Course code: ENT-302

Course title: Introductory Entomology

Credit hours: 3(2-1)

Course contents

THEORY Introduction; phylum Arthropoda and its classification; morphology, anatomy and physiology of a typical insect, metamorphosis and its types; insect classification, salient characters of insect orders; families of economic importance with examples of each family.

PRACTICALS Characters of classes of Arthropoda; collection and preservation of insects; morphology and dissection of a typical insect (digestive, reproductive, excretory, nervous, circulatory and tracheal systems); temporary mounts of different types of appendages of insects; types of metamorphosis.

BOOKS RECOMMENDED 1. Ahmad, I. 2010. Hashriat ―Insects. National Book Foundation, Lahore 2. Awastheir, V.B. 2009. Introduction to General and Applied Entomology. Scientific Publisher, Jodhpur, India. 3. Dhaliwal, G.S. 2007. An Outline of Entomology. Kalyani Publishers, Ludhiana. 4. Elzinga, R.J. 2003. Fundamentals of Entomology. Prentice Hall. 5. Lohar, M.K. 2001. Introductory Entomology. Discipline of Entomology, Sindh Agriculture University Tandojam Sindh, Pakistan. 6. Richards, O.W. and Davies, R. G. 2004. Imm‘s General Text-book of Entomology, Vol. I. and II, 10th Ed. Chapman & Hall, London, N.Y. 7. Triplehorn, C.A. and Jhonson, N.F. 2005. Borror and DeLong‘s Introduction to the study of Insects. Brooks Cole. 7th Ed. 8. Trigunayat, M.M. 2009. A Manual of PRACTICALS Entomology. 2nd Edition Scientific Publisher (India) Judhupur.

ENT-605 Insecticides and their Application 3(2-1)

THEORY

Introduction; nomenclature, classification on the basis of mode of entry, chemical nature, mode of action, toxicity and insecticides formulations; compatibility, physicochemical properties, mode of action, residues of insecticides; hazards and safety measures; functioning of various types of hand and power operated equipments for insecticide application.

PRACTICALS

Computation, preparation and field application of different formulations of insecticides; identification, classification, handling and maintenance of application equipments.

BOOKS RECOMMENDED

1. Dovener, R.A. Mueninghoff, J.C. and Volgar, G.C. 2002. Pesticides formulation and delivery systems: meeting the challenges of the current crop protection industry. ASTM, USA

2. Dodia, D.A. Petel, I.S. and Petal, G.M. 2008. Botanical Pesticides for Pest Management. Scientific Publisher (India) Jodhpur.

3. Ishaaya, I. and Degheele, D. 1998. Insecticides with Novel Modes of Action:

Mechanism and Application. Norosa Publishing House, New Delhi.

4. Mathews G.A. 2002. Pesticide Application Methods. 4th Ed. Intercept. UK.

5. Otto, D. and Weber, B. 1991. Insecticides: Mechanism of Action and Resistance.

Intercept Ltd., U.K.

6. Roy, N.K. 2006. Chemistry of Pesticides. Asia Printograph Shahdara Delhi.

7. Saleem, M.A. 2004. Principles of Insect Toxicology. Vol.-I. Izhar sons Printers.

ENT-507 Insect Pests of Household, Man and Animals 3(2-1)

THEORY Introduction; identification, biology and control of different insect pests like ants, termites, cockroaches, silver-fish, cricket, powder-post beetle, carpet beetle, cloth- moths, psocids, lice, bed-bugs, fleas, mosquitoes, house flies, sand flies, stable flies, flesh flies, blow flies, tsetse flies, black flies, midges etc.

PRATICALS Collection, identification, and demonstration of control of different household, man and animal insect pests.

BOOKS RECOMMENDED 1. Aldridge, B. 2004. Medical Entomology. Text book of Public Health and Veterinary Sciences. Chapman and Hall, London. 2. Agarual, S. 2009. Insect Pests of Cereals and their Management. Oxford Book Co. India 3. Atwal, A.S. 2005. Agricultural Pests of Southeast Asia and their Management. Kalyani Publishers, Ludhiana.

ENT-601 Integrated Pest Management 3(2-1)

THEORY Introduction; history and concept of Integrated Pest Management (IPM); economics of pest management, population sampling, fluctuation and its measurement; different methods of insect pest scouting and forecasting; losses caused by insect pests to different crops; methods of pest management: cultural, physical, mechanical, legislative, chemical, biological, microbial, biotechnological and genetical measures along with antimetabolites, feeding deterrents, hormones and pheromones.

PRACTICALS Demonstration of cultural practices and different methods of pest scouting and monitoring, nature and extent of damage; assessment of crop losses by different methods; determination of economic threshold levels of 23 different crop pests; identification of important bio-control agents; installation of light and pheromone traps; familiarity with radiation techniques.

BOOKS RECOMMENDED 1. Atwal, A.S. and Bains, S.S. 2005. Agricultural Pests of South East Asia and their Management. Kalyani Publishers, Ludhiana.

2. Awasthi, V.B. 2007. Agricultural Insect Pests and their Control. Scientific Publishers (India) Jodhpur.

3. Binns, M.R. 2000. Sampling and Monitoring in Crop Protection. CABI Publishing Co.

4. Dent, D. 1996. Integrated Pest Management. Chapman & Hall, London.

5. Dhaliwal, G.S. and Arora, R. 2006. Integrated Pest Management. Kalyani Pub. Ludhiana.

6. Goodenough, J.L. and Mckineon, J.M. 1992. Basics of Insect Modelling. Amer. Soc. Agri. Engineers, USA.

7. House, P. Stevens, I. and Jones, O. 1998. Insect Pheromones and their use in Pest Management. Chapman and Hall, London.

8. Maredia, K.M. Dakouo, D. and Mota-Sanclez, D. 2003. Integrated Pest Management in the Global Arena. CABI publishing UK.

9. Metcalf, R.L. and Luckmann, W.H, 1994. Introduction to Insect Pest Management. 3rd Ed. Intercept Ltd. U.K.

10. Pedigo, L.P. 2007. Entomology and Pest Management. 5thEd. Prentice Hall, Intl. Limited, London.

11. Subba, R.N.S. Balagopalan, C. and Ramakrishna, S.V. (Eds) 1992, New Trends in Biotechnology. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi.

12. Upadhyay, R. K. Mukerji, K. G. Chamola, B. P. and Dubly, O. P. 1998. Integrated Pest and Disease Management. A.P.H. Publ. Co., New Delhi.

13. Verma,L.R. Verma, A.K. and Gantam, D.C. 2004. Pest Management in Horticultural Crops (Principles & Practices). Asiatech Publishers Inc.

PHYLUM ARTHROPODA

All living organisms are divided into five major groups or kingdoms, viz., Monera, Trista, Fungi, Plantae and Animalia. The kingdom Animalia like other kingdoms is further divided into several groups or phyla (sing. phylum), each phylum into many classes, each class into many orders, each order into many families, each family into many genera (sing. genus) and each genus into a number of species (sing. also species). There are also some intermediate categories, which are omitted at this level. These categories or taxa (sing. taxon) can be represented as below:

Kingdom
Phylum
Class
Order
Family
Genus
Species

CHARACTERS OF PHYLUM ARTHROPODA

The animals belonging to this largest phylum have jointed legs among all the invertebrates. They differ in structure but have the following important common characters:

1. Segmented body: The body is made up of a number of joints or segments. These segments are broadly grouped into two or three regions.

2. Sclerotised exoskeleton: They have a hardened outer covering of the body.

3. Paired jointed appendages: Some or all body segments of its members have outgrowths (e.g. antennae and legs) which are in pairs and made up of joints or pieces.

4. Bilateral symmetry: The right and left sides of the body have normally similar structures.

5. Body cavity: The body cavity is called haemocoel as it is filled with haemolymph or blood.

6. Division of gut: The alimentary canal or food tract is divided into fore gut, mid gut and hind gut.

7. Dorsal blood vessel: The narrow tube-like dorsal vessel lies in the upper part of the body just beneath the body covering. It consists of a posterior heart and an anterior aorta.

8. Ventral nervous system: The central nervous system (except brain) lies in the lower part of the body just inner to the body covering.

9. Striated muscles: The muscles of the body are almost entirely made up of fine, long, thread-like fibres, each having alternate light and dark areas or bands.

CLASSIFICATION OF PHYLUM ARTHROPODA

The phylum Arthropoda has been classified differently by different authors but the major and widely accepted classes of the living arthropods are as follows:

1. Class Onychophora (Fig. 1A): It includes *Peripatus*, etc. The body is almost cylindrical, apparently unsegmented and differentiated into head and trunk. The head contains a pair of short, thick, ringed antennae, a pair of simple eyes, a pair of oral papillae and a circular mouth below. The trunk bears at least 15 pairs of stumpy legs. The respiration is through tracheae.

2. Class Chilopoda (Fig. 1B): It includes centipedes or hundred-legged worms. The body is long, flattened and divided into head and trunk. The head bears a pair of long antennae and usually two clusters of simple eyes. The trunk carries a pair of legs on each segment, the first pair modified as poison-claws. They respire through tracheae.

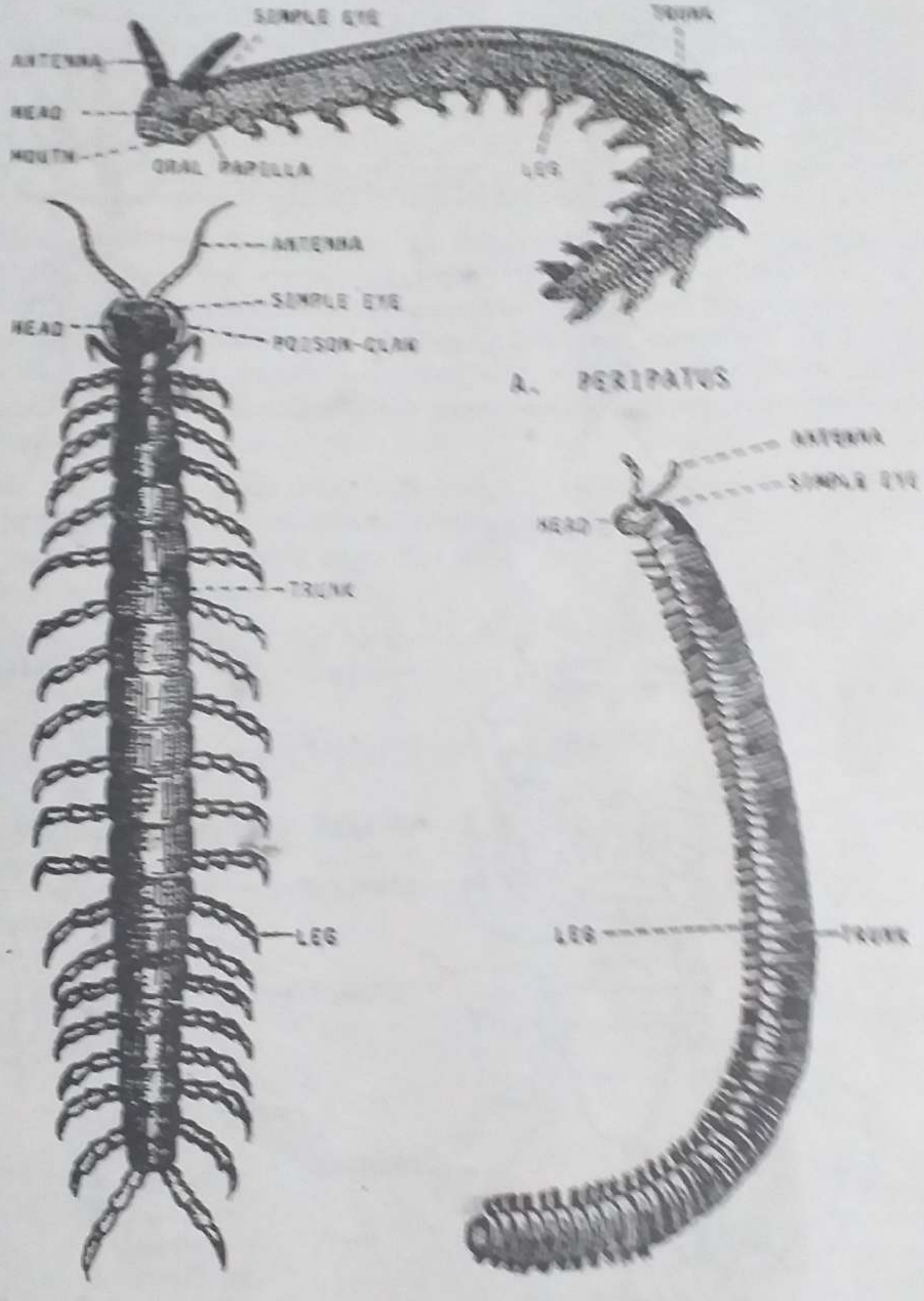
3. Class Diplopoda (Fig. 1C): It includes millipedes or thousand-legged worms. The body is long, cylindrical and divided into head and trunk. The head contains a pair of short antennae and usually two clusters of simple eyes. The trunk bears two pairs of legs on each segment except the first four (of which Ist is without and 2-4 each with a pair of legs). The respiration is through tracheae.

4. Class Symphyla (Fig. 2A): It includes symphylans. These are very small arthropods in which the body is divided into head and trunk. The head bears a pair of long antennae and no eyes. The trunk has 12 pairs of legs and ends in a pair of stout cerci (sing. cercus). Tracheae are the respiratory organs.

5. Class Pauropoda (Fig. 2B): It includes pauropods. These are minute arthropods with body divided into head and trunk. The head bears a pair of 3-branched antennae and no eyes. The trunk contains 9 pairs of legs. Tracheae are the respiratory organs.

Note: Previously, the classes 2-5 were collectively called Myriapoda.

6. Class Arachnida (Fig. 2C, D): It includes scorpions, spiders, ticks and mites. Examine the following characters in a scorpion and a mite and note the difference. The body is divided into cephalothorax (head + thorax) and abdomen (both divisions fused into a single structure in a mite). The cephalothorax bears a pair of very small chelicerae, a pair of pedipalpi (having pincers in scorpion), four pairs of walking legs, two to eight simple eyes and no antennae. The abdomen is long, segmented and with a terminal sting (in scorpion) or short, unsegmented and fused with the cephalothorax (in mite). They respire through book-lungs (i.e. leaf-like external gills present on the base of ventral side of abdomen), tracheae or body wall.



B. CENTIPEDE C. MILLIPEDE

FIG.1. ARTHROPODS

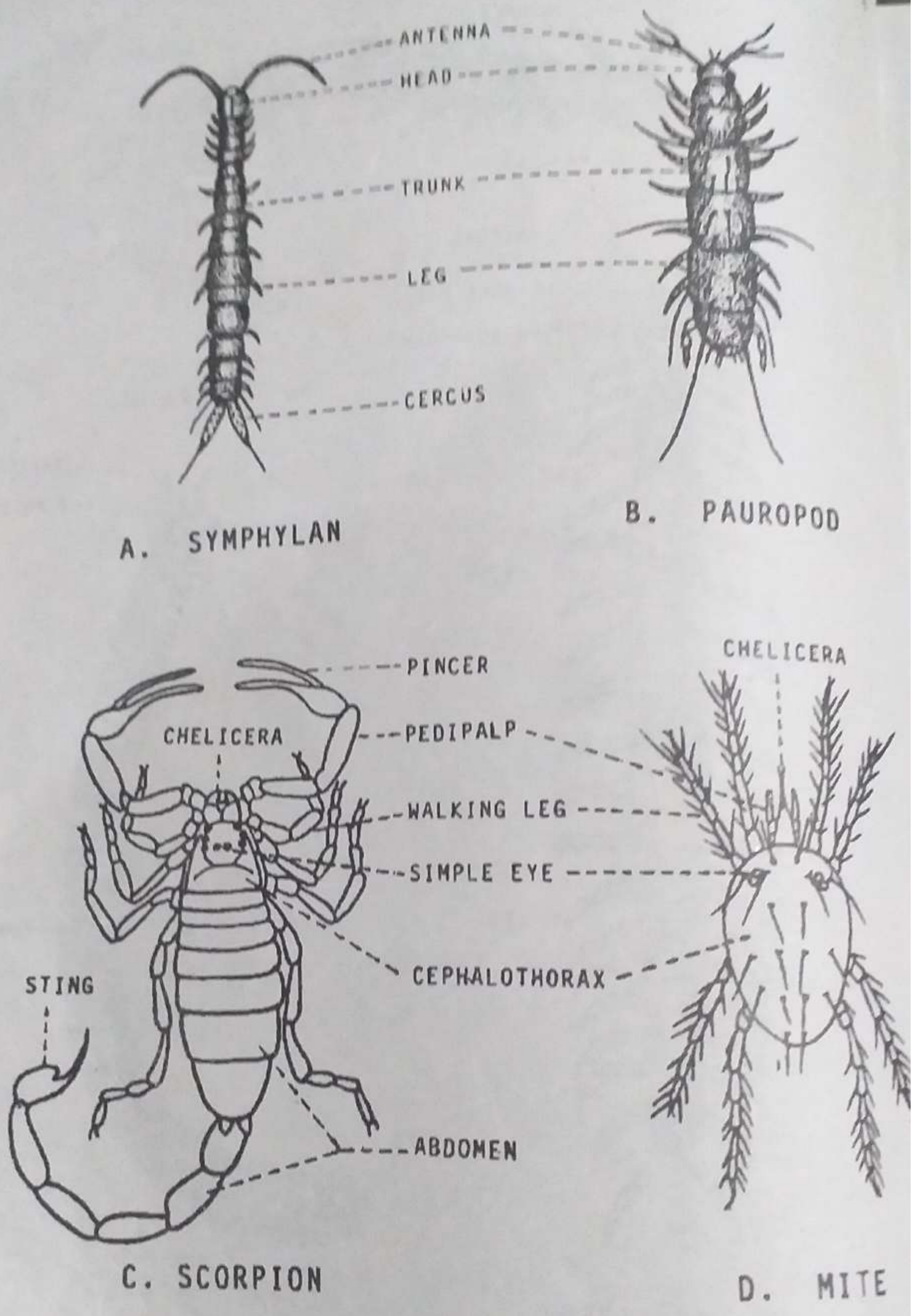


FIG.2. ARTHROPODS

7. Class Crustacea (Fig. 3A, B): It includes crayfish, crabs, prawns, lobsters, barnacles, etc. Examine the following characters in a crayfish and a crab. The body is divided into cephalothorax (head + thorax) and abdomen. The cephalothorax is covered by a hard carapace and bears two pairs of antennae (long antennae and short antennules), a pair of stalked compound eyes and five pairs of walking legs (the first pair is modified into chelipeds having chelae or pincers at the end). The abdomen carries five pairs of swimming legs or swimmerets, a telson and uropods (absent in crab). They breathe by means of gills or through body wall.

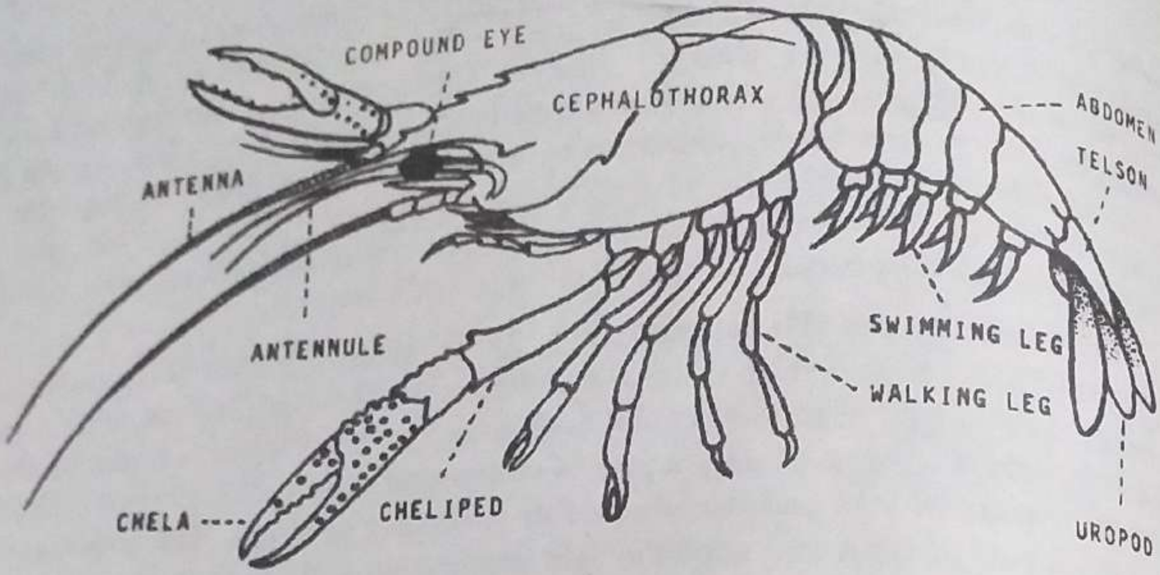
8. Class Insecta (Hexapoda) (Fig. 4): It includes insects (e.g. grasshoppers, bugs, butterflies, house flies, wasps and beetles). The body of an adult insect is normally divided into head, thorax and abdomen. The head contains a pair of antennae (absent in order Protura), usually a pair of compound eyes and mouthparts. The thorax bears three pairs of legs and usually one or two pairs of wings. The abdomen carries generally a pair of cerci and genitalia. The respiration is through tracheae which open out by means of spiracles.

Note: The subject which deals with insects is called entomology. To define insects as 6-legged animals seems unreliable because some mites (e.g. ber mite) have also three pairs of legs in the adult stage. The adult females of most scale insects and of the stylopids are altogether without legs.

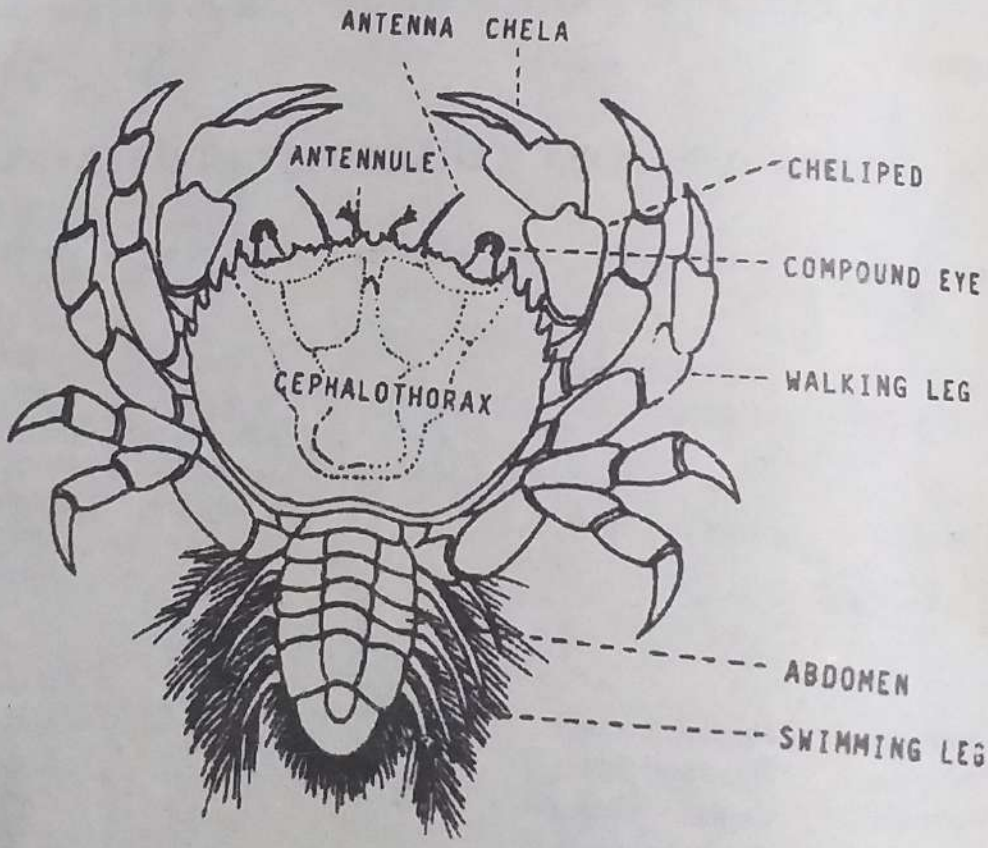
Some important characters of the above classes are tabulated below for a quick comparison.

