(فسيولوجي حشرات)

401ش

(الجزء النظري)

الفصل الدراسي الأول

إعداد

د. سلوى إبراهيم سباق علي

كلية العلوم

قسم علم الحيوان

2023-2022

بيانات الكتاب

الكلية: العلوم

الفرقة: الرابعة

التخصص: علم الحشرات

تاريخ النشر: الفصل الدراسي الأول

2023-2022

رؤية كلية العلوم

التميز في تعليم العلوم الاساسية والبحث العلمي للمساهمة في التنمية المستدامة

رسالة كلية العلوم

تقديم تعليم مميز في مجالات العلوم الاساسية وانتاج بحوث تعليمية تطبيقية للمساهمة في التنمية المستدامة من خلال اعداد خريجين متميزين طبقاً للمعايير الاكاديمية القومية وتطوير مهارات وقدرات الموارد البشرية وتوفير خدمات مجتمعية وبيئية تلبي طموحات مجتمع جنوب الوادي وبناء الشراكات المجتمعية الفاعلة .

رؤية القسم

خريجون وباحثون متميزون علمياً وبحثياً في دراسة ضرر ونفع الكائنات الحيوانية خدمة للمجتمع وتنمية للبيئة

رسالة القسم

يسعى قسم علم الحيوان والحشرات بكلية العلوم جامعة جنوب الوادي من خلال ما يقدمة من برامج تعليمية باستخدام الوسائل العلمية والتعليمية المتطورة والتي تكشف عن المزيد من ضرر ونفع الكائنات الحية وباحثين وخريجون متميزين علمياً وبحثياً ينتفع بهم المجتمع وترتقي بهم الامة .

INSECT PHYSIOLOGY

INTRODUCTION

- **Insect physiology** is the study of how insects live and reproduce.
- Insects are arthropods meaning they have an external skeleton that covers the internal tissues.
- The exoskeleton protects the internal tissue but also allows for sensory systems to function.

Main topics

- **Integumentary System of insects**
- **Growth and metamorphosis**
- **Digestive system**
- **Respiratory system of insects**
- **Excretory system of insects**
- **Circulatory system of insects**
- **Nervous system of insects**
- **Endocrine system of insects**
- **Communication of insects**
- **Sensory organs of insects**
- **Muscles and locomotion of insects**
- **Reproduction of insects**
- **Immunology**

- Integumentary System of insects

STRUCTURE OF INTEGUMENT

The integument or body wall of insects is the outer layer of its body comprising of the epidermis.

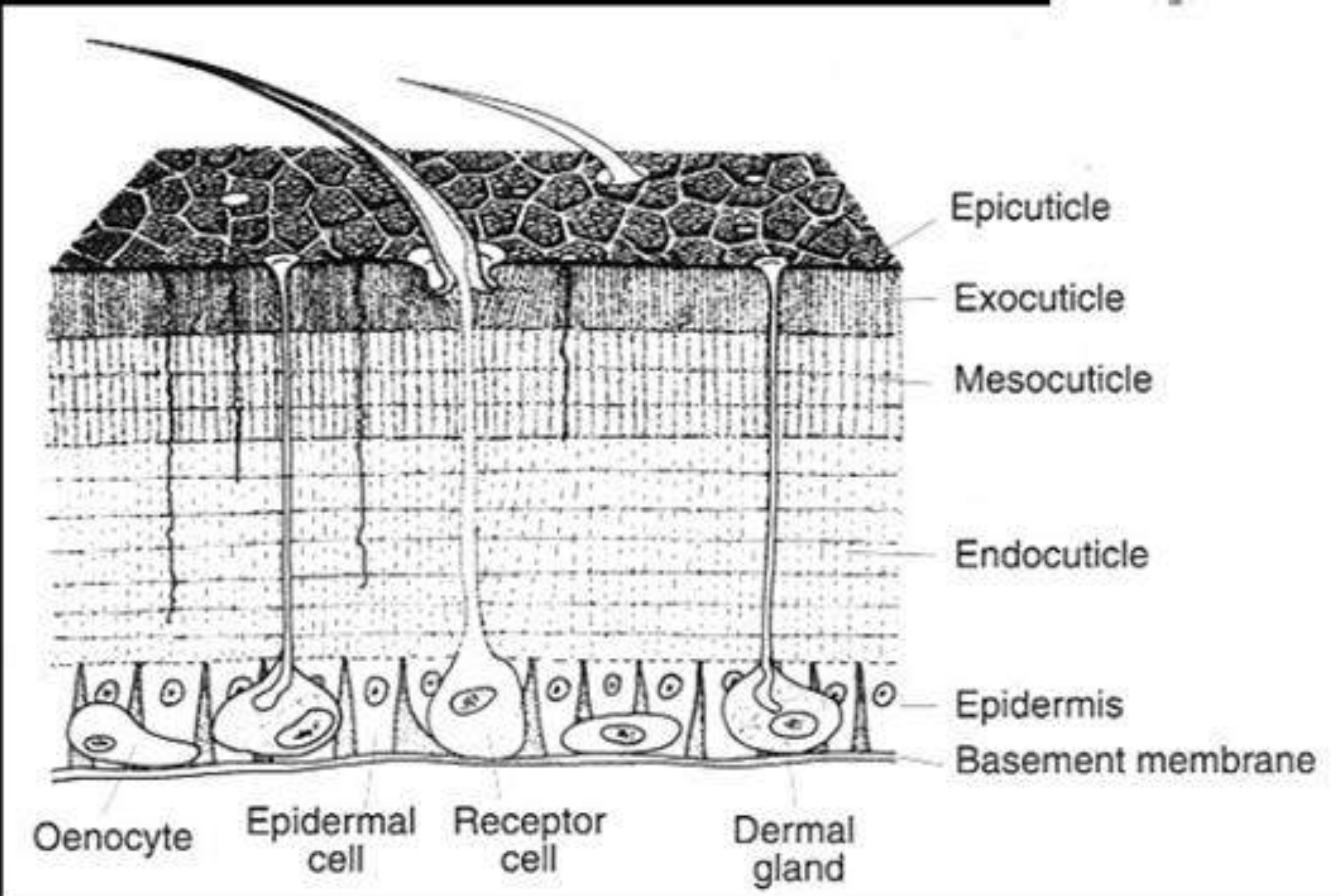
- **The integument consists of**
- Inner basement membrane
- Middle epidermal cell layer – epidermis (or hypodermis)
- Non-living outer cuticle.

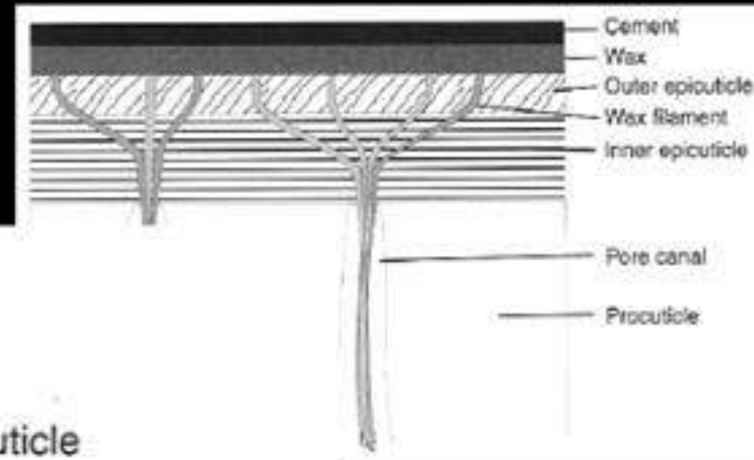
- Cuticle is a characteristic of Phylum Arthropoda.
- Cuticle plays a crucial role in insect survival and dominance.

FUNCTIONS OF INTEGUMENT

- Composed of Chitin –Strong, rigid, and flexible
- Provides large area for muscle attachment
- Conserves water, minimizes water loss and hence prevents desiccation.
- Prevents mechanical injury.
- Protective coloration.
- Act as a tool for various activities like digging, oviposition, and preying.
- Gives physical strength without making the insect body heavier.

STRUCTURE AND CHEMISTRY OF INTEGUMENT


Epicuticle
Exocuticle
Mesocuticle
Endocuticle
Epidermis
Basement membrane
Oenocyte
Epidermal cell
Receptor cell
Dermal gland


Cement
Wax
Outer epicuticle
Wax filament
Inner epicuticle
Pore canal
Procuticle

Structure of the Integument

- Basement membrane: a continuous sheet of mucopolysaccharide, as much as 0.5 mm in thickness; initially secreted by haemocytes.

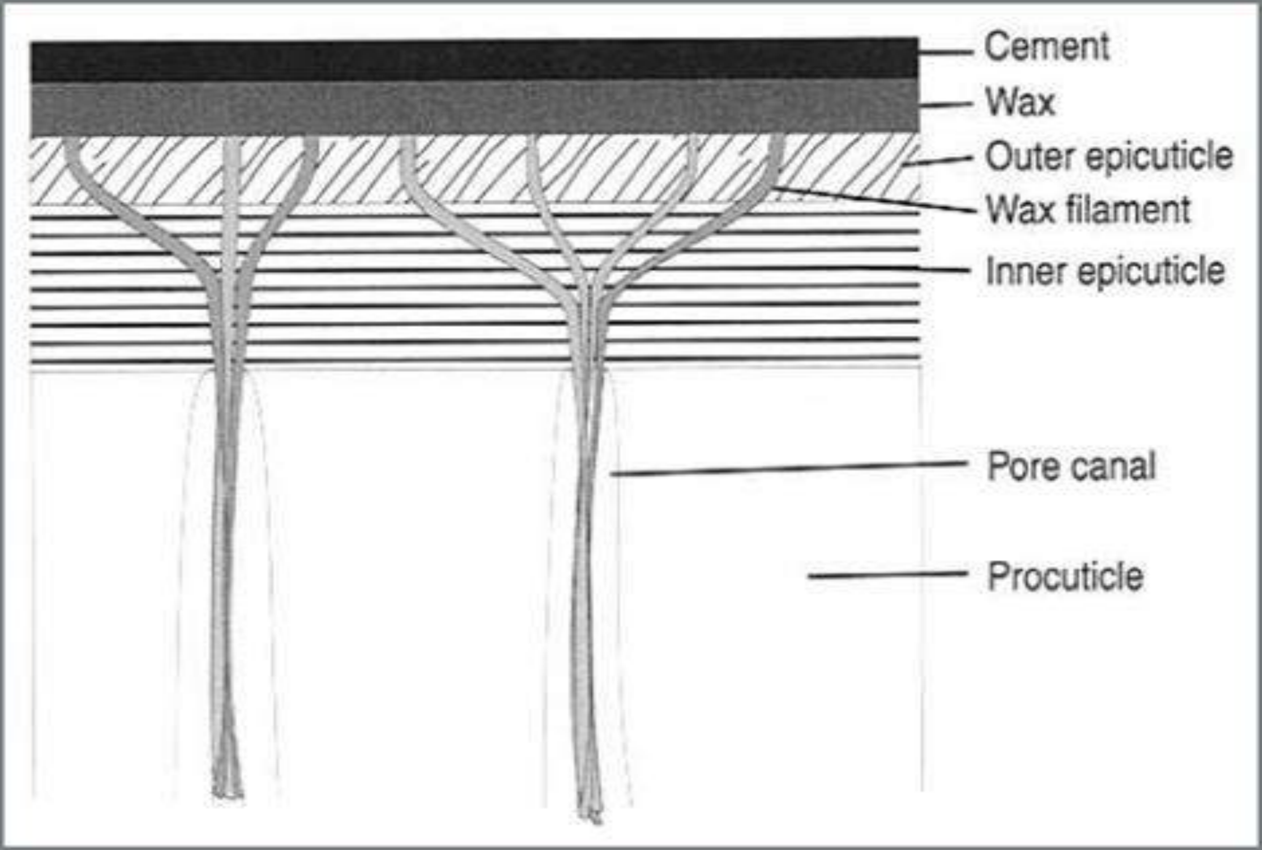
- Epidermis: the only living portion of the integument; modifications of these cells produce dermal glands, sensory receptors and their support cells, and oenocytes.

- **Cuticle**: secreted by epidermis; divided into two main regions:

- **Epicuticle:**
- consists of cement layer, wax layer, polyphenol layer, and the cuticulin layer.
- This is the outermost, thinnest cuticular layer devoid of chitin.

- **Procuticle**:
- Inner cuticular layer consists of exocuticle, mesocuticle, and endocuticle, constituted largely of chitin and protein.

PORE CANAL - LONGITUDINAL VIEW



The Epicuticle

- The epicuticle is a complex layer consisting of several layers that are produced by both the epidermal cells and dermal glands.

- **Cement layer**:
- Consists mostly of lipoprotein secreted by dermal glands.
- Functions as a varnish, provides protective external surface to integument.
- Prevents water loss from the body
- Absent in honey bees.

- **<u>The wax layer</u> :**
- 0.25 microns thick
- Contains hydrocarbons with 25-31 carbon atoms, alcohols of 24-34 carbon atoms, and esters of fatty acids.
- produced by the epidermal cells.
- Act as a waterproof layer of the integument as it contains tightly packed wax molecules.

- **<u>The Polyphenol layer</u> :**
- Non-static layer
- composed of polyhydric phenols.
- Phenols are transported from epidermal cells through the pore canals and are accumulated on the outer surface of the cuticulin layer.

- **Cuticulin layer:**
- Amber coloured.
- Consist of a lipoprotein – Cuticulin
- Highly resistant to mineral acids and most organic solvents.
- Serves as a permeability and growth barrier
- Determines the surface properties of integument

- **The Chitinous cuticle (Procuticle)**
- The procuticle is secreted by the epidermal cells and consists largely of chitin and protein.

- **exocuticle:** the proteins become heavily cross-linked and insoluble; are not broken down during the molting cycle; pigments deposited within it

- **endocuticle:** synthesis continues after the old cuticle is shed, often in daily layers; cross-linking is reduced; completely broken down during molting process

- **mesocuticle:** as a transitional layer in which the proteins are untanned like the endocuticle but impregnated with lipid and proteins like the exocuticle

Procuticle

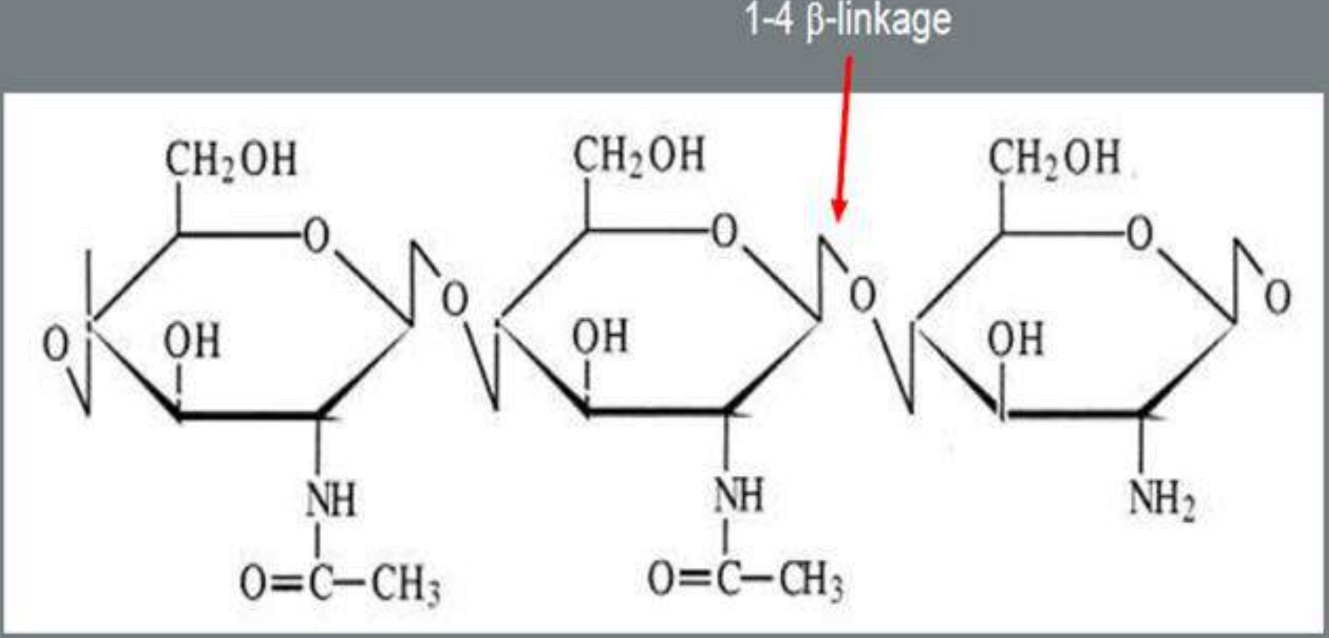
Exocuticle	Endocuticle
• Darkly pigmented	• Light colored
• Hard and sclerotized	• Soft and unsclerotized
• Consisting mainly chitin and hard protein called Sclerotin.	• Consisting more chitin
	• Lack of Sclerotin

- **Chitin – Protein Microfibrils :** Chitin and protein are crucial elements of arthropods forming major constituents of body wall.

- In insects they form the framework of cuticle and also constituents of peritrophic membrane of gut.

- **Chitin** :
- Nitrogenous polysaccharide.
- Made of long chains of acetylated glucosamine residues -- N-Acetyl glucosamine (C8H13O5N)n
- Adjacent chains are held together by β –glycosidic linkages.

CHITIN MOLECULAR STRUCTURE



N-acetyl-D-glucosamine

glucosamine

- **Protein :** Proteins are of 3 types:
- **Arthropodin :** Water-soluble protein found in the endocuticle. Untanned, elastic protein.
- **Resilin:** Rubber-like protein occurs as colourless cuticular ligament such as wing-hinge ligament. Elastic in nature.
- **Sclerotin:** Tanned protein. Occurs in the exocuticle. It is in fact tanned athropodin.

- **Lime :**
- In some aquatic insects, lime or CaCO3 is deposited and may form a major constituent of exocuticle.

- **Pigments :**
- The insect cuticle posses various pigments such as melanin, carotenoids, pterins (pigment which gives fluorescent color to butterfly wings).

CHEMISTRY OF CUTICLE

- The insect cuticle is composed largely of

<u>Proteins</u>

- comprise more than half the dry weight of the insect cuticle.
- Primarily distributed within the Procuticle.
- Synthesized mainly by epidermal cells

<u>Chitin</u>

- Consisting of 20-40% of the total dry weight of the cuticle.
- Polymer of N-acetyl-D-glucosamine.
- Synthesized by epidermal cells

<u>Lipids</u>

- Mainly located in the wax layer of epicuticle
- Synthesized largely by the Oenocytes and the fat body

Cuticular appendages

Non-cellular

- no epidermal association
- rigidly attached.
- Eg. minute hairs and thorns

Cellular

- epidermal association

unicellular

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

Bristles. e.g.flies

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

Glandular seta. eg. caterpillar

Sensory setae - associated with sensory neuron or neurons

Seta - hair like out growth from epidermis

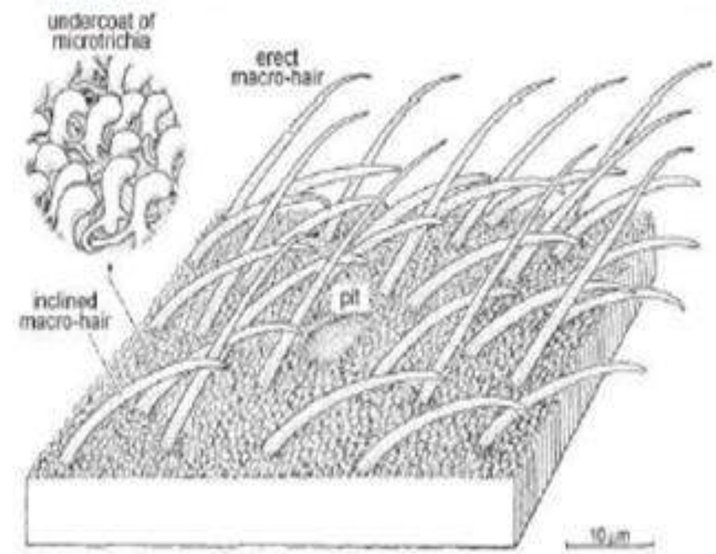
multicellular

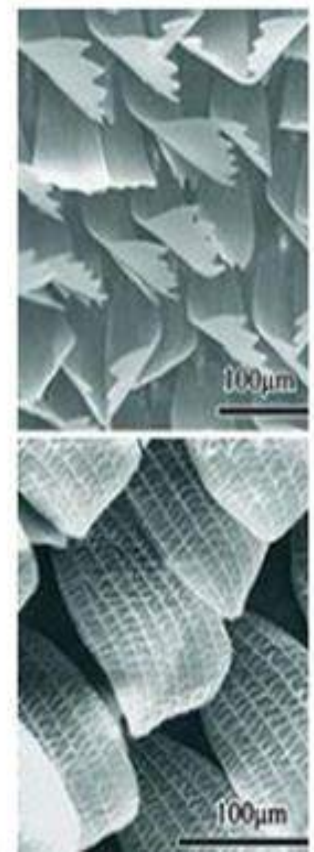
Movable e.g. Spur

Immovable e.g. Spine

External appendages of the integument

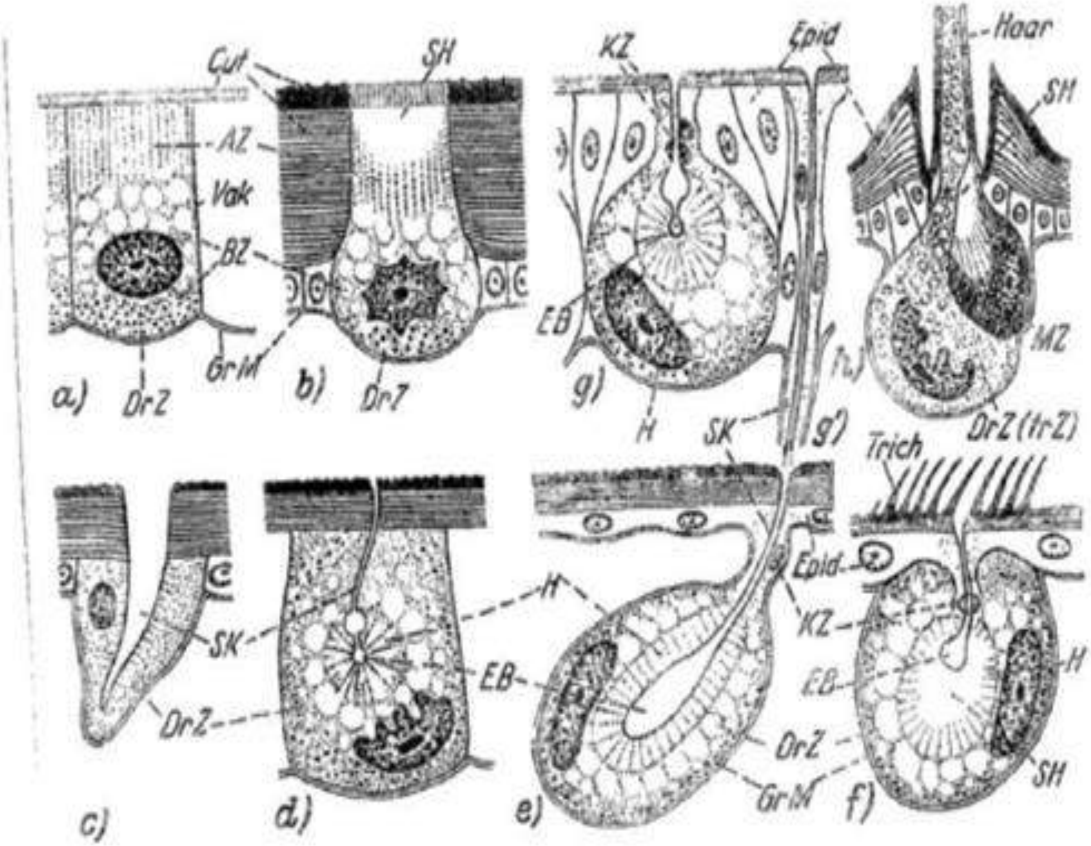
- tiny, false hairs (microtrichia)
    - produced by special epidermal cells
- bigger true hairs (macrotrichia, setae)
    - produced by seta forming (trichogen) cells
    - around them often socket constructing (tormogen) cells
- scales
    - produced by special scale constructing cells
- other cuticle formations constructing sensory organs and other special organs

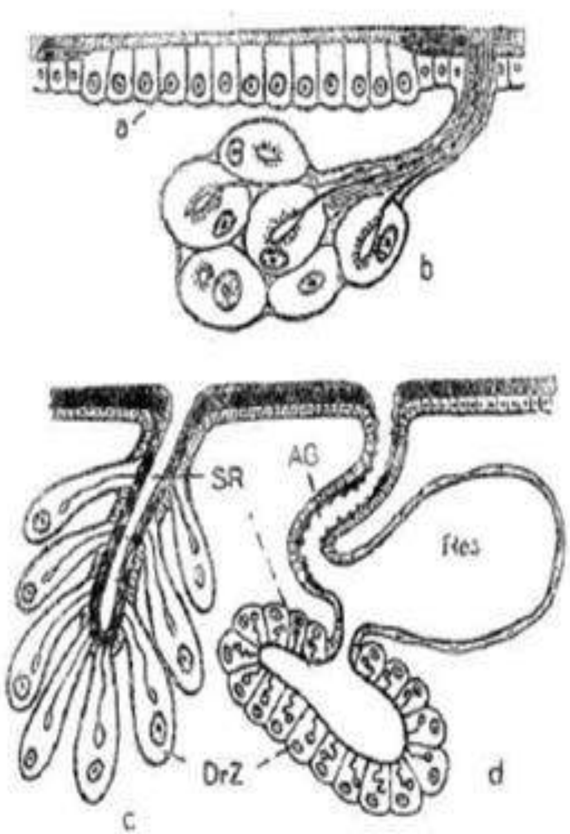




- **Glands of the insect integument, dermal glands (glandulae)**
- **Classification of glands according to their structure**
- unicellular glands
- complex glands: a group of adjacent unicellular glands both can occur within the epidermis (intraepithelial) or under the epidermis (subepithelial)
- polycellular glands always occur subepithelial their structure is nodular or tubular
- **Classification of glands according to their function**
- wax glands, enamel glands, cement glands, lubricant producing glands, adhesion helping glands, pheromone producing glands, odour glands, stink glands, venom producing glands

Several types of unicellular and polycellular dermal glands





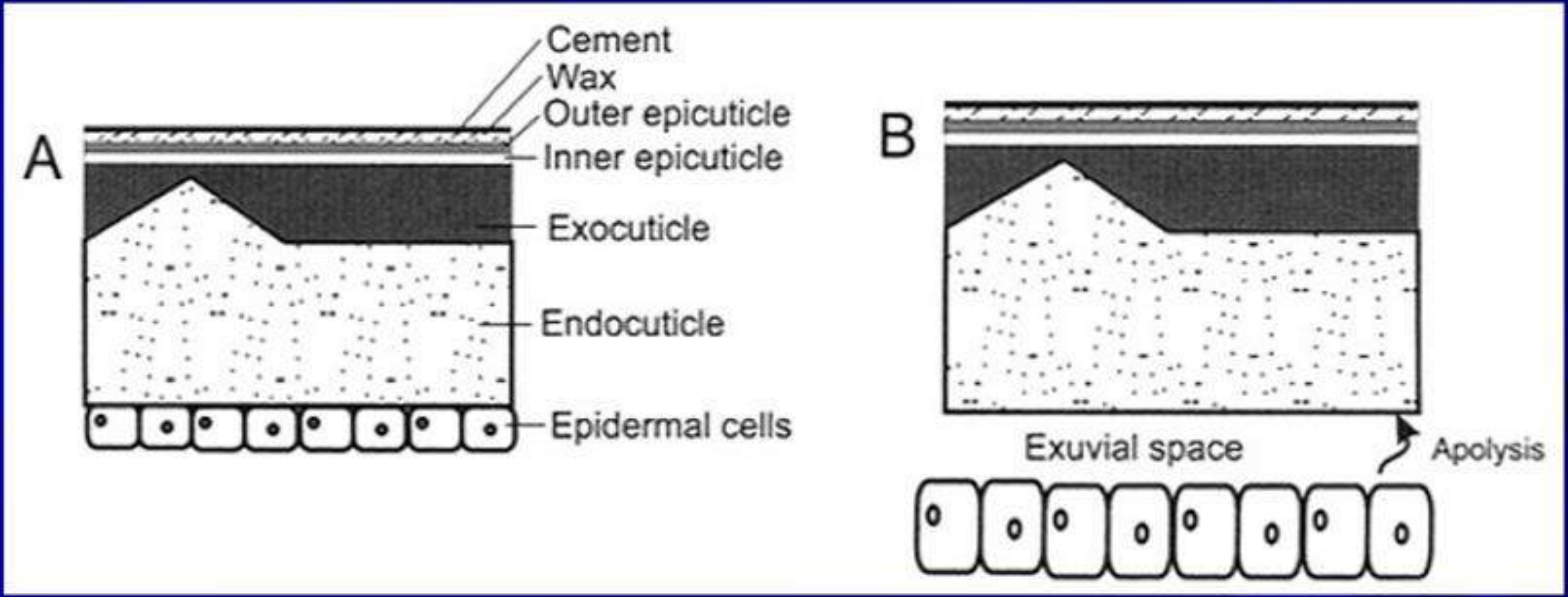
Insect Growth and Development

- The growth and development of insects are largely a function of the growth and development of their integuments.
- Molting
- Metamorphosis

