue butter fly : *Catochrysops cnejus*

- Medium sized butterflies with upper surface of wings being metallic blue or coppery, dark brown or orange, and under surface more sobre with delicate streaking or dark centered eye spots.
- *Hind wings are with delicate tail like prolongations*.
- Usually *male is with shining blue, and female is iridiscent brown*.
- Each compound eye is surrounded by a rim of white scales and antenna ringed with white
- Legs are normal except fore legs of males may possess more or less shortened tarsi, and may one or more claws wanting
- Larvae are characteristic with both ends tapering, and broad projections sides concealing legs.
- Larva are voracious feeders, some species are carnivores
- Pupa is attached to the surface by its anal end, and is held by a central girth of silk

FAMILY : ARCTIIDAE (TIGER MOTHS / WOOLY BEARS)

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.


Bihar Hairy Caterpillar (బిహారీ గొంగళి పురుగు)


Utetheisia pulchella *Argina astria*

Sunhemp Hairy Caterpillar (జనుము గొంగళి పురుగు)


Red Hairy Caterpillar (ఎర్ర గొంగళి పురుగు)

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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 tubercles* 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

(నిమ్మ సీతాకోకచిలక / ఆకు తిను పురుగు)

FAMILY : BOMBYCIDAE (SILKWORM MOTHS)

Mulbery silkworm : *Bombyx mori*



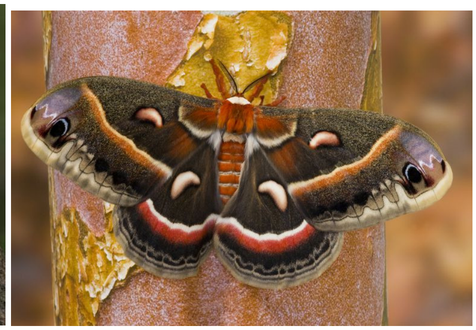
Silkworm (పట్టు పురుగు)

- *Antenna bi-pectinate*
- Larvae is either with tuft of hairs or glabrous with medio dorsal horn on the 8th abdomenal segment
- Pupation occurs in *dense silken cocoon*

Family : SATURNIIDAE (Wild silk moths / Royal moths)

Luna Moth *Actias luna*

Cecropia moth *Hyalophora cecropia*



- The family contains some of the *largest species of moths in the world*. Notable members include the emperor moths, royal moths, and giant silk moths.
- *Adults are characterized by large, lobed wings*, heavy bodies covered in hair-like scales, and reduced mouthparts.
- They lack a frenulum, but the hindwings overlap the forewings to produce the effect of an unbroken wing surface.
- Saturniids are sometimes brightly colored and often have translucent eyespots or "windows" on their wings.
- Males generally are distinguished by their larger, broader antennae. The antenna is pectinate.
- The larvae are stout and smooth, and differ from other families in possessing scoli

LECTURE : 29 & 30

COLEOPTERA

General characters; Scarabaeidae, Coccinellidae, Chrysomelidae, Cerambycidae, Bruchidae, Apionidae and Curculionidae - Characters with examples

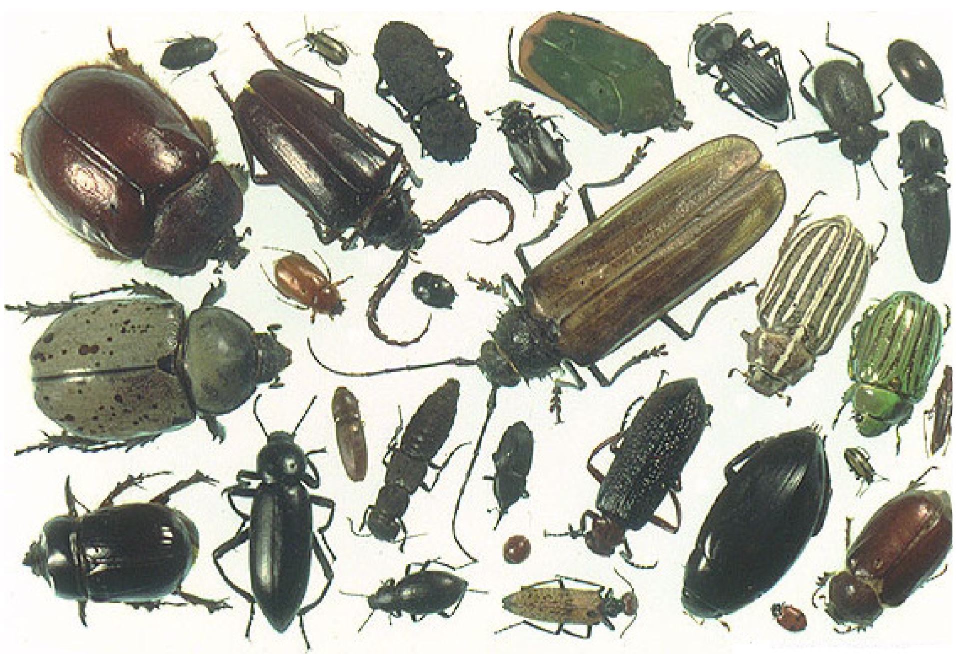
ORDER : COLEOPTERA

Coleo: Sheath, Ptera : Wings, Sheathed winged Insects

BEETLES AND WEEVILS

(పెంకు పురుగులు / ముక్కు పురుగులు)

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.



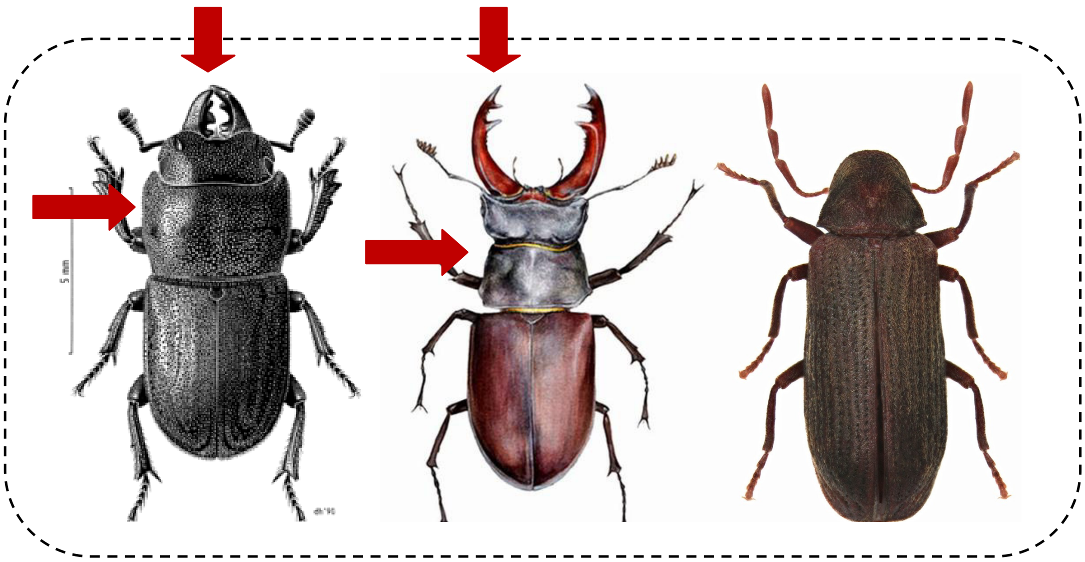
Taxonomic characters:

