LECTURE 1. Anatomy: Digestive system

Digestive system

The **digestive system** (sometimes referred to as the **alimentary canal**) should be easily seen in the dissected specimens. It is a long tube-like structure that runs from the mouth to the anus and is centrally located within the body cavity, or **hemocoel**. The anteriormost region is called the **foregut** (or **stomodeum**) which includes the Buccal cavity, the esophagus, and the crop. The primary function of the foregut is to begin the breakdown of food particles and transport them to the next region, the **midgut** (or **mesenteron**). The midgut is the major area of digestion and absorption. Undigested food particles then pass into the third region, the **hindgut** (or **proctodeum**), which consists of the ileum, colon, **rectum**, and (often) rectal pads. The hindgut functions in water and solute reabsorption and waste excretion.

The three sections of the digestive tract can be easily identified by structures found at the junction of each region. **Gastric caecae**, for example, mark the end of the foregut and beginning of the midgut. It is believed that the purpose of these structures is to increase surface area for greater nutrient absorption. The constriction at the gastric caecae also marks the spot of the cardiac valve (or sphincter).

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

1. **Foregut**: It is ectodermal in origin. Anterior invagination of ectoderm forms foregut (Stomodeum). Internal cuticular lining is present. Terminal mouthparts leads into a

preoralcavity. Preoralcavity between epipharynx and hypopharynx is called as Cibarium.
Preoralcavity between hypopharynx and salivary duct is Salivarium. Behind the mouth a
well musculated organ called Pharynx is present which pushes the food into
oesophagous. Pharynx acts as a sucking pump in sap feeders. Oesophagous is a narrow
tube which conduct food into crop. Crop is the dilated distal part of oesophagus acting as
food reservoir. In bees crop is called as honey stomach where nectar conversion occurs.
Proventriculus or Gizzard is the posterior part of foregut and is musculated. It is found in
solid feeders and absent in fluid feeders or sap feeders. Food flow from foregut to midgut
is regulated through cardial or oesophageal valve. The internal cuticle of gizzard is
variously modified as follows.
i. Teeth like in cockroach to grind and strain food.
ii. Plate like in honey bee to separate pollen grains from nectar
iii.Spine like in flea to break the blood corpuscles
2. **Midgut**: It is endodermal in origin and also called as mesentron. This part contains no
cuticular lining. Midgut is made up of three types of epithelial cells. (i) Secretory cells
(Columnar cells) (ii) Goblet cells (aged secretory cells), (iii) Regenerative cells which
replaces secretory cells. Important structures present in midgut are as follows:
a. **Peritrophic membrane**: It is the internal lining of midgut, secreted by anterior or
entire layer of midgut epithelial cells. Present in solid feeders and absent in sap feeders.
This layer is semipermeable in nature to digestive juices and digestion products. It
lubricate and facilitate food movement. Envelops the food and protects

the midgut
epithelial cells against harder food particles.
(ii) **Gastric caecae**: (Enteric caecae or Hepatic caecae) Finger like outgrowths found in
anterior or posterior ends of midgut. This structure increases the functional area of
midgut and shelter symbiotic bacteria in some insects.
(iii) **Pyloric valve**: (Proctodeal valve) Midgut opens into hindgut through pyloric valve,
which regulate food flow. In certain immature stages of insects midgut is not connected
to hindgut till pupation. e.g. Honey bee grub.
(iv) **Filter chamber**: It is a complex organ in which two ends of ventriculus and the
begining of hind gut are enclosed in a sac. This is useful to short circuit excess water
found in liquid food in homopteran insects. This process avoids dilution of digestive
enzymes and concentrates food for efficient digestion. Also helps in osmoregulation by
preventing dilution of haemolymph.
3. **Hindgut**: It is ectodermal in origin and produced by the posterior invagination of
ectoderm. Internal cuticular lining is present, which is permeable to salts, ions,
aminoacids and water. The main functions of hindgut are the absorption of water, salt and
other useful substances from the faeces and urine. Hindgut is differentiated into three
regions viz., **ileum, colon and rectum**. In the larva of scarabids and termites, illeum is
pouch like for housing symbionts and acts as fermentation chamber. Rectum contains
rectal pads helping in dehydration of faeces and it opens out through anus.
Gut physiology: Primary functions of the gut is to digest the ingested food and to absorb

the metabolites. Digestion process is enhanced with the help of enzymes produced by
digestive glands and microbes housed in special cells.