COMPARISON OF CHARACTERS OF DIFFERENT CLASSES

	Class	Body regions	Antennae (pairs)	Legs (pairs)	Nature of eyes	Respiratory organs
1.	Onychophora	Head and trunk	1	15 or more	Simple	Tracheae
2.	Chilopoda	Head and trunk	1	15 or more (one pair per segment)	Simple (sometimes absent)	Tracheae
3.	Diplopoda	Head and trunk	1	25 or more (two pairs per segment except Ist four)	Simple (sometimes absent)	Tracheae
4.	Symphyla	Head and trunk	1	12	Absent	Tracheae
5.	Pauropoda	Head and trunk	1	9	Absent	Tracheae
6.	Arachnida	Cephalothorax and abdomen (fused in ticks and mites)	None	4	Simple (rarely absent)	Book-lungs, tracheae or body wall
7.	Crustacea	Cephalothorax and abdomen	2	5 or more	Compound (often stalked)	Gills or body wall
8.	Insecta	Head, thorax and abdomen	1 (absent in order Protura)	3	Compound to simple (rarely absent)	Tracheae



A. CRAYFISH



B. CRAB

FIG.3. ARTHROPODS

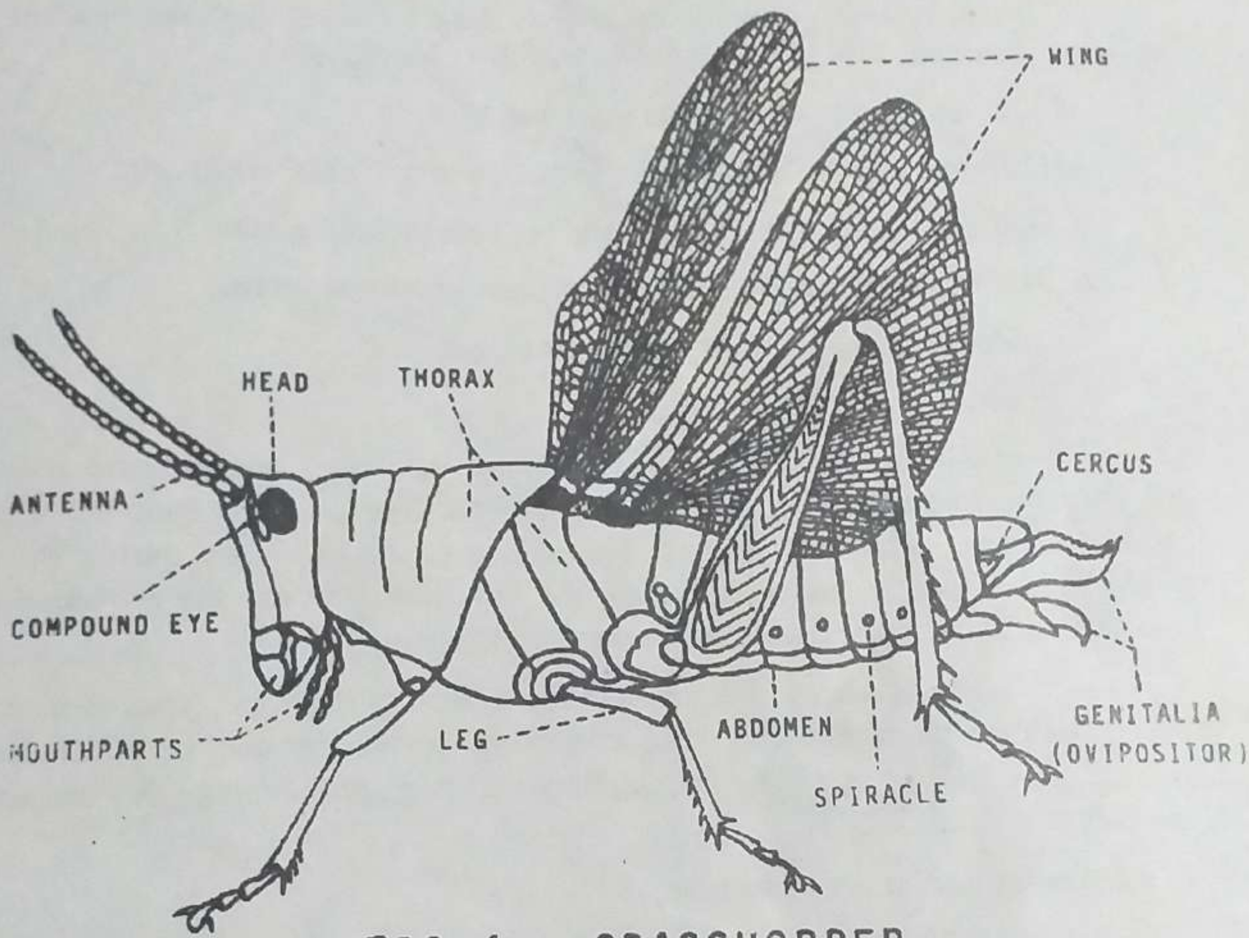


FIG.4. GRASSHOPPER

COLLECTION AND PRESERVATION OF INSECTS

COLLECTING

Here naturally the question arises: where, when and how to collect the insects?

Where: The insects are found in large number almost every where and can be collected from the following locations:

1. On or within plant parts like roots, stems, leaves, flowers, fruits, etc.

2. Inside or around human habitats feeding on food, clothing, furniture, grain and other materials.

3. Various sources of artificial light during night.

4. Different aquatic habitats like ponds, streams, lakes, rivers, etc.

5. Bodies of other insects, birds and animals including man.

6. Rotting and decaying materials of plant or animal origin.

7. Under stones, bark, logs, debris, litter, etc.

8. In soil up to a great depth.

When: The majority of insects hibernate in winter and become active from early spring to late fall, During this period, the best time to collect them is the summer. It is also of great value to collect the hibernating stages of insects during winter. The diurnal species can be collected during the day time whereas the nocturnal species should be collected during different months of the year.

How: There is a special equipment for collecting different types of insects. The students will be demonstrated these collecting devices in the laboratory. But for making a good collection of the insects, they will prepare their own devices according to the following details:

1. Insect net: It is of two types:

(a) Aerial net (Fig. 5A): It consists of a handle, a wire rim and a cloth-bag. The wooden handle should be light, strong and about a yard long. The stout metal rim with a diameter of about 12 inches should permanently be attached to the end of the handle. The muslin cloth-bag, which is double the width of the metal ring (i.e. 24 inches) and is generally cone-shaped (tapering towards bottom), should be attached to the metal ring. The students can also construct a net whose handle can easily be detached for transporting purposes. After sweeping through vegetation or swinging at the insects, the net must be turned over immediately for preventing the escape of active insects.

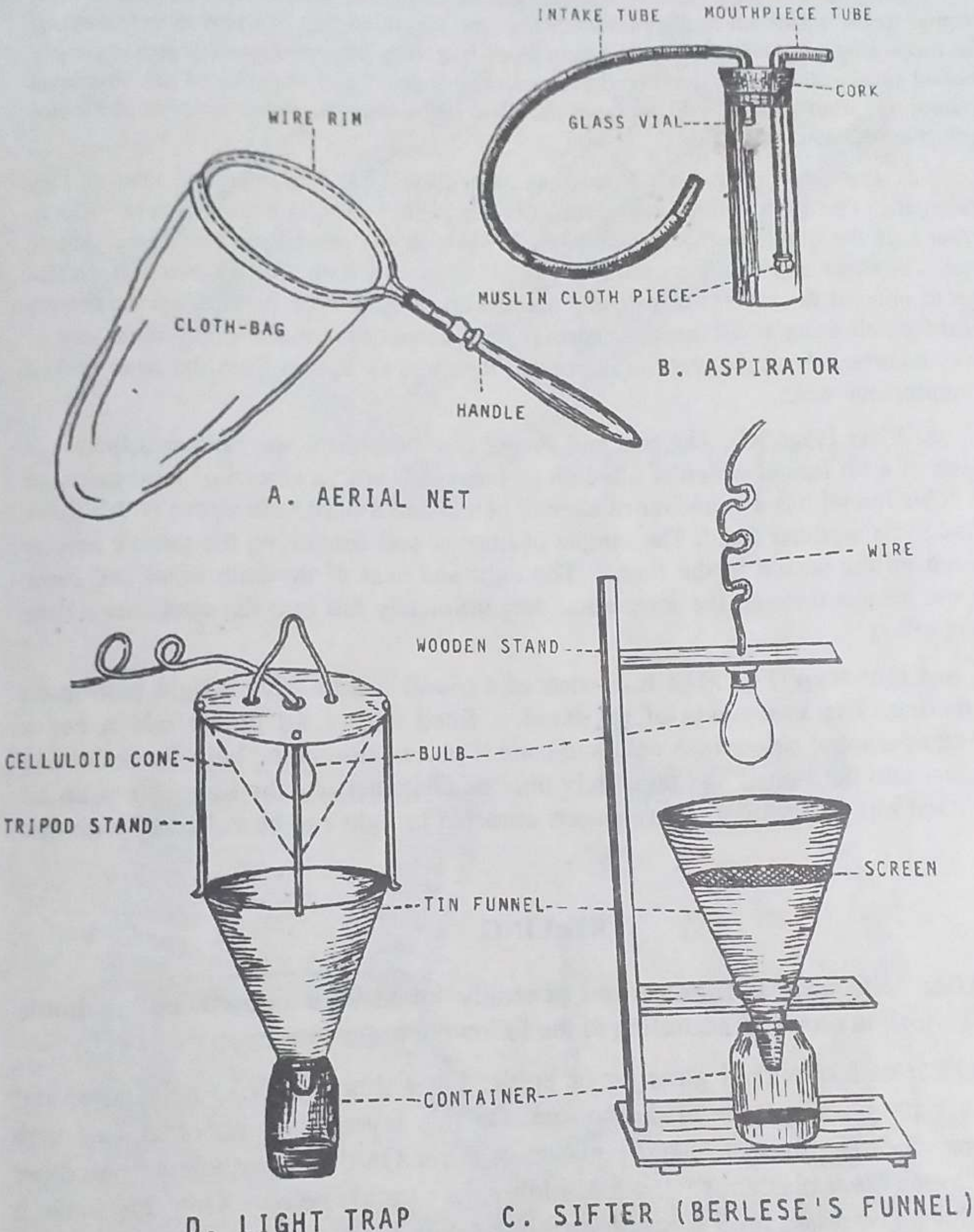


FIG. 5. COLLECTING EQUIPMENT

(b) Dip net: The aquatic insects can be collected with a dip net. It is almost similar to the aerial net but is shallower (i.e. the length of bag is equal to the width of the metal ring) and has a stronger nylon cloth-bag with fine meshes. The net is simply dipped into water for collecting the swimming insects and then lifted up. But in a stream, its mouth is placed against the flow of water at some narrow place for collecting the aquatic insects.

2. Aspirator (Fig. 5B)**:** It consists of a glass vial, a mouthpiece tube and an intake tube. The glass vial is fitted with a cork or rubber stopper having two holes in it. In one hole the mouthpiece tube is inserted, while in the other hole the intake tube is fitted. The inner end of the mouth piece tube is covered with a small piece of muslin cloth to prevent the insects from being sucked up into the mouth. This device is very useful for collecting small insects, especially for keeping them alive. The outer end of the intake tube is brought near the insect and then it is sucked in from the outer end of the mouthpiece tube.

3. Sifter (Fig. 5C)**:** The best and simple type of sifter is the Berlese's funnel. It consists of a tin funnel which is fitted on its inner side with a screen of wire-gauze or cloth. This funnel has a container of alcohol below and a light bulb above it. All these are fitted in a wooden stand. The sample of litter or soil containing the minute insects is placed on the screen in the funnel. The light and heat of the bulb repel and force down the insects through the screen and they ultimately fall into the container where they are killed.

4. Light trap (Fig. 5D)**:** It consists of a tripod stand having a light bulb in its top covering. The lower side of the stand is fitted with a tin funnel which has a container of alcohol below it. A celluloid cone is placed around the bulb for deflecting the insects into the funnel and ultimately into the container. As the light shines on all sides except top and bottom, many insects attracted to light can be collected with this trap.

KILLING

After collecting, the insects are generally killed in a cyanide killing bottle (Fig. 6A) which is prepared according to the following procedure:

Take a wide-mouthed glass jar or bottle. Put a thin layer of finely powdered sodium or potassium cyanide at the bottom. On this layer, place an other half inch layer of some porous material like dry plaster of Paris. On this layer, add still an other half inch layer of wet plaster of Paris for holding the cyanide below. After this, leave it uncorked for a few hours until it is completely set and dried. Now close it tightly with a cork and finally label it as 'POISON'.

Note: Remove the insects immediately after they are killed because a long exposure to cyanide results in discolouration, especially in brilliantly coloured specimens. Besides, the body appendages may become stiff and distorted.

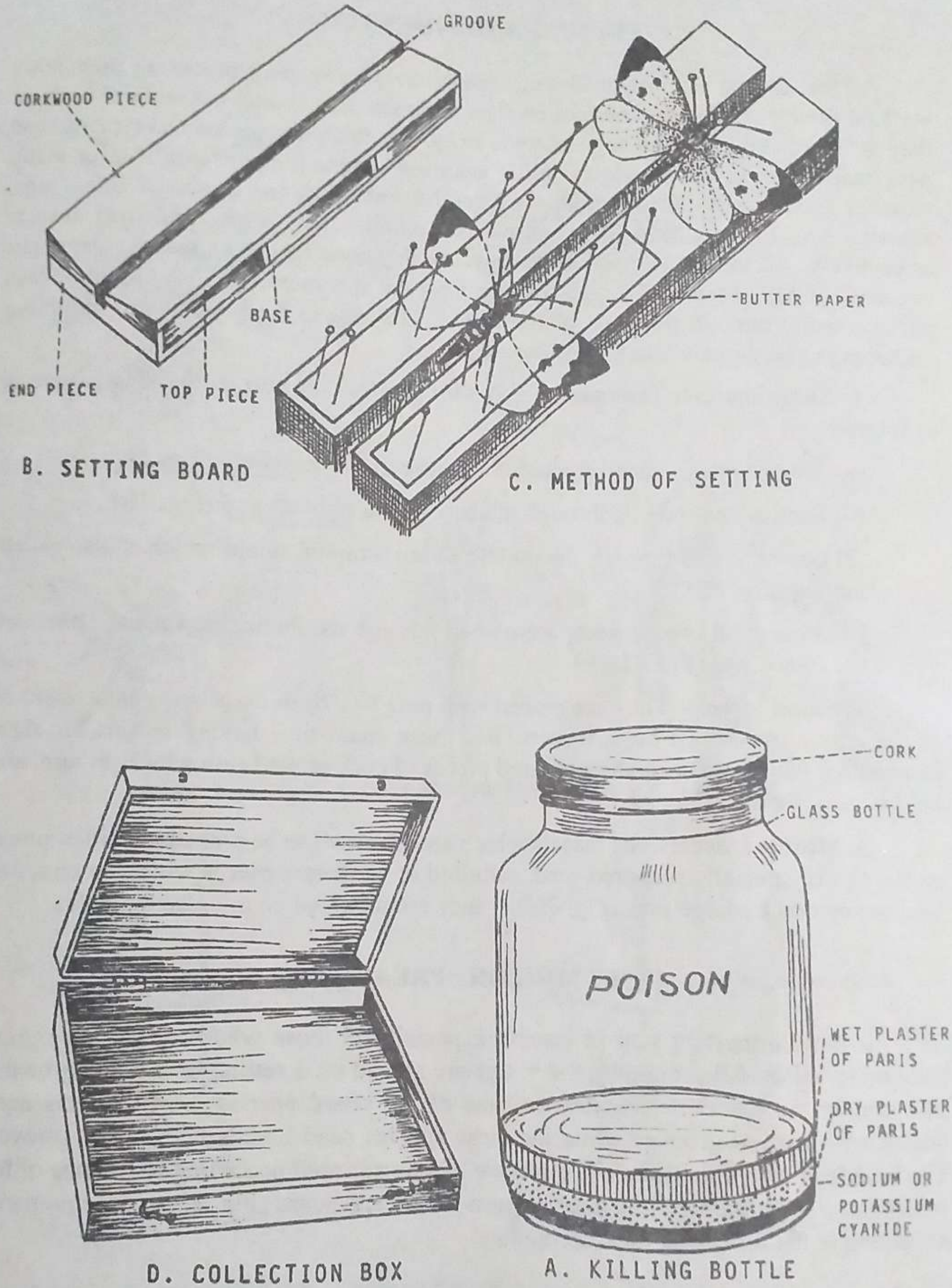


FIG. 6. KILLING, SETTING AND STORING EQUIPMENT

PINNING AND MOUNTING

After killing, the insects should immediately be pinned, otherwise their body parts on drying are likely to be broken. The common pins should not be used because they are short and thick and soon become rusty. For this purpose, special type of steel pins (insect pins or entomological pins) are used. These pins are available in many varieties according to their variable sizes. But generally two types of these pins, namely, No. 16 and No. 20 are used for pinning the large and small insects respectively. All insects should be mounted on the same height by leaving the upper one-third of pin which is sufficient for grasping the specimen. The pin should always pass vertically through the body of the insect. The insects for pinning and mounting purposes can be divided into the following groups.

1. Large insects: They are pinned with pins No. 16 and the pinning pattern is as follows:

(a) True bugs are pinned through the centre of the scutellum (Fig. 7A).

(b) Beetles and weevils through the base of the right elytron (Fig. 7B).

(c) Grasshoppers through the middle of the pronotal shield which is also called notalia (Fig. 7C).

(d) Almost all other insects are pinned through the thorax between the bases of the fore wings (Fig. 7D, E).

2. Small insects: They are pinned with pins No. 20 in exactly the same manner as the above mentioned large insects. But these small pins having insects are then fastened on the tips of specially prepared pieces of cork or read-pith which, in turn, are held in position by large pins (Fig. 7F).

3. Minute insects: The insects which are too small to be pinned are either glued on the tips of specially prepared card, celluloid or cardboard pieces which, in turn, are held in position by large pins (Fig. 7G) or they are mounted on microscope slides.

SETTING OR SPREADING

It is an important step in insects, especially in those whose wings have great taxonomic value. After pinning, the wings are spread on a setting or spreading-board. The size of the insect determines the size of the board needed. Small insects need boards with narrow grooves while the large species need boards with wider grooves. The boards in which the size of the groove can be adjusted according to the size of the insect can also be prepared. A general purpose setting-board (Fig. 6B) can be prepared according to the following measurements:

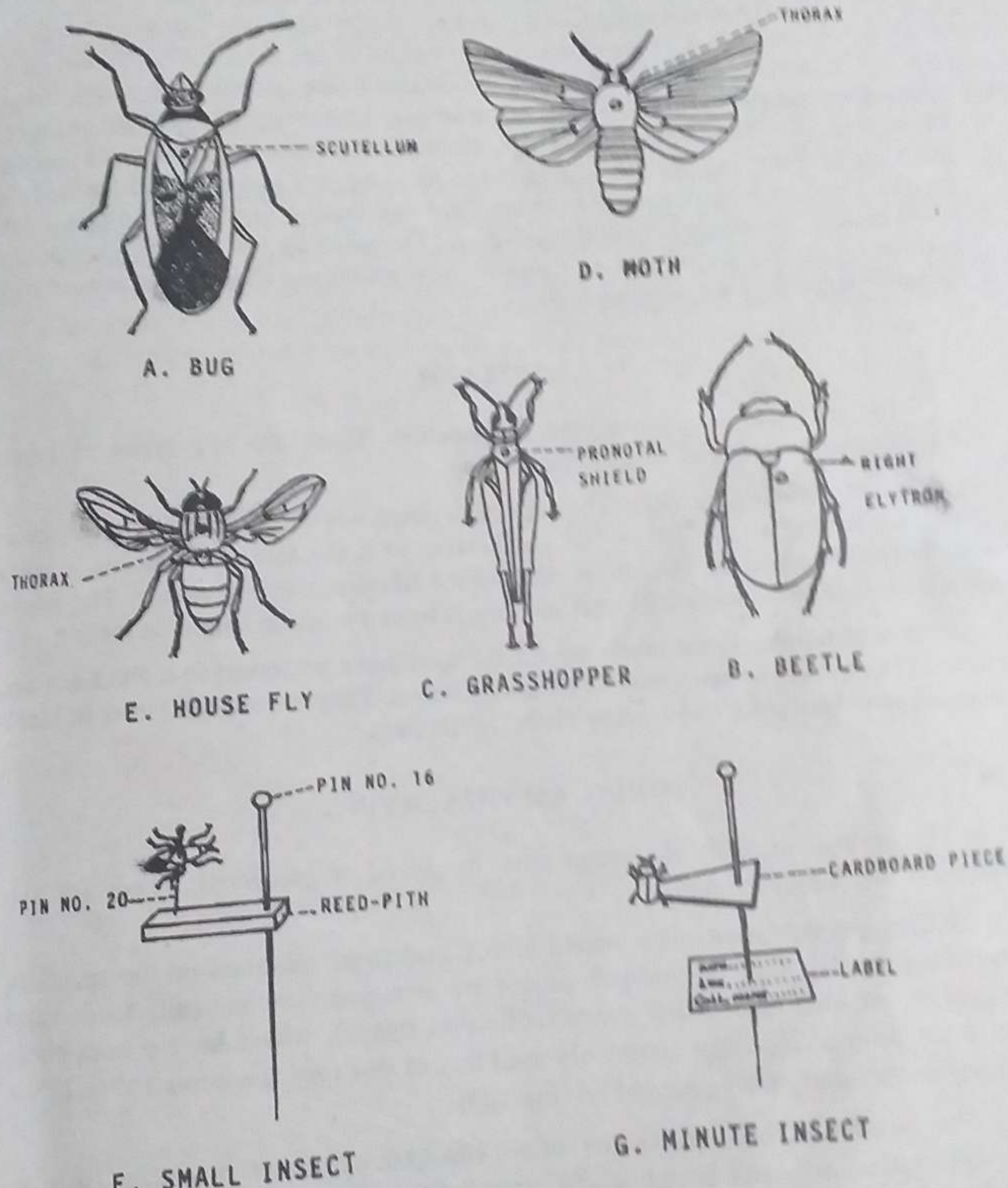


FIG. 7. PINNING. MOUNTING AND LABELLING

1. A hardwood base 12″ × 3″ × 1/12″
2. Two hardwood end pieces 1/2″ × 3″ × 3/4″
3. Two softwood top pieces 12″ × 1 ¼″ × 1/2″
4. Two flat corkwood pieces 12″ × 1 ¼″ × 1/2″

The pinned insect should be accommodated in the groove by inserting the pin so much so that the wing bases come at the level of the surface of the board or slightly above (Fig. 6C). Now spread the wings. To move the wings into a desired position make use of dissecting needles or pins. When the wings are in the desired position, lay parallel strips of butter paper over them. Then pin these strips to the surface of the board close to the wings but not through them. The antennae and abdomen are held in position by careful use of pins as a support. The specimens should be removed from the board when they are completely dry.

LABELLING

The collected specimens must be labelled. There are two types of labels according to the method of insect preservation.

1. Dry labels (Fig. 7G): They are made from white stiff paper in rectangular form, each having a size of 1″ × 1/2″ and bearing on it the date of collection, locality and the collector's name. sometimes, the printed labels are also available. The labels are always held underneath the insect and should be at a uniform height on the pin.

2. Wet labels: These labels are for the specimens preserved in a fluid and are prepared in exactly the same way as described above. They are written either in black India ink or in lead pencil and finally placed in the fluid.

STORING OR PRESERVING

For permanent study the insect must be stored or preserved. There are two methods of insect preservation.

1. Dry preservation: The pinned insects and those mounted on the specially prepared cardboard, cork or reed-pith pieces are arranged systematically (order and family wise) in lines in wooden boxes (collection boxes), which have a cork-sheet fitted at the bottom. The most commonly used box of this type measures 18″ × 12″ × 3″. It has also a tightly fitting hinged lid (Fig. 6D).

The insects in these boxes are often attacked by insect predators such as dermestid beetles, ants and booklice. To protect the collection from these enemies, place naphthalene balls in the boxes that will repel the predators. The balls can be mounted on pins by heating the pin-head and then thrusting it into the ball. Place many such balls in a box. Paradichlorobenzene kills the insect pests very effectively by fumigation when placed in the boxes. Coopex powder or some other insect killing powder can also be dusted lightly for this purpose.

2. Wet preservation: All soft-bodied adults (mayflies, stoneflies, caddisflies, mosquitoes and midges), minute insects (springtails, doubletails, thrips, whiteflies, aphids, fleas and lice), larvae and nymphs of most insects are preserved in a fluid. The most commonly used preserving fluids for adult and young stages are 70-80 per cent ethyl alcohol and 2 per cent formalin. Frequently, a few drops of glycerin are added in the former to have a good storage of the insects.

KAAD mixture (95 per cent ethyl alcohol = 70-100 ml, kerosene = 10 ml glacial acetic acid = 20 ml and dioxane = 10 ml) has proved to be a satisfactor[y] preservative for almost all types of insect larvae. The insects (both young and adults) which are preserved in fluids generally lose their colours. Kahle's solution (95 per cen[t] ethyl alcohol = 30 ml, formaldehyde = 12 ml, glacial acetic acid = 4 ml and water = [illegible] ml) is also considered to be a good preservative, especially for colours.

INSECT METAMORPHOSIS

All changes of form from hatching to maturity of an insect are collectively termed metamorphosis (pl. metamorphoses). All insects during their postembryonic development go on shedding or moulting their skin. This process is called ecdysis. The moulted skin is termed exuvium (pl. exuvia). The particular form or shape of an insect between two moultings is known as instar. Thus for example, the first instar is between hatching and first moulting, the second instar between the first and the second moultings, the third instar between the second and the third moultings and so on. The period between two moultings is called stadium (pl. stadia). The adult of an insect is called imago (pl. imagoes or imagines).