Head — *Highly sclerotized*, *free*, normal (beetles) or prolongated into snout (weevils)

Antennae — Variable, usually *11 segmented*

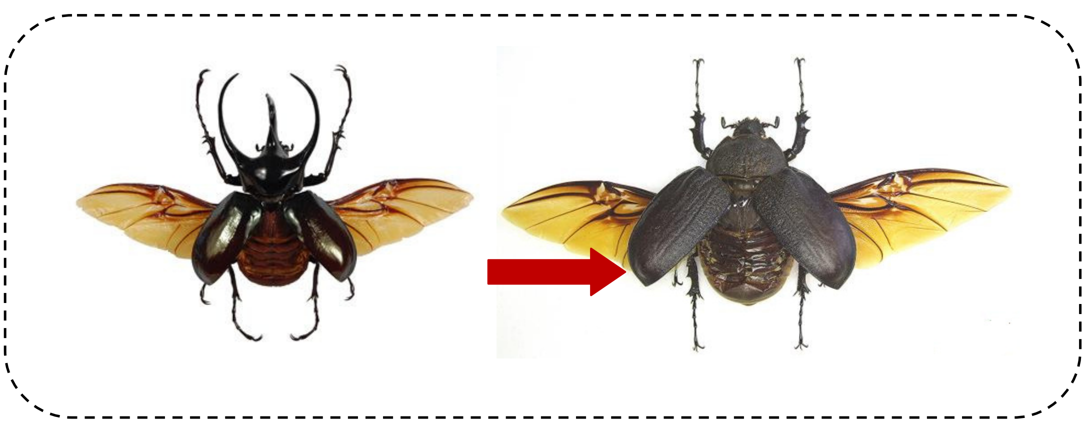
Compound eyes — Normal, ocelli absent

Mouth parts — *Chewing type with well developed mandibles*.
The mandibles attain their greatest size in males of stag beetles (Family Lucanidae)

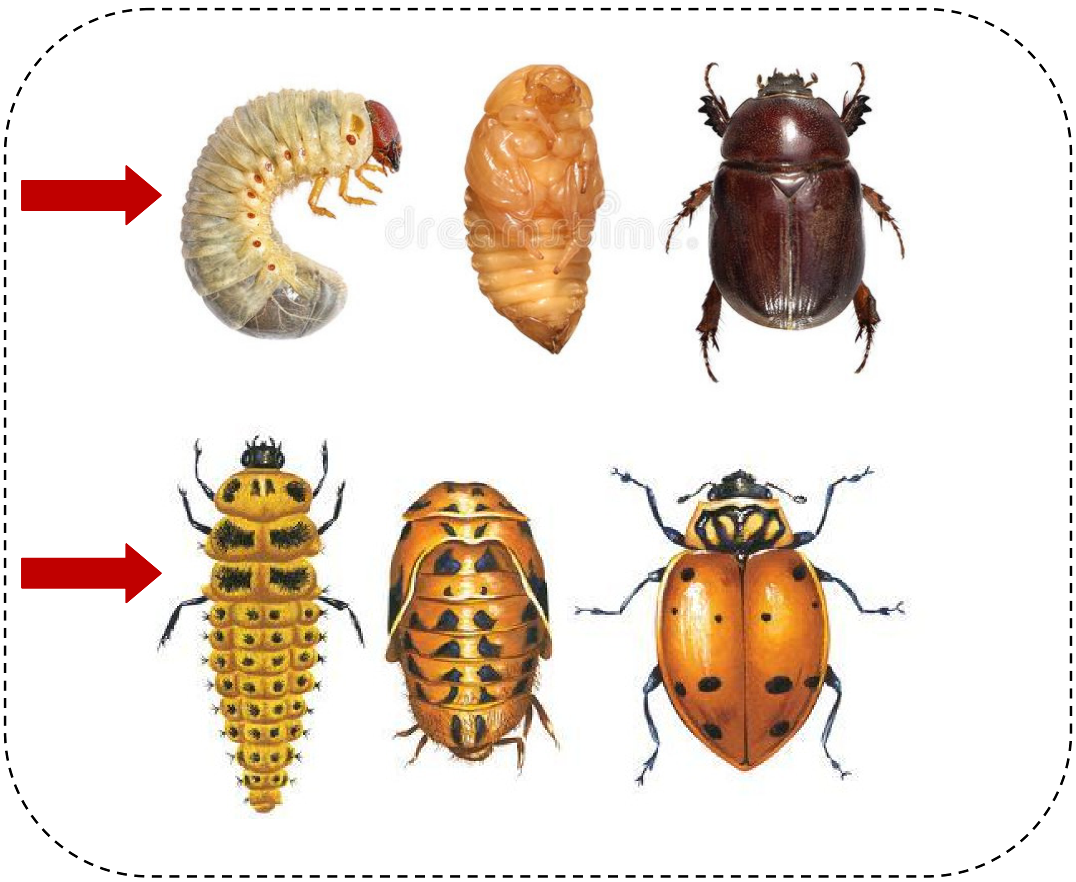


Thorax — *Prothorax large and freely movable*. Mesothorax much reduced and fused with metathorax, and the tergum of these segments is divisible into prescutum, scutum and scutellum.

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 are *principle feeding stages*, but some of the beetle larvae are predacious in nature (coccinellidae). Grubs are with hardened head, soft body, with chewing mouth parts. Some grubs are highly mobile (*Campodeiform* in Coccinellids), and some resemble hardened worms with dark head capsule and minute thoracic legs (*Scarabaeifrom* larva in Scarabidae). Abdomenal legs absent in Grubs.