LECTURE 2. Digestive glands:

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

1. To moisten and to dissolve food
2. To lubricate mouthparts
3. To add flavour to gustatory receptors
4. In cockroach the saliva contains amylase for the digestion of starch.
5. In honey bee saliva contains invertase for sucrose digestion
6. In Jassid saliva contains lipase and protease for lipids and protein digestion. Jassid
saliva also contains toxins which produces tissue necrosis and phytotoxemia on the plant
parts.
7. In plant bug saliva contains pectinase which helps in stylet penetration and extra
intestinal digestion.
8. In mosquito, saliva contains anticoagulin which prevents blood clotting.
9. In gall producing midges saliva contains Indole Acetic Acid (IAA).
10. In disease transmitting ectors the saliva paves way for the entry of pathogens.

b. **Hepatic caecae and midgut epithelial cells**: It secretes most of the digestive juices.

Two types of cells were involved in the enzyme secretion.

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

Merocrine : Enzyme secretion occurs without cell break down.

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

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

LECTURE 3. Anatomy: Excretory system

Excretory system

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

Near the junction of the midgut and hindgut are long, thin structures called **Malpighian tubules**. These range in number from a few to hundreds, but only aphids (Order Homoptera) are currently known to have none. Malpighian tubules are creamy to

yellow in color and work in conjunction with the ileum to provide the primary site for
osmoregulation and excretion.

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

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

Excretion and Osmoregulation: Insect faeces, either in liquid form or solid pellets,
contains both undigested food and metabolic excretions. Aquatic insects excrete dilute
wastes from their anus directly into water by flushing with water. But, Terrestrial insects
must conserve water. This requires efficient waste disposal in a concentrated or even dry
form, simultaneously avoiding the toxic effects of nitrogen. Both terrestrial and aquatic
insects must conserve ions, such as sodium (Na), potassium (K) and chloride (Cl), that
may be limiting in their food or lost into the water by diffusion. Therefore

the production
of insect excreta (urine or pellets) is a result of two related processes: excretion and
osmoregulation (maintenance of favourable osmotic pressure and ionic concentration of
body fluid). The system responsible for excretion and osmoregulation is referred to as
excretory system and its activities are performed
largely by the Malpighian tubules and hindgut. However in fresh water insects,
haemolymph composition is regulated in response to loss of ions to the surrounding
water, with the help of excretory system and special cells. Special cells are called
Chloride cells which are present in the hindgut, capable of absorbing inorganic ions from
the dilute solutions. (e.g. Naids of dragonflies and damselflies).

LECTURE 4. Malpighian Tubules

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

differentiation of the tubules was seen, with the distal secretory region and proximal
absorptive region.

Physiology: The malpighian tubules produce a filtrate (the primary urine) which is
isosmotic but ionically dissimilar to the haemolymph and selectively reabsorbs water and
certain solutes, but eliminates others. The malpighian tubules produces an iosmotic
filtrate which is high in K
and low in Na
with Cl
as major anion. The active transport of
ions especially K
into the tubule lumen generates an osmotic pressure gradiant for the passive flow of water.
Sugars and most amino acids are also passively filtered from the haemolymph via
junctions between the tubule cells, where as amino acids and non-metabolizables and
toxic organic compounds are actively transported into the tubule lumen. Sugar is resorbed
from the lumen and returned to the haemolymph. The continuous secretory activity of
each malpighian tubule leads to a flow of primary urine from its lumen towards and into
the gut. In the rectum, the urine is modified by removal of solutes and water to maintain
fluid and ionic homeostasis of the body.