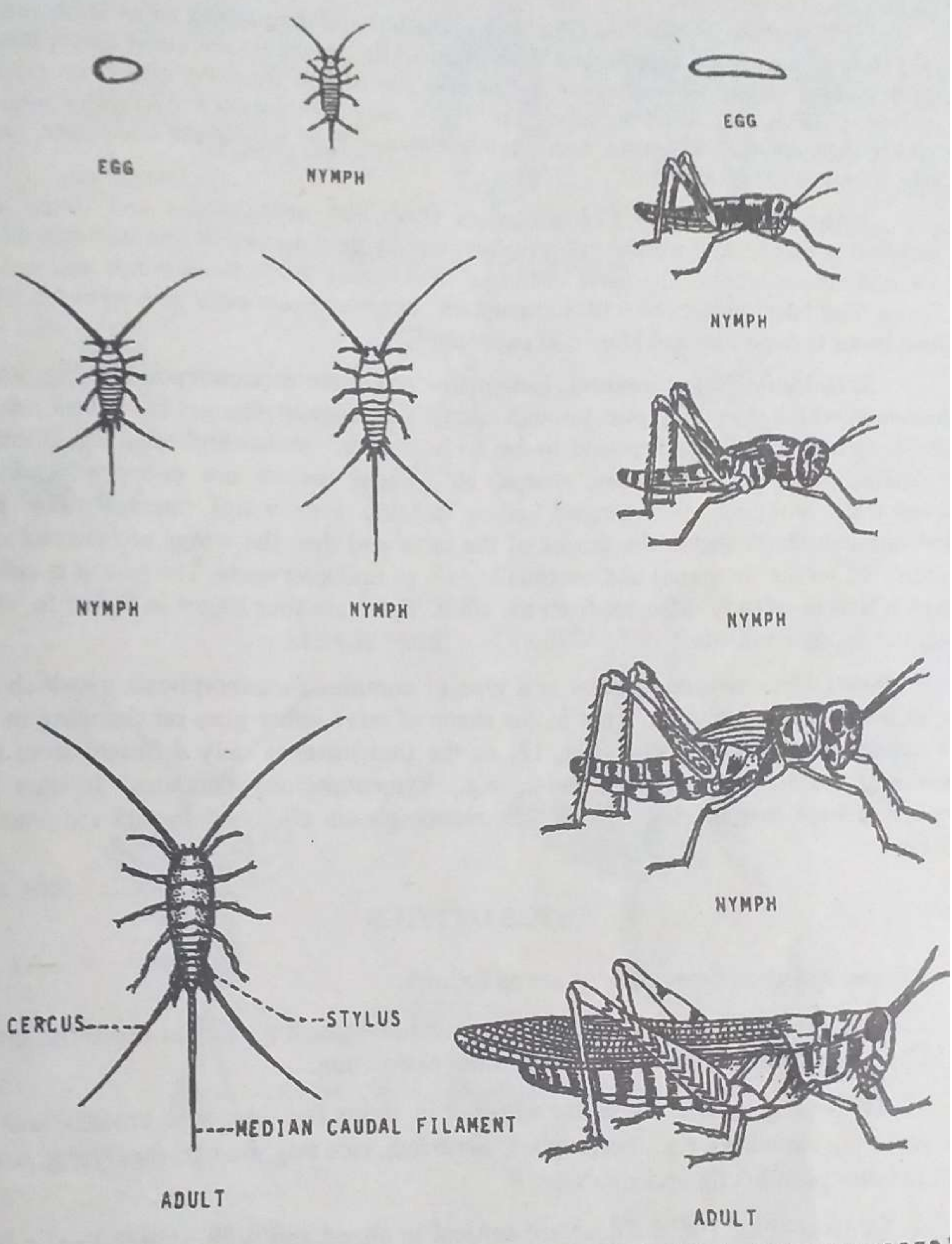
TYPES OF METAMORPHOSIS

According to the degree of change in form, the insects are divided into the following groups.

1. Ametabola (without metamorphosis) (Fig. 8A): Insects in which the young pass through no or slight changes to become adults are said to be without metamorphosis, e.g., silverfish, telsontails, springtails, etc. Although slight changes occur (e.g. absence of abdominal scales and styli in early instars of silverfish and addition of abdominal and antennal segments in telsontails and springtails respectively), but they do not change the appearance of the young. As these insects are considered to be primitively wingless, they are called Apterygota. The young is called nymph which is similar in appearance to the adult, but smaller in size. These insects have three life stages, viz., egg, nymph and adult.

Note: Anamorphosis is an increase in the number of segments during the postembryonic development of an insect. For example, the nymphs of telsontails have eight abdominal segments and a telson at the time of hatching. But three more segments are added between the last segment and the telson during the development. Thus making a total of eleven abdominal segments and a telson in the adult. As this increase or anamorphosis does not change the appearance of the young, it is included in the ametabola.

2. Hemimetabola (simple, direct or incomplete metamorphosis) (Fig. 8B): Insects in which the young pass through simple or gradual changes to become adults and have no pupal stage are said to be with simple metamorphosis, e.g., grasshoppers, crickets, cockroaches, termites, bugs, etc. These insects are either winged or secondarily wingless. The winged insects develop their wings externally (i.e. from the wing-pads or buds readily visible on the thorax of the nymph) and are thus known as Exopterygota. The young is called nymph which is similar to the adult, but smaller in size and with incompletely developed wings.



A. AMETABOLA (SILVERFISH) B. HEMIMETABOLA (GRASSHOPPER)

FIG. 8. INSECT METAMORPHOSIS

The nymphs of mayflies (Fig. 9C), stoneflies and dragonflies, in addition to the above differences, are aquatic and with gills, while the adults are aerial and without gills. Such nymphs which have a different mode of life from the adults are called naiads. Their aquatic life and possession of gills are of temporary and adaptive nature. Hence these insects also come under hemimetabola. They have three life stages, viz., egg, nymph (naiad) and adult.

Note: Some insects like whiteflies (Fig. 9B), male scales and thrips are included in this type of metamorphosis, but actually they neither fit into hemimetabola nor into holometabola. The early instars of their young are without wings and called larvae. The later instars are with rudimentary wings and resemble with nymphs. The final instar is pupa-like and known as pseudopua.

3. Holometabola (complex, indirect or complete metamorphosis) (Fig. 9A): Insects in which the young pass through complex or marked changes to become adults and have a pupal stage are said to be with complex metamorphosis, e.g., moths, butterflies, beetles, flies, bees, wasps, etc. These insects are either winged or secondarily wingless. The winged insects develop their wings internally (i.e. the development starts within the thorax of the larva and then the wings are everted and completed within the pupa) and are thus known as **Endopterygota**. The young is called larva which is entirely different from the adult. There are four stages in their life, viz., egg, larva, pupa and adult.

Note: Hypermetamorphosis is a type of complex metamorphosis in which all larval instars are not similar. That is, the shape of larva either goes on changing in all the instars, e.g., blister beetle (Fig. 12) or the first instar is only different from the remaining instars which are similar, e.g., hymenopterous parasites. It may be mentioned here that in case of complex metmorphosis all larval instars are usually similar.

TYPES OF EGGS

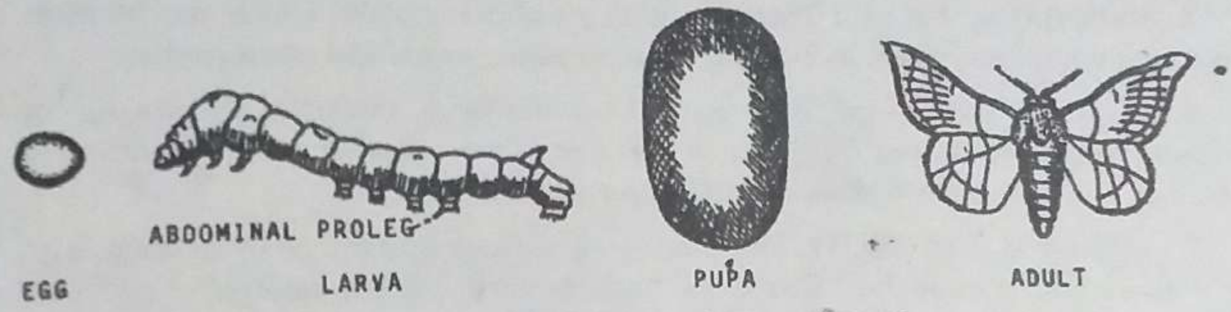
Some common types of eggs are as follows:

1. Spherical (Fig. 10A)**:** These are rounded eggs, e.g., lemon butterfly, citrus leaf miner, hawk moth, gram cutworm and red cotton bug.

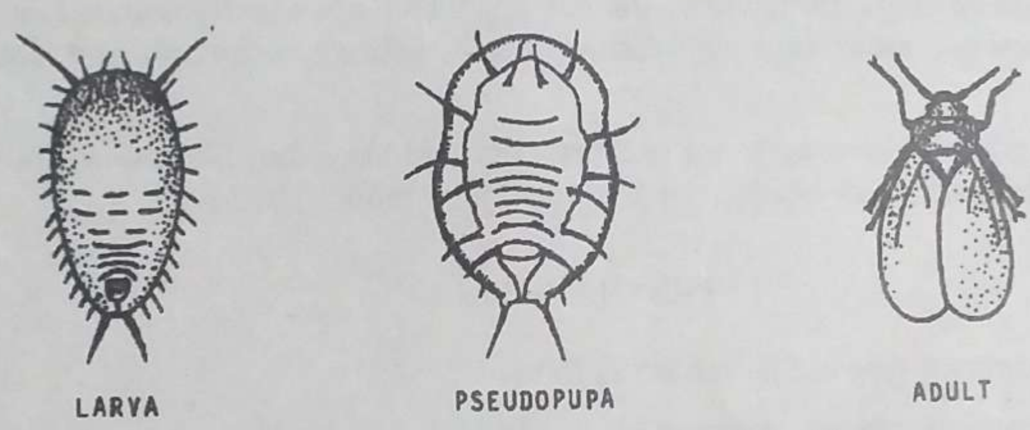
2. Oval (Fig. 10B)**:** These are egg-like in shape (i.e. one side broadly and the other narrowly rounded), e.g., bean aphid, silverfish, rice bug, mango mealybug, maize borer, red pumpkin beetle and rice weevil.

3. Conical (Fig. 10C)**:** These are conical in shape and with longitudinal ridges, e.g., beet armyworm.

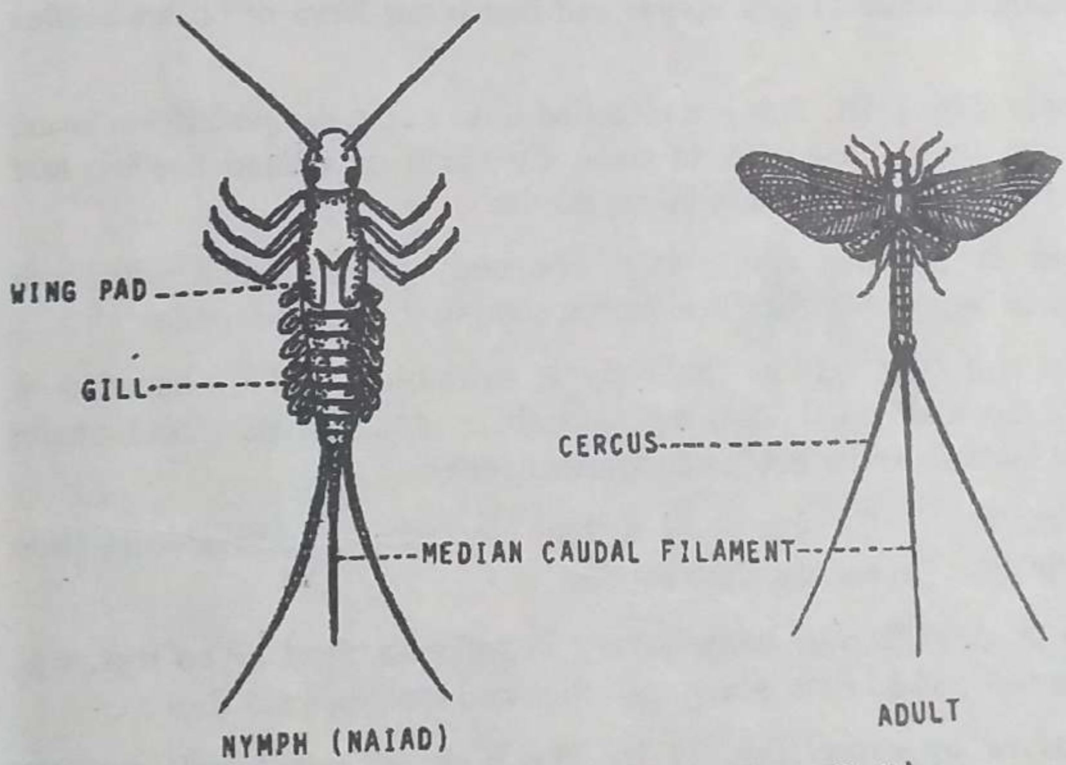
4. Elongate (Fig. 10D)**:** These are elongate, e.g., house fly, ak grasshopper, cotton jassid, fig borer, sand fly and bot fly.



A. HOLOMETABOLA (SILKWORM)



B. HEMIMETABOLA (WHITEFLY)



C. HEMIMETABOLA (MAYFLY)

FIG. 9. INSECT METAMORPHOSIS

5. Stalked (Fig. 10E, F): These are with a pedicel or stalk, which may be short or long, e.g., whiteflies, green lacewings, most parasitic wasps and citrus psylla.

6. Appendiculate (Fig. 10G, H): These are with thread-like processes or appendages which come out from the upper side. Their number varies in different insects, e.g., water scorpions (*Ranatra* and *Nepa*) and stink bugs.

7. Sculptured (Fig. 10I, J): These are with various designs or sculpturing, e.g. malarial mosquito, spotted boll-worm, cabbage butterfly, gram caterpillar and pink gramineous borer.

8. Elliptical (Fig. 10K): These are the eggs which are equally rounded on both ends, e.g., earwigs, natal fruit fly (*Ceratitis* sp.), sesame webworm and cottony cushion scale.

9. Scale-like: These eggs are rounded, flat and very thin like the scales of a fish, e.g., maize borer, dark-headed rice borer and jelly moth.

TYPES OF LARVAE

Some common types of larvae are as follows:

1. Campodeiform or oligopod (Fig. 11A): It has an elongate and flattened body, long thoracic legs and usually cerci on the end of abdomen, e.g., diving beetles, rove beetles, caddisflies, nerve-winged insects and first instar larva of blister beetles and stylopids.

2. Carabiform (Fig. 11B): This is a modified form of the campodeiform larva. It has flattened body, shorter legs and no cerci, e.g., crab or ground beetles, leaf beetles, fireflies and second instar larva of blister beetles.

3. Eruciform or polypod (Fig. 11C): The body is cylindrical with both thoracic and abdominal legs, e.g., butterflies, moths, scorpionflies and sawflies.

4. Scarabaeiform (Fig. 11D): The body is cylindrical and C-shaped with usually thoracic but no abdominal legs, e.g., scarab or dung beetles, cock-chafer beetles, powder-post beetles, spider beetles and pulse beetles.

5. Elateriform (Fig. 11E): The body is thin, elongate, cylindrical with short thoracic legs, e.g., click beetles and darkling beetles.

6. Platyform (Fig. 11F): The body is very broad with short or no legs, e.g. some syrphid flies, hump-backed flies, platypezid flies and lonchopterid flies.

7. Vermiform or apodous (Fig. 11G): The body is cylindrical, elongate narrowing anteriorly and without legs, e.g., true flies, fleas and most parasitic wasps.

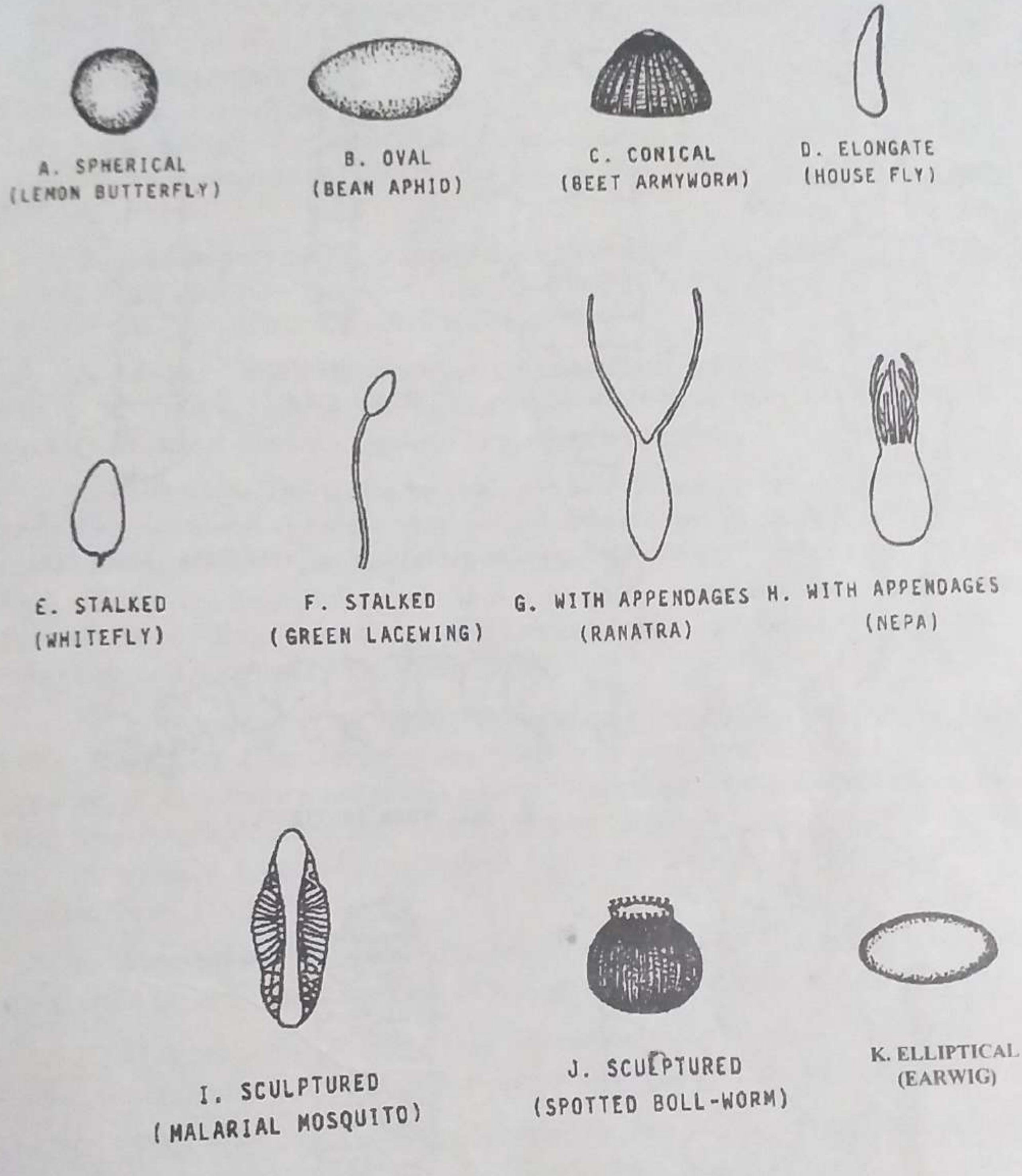


FIG.10. TYPES OF EGGS

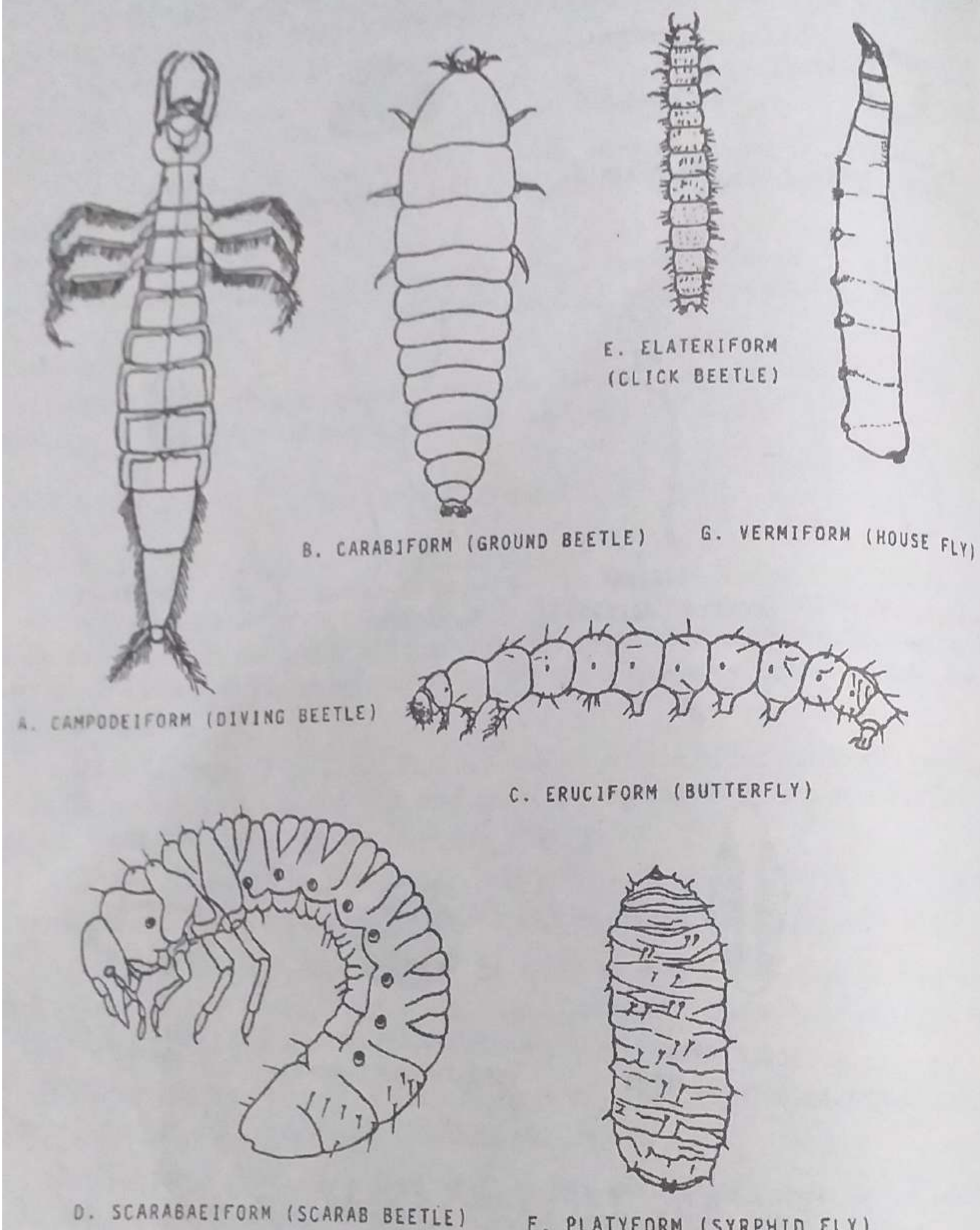


FIG.11. TYPES OF LARVAE

COMMON NAMES OF LARVAE

1. Caterpillar: The larvae of Lepidoptera (butterflies and moths), Tenthredinidae (sawflies) and Mecoptera (scorpionflies) having both thoracic and abdominal legs are called caterpillars. Most lepidopterous caterpillars have five pairs of abdominal prolegs (more in sawflies and scorpionflies) on segments 3-6 and 10 (Fig. 11C).

2. Semilooper: Some caterpillars of Noctuidae (Lepidoptera) with only three pairs of abdominal pro-legs on segments 5-6 and 10 are known as semiloopers. They crawl by making half a circle of the abdomen.

3. Looper: The caterpillars of Geometridae (Lepidoptera) bearing only two pairs of abdominal prolegs on segments 6 and 10 have been named loopers. They move by making a complete circle or loop of their abdomen.

4. Cutworm: The larvae belonging mostly to the genera *Agrotis* and *Euxoa* of the family Noctuidae (Lepidoptera) are called cutworms or surface caterpillars. They are nocturnal in habits, i.e., they remain hidden under leaf-litter or in the soil near the plants during day time and come out at soil surface at night. They cut the shoots or stems of the seedlings from the ground level and feed on them. They are very serious pests of certain crops and vegetables.

5. Armyworm: The larvae of the genera *Mythimna* and *Spodoptera* in the family Noctuidae (Lepidoptera) are known as armyworms due to their habit of appearing in very large numbers on a crop. When their food becomes exhausted at one place, they march in gregarious swarms to find the fresh food plants at an other place. They are usually sporadic pests which attack the cereals and many other crops to defoliate them.

6. Wireworm (Fig. 11E)**:** The larvae of the family Elateridae (Coleoptera) are called wireworms because they are thin, elongate and cylindrical just like a wire.

7. Maggot (Fig. 11G)**:** The legless larvae of true flies (Diptera), fleas (Siphonaptera) and parasitic wasps (Hymenoptera) are said to be maggots.

8. Grub (Fig. 11D)**:** The C-shaped larvae, more specifically of the orders Coleoptera and Hymenoptera, are popularly known as grubs.

9. Triungulin (Fig. 12)**:** The first instar larvae of the blister beetles (Meloidae) which are quite different from the remaining instars due to hypermetamorphosis are called triungulins. They are campodeiform, i.e., with long thoracic legs and cerci.