The Molting Process

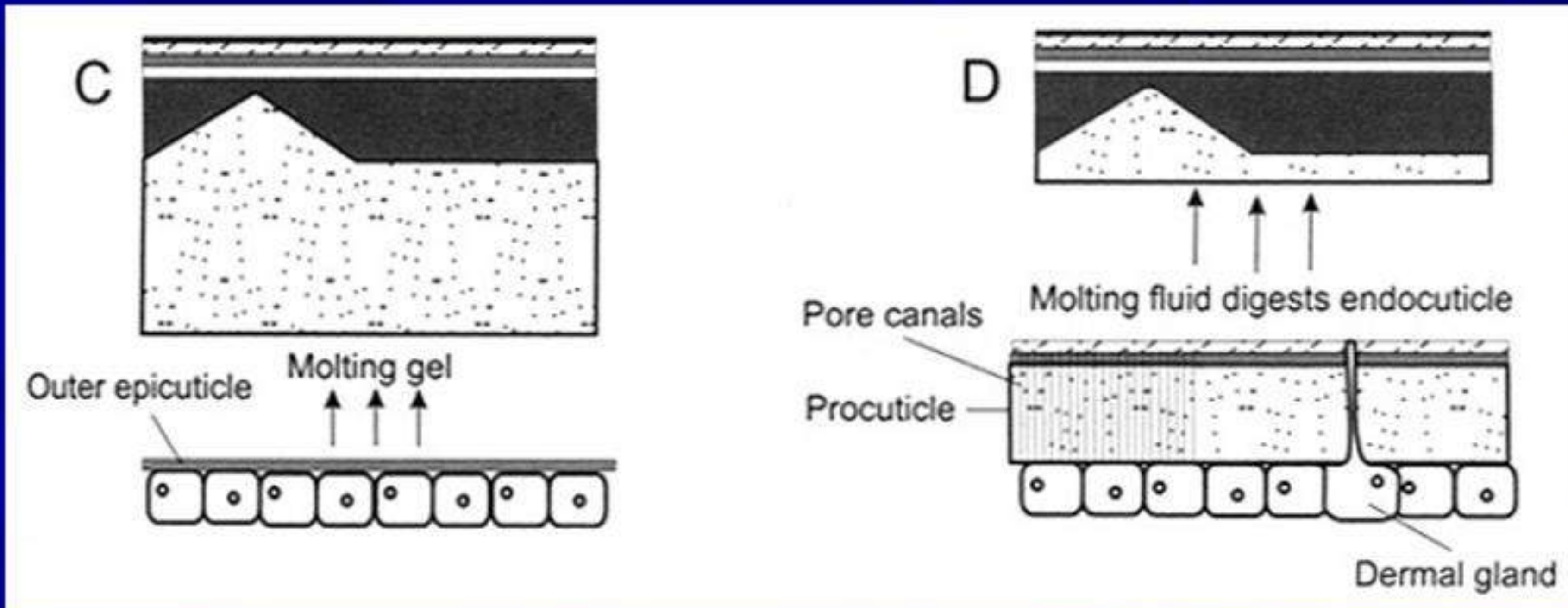
- The molting process involves an elaborate sequence of events that produces a new cuticle capable of significant expansion before the old one is discarded.
- The molting process begins with apolysis and ends with ecdysis.
- **Apolysis:** the separation of the epidermal cells from the old cuticle
- **Ecdysis:** the casting off of the old cuticle

The Steps of Molting Process



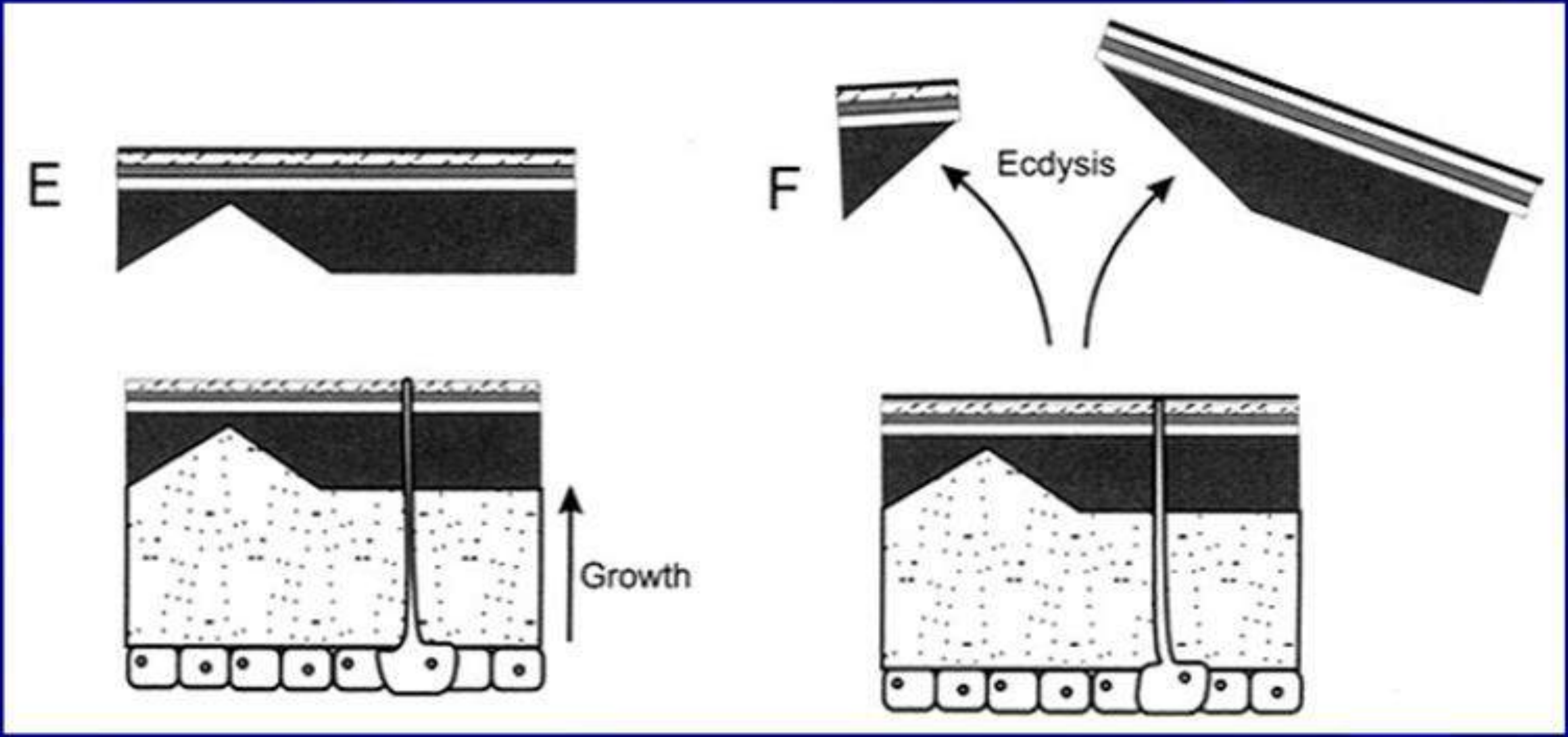
Exuvial space: the area between the cuticle and epidermis; fills with a molting gel that contains inactive enzymes including a chitinase and proteases for digesting the old cuticle.

The Steps of Molting Process



- The epidermal cells secrete a new outer epicuticle (lipoprotein: cuticulin);
- The activation of the enzyme in the molting gel, now called the molting fluid;
- The molting fluid begin the digestion of the old unsclerotized endocuticle;
- The epidermal cells begin to secrete the new procuticle;
-

The Steps of Molting Process



- Formation of the new epicuticle;
- Absorption of the molting fluid;
- Ecdysis: induced by eclosion hormone.

Summary of Molting

Step 1: Apolysis -- separation of old exoskeleton from epidermis

Step 2: Secretion of inactive molting fluid by epidermis

Step 3: Production of cuticulin layer for new exoskeleton

Step 4: Activation of molting fluid

Step 5: Digestion and absorption of old endocuticle

Step 6: Epidermis secretes new procuticle

Step 7: Ecdysis -- shedding the old exo- and epicuticle

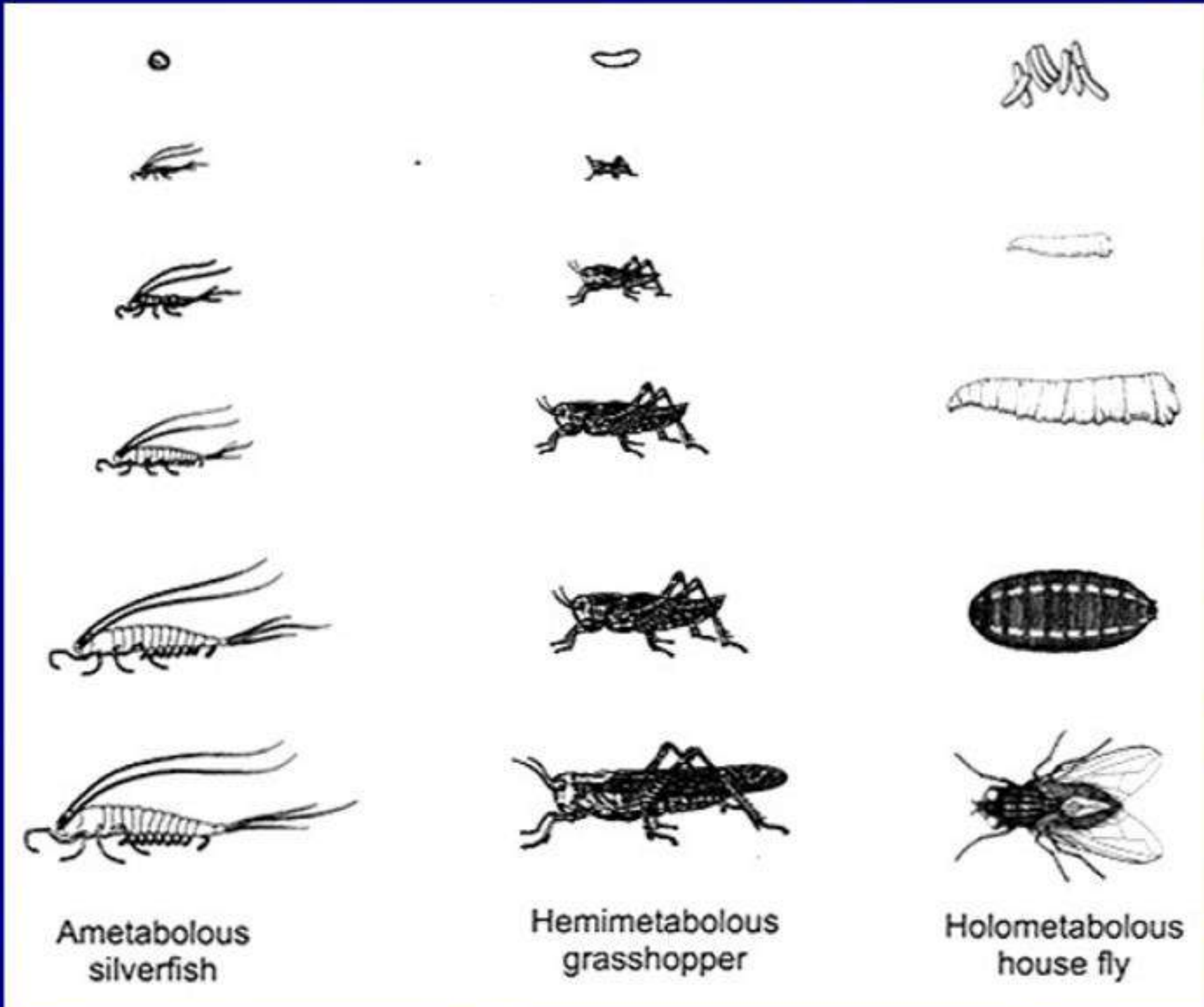
Step 8: Expansion of new integument

Step 9: Tanning -- sclerotization of new exocuticle

Strategies for Growth

- **Metamorphosis:** the change that occurs as an insect develops from an immature to an adult; separates and early feeding stage from a later reproductive stage.
- **Ametabolous development** - continue to molt as sexually mature adults and there is no real metamorphosis
- **Hemimetabolous (incomplete) development** - immatures lack wings and genitalia (exoptergotes)
- **Holometabolous (complete) development** – a sometimes very radical change in form and ecological habits between immatures and adults (endopterygotes)

Three Major Types of Metamorphosis in Insects




INSECT
DIGESTIVE
SYSTEMS

Digestive system/alimentary canal

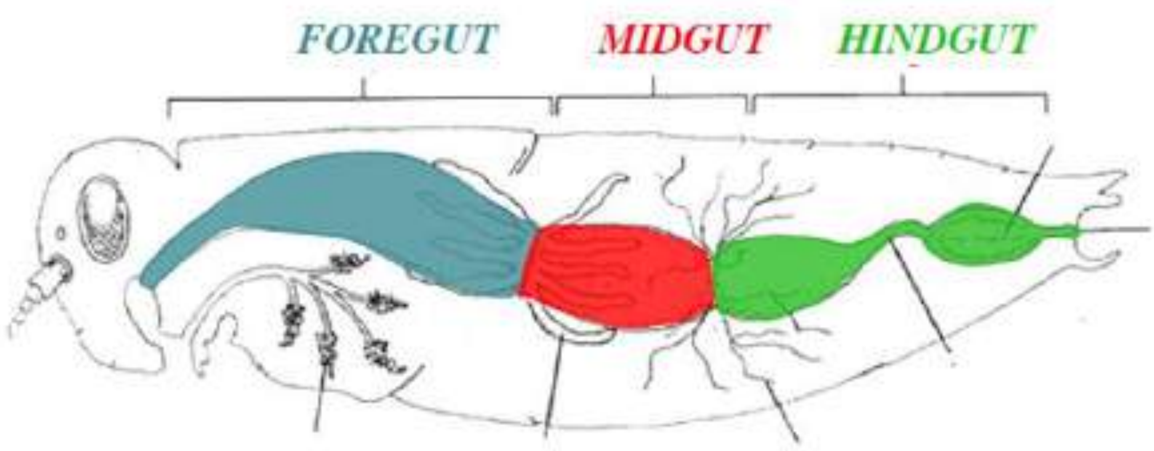
- long tube-like structure that runs from the mouth to the anus
- centrally located within the body cavity, or hemocoel

1- **Foregut/ stomodeum**

- The anterior-most region which includes the cavity, the esophagus, and the crop.
- Begins the breakdown of food particles and transport them to the next region, the midgut (or mesenteron).

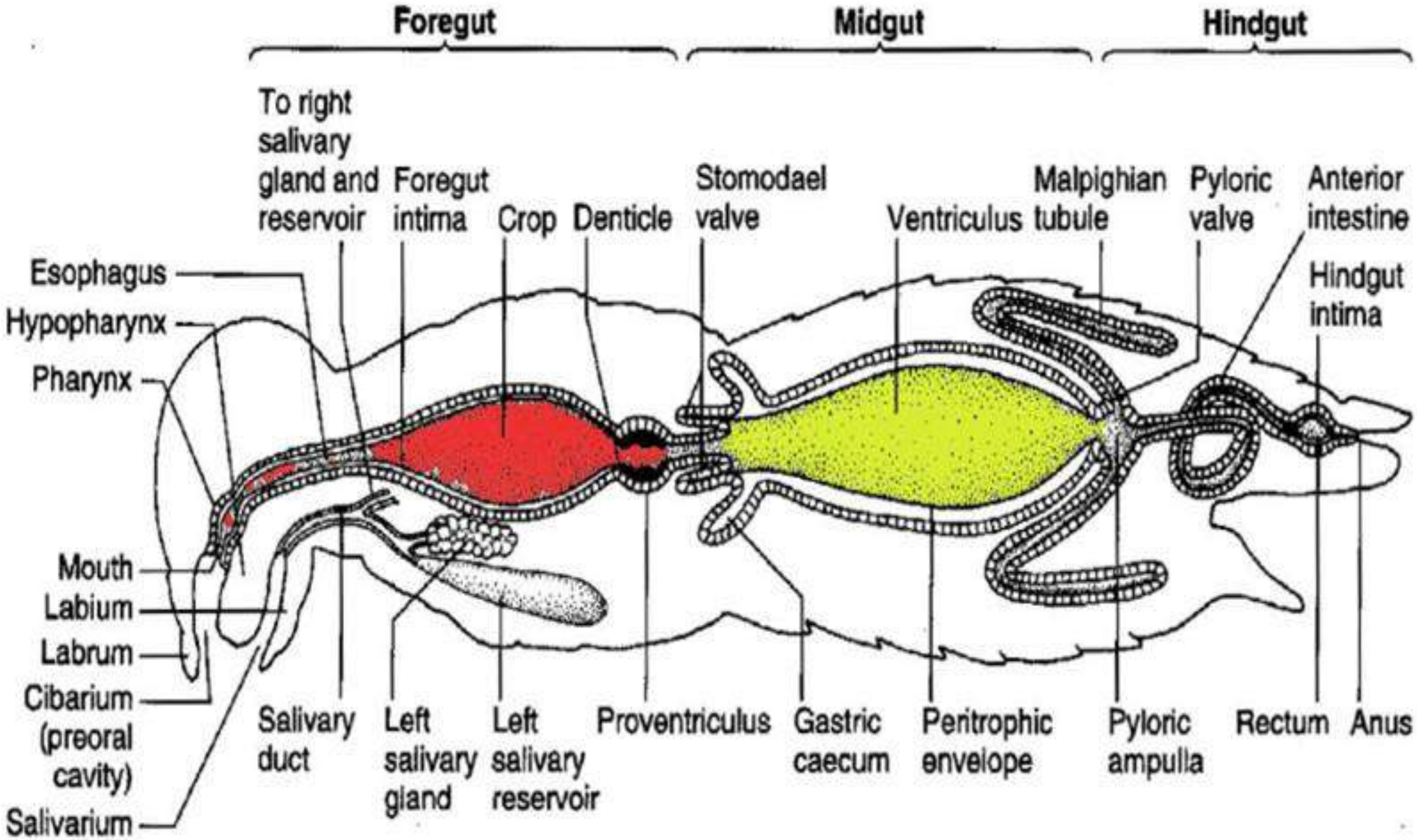
2- The midgut is the major area of digestion and absorption.

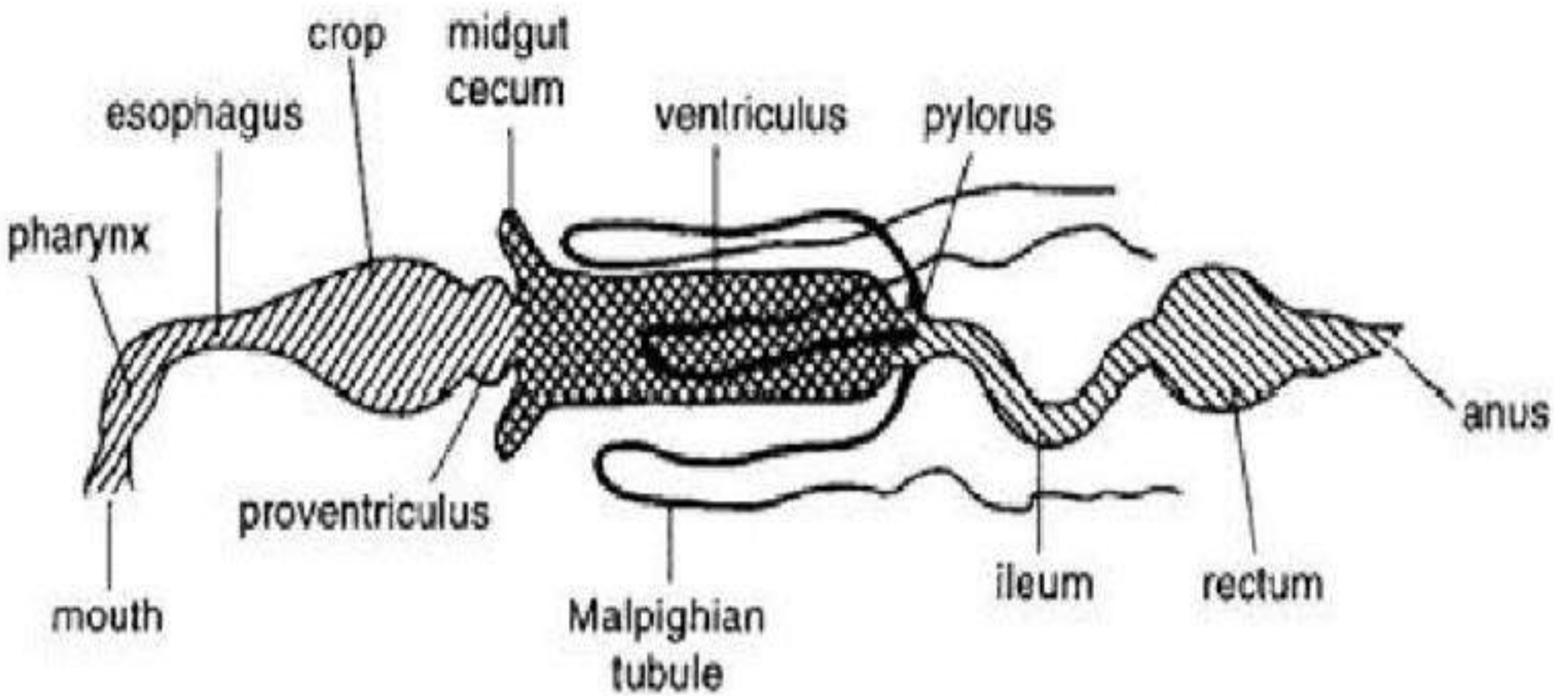
3- The hindgut/ proctodeum) consists of the ileum, colon, rectum, and (often) rectal pads. The hindgut functions in water and solute reabsorption and waste excretion.



FOREGUT
MIDGUT
HINDGUT

A. Digestive system

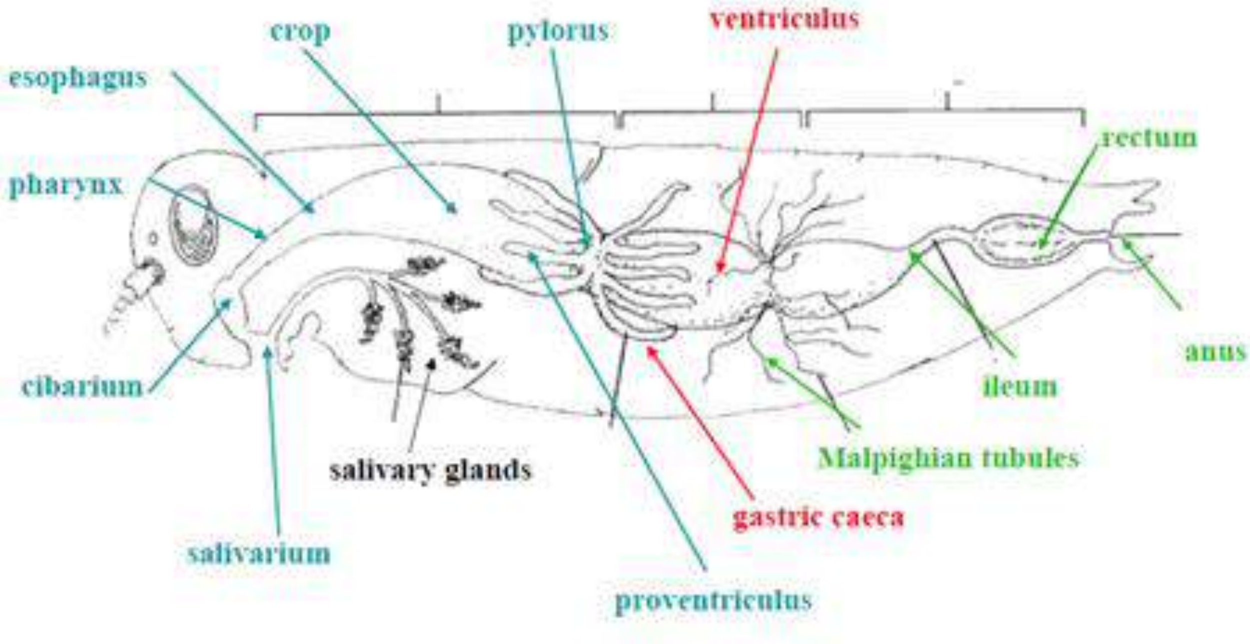



crop
midgut
cecum
esophagus
ventriculus
pylorus
pharynx
anus
proventriculus
ileum
rectum
mouth
Malpighian
tubule

- Insects may be phytophagous, entomophagous, wood borers, wool feeders (or) saprophytic, they mainly feeds on the solid food material or liquid food material.
- If the food ingested in a liquid form, it may be a **plant sap (or) nectar (or) blood**
- Based on the food material ingested, there are **structural modifications in** the digestive system of insects.
- Insects having the habit of feeding on the **solid food material, possess the biting and chewing type of mouth parts where as sap feeding ones have sucking type.**
- **Sap suckers** possess a **filter chamber** and **solid feeders** have well developed **gizzard.**

Functions of the Gut

- Obtaining food
- Mechanically breaks good down into smaller particles that facilitate the activity of digestive enzymes
- Enzymatic breakdown of larger food molecules into molecules that can enter the hemolymph
- Produce molecules that coordinate feeding and other digestive activities


crop
pylorus
ventriculus
esophagus
rectum
pharynx
cibarium
anus
ileum
salivary glands
Malpighian tubules
gastric caeca
salivarium
proventriculus

1) Foregut (stomodaeum)

2) Midgut (mesenteron)

3) Hindgut (proctodaeum)

- These divisions are seperated by **cardiac valve in the front and pyrolic valve in the rare**

Foregut

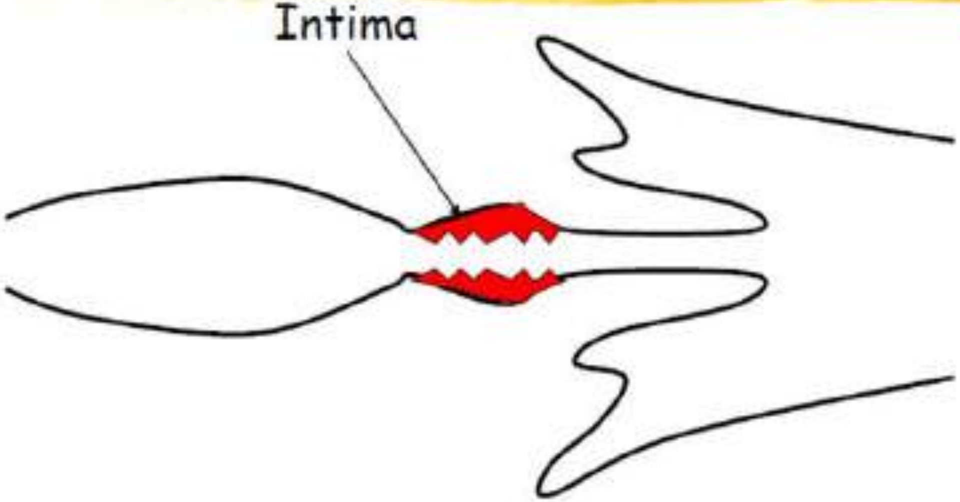
- **Ectodermal in origin and lined by intima**
- Preoral cavity between epipharynx and hypopharynx is called **cibarium**
- Preoral cavity between hypopharynx and salivary duct is called **salivarium**

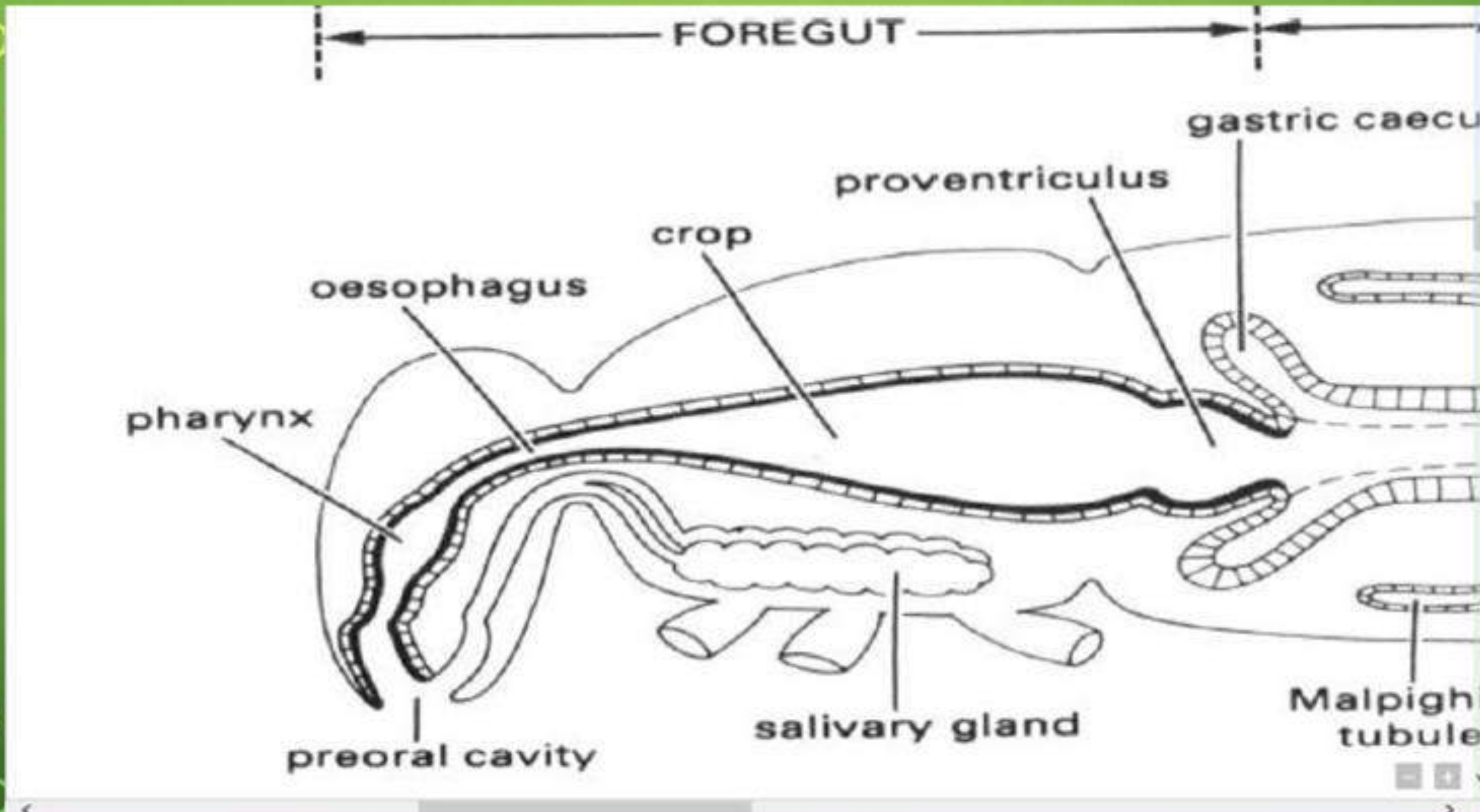
1)**pharynx-** acts as sucking pump in sap feeders