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

more amount of water for waste product removal. This type of excretion is known as
Ammonotelism.
Cryptonephry: The distal ends of the Malpighian tubules are held in contact with the
rectal wall by the perinephric membrane, which is concerned either with efficient
dehydration of faeces before their elimination or ionic regulation. (e.g. Adult Coleptera,
larval Lepidoptera and larval symphyta).
Functions of malphighian tubule: Excretory in function, mainly concerned with
removal of nitrogenous wastes. The other accessory functions are as follows:
1. Spittle secretion in spittle bug
2. Light production in Bolitophila
3. Silk production in larval neuroptera
Storage Excretion: The excretory waste materials are retained within the body in
different sites.
i. Uric acid is stored as urates in the cells of **fat body** e.g., American cockroach.
ii. Uric acid is stored in the **body wall**, giving white colour. e.g. Red cotton bug.
iii. Uric acid is stored in the **male accessory glands** to produce the outer coat of
spermatophore, which is excreted during copulation.
iv. Uric acid is stored in the **wing scales** giving white colour. e.g., Pierid butterflies.
v. Waste products of pupal metabolism (**Meconium**) is stored and released during adult
emergence.

LECTURE 5.

Anatomy: Respiratory system

Respiratory System

The insect respiratory system is made up of a series of tubes that originate

from **spiracles**
(openings of the exoskeleton that allow for gas exchange) and extend throughout the
body. Internally, the tubes, or **trachea**, appear as thin white lines throughout the
hemocoel and are particularly noticeable surrounding internal organs. Trachea deliver
oxygen to internal organs and tissues.
Compare the tracheae with the Malpighian tubules. They are often very similar in
appearance. Did you confuse tracheae with Malpighian tubules earlier?
Two ways to distinguish the structures are color and location. Tracheae have a ‘shinier’
appearance under the scope and may even appear ‘silvery’. As for location, Malpighian
tubules are found at the junction of the midgut and hindgut (although they may extend
outward into the hemocoel), whereas tracheae are positioned throughout the body.

Respiratory system

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

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

Organs of respiration

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

Tracheoles are less than 1 μm in diameter and they end blindly and closely contact the
respiring tissues. Taenidia and waxlayer is absent. Cuticulin layer is permeable to gases.
It is intracellular in nature, but enclosed only in the cytoplasm of tracheal and cell called
tracheoblast. Gaseous exchange occurs across tracheoles. There are four

tracheal trunks
viz., lateral, dorsal, ventral and visceral, helping in the passage of air. In the trachea, thin
walled-collapsable sac like dilations are present, called as airsacs where taenidia is
absent. **Airsacs** acts as oxygen reservoir. Provide buoyancy to flying and aquatic insects.
Provide space for growing organs. Acts as sound resonator and heat insulators.

Mechanism of respiration

Oxygen enters the spiracle and passes through the length of the tracheae to the
tracheoles and into the target cells by a combination of ventilation and diffusion along a
concentration gradient, from high in the external air to low in the tissue. Where as the net
movement of oxygen molecules in the tracheal system is inward (Inspiration), the net
movement of CO
2
and water vapour molecules is outward (Expiration).

Respiration in aquatic insects:

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

2. **Open tracheal system**:

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

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

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

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

LECTURE 6.

Anatomy: Circulatory system

Circulatory system

Unlike the “closed” circulatory system of humans, insect circulatory systems are said to be “open”, meaning that they lack a complex network of veins and arteries to help transport blood throughout the body. Instead, insect blood (called **hemolymph**) flows relatively “freely” throughout the hemocoel.

Figure 8-2. Circulatory system. Arrows indicate direction of flow of hemolymph.

Only one vessel is present in the insect circulatory system: the **dorsal vessel**. Posteriorly (in the abdominal region), the dorsal vessel acts as the **heart**, pumping hemolymph forward into the anterior region (in the head and thorax), where it acts as the **aorta** and dumps the hemolymph into the head. It flows posteriorly and is returned to the heart via **ostia**, which are small slits in the heart region of the dorsal vessel designed for hemolymph uptake.

To view the dorsal vessel, examine the “back” (or dorsal region) of the insect’s body cavity for a very thin line that runs longitudinally from the head to the tip of the abdomen. Use the grasshopper or specimen that was ventrally dissected, as dorsal dissections will likely mutilate the vessel. Do not be discouraged if you have trouble finding it on your specimen. The dorsal vessel is very, very thin. Compare your

specimen to those of your classmates.