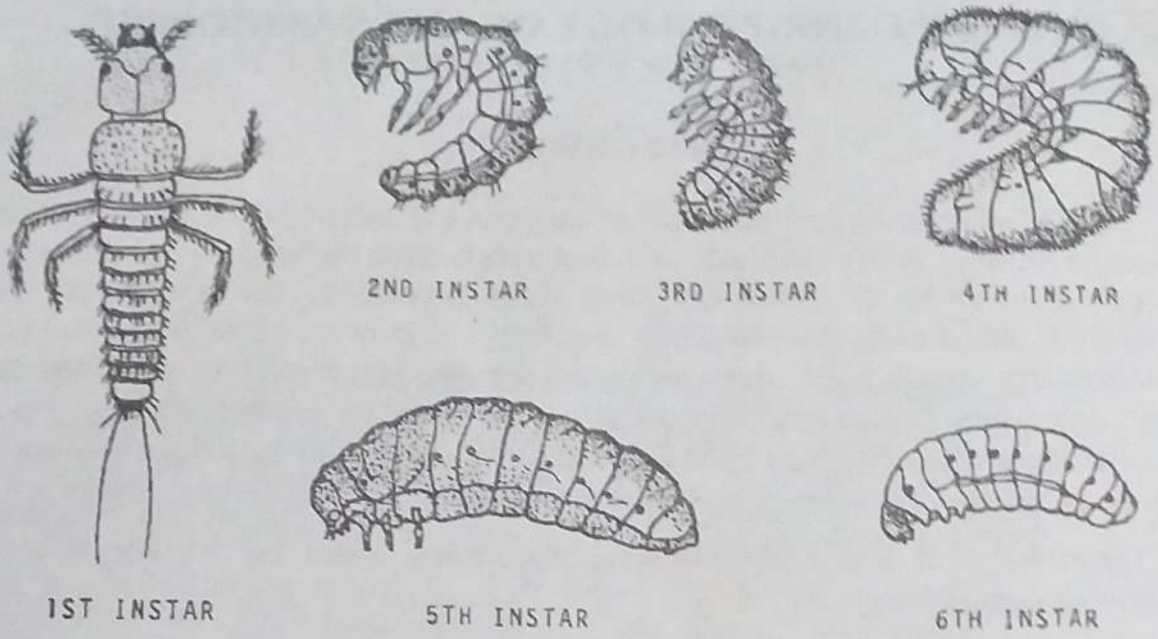


FIG.12. HYPERMETAMORPHOSIS
(LARVAL INSTARS OF A BLISTER BEETLE)

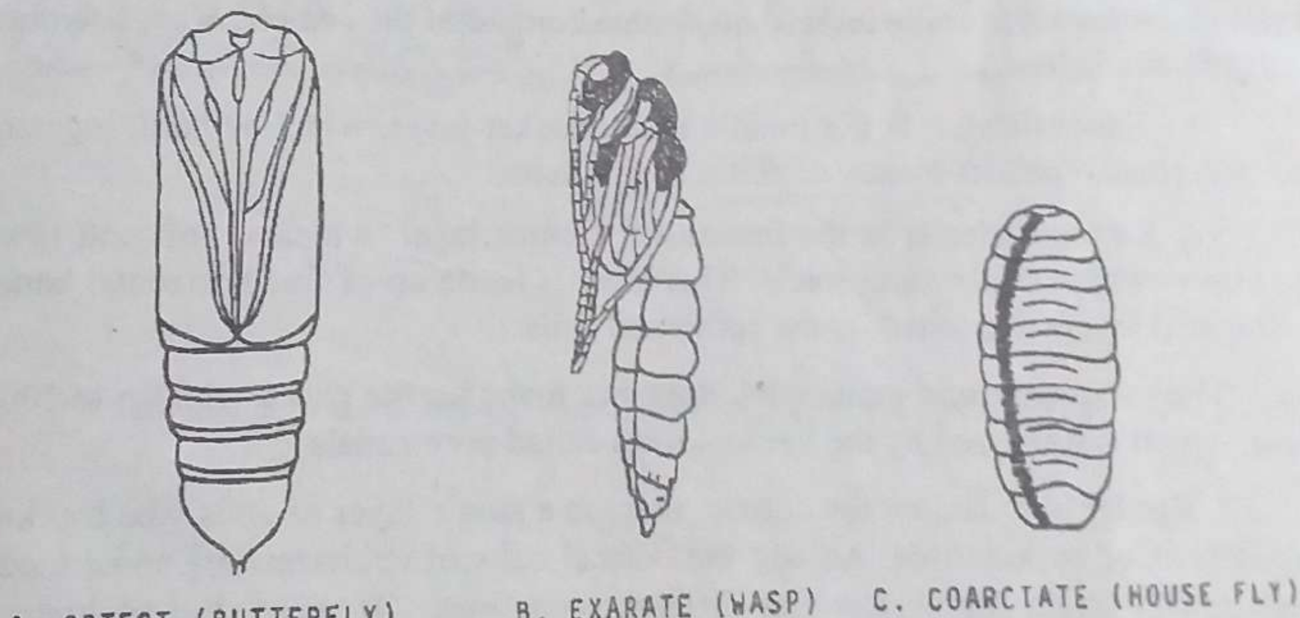


FIG.13. TYPES OF PUPAE

EXTERNAL MORPHOLOGY OF AK GRASSHOPPER
(POEKILOCERUS PICTUS)

INTEGUMENT

The outer covering or body wall of an insect is called integument. The body wall having muscles on its inner side is called exoskeleton. It bends or grows into the body cavity at different points to form rigid processes, the apodemes. They collectively make an endoskeleton. There are many outgrowths of the body wall (such as antennae, legs, wings, etc.) which are called appendages. The body wall consists of a number of hardened areas or plates, the sclerites. These are separated by the grooves called sulci (sing. sulcus). The grooves representing the line of fusion of two sclerites are still known as sutures (e.g. epicranial suture).

The integument (Fig. 13A) consists of three main layers, viz., cuticle, epidermis and basement membrane.

1. Cuticle: It is the outer non-cellular layer, which is secreted by the epidermal cells below it. When newly formed it is flexible and elastic, but later on it becomes generally hard through the process of sclerotization. It protects the insects from water loss, penetration of insecticides and provides ground for the attachment of muscles. It is further divided into the following three layers.

(a) Epicuticle: It is the outermost non-chitinous and very thin layer, which is 1. 4 μm in thickness. In some insects this further comprises the cement, wax, polypheno and cuticulin layers.

(b) Exocuticle: It is the middle much thicker layer, which is hard, pigmente and darker and consists mostly of chitin and protein.

(c) Endocuticle: It is the innermost thickest layer, which is soft and flexibl and also contains chitin and protein. This layer is made up of fine horizontal lamella or stratified layers deposited by the epidermal cells.

The exocuticle and endocuticle together make up the procuticle (up to 200 μ thick), which is traversed by the vertical lines called pore canals.

2. Epidermis: Below the cuticle, there is a single layer of cells which is know as epidermis or hypodermis. Among the normal cells of epidermis are some modifie or specialized cells for performing different functions. Of these, the trichogen ar tormogen cells participate in the formation of setae or hair, while the glandular cel throw their secretions through their ducts on the surface of cuticle. For forming a set a single trichogen cell becomes greatly enlarged. Another adjoining cell or tormogen also enlarged to form a cup-like socket or pit and an articular membrane of the hair its base.

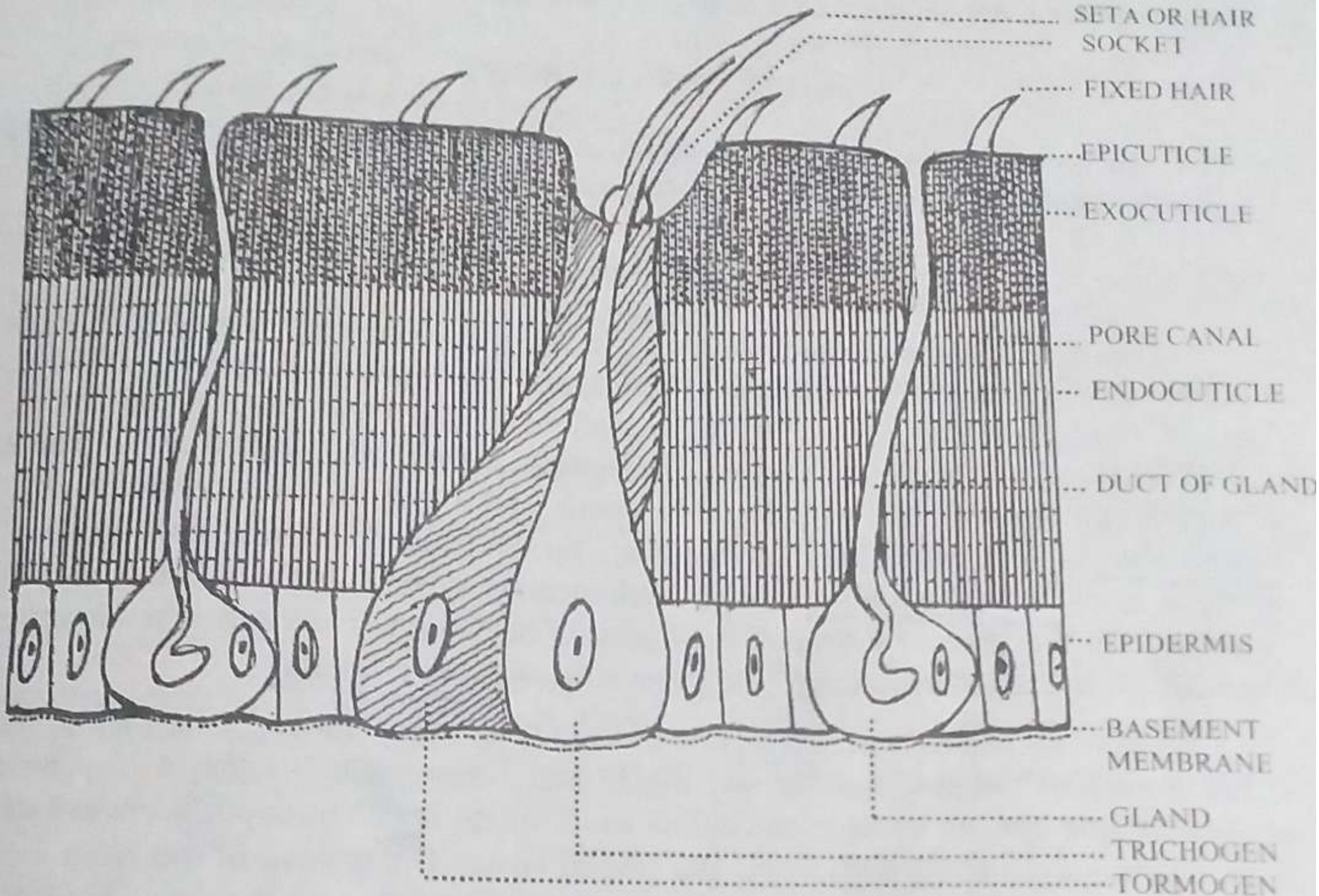


FIG. 13A. TYPICAL INSECT INTEGUMENT

3. Basement membrane: It is a very thin (up to 0.5 μm thick) non-cellular layer lying beneath the epidermis. The epidermal cells stand on it. It appears to be amorphous granular under the electron microscope.

The external surface of cuticle bears a number of fixed processes, such as spines, horns, minute fixed hair, tubercles, etc., and movable appendages, in addition to the segmental appendages, like setae and spurs.

DIVISION OF BODY

The body consists of a series of joints or segments which are grouped into three regions or tagmata (sing. tagma), viz., head, thorax and abdomen.

HEAD

This is the first region of the body. If you press the head from top, it clearly becomes demarcated from the thorax. The hard outer covering of the head is the head capsule. This type of head having the mouthparts (see their types under INSECT APPENDAGES) on its lower side and projecting downward is called hypognathous. Compare this type of head with that of a beetle and a bug. In a beetle the head is of prognathous type in which the mouthparts are on the front side and project forward. In a bug it is of opisthognathous or opisthorhynchous type with the mouthparts on its lower side in the form of a proboscis projecting backward. The head is made up of 6 segments, fused together to form a box-like structure, the cranium.

First of all examine the front side of head (Fig. 14A). Its upper half is the frons. It has a median longitudinal furrow, the frontal furrow which bears a tiny median ocellus (simple eye) in it. Note an ocellus has a single lens. On upper one-third of the frons, there is a grooved high ridge, the frontal costa. The groove of the frontal costa merges below into that of the frontal furrow. On the sides of the frontal costa are depressions, the antennal sockets. From each socket arises a thread-like antenna (see its parts and types under INSECT APPENDAGES). On the margin of an antennal socket, just inner to the anterior end of a compound eye, lies a lateral ocellus (pl. ocelli). Below the frons is an other somewhat raised sclerite, the clypeus. It is separated from the frons by a transverse frontoclypeal or epistomal sulcus. The clypeus is partially divided by a trans sulcus (only clear from sides) into two parts. The anterior narrow part is the anteclypeus while the posterior broader part is the postclypeus. Below the clypeus is an other sclerite, the labrum. It is separated from the clypeus by a transverse clypeolabral sulcus. On each side of clypeus and labrum the grooved outer surface of the mandible is visible. See the mandible by lifting up the labrum with your dissecting needle. Also note the segmented maxillary and labial palpi (sing. palpus) on the sides of the mouth.

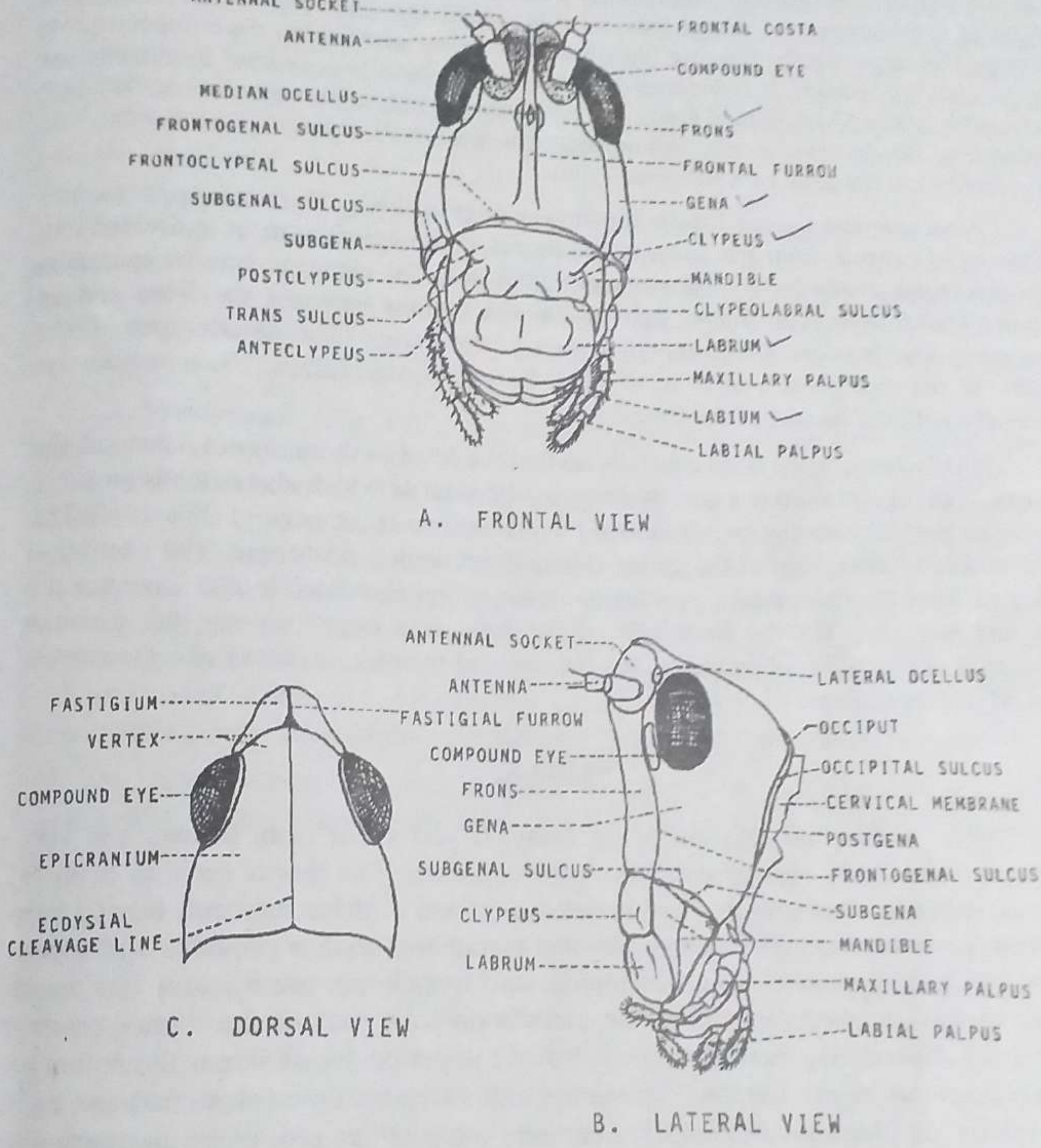


FIG. 14. HEAD OF AK GRASSHOPPER

Now examine the head from the lateral side (Fig. 14B). On its upper part is a large compound eye which consists of innumerable hexagonal areas, the facets. Each facet is a transparent biconvex lens through which the light passes for making an image. The large sclerite forming the whole side below and behind the compound eye is the gena (pl. genae). It is separated from the frons by a longitudinal frontogenal or subocular sulcus. It descends from the posterior margin of the antennal socket just anterior to the compound eye. Below the gena is a small sclerite, the subgena. It is separated from the gena by a subgenal sulcus.

Now examine the head from the dorsal side (Fig. 14C). The entire upper surface of the head capsule from the frons to the thorax is the epicranium. It is divided into two epicranial plates by a median longitudinal ecdysial cleavage line or epicranial suture. The anterior constricted part of the epicranium between the frons and an imaginary line between the compound eyes is the vertex. The anterior part of the vertex is the fastigium which is divided by a fastigial furrow. It is continuous anteriorly with the furrow of the frontal costa.

Finally remove the head carefully so that the head or thorax is not damaged. On the end of the epicranium is a narrow semicircular sclerite which also extends on sides. The upper part of this sclerite just behind the epicranium is the occiput (Fig. 14B). The sides of this sclerite behind the genae (cheeks) are called postgenae. The occiput is separated from the epicranium by a semicircular occipital sulcus. It also separates the gena and postgena. On the back side of the head is a large opening, the foramen magnum or occipital foramen. Also note the cervical membrane (neck) which connects the head with prothorax.

THORAX

This is the second division of the body. If you see it from below, it is very broad and thus clearly distinguished from the abdomen. The thorax consists of three segments: prothorax, mesothorax and metathorax. Each of these segments bears a pair of legs on the lower side. The mesothorax and metathorax each is provided with a pair of wings on the upper side. The mesothorax and metathorax are more or less fused together to form a single structure, the pterothorax (the part of the thorax bearing wings). Each thoracic segment has four sides: the upper or dorsal side is the notum or tergum (pl. nota or terga), the lower or ventral side is the sternum (pl. sterna) and each lateral side is the pleuron (pl. pleura). Generally the prefixes pro, meso and meta are used for indicating a sclerite or a leg on the prothorax, mesothorax and metathorax respectively.

A. Prothorax: Press the prothorax and see that it is not firmly united with the rest of the thorax. Remove it alongwith the first pair of legs, the prolegs, and study the following:

1. Pronotum (Fig. 15A): It is a large saddle-like structure which is present between the head and bases of fore wings. It covers the upper and lateral sides of the prothorax. The parts covering the sides are called lateral lobes. It is produced posteriorly to form a hood-like structure, the notalia which overlaps the sides slightly and the upper side of the mesothorax entirely. The pronotum has three transverse pronotal furrows and very fine rather an ill-defined longitudinal ridge, the median carina. The last furrow is more prominent and bent forward from its mid-dorsal line to form the tergal notch.

2. Propleuron (Fig. 15B): The only visible part is an anterior small triangular sclerite in front of the leg base and just below the anterior part of the lower margin of the lateral lobe. It is called proepisternum. Remove the overlapping lateral lobes of pronotum with the help of a blade and note a smaller posterior sclerite of proepimeron slightly above the leg base and just posterior to the former sclerite. These sclerites are separated by a well-defined propleural sulcus.

3. Prosternum (Fig. 15C): It is between the bases of the front legs and more deeply sunk as compared with meso-and metasternum. It is roughly rectangular and divided into three sclerites. The anterior one is the narrow sclerite of presternum. It is followed by the broader basisternum which bears a stout peg-like prosternal process. These two sclerites are separated by a presternal sulcus. The last is the shield-like spinasternum which has a narrow longitudinal spinal pit in the centre. It is separated from the basisternum by a transverse profurcal sulcus which lies just posterior to the prosternal process. At the ends of this sulcus are two pits, the apophyseal or furcal pits. Each pit located on the side of the prosternal process lies in an oblique fashion. On the lateral and posterior sides of the spinasternum is an intersegmental membrane.

B. Pterothorax: The mesothorax and metathorax are more or less welded together to form the pterothorax. After the removal of the prothorax, it looks like a strong box.

Note that the anterior pair of wings arises from the mesothorax and the posterior pair from the metathorax. The wings are articulated by a very complicated system of small sclerites which are beyond the scope of this introductory course. The fore wings are narrow and slightly thickened to form tegmina which function mainly for the protection of hind wings. The hind wings are thin, membranous and folded like a fan under the fore wings when the insect is at rest. They are the main organs of flight (see the structure, types, etc. of wings under INSECT APPENDAGES).

On each side of the thorax there are two small nearly oval breathing pores, the spiracles. The anterior one is situated in the membrane between the prothorax and mesothorax. It is covered by the lateral lobe of the pronotum and is called the spiracle of the mesothorax. The posterior one is situated between the mesothorax and metathorax slightly posterior to and above the base of the middle leg. It is called the spiracle of the metathorax. The insect respires through the spiracles.

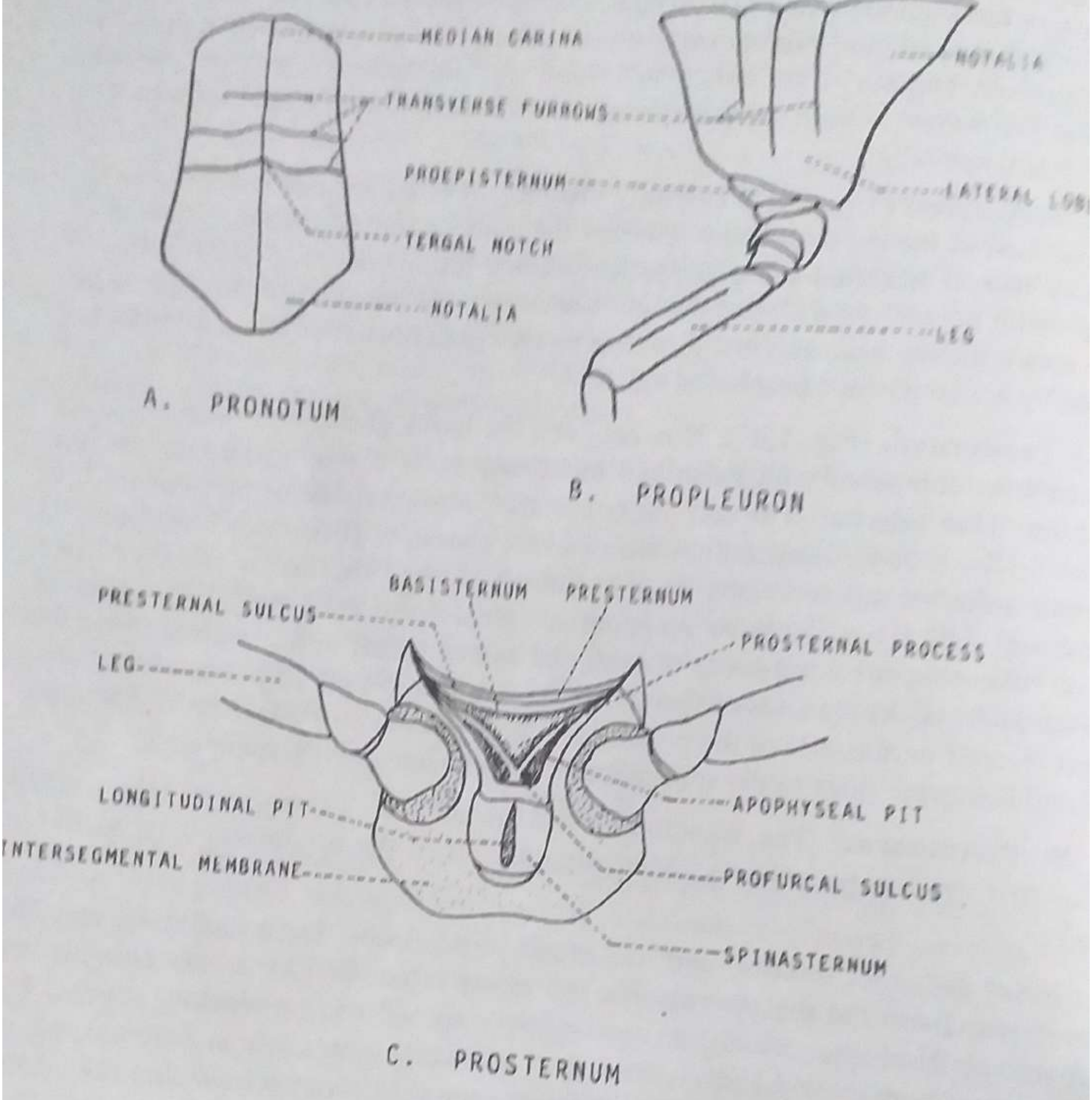


FIG. 15. PROTHORAX OF AK GRASSHOPPER

The legs of the mesothorax are called mesolegs and those of the metathorax as metalegs (see the parts and types of legs under INSECT APPENDAGES).

Now carry the wings on sides and study the sclerites and sulci of the two segments separately.

(a) Mesothorax: Study the main sclerites and sulci of the following sides.

1. Mesonotum (Fig. 16A)**:** On detaching the prothorax, a large membrane is seen at the anterior end of the mesonotum. It is followed by a broadly V-shaped intersegmental sclerite, the acrotergite (precosta). It is limited posteriorly by the antecostal sulcus. Behind the acrotergite is the largest somewhat raised sclerite of scutum which appears to be divided into two parts. On the sides of its anterior part are two depressed and nearly triangular areas which collectively form the prescutum. Each part of the prescutum is separated from the scutum by a prescutal sulcus. Posterior to scutum is an elevated, median and backwardly directed triangular sclerite, the scutellum. On its sides are two small oval areas which are considered to be the parts of scutum. At the end of mesonotum is a transverse membranous fold which by some morphologists is considered to be the part of scutellum.

2. Mesopleuron (Fig. 16B)**:** It consists of two large sclerites between the bases of mesoleg and fore wing. The anterior sclerite is called the mesoepisternum while the posterior is the mesoepimeron. They are separated by the mesopleural sulcus which is located at the level of middle of coxa. The mesopleuron is separated anteriorly from the propleuron by a very clear interpleural sulcus which contains a spiracle on its lower end. The mesopleuron is also separated posteriorly from the metapleuron by a well-defined interpleural sulcus which also contains a spiracle on its lower end.

3. Mesosternum (Fig. 16C)**:** At its anterior end is a narrow transverse sclerite, the presternum. It is followed by the large basisternum. These two sclerites are separated by the presternal sulcus. The basisternum is limited posteriorly by a rather broader groove, the mesofurcal sulcus which has three pits in it. The lateral ones are oblique, elongated and called apophyseal pits. The middle one is the spinal pit and represents the rudimentary spinasternum. The basisternum is extended back from the sides to form large mesosternal lobes which represent the sternellum. These lobes are widely separated by the mesosternal interspace. This space accommodates the anterior median prolongation of the metasternum.

(b) Metathorax: Study the main sclerites and sulci of the following sides.