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
(అక్షింతల పురుగులు)

A predator on Aphids : *Menochilus sexmaculata*
Coccinella septumpunctata
A predator on cottony cushiony scale : *Rodolia cardinalis*
Hadda Beetles on Brinjal (PEST) : *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.


Menochilus sexmaculatus
పేనుబంక తినే
అక్షింతల పురుగులు

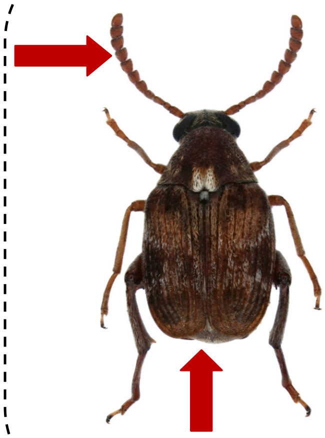

Rodolia cardinalis
పొలుసు పురుగులను తినే
అక్షింతల పురుగులు


Henosepilachna spp.
వంకాయ ఆకుతినే
అక్షింతల పురుగులు

- 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.

FAMILY : BRUCHIDAE
(SEED BEETLES, PULSE BEETLES)
(అపరాల తినే పెంకు పురుగు)

Pulse beetles : *Callosobruchus chinensis, Callosobruchus 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.

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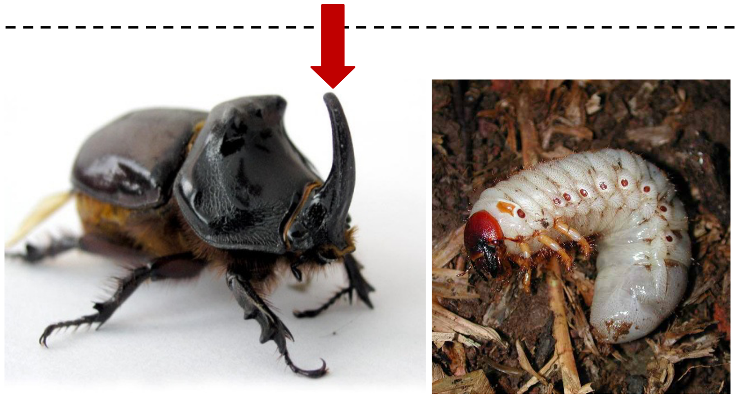
FAMILY : SCARABAEIDAE
(CHAFER /HORN BEETLES, DUNG ROLLERS, ROOT GRUBS)
(కొమ్ము పురుగు / పేడ పురుగు / వేరు పురుగు)

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



Coconut Rhinoceros Beetles (కొబ్బరి కొమ్ము పురుగు)

Holotrichia consanguina (వేరు పురుగు)

- 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*

Rice Hispa
(వరి తాటాకు తెగులు)

Red Pumpkin Beetle
(గుమ్మడి పురుగులు)

Tortoise Beetle
(తాబేలు లాంటి పెంకుపురుగులు)

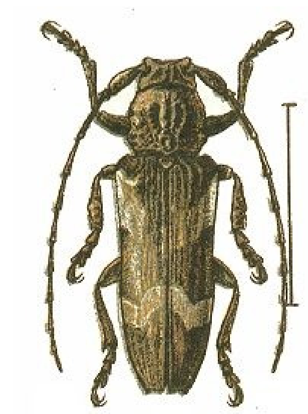
- Usually small to medium, *oval or sphere shaped beetles* with the *upper surface of the body generally bare and shining, frequently with metabolic colouration*
- Antennae short or moderate length usually with 11 segments, except in this character, they usually resemble cerambycids
- *Legs short. Hind femora enlarged for jumping* in many. *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.
- Adults generally feed on leaves causing numerous holes and also on flowers.
- Some grubs feed on foliage, some act as leaf miners and some feed on roots and stems also.

FAMILY : CERAMBYCIDAE
(LONG HORNED WOOD BORING BEETLES)
(కాండంతొలుచు పెంకుపురుగులు)

Mango stem borer : *Batocera rufomaculata*
Cashew Tree Borer : *Plocaederus ferrugineus*
Grape stem borer : *Crelosterna scabrator*
Grapevine stem girdler : *Sthenias grisator*

Mango stem borer
మామిడి
కాండంతొలుచుపురుగు

Cashew tree borer
జీడిమామిడి
కాండంతొలుచుపురుగు

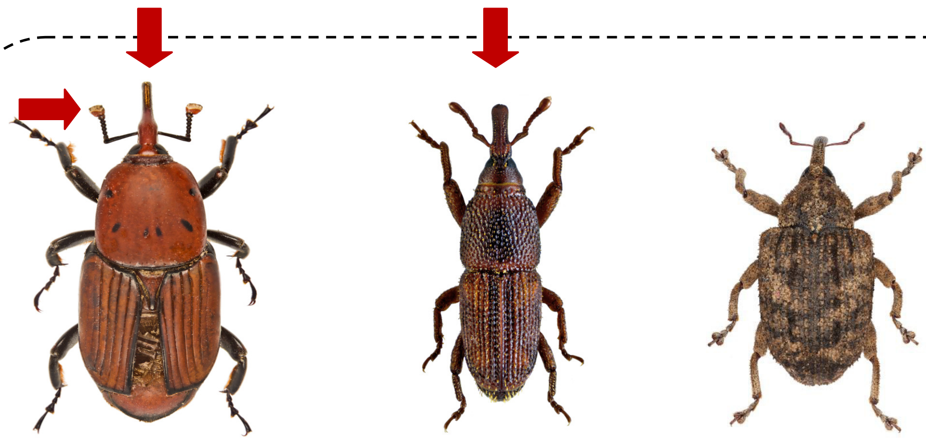


Grape stem girdler
ద్రాక్ష కాండంపురుగు

- These are *elongate and cylindrical beetles*
- Have *very long filiform / serrate 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
- Most of the *grubs are tree borers*. Few are confined to roots with powerful mandibles boring into deep and hardwoods, and also highly destructive.
- Most of the *adults feed on flowers and some of them produce squeaking sound when picked up*.