Circulatory system in insects

Aorta portion of
dorsal vessel

Heart portion of
dorsal vessel

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

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

to the pericardial sinus and dorsal vessel.
Another important component of the insect circulatory system is the **ventral diaphragm**,
a fibromuscular septum that lies in the floor of the body cavity associated with the ventral
nerve cord. Circulation of the haemolymph is aided by active peristaltic contractions of
the ventral diaphragm which direct the haemolymph backwards and laterally in the
perineural sinus below the diaphragm. These movements are important in insects that
use the circulation in thermoregulation. Ventral diaphragm also facilitates rapid exchange
of chemicals between the ventral nerve cord and the haemolymph.
Haemolymph is generally circulated to appendages unidirectionaly by various tubes,
septa, valves and pumps. The muscular pumps are termed **accessory pulsatile organs**
and occur at the base of the antennae and legs. Antennal pulsatile organs releases
neurohormones that are carried to the antennal
lumen to influence the sensory neurones. Circulation occurs in the wings of young adult.
In wing circulation is sustained by influxes of air into the wing veins, rather than any
pulsatile organs. Pulses of air in the fine tracheal tubes of the veins push the haemolymph
through the enclosed space of the veins.
The insect circulatory system shows high degree of co-ordination between dorsal vessel,
fibro-muscular diaphragms and accessory pumps.

LECTURE 7.

Haemolymph and its functions

Haemolymph is a watery fluid containing ions, molecules and cells. It is often clear and
colourless but may be variously pigmented or rarely red due to

haemoglobin in the
immature stages of few aquatic and endoparasitic flies (e.g., Chironomid larva).
Haemolymph performs the function of both blood and lymph. It is not involved in gas
transporting function (respiration). Haemolymph contains a fluid portion called plasma
and cellular fractions called haemocytes.
1.**Plasma**: Plasma is an aqueous solution of inorganic ions, lipids, sugars (mainly
trehalose), amino acids, proteins, organic acids and other compounds. pH is usually
acidic (6.7). Density is 1.01 to 1.06. Water content is 84-92 per cent. Inorganic ions
present are `Na' in predators and parasites, `Mg' and `K'in phytophagous insects.
Carbohydrate is in the form of trehalose sugar. Major proteins are lipoproteins,
glycoproteins and enzymes. Lipids in form of fat particles or lipoproteins. Higher
concentration of amino acids leads to a condition called aminoacidemia which effects the
osmosis process. In high altitude insects glycerol is present which acts as a anti freezing
compound. Nitrogenous waste is present in the form of uric acid.
2. **Haemocytes**: The blood cells or haemocytes are of several types and all are nucleate.
Different types of haemocytes are as follows:
a. Prohaemocyte : Smallest of all cells with largest nucleus.
b. Plasmatocyte (Phagocyte) aids in phagocytocis
c. Granular heamocyte: Contains large number of cytoplasmic inclusions
d. Spherule cell: Cytoplasmic inclusions obscure the nucleus
e. Cystocyte(Coagulocyte): Role in blood coagulation and plasma precipitation.
f. Oenocytoids: Large cells with ecentric nucleus
g. Adipo haemocytes: Round or avoid with distinct fat droplets
h. Podocyte: Large flattened cells with number of protoplasmic

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

Functions of haemolymph

1. **Lubricant** : Haemolymph keeps the internal cells moist and the movement of internal organs is also made easy.
2. **Hydraulic medium** : Hydrostatic pressure developed due to blood pumping is useful in the following processes.

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

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

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

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

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

7. **Reflex bleeding**: Exudation of heamolymph through slit, pore etc.

repels natural
enemies. e.g. Aphids.
8. **Metabolic medium:** Haemolymph serves as a medium for on going metabolic
reactions (trahalose is converted into glucose).

LECTURE 8.