1. Metanotum (Fig. 16A)**:** It has the same sclerites and sulci as mesonotum plus an additional sclerite, the postnotum at the end. The acrotergite is much narrower than that of the mesonotum and almost entirely overlapped by the transverse membranous fold of the mesonotum. The two triangular areas of the prescutum are also much smaller than those of the mesonotum. Two large triangular areas on the sides of the scutellum are also considered as parts of the scutum. Behind the

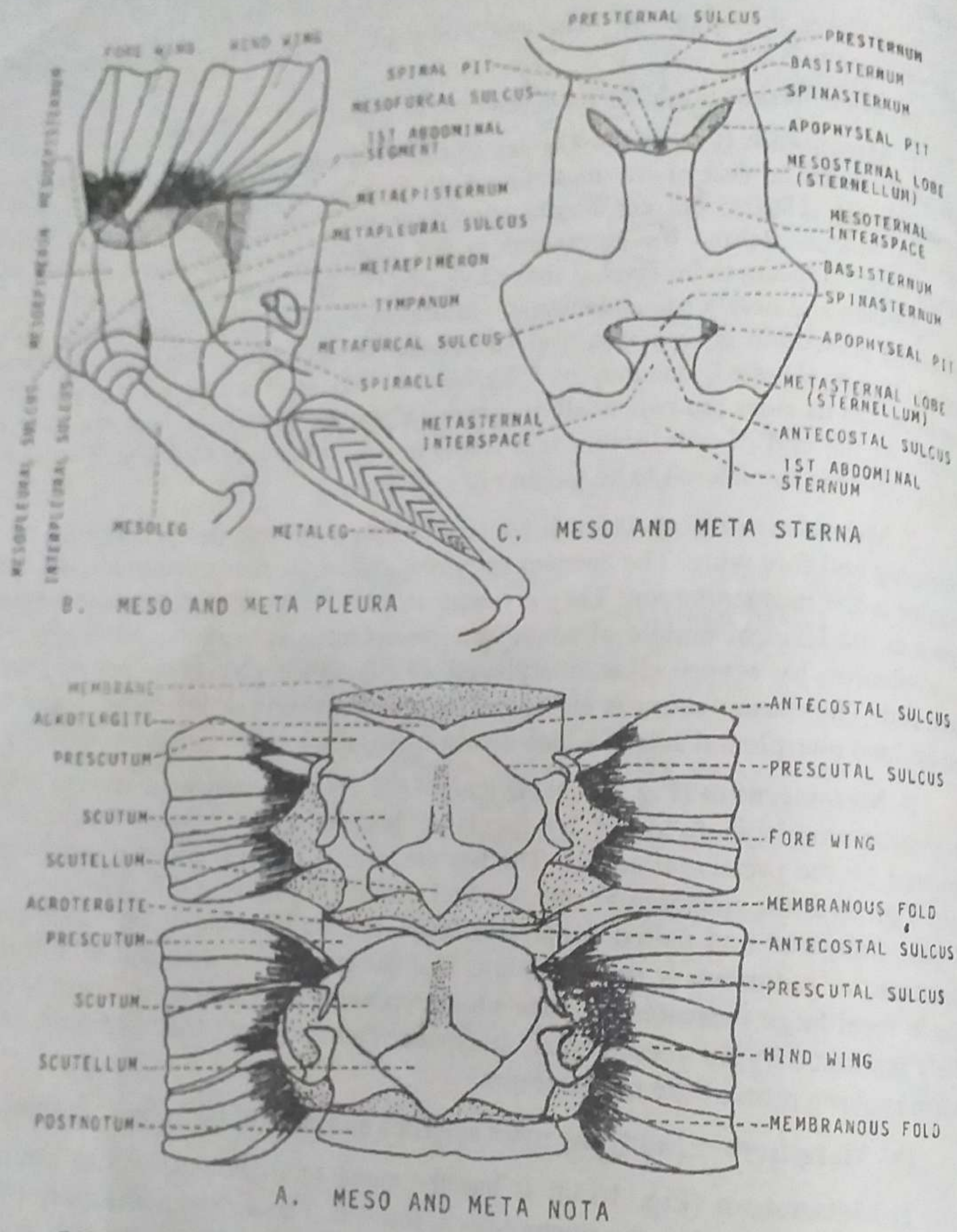


FIG. 16. PTEROTHORAX OF AK GRASSHOPPER

membranous fold is a broad transverse intersegmental sclerite, the postnotum (postscutellum).

2. Metapleuron (Fig. 16B): It is similar in structure to the mesopleuron. It has two large sclerites, the anterior one is the metaepisternum while the posterior one is the metaepimeron. These are separated by the metapleural sulcus lying at the level of middle of coxa.

3. Metasternum (Fig. 16C): It is broader than mesosternum. It largely consists of basisternum whose anterior broad prolongation is fitted into the mesosternal interspace. The basisternum is followed by a small rectangular sclerite, the spinasternum from which the spinal pit and its corresponding internal process have disappeared. The basisternum and spinasternum are separated by the metafurcal sulcus which has two widely separated apophyseal pits on its lateral ends. The spinasternum is separated from the first abdominal sternum by the antecostal sulcus. The basisternum is extended back from the sides to form smaller metasternal lobes which together form the sternellum. These lobes are separated by a large gap which is called metasternal interspace. This space accommodates the anterior median prolongation of the first abdominal sternum.

ABDOMEN

This is the third and last division of the insect body. It is long, narrow and consists of eleven segments (Fig. 17A). Some of its posterior segments are so modified for mating and oviposition that they do not look like segments. Each segment is divided into two parts: the large dorsal part which also covers the sides is the tergum and the smaller ventral part is the sternum. These two are separated by a longitudinal sulcus which represents the greatly reduced lateral area (pleuron). The first abdominal segment is the largest one. It looks like a part of the thorax than of the abdomen and is intimately fused with the thorax. Its sternum (Fig. 16C) is very broad with its anterior median prolongation fitted into the metasternal interspace. On its each side just above the hind coxa is a white membrane, stretched across an oval cavity, which is called tympanum or outer membrane of the ear. Note a nearly circular spiracle in front of the tympanum. Segments two to eight are similar, each having a tiny spiracle at the lower anterior angle of its tergum on each side. The 9th and 10th terga, especially the former in the male (Fig. 17B), are narrow in both sexes. They are partially fused because the sulcus between them is obsolete on the lower side. The 11th tergum is represented by a triangular plate above the anal opening which is called epiproct or supra-anal plate. On the sides and slightly concealed under the epiproct are two lateral plates, the paraprocts or podical plates. They represent the 11th sternum. On each paraproct is a conical process, the cercus (p1. cerci). It comes out from a membrane on the posterior margin of the 10th tergum. It is very small in the female as compared with that of the male. The last visible sternum is 8th in the female and 9th in the male (Fig. 17A, B). In both the sexes it is called a subgenital plate which will be discussed below as a part of the external genitalia.

External genitalia:

1. **Female:** The subgenital plate is very large and produced backwards beyond the limits of its corresponding tergum (Fig. 17A). Its posterior margin bears a median process called egg-guide and two lateral lobes (if seen from ventral side). The egg-guide is triangular or conical and wedged between the bases of the ventral valves of the ovipositor.

The ovipositor (Fig. 17C) consists of a dorsal pair and a ventral pair of valves with their tips directed in opposite directions. The dorsal and ventral pairs of valves can be spread apart and brought together. These are used as digging organs in oviposition. Push apart the dorsal and ventral pairs of valves with your dissecting needle and note a small inner pair of valves or the forked organ concealed between them. The inner valves and the egg-guide are used for placing the eggs in the egg-pod.

2. **Male:** The subgenital plate (Fig. 17B) is a large boat-like structure. It forms the genital chamber on its upper side which conceals the male genital organs. The copulatory or genital organs are collectively known as aedeagal or phallic complex. The posterior end of the subgenital plate which incurves into the genital chamber to cover the tip of the phallic complex is called pallium. Expose the phallic complex by depressing the posterior end of the subgenital plate with a dissecting needle and take it out. It consists of two parts, the aedeagus and the epiphallus.

The aedeagus (Fig. 17D) is nearly flask-shaped, strongly sclerotised and wrapped (except tip) in a thick membranous sac, the ectophallic membrane. Now remove this membrane to see the parts clearly. The aedeagus consists of a pair of large basal valves which are connected with two long, narrow and curved apical lobes. Tips of these lobes are separated by a narrow slit which leads into a large cavity, the phallotreme cleft. This cleft contains penis between two penal valves. There is a small depression at the junction of the basal valves and apical lobes. Also see the lateral view of the aedeagus (Fig. 17E).

The epiphallus (Fig. 17F) is a collar-like or bridge-shaped sclerotised structure which is present on the dorsal side of the aedeagus. It is also removed along the ectophallic membrane, with which it is attached. It consists of two long lateral sclerites which are connected sub-basally by a bridge. They also have two small triangular hook-like posterior projections which slightly project outwards. The epiphallus contains two lateral appendices which are also connected at their bases.

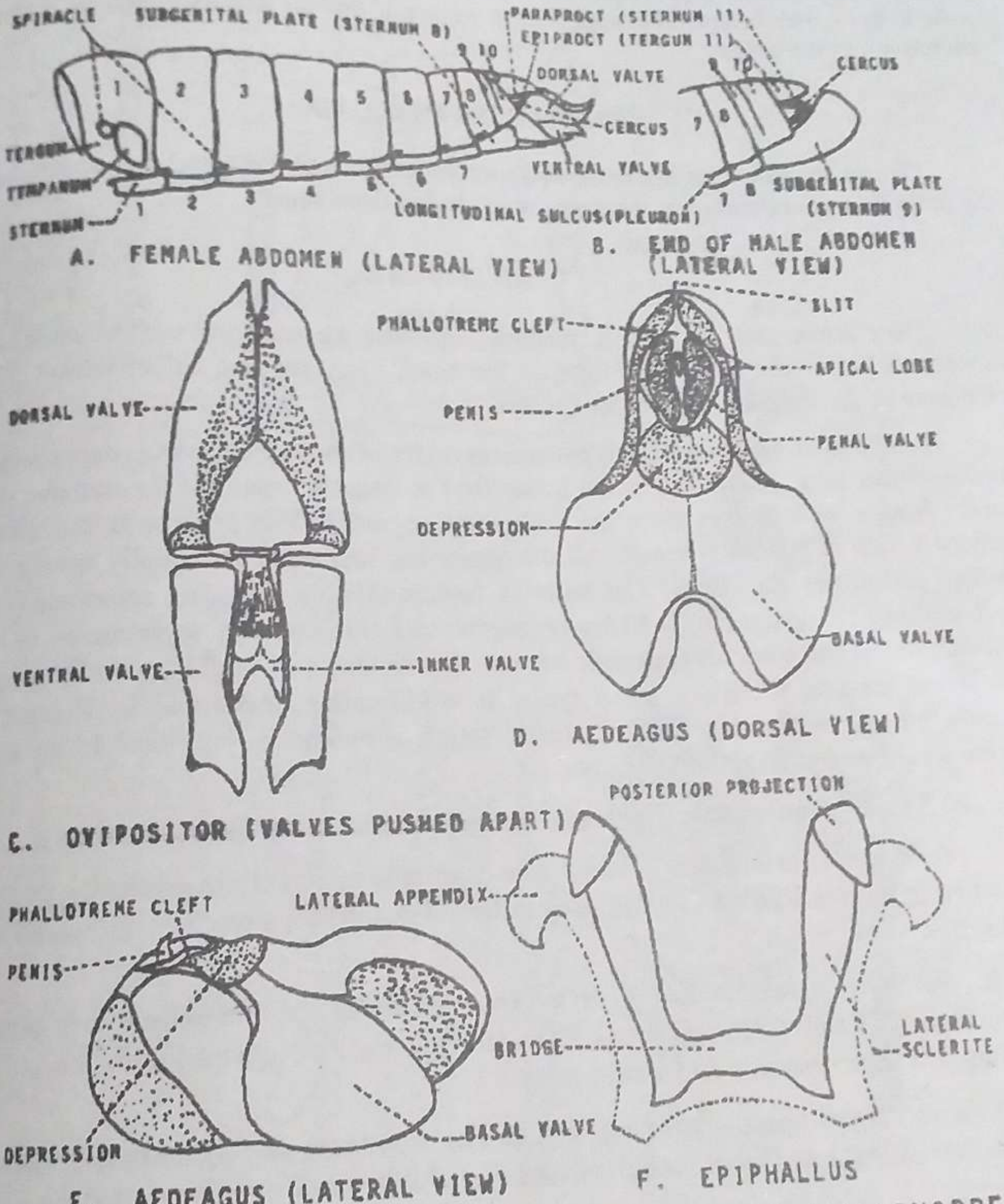


FIG. 17. ABDOMEN AND GENITALIA OF AK GRASSHOPPER

INSECT APPENDAGES

These are the outgrowths of the body wall which are movable and connected with it by a membrane. The appendages of head, thorax and abdomen in different insects are given below.

APPENDAGES OF HEAD

These comprise the antennae and mouthparts. It may be noted that according to the definition of appendages, the eyes are excluded from them.

ANTENNAE

They are a pair of jointed, primarily sensory appendages which are located between or below the compound eyes on the head. They are also called feelers. They are absent in the insects of the order Protura.

(a) Parts of antenna: Each antenna consists of three parts, viz., scape, pedicel and flagellum (Fig. 18B). The scape is the first or basal segment of the antenna. It is usually longer and thicker than the following segment. The pedicel is the second segment which is generally small. All the remaining segments are usually similar and together called the flagellum. The latter is further divided into ring segments (very small and ring-like), funicle (ordinary segments) and club (swollen segments as in Fig. 18K) in most of the chalcids (parasitic wasps). As the shape of flagellum varies greatly in different insects, there are many types or modifications of antennae. It must be remembered that while describing different types of antennae, you have to consider only the shape of the flagellar segments.

(b) Types of antennae: The important types of antennae are as follows:

1. Setaceous (bristle-like) (18A)**:** The segments of flagellum gradually taper or narrow towards apex like a hair, e.g., dragonflies, damselflies, stoneflies, silverfish and cockroaches.

2. Filiform (thread-like) (18B)**:** The segments of flagellum are almost cylindrical and of the same thickness like a thread, e.g., ak grasshopper, locust, red cotton bug, earwigs, psocids and shield bugs.

3. Moniliform (bead-like) (Fig. 18C)**:** The segments of flagellum are more or less globular like a bead, e.g., termites, doubletails, beaded lacewings and wrinkled bark beetles.

4. Serrate or dentate (saw-like or tooth-like) (Fig. 18D)**:** The segments of flagellum have short triangular or tooth-like projections on one side, e.g., pulse beetles (dhora) and most click beetles.

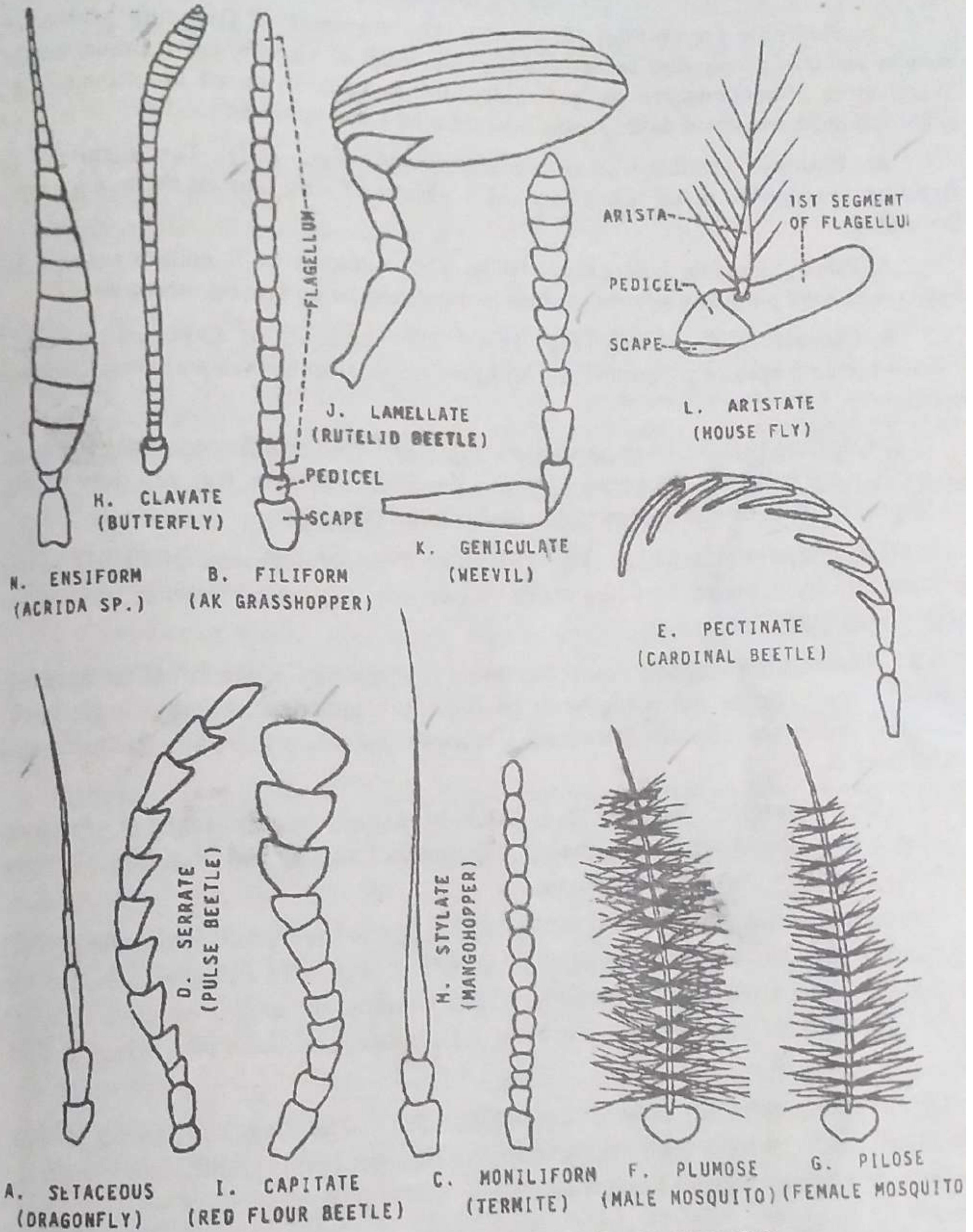


FIG. 18. ANTENNAE OF INSECTS

5. Pectinate (comb-like) (Fig. 18E): The segments of flagellum have long, slender and stiff projections on one side like the teeth of a comb, e.g., cardinal beetle. When these projections are on both sides, the antenna is called bipectinate, e.g., silkworm moth, saturniid moths, some noctuid moths and sphingid moths.

6. Plumose (feather-like or densely hairy) (Fig. 18F): The segments of flagellum (except the distal ones) have thick whorls of long hair on them, e.g., male mosquitoes.

7. Pilose (sparsely hairy) (Fig. 18G): The segments of flagellum (except the distal ones) have very thin whorls of short hair on them, e.g., female mosquitoes.

8. Clavate (club-shaped) (Fig. 18H): The segments of flagellum gradually broaden towards apex, e.g., butterflies, antlions, trogossitid beetles and some darkling beetles.

9. Capitate (knob-like or head-like) (Fig. 18I): One or a few terminal segments of flagellum are suddenly thickened to form a head-like structure, e.g., red flour beetle, powderpost beetles, nitidulid beetles and amblyceran biting lice.

10. Lamellate (Leaf-like) (Fig. 18J): The terminal segments of flagellum are expanded into long, broad, leaf-like plates on one side, e.g., rutelid beetles, rhinoceros beetles and dungrollers.

11. Flabellate (tongue-like): It has some resemblance to the lamellate antenna. But in this type one or more segments of flagellum are produced into long, thick, tongue-like processes slightly broadening towards apices, e.g., male stylopids and sandalid beetles.

12. Geniculate (elbow-like) (Fig. 18K): In this antenna the scape is very long and forms a sharp bend with the remaining segments like a flexed arm, e.g., weevils, honeybees, chalcid wasps and stag beetles.

13. Aristate (arista-like) (Fig. 18L): The scape is very small while the pedicel is large and triangular. The first segment of flagellum is greatly enlarged, whereas the remaining segments are modified into a large hairy bristle, the arista, which is attached to the first segment on the dorsum of its base, e.g., house flies, fruit flies, syrphid flies, etc.

14. Stylate (styliform or setiform) (Fig. 18M): The flagellum forms a long, unsegmented, terminal hair, e.g., mango hoppers (leafhoppers), planthoppers, cicadas, robber flies, delphacid bugs and mayflies.

15. Ensiform (sword-like) (Fig. 18N): The segments of flagellum are thin, flattened and gradually taper towards apex like a leaf-blade or a sword, e.g., green grasshoppers (*Acrida* sp.).

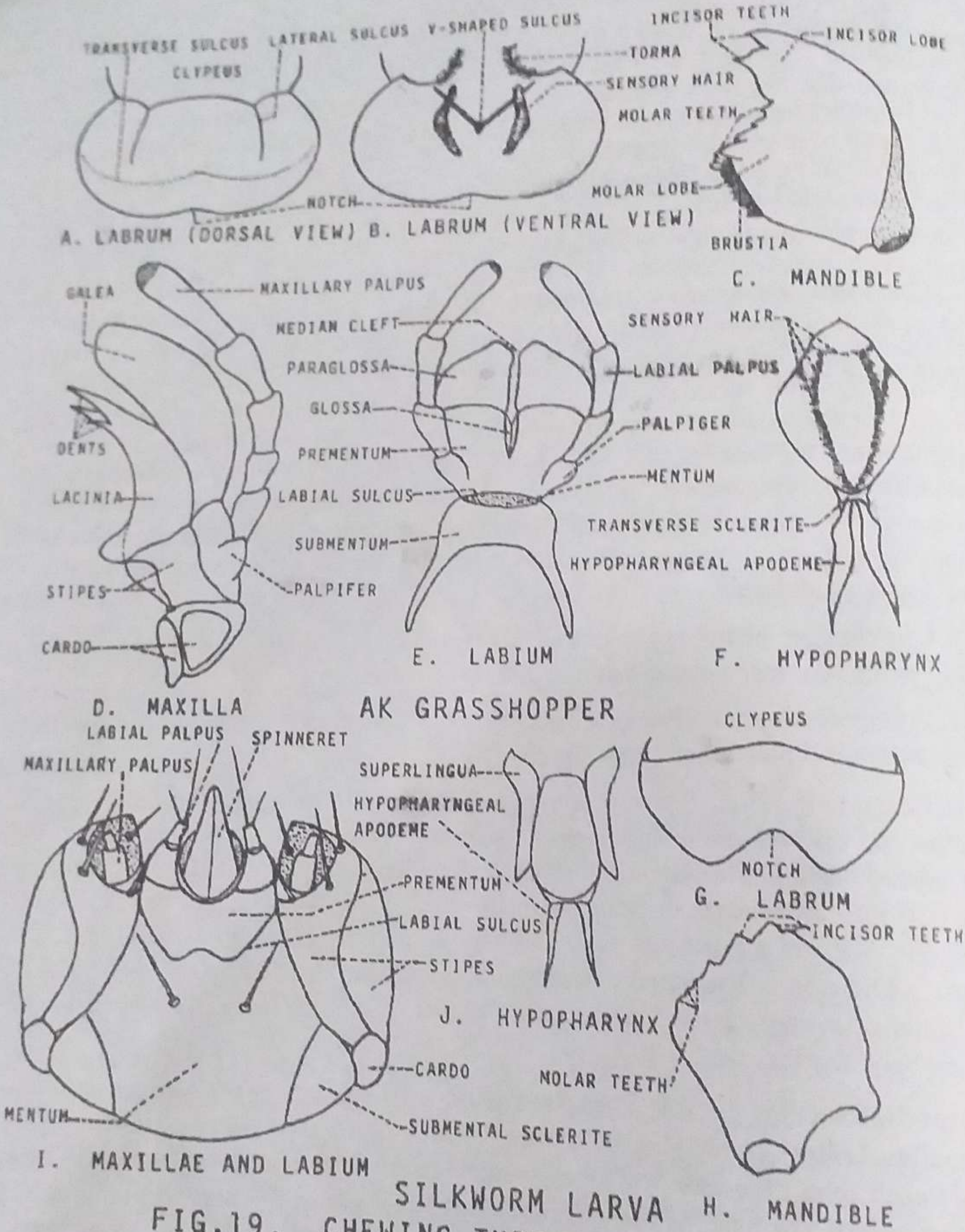


FIG.19. CHEWING TYPE OF MOUTHPARTS

Maxillae (Fig. 19D): These are paired structures lying below the mandibles. They move sideways just like mandibles. Each maxilla consists of a basal sclerite, the cardo (pl. cardines) which on its apex has another sclerite, the stipes (pl. stipites). The cardo has further two parts, an outer broad and triangular and an inner long and narrow one. Similarly the stipes has also two parts, an outer broad and rectangular and an inner long and narrow one. The stipes contains three structures on it. On its outer side is a small process called palpifer which bears on it an antenna-like 5-segmented structure, the maxillary palpus (pl. palpi). The stipes on its apex bears two lobe-like structures. The outer one is broad, elongate and called the galea while the inner one is basally broad but tapering anteriorly and known as the lacinia. The latter is strongly sclerotised and has three black pointed dents at its apex.

Note: When the two lobes on the stipes fuse and form a single structure, it is called mala.

Labium (Fig. 19E): It is a single structure lying below the maxillae. It closes the mouth from the lower side. It is divided by an ill-defined transverse labial sulcus into two main parts: the posterior one, the postmentum and the anterior one, the prementum. The postmentum is further divided into two parts: the lower very large is the submentum while the upper very small (in the form of a narrow transverse belt) is the mentum. The prementum contains three pairs of structures on it. It bears at its apex two large triangular lobes, the paraglossae which are separated by a deep median cleft. At the base of this cleft are two small and narrow lobes, the glossae. The prementum, on either side of its base, has a small process which is fused with it and called palpiger. Each palpiger bears on it an antenna-like 3-segmented structure, the labial palpus.

Note: When the four lobes of the prementum are fused and form a single structure, it is called ligula.

Hypopharynx (Fig. 19F): When the labrum and mandibles are removed, a large median fleshy lobe, the hypopharynx, is seen in the mouth cavity. It is attached to the base of the labium. The hypopharynx is broad from the middle and tapers anteriorly as well as posteriorly. Its anterior end looks like a triangular lobe. Its dorsal side bears two slightly curved longitudinal rows of sensory hair which after branching near their anterior ends merge into a transverse row. The hypopharynx has also a posterior transverse sclerite from which come out two hypopharyngeal apodemes or processes for the attachment of muscles.