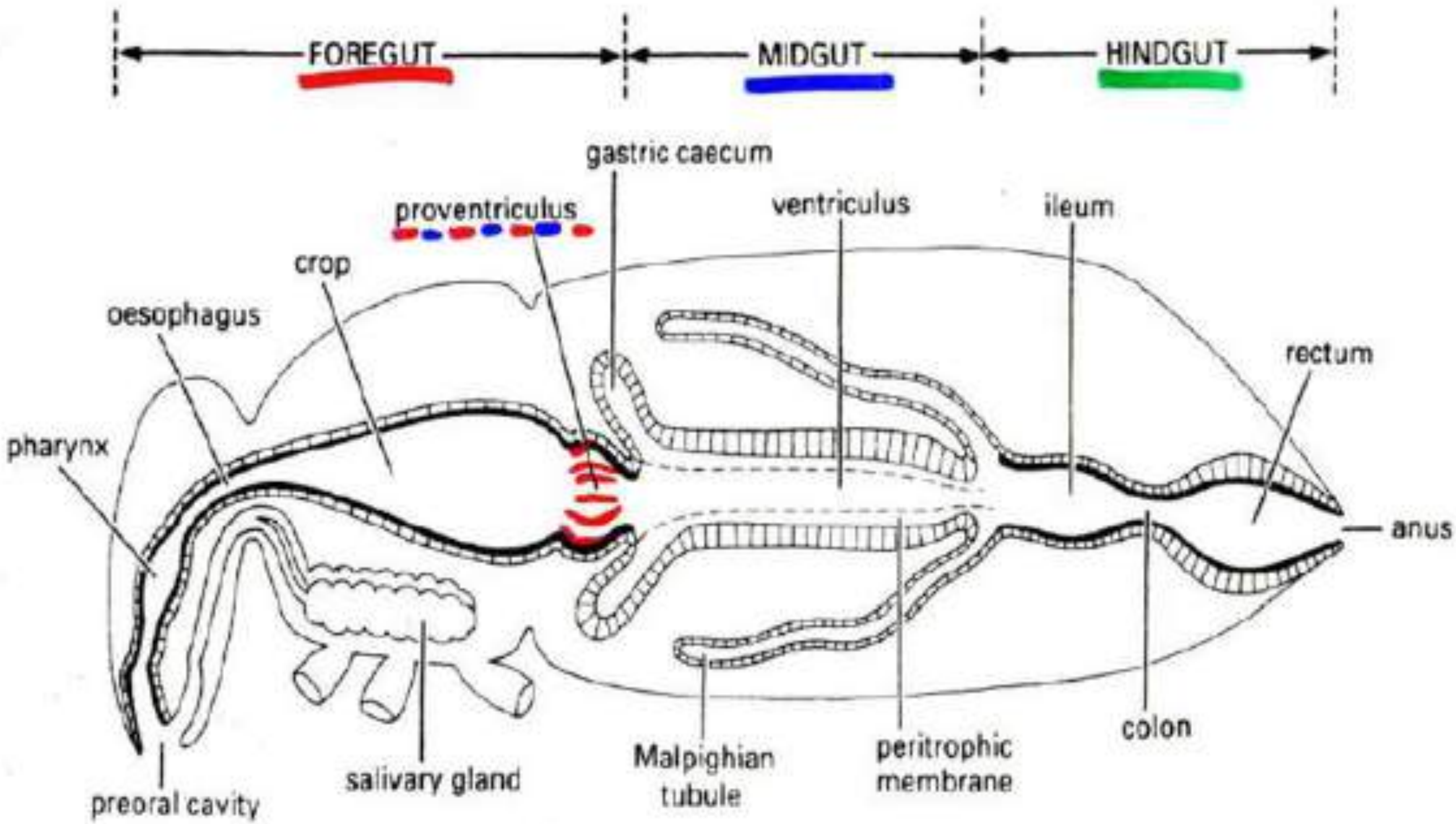
2)**crop-** acts as food reservoir and in honey bees crop is called as honey stomach where the nectar conversion takes place

3) **Proventriculus or gizzard-** it is the posterior part of the foregut and found only in solid feeders and absent in liquid feeders

Proventriculus of Grasshopper




FOREGUT
gastric caecu
proventriculus
crop
oesophagus
pharynx
preoral cavity
salivary gland
Malpighi
tubule


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

- Inner surface of gizzard is

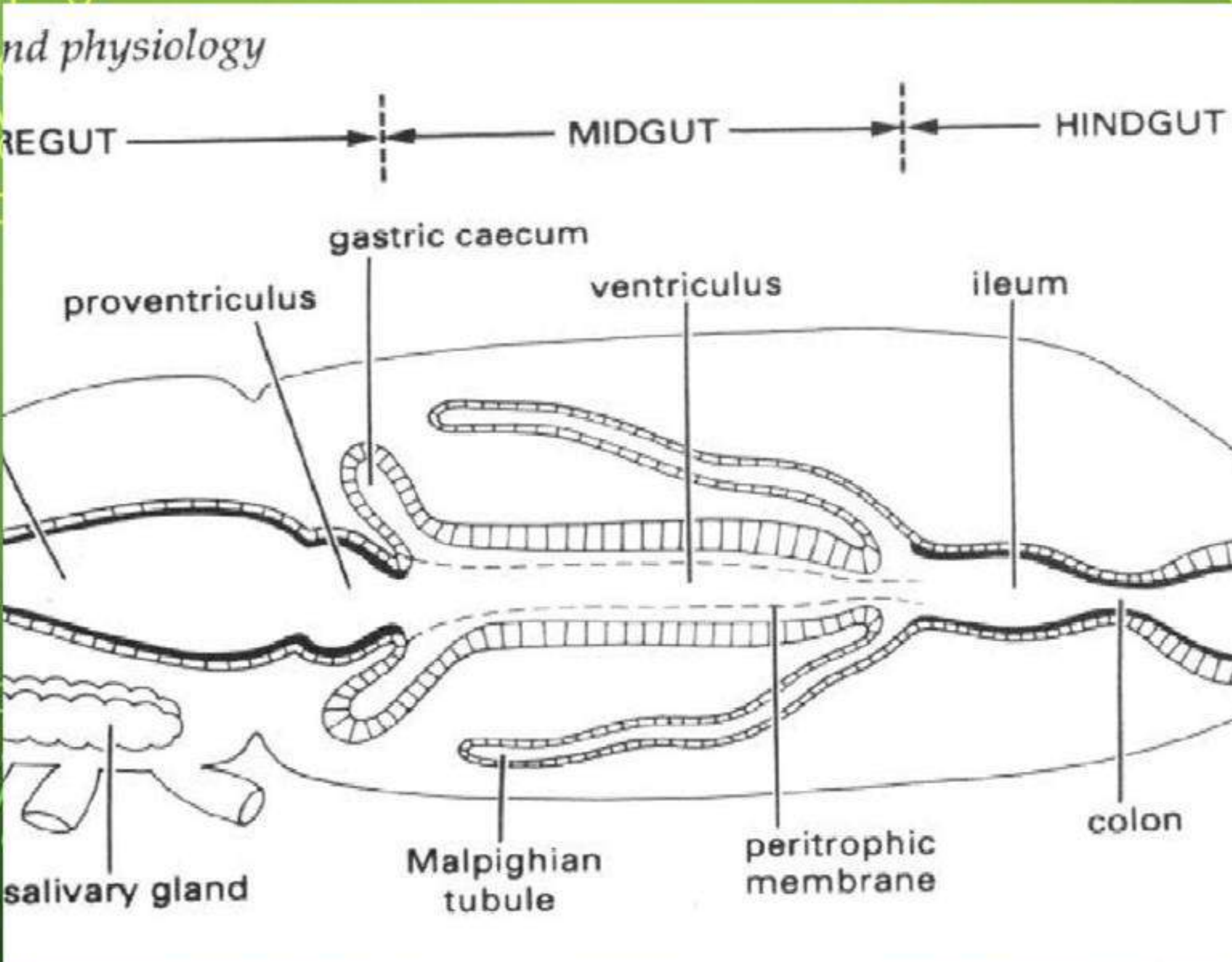
1)Teeth like – cockroach

2)Plate like- honey bees to separate pollen and nectar

3) Absent in blister beetle and caterpillar

Midgut

- It is **endodermal in origin**
- It has association with gastric caecae/enteric caecae/hepatic caecae anteriorly
- It is **the main site of digestion and absorption**
- It is also called as stomach or ventriculus


nd physiology
REGUT
MIDGUT
HINDGUT
gastric caecum
proventriculus
ventriculus
ileum
salivary gland
Malpighian tubule
peritrophic membrane
colon

- Midgut is made up of 3 types of epithelial cells

1)Secretary cells(columnar cells)

2)Goblet cells (aged secretary cells)

3)Regenerative cells

- Midgut is lined by **peritrophic membrane** and the membrane is absent in many fluid feeding insect
- **Gastric caecae** –are **finger like outgrowths found in anterior end of midgut which gives shelter for symbiotic bacteria**
- The number of gastric caecae varies in number

o 2 caecae- diptrean insect

o 8 in dictyoptera

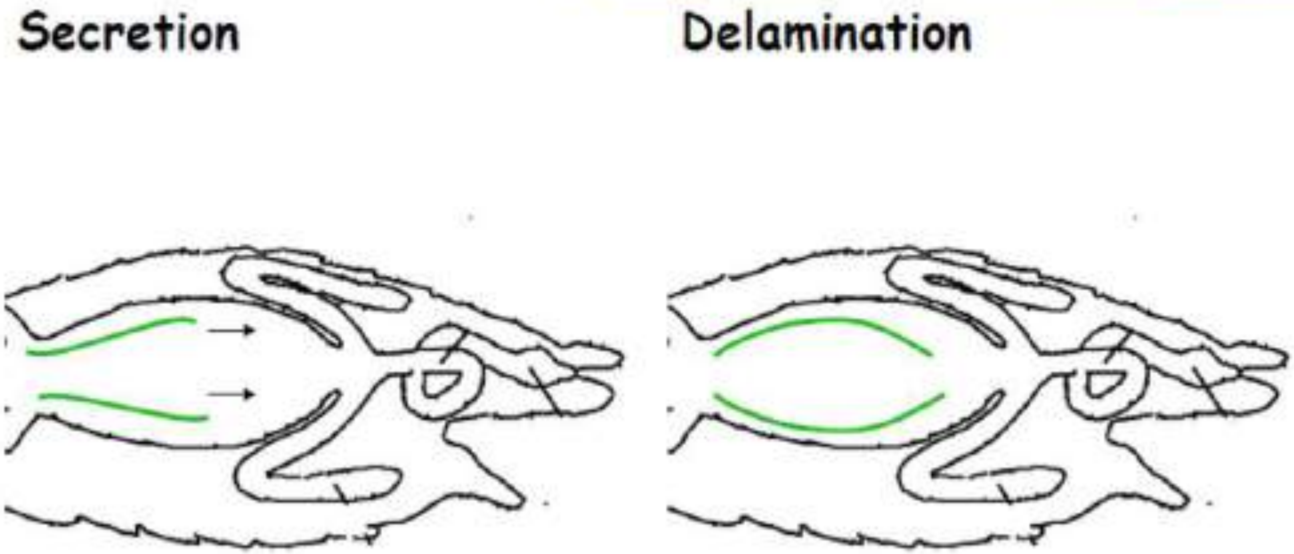
o Numerous – larvae af scarabidae

o Absent in- collembola, honey bee and lepidoptrean caterpillar

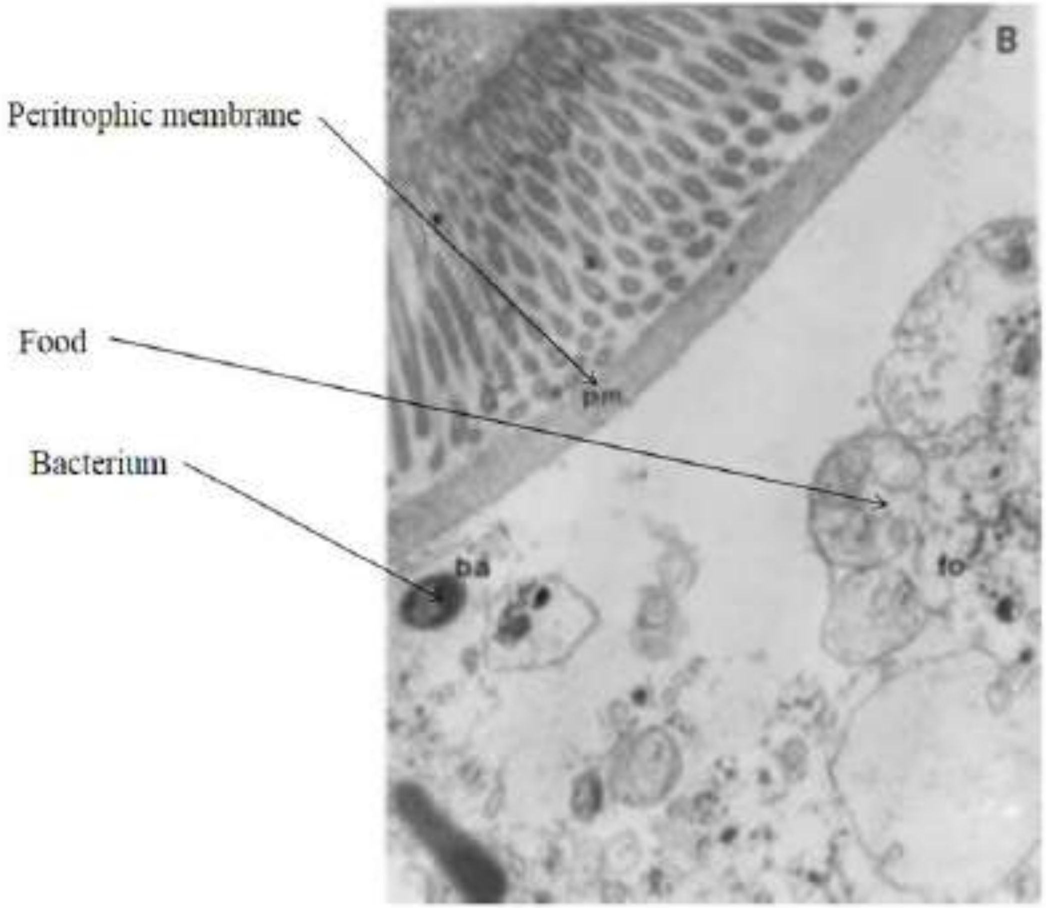
Peritrophic Membrane

- Secreted by microvillate columnar epithelial cells
- Made up of an amorphous sheet of polysaccharide, chitin, glycoprotein, and protein
- Tubular film that surrounds the bolus and within which considerable digestion occurs
- Numerous insect pathogens center activity on peritrophic membrane

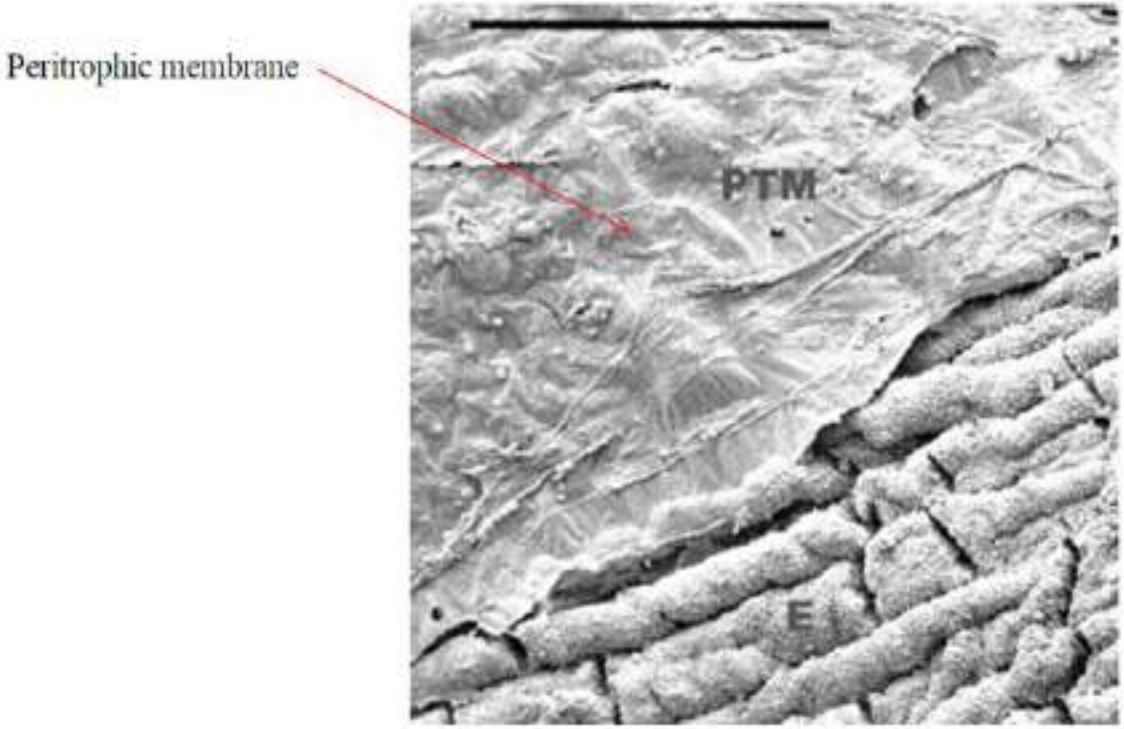
Peritrophic Membrane



Peritrophic membrane



Peritrophic membrane



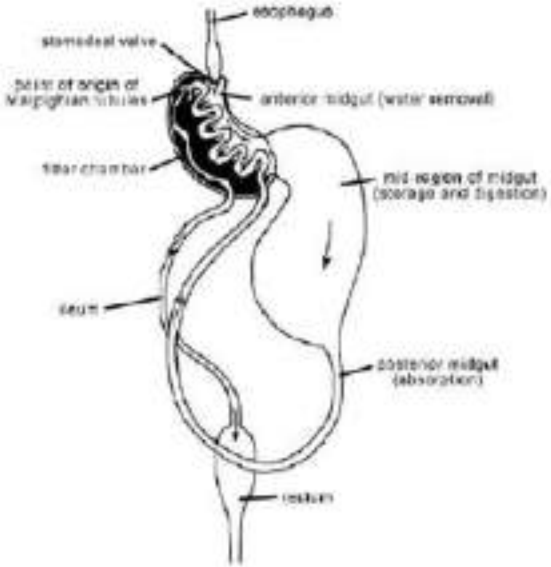
Filter chamber

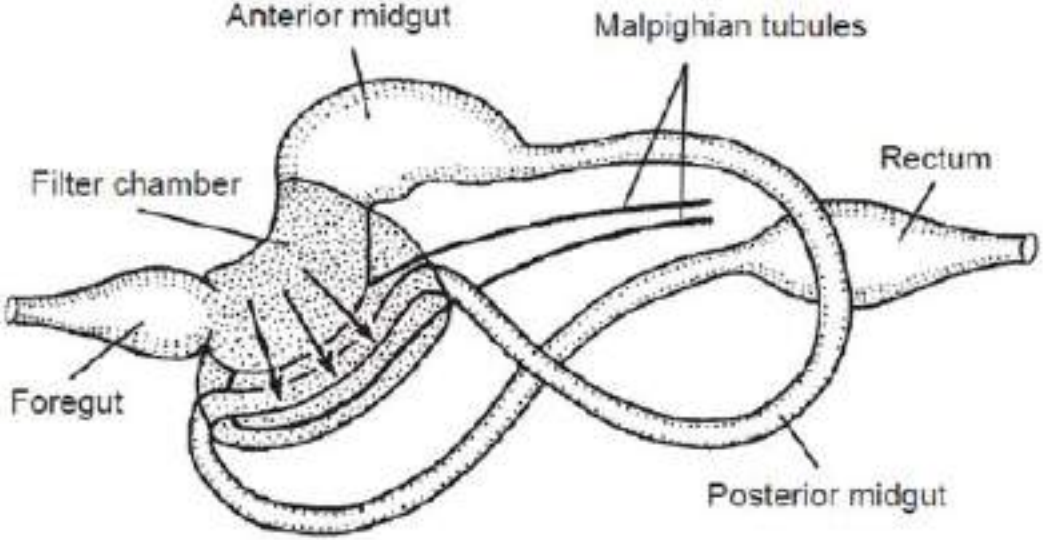
- It is a complex organ in which **two ends of ventriculus and beginning of hindgut are enclosed in a sac like structure.**
- This is useful **in liquid feeding insects and helps in osmoregulation by preventing dilution of haemolymph.**
- **<u>Hindgut</u>**
- It is **ectodermal in origin**
- In most of the insects 3 regions are recognised

1)**ileum-** pouch like structure for housing symbionts and acts as fermentation chamber in scarabids and termites

2)**Colon**

3)**Rectum** –contain rectal pads


esophagus
stomodeal valve
anterior midgut (water removal)
filter chamber
mid region of midgut
(storage and digestion)
posterior midgut
(absorption)
rectum


Anterior midgut
Malpighian tubules
Filter chamber
Rectum
Foregut
Posterior midgut

HINDGUT

1. Major refuse dumping area for waste products from midgut and Malpighian tubules

2. In insects that feed on dilute foods (i.e., low in amino acids), such as plant saps or blood, the hindgut is involved in getting rid of excessive water and also in housing symbionts that use these waste products to produce substances the insect needs.

3. Many insects have special adaptations of the hindgut region that aid in reabsorption of certain salts and amino acids.

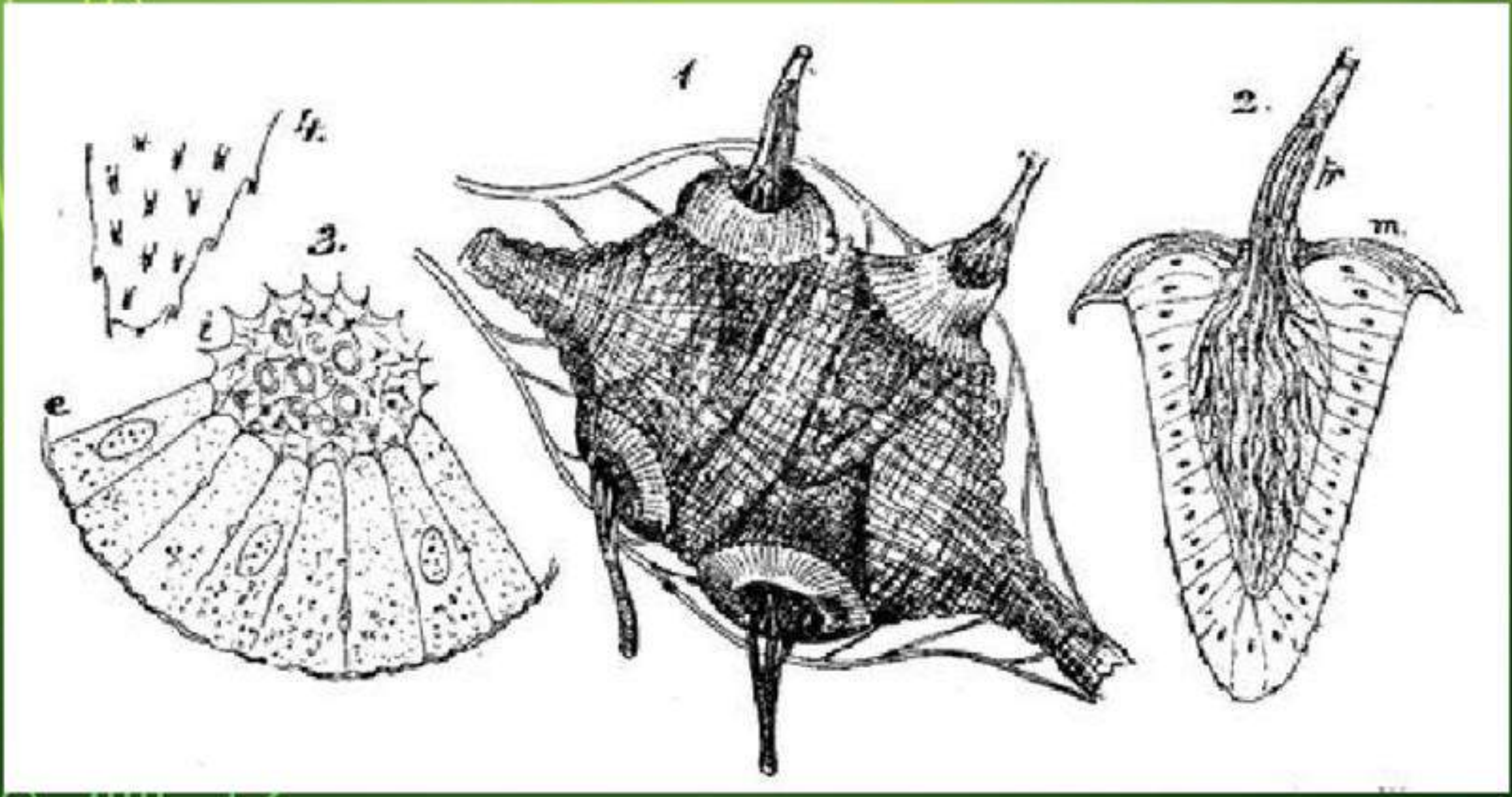
4.Water absorption from feces into the hemolymph

5. Pheromone production-Male scolytid beetles produce an aggregation pheromone.

6. Respiration in larvae of Anisoptera (Dragonflies)

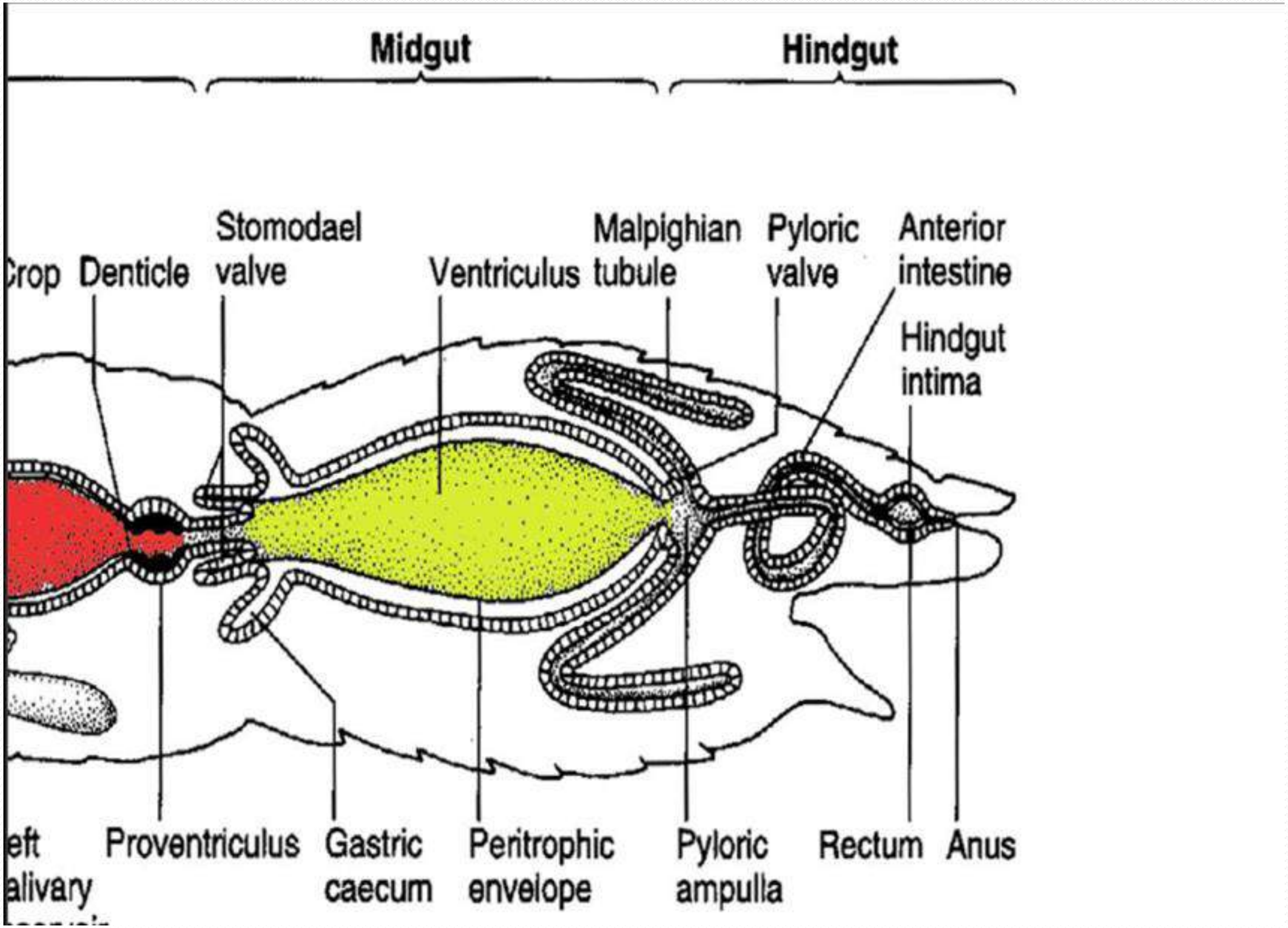
Rectal papillae of flies and rectum

The various types of papillae in the rectum of insects are involved in reabsorption of water and the movement of ions for osmoregulation



HINDGUT AND ITS SYMBIONTS

- Insects have relied upon and have taken up symbionts to either aid in digestion of molecules they can't digest (e.g., Cellulose) or provide the insect with essential nutrients, especially various vitamins, etc., that they would be unable to get from diets poor in these substances.
- 1. Termites and digestion of cellulose
- 2. Insects feeding on blood or on plant saps.