FAMILY : CURCULIONIDAE
(WEEVILS OR SNOUT BEETLES)
(ముక్కు పురుగులు)

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*



Red Palm Weevil (కొబ్బరి ముక్కుపురుగులు)   *Rice weevil* (బియ్యం ముక్కుపురుగులు)   *Mango Nut Weevil* (మామిడి టెంకెపురుగు)

- 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 : APIONIDAE (PEAR SHAPED WEEVILS)

Jute stem weevil : *Apion corchori*

- Antenna clavate, rarely geniculate
- Trochanter elongated
- Ventral surface of mentum without projecting setae
- In the larvae, the abdomenal segments have only two dorsal folds and the frontal sulci extended to the mandibular articulation

LECTURE : 31

HYMENOPTERA

General characters

Tenthredinidae, Ichneumonidae, Braconidae, Chalcididae, Trichogrammatidae, and Apidae- Characters with examples

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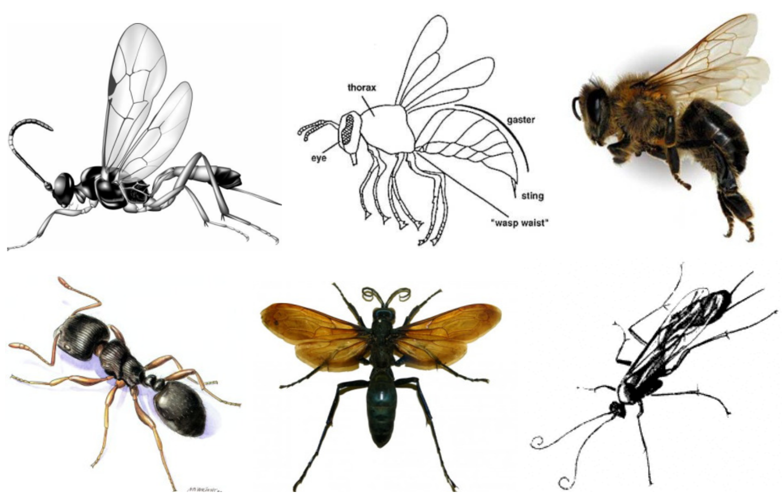
ORDER : HYMENOPTERA

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

(WASPS, ANTS, BEES, SAWFLIES) (కందిరీగలు, చీమలు, తేనెటీగలు)

This is the *most important beneficial order* in class Insecta comprising parasites, predators and bees involved in pollination and honey production. The name refers to *hymen: membrane and pteron: wing.* The hindwings are connected to the forewings by a series of hooks called *hamuli*.

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.

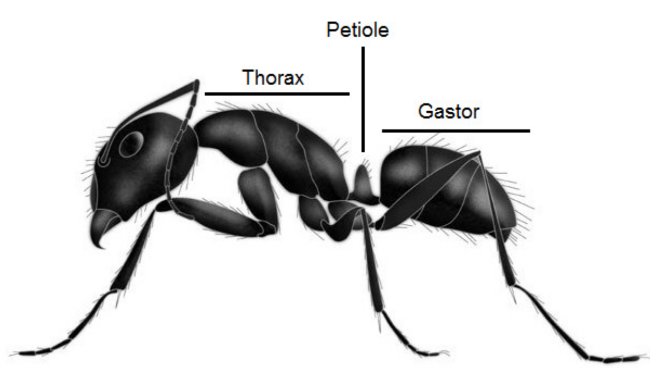


Taxonomic characters:

Head — Varied in size and shape. *Head is free from thorax and often extremely mobile*.

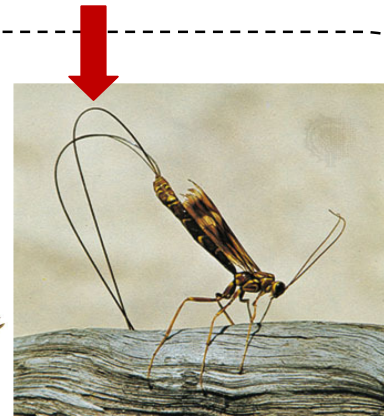
Antennae — Variable, usually exhibit *sexual dimorphism* being longer in males.

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 abdomenal segments are enlarged, collectively called *gastor*.

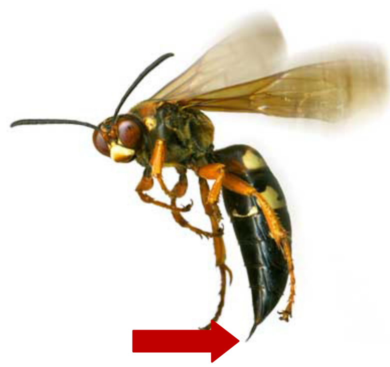


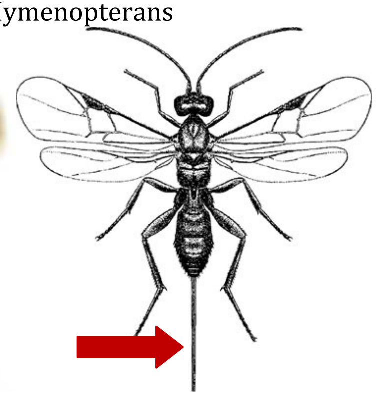
Ovipositor	Very well developed and modified for sawings, boring and piercing. It is *modified for piercing*, and, in some cases, is several times the length of the body. In some species, the ovipositor has become *modified as a stinger*, and the eggs are laid from the base of the structure, rather than

from the tip, which is used only to inject venom. The stinger is typically used to immobilize prey, but in some wasps and bees may be used in defense.



Ovipositors in Hymenopterans





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 prolegs (sawfly)*.

Pupa — Exarate and a cocoon is generally present.