2. Silkworm Larva (*Bombyx mori*): Dissect out the mouthparts and mount them on a slide in a drop of glycerin. Note that the larvae of butterflies and moths have the chewing type whereas their adults have the siphoning type of mouthparts. The latter will be described at the end of the mouthparts.

Labrum (Fig. 19G): It is a small sclerite which has a deep notch in the anterior border. Its base is attached to a narrow and transversely elongated clypeus. The epipharynx is not differentiated on its lower surface.

channels: the upper food channel or suction tube and the lower salivary channel or salivary tube. They form the inner pair.

Note: The stylets of mandibles and maxillae cling together to form a single structure, the fascicle. It lies in the groove of the labium.

Labium: It is the principal structure which is modified to form an antenna-like 4-segmented proboscis. It has a dorsal groove like that of a knife to accommodate the fascicle. Its tip is provided with small sensory hair. It does not penetrate into the plant.

Note: The head of a weevil is prolonged anteriorly to form a beak-like structure. This beak appears to be a sucking proboscis. But actually the mouthparts are of chewing type as this beak has the chewing mandibles at its tip.

III. Sponging type: e.g. house fly (*Musca domestica*) (Fig. 20B): The mouthparts are greatly modified and visible in the form of a short, thick, elbow-shaped fleshy proboscis on the lower side of the head. Press the head with a needle and see that the proboscis is dissected out. It consists of three main parts, viz., rostrum haustellum and labellum.

Rostrum: It is the basal cone-shaped portion of the proboscis. A pair of unsegmented, club-shaped, hairy maxillary palpi are present on its distal end.

Haustellum: The part of the proboscis between maxillary palpi and labellum is called haustellum. It has a groove on its dorsal side (Fig. 20B shows the lateral view) which contains a pair of needle-like structures, the hypopharynx and labrum. The former lies at the bottom of the groove and forms the salivary channel because it has a canal within it. The latter is ventrally grooved and lies on the hypopharynx and thus forms the food channel by closing its groove from below by the hypopharynx. Normally these two structures are not visible outside. Press the haustellum gently, you will see that they become easily visible.

Labellum: It is the terminal portion of the proboscis which has a pair of large, sponge-like, fleshy lobes, the labella. They contain numerous fine tubes, the pseudotracheae which open outside.

IV. Siphoning type: e.g. lemon butterfly (*Papilio demoleus*) (Fig. 20C): The mouthparts are highly modified and visible in the form of a long but coiled proboscis below the head. It is straightened only at the time of feeding. Many parts are either absent or greatly reduced and thus not visible. Examine the KOH treated head and note that only the following parts are visible.

Labrum: It is a narrow, transverse sclerite which is provided with a median triangular lobe, the epipharynx and two prominent lateral lobes, the pilifers.

Maxillae: The galeae of the maxillae are greatly elongated to form the suctorial proboscis. They are grooved on their inner sides and hooked together to form a sucking tube. The maxillary palpi are greatly reduced and appear as small knobs.

Mandibles (Fig. 19H): These are small, paired and strongly sclerotised structures lying below the labrum. The biting surface of each mandible has both the incisor and molar teeth. The former are pointed and the latter are blunt.

Maxillae (Fig. 19I): These are paired structures lying below the mandibles. They are fused with the labium on its sides. Take out the entire lobe consisting of labium and maxillae with the help of your dissecting needle. Each maxilla consists of a small basal sclerite, the cardo. It has on it a large, characteristic, longitudinally divided sclerite, the stipes which contains 2-segmented maxillary palpus on a palpifer. The galea and lacinia are fused and not differentiated.

Labium (Fig. 19I): It is present between the maxillae and closes the mouth from the lower side. It consists of three main parts, viz., submentum, mentum and prementum. The submentum comprises a pair of widely separated triangular submental sclerites present at the base of the maxillae. The mentum is very large and present between two stipites. It is separated from the prementum by a W-shaped labial sulcus. The prementum is large and carries a median process, the spinneret on its distal side. It is formed from the fusion of glossae and paraglossae. On the sides of the spinneret are two very small labial palpi, each consisting of 2 segments.

Hypopharynx (Fig. 19J): After removing the labrum and mandibles, the hypopharynx becomes visible. It is a median pad-like lobe which is attached to the base of the labium in the mouth cavity. There are two lobes on its sides which are called superlinguae. Also note the hypopharyngeal apodemes.

II. Piercing-sucking type: e.g. red cotton bug (*Dysdercus koenigii*) (Fig. 20 A): The mouthparts are greatly modified and visible only in the form of a long, slender beak or proboscis. The proboscis comes out from the front of the triangular head. It bends downwards and backwards and thus lies beneath the body between the legs when not in use. Try to straighten this structure two or three times with a dissecting needle. You will see that the labrum is automatically separated from its base. If this method is not satisfactory, lift the labrum from the base of the proboscis with a dissecting needle. Similarly lift out the needles (forming a single structure). Now separate the four hair-like needles by teasing them gently with a dissecting needle. Remove the insect head and study the structure of mouthparts as given below.

Labrum: It is a short structure, broad at base and narrowing towards apex. It is attached to the clypeus and covers the groove of the labium up to the end of its first segment. It keeps the needles in the groove of the labium by pressing them.

Mandibles: These are paired, long, hair-like needles called stylets. Their tips are slightly curved and serrated or provided with short teeth (when seen under high magnification) for piercing the plant. They form the outer pair.

Maxillae: These are also paired, long, hair-like needles called stylets. Each maxillary stylet has a double groove along its inner side (if seen under high magnification). When the two maxillae fit together, their grooves form two tubes or

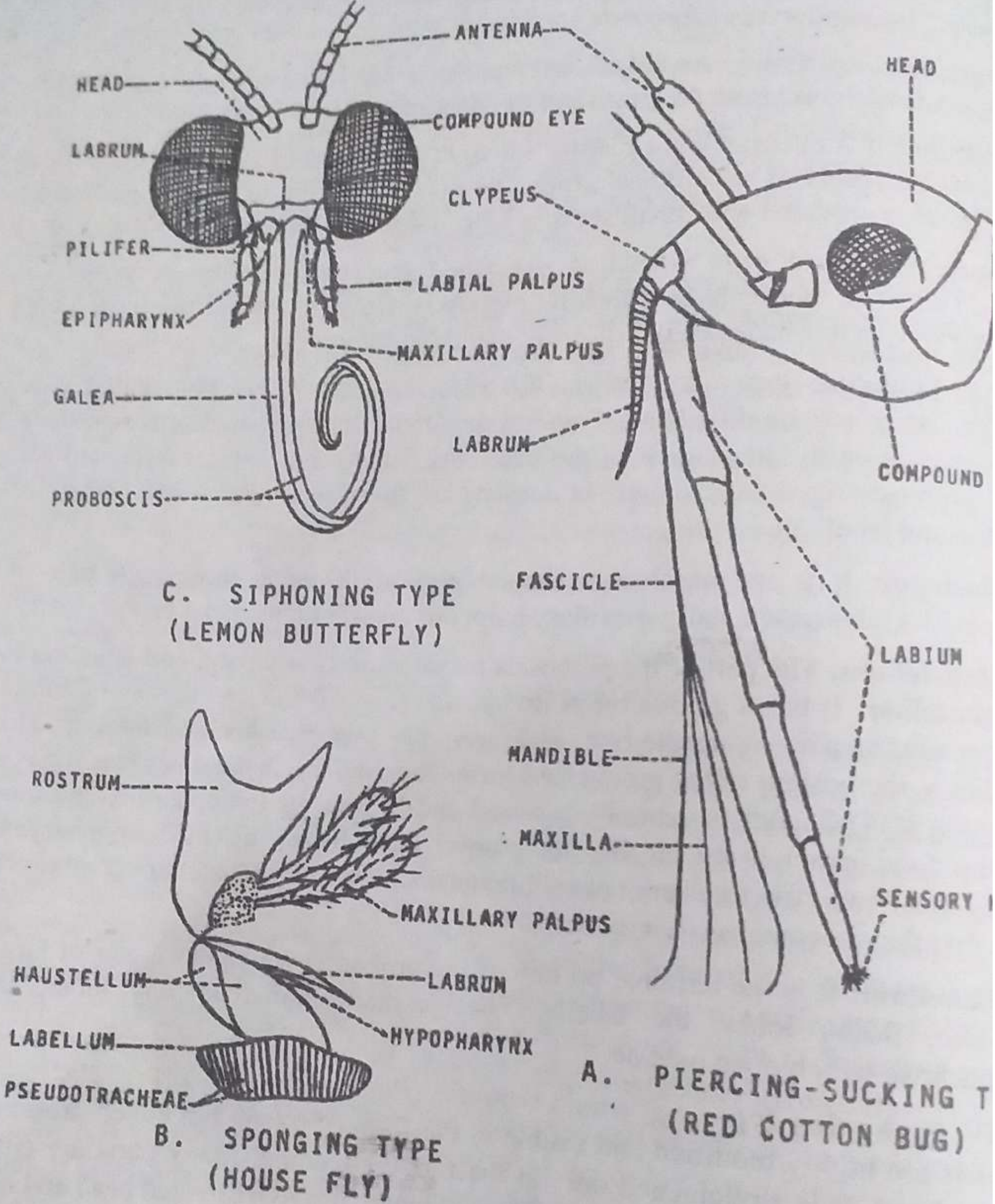
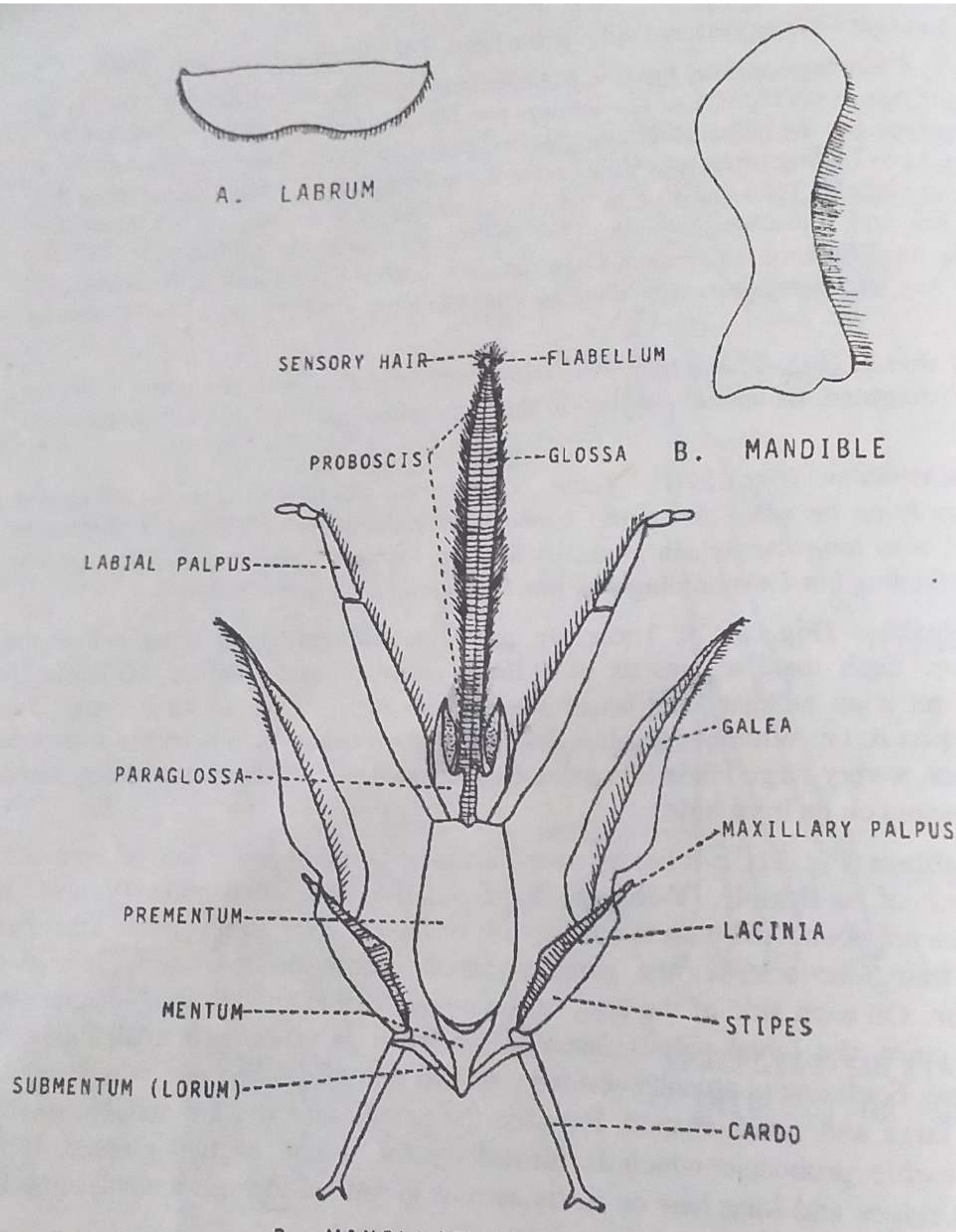


FIG.20. SUCKING TYPE OF MOUTHPARTS



C. MAXILLAE AND LABIUM

FIG.21. CHEWING-LAPPING TYPE OF MOUTHPARTS (HONEYBEE)

APPENDAGES OF THORAX

These consist of the wings and legs.

WINGS

These are the membranous, paired appendages of flight which are located dorsolaterally on the thorax.

(a) Occurrence of wings: The insects have either no wings or a pair of wings (on the mesothorax) or two pairs of wings (first on the mesothorax and second on the metathorax). Examine these conditions in a silverfish (Fig. 8A), house fly (Fig. 7E) and grasshopper (Fig. 4) respectively. Note that the prothorax never bears wings.

(b) Development of wings: The wingless insects are called the apterous, with reduced wings the brachypterous and with complete wings the macropterous. The undeveloped wings of nymphs and naiads are called wing-pads (Fig. 9C).

The insects which are supposed primitively wingless are known as Apterygota, e.g., silverfish (Fig. 8A), doubletails, telsontails and springtails. The insects which are winged or secondarily wingless are called the Pterygota. It has further two types. The insects which develop their wings outside the body are called Exopterygota, e.g., grasshoppers (Fig. 8B), bugs, etc. The insects which develop their wings inside the body are known as Endopterygota, e.g., flies, wasps, moths (Fig. 9A), butterflies, beetles, etc.

(c) Wing margins and angles: Place the hind wing of an ak grasshopper (Fig. 22H) between two slides under a microscope and note the following: It is almost triangular in shape. Its anterior border is called the costal margin, outer border the apical margin and inner border the anal margin. The following three angles are also defined: the humeral angle between the costal and anal margins, the apical angle between the costal and apical margins, and the anal angle (tornus) between the anal and apical margins.

(d) Wing venation (Fig. 22A): The wings of most insects are membranous. They are supported by a framework of hollow ribs or thickened ridges, the veins. Most of these veins extend lengthwise in the wing and are called longitudinal veins. A few of them connect the longitudinal veins and are called cross veins. The arrangement of veins in a wing is called venation or neuration.

In the wings of certain insects, the areas between the longitudinal veins contain an irregular network of veins called archedictyon, e.g., dragonflies, mayflies, stoneflies and ant-lions. The wings of these insects are also called net-veined.

The longitudinal veins and most of the cross veins bear names. These names (from the anterior to the posterior) with their abbreviations are as follows:

Longitudinal veins	**Cross veins**
1. Costa (C)	1. Humeral (h)
2. Subcosta (Sc)	2. Radial (r)
3. Radius (R)	3. Sectorial (s)
4. Media (M)	4. Radiomedial (r-m)
5. Cubitus (Cu)	5. Medial (m)
6. Anals (A)	6. Mediocubital (m-cu)

Note the abbreviations of longitudinal veins are always in capital letters and those of cross veins always in small letters.

The longitudinal veins may be simple or branched in varying degrees in different insects. But the basic hypothetical or primitive arrangement is as follows: The costa is unbranched. It forms either the anterior margin or lies along the anterior margin. The subcosta is 2-branched distally. The radius is divided into two branches: R1 and the radial sector (Rs). The radial sector divides into two branches and each branch further divides into two. The radius is thus 5-branched. The media is divided into two branches: anterior media (MA) and posterior media (MP). The anterior media divides into two branches. Similarly the posterior media divides into two branches and each branch divides again into two. The media is thus 6-branched. The cubitus is 2-branched, with its first branch further divided into two. There are 3 or 4 anals which are typically unbranched.

It must be remembered that the abbreviations of the main longitudinal veins are generally written at their bases, while their final branches are indicated at the wing margin (Fig. 22A).

The most important cross veins are: the humeral connects the costa and subcosta near the base of the wing. The radial connects R1 and radial sector (Rs). The sectorial connects R3 and R4. The radiomedial connects radius and media, usually near the middle of the wing. The medial connects M2 and M3. The mediocubital connects media and cubitus.

This hypothetical or primitive wing venation can not be seen in any wing at present because some veins or their branches have either lost or fused together. The fusion of two branches (e.g. R4 and R5) is written as R4+5.

(e) Cells of wings: The longitudinal and cross veins surround the areas of various shapes which are called cells. There are two types of cells. If the area is entirely surrounded by veins, it is a closed cell (Fig. 22A). If the area extends to the wing margin, it is an open cell (Fig. 22A). A cell is named after the vein which forms its anterior border. In some insects certain cells have special names, e.g., discal cell of butterflies and moths (Fig. 23A).

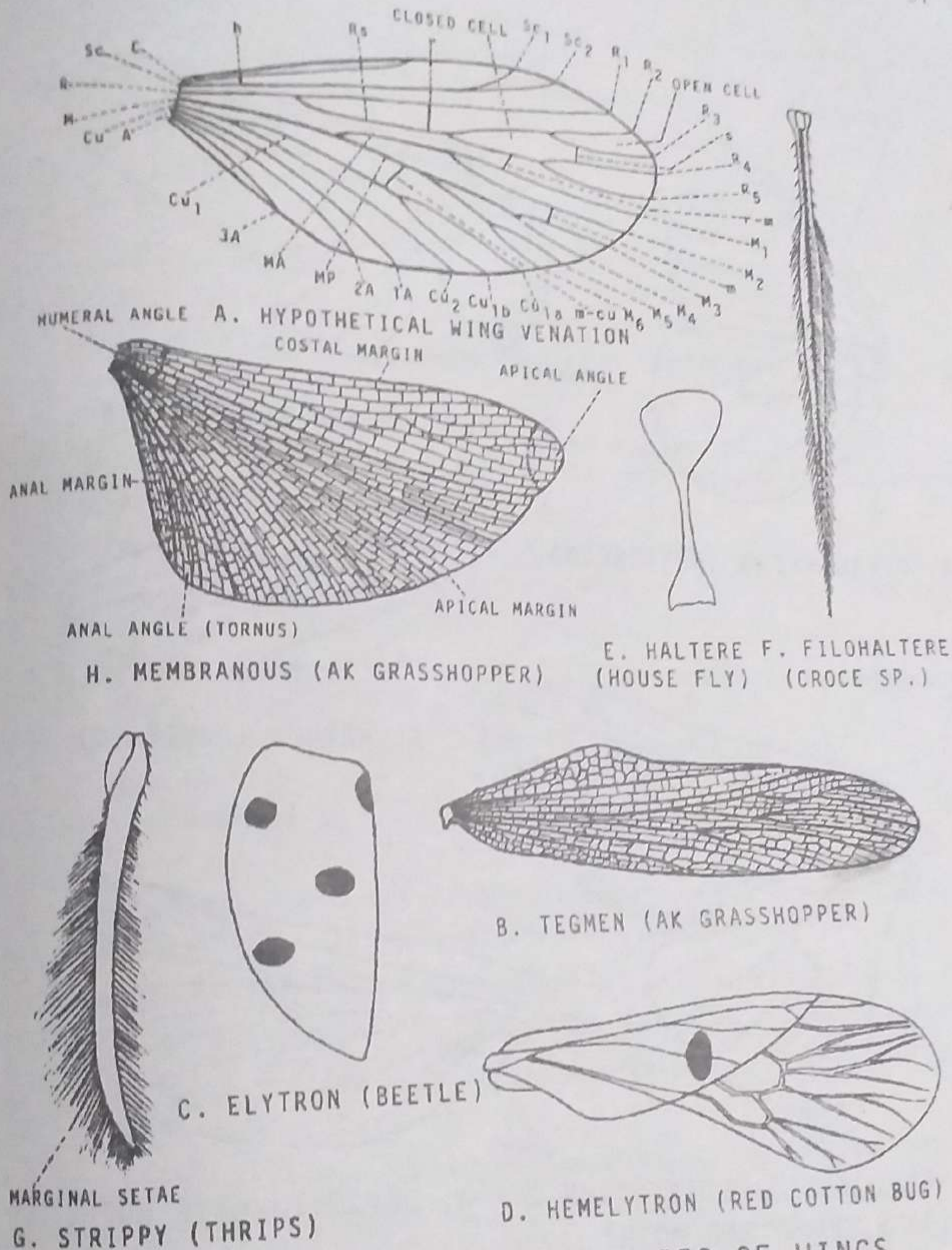


FIG.22. STRUCTURE AND TYPES OF WINGS

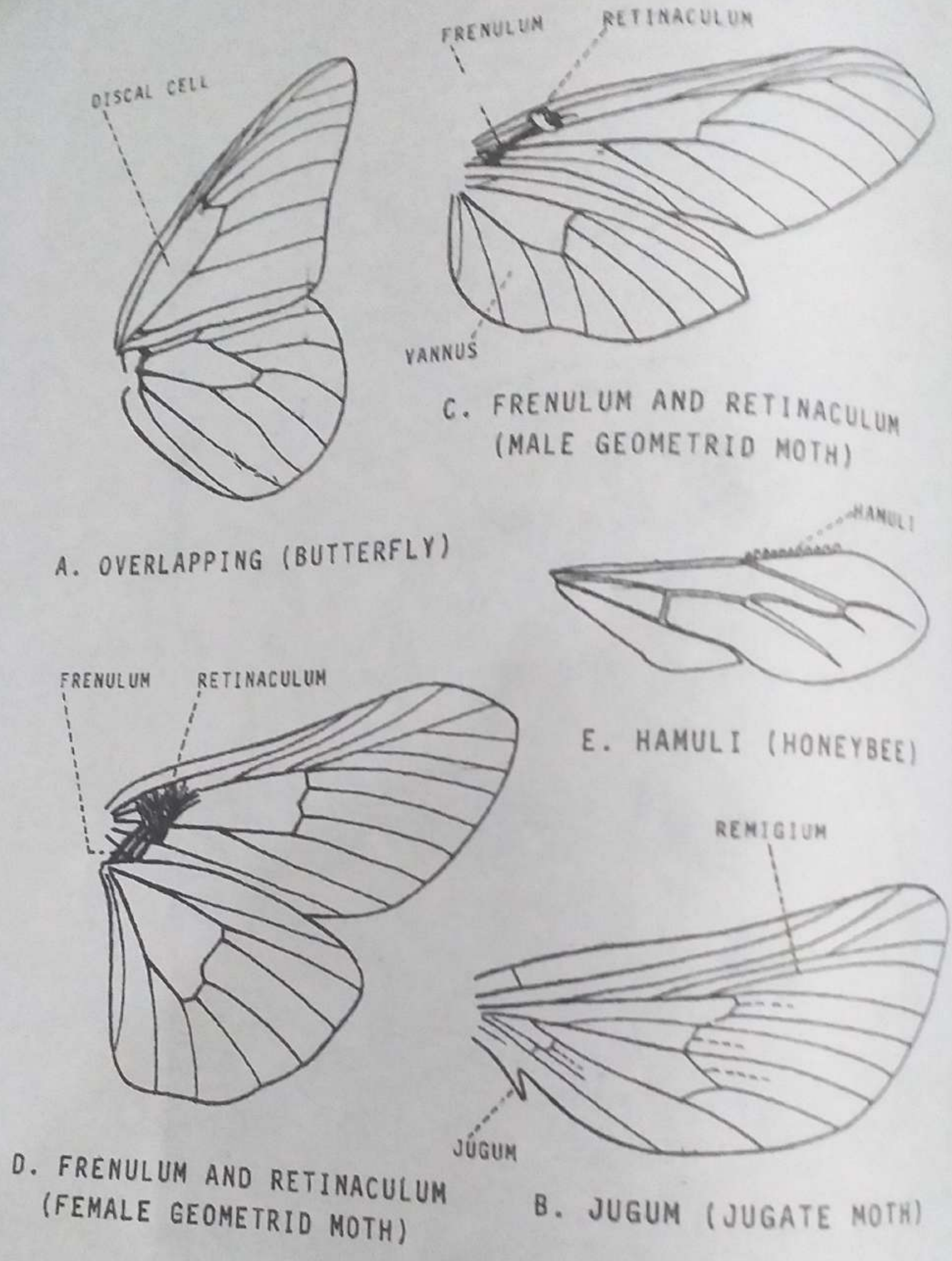


FIG.23. WING COUPLING APPARATUS

(f) Areas of wings: The central area of the wing is called the disc. The area of the wing having the maximum number of veins is called remigium (Fig. 23B). The area containing only the anal veins is termed the annal or vannal area (Fig. 23C).

(g) Special structures of wings: Some insects have a thick pigmented spot along the costal border near the apex of the wing which is called Pterostigma, e.g., dragonflies, damselflies, most hymenopterous insects, etc. A thick, short, cross vein descends from the middle of the anterior border which is called nodus in dragonflies. The border appears to be broken and jointed at this point. The wings of butterflies and moths are covered with scales of various shapes. The rod-like wings of thrips have fringes of long hair which are called marginal setae (Fig. 22G).

(h) Types of wings: Some important types or modifications of wings are as follows:

1. Tegmina (Fig. 22B)**:** The fore wings are modified into long, narrow, hard and slightly thick structures, the tegmina (sing. tegmen), e.g., grasshoppers, cockroaches, mantids, crickets, etc.