Midgut
Hindgut
rop
Denticle
Stomodael valve
Ventriculus
Malpighian tubule
Pyloric valve
Anterior intestine
Hindgut intima
eft
alivary
Proventriculus
Gastric caecum
Peritrophic envelope
Pyloric ampulla
Rectum
Anus

Gut physiology

- Primary functions of the gut is to digest the ingested food and to absorb the metabolites. Digestion process is enhanced with the help of enzymes produced by **digestive glands and microbes housed in special cells.**
- **Digestive glands**
- **A. Salivary glands**: In Cockroach a pair of labial glands acts as salivary gland where the salivary ducts open into salivarium. In caterpillars mandibular glands are modified to secrete saliva, where the salivary glands are modified for silk production in silk worm larva.
- **Functions of saliva:**

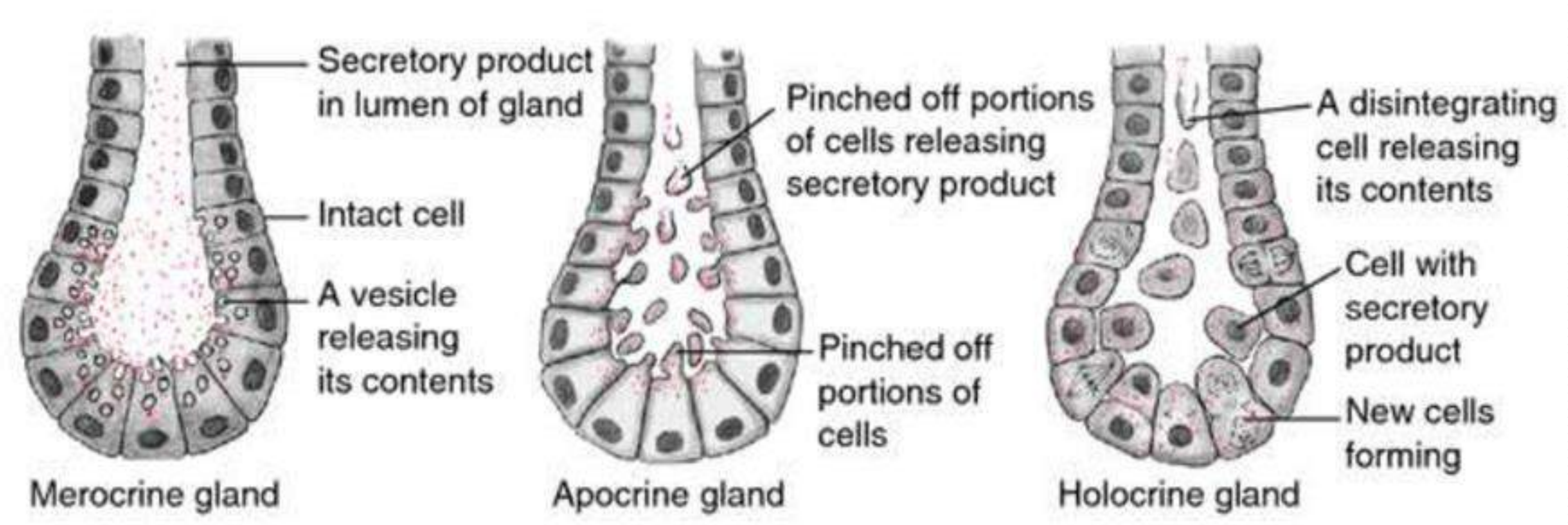
1. To moisten and to dissolve food
2. To lubricate mouthparts
3. To add flavour to gustatory receptors
4. In cockroach the saliva contains amylase for the digestion of starch.
5. In honey bee saliva contains invertase for sucrose digestion

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 mosquito, saliva contains anticoagulants which prevents blood clotting.

8. In disease transmitting vectors the saliva paves way for the entry of pathogens

- B. **Hepatic caecae and midgut epithelial cells**: It secretes most of the digestive juices. Two types of cells were involved in the enzyme secretion.
- **Holocrine** : Epithelial cells disintegrate in the process of enzyme secretion.
- **Merocrine** : Enzyme secretion occurs without cell break down.



Digestive enzymes

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

C. Microbes in digestion:

- In the insect body few cells were housing symbiotic microorganisms called as **mycetocyte**. These mycetocytes aggregate to form an organ called **mycetome.**
- Flagellate protozoa - It produces cellulase for cellulose digestion in termites and wood cockroach.
- Bacteria - It helps in wax digestion in wax moth.
- Bed bug and cockroach obtain vitamin and amino acids from microbes.
- These microbes were transmitted between individuals through food exchange **(mouth to mouth feeding)** called **trophallaxis** and through **egg** called as **transovarial transmission**.

Absorption

- 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, absorption 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.

Essential Nutrients for Insects

Water

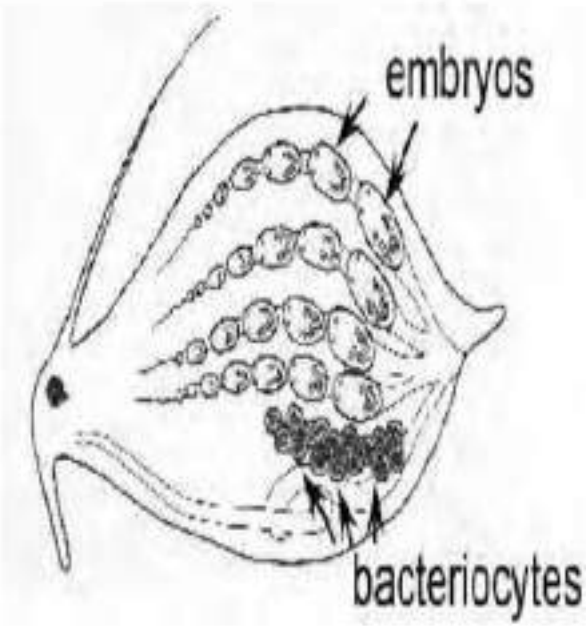
This is the ultimate challenge for many terrestrial insects

- ❑ Drinking or moisture in food
- ❑ Oxidative metabolism
- ❑ Absorption of water vapor

Carbohydrates

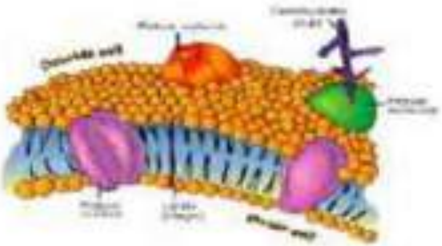
- Oxidation of carbohydrates, fats, organic acids and suitable amino acids provide energy
- Requirements can be quite high; certain insect flight muscles convert more energy per unit weight than any other animal tissue
- Varies in different insects

Essential Amino Acids



- Insects need at least the same 10 amino acids in their diet
- Predators have little problem with this
- Phytophagous insects, particularly sap-suckers have problems of amino acids

Essential Lipids



Insects are unable to synthesize polyunsaturated fatty acids; Involved in formation of phospholipids of cell membranes

Unlike in mammals, sterols are required for many hormones; they are derived from cholesterols (animal food) or β-sitosterol (plant food)

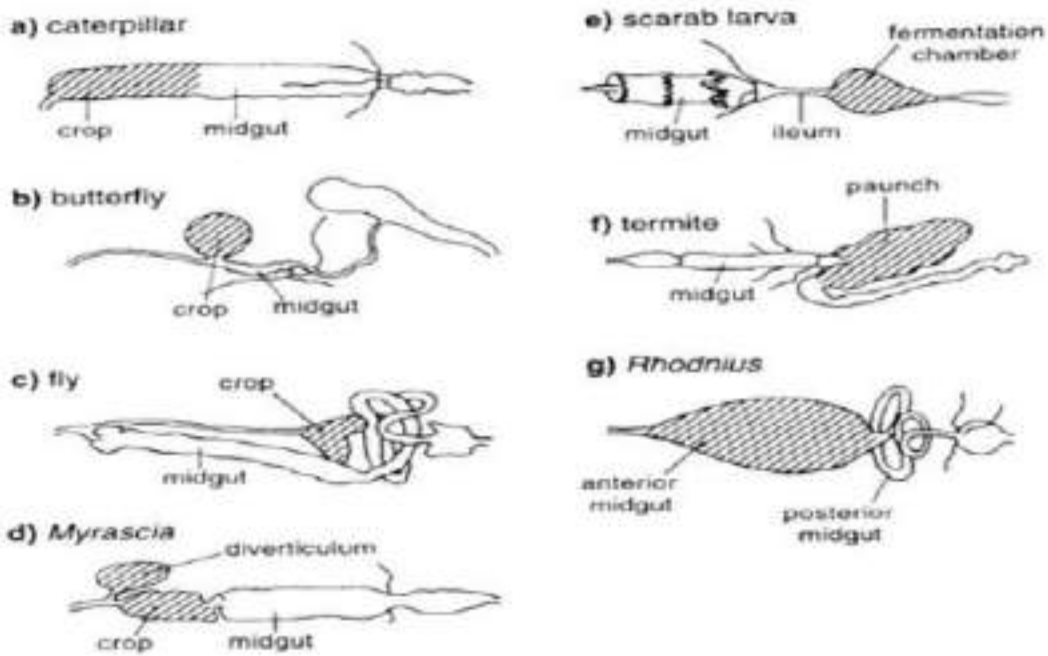
Growth factors (Vitamins)

- Vitamin Bs particularly are important
- Vertebrate blood is particularly low in these

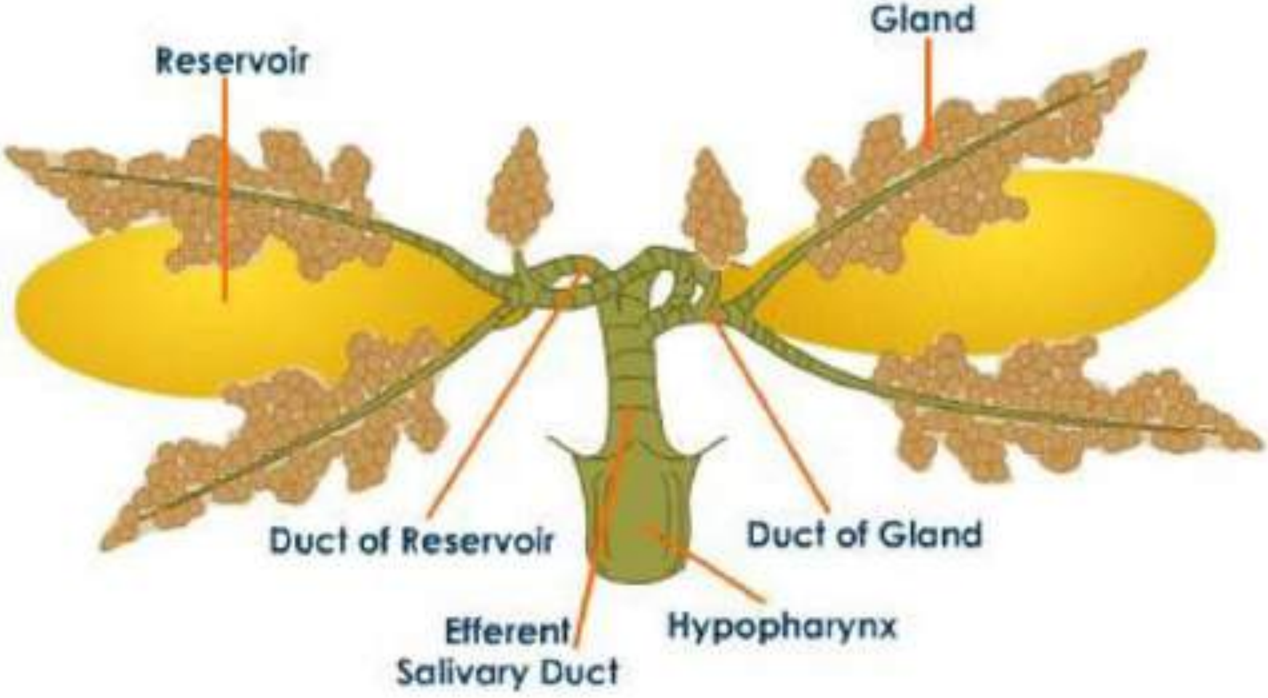
Minerals

Requirements essentially the same across animal kingdom

Modifications of the Gut



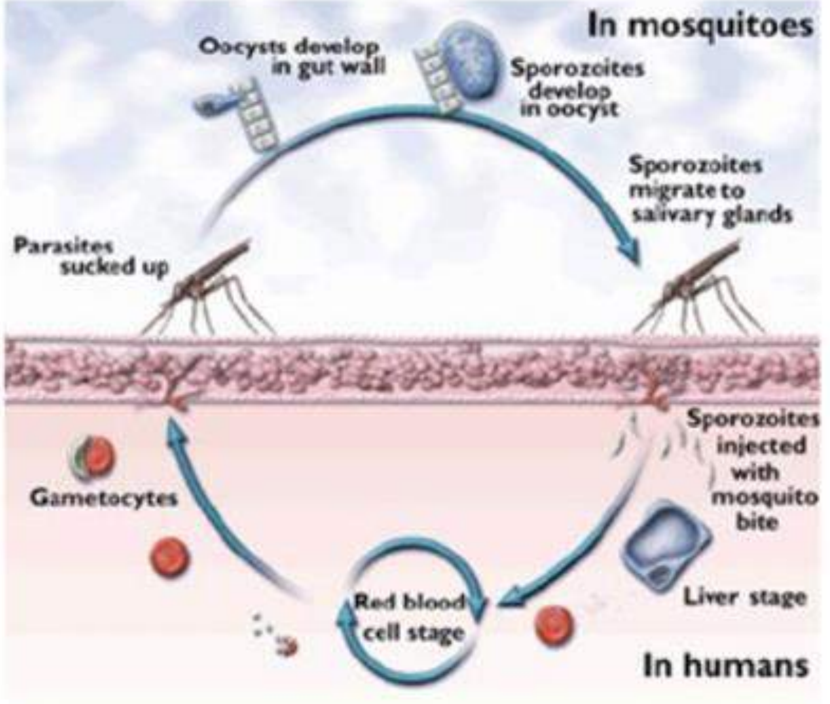
Salivary Glands



Functions of Salivary Glands

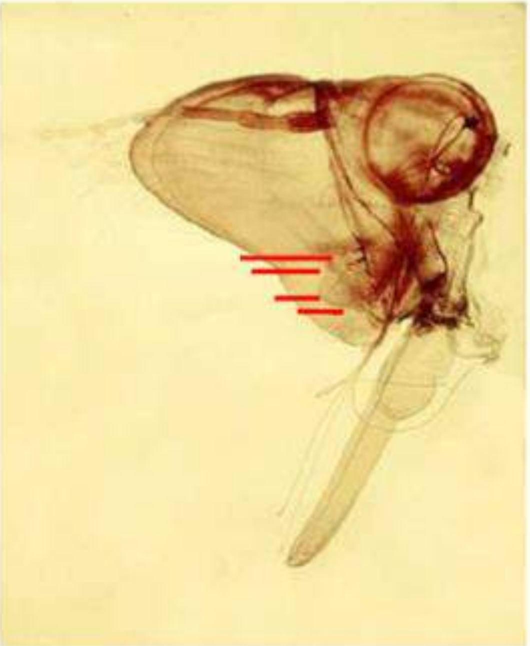
1. Moisten food
2. Lubricate mouthparts
3. Contains digestive enzymes
    3a. Amylase – complex sugars to simple sugars
    3b. Salivary enzymes for preoral digestion
4. Non-digestive functions
    4a. Toxins of predators that affect CNS of prey
    4b. Counter toxins of plant allelochemicals
    4c. Anti-coagulants
    4d. Silk production

Salivary glands are involved in disease transmission

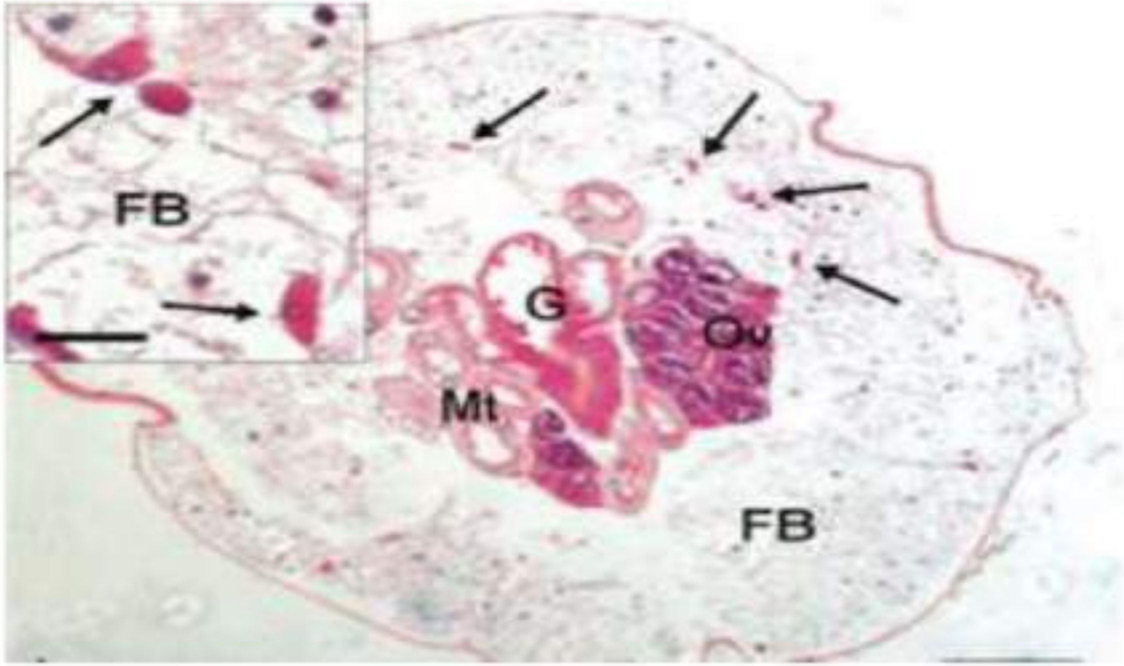


Location of Salivary Glands

Cicada (Homoptera)



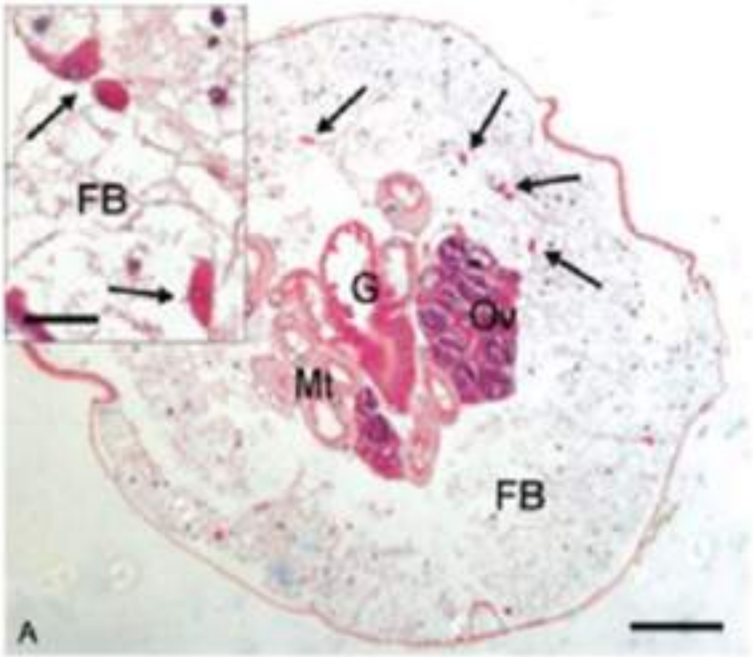
Cross section of a mosquito showing the Fat body (FB)



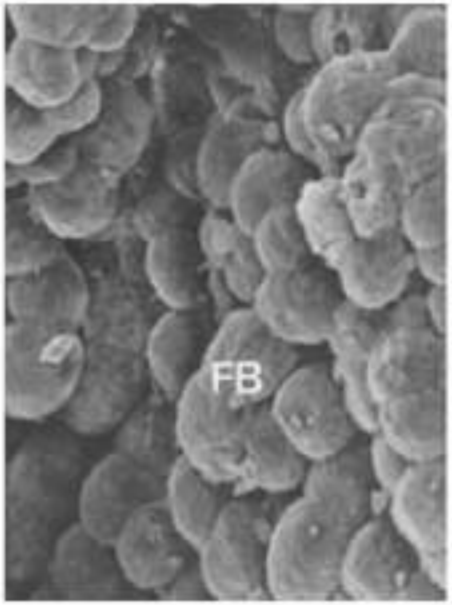
Functions of the Fat Body

- metabolism of carbohydrates, lipids and nitrogenous compounds
- storage of glycogen, fat and protein
- regulation of blood sugar
- synthesis of major hemolymph (blood) proteins (haemoglobins, vitellogenins, storage proteins)

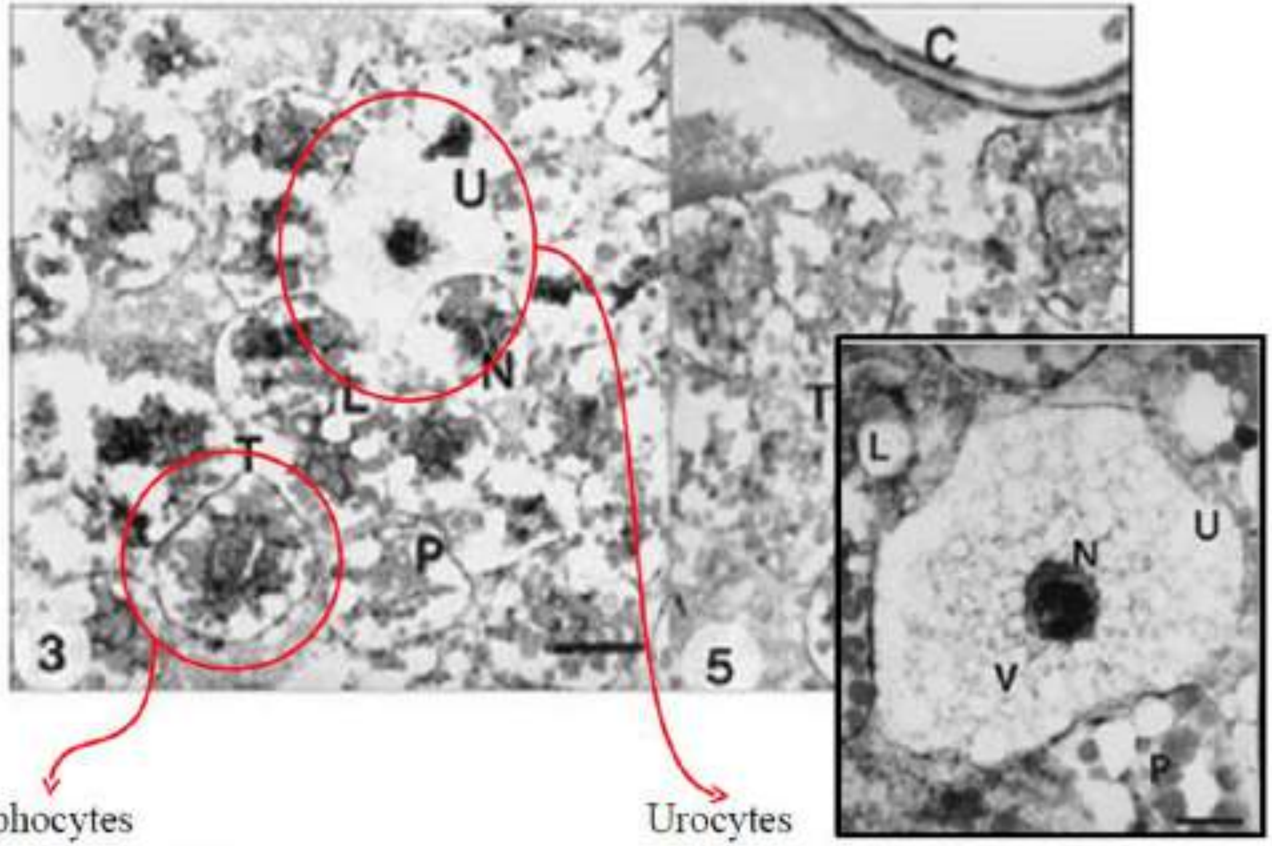
Fat Body



Cross section of mosquito abdomen (FB = fat body)



Fat Body – cell types



Trophocytes
-carry out most of
functions of fat body

Urocytes
- storage of urates/uric acid

STRUCTURE AND FUNCTION OF INSECT RESPIRATION SYSTEM

RESPIRATION

- A process of interchange of gases between environment and the blood or cellular tissues of organisms.
- .Respiratory system is ectodermal origin.

GENERAL VS. INSECT RESPIRATION

GENERAL RESPIRATION

- A process in living organisms involving the production of energy, typically with the intake of oxygen and the release of carbon dioxide from the oxidation of complex organic substances.

INSECT RESPIRATION

- It is a complex network of tubes (called a tracheal system) that delivers oxygen-containing air to every cell of the body. Air enters the insect's body through valve-like openings in the exoskeleton.

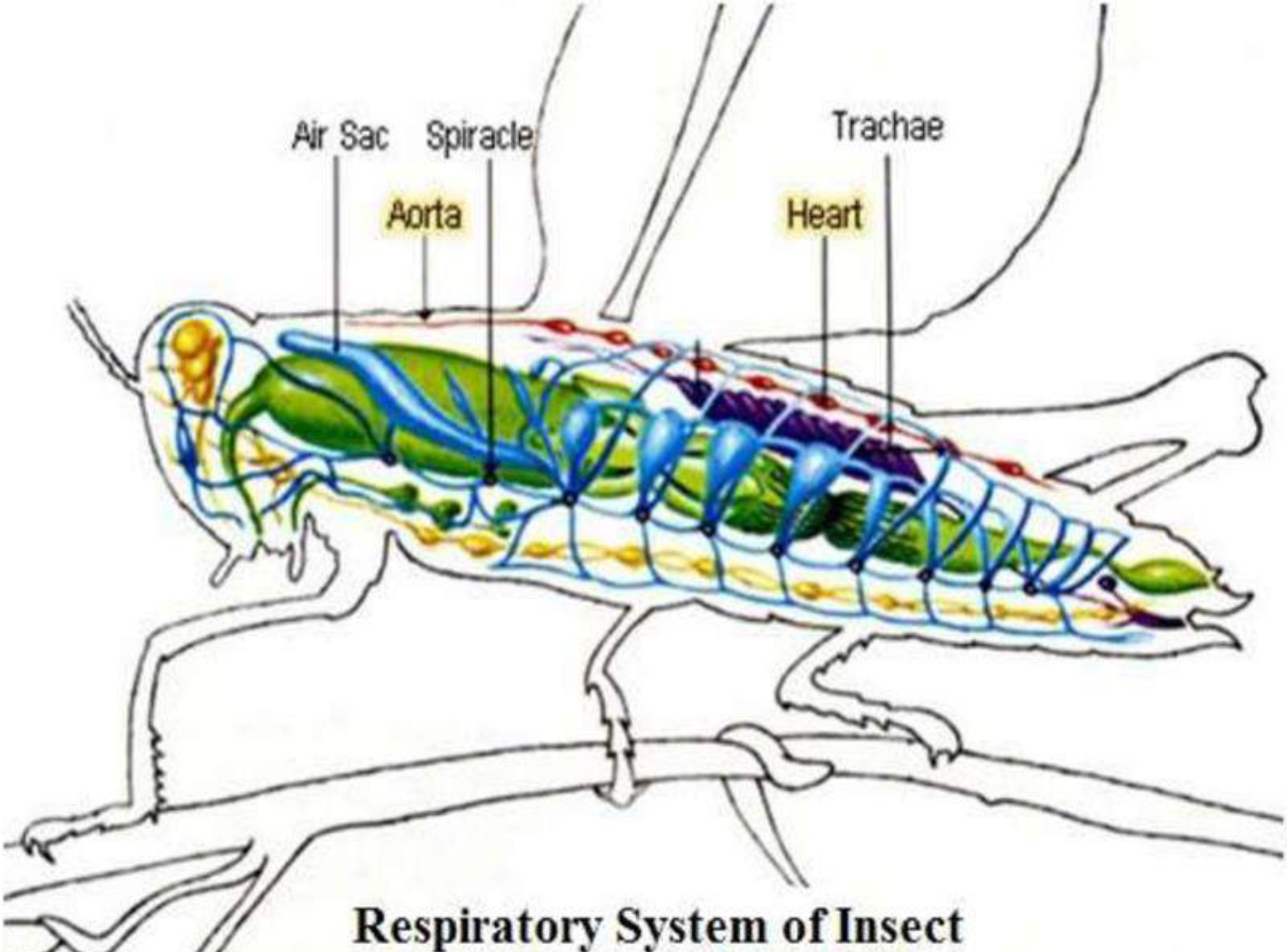
Respiratory systems

- Allow oxygen to body for cellular respiration
- Remove carbon dioxide from cells
- Respiratory systems of insect are developed from ectoderm.