Metamorphosis — Complete

FAMILY : TENTHREDINIDAE
(SAW FLIES OR WOOD WASPS)

Mustard saw fly : *Athalia lugens proxima*

Mustard Sawfly (ఆవాలు ఆకుతినేపురుగు)

- 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 prolegs (while lepidopteran larvae will never have morethan 5 pairs of prolegs/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 attack stored products (Indian meal moth, *Plodia interpunctella*), nuts
Apanteles flavepis (=Cotesia 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

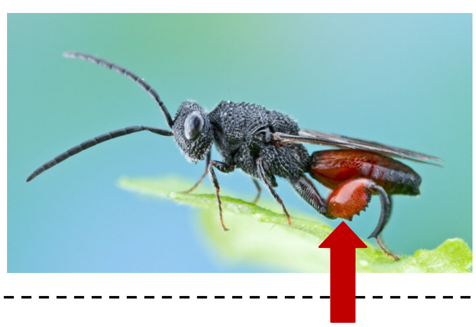
- Family of *parasitoid wasps* & *one of the richest families of insects, with* 150,000 sps

- 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 : CHALCIDAE
(CHALCID WASPS)

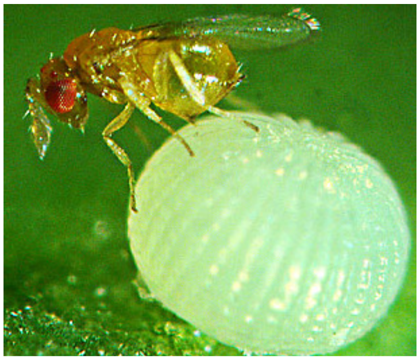
Brachymeria nephantidis *A pupal parasite on coconut black headed caterpillar*



- Medium to small sized insects
- *Hind coxa are 5 to 6 times larger than the fore coxa*
- Hind tibial spurs are larger than mid tibial spurs
- Hind femora are larger with a row of short teeth beneath
- *Wing venation is reduced to single anterior vein*
- Ovipositor short and straight

Family : **TRICHOGRAMMATIDAE (Trichogrammatids)**
(పురుగుల గుడ్లు మీదబతికే బదనికలు)

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

FAMILY : APIDAE
(HONEY BEES) (తేనెటీగలు)

Indian Honey Bee : *Apis indica*


- Body is covered wih branching or plumose hairs
- Mouth parts are *chewing and lapping type*
- Mandibles are suitable for crushing and shaping wax for building combs
- *Legs specialized* for pollen collection, and scope (pollen basket) is present in hind tibia
- They are *social insects* with three castes *viz.,* queen, drones and workers

LECTURE : 32

DIPTERA

General characters
Culicidae, Cecidomyiidae, Muscidae, Tachinidae, Agromyzidae and Tephritidae - Characters with examples

ORDER : DIPTERA

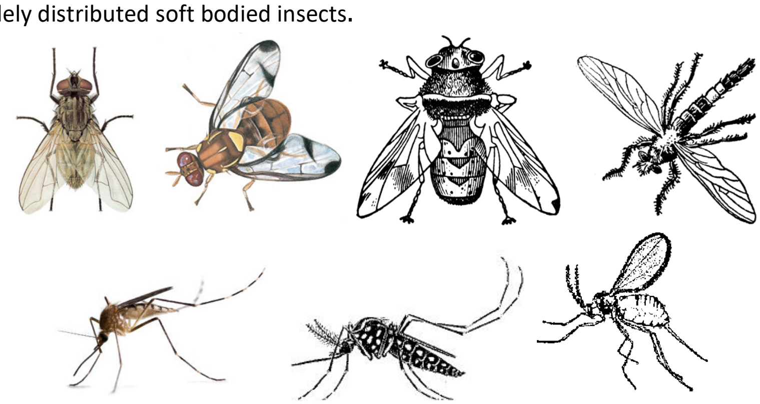
(TRUE FLIES, MOSQUITOES, MIDGES)

(ఈగలు, దోమలు, రెండు రెక్కల పురుగులు)

(Di: two; ptera: wings; two winged insects)

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.

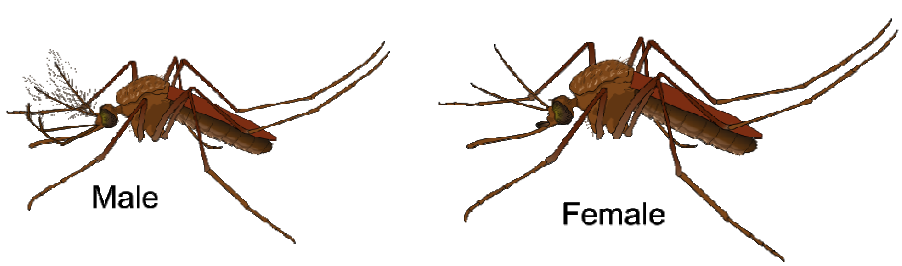
Order Diptera is *economically very important* comprising of important crop pests, parasites, blood sucking mosquitoes acting as vectors of human disease, predators etc. Diptera is a large order, containing an estimated 2,40,000 species of mosquitoes, gnats, midges and others. They are an incredibly 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. They are 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, House flies-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 : CULICIDAE
(MOSQUITOES) (దోమలు)
Anopheles spp; Culex spp



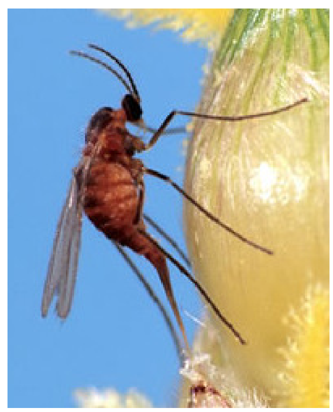
- They are delicate, fragile and slender insects
- Females have piercing and sucking mouth parts with 6 stylets
- *Antenna is plumose (bushy) in male and pilose in female*
- Wings are fringed with hairs and scales on hind margin, and on some veins

- Males are short lived and feed on nector or decaying fruits
- Females live long and are blood suckers
- *Larvae are called wrigglers*
- Larval head is large with chewing mouth parts
- Respiratoy siphon in located in the penultimate abdomenal segment
- Anal gills are present at the terminal end of the abdomen
- *Pupa is called tumbler*, is active. It has pair of prothoracic horns which houses the anterior parts of spiracles
- A pair of anal paddles is present at the terminal end aids in swimming

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*

Rice Gall Midge
వరి ఉల్లికోడుదోమ


Sorghum Earhead Midge
జొన్న కంకినల్లి

- 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 Diptera. Broad wing with few longitudinal veins (3 to 5), most part unbranched with no obvious cross veins

- *Larva live in plants 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)(పండు ఈగ)

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* (పాము పొడ తెగులు)
Pea stem fly : *Ophiomyia phaseoli (Melanagromyza phaseoli)*
Red gram pod fly : *Melanagromyza obtuse*

- 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) (కాండం ఈగ)

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

FAMILY : TACHINIDAE
(TACHINID FLIES – PARASITIC FLIES)

Sturmia bimaculata *Parasitoid on Spodoptera litura and other caterpillars*
Exorista civiloides *Parasitoid on many caterpilars*

- Small to medium, conspicuously bristly or hairy, active flies
- Head is large an free.
- Arista on antenna often bare
- Pteropleural bristles are present
- Wings are large, rarely mottled
- Larvae mostly parasitoids