2. Elytra (Fig. 22C)**:** The fore wings are modified into very thick and hard structures, the elytra (sing. elytron), e.g., beetles, weevils and earwigs. They form a protective covering for hind wings when the insect is in rest.

3. Hemelytra (Fig. 22D)**:** The basal part of the fore wing is thick and hard while the apical part is thin and membranous. Such wings are called hemelytra (sing. hemelytron), e.g., true bugs (like red cotton bug).

4. Halteres (Fig. 22E)**:** The hind wings are modified into tiny, knobbed structures, the halteres, e.g., flies (like house fly), male coccids (like mango mealybug).

5. Pseudohalteres: When the fore wings are modified into halteres, they are known as pseudohalteres, e.g., male stylopids.

6. Filohalteres (Fig. 22F)**:** When the hind wings are modified into very long, thread-like structures, they are termed filohalteres, e.g., some lacewings (*Croce sp.*).

7. Strippy (Fig. 22G)**:** The wings are modified into strips or rod-like structures and fringed with long hair, e.g., thrips.

8. Membranous (Fig. 22H)**:** The hind wings are very thin and broad like a membrane, e.g., grasshoppers, locusts, crickets, earwigs, beetles, etc.

(i) Wing coupling apparatus: The mechanism by which the two wings of one side are linked together and act as a unit during the flight is called wing coupling apparatus. Study the following devices:

1. Overlapping (Fig. 23A)**:** This Is the simplest method in which the fore wing overlaps the anterior border of the hind wing, e.g., butterflies.

2. Jugum (Fig. 23B): This is a finger-like process at the base of the posterior border of the front wing which projects under the hind wing, e.g., jugate moths.

3. Frenulum (Fig. 23C, D): This is a single stout spine (in males) or several spines (in females) on the humeral angle of the hind wing, e.g., geometrid moths.

4. Retinaculum (Fig. 23C, D): It is a strong curved process (in males) or a group of strong hair (in females) on the lower side of the fore wing. The frenulum is held by the retinaculum, e.g., geometrid moths.

5. Hamuli (Fig. 23E): These consist of a row of minute hooks on the anterior border of the hind wing that catch into the uprolled hind border of the fore wing, e.g., honeybees.

LEGS

These are paired, jointed, primarily locomotary appendages which are articulated on the ventral side of the thorax.

The adult insects normally have three pairs of legs. The first pair is on the prothorax, the second on the mesothorax and the third on the metathorax. Now pull out the metaleg of an ak grasshopper (Fig. 24B), which is considered to be a typical or generalised leg, and study its parts.

(a) Parts of leg: A typical leg consists of the following parts:

1. Coxa: It is the first or basal segment which is large, elongated and more or less triangular in shape. It is attached with the body by a membrane, the coxal corium.

2. Trochanter: It is a small, triangular segment which is rigidly fixed to the femur.

3. Femur: It is a very long and thick segment which is provided with fishbone-shaped leaping muscles. It has a ventral groove, the femasulcus to accommodate tibia in it. The femasulcus contains a small tubercle, the Brunner's organ on its inner margin near the proximal end. The femur narrows toward its apex which is expanded to form the lateral genicular lobes. These are separated by a deep groove which allows free movement of tibia.

4. Tibia: It is very long and slender segment armed with two rows of spines on its dorsal surface. Its apex contains an outer and an inner pair of strong, curved spurs.

5. Tarsus: It consists of three segments. The first segment is longer than the second, while the third one is the longest. The first segment bears three pairs of small pad-like structures, the plantulae, on its lower surface. The second segment contains a single pair, while the third segment has a single elongated pair of these structures. The tarsus ends in a pair of hair-like, strong, curved claws or ungues, which contain a bladder-like lobe, the arolium, between them. The claws and arolium together are called the pretarsus by some morphologists.

Also examine the tarsus of a robber fly (Fig. 24C). It also ends in two long, strong, curved claws. Below them is a pair of long and broad pads, the pulvilli (sing. pulvillus). Between the claws is a strong bristle-like structure, the empodium.

(b) Types of legs: The legs of insects are greatly modified for performing different functions. Some important modifications or types are as follows.

1. Cursorial (ambulatory or walking) (Fig. 24 A)**:** The femur is normal and not thickened, e.g., metaleg of cockroach.

2. Saltatorial (leaping or jumping) (Fig. 24B)**:** The femur contains powerful muscles and is greatly thickened, e.g., metaleg of grasshopper.

3. Raptorial (catching or grasping) (Fig. 25A)**:** The coxa is very long. The femur is long, thick, with double row of spines and a groove on the lower side. The tibia is shorter, spiny and fits into the groove of the femur, e.g., proleg of a mantid.

4. Fossorial (digging) (Fig. 25 B)**:** The parts are reduced and flattened to become strong for digging. The tibia has finger-like projections on its apex. The tarsus is also produced into three finger-like processes which are seen below those of the tibia, e.g., proleg of mole cricket.

5. Natatorial (swimming) (Fig. 25C)**:** All parts are flattened and tarsus, in addition, has long hair, e.g., metaleg of giant water bug and water beetle.

6. Clinging (Fig. 25D)**:** The tibia has a small process at its apex. The tarsus is 1-segmented and bears a claw that fits against the tibial process for clinging to the hair of the host, e.g., louse.

7. Silk secreting (Fig. 25E)**:** The first segment of the fore tarsus is greatly swollen and contains silk glands, e.g., proleg of female webspinner.

8. Antenna cleaner (Fig. 24D)**:** There is a large spur on the apex of the tibia which fits into a semicircular notch on the proximal end of the tarsus. This notch also contains fine hair. The antennae are drawn through this structure so that the pollens, etc., clinging to them are removed, e.g., proleg of worker honeybee.

9. Pollen collecting (Fig. 24E)**:** This type has a polliniferous apparatus. The tibia is greatly dilated. Its outer surface is smooth, bordered on each side with a fringe of long curved hair, which is called corbicula or pollen basket. On the distal end of tibia is a row of hair, the pecten or pollen rake. The basitarsus (first or basal segment of tarsus) on its base has a small ear-like lobe that contains a row of small hair. This lobe is called auricle. The basitarsus is greatly enlarged. It bears on its inner surface several transverse rows of short stiff hair which form scopa, pollen comb or pollen brush, e.g., metaleg of worker honeybee.

10. Basket-like: There is no morphological modification in this type of leg. But during flight, all legs come together to form a basket below the mouth for catching and eating insects. Note, the trochanter is 2-segmented, e.g., dragonfly and damselfly.

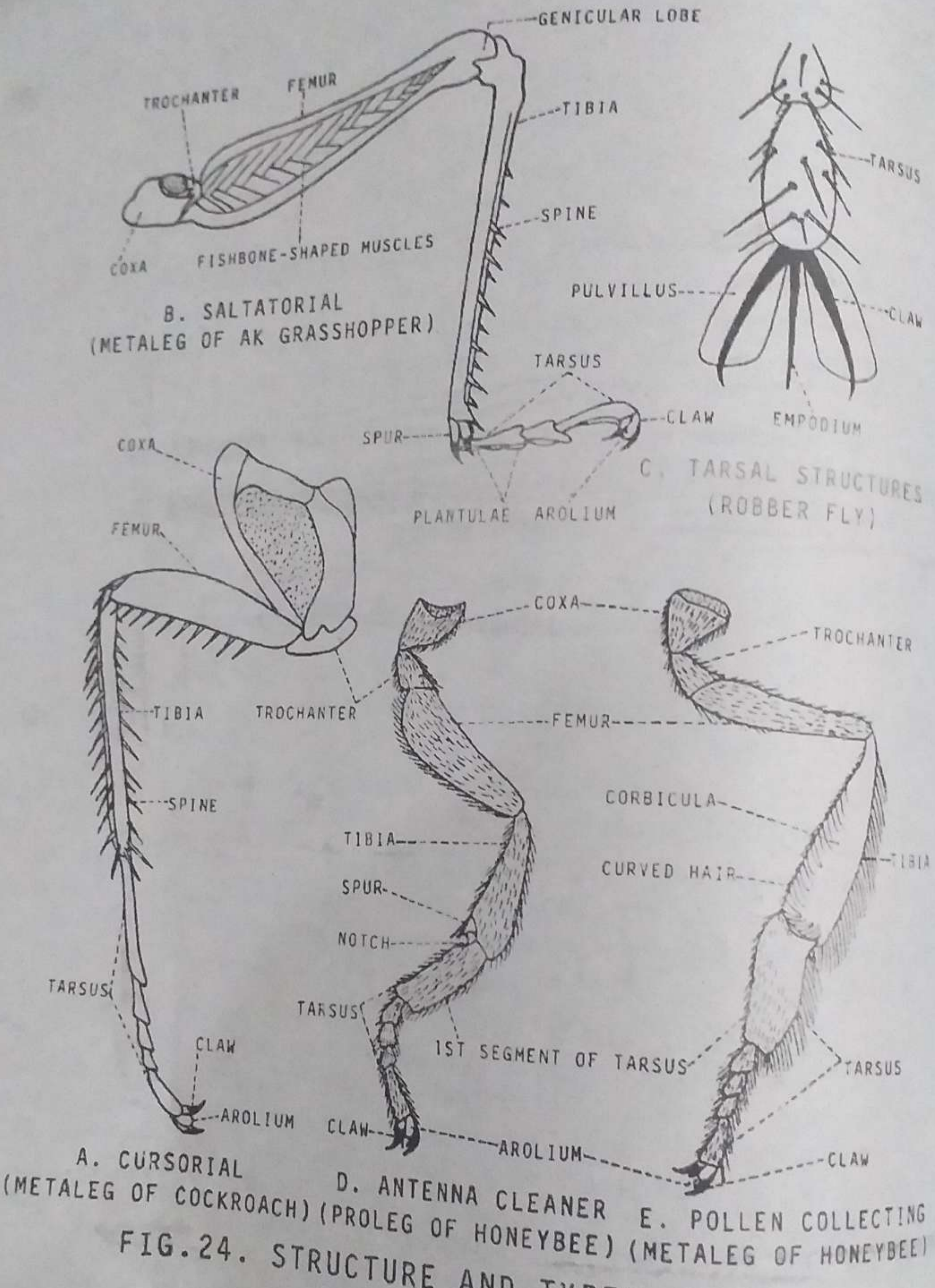


FIG.24. STRUCTURE AND TYPES OF LEGS

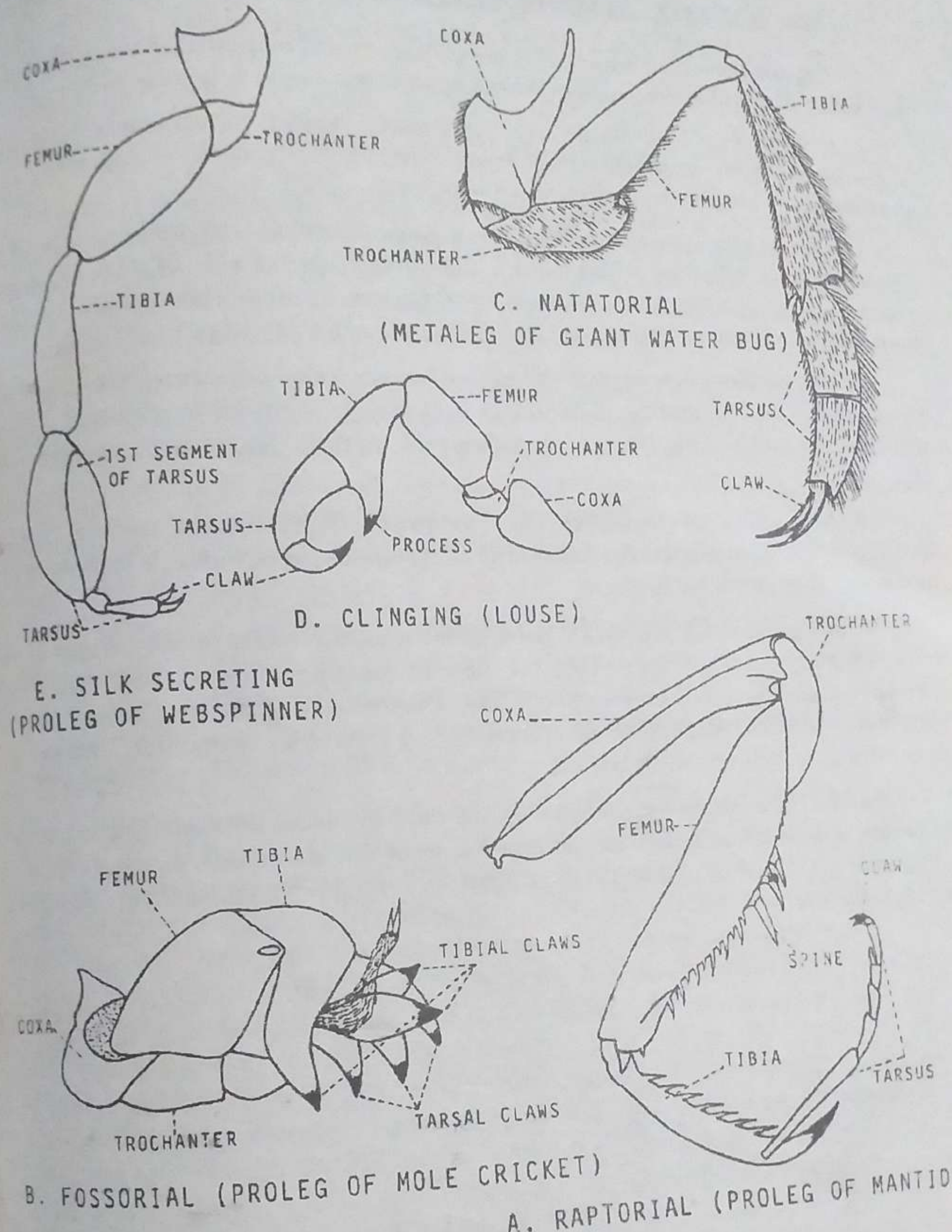


FIG.25. TYPES OF LEGS

APPENDAGES OF ABDOMEN

The most common appendages are styli, cerci and ovipositor in the adult insects and abdominal prolegs and gills in the young insects.

1. Styli (Fig. 8A): These are paired, short, slender, unsegmented, finger-like appendages which arise from the lower side of the abdominal segments, e.g., bristletails, doubletails, cockroaches and mantids.

2. Cerci (Figs. 4, 17A): They are a pair of short to very long, segmented or unsegmented, needle-like appendages which arise from the side of 11th abdominal segment, e.g., grasshoppers, crickets, cockroaches, mantids, bristletails, mayflies, stoneflies, etc. They may be in the form of forceps such as earwigs.

3. Ovipositor (Fig. 4): It is the egg-laying apparatus or external genitalia of the female that is present at the end of abdomen. It may be short (having different shapes) to very long and needle-like, e.g., grasshoppers, crickets, leafhoppers, planthoppers, etc.

4. Abdominal prolegs (9A): These are paired, fleshy, more or less conical, leg-like appendages present on the lower side of the abdomen of larvae, e.g., butterflies, moths, sawflies, scorpionflies, etc.

5. Gills (Fig. 9C): These are paired, thin-walled, respiratory appendages of the young of many aquatic insects. They are more frequently present on the abdomen and may have a lateral, dorsal or ventral position. They may be of different shapes such as plate-like, leaf-like, finger-like or spine-like, e.g., mayflies, stoneflies, dragonflies, damselflies, caddisflies, some beetles, etc.

Some less common appendages are the median caudal filament (bristletails and mayflies), a pair of cornicles on the upper side of 5th abdominal segment (aphids), urogomphi at the end of abdomen (some beetles), ventral tube, retinaculum and furcula (springtails), etc.

INTERNAL MORPHOLOGY (ANATOMY) OF AK GRASSHOPPER (*POEKILOCERUS PICTUS*)

It consists of the endoskeleton and various systems inside the body.

ENDOSKELETON OF HEAD

At various points the body wall becomes inpushed or invaginated to form rigid processes, the apodemes. These strengthen the body wall and also serve for the attachment of muscles. The framework of these apodemes is called endoskeleton. It consists of the endoskeleton of head (tentorium), the endoskeleton of thorax and the endoskeleton of abdomen. Of these, only the tentorium will be dissected and studied.

Tentorium (Fig. 26): For dissecting out the tentorium, detach the head from rest of the body. Hold the insect head from its antennae and top in the left hand. Remove away the mouthparts by giving a cut with very fine scissors at the level of the frontoclypeal sulcus. Clean out all muscles with a dissecting needle from the cavities by keeping the head with its biggest and rounded cavity upwards. Now cut away the top of head including the compound eyes and place the tentorium on a slide to see it under the binocular microscope.

The tentorium is named from its resemblance with a tent which is tightened by four ropes. It divides the foramen magnum into four openings: an upper, two lateral and a lower one. The upper is the biggest and called alaforamen, through which passes the alimentary canal. The lower is the neuraforamen, through which passes the central nervous system. The lateral have no names.

The tentorium is nearly X-shaped and consists of a central body with twc anterior, two posterior and two dorsal arms. The central body is a large triangular plat which is called corpotentorium. If the tentorium is held in its natural position with th alaforamen above and the neuraforamen below, the anterior arms are the lower on (because they are towards mouth which is on the lower side) and the posterior tl upper ones. But in books it is described with its neuraforamen above and alaforam below (this unnatural position is not followed here). The two anterior ar (pretentoria) are broadened at their anterior ends and are the ingrowths from t anterior tentorial pits located in the frontoclypeal sulcus. The two posterior ar (metatentoria) are broader at their posterior ends and are the invaginations from t posterior tentorial pits located on the ends of the postoccipital sulcus. The two dor arms (supratentoria) are the outgrowths from the bases of the anterior arms. They the sclerotised threads slightly broadened at their tips and are generally broken at time of removing muscles.

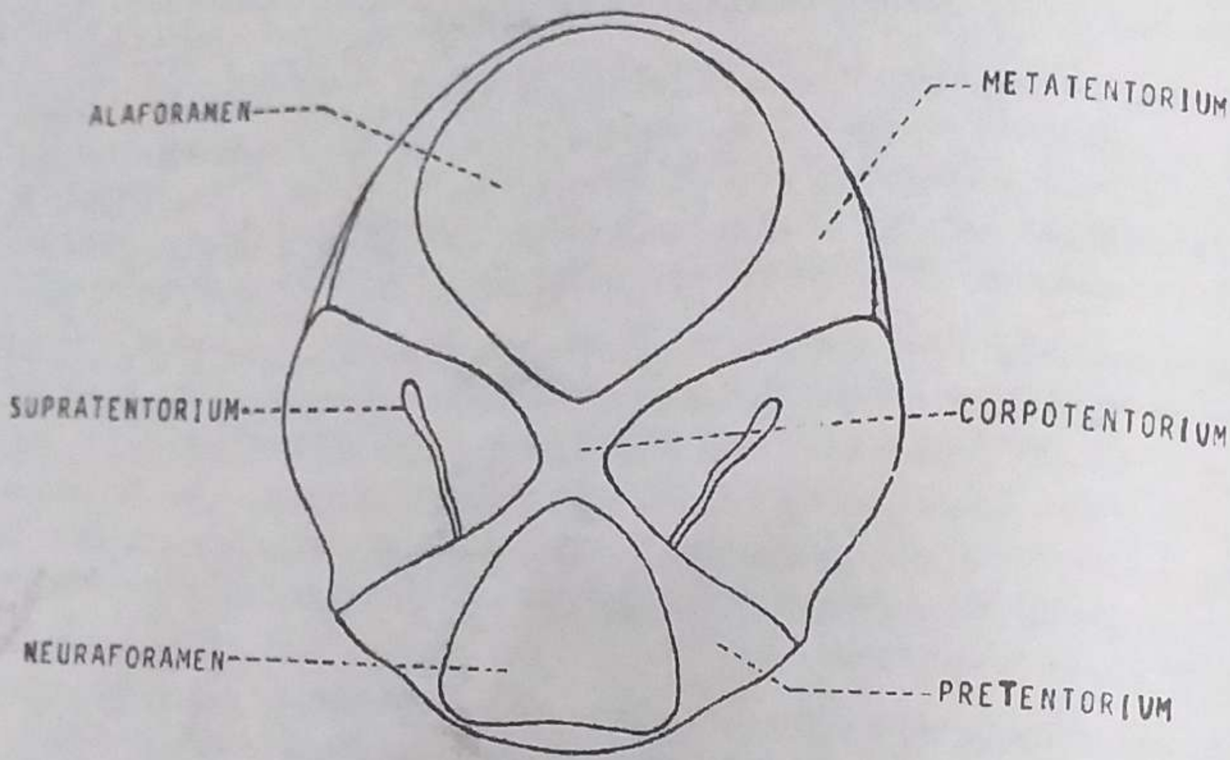


FIG.26. ENDOSKELETON OF HEAD (TENTORIUM)

For dissecting the grasshopper, remove its wings and antennae and hold it in its natural sitting position. Give a cut with very fine scissors along the mid-dorsal line. Start this incision from the extreme posterior end and continue it to the extreme anterior end. Place it in the dissecting pan in its natural sitting position with sufficient water to cover it. Open the two flaps gently apart with dissecting needles and pin them to the wax bottom of the pan. Also pin through the femora of the legs. Leave the dissection as such (if the specimens are not freshly killed) for 7-10 minutes so that the internal organs are well-soaked. For studying the circulatory system, dissect the insect from the ventral side. The remaining procedure is the same as already described. Now remove the masses of pale yellow or white fat bodies and other loose tissues with the help of a camel-hair brush. Place this dissection under the binocular microscope and study the following systems.

1. Digestive system (Fig. 27): It consists of the alimentary canal (gut) and the associated glands which help in digestion. The alimentary canal extends from the mouth to the anus. It is differentiated into the following three main regions:

(a) Foregut (stomodaeum)

(b) Midgut (mesenteron, ventriculus or stomach)

(c) Hindgut (proctodaeum or intestine)

(a) Foregut: The foregut consists of the mouth or oral cavity, pharynx, oesophagus, crop and gizzard (proventriculus). The foregut starts from the mouth cavity into which open the salivary glands. The glands are grape-like clusters of circular acini (sing. acinus) which give their secretion into two salivary ducts, one on each side of the alimentary canal in the thorax. Two salivary ducts unite to form a common salivary duct which opens below the hypopharynx. The mouth cavity leads into a short thicker anterior portion of the foregut, the pharynx (throat). The pharynx forms posteriorly a narrow and curved tube, the oesophagus. The oesophagus gradually widens behind to form the large crop which acts as a food reservoir. The crop opens into the gizzard (proventriculus) which narrows posteriorly and is not clearly differentiated externally from the former. The gizzard is surrounded by the anterior lobes of the gastric caeca (sing. caecum). The junction of foregut and midgut is provided internally with a cardiac (oesophageal) valve which regulates the passage of food.

(b) Midgut: The midgut is comparatively a short, cylindrical and straight tube. At its anterior end arise six large, elongated sacs, the gastric caeca which are the evaginations (outgrowths) of its anterior end. Each gastric caecum consists of a longer anterior lobe and a shorter posterior lobe. The posterior lobes are filled with food whereas the anterior lobes have only the secretary function. The midgut on its inner side has a very thin peritrophic membrane for the protection of its secretary cells from

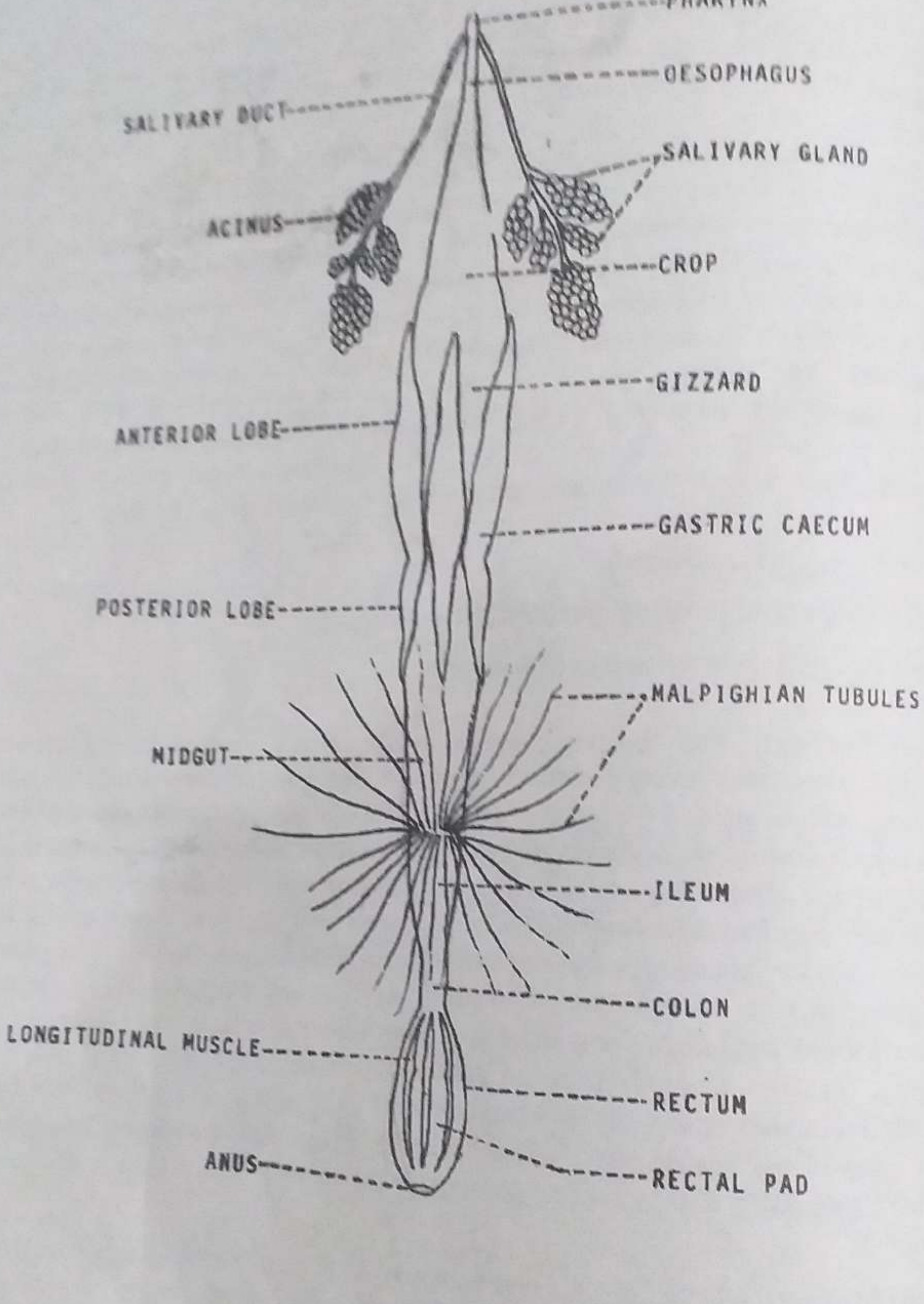


FIG.27. DIGESTIVE SYSTEM OF AK GRASSHOPPER

the friction of the food particles. This permeable membrane also extends into the hindgut. The posterior end of the midgut is marked by the presence of malpighian tubules. At the junction of the midgut and hindgut is a pyloric valve.