Anatomy: Nervous system
Nervous System
To view the **ventral nerve cord**, examine the ventral region of the roach's body cavity
(or specimen you performed the dorsal dissection on) for something that resembles a
railroad track running from the head posteriorly to the abdominal region. The "railroad
track" is made up of two nerve cords (**connectives**) that run longitudinally with a series
of node-like **ganglia**.
The anterior most region of the ventral nerve cord is called the **subesophageal ganglion**.
Just dorsal to that structure is the insect "brain" (or **supraesophageal ganglion**).
The basic component in the nervous system is the nerve cell or neuron, composed
of a cell body with two projections (fibers) the dendrites that receive stimuli and the axon
that transmits information, either to another neuron or to an effector organ such as a
muscle. Axon may have lateral branches called Collateral and terminal arborization and
synapse. Insect neurons release a variety of chemicals at synapses either to stimulate or to
inhibit effector neurons or muscles. Acetylcholine and catecholamines such as dopamine
are the important neurotransmitters involved in the impulse conduction.

Neurons are of
following types based on structure and function.

A. On structural basis

i. Monopolar: neuron with a single axon

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

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

B. Functional basis

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

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

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

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

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

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

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

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

i. Central nervous system (CNS)

ii. Visceral nervous system (VNS)

iii. Peripheral nervous system (PNS)

i. Central nervous system: It contains double series of nerve centers (ganglia). These
ganglia are connected by longitudinal tracts of nerve fibers called

connectives and
transverse tracts of nerve fibers called **commissures**. Central nervous system includes the
following.
a. **Brain**: Formed by the fusion of first three cephalic neuromeres.
Protocerebrum: Large, innervate compound eyes and ocelli.
Deutocerebrum: Found beneath protocerebrum, innervate antennae.
Tritocerebrum: Bilobed, innervate labrum.
Brain is the main sensory centre controlling insect behaviour.
b. **Ventral nerve cord**: Median chain of segmental ganglia beneath oesophagus.
c. **Sub esophageal ganglia**: Formed by the last three cephalic neuromeres which
innervate mandible, maxillae and labium.
d. **Thoracic ganglia**: Three pairs found in the respective thoracic segments, largest
ganglia, innervate legs and muscles.
e. **Abdominal ganglia**: Maximum eight pairs will present and number varies due to
fusion of ganglia. Innervate spiracles.
f. **Thoraco abdominal ganglia** : Thoracic and abdominal ganglia are fused to form a
single compound ganglia. Innervate genital organs and cerci.
ii. Visceral nervous system: The visceral (sympathetic) nervous system consists of three
separate systems as follows: (1) the stomodeal/stomatogastric which includes the frontal
ganglion and associated with the brain, aorta and foregut; (2) Ventral visceral, associated
with the ventral nerve cord; and (3) Caudal visceral, associated with the posterior
segments of abdomen. Together the nerves and
Acetylase
Acetyl CO-A + Choline chloride Acetyl choline
Acetyl Choline Esterase
Acetyl choline Choline + Acetic acid
ganglia of these subsystems innervate the anterior and posterior gut,

several endocrine
organs (Corpora cardiaca and Corpora allata), the reproductive organs, and the tracheal
system including the spiracles.

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

LECTURE 9.

Anatomy: Reproductive system

Reproductive System

It is important to note here that variation among insect reproductive systems is great. Closely
related species are often isolated from one another via small variations in the morphology of
reproductive organs that prohibit interspecies mating. However, a generalized system can be
constructed that closely represents all sexually reproducing insects. Do not be alarmed if you
are unable to locate the indicated structures on your dissected specimens. Be familiar with
differences in male and female genitalia and be able to identify structures when given a
diagram. Directions are provided if you wish to attempt seeing the reproductive system of
your specimen.