COMMON NAMES & SCIENTIFIC NAMES

Order	Common Name	Family	Common Name
APTERYGOTA			
Thysanura	Silver fish Bristle tails		
Diplura	Pronged Bristletails Diplurans		
Protura	Proturans Telson tails		
Collembola	Springtails Snow fleas		
EXOPTERYGOTA			
Ephemeroptera	May-flies		
Odonata	Dragon flies Damsel flies		
Plecoptera	Stone-flies		
Grylloblattodea	Ice bugs/Rock Crawlers		
Orthoptera	Grasshoppers Locusts Crickets Mole Crickets	Acrididae	Short Horned Grass Hoppers, Locusts
		Tettigonidae	Long Horned Grasshoppers, Kaytids
		Gryllidae	Crickets
		Gryllotalpidae	Mole Crickets
Phasmida	Stick-Insects		
Dermaptera	Earwigs		
Embioptera	Web Spinners		
Dictyoptera	Cockroaches Mantis	Mantidae	Mantis Stick Insects
		Blattidae	Cockroaches
Isoptera	Termites	Termitidae	Termites White Ants
Zoraptera	--		
Psocoptera	Book lice Bark lice		
Mallophaga	Biting Lice		
Siphunculata	Sucking Lice		

Hemiptera	True Bugs	Cimicidae	Bed Bugs
		Pentatomidae	Stink Bugs Shield Bugs
		Lygaeidae	Seed Bugs
		Miridae	Mirid Bugs
		Pyrrhocoreidae	Red cotton bugs Cotton stainers
		Coreidae	leaf footed bugs
		Cicadellidae	leaf hoppers / jassids
		Delphacidae	plant hoppers
		Aphididae	Aphis Plant Lice
		Pseudococcidae	Mealy Bugs
		Coccidae	Scales
		Aleurodidae	Whiteflies Blackflies
		Lophopidae	Aeroplane Bugs
Thysanoptera	Thrips	Thripidae	Thrips
ENDOPTERYGOTA			
Neuroptera	Lacewings Aphid Lions Ant lions Snakeflies Alderflies	Chrysopidae	Green Lacewings Aphid lions
Mecoptera	Scorpionflies		
Siphonaptera	Fleas		
Coleoptera	Beetles	Coccinellidae	Ladybird beetles
		Bruchidae	Seed Beetles Pulse Beetles
		Scarabaeidae	Chaffer Beetles Horn Beetles Dung Rollers Root Grubs
		Chrysomelidae	Flea Beetles Leaf Beetles Tortoise Beetles
		Cerambycidae	Long Horned Beetles
		Curculionidae	Weevils Snout Beetles
		Apionidae	Pear shaped weevils
Strepsiptera	Stylops		

Diptera	True Flies Mosquitoes	Culicidae	Mosquitoes
		Cecidomyiidae	Gall Midges Gall Flies
		Tephritidae	Fruit flies
		Agromyzidae	Leaf Miners
		Muscidae	Shoot flies
		Tachinidae	Tachinid flies
Lepidoptera	Butterflies Moths	Noctuidae	Army worms Cut Worms
		Lymantriidae	Tussock Moths Gypsy Moths
		Sphingidae	Sphinx moth Hawk Moth Horn Worms Deaths Head Moth
		Piridae	Whites, Sulphurs
		Pyralidae	Snout Moths
		Gelechiidae	Grain Moths Tuber Moths
		Lycaenidae	Coppers
		Arctiidae	Tiger Moths Wooly Bears
		Papilionidae	Swallow Tails
		Bombycidae	Silkworm Moths
		Saturnidae	Wild Silkworm Moths Tiger Moths
Trichoptera	Caddis-flies		
Hymenoptera	Ants Bees Wasps	Tenthredinidae	Saw flies
		Ichneumonidae	Ichneumonid wasps
		Braconidae	Braconid Wasps
		Chalcidae	Chalcid Wasps
		Trichogrammatodae	Egg Parasitoids
		Apidae	Honey bees

Family	Name of the Insect	Scientific Name
Acrididae	Rice grasshopper	*Hieroglyphus banian*
	Rice small grasshopper	*Oxya nitidula*
	Desert Locust	*Schistocerca gregaria*
Tettigonidae	Surface grasshopper	*Conocephalus indicus*
Gryllidae	Common cricket	*Gryllus personatus*
Gryllotalpidae	Oriental Mole Cricket	*Gryllotalpa orientalis*
Mantidae	Greenhouse mantis	*Mantis religiosa*
Blattidae	American cockroach	*Periplanata Americana*
	Oriental cockroach (common cockroach)	*Blatta orientalis*
Termitidae	Termites	*Odontotermis obesus, Microtermis obesi*
Thripidae	Chilli Thrips	*Scirtothrips dorsalis*
	Onion Thrips	*Thrips tabaci*
Cimicidae	Bed Bugs	*Cimex lecturalis*
Pentatomidae	Green Stink Bug	*Nezara viridula*
	Cabbage Painted Bug	*Bagrada cruciferarum*
	Red Pumpkin Bug	*Aspongopus janus*
Lygaeidae	Dusky Coton Bug	*Oxycarenus laetus*
	Groundnut Pod Bug	*Elasmolomus (=Aphanus) sordidus*
Miridae	Paddy Mirid Bug	*Cyrtorhinus lividipennis*
	Tea Mosquito Bug	*Helopeltis antonii*
Pyrrhocoreidae	Red cotton bug	*Dysdercus cingulatus*
Coreidae	Rice gundhy bug	*Leptocorisa vericornis*
	Pulse pod bugs	*Clavigralla gibbosa*
Cicadellidae	Cotton leaf hopper	*Amrasca biguttula biguttula*
	Paddy leaf hopper	*Nephotettix virescens*
	Mango leaf hopper	*Amritodus atkinsoni*
Delphacidae	Brown plant hopper (BPH) on paddy	*Nilaparvata lugens*
	White backed plant hopper (WBPH) in paddy	*Sogatella furcifera*
Aphididae	Cotton aphid	*Aphis gossypii*
	Maize / tobacco aphid	*Myzus persicae*
	Bean/groundnut aphid	*Aphis craccivora*
	Apple aphid	*Eriosoma lanigerum*
Pseudococcidae	Sugarcane Mealy Bug	*Saccharicoccus sacchari*
	Grapevine Mealy Bug	*Mecanellicoccus hirsutus*
	Brinjal Mealy Bug	*Centrococcus insolitus*
Coccidae	Sugarcane Scales	*Melanapsis glomerata*
	Cottony Cushiony Scale/Citrus Scale	*Icerya purchase*