(c) **Hindgut:** The hindgut is further differentiated into an ileum, colon and rectum. The ileum (small intestine) is a thick and straight tube which narrows posteriorly. The colon (large intestine) is a short, narrower tube (very rarely coiled) which dilates posteriorly to merge into the rectum. The rectum is a wider tube which is externally provided with six bands of longitudinal muscles alternating with six long rectal pads (papillae). The rectum ends in an anal opening.

2. **Excretory system** (Fig. 27)**:** It consists of malpighian tubules and fat bodies. The malpighian tubules are long, very slender, blind tubes which arise as evaginations from the anterior end of the hindgut. They extend anteriorly and posteriorly around the gut. The fat bodies are yellow or white masses of cells surrounding the gut. The principal function of the fat bodies is to store the food reserves like fat, glycogen and protein but they also carry out the excretory function.

3. **Reproductive system:** It should be studied separately in male and female sexes.

The male reproductive system (Fig. 28) consists of a pair of testes (sing. testis). These testes are closely associated into a single yellow structure which generally lies on the midgut of the alimentary canal. Give a longitudinal cut with a blade along its mid-dorsal line to separate it into two parts. Each testis is composed of a large number of tubular testicular follicles. Each follicle opens by means of a short, slender duct, the vas efferens (p1. vasa efferentia), into the long genital duct or vas deferens (p1. vasa deferentia). The follicles are attached to the body wall by a suspensory ligament. The vasa deferentia run posteriorly to open into a wider tube, the ejaculatory duct, below the ventral nerve cord. Just anterior to the points of opening of vasa deferentia, two groups of long tubular accessory glands also open into the ejaculatory duct. A medial pair of these glands becomes fairly dilated to serve as seminal vesicles (vesiculae seminales) for storing the sperms. The ejaculatory duct opens posteriorly into a large pouch-like structure, the ejaculatory sac, which opens into the aedeagus (part of external genitalia).

The female reproductive system (Fig. 29) consists of a pair of ovaries. These ovaries are closely associated into a single body which lies on the midgut and a part of the hindgut. Also separate it into two component parts by giving a longitudinal cut along its mid-dorsal line. Each ovary is composed of a large number of tubular ovarioles which arise from the side of the oviduct. The ovarioles end in thread-like filaments which unite to form a suspensory ligament by which they are attached to the body wall. The oviducts also extend anteriorly to form two accessory glands. Then the oviducts run posteriorly and after making a short bend unite into a fairly dilated common oviduct (vagina) below the ventral nerve cord. The vagina terminates in the genital chamber. The spermatheca is a sac-like oval body which receives and stores the

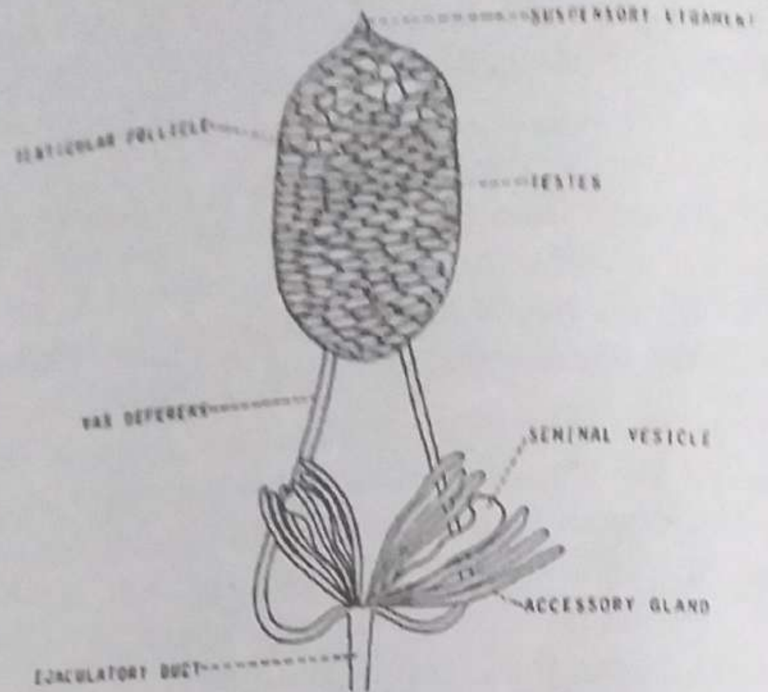


FIG.28. REPRODUCTIVE SYSTEM OF
MALE AK GRASSHOPPER

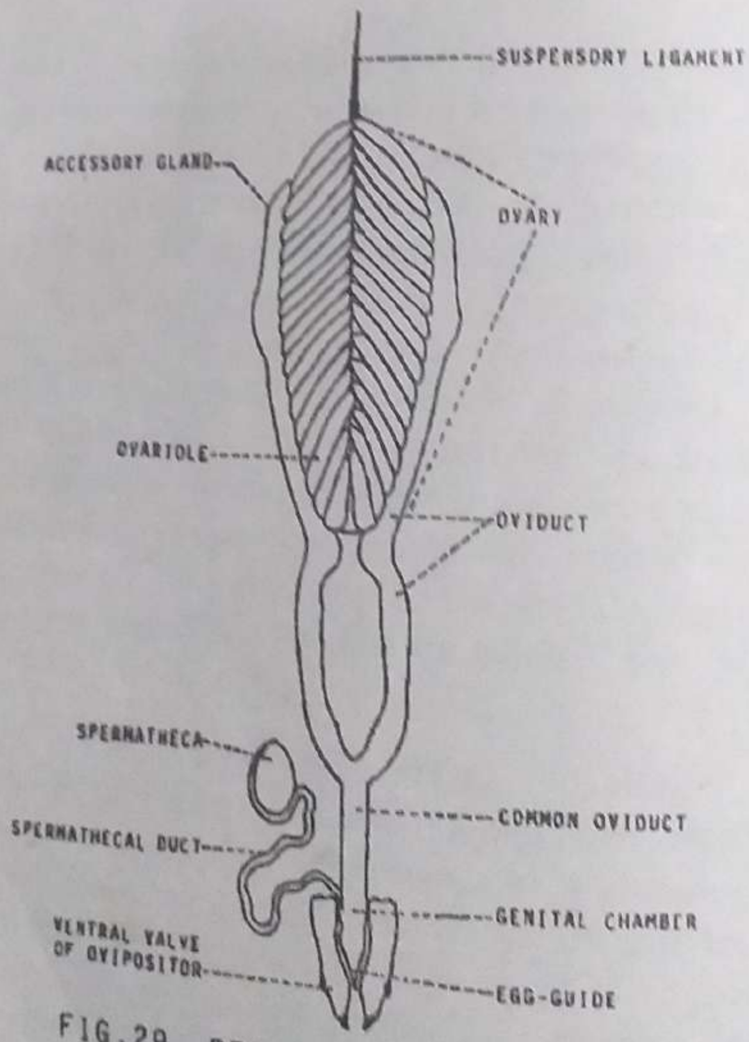


FIG.29. REPRODUCTIVE SYSTEM OF
FEMALE AK GRASSHOPPER

sperms. It opens by means of a coiled spermathecal duct into the genital chamber. The latter ends into an egg-guide which is situated between the ventral valves of the ovipositor (part of external genitalia).

Types of reproduction: Insects have the following types of reproduction.

1. Oviparity: This is the most common mode of reproduction. The insects lay the fertilized eggs, which hatch outside the body of the female. Such insects are said to be oviparous, e.g., bristletails, springtails, mayflies, dragonflies, grasshoppers, locusts, bugs, butterflies, moths, flies, beetles and many other insects.

2. Viviparity: The eggs complete their embryonic development and hatch within the body of the female. Hence, the female gives birth to the young. The insects having this type of reproduction are called viviparous, e.g., aphids, certain flies and stylopids.

3. Parthenogenesis: The females lay the unfertilized eggs, which have the haploid (half) or diploid (double) number of chromosomes. These eggs undergo full development and give rise to males, females or both sexes. It is observed in aphids, bees, wasps, some whiteflies and thrips.

4. Paedogenesis: When immature stages, such as larvae or pupae, start reproducing parthenogenitically, it is called Paedogenesis. In some cecidomyids (*Miastor* and *Oligarces*) the larva gives birth to other larvae, which become adult under favourable conditions. In certain midges (*Henria* and *Tanytarsus*) the pupa produces larvae, some of which become the normal adults. A few beetles (*Micromalthus*) also show this phenomenon.

5. Polyembryony: When a single egg produces two or more larvae, it is known as polyembryony, e.g., several parasitic wasps, some cecidomyids and a few stylopids.

6. Hermaphroditism: It is an extremely rare phenomenon in which an individual has both the male and female reproductive organs. In the scale insect *Icerya purchasi* the outer cells of the gonads (undifferentiated testes or ovaries) produce eggs, while the inner ones give rise to sperms. Thus, the eggs are fertilized in the gonads by sperms in the same individual. In the phorid flies of the genus *Termitostroma* each individual has a pair of ovaries and a testis to release the eggs and sperms.

4. Circulatory system: It consists of the dorsal blood vessel and the accessory pulsating organs present at the bases of appendages. The circulatory system in insects is an open one, i.e., there are no arteries and veins (except the single dorsal blood vessel) and the blood circulates freely in the body cavity, the haemocoel. The latter has two longitudinal diaphragms (partitions) of membranous connective tissue: the dorsal and the ventral diaphragms. These diaphragms divide the body cavity into three sinuses: the dorsal (pericardial) sinus, the large central (perivisceral) sinus and the ventral (perineural) sinus.

(iv) Some insects have a special store of air in the form of a thin film, which is held by the hydrofuge hair in such a way that its volume remains constant. It is called plastron respiration. It needs no renewal and thus the insect remains continuously submerged in water e.g., some aquatic bugs and beetles.

3. Respiration in endoparasitic insects: These insects live in semi-liquid medium, i.e., haemolymph (blood) of the host, which is almost similar to that of the aquatic insects. So like the aquatic insects, they should extract oxygen from the blood of the host or make a contact with the atmospheric oxygen for respiration. These parasites have the following mechanisms of respiration.

(a) In many ichneumonid, brachonid and young dipterous larvae, the tracheal system is not functional. Thus, these parasites have cutaneous respiration, i.e., the oxygen from the blood of the host diffuses through the thin body wall of the parasite, which has a rich tracheal supply beneath it.

(b) In some brachonid parasites the hind gut is everted through the anus to form a bladder-like thin-walled caudal vesicle, which is closely associated with the last chamber of the heart of the host for taking oxygen from it.

(c) In the parasite of scale insects, there are two long caudal filaments which are richly supplied with tracheae. These filaments get entangled with the tracheae of the host for getting oxygen from them.

(d) The larvae of Conopidae (Diptera) attach themselves to the tracheal trunk of the host for supply of atmospheric oxygen.

(e) The chalcid larvae connect themselves to the outside by means of the hollow egg-stalk and place their posterior spiracles with the funnel-shaped inner end of the stalk to have the atmospheric oxygen.

(f) Some other parasitic larvae perforate the body wall or tracheae of the host and then place their spiracles with them in order to have a contact with the atmospheric air.

The dorsal blood vessel (Fig. 30) lies along the midline in the pericardial sinus just below the body wall. It is a long, straight, white tube extending from the head to the 10th abdominal segment. It consists of two parts. The posterior part that lies in the abdomen is called the heart. It becomes segmentally dilated to form chambers (ampullae) which are provided with paired dorsolateral openings, the ostia (sing. ostium), having valves in them. The heart tapers posteriorly and ends blindly in the 10th segment. Eight pairs of alary muscles which arise from the sides meet broadly beneath the heart. The anterior part that lies in the thorax and head is called the aorta. It is a delicate tube which is slightly dilated at three places. It ends near the brain. The blood (haemolymph) enters the heart through ostia from the haemocoel, carried anteriorly in the heart and aorta, and again returned to the haemocoel in the head.

5. Nervous system: It comprises the following three divisions:

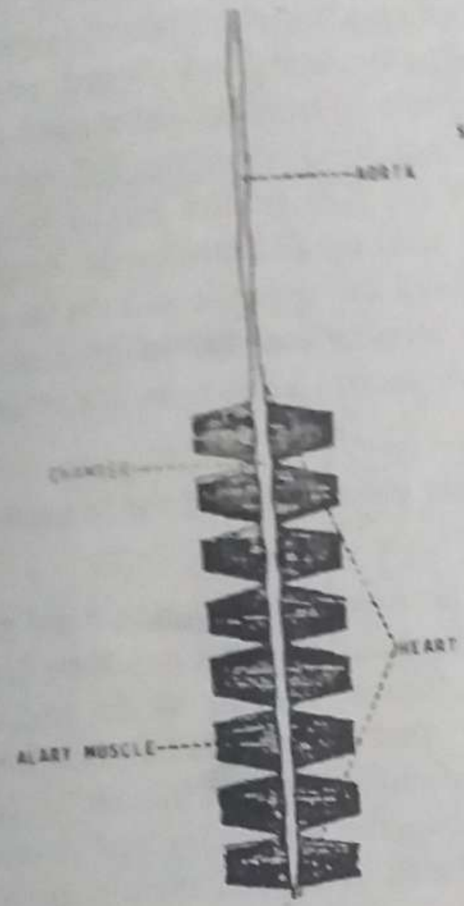
(a) Central nervous system (Fig. 31)**:** It is the main division and consists of the supraoesophageal ganglion (brain), suboesophageal ganglion and the ganglionated ventral nerve cord.

(b) Peripheral nervous system: It consists of the nerves that connect the central nervous system with the peripheral sense receptors (sense organs).

(c) Visceral or sympathetic nervous system: It consists of the nerves and ganglia that connect the central nervous system with the viscera (different organs in the body such as gut, heart, reproductive organs, etc.).

For this introductory course, only the central nervous system will be dissected and studied. It lies in the median line of the body below the alimentary canal except the brain which is dorsal to it. It extends from the head to the eighth abdominal segment. For clearing the central nervous system, remove the ventral diaphragm carefully with the help of fine forceps and a dissecting needle. Now trace the ventral nerve cord and proceed towards the head. The central nervous system (Fig. 31) consists of a large compound ganglion (pl. ganglia) known as supraoesophageal ganglion (brain), which lies in the head above the oesophagus. The brain (when seen under high magnification) is further differentiated into three pairs of lobes: protocerebrum (fore brain), deutocerebrum (mid brain) and tritocerebrum (hind brain). The brain is connected with the suboesophageal ganglion which lies in the head below the oesophagus. It is connected with a ventral nerve cord which has three thoracic and five abdominal ganglia. The last ganglion is the composite one and biggest of all the abdominal ganglia.

The ganglion of one segment is connected with that of an other by means of paired connectives. In each segment there are actually two ganglia which are transversely connected by means of commissures and fused into a single ganglion. All ganglia innervate (i.e. supply nerves) to the different body sclerites or organs.



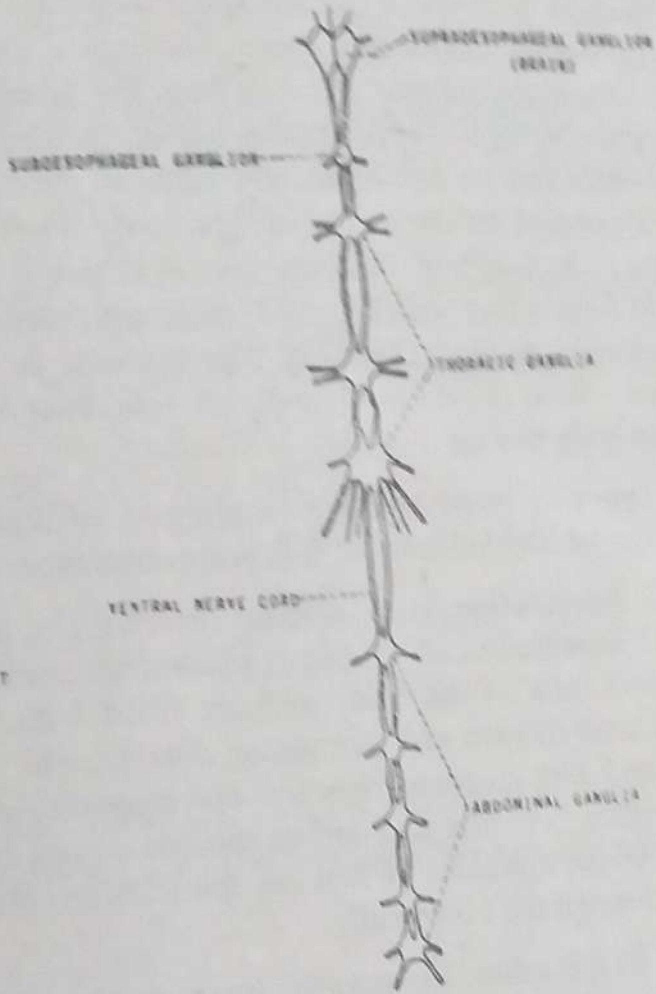


FIG.30. DORSAL BLOOD VESSEL OF AK GRASSHOPPER

FIG.31. CENTRAL NERVOUS SYSTEM OF AK GRASSHOPPER

6. Respiratory system: It consists of paired lateral spiracles, tracheae and tracheoles. The spiracles are the external openings through which the air enters and leaves the body. They can be closed because they are provided with a closing mechanism. The ak grasshopper has 10 pairs of spiracles, two thoracic (one between the prothorax and mesothorax and the other between the mesothorax and metathorax-- Fig.16B) and eight abdominal (one on each of the first eight abdominal segments -- Fig. 17A). The spiracles open into elastic internal tubes, the tracheae (sing. trachea). The tracheae from the adjoining spiracles unite to form longitudinal trunks. There are six longitudinal trunks: two dorsal, two ventral and two lateral. When the grasshopper is dorsally dissected and the two flaps are brought on sides and pinned, one dorsal trunk goes on each side as shown in Fig. 32. The two ovaries are united into a single body which lies on the alimentary canal in the abdominal segments 3-5. One lateral trunk is located on each side of this body, while the two ventral trunks are present below it. The tracheae from the spiracles also extend on the inner side, branch and dilate to form white air-sacs which unite with those of the opposite side on the ovaries in a beautiful fashion (Fig. 32). The tracheae or longitudinal trunks give numerous branches which divide and subdivide into finer branches known as tracheoles that enter the body tissues.

Types of respiration: According to different modes of life, the respiration in insects can be divided into the following three types:

1. Respiration in terrestrial insects: The air enters the spiracles and passes through the tracheae and ultimately reaches the tracheoles. The latter penetrate into the tissues and cells of the body and are filled with liquid. The air in the tracheoles contains more oxygen and less carbon dioxide, while that in the cells has more carbon dioxide and less oxygen. Now on the principle of differential diffusion of gases, oxygen enters the cells and carbon dioxide comes into the tracheoles and ultimately goes out of the spiracles. When the spiracles are closed or absent, the air enters the tracheae through the body wall.

2. Respiration in aquatic insects: These insects respire in water by the following mechanisms:

(a) Extraction of oxygen by gills: In this type all the spiracles are closed and non-functional. The molecular oxygen present in water is extracted by thin-walled gills, which are of three types.

The tracheal gills are outgrowths or evaginations of the tracheae, which are thread-like or leaf-like and richly supplied with tracheae and tracheoles. They are usually present on the sides or end of abdomen, e.g., nymphs of mayflies, stoneflies, dragonflies and damselflies and larvae of caddisflies, many true flies and some beetles.

In some larvae and pupae of true flies and beetles with closed and non-functional spiracles, the spiracular gills are used for respiration. These gills are the outgrowths of the spiracles that directly open into the tracheae.

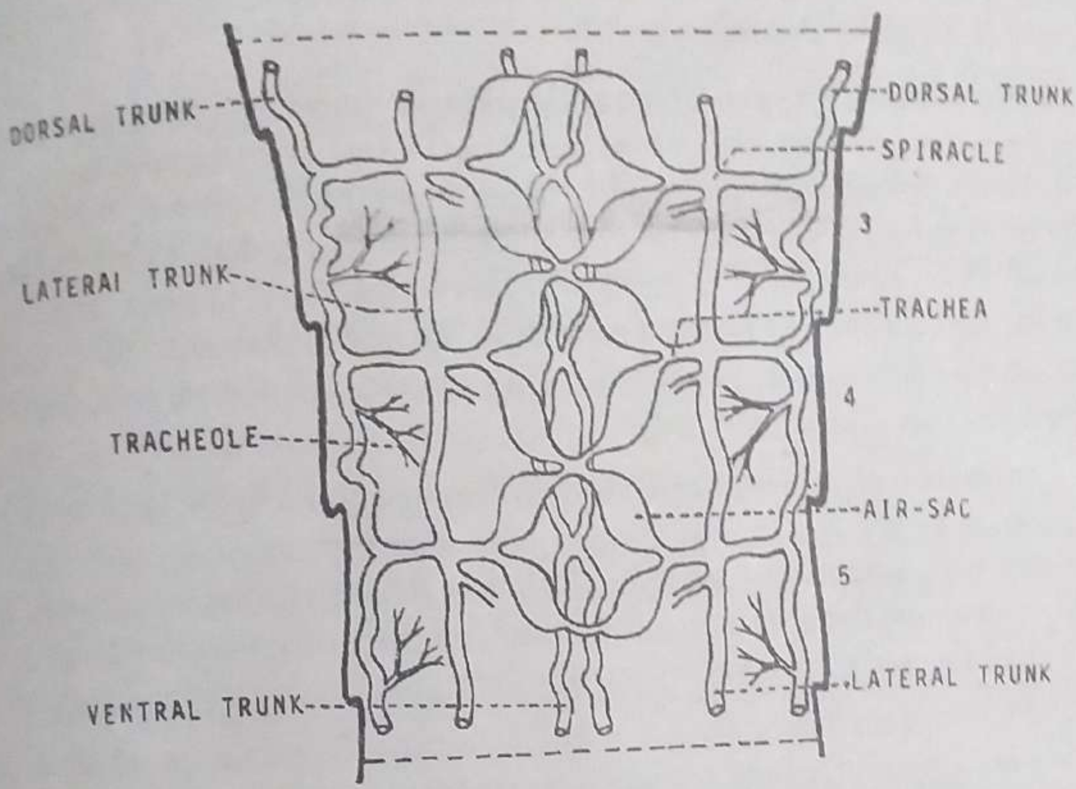


FIG.32. RESPIRATORY SYSTEM
(3-5 ABDOMINAL SEGMENTS) OF AK GRASSHOPPER

The blood gills, which are filled with blood, are finger-like and very rarely used as organs of respiration, e.g., some larvae of true flies.

(b) Diffusion of oxygen through body wall: In the insects with closed tracheal system, the oxygen from water enters the tracheae by diffusion through the body wall. It is called cutaneous respiration, which partially occurs in all the above mentioned insects under gills. In the first instar larvae of *Chironomus* and *Simulium* (Diptera) it meets the whole oxygen consumption.

(c) Utilization of oxygen of aquatic plants: Some insects with open tracheal system may get oxygen from the submerged vegetation. They capture the air bubbles from the surface of plants with hydrofuge (non-vettable) hair present on different parts of the body or thrust their spiracles into the intercellular air spaces to get oxygen. Such insects usually live in the bottom mud with very little free oxygen and have their spiracles at the tip of a sharply pointed process at the end of abdomen for inserting into the tissues, e.g., larvae and pupae of many genera of the orders Diptera and Coleoptera.

(d) Utilization of atmospheric oxygen: Some insects with open spiracles use different methods to get the atmospheric oxygen for respiration. These insects either maintain a semi-permanent connection with the air through a long respiratory tube or siphon which enables them to remain submerged for an indefinite time or make frequent visits to the surface of water to renew their gases in the tracheal system.

(i) The larva of the hover fly *Eristalis* (Diptera) which lives on the bottom mud has a spiracle on the tip of a long telescopic (extendable) siphon present at the end of abdomen. At the time of respiration, the siphon is extended, which by breaking the water surface (surface film) reaches the atmosphere to get oxygen. When it retracts, the oily secretions of the peristigmatic glands around it keep the water away from entering into the spiracle. A similar but short respiratory siphon is present in some culicid and stratiomyid larvae.

(ii) In some insects, the respiratory tubes (siphons) present at the end of abdomen carry the spiracles at their bases. These spiracles are surrounded either by a dense group of hydrofuge hair, e.g., water scorpions of the genera *Nepa* and *Ranatra* (Hemiptera) or provided with valves as in mosquito larvae. These structures (hair and valves) close when the insects dive to prevent the entry of water and open or spread at the water surface for entry of oxygen.

(iii) Many aquatic insects when visit the water surface take the air-bubbles beneath their elytra, e.g., diving beetles (Dytiscidae) or trap them in a group of hydrofuge hair present on other parts of the body, e.g., *Notonecta* (Hemiptera). Such bubbles are in contact with spiracles for respiration. When oxygen is removed from the bubble, more oxygen quickly diffuses into it from the water. In spite of this, the insect requires the periodic renewal of oxygen from the atmosphere.