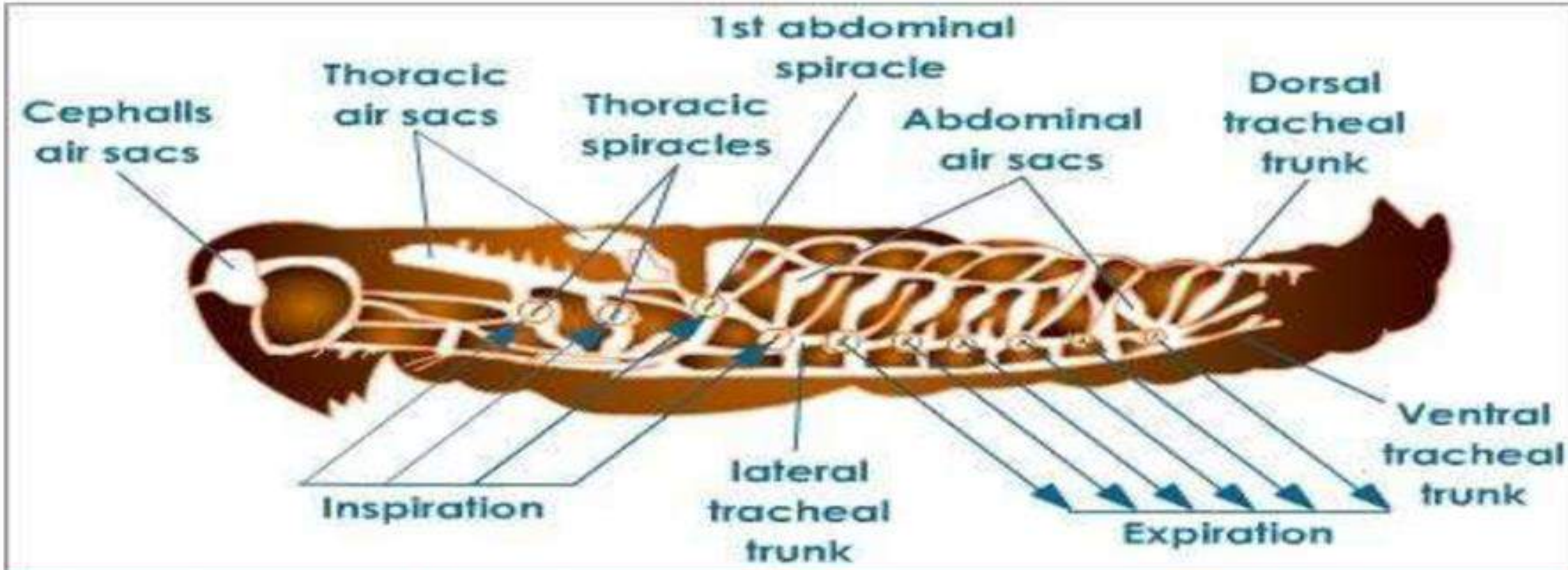
✓All insects are aerobic organisms

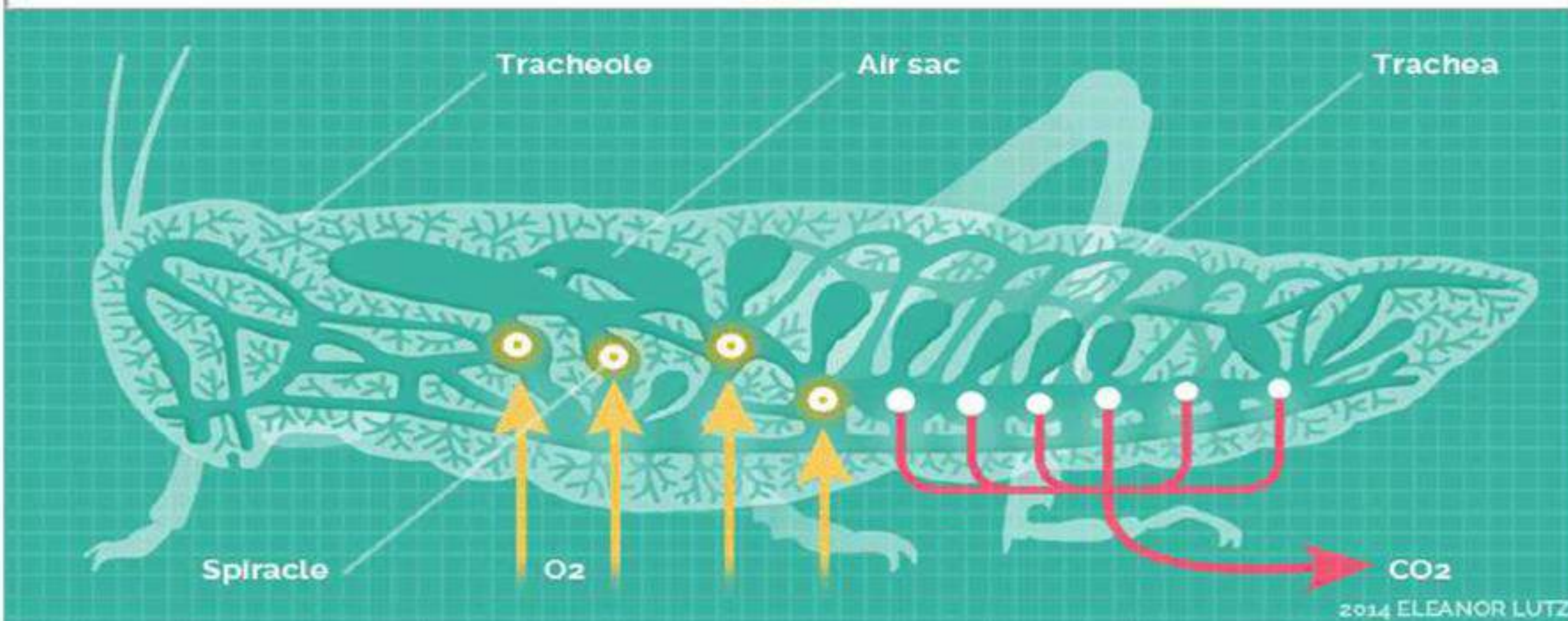
✓They get oxygen directly from environment

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2 + \text{energy}$$



Respiratory System of Insect

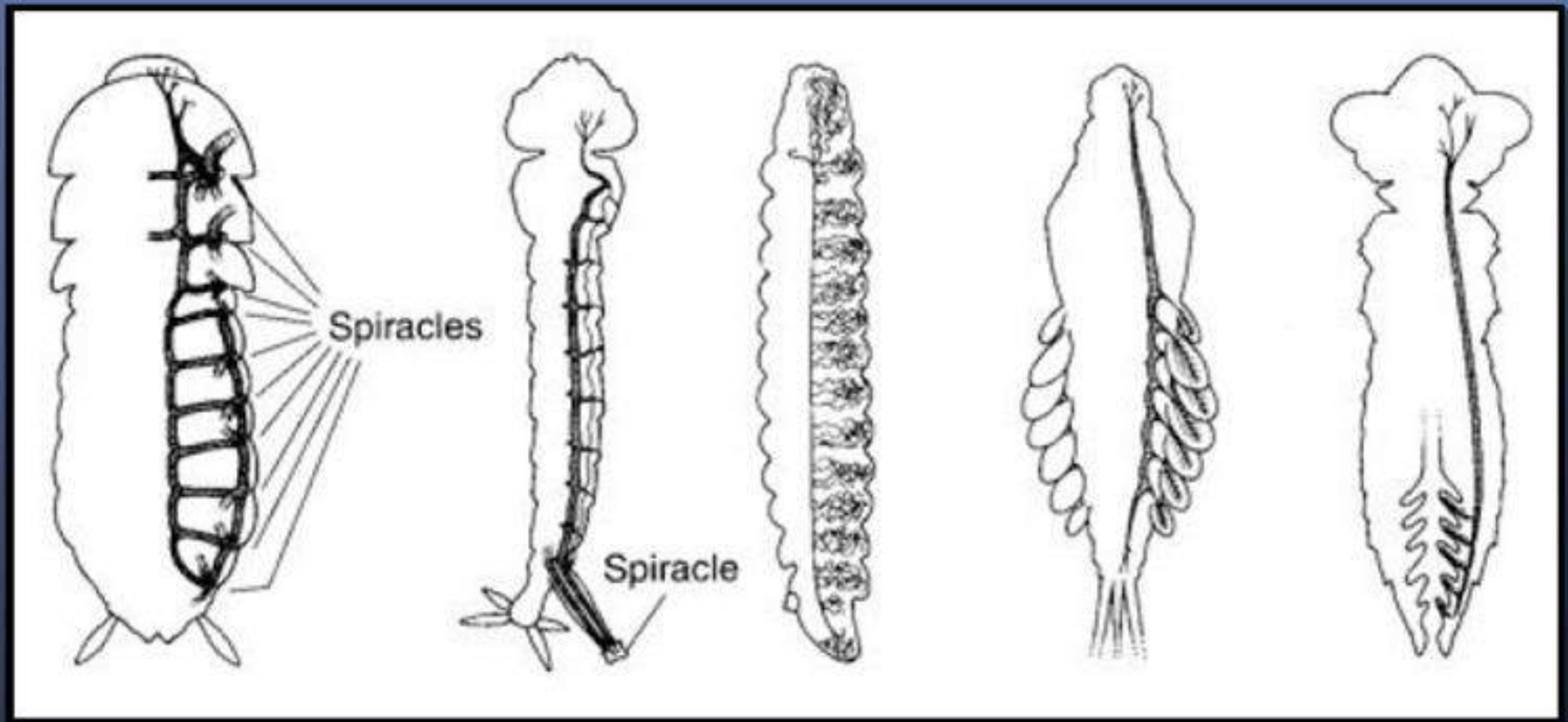

1st abdominal spiracle
Thoracic air sacs
Cephalis air sacs
Thoracic spiracles
Abdominal air sacs
Dorsal tracheal trunk
Ventral tracheal trunk
Inspiration
lateral tracheal trunk
Expiration


Tracheole
Air sac
Trachea
Spiracle
O2
CO2
2014 ELEANOR LUTZ

TYPES OF RESPIRATORY SYSTEM

✓ Keilin (1944) classified respiratory system of insects on the basis of the number and distribution of the functional spiracles are :

1. Holopneustic: All functional (2 thorax & 8 abdomen). E.g. Grasshopper
2. Hemipneustic: 1 or 2 non-functional. E.g. larvae
3. Peripneustic: 9 functional – (1 in thorax & 8 in abdomen). E.g. Caterpillar
4. Amphipneustic: 2 functional - (1 Anterior &1 Posterior abdomen). E.g. maggot.
5. Propneustic: 1 functional – (Prothorasic) . E.g. Puparium
6. Metapneustic: 1 functional – (last abdominal) . E.g. Wriggler
7. Hypopneustic: 7 functional (1 thorax & 6 abdominal) .E.g. head louse
8. Apneustic: All spiracles closed. E.g. Aquatic and Endoparasite.
9. Hyperpneustic: Presence of more than the normal spiracles. E.g.Japygidae.
10. In collembola in smithurids one pair of spiracles present between head and thorax



Holopneustic **Metapneustic** **Apneustic**

Cockroach *Mosquito larvae* | *Mosquito larvae* *May fly larvae* *Dragon fly*

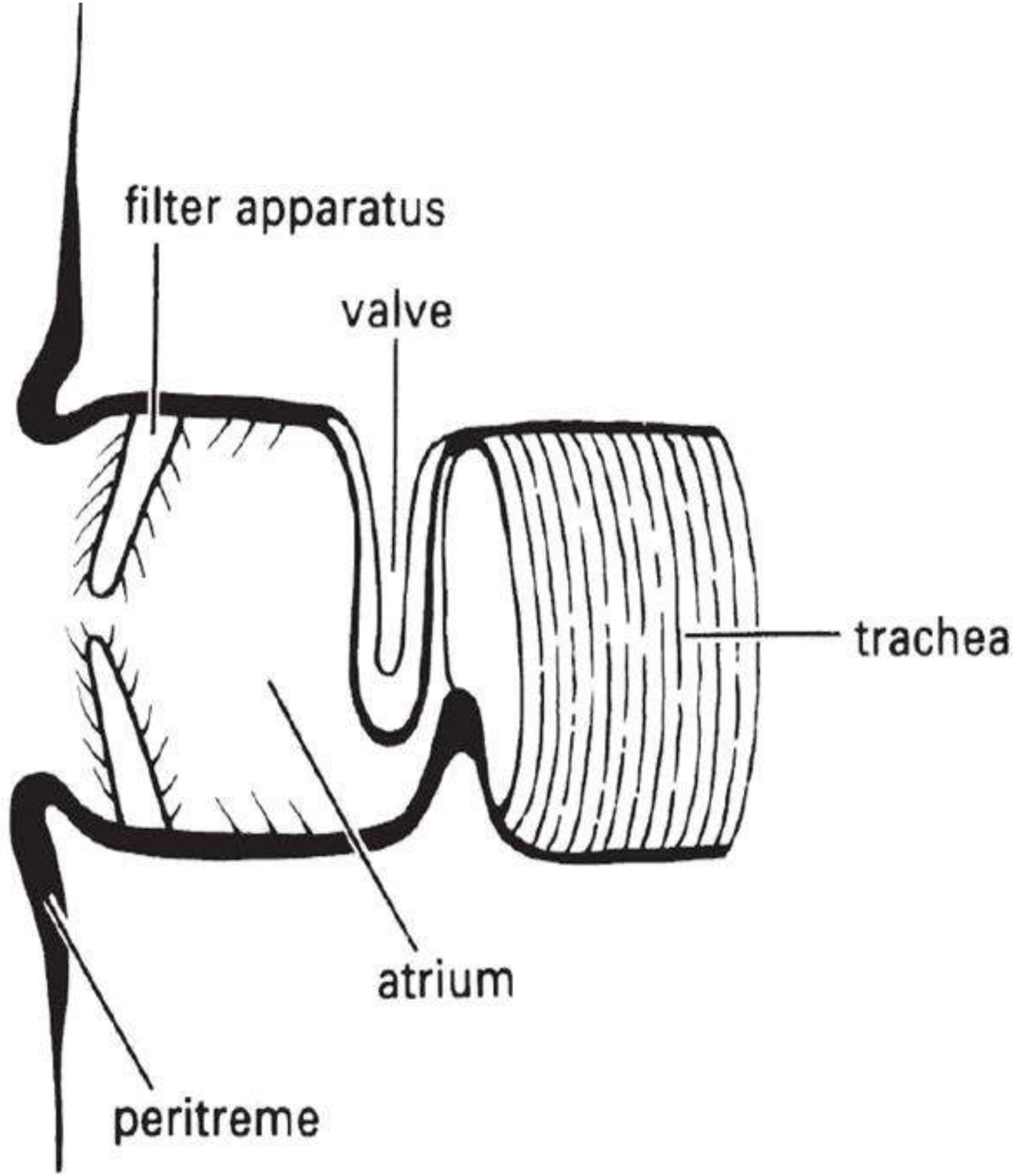
OPEN **CLOSED**

COMPONENTS OF RESPIRATORY SYSTEM

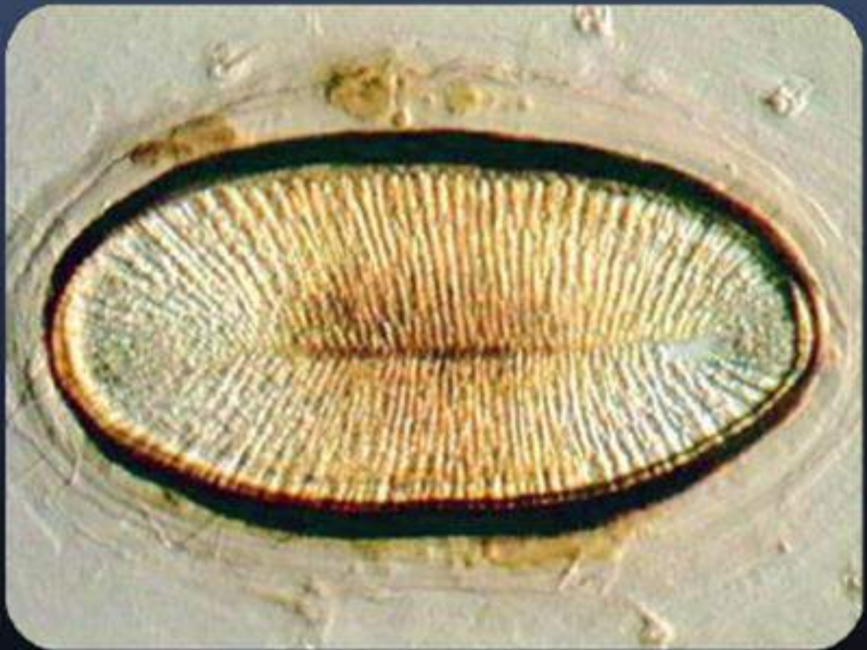
- Spiracle
- Tracheae
- Tracheoles
- Tracheaoblast
- Air sacs

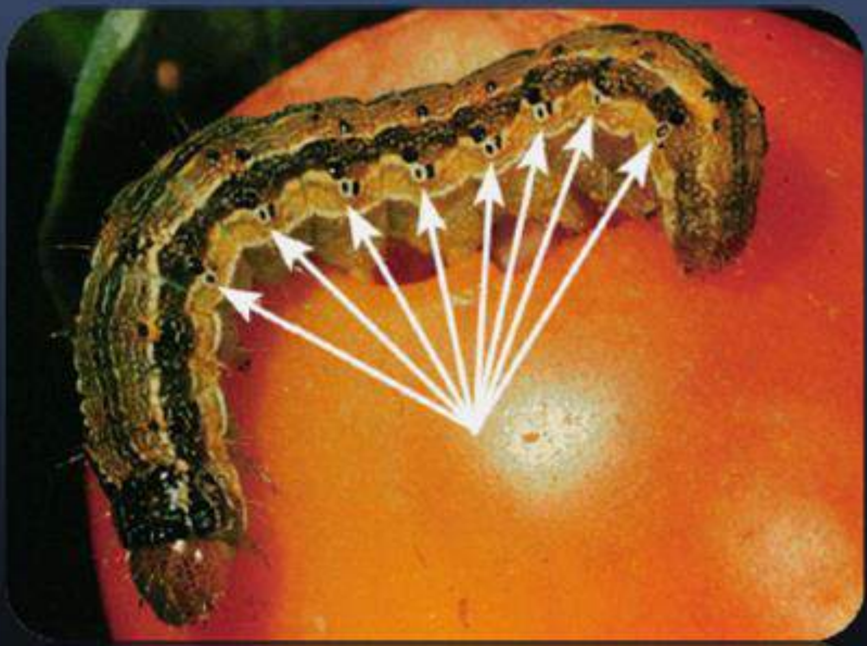
SPIRACLE

- ✓ It is the external opening through which air enters into the trachea.
- ✓ Insects have about ten pairs of openings, called spiracles, in their exoskeletons.
- ✓ It has a chamber or atrium with a opening and closing mechanism called Atrial valve.
- ✓ spiracle is surrounded by a Sclerite called Peritreme.
- ✓ Closing and opening of spiracle is regulated by atrial valve.
- ✓ In dipterans coleopterans ,lepidopterans,spiracles consists of sieve plate.
- ✓ Peristgmatic glands present around the spiracle that prevents the wetting of organs.

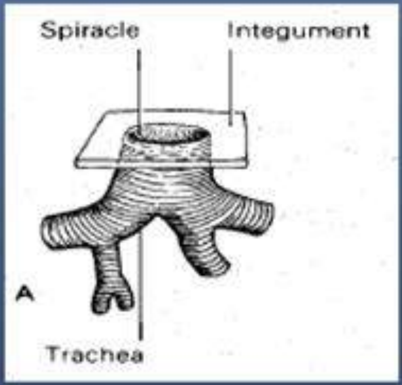

filter apparatus
valve
trachea
atrium
peritreme

SPIRACLE



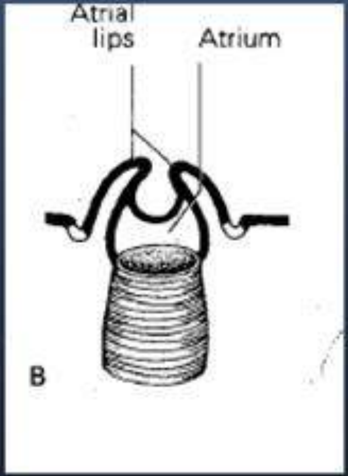


TYPES OF SPIRACLES



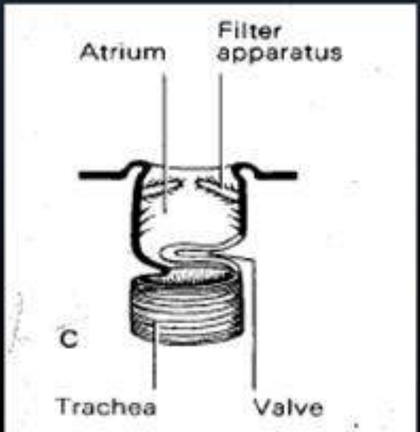
Simple or non- Atriate:

- ✓ An opening with no lip closure or filter chamber.



Atriate with lip closure:

- ✓ Slit like apparatus with two movable valves/lips.

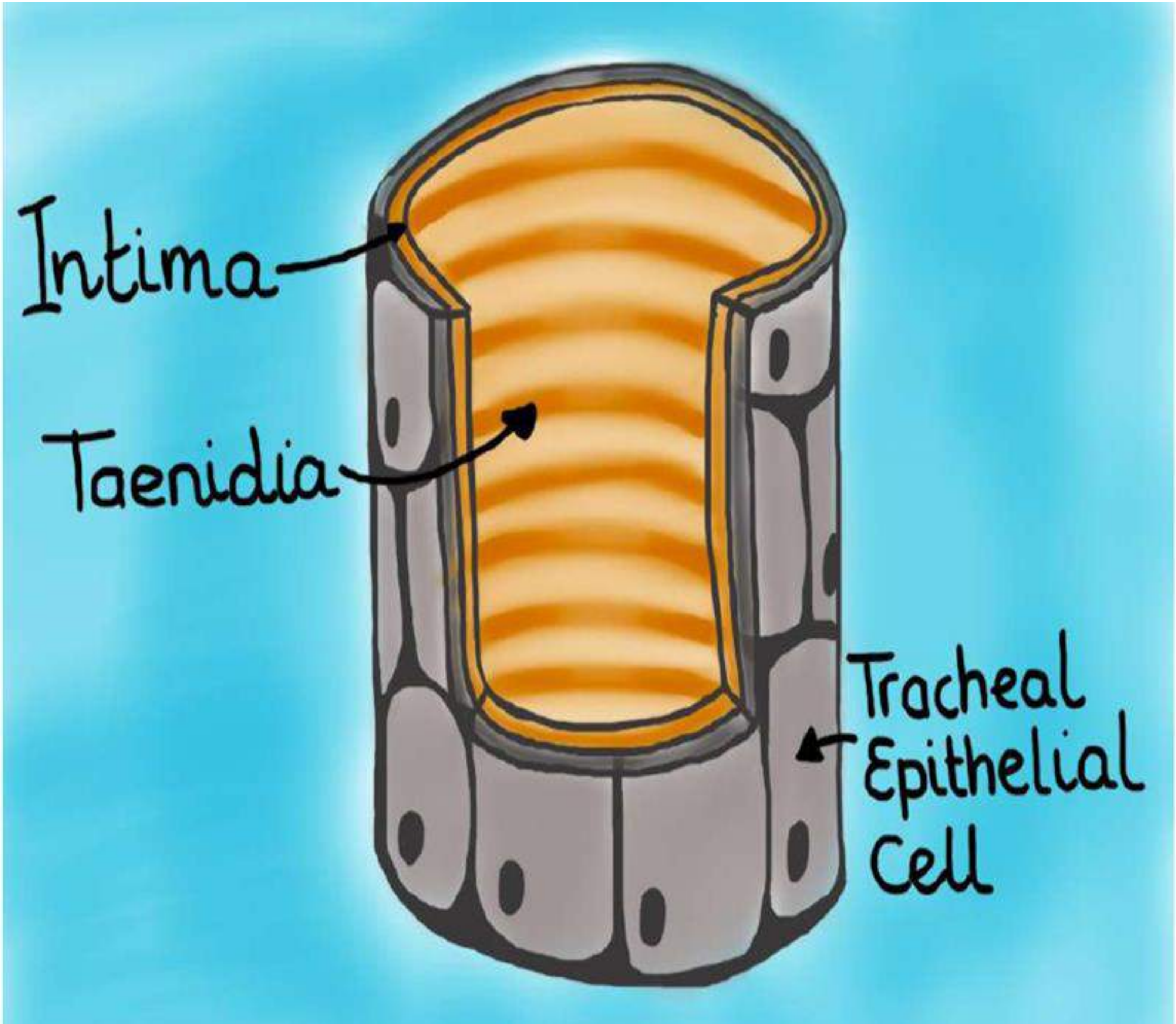


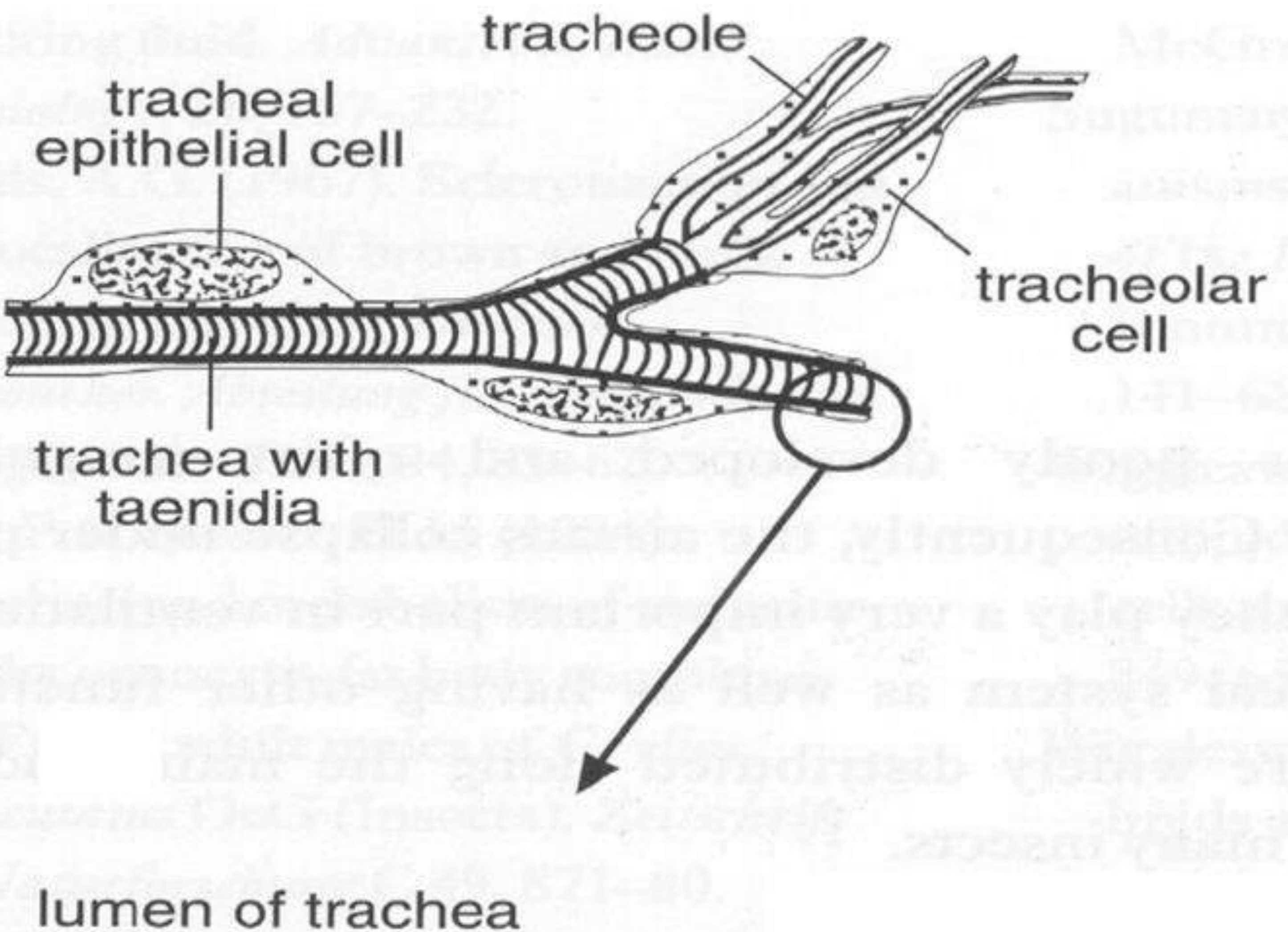
Atriate with filter-apparatus:

- ✓ Atrium is lined with tiny hairs.

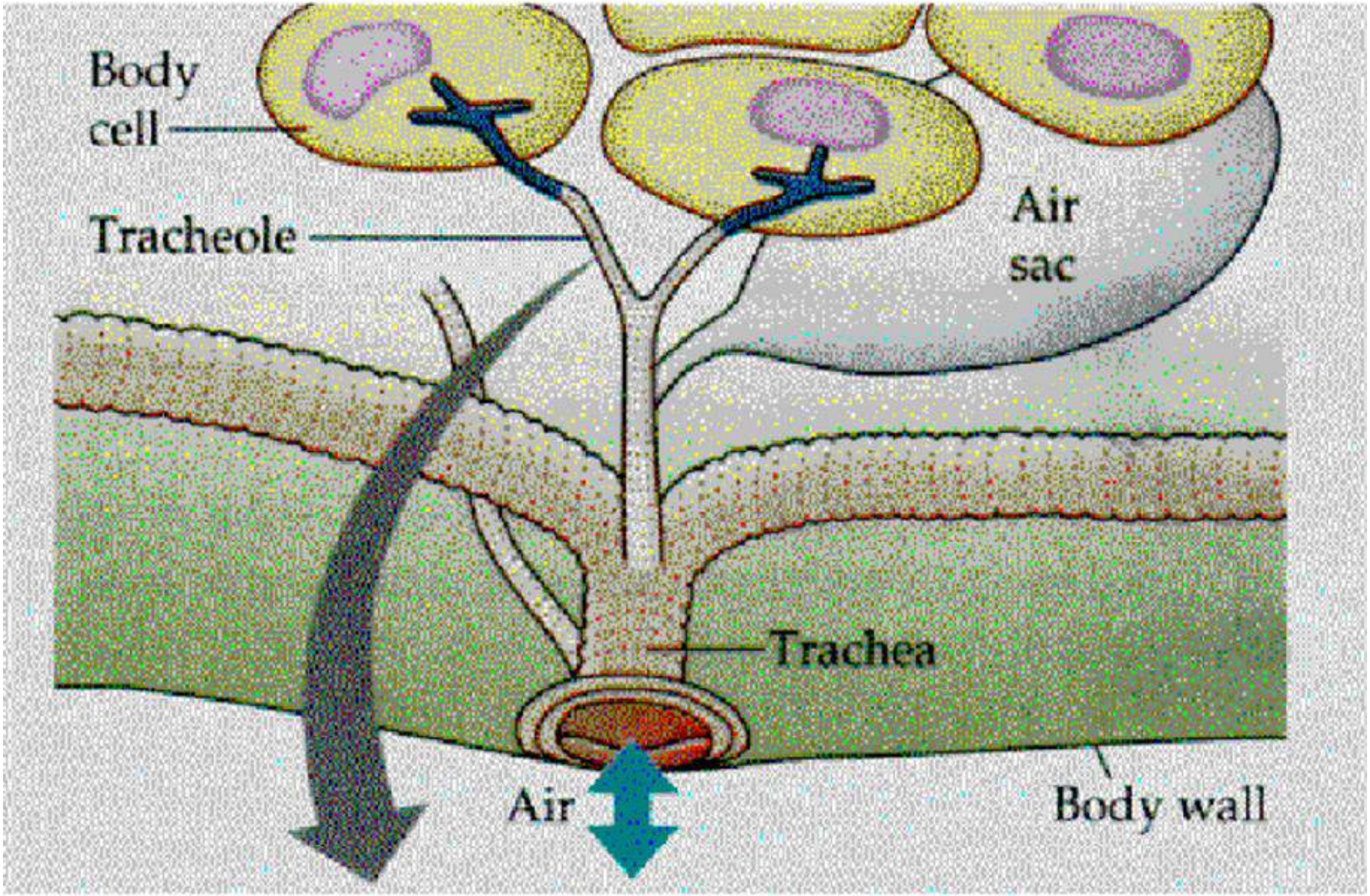
TRACHEA

- The tracheae are the larger tubes of the tracheal system.
- Ectodermal in origin.
- Consist of epithelial cells (ectotrachea) and cuticular lining called **INTIMA.**
- Helical folds of cuticular lining – **TAENIDIA.**


Intima
Taenidia
Tracheal Epithelial Cell


tracheole
tracheal
epithelial cell
tracheolar
cell
trachea with
taenidia
lumen of trachea

Tracheoles supply tissues



TRACHEOLES

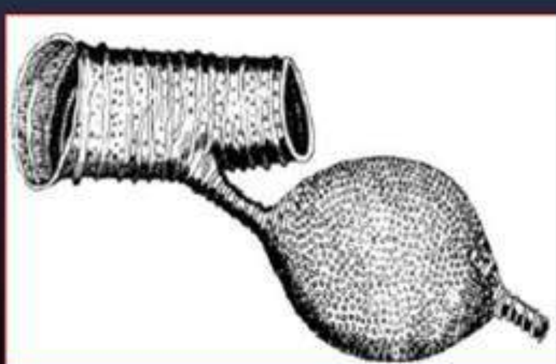
- It is less than 1 μm in diameter and they end blindly and closely contact the respiring tissues.
- Gaseous exchange occurs across tracheoles.