Aleurodidae	Cotton Whitefly	*Bemisia tabaci*
	Citrus Whitefly	*Dialeurodes disperses*
	Sugarcane Whitefly	*Aleurolobes barodensis*
	Spiralling Whitefly	*Aleurodicus disperses*
Lophopidae	Sugarcane Leafhopper	*Pyrilla perpusilla*
Chrysopidae	Common Green Lacewing	*Chrysoperla carnea*
Noctuidae	Gram Pod Borer Tomato Fruit Borer Chilli Fruit Borer	*Helicoverpa armigera*
	Tobacco Cut Worm/ Caterpillar	*Spodoptera litura*
	Castor Semi Looper	*Achaea 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* *Eudocema (Othreis) fullonia*
Lymantriidae	Hairy caterpillar on fruit trees, pulses, castor	*Euproctis fraternal* *Euproctis scintillans*
	Gypsy Moth	*Lymantria dispar*
Sphingidae	Gingelly deaths head moth	*Acherontia styx*
Piridae	Diancha butterfly	*Eurema hecabe*
Pyralidae	Paddy Stem Borer	*Scirpophaga incertulas*
	Jowar Stem Borer	*Chilo partellus*
	Brinjal Shoot & Fruit Borer	*Leucinodes orbonalis*
	Mango Leaf Webber	*Orthaga exvincea*
	Sapota leaf webber	*Nephopteryx eugraphylla*
Gelechiidae	Groundnut Leaf Miner	*Aproaerema modicella*
	Potato Tuber Moth	*Phthormoea operculella*
	Cotton Pink Boll Worm	*Pectinophora gossypiella*
	Angomois grain moth	*Sitotroga cerealella*
Lycaenidae	Pomegranate fruit borer	*Virachola isocrates*
Arctiidae	Bihar Hairy Caterpillar	*Spilosoma obliqua*
	Sunhemp Hairy Caterpillar	*Utetheisa pulchella, Argina astria*
	Red Hairy Caterpillar	*Amsacta albistriga*
Papilionidae	Citrus Butter fly	*Papilio demoleus*
	Curry leaf butter fly	*Papilio polytes*
Bombycidae	Mulbery silkworm	*Bombyx mori*
Saturnidae	Luna Moth	*Actias luna*
	Cecropia moth	*Hyalophora cecropia*

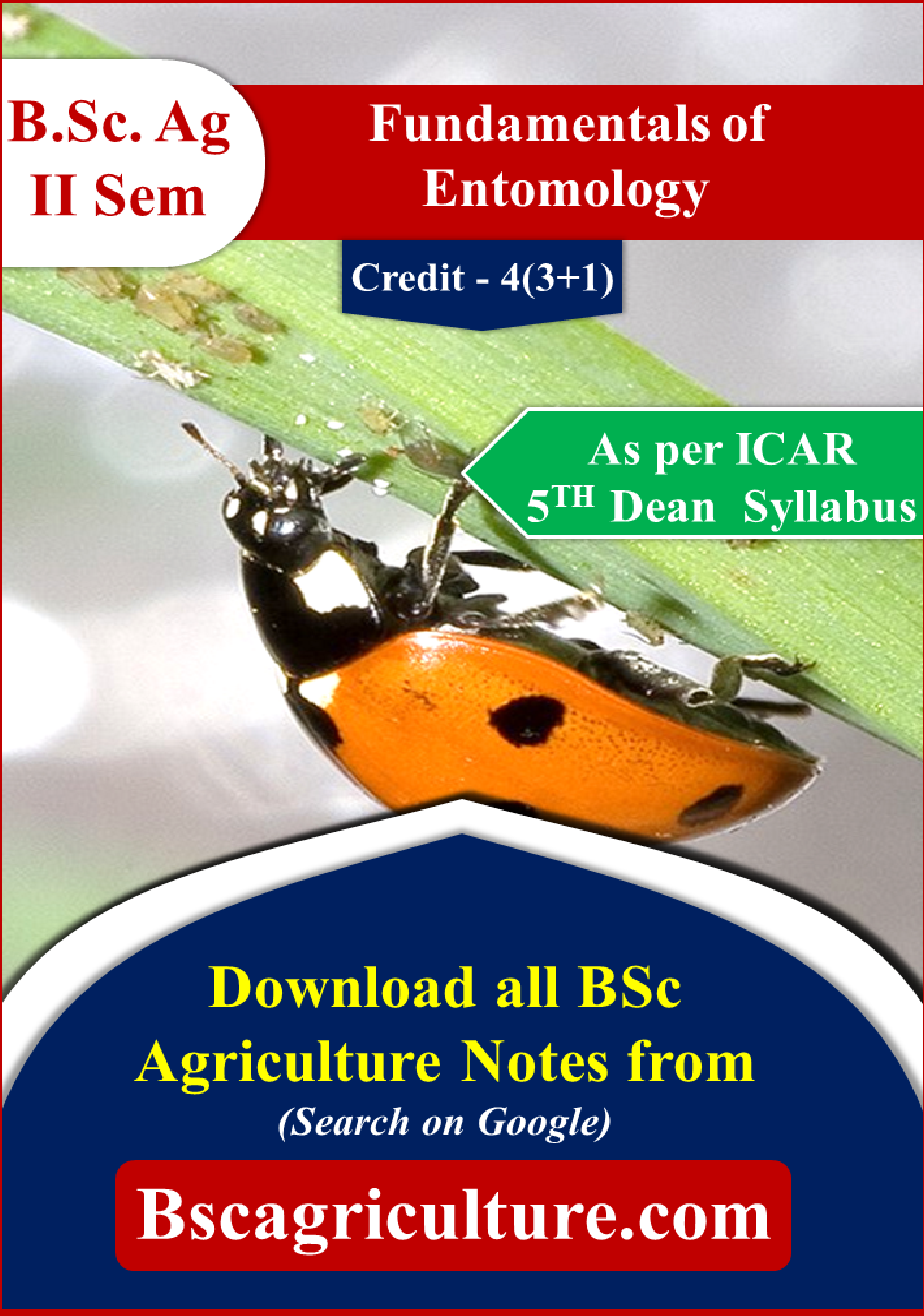
Coccinellidae	A predator on Aphids	*Menochilus sexmaculata* *Coccinella septumpunctata*
	A predator on cottony cushiony scale	*Rodolia cardinalis*
	Beetles on Brinjal (PEST) – Hadda Beetle	*Henosepilachna vigintioctopunctata* *Henosepilachna dodecastigma*
Bruchidae	Pulse Beetles	*Callosobruchus chinensis* *C. maculatus*
Scarabaeidae	Coconut Rhinoceros Beetle	*Oryctes rhinoceros*
	Root Grub in Sugarcane	*Holotrichia serrata,* *H. consanguina*
Chrysomelidae	Rice Hispa	*Dicladispa armigera*
	Red Pumpkin Beetle	*Aulacophora foveicollis*
Cerambycidae	Mango stem borer	*Batocera rufomaculata*
	Cashew Tree Borer	*Plocaederus ferrugineus*
	Grapevine stem girdler	*Sthenias grisator*
Curculionidae	Coconut red palm weevil	*Rhynchophorus ferrugineus*
	Rice weevil	*Sitophilus oryzae*
	Sweet potato weevil	*Cylas formicarius*
	Mango stone weevil	*Sternochetus mangiferae*
Apionidae	Jute stem weevil	*Apion corchori*
Tenthredinidae	Mustard saw fly	*Athalia lugens proxima*
Ichneumonidae	Larval parasitoid of sugarcane top shoot borer	*Isotoma javensis*
	Pupal parasitoid of jowar stem borer	*Xanthopimpla stemmator*
Braconidae	Larval parasitoid of several species of pyralid moths, that attack stored products (Indian meal moth, *Plodia interpunctella*), nuts	*Bracon hebetor*
	Larval parasitoid of several cereal stems borers	*Apanteles (=Cotesia) flavepis*
Chalcidae	*A pupal parasite on coconut black headed caterpillar*	*Brachymeria nephantidis*
Trichigrammatidae	Egg parasitoid on lepidopterans	*Trichogramma chilonis*
Apidae	Indian Honey Bee	*Apis indica*