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

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

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

Female reproductive system

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

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

of a cluster of
egg or ovarian tubes, the **ovarioles**, each consisting of a terminal filament, a germarium
(in which mitosis gives rise to primary oocytes), a vitellarium (in which oocytes grow by
deposition of yolk in a process known as **vitellogenesis**) and a pedicel. An ovariole
contain a series of developing oocytes each surrounded by a layer of follicle cells forming
an epithelium (the oocyte with its epithelium is termed a **follicle**), the youngest oocyte
occur near the apical germarium and the most mature near the pedicel. There are different
types of ovarioless based on the presence or absence of specialized nutritive cells called
trophocytes / nurse cells for nourishment of oocytes.
Paniostic ovariole: Lacks specialized nutritive cells so that it contains only a string of
follicles, with the oocytes obtaining nutrients from the haemolymph via the follicular
epithelium. e.g. Cockroach.
Telotrophic ovariole: (Acrotrophic) The trophocyte is present and its location is
confined to the germarium and remain connected to the oocytes by cytoplasmic strands as
the oocytes move down the ovariole. eg. bugs.
Polytrophic ovariole: A number of trophocytes are connected to each oocyte and
trophocytes moves down along with the ovariole, providing nutrients until depleted. Thus
individual oocytes are alternated with groups of smaller trophocytes in the ovarioles. e.g.
moths and flies.
Accessory glands of the female reproductive tract are often called as **colleterial
or cement glands**, because their secretions surround and protect the eggs or cement them

to the substrate. e.g. egg case production in mantis, ootheca formation in cockroach,
venom production in bees.

LECTURE 10.

Male reproductive system

The main functions of the male reproductive system are the production and
storage of spermatozoa and their transport in a viable state to the reproductive tract of the
female. Morphologically, the male tract consists of paired **testes**, each containing a series
of **testicular tubes or follicles** (in which spermatozoa are produced) which open
separately into the **sperm duct or vas deferens.** This vas deferens expands posteriorly to
form a sperm storage organ or **seminal vesicle**. Tubular paired **accessory glands** are
formed as diverticula of the vasa deferentia. Some times the vasa deferentia themselves
are glandular and fulfil the functions of accessory glands. The paired vasa deferentia
unite where they lead into **ejaculatory duct** (the tube that transports the semen or the
sperm to the gonopore). Accessory glands are 1-3 pairs associated with vasa
deferentia or ejaculatory duct. Its function is to produce seminal fluid and **spermatophores** (sperm containing capsule).

Types of reproduction

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

developing young
within the mother. Four main types of viviparity are observed in different insect groups.

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

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

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

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

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

a. **Based on occurrence**

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

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

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

e.g.aphid.

b. **Based on sex produced**:

i. Arrhenotoky: Produce male e.g. bee

ii. Thelytoky: produce female e.g. aphids

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

c. **Based on meiosis**:

i. Apomictic : no meiosis occurs

ii. Automictic : meiosis occurs, but diploidy is maintained

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

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

i. Larval paedogenesis - e.g. Gall midges

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

LECTURE 11. Sense organs

Sense organs

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

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

1. Mechano receptors (detect mechanical forces)

i. **Trichoid sensilla**: Hair like little sense organ. Sense cell associated with spur and seta.

These cells are sensitive to touch and are located in antenna and trophi (mouth parts).

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

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

Functions :

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

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

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

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

2. Auditory receptors (detect sound waves)

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

ii. Tympanum: This is a membrane stretched across tympanic cavity

responds to sounds
produced at some distance, transmitted by airborne vibration. Tympanal membranes are
linked to chordotonal organs that enhance sound reception. Tympanal organs are located
* Between the metathoracic legs of mantids.
* The metathorax of many nectuid moths.
* The prothoracic legs of many orthopterans.
* The abdomen of short horned grasshopper, cicada.
* The wings of certain moths and lacewings.

3. Chemoreceptors (detect smell and taste)

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

4. Thermoreceptors (detect heat)

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

5. Photoreceptors (detect light energy)

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

Optic part

contains a cuticular lens called **corneal lens** secreted by corneagenous cells and
crystalline cone covered by **primary pigment cells**. Function of the optic part is to
gather light. **Sensory part** contains six to ten
visual cells called **retinular cells** covered by secondary pigment cells which collectively
secrete a light sensitive rod at the centre called **rhabdom**. Rhabdom contains light
sensitive pigments called **rhodopsin**. Each ommatidium is covered by a ring of light
absorbing pigmented cells, which isolates an ommatidium from other. Nerve cells are
clustered around the longitudinal axis of each ommatidium.