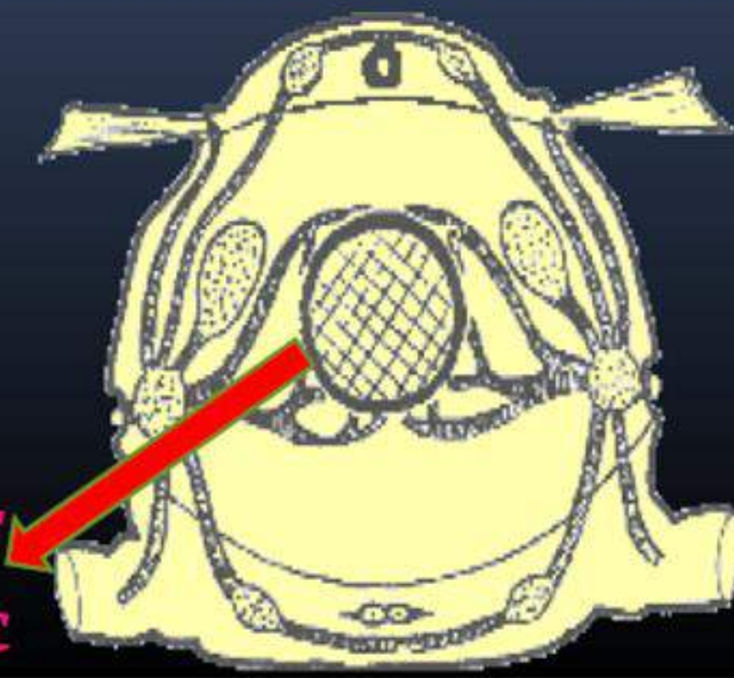
TRACHEOBLAST

- The branches of tracheae end in polygonal cells.
- consist of Plasma lemma, Cytoplasm, Nucleolus.

AIRSACS

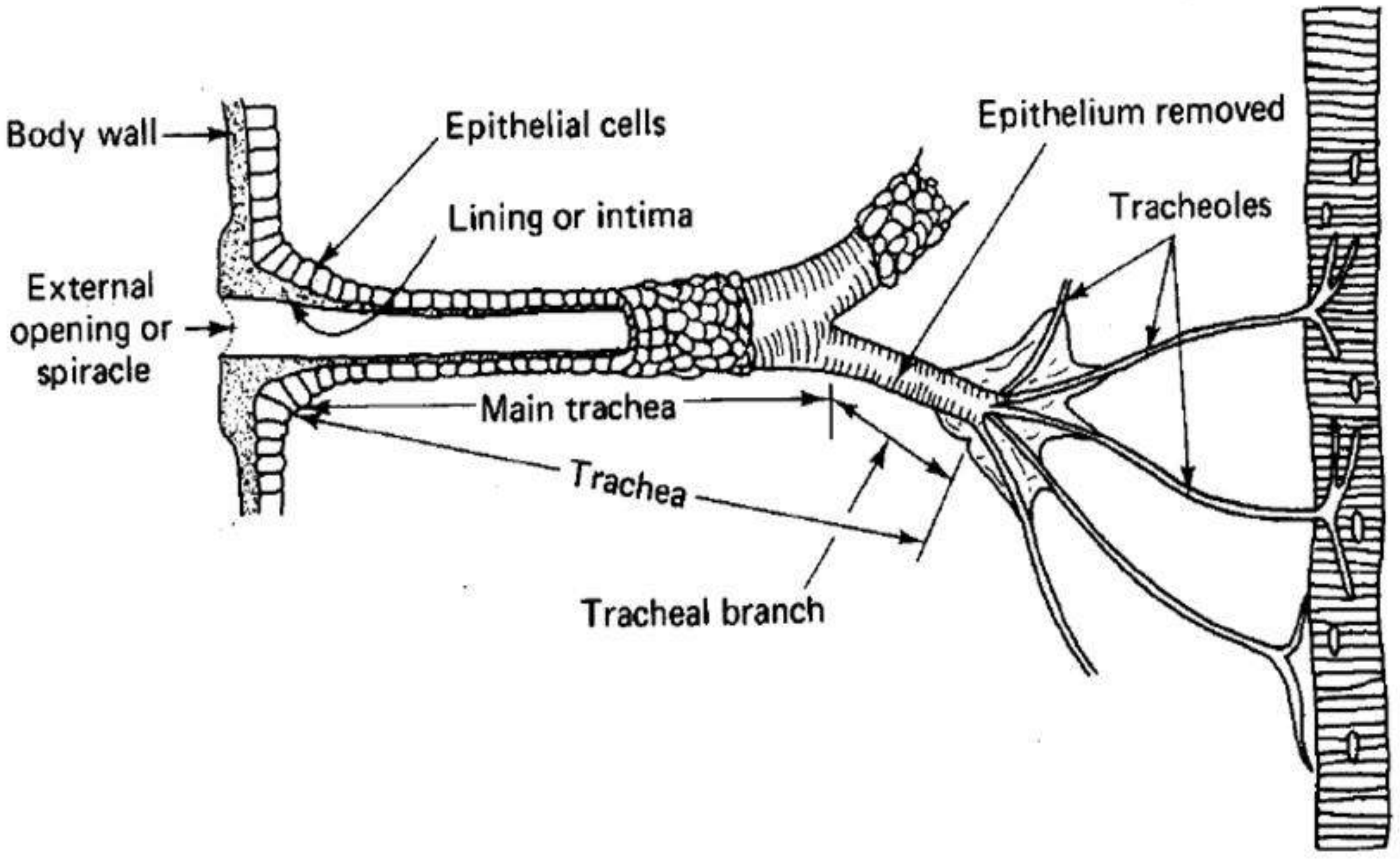
- Balloon-like structures acts as oxygen reservoir.
- Provide buoyancy to flying in aquatic insects.
- In dry terrestrial environments, this temporary air sacs allows an insect to conserve water by closing its spiracles during periods of high evaporative stress.





Air sac

TRACHEAL SYSTEM OF RESPIRATION



MECHANISM OF RESPIRATION

- There are thus two distinct phases in the

  transport of gases.

  - one through the tracheal system known as air-tube transport.
  - one through the tissues in solution in the cytoplasm, known as tissue diffusion.

DIFFUSION

- ✓ Net movement of atoms or molecules from high concentration to low concentration is known as diffusion.
- ✓ Rate of diffusion inversely proportional to the square root of the molecular weight of the gas, so that in air, oxygen, with a molecular weight of 32, diffuses 1.2 times faster than carbon dioxide, with a molecular weight of 44

- As carbon dioxide is less soluble, it is present in much higher concentrations in the blood and tissues than oxygen, generally in the form of bicarbonate.
- Carbonic anhydrase is required to quickly convert bicarbonate to carbon dioxide, this enzyme is reported to occur in the tissues but not the blood.

CONVECTION

- Convection is the bulk flow of fluid, driven by a pressure gradient.
- diffusion can suffice for gas exchange of many insects, why is convection so common?
- Theoretical studies have demonstrated that use of convection rather than diffusion can decrease water loss rates, even in small insects.
- Insects produce compression of the air sacs and tracheae in multiple ways. The best understood is abdominal pumping.

- ✓ Abdominal compression leads to a reduction of body volume and a rise in hemolymph pressure that causes expiration.
- ✓ Expansion of the air sacs and inspiration result from the reduction of pressure due to the muscular or elastic expansion of the abdomen.
- ✓ Changes in abdominal volume may be produced in various ways.
- Heteroptera and Coleoptera, the tergum moves up and down.
- Odonata, Orthoptera, Hymenoptera
- and Diptera, both tergum and sternum move

VARIATION IN GAS EXCHANGE

- ✓ Higher metabolic rates demand higher levels of oxygen intake. This is most obvious in flight, when metabolic rates can rise 5–30 fold.

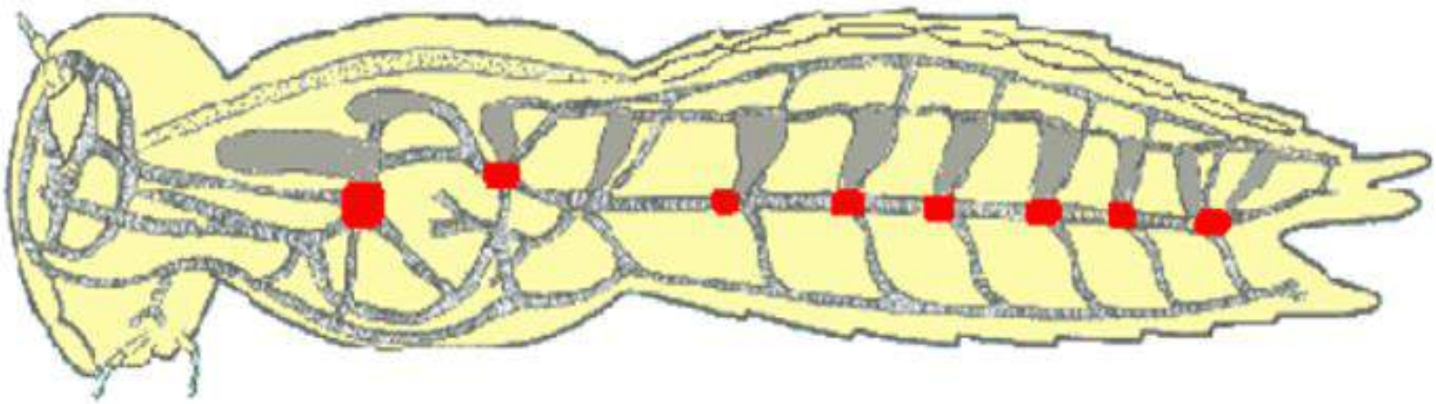
GAS EXCHANGE IN FLIGHT:

- ✓ The massive increase in oxygen consumption that occurs when an insect flies requires a greatly increased airflow through the tracheae to the flight muscle.

FUNCTIONS OF THE RESPIRATORY SYSTEM

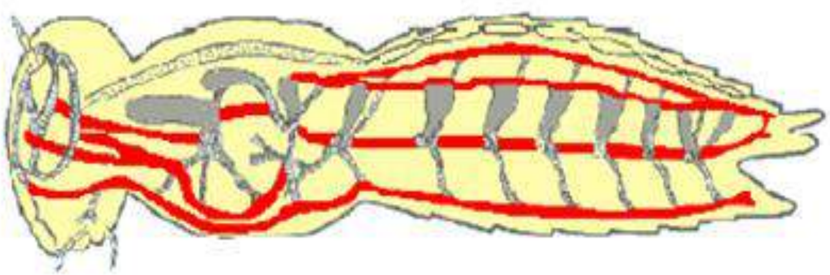
- ✓ Provide the cells and tissues with oxygen.
- ✓ To eliminate carbon dioxide a product of respiration.
- ✓ It gives some degree of buoyancy in aquatic insects in phantom midge *Chaoborus(*Diptera).
- ✓ Hemolymph circulation.
- ✓ Act as connective tissues and binds the organs together.
- ✓ Air sacs allow growth of the body.
- ✓ Tracheal system involves In sound production in *Gromphodorrhina (*Blattodea) by forcing air through the spiracles.
- ✓ Air sacs also helps as heat insulators and to maintain body temperature.
- ✓ Traceoles involves in light emission in fire flies.

- Air enters the insect's body through valve-like openings in the exoskeleton. These openings called spiracles are located laterally along the thorax and abdomen of most insects usually one pair of spiracles per body segment.
- Air flow is regulated by small muscles that operate one or two flap-like valves within each spiracle contracting to close the spiracle, or relaxing to open it.

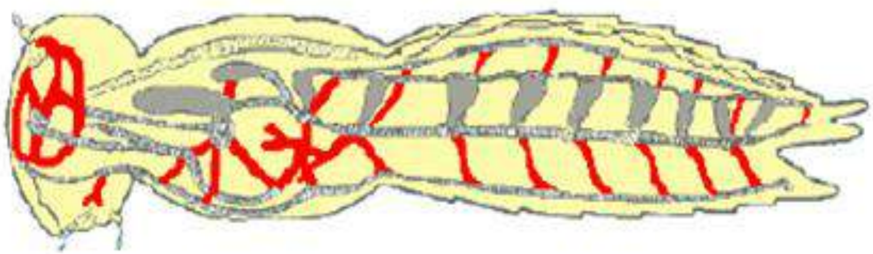


- After passing through a spiracle, air enters a longitudinal tracheal trunk, eventually diffusing throughout a complex, branching network of tracheal tubes that subdivides into smaller and smaller diameters and reaches every part of the body.

Tracheal Trunk



Tracheal Tubes

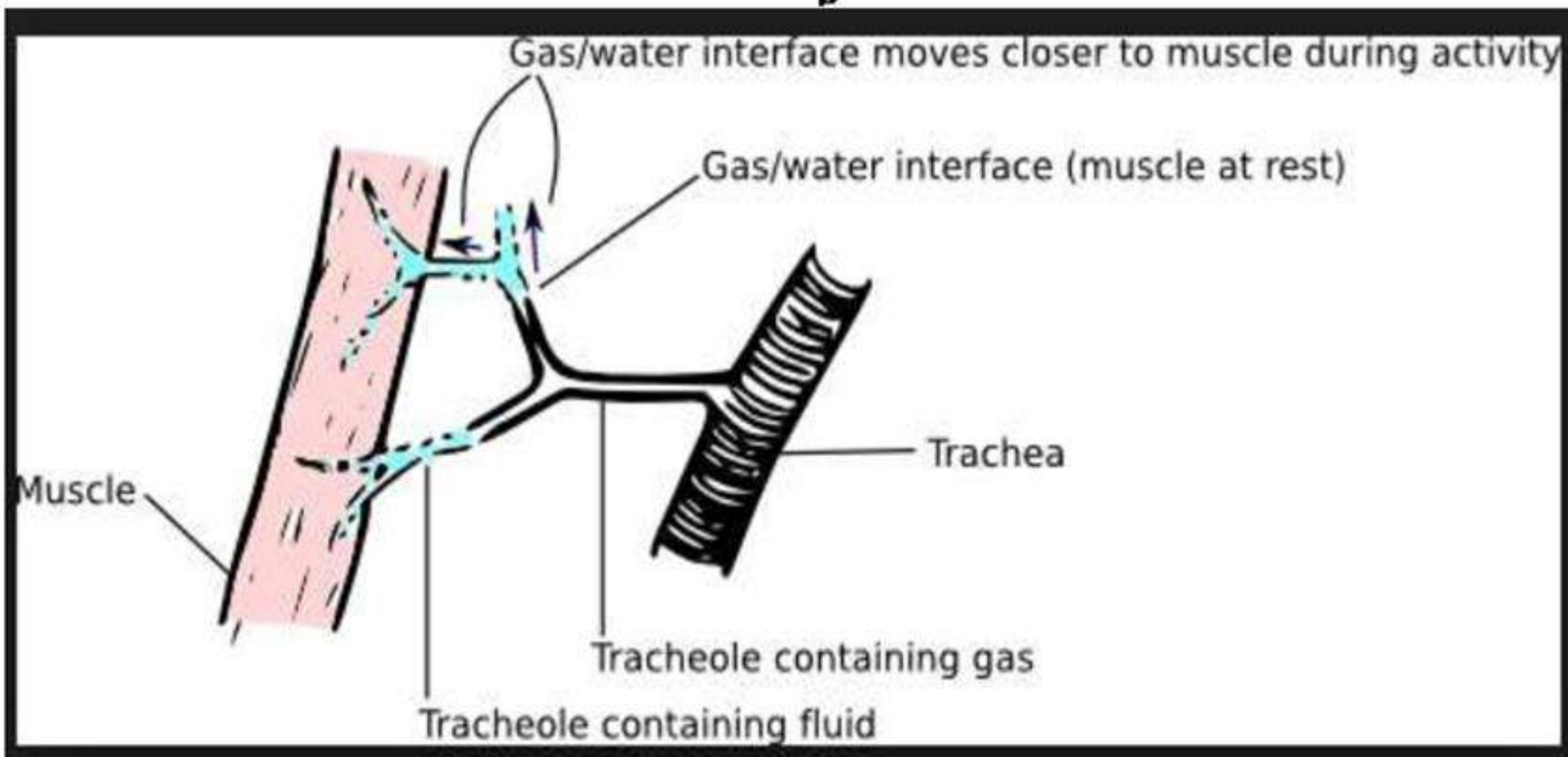


- At the end of each tracheal branch, a special cell (the **tracheole**) provides a thin, moist interface for the exchange of gasses between atmospheric air and a living cell.

- Oxygen in the tracheal tube first dissolves in the liquid of the tracheole and then diffuses into the cytoplasm of an adjacent cell.

- At the same time, carbon dioxide, produced as a waste product of cellular respiration, diffuses out of the cell and, eventually, out of the body through the tracheal system.

Tracheole



Gas/water interface moves closer to muscle during activity
Gas/water interface (muscle at rest)
Trachea
Muscle
Tracheole containing gas
Tracheole containing fluid

RESPIRATION IN AQUATIC INSECTS

- Aquatic insects obtain oxygen directly from air or from that dissolved in water.

Respiration in Aquatic Insects

1. **Cuticular Respiration**

- Many aquatic species have a relatively thin integument that is permeable to oxygen (and carbon dioxide). Diffusion of gasses through this body wall (cuticular respiration) may be sufficient to meet the metabolic demands of small, inactive insects -- especially those living in cold, fast-moving streams where there is plenty of dissolved oxygen. Larger insects, more active ones, or those living in less oxygenated water may need to rely on other adaptations (see below) to supplement cuticular respiration.

SPECIAL STRUCTURE

- ✓ Respiratory siphon
- ✓ Hydrofuge hairs
- ✓ Air stores

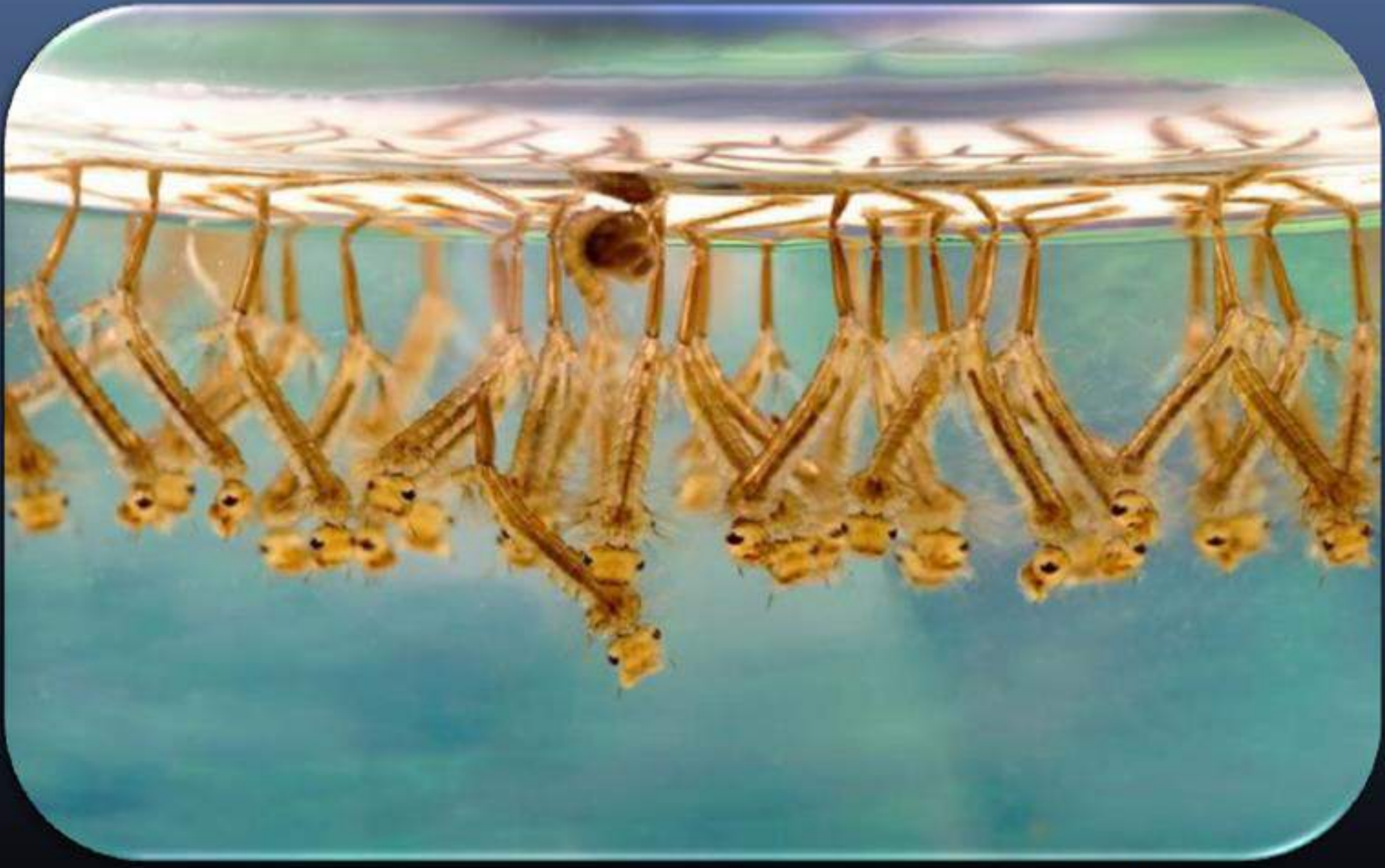
RESPIRATORY SIPHON

- ✓ Most aquatic insects obtain oxygen from air by making frequent visits to the surface of water or by having semi -permanent connections (siphon) with the air.

3. Breathing Tubes

- Although many aquatic insects live underwater, they get air straight from the surface through hollow breathing tubes (sometimes called **siphons**) that work on the same principle as a diver's snorkel. In mosquito larvae, for example, the siphon tube is an extension of the posterior spiracles.

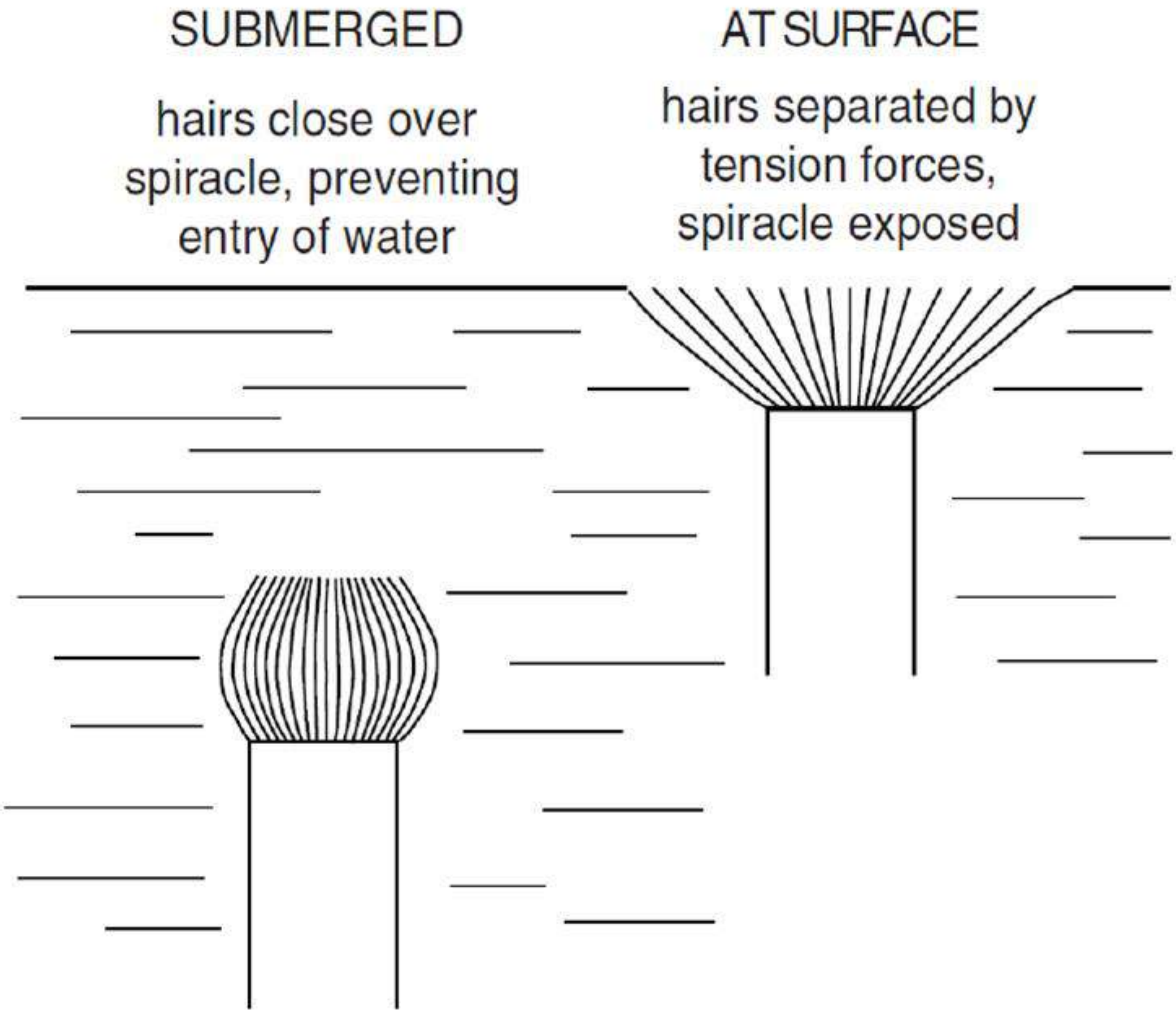
E.g. Mosquitoes larvae



photobucket.com

HYDROFUGE HAIRS

- ✓ The spiracles area develops special hairs having a coating of non- wettable wax on one side enabling the larvae to stay in the water surface and expose their spiracles to the air.
- ✓ They store air in the pile of erect hydrofuge hairs.
- ✓ It enables the insects to remain submerged in water for longer time.



SUBMERGED
hairs close over spiracle, preventing entry of water
AT SURFACE
hairs separated by tension forces, spiracle exposed

HYDROFUGE HAIRS

E.g. Culidiae
Mosquito larvae

AIR BUBBLES

- ✓ Some aquatic insects carry a bubble of air, whenever they dive beneath the water surface.

- ✓ This bubble may be held under the elytra or it may be trapped against the body by specialized hairs.

- ✓ The bubble usually covers one or more spiracles so the insect can "breathe" air from the bubble while submerged.

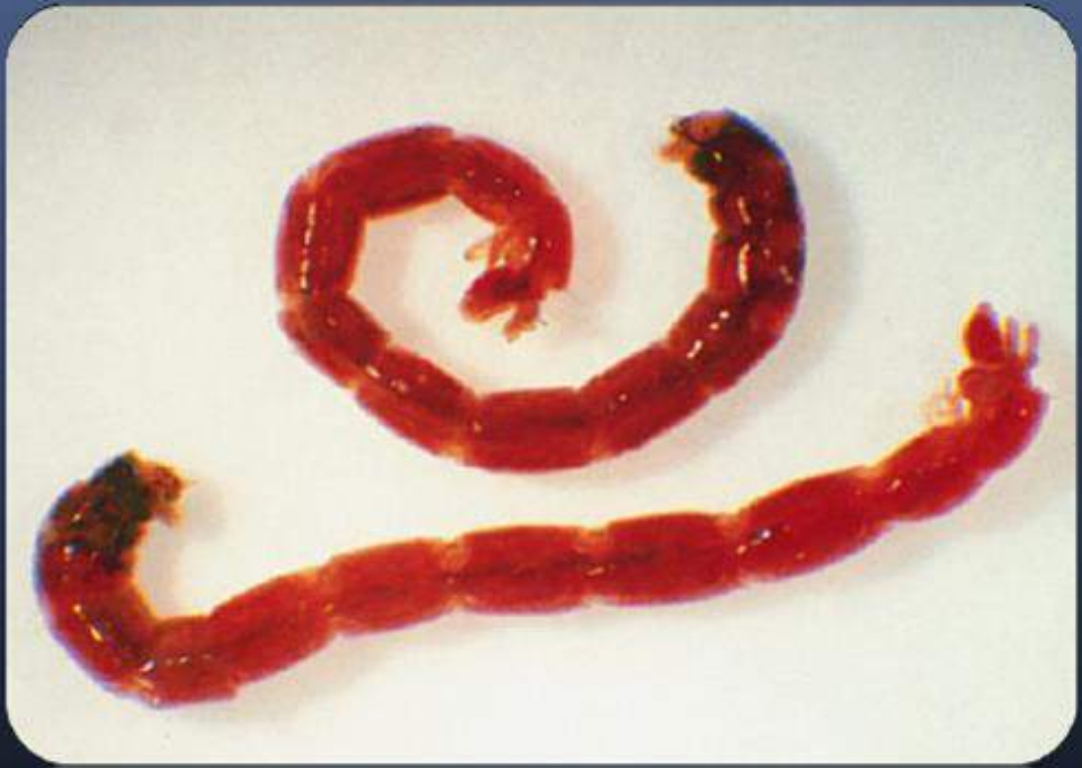
E.g. water beetles

OXYGEN DISSOLVED IN WATER

CUTANEOUS RESPIRATION

- ✓ In many aquatic larvae, even when tracheal gills are present where the integument is extremely thin, respiration is accompanied by simple diffusion of gases through their skin.