Culicidae	Mosquitoes	*Culex spp, Anopheles spp.*
Cecidomyiidae	Rice Gall Midge	*Orseolia oryzae*
	Sorghum earhead midge	*Contarinia sorghicola*
	Midge on Chilli	*Asphondylia capsici*
Tephritidae	Mango fruit fly	*Bactrocera dorsalis*
	Cucurbit fruit fly	*Bactrocera cucurbitae*
Agromyzidae	American serpentine leaf miner	*Liriomyza trifolli*
	Pea stem fly	*Ophiomyia phaseoli (Melanagromyza phaseoli)*
	Red gram pod fly	*Melanagromyza obtuse*
Muscidae	Jowar shoot fly	*Atherigona varia soccata*

CHARACTERISTIC FEATURES OF DIFFERENT FAMILIES

CHARACTERISTIC FEATURE	FAMILY	EXAMPLES
Short-horned grasshoppers; femoro-alary type stridulation	Acrididae	Short horned grasshoppers
Fenestrae; Ootheca	Blattidae	Cockroach
Triangular Head, Raptorial fore legs	Mantidae	Preying Mantis
Moniliform Antenna; Frontonella	Termitidae	Termites
Fringed wings; rasping and sucking type of (asymmetrical) mouth parts	Thripidae	Thrips
5 segmented antenna; odoriferous glands; shield shape	Pentatomidae	Stink / shield bugs
4 segmented antenna; leaf like dilations on hind legs	Coreidae	Leaf footed bugs
Wingless bugs; human blood suckers	Cimicidae	Bed bugs
Wedge shaped; one or two rows of spines on hind tibia	Cicadellidae	Leaf hoppers
Large mobile apical spur on hind tibia	Delphacidae	Plant hoppers
Pair of cornicles on 5th or 6th abdomenal segments	Aphididae	Aphids
Wingless females; all instars freely moving	Pseudococcidae	Mealy bugs
Females are flattened, elongated insects with exoskeleton covered with wax	Coccidae	Scale insects
Vasiform orifices in last abdomenal segments	Aleurodidae	Whiteflies
Green lace wings; campodeiform larva; carnivores	Chrysopidae	Green lace wings
Larvae are cutworms, semiloopers; adults fruit sucking moths	Noctuidae	Army worms, cut worms
Snout moths, larvae are stem borers, leaf rollers, case worms	Pyralidae	Snout moths
Labial palpi upcurved	Gelechidae	Gelechids
Adults are tiger moths; larvae are wolly bears	Arctidae	Tiger moths
Tail-like prolongation in hind wings; fleshy dorsal tubercles on 4th segment	Papilionidae	Swallow tails
Long proboscis; larvae with horn on dorsum of 8th abdomenal segment	Sphingidae	Sphinx moth, horm worms

Bipectinate antenna; larvae are silk producers; meso dorsal horn on 8th abdomenal segment	Bombycidae	Silkworms
Big sized silk moths with attractive colors, can be reared on castor	Saturnidae	Eri and Tussar Silk worms
Elytra covers the abdomen completely; All species are predacious except *Henosepilachna*	Coccinellidae	Ladybird beetles
Short elytra never covers the tip of the abdomen; grubs undergo hyper metamorphosis	Bruchidae	Pulse beetles
Adult beetle with frontal horn, grubs "C" shaped	Scarabaeidae	Root grubs, chaffer beeltes
Flea / leaf beetles causing holes on leaves; grubs leaf miners	Chrysomelidae	Flea beetles
Beetles with long antenna capable of being flexed backwards; grubs tree borers	Cerambycidae	Long horned beetles
Phytophagous Hymenopterans; larvae with 10-11 pairs of legs	Tenthredinidae	Saw flies
Parasitic wasps; trochanter 2-segmented; long curved petiole, long ovipositor	Ichneumonidae	Ichneumonids
Stout parasitic insects; abdomen sessile; grubs pupate in silken cocoon on the body of host	Braconidae	Braconids
Hymenopteran family exclusive of egg parasitoids	Trichogrammatidae	Trichogrammatids
Flattened ovipositor; sub costa bends apically	Tephritidae / Trypeetidae	Fruit flies
Maggots leaf miners; bore into stems of seedlings	Agromyziidae	Leaf miner flies
Dark flies; maggots phytophagous; scavengers	Muscidae	Shoot flies
Sternal spatula / breast bone; paedogenesis is common	Cecidomyiidae	Gall flies / Gall Midges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