Types of ommatidia

i. **Apposition type** (light tight): Due to the presence of primary pigment cells light cannot
enter the adjacent cells. The mosaic image formed is very distinct. The image formed by
the compound eye is of a series of opposed points of light of different intensities. This
functions well in diurnal insects.

ii. **Super position type**: Primary pigment cells are absent allowing light to pass between
adjacent ommatidia. Image formed in this way are indistinct, bright and blurred. This
type is seen in nocturnal and crepuscular insects.

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

c. Dorsal ocelli: Visual organs of nymph and it vary from 0-3 in numbers. It contains a
single corneal lens with many visual cells individually secreting the rhabdomere. Dorsal

ocelli perceive light to maintain diurnal rhythm and is not involved in image perception.

LECTURE 12.

Metamorphosis: Egg structure and types of eggs

Metamorphosis and immature stages in insects

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

1. **Ametabola:** (No metamorphosis) e.g. Silver fish. These insects have only three stages in their life namely egg, young ones and adult. It is most primitive type of metamorphosis. The hatching insect resembles the adult in all respects except for the size and called as juveniles. Moulting continues throughout the life.

2. **Hemimetabola**: (Incomplete metamorphosis) e.g. Dragonfly, damselfly and may fly.

These insects also have three stages in their life namely egg, young one and adult. The young ones are aquatic and are called as **naiads**. They are different from adults in habit and habitat. They breathe by means of tracheal gills. In dragonfly naiad the lower lip (labium) is called mask which is hinged and provided with hooks for capturing prey.

After final moult, the insects have fully developed wings suited for aerial life.

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

The young ones are called **nymphs**. They are terrestrial and resemble the adults in general body form except the wings and external genitalia. Their compound eyes and

mouth parts are similar to that of adults. Both nymphs and adults share the same habitat.
Wing buds externally appear in later instars. The genitalia development is gradual. Later
instar nymphs closely resemble the adult with successive moults.
4. **Holometabola**: (Complete metamorphosis) e.g. Butterfly, moth, fly and bees.
These insects have four life stages namely egg, larva, pupa and adult. Majority of insects
undergo complete metamorphosis. Larvae of butterflies are called caterpillar. Larva
differs greatly in form from adult. Compound eyes are absent in larva. Lateral ocelli or
stemmata are the visual organs. Their mouth parts and food habit differ from adults.
Wing development is internal. When the larval growth is completed, it transforms into
pupa. During the non-feeding pupal stage, the larval tissues disintegrate and adult organs
are built up.
1. **Eggs**: The first stage of development in all insects is egg. Majority of insects are
oviparous. Egg stage is inconspicuous, inexpensive and inactive. Yolk contained in the
egg supports the embryonic development. Eggs are laid under conditions where the food
is available for feeding of the future Youngones. Eggs are laid either individually or in
groups. The outer protective shell of the egg is called chorion. Near the anterior end of
the egg, there is a small opening called micropyle which allows the sperm entry for
fertilization. Chorion may have a variety of textures. Size and shape of the insect eggs
vary widely.
TYPES OF EGGS :
a) **SINGLY LAID** :

1) **Sculptured egg :** Chorion with reticulate markings and ridges e.g. Castor butterfly.
2) **Elongate egg** : Eggs are cigar shaped. e.g. Sorghum shoot fly.
3) **Rounded egg**: Eggs are either spherical or globular. e.g. Citrus butterfly
4) **Nit :** Egg of head louse is called nit. It is cemented to the base of the hair. There is an
egg stigma at the posterior end, which assists in attachment. At the anterior end, there is
an oval lid which is lifted at time of hatching.
5) **Egg with float :** Egg is boat shaped with a conspicuous float on either side. The lateral
sides are expanded. The expansions serve as floats. e.g. *Anopheles* mosquito.
b**) EGGS LAID IN GROUPS** :
1) **Pedicellate eggs :** Eggs are laid in silken stalks of about
1.25mm length in one groups on plants. e.g. Green lacewing fly.
2) **Barrel shaped eggs :** Eggs are barrel shaped. They look like miniature batteries. They
are deposited in compactly arranged masses. e.g. Stink bug.
3) **Ootheca** (Pl. Oothecae) : Eggs are deposited by cockroach in a brown bean like
chitinous capsule. Each ootheca consists of a double layered wrapper protecting two
parallel rows of eggs.Each ootheca has 16 eggs arranged in two rows. Oothecae are
carried for several days protruding from the abdomen of female prior to oviposition in a
secluded spot. Along the top,there is a crest which has small pores which permit gaseous
exchange without undue water loss. Chitinous egg case is produced out of the secretions
of colleterial glands.
4) **Egg pod :** Grasshoppers secrete a frothy material that encases an egg mass which is
deposited in the ground. The egg mass lacks a definite covering. On the top of the egg,the

frothy substance hardens to form a plug which prevents the drying of eggs.