CUTANEOUS RESPIRATION



E .g. *Chironomus larvae*

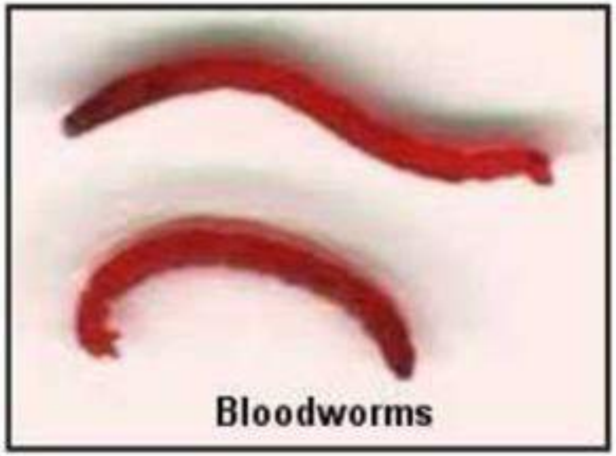
5. Plastron

- A **plastron** is a special array of rigid, closely-spaced hydrophobic hairs (setae) that create an "airspace" next to the body. Air trapped within a plastron operates as a physical gill (just like air in a bubble)

6. Hemoglobin

- Hemoglobin is a respiratory pigment that facilitates the capture of oxygen molecules. It occurs only rarely in insects -- most notably in the larvae of certain midges (family Chironomidae) known as bloodworms.

- These distinctive red "worms" usually live in the muddy depths of ponds or streams where dissolved oxygen may be in short supply. Under normal (aerobic) conditions, hemoglobin molecules in the blood bind and hold a reserve supply of oxygen.



- Whenever conditions become anaerobic, the oxygen is slowly released by the hemoglobin for use by the cells and tissues of the body. This back-up supply may only last a few minutes, but it's usually long enough for the insect to move into more oxygenated water.

TRACHEAL GILLS

- ✓ The immature stages of many aquatic insects lack a distinct communication with the exterior, the spiracle being closed or absent .
- ✓ In such insects there is an extensive network of fine trachea beneath the integument, either concentrated in some regions or distributed all over as in tracheal gills of immature stages.
- ✓ Gills take an active part in respiratory activity particularly in the summer months and when water is poor in oxygen.

2. Biological Gills

- A **biological gill** is an organ that allows dissolved oxygen from the water to pass (by diffusion) into an organism's body. In insects, gills are usually outgrowths of the tracheal system. They are covered by a thin layer of cuticle that is permeable to both oxygen and carbon dioxide.

Lamellate gills - Mayfly naiad

Rectal gills - dragonfly naiad

Filamentous gills - damselfly naiad

BLOOD GILLS

- ✓ Thin –blood filled sacs without tracheae project from the exceedingly thin body surface in some dipterans larvae .

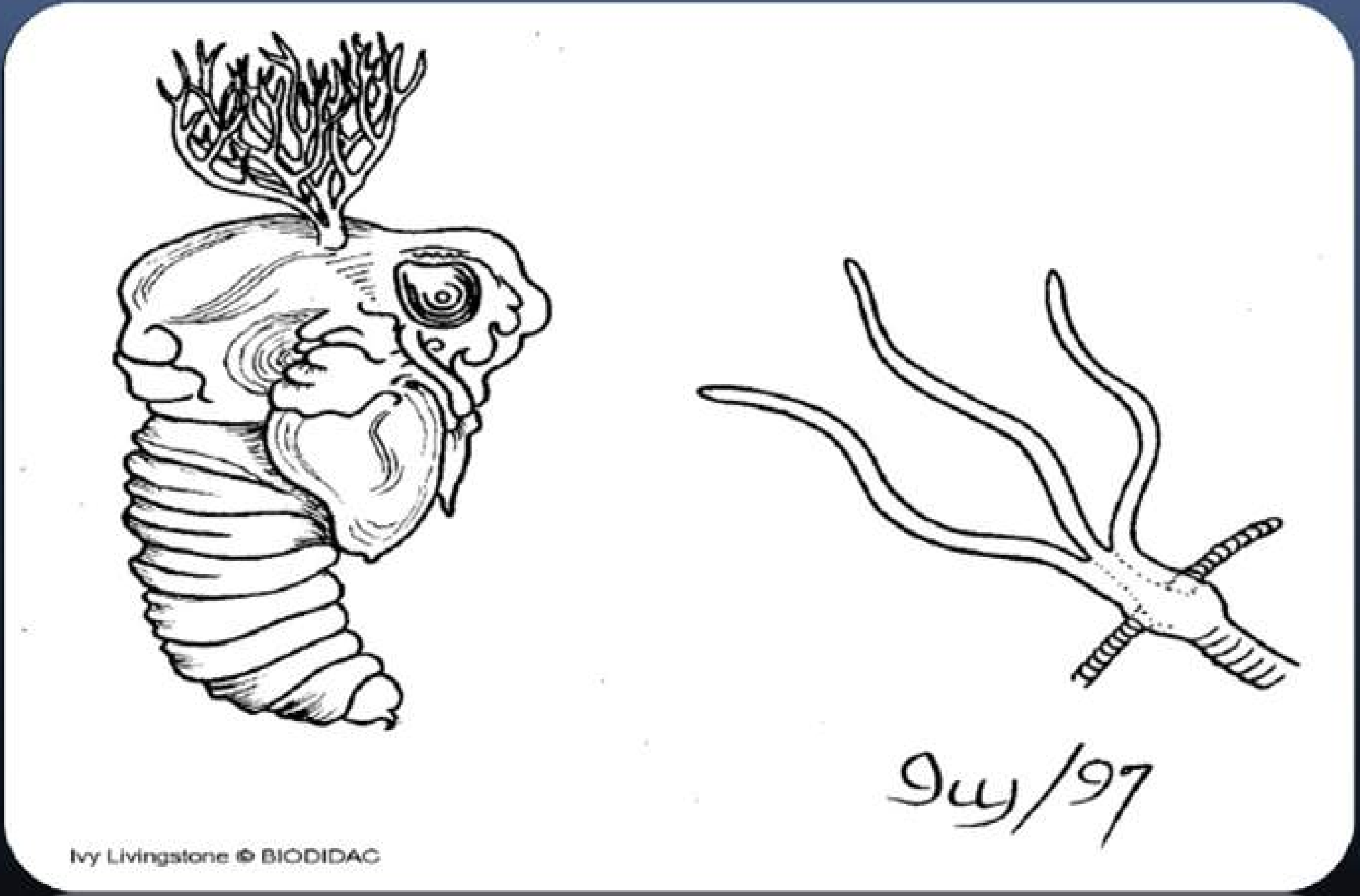
- ✓ They help in the absorption of water , inorganic ions and respiration.

E.g. Tricopteran and dipterans maggot.

SPIRACULAR GILLS

- It is the extension of the cuticle surrounding a spiracle and bearing a plastron connected to the tracheal system by Aeropyles.

SPRACULAR GILLS IN PUPAE OF DIPTERAN



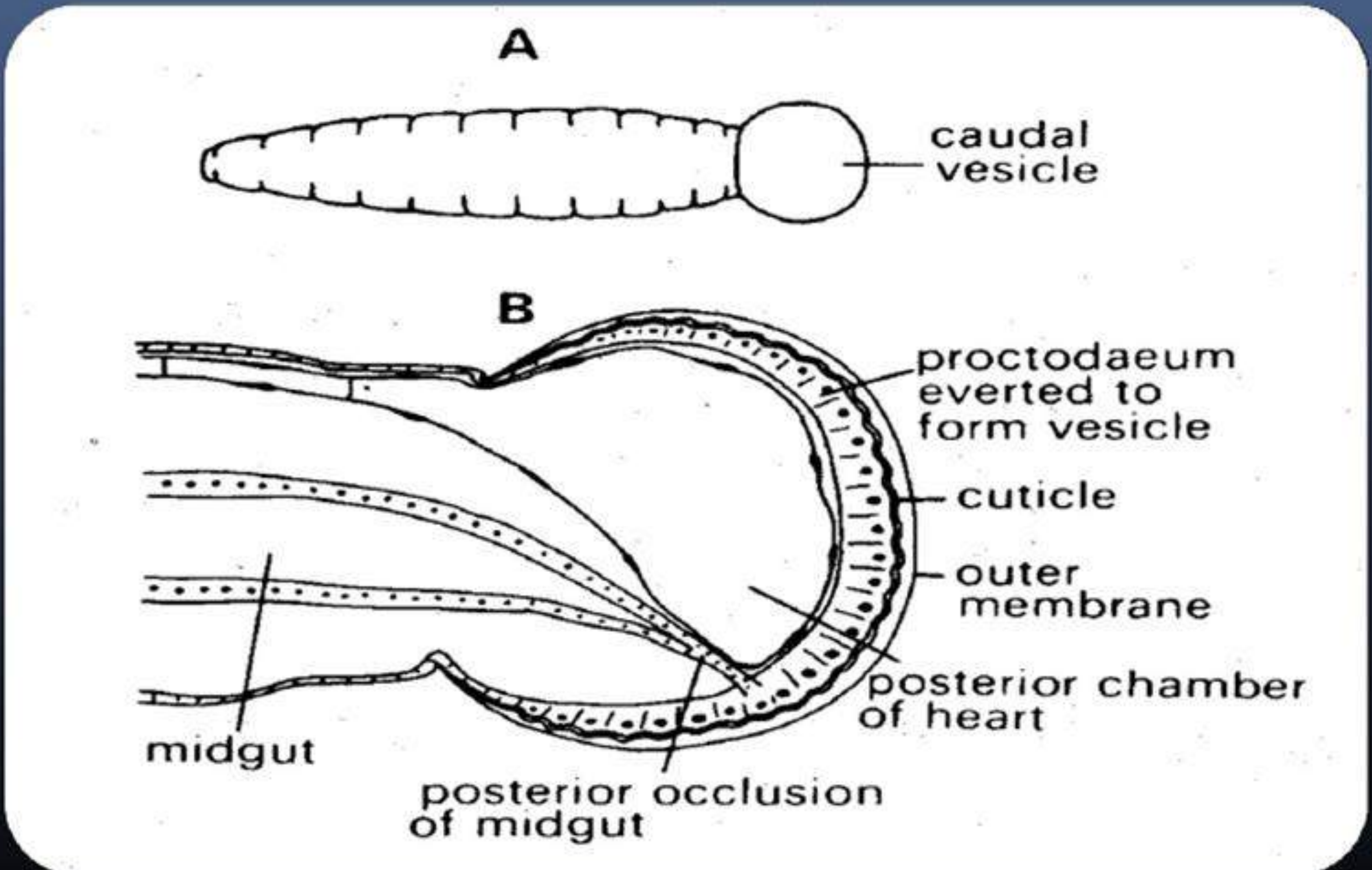
RESPIRATION IN ENDOPARASITIC INSECTS

- ✓ Endoparasitic insects may obtain their oxygen directly from the air outside the host or by diffusion through the cuticle from the surrounding host tissues.

CAUDAL VESICLE

- ✓ In braconid larvae the hindgut is everted through the anus to form a caudal vesicle.
- ✓ In some insects like *Apanteles*, it is relatively thin-walled and closely associated with the heart so that oxygen passing in is quickly carried around the body

E.g. *Bracon brevicornis* on *Opisina arenosella*.



- ✓ In *Cryptochaetum iceryae* (Diptera), a parasite of scale insects, there are two caudal filaments, which in the third-instar larva are ten times as long as the body and are packed with tracheae.
- ✓ These filaments often get entangled with the host tracheae and so provide an easy path for oxygen transfer.
- ✓ **Chalcidid (Hymenoptera) larvae are connected to the outside from the first instar onwards by the hollow egg pedicel, which projects through the host's body wall.**

Insect excretory system

Excretory system

✓Removal of waste products of metabolism, especially nitrogenous compounds from the body of insects is known as **excretion**.

✓excretion process helps insect to maintain salt water balance and thereby physiological homeostasis.

✓**The principal structures of excretion are,**

✓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 1st discovered by **Marcello Malpighi.**

✓**Number of malphigian tubules varies in** different insects

✓**2- in scale insects**

✓**200- in grasshopper**

✓**60 in cockroach**

✓**06- in odonata and absent in aphids and collembola**

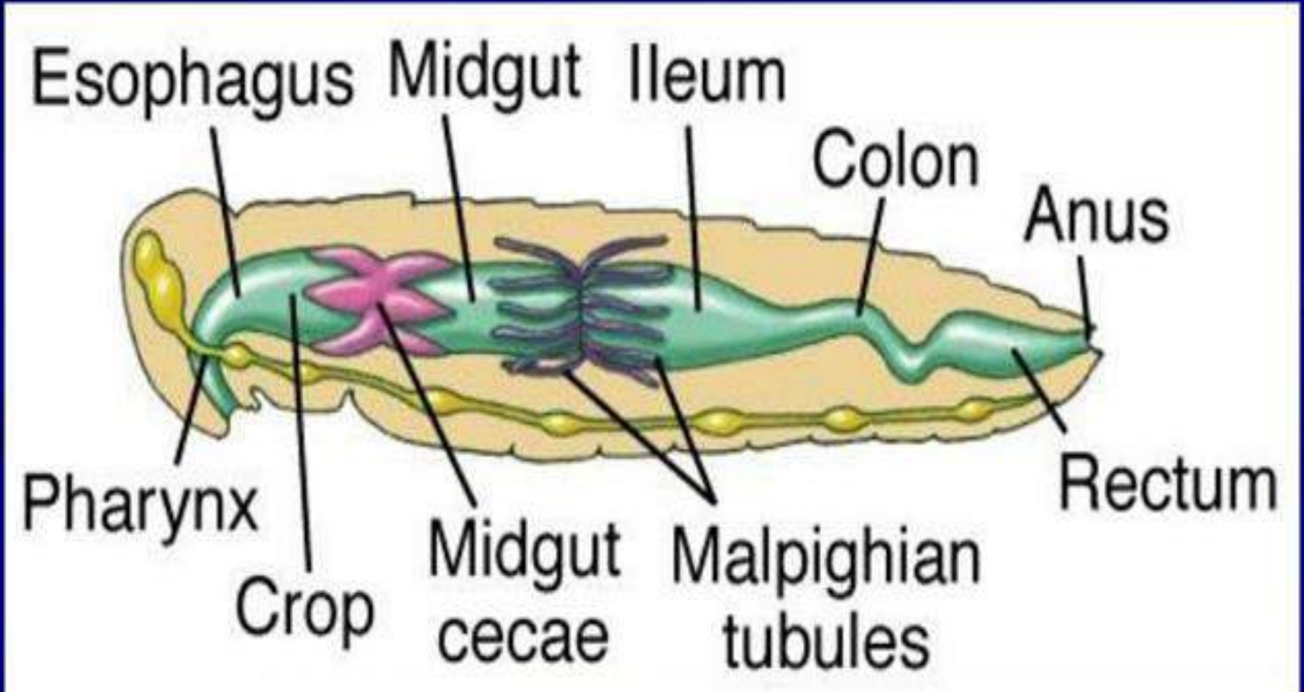
- 2. **Nephrocytes:** Cells that sieve the haemolmph for products that they metabolize (pericardial cells).
- **3. Fat bodies** : A loose or compact aggregation of cells, mostly trophocytes, suspended in the haemocoel, responsible for storage and excretion.
- **4. Oenocytes**: These are specialised cells 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.

- **Physiology of excretion**
- **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.
- ✓ Uric acid is stored as urates in the cells of fat body e.g., American cockroach.
- ✓ Uric acid is stored in the **body wall, giving white colour**. e.g. Red cotton bug.
- ✓ Uric acid is stored in the male accessory glands to produce the outer coat of spermatophore, which is excreted during copulation.
- ✓ Uric acid is stored in the **wing scales giving white colour**. e.g., Pierid butterflies.
- ✓ Waste products of **pupal metabolism (Meconium)** is stored and released during adult emergence.

- Excretory organs of insects
  - Malpighian tubules – collect a filtrate from the hemolymph and pass this primary urine to the hindgut.
  - Hindgut – secrete additional components into the secreta, and reabsorbe some substances into the hemolymph.



- The major function of excretory system is to maintain the internal environment of an organism by separating and eliminating metabolic wastes and other toxic substances.
- Because metabolic wastes are often dissolved in water, excretory processes are also closely associated with osmoregulation and the maintenance of water balance.

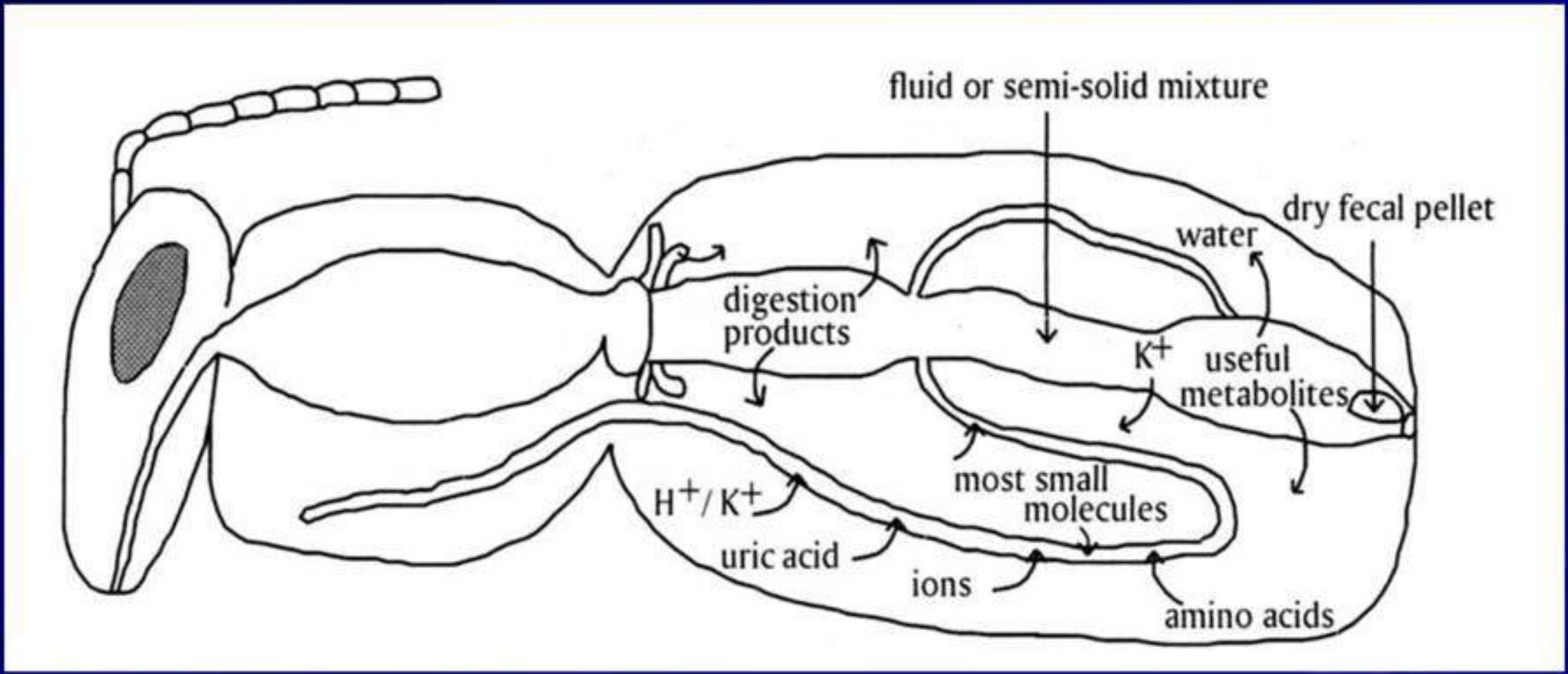


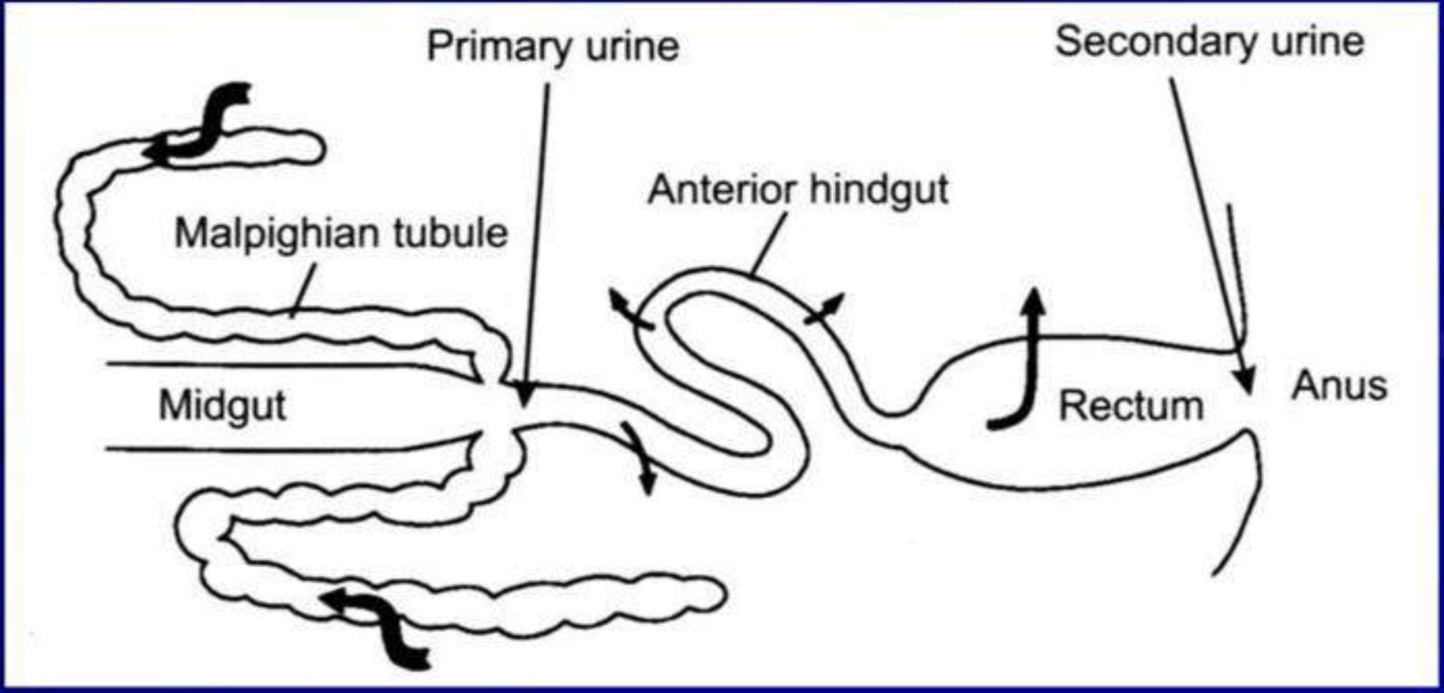
Fig. A generalized scheme of excretion showing the collection of fluid in the Malpighian tubules, and extensive reabsorption of water, K^+, and useful substances from the hindgut, primarily the rectum.

Malpighian Tubules

- Malpighian tubules are primary excretory organs of insects
- Malpighian tubules are long, tubular structures, usually arising at the junction of the mid- and hindgut and terminating blindly in the hemocoel.
- The tubules vary in number from 2 to more than 100 in various insect species.
- Tracheal connections to Malpighian tubules are numerous.
- A small spiral muscle frequently runs along the surface of a tubule. (next slide)

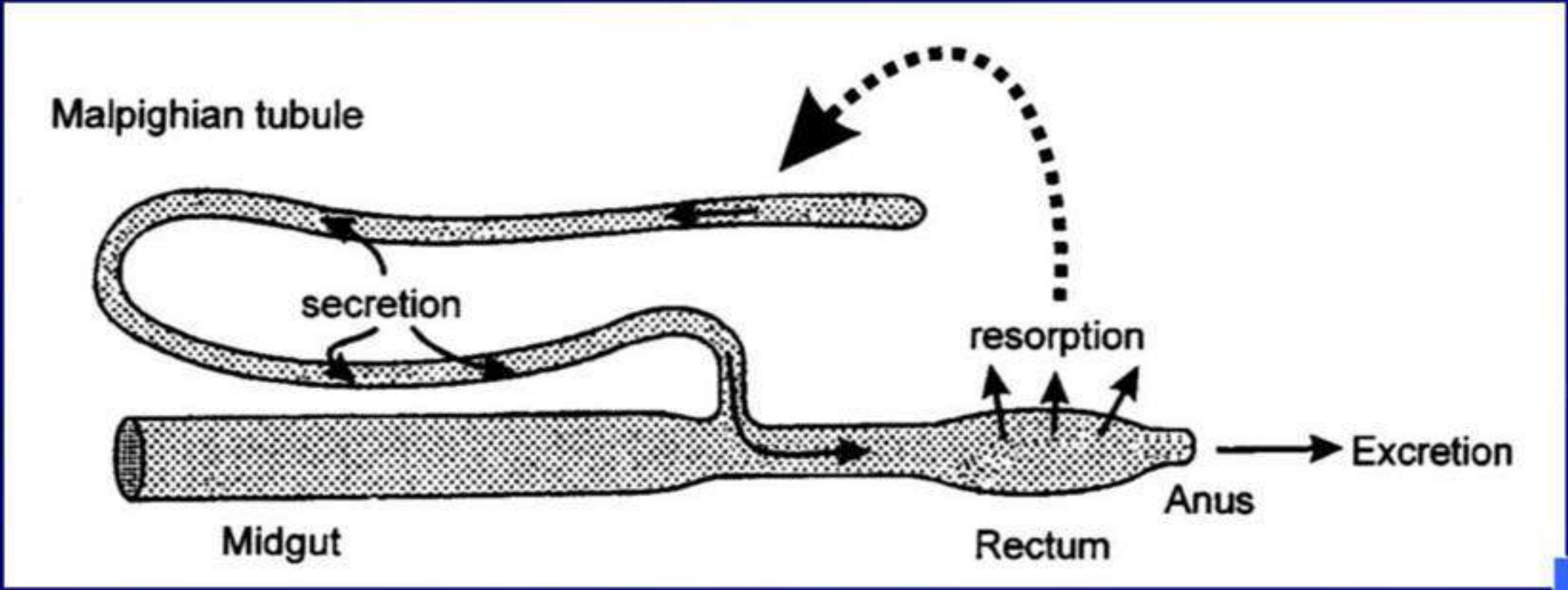
Malpighian Tubules

- The Malpighian tubules arise during embryogenesis as evaginations of the gut, usually originating at the junction of the midgut and hindgut.
- The tubule walls consist of a single cell layer of epithelial cells and are differentiated by structure and function along the length of the tubule.



Malpighian Tubules

- The process of excretion is a <u>two-step process</u>, with much of the fluid that is taken up by the tubules resorbed by the hindgut before is passes out of the body.

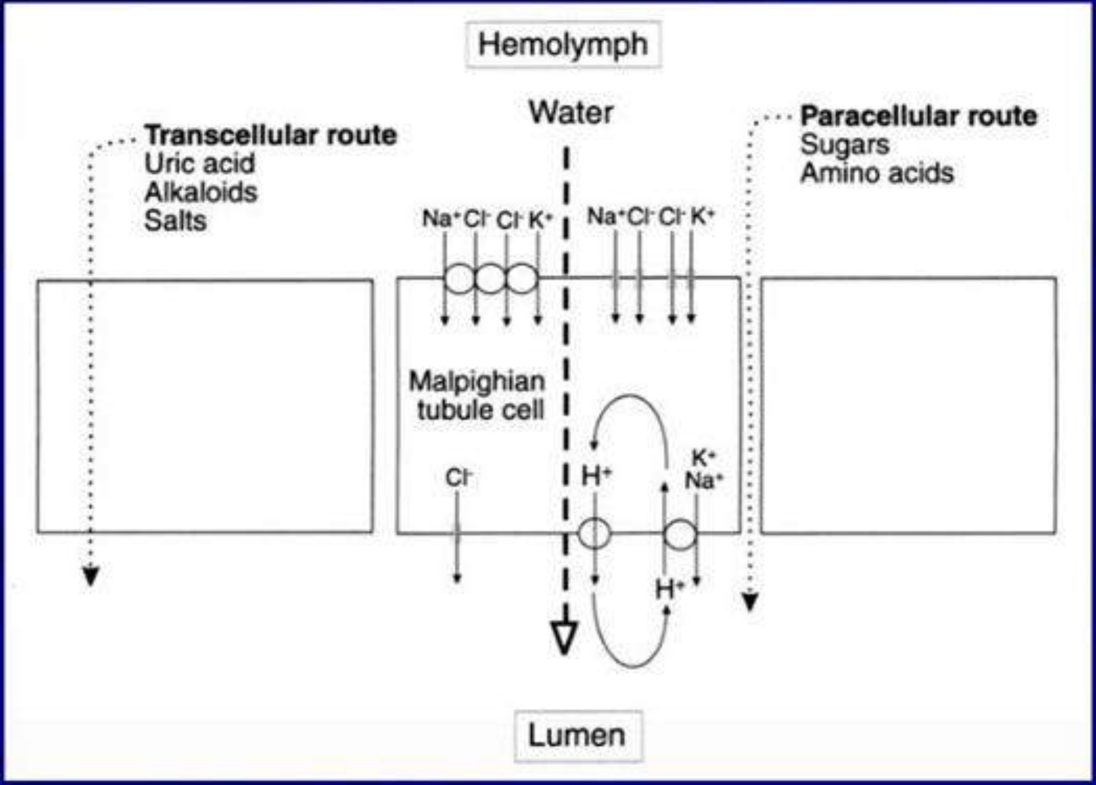


Ultrastructure of Malpighian Tubule Cells

- A single layer of epithelial cells surrounds the lumen of a tubule.
- Several different cell types have been identified, but their specific functions have not been elucidated in many cases.
- Type 1 (or principal tubule cells) – tubule cells have a brush border of microvilli on the apical surface. (next slide)

Transport of Substances Through the Malpighian Tubule Cells

- The primary urine formed in the lumen of the Malpighian tubules is a filtrate of the hemolymph, and it contains most of the small ions and molecules that occur in the hemolymph.