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

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

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

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

LECTURE 13. Larva and types of larvae

LARVAE

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

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

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

a. Campodeiform : They are so called from their resemblance to the dipluran genus Campodea. Body is elongate, depressed dorsoventrally and well sclerotised. Head is prognathous. Thoracic legs are long. A pair of abdominal cerci or caudal processes is

usually present. Larvae are generally predators and are very active. e.g. grub of antlion or
grub of lady brid beetle.
b. Scarabaeiform : Body is `C' shaped, stout and subcylindrical. Head is well developed.
Thoracic legs are short. Caudal processes are absent. Larva is sluggish, burrowing into
wood or soil. e.g. grub of rhinoceros beetle.
2. POLYPOD or ERUCIFORM : The body consists of an elongate trunk with large sclerotised head capsule. Head bears a pair of powerful mandibles which tear
up vegetation. Two groups of single lensed eyes (Stemmata) found on either side of the
head constitute the visual organs. The antenna is short. Three pairs of thoracic legs and
upto five pairs of unjointed abdominal legs or prolegs are present. Thoracic legs are
segmented and they end in claws which are used for holding on to the leaf. Bottom of the
proleg is called planta which typically bears rows or circlet of short hooked spines or
crochets which are useful in clinging to the exposed surface of vegetation and walking.
Abdominal segments three to six and ten typically bear prolegs. e.g. Caterpillar (larvae of
moths ad butterflies).
a. Hairy caterpillar : The body hairs may be dense, sparse or arranged in tufts. Hairs may
cause irritation, when touched. e.g. Red hairy caterpillar.
b. Slug caterpillar : Larva is thick, short, stout and fleshy. Laval head is small and
retractile. Thoracic legs are minute. Abdominal legs are absent. Abdominal segmentation
is indistinct. Larva has poisonous spines called scoli distributed all over the body. Such
larva is also called platyform larva.
c. Semilooper : Either three or four pairs of prolegs are present. Prolegs

are either
wanting or rudimentary in either third or third and fourth abdominal segments. e.g. castor
semilooper.
d. Looper : They are also called measuring worm or earth measurer or inch worm. In this
type, only two pairs of prolegs are present in sixth and tenth abdominal segments. e.g.
Daincha looper.
3. APODOUS: They are larvae without appendages for locomotion. Based on the degree
of development and sclerotization of head capsule there are three subtypes.
a. Eucepalous : Larva with well developed head capsule with functional mandibles,
maxillae, stemmata and antennae. Mandibles act transversely. e.g. Wriggler (larva of
mosquito) and grub of red palm weevil.
b. Hemicephalous : Head capsule is reduced and can be withdrawn into thorax.
Mandibles act vertically.
e.g. Larva of horse fly and robber fly.
c. Acephalous : Head capsule is absent. Mouthparts consist of a pair of protrusible curved
mouth hooks and associated internal sclerites. They are also called vermiform larvae. e.g.
Maggot (larva of house fly).

LECTURE 14. Pupa and types of pupae

PUPA :

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

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

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

b. Tumbler : Pupa of mosquito is called tumbler. It is an obtect type of pupa. It is comma shaped with rudimentary appendages. Breathing trumpets are present in the cephalic end and anal paddles are present at the end of the abdomen. Abdomen is capable of jerky movements which are produced by the anal paddles. The pupa is very active.

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

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

PUPAL PROTECTION

In general pupal stage lacks mobility. Hence it is the most vulnerable stage. To get protection against adverse conditions and natural enemies, the pupa is enclosed in a

protective cover called cocoon. Based on the nature and materials used for preparation of
cocoons, there are several types.

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