Primary Urine Formation

- Urine formation in Malpighian tubules mainly relies on a proton pump in the apical membrane of Malpighian tubule cells that actively secretes protons (H^+) into the tubule lumen against an electrochemical gradient.
- The pump causes the tubule lumen to become positive to the hemolymph, and creates highly variable gradients in pH across the apical membrane of principal cells.
- The proton gradient provides the energy for an antiporter mechanism that exchanges K^+ for H^+ across the apical membrane. (next slide)

Primary Urine Formation

- Secretion of cations (H^+, Na^+, and K^+) across the apical membrane appears to be electrically coupled with Cl^- transport in the basolateral membrane of tubule cells. (next slide)
- The formation of urine volume is highly dependent on the K^+ concentration in hemolymph or saline. (next slide)
- The process driven by the proton pump has been called a standing gradient process.
- Additional processes might be involved in substances interring the tubule lumen. (next slide)

Hormonal Control of Urine Formation

- The rates of urine formation and ion secretion are controlled by diuretic hormones and certain non-peptide compounds, such as 5-hydroxytryptamine (5-HT or serotonin)
- The diuretic neuropeptides isolated from insects fall into one of two hormone families:
  - Corticotropin-releasing factor (CRF)-related peptides: range in size from 30-46 amino acids; has approximately 30% sequence homology with the CRF family of vertebrate peptides.
  - Insect kinins: small peptides of between 6 and 15 amino acids

Anatomical Specialization of Hindgut Epithelial Cells

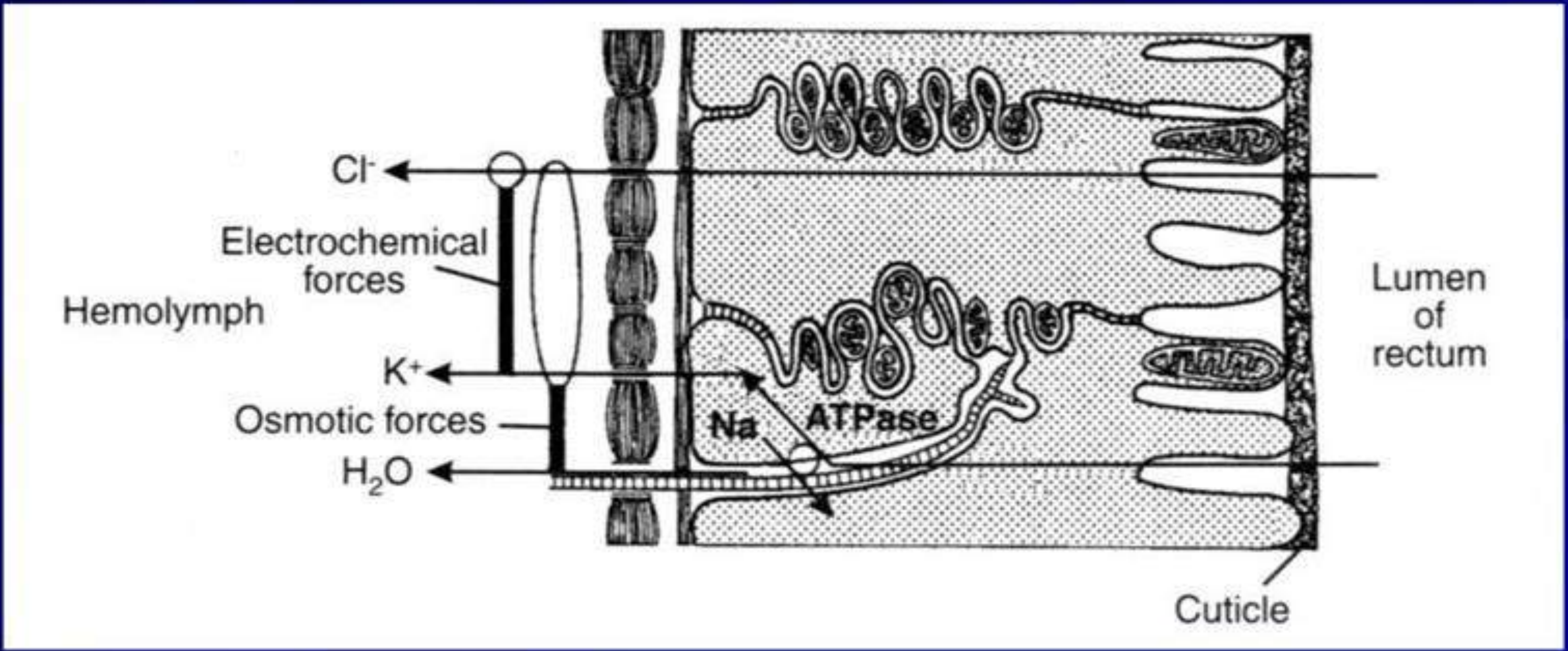
- The hindgut is the second system that completes the excretion process by
  - selectively reabsorbing some substances into the hemolymph
  - leaving others in the lumen
  - actively secreting some substance into the hindgut lumen
- The rectal cuticular lining has greater permeability than the cuticular lining on foregut cells.
- The epithelial cells of the hindgut are specialized for both active secretion and active reabsorption.

Anatomical Specialization of Hindgut Epithelial Cells

- Rectal cells (or rectal pad cells, rectal papillae cells) – a group cells in the rectum that have special modifications for reabsorption. (next slide)
- In Diptera, the cells of a rectal papilla are large, usually cuboidal cells that surround a central channel in the papilla that opens into the hemolymph space through a valve. (next slide).

A Rectal Cell and Its Ion Transport

- The rectum consists of the enlarged posterior-most section of the hindgut, often containing specialized structures called papillae or rectal pads that are enlarged epithelial cells.
- The rectum transports water and ions from the material within the gut lumen into the hemolymph.



Secretion and Reabsorption in the Ileum

- The ileum is the most anterior part of the hindgut, occurring just posterior to the origin of the Malpighian tubules in most insects.
- In locust *S. gregaria*, the ileum is a major site for
  - isosmotic fluid reabsorption
  - active Na^+ and Cl^- reabsorption
  - active secretion of proline as an energy source

Secretion and Reabsorption in the Ileum

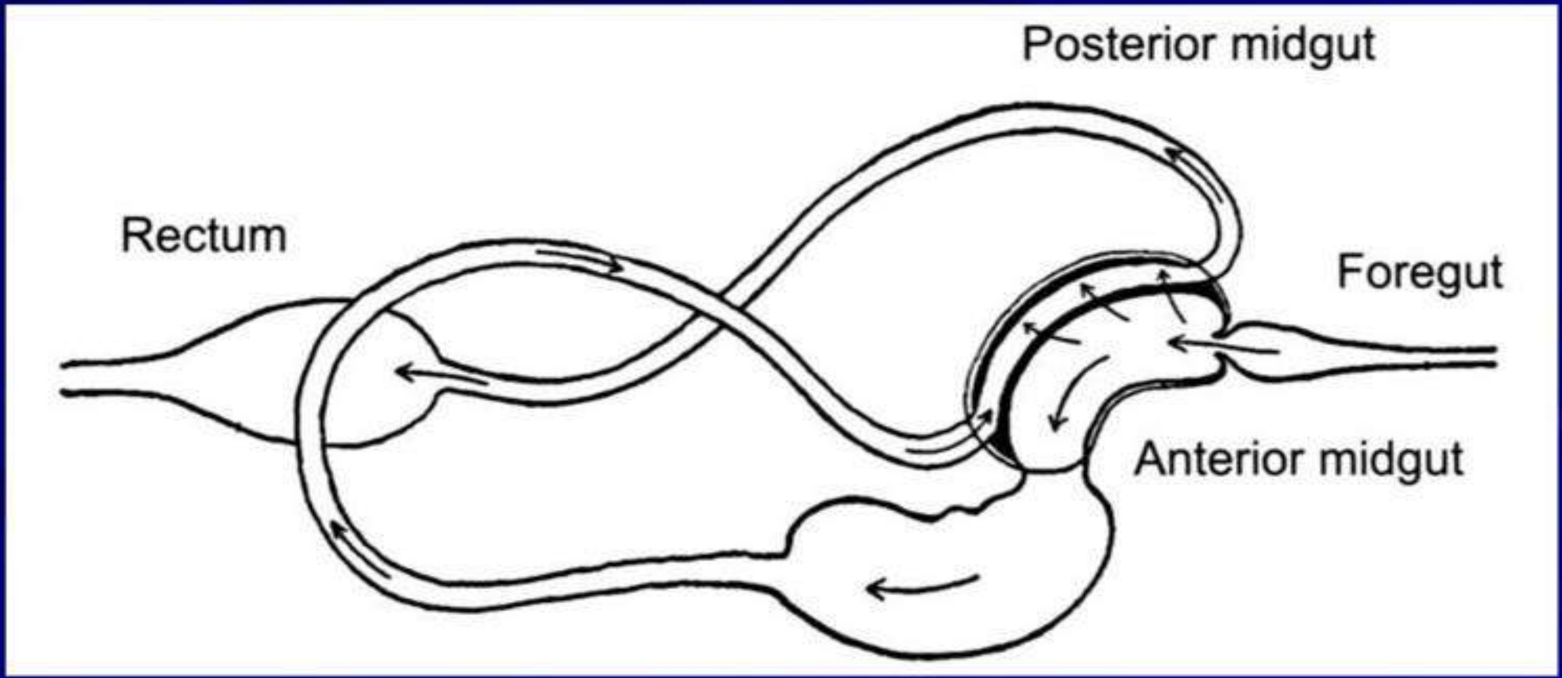
- The driving mechanism for ion and water reabsorption in the ileum is an electrogenic Cl^- pump.
- A neuropeptide, the ion transport peptide (ITP) stimulates Na^+, Cl^- and water reabsorption, and promotes passive reabsorption of K^+ by electrical coupling.
- The ileum plays a major role in acid-base balance by secretion of H^+ into the lumen, formation of NH_4^+, and reabsorption of HCO_3^-.

Reabsorption in the Rectum

- The rectum is the final and major site for reabsorption of ions, water, and nutrients.
- It is capable of reabsorbing fluid against strong osmotic gradients, ultimately producing a very concentrated hyperosmotic excreta in many insects.
- The driving mechanism for cation and water reabsorption, as in the ileum, is an electrogenic Cl^- pump under the influence of a neuropeptide hormone, chloride transport stimulating hormone (CTSH), from the corpora cardiaca.

A Filter Chamber

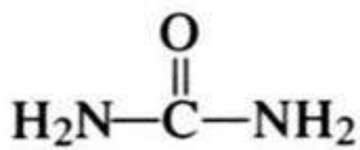
- In some Homopterans that feed exclusively on plant juices containing low concentrations of nutrients, the digestive tract forms an arrangement known as a filter chamber.



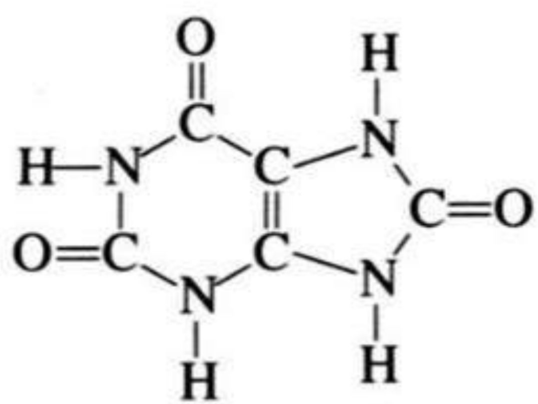
Excretory Molecules that Incorporate Nitrogen

NH_3

Ammonia



Urea



Uric acid

Storage Excretion

- Because uric acid is so insoluble, it can be easily stored without it interacting with other physiological processes.
  - Some cockroaches accumulate up to 10% of their dry weight in uric acid stored in specialized urate cells in the fat body, which can be utilized during periods of dietary stress.
  - In some lepidoptera, the fat body shifts from excretion of uric acid to its storage during the last larval instar.

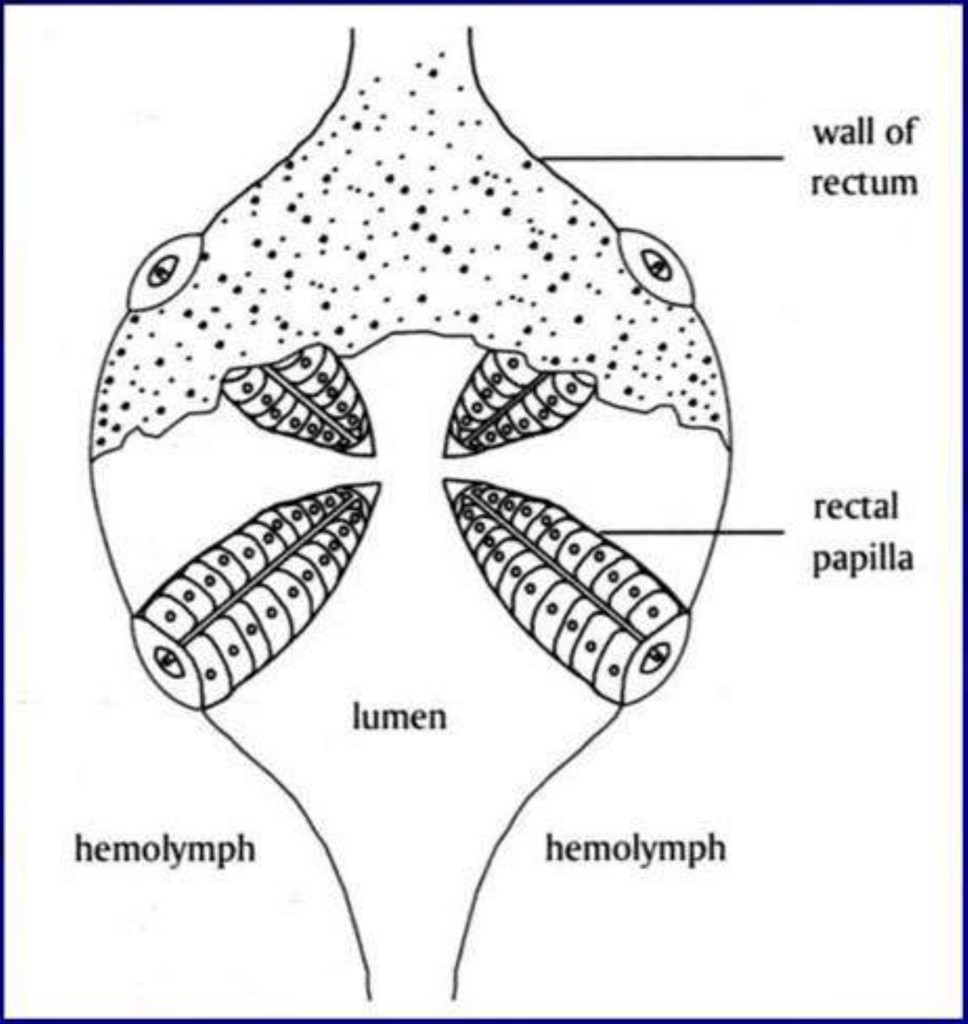
A Cryptonephridial Complex

- Many families of Coleoptera, Lepidoptera and some saw-fly larvae, that live under extremely dry conditions, the ends of the Malpighian tubules do not lie free in the hemocoel.
- Instead, the terminal segments of the tubules are closely associated with the wall of the rectum in what is called a cryptonephridial complex. (next slide)
- It appears to be an arrangement that enables very efficient conservation of water.

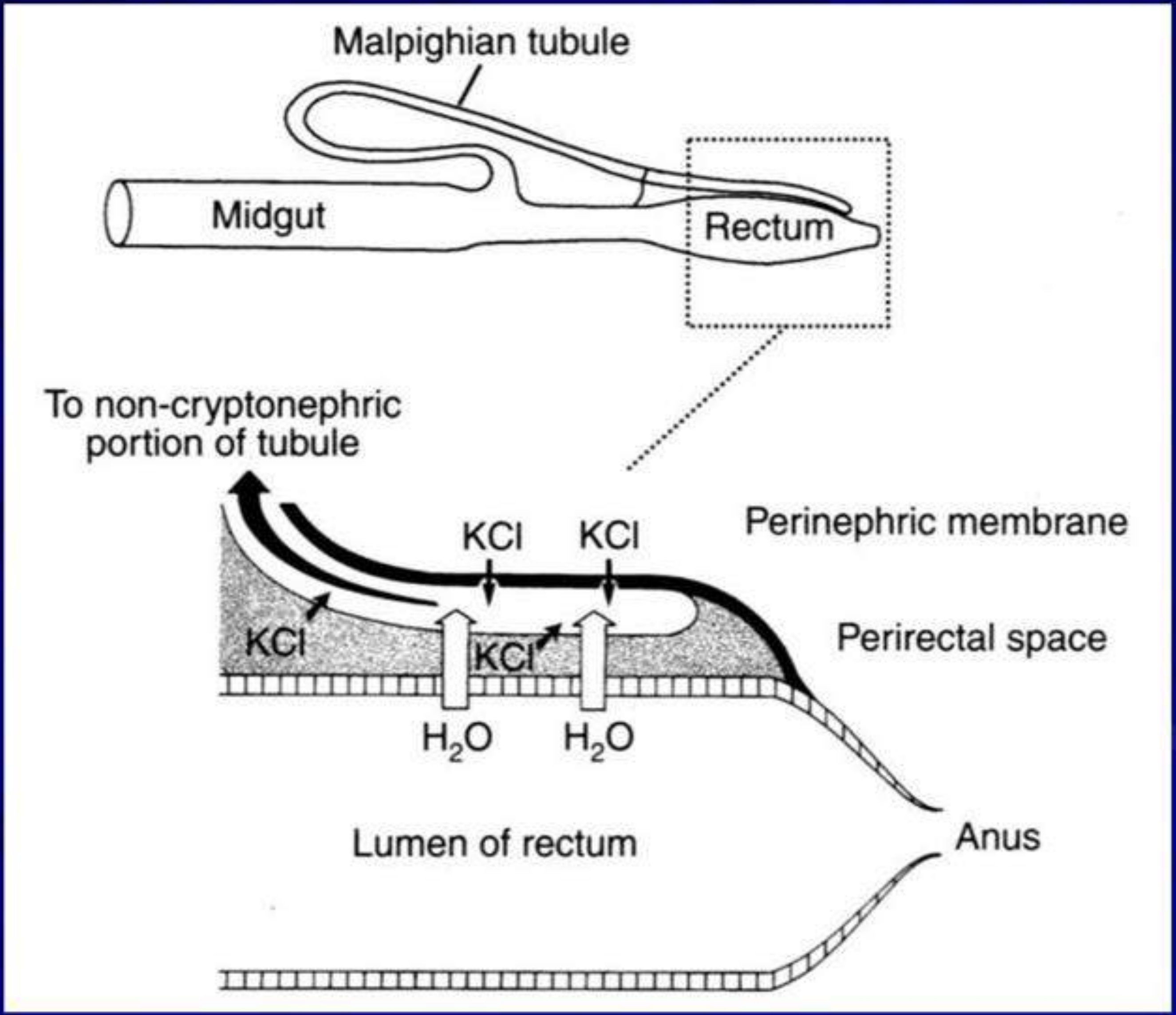
A Cryptonephridial Complex

- The cryptonephridial complex is found in most lepidopteran larvae and many coleopterans.
- The cryptonephridial complex performs two functions:
  - Resorb water from the hindgut very efficiently. (next slide)
  - In some insects is able to absorb atmospheric water from the humidity in the hindgut.

A diagram of the Rectal Papillae in the Rectum of Adult Dipterans



A Cryptonephridial Complex



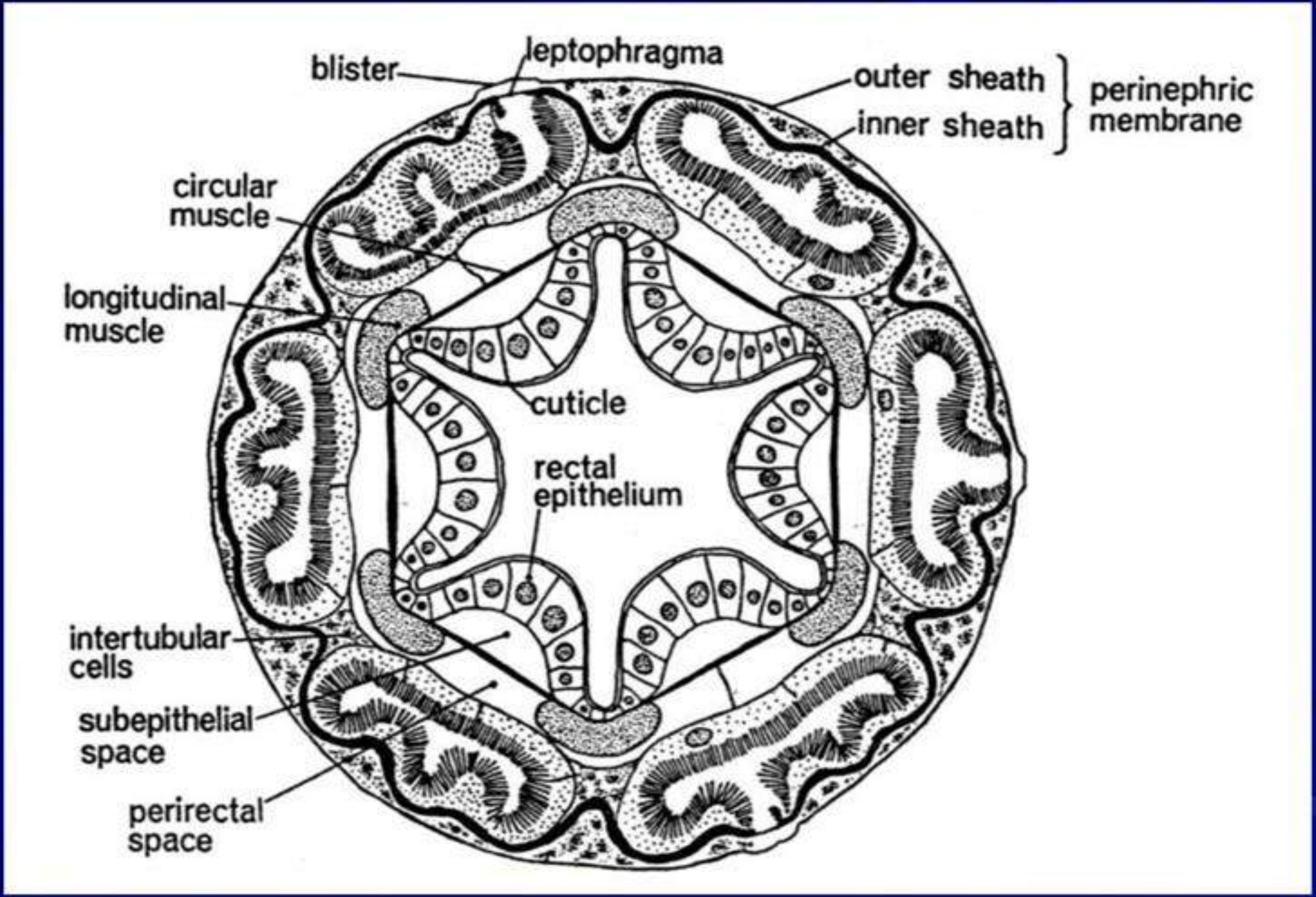


Fig. Cross-sectional view of the rectum with cryptonephridial tubules from the yellow mealworm *Tenebrio molitor*.

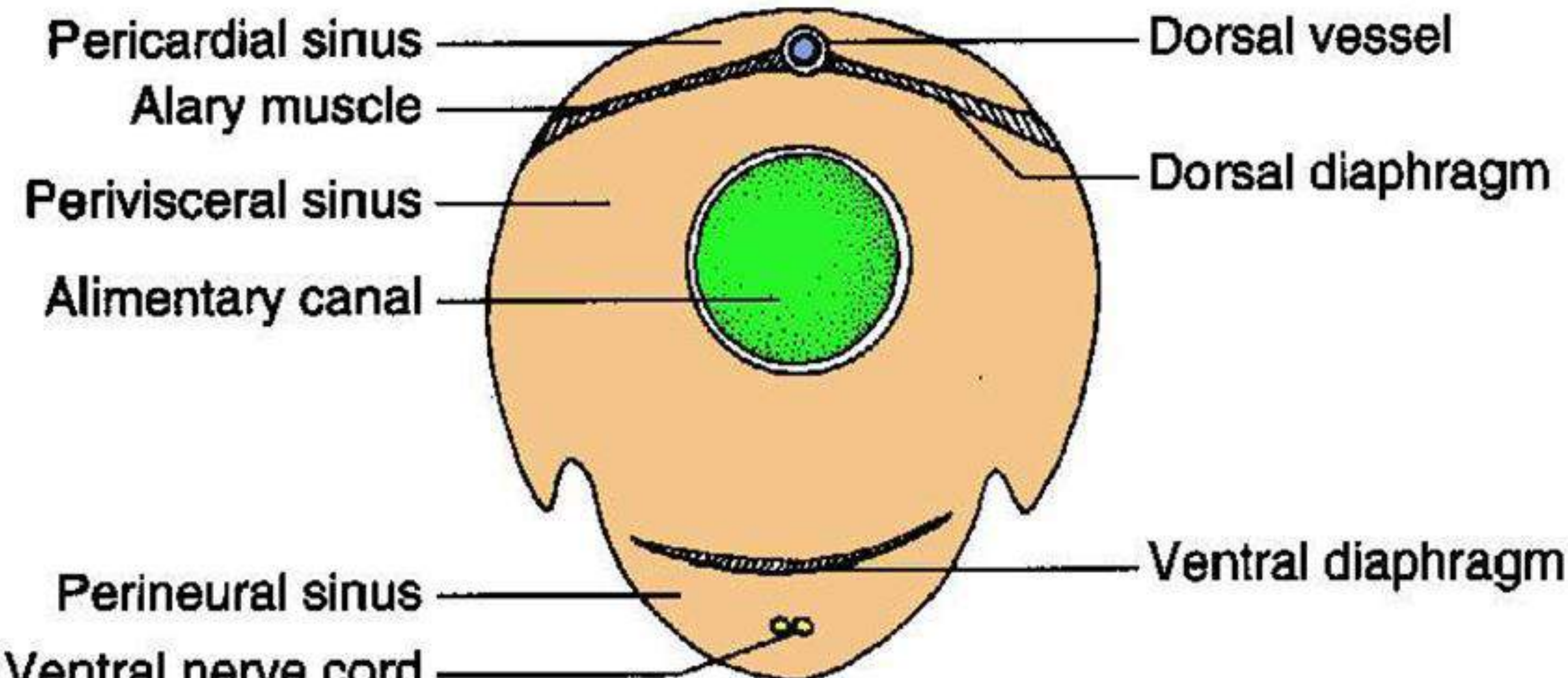
Insect Circulatory System

FORTALEZA, M. A. ENT 101

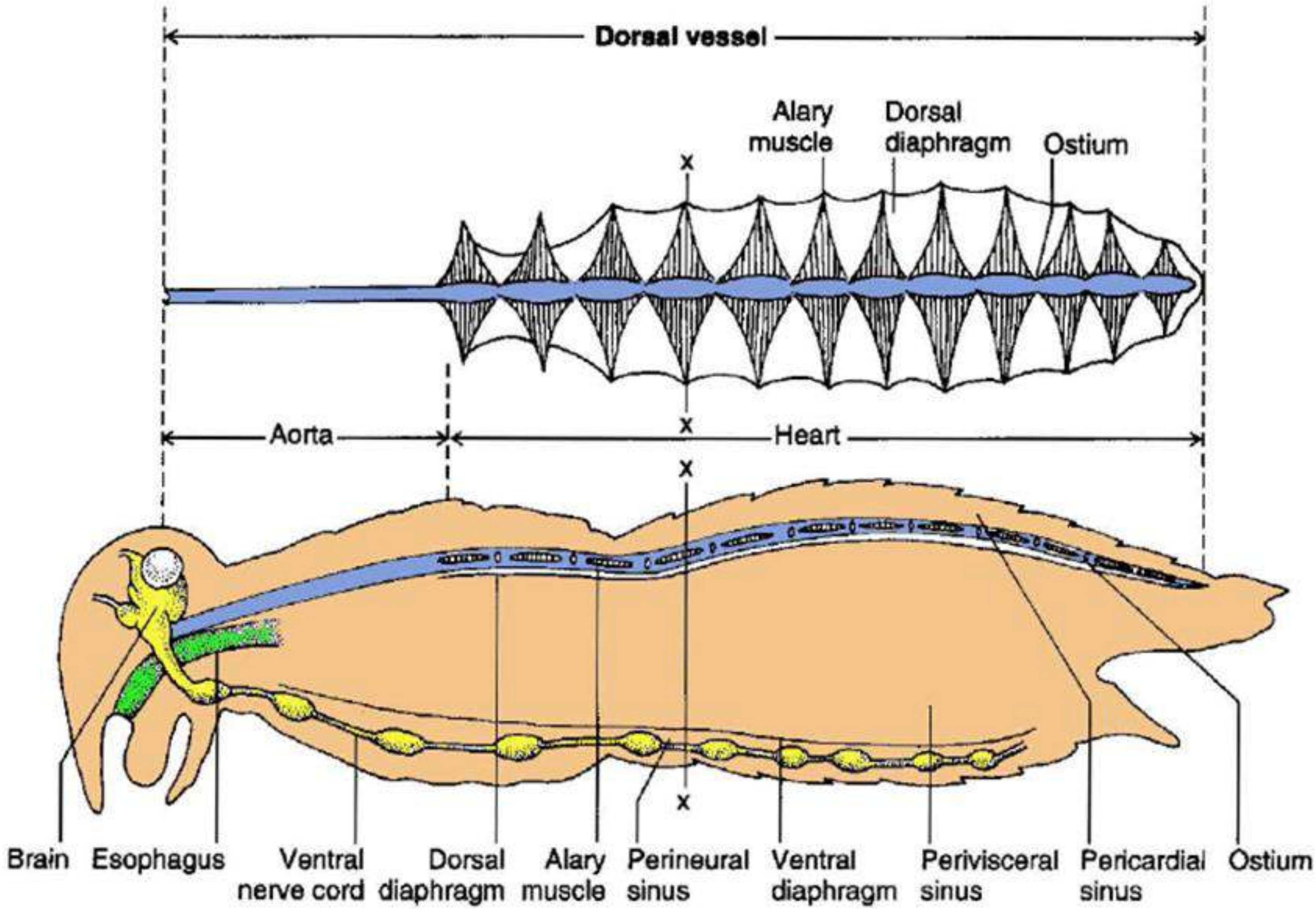
Circulatory system

- There are two types of circulatory systems in the animal kingdom.
- In many animals , the blood travels through vessels like arteries, capillaries and veins. This is known as **closed type of circulatory system**.
- In insects the blood flows through the body cavity (i.e., heamocoel) irrigating various tissues and organs. It is known as **open type of circulatory system**.

- **The hemocoel** is filled with hemolymph that bathes the organs
- **Haemocoel** of the insects is divided into **3 sinuses** (or) regions due to the presence of **two fibro muscular septa (or) diaphragms** composed of connective tissues
- 1) **Dorsal or Pericardial Sinus**: The area lying in between the tergum and dorsal diaphragm. **It contains heart**.
- 2) **Ventral or Perineural Sinus**: The area lying in between the sternum and ventral diaphragm. **It contains nerve cord**.
- 3) **Visceral Sinus**: The area in between dorsal and ventral diaphragms. It harbour the visceral organs like **alimentary canal and gonads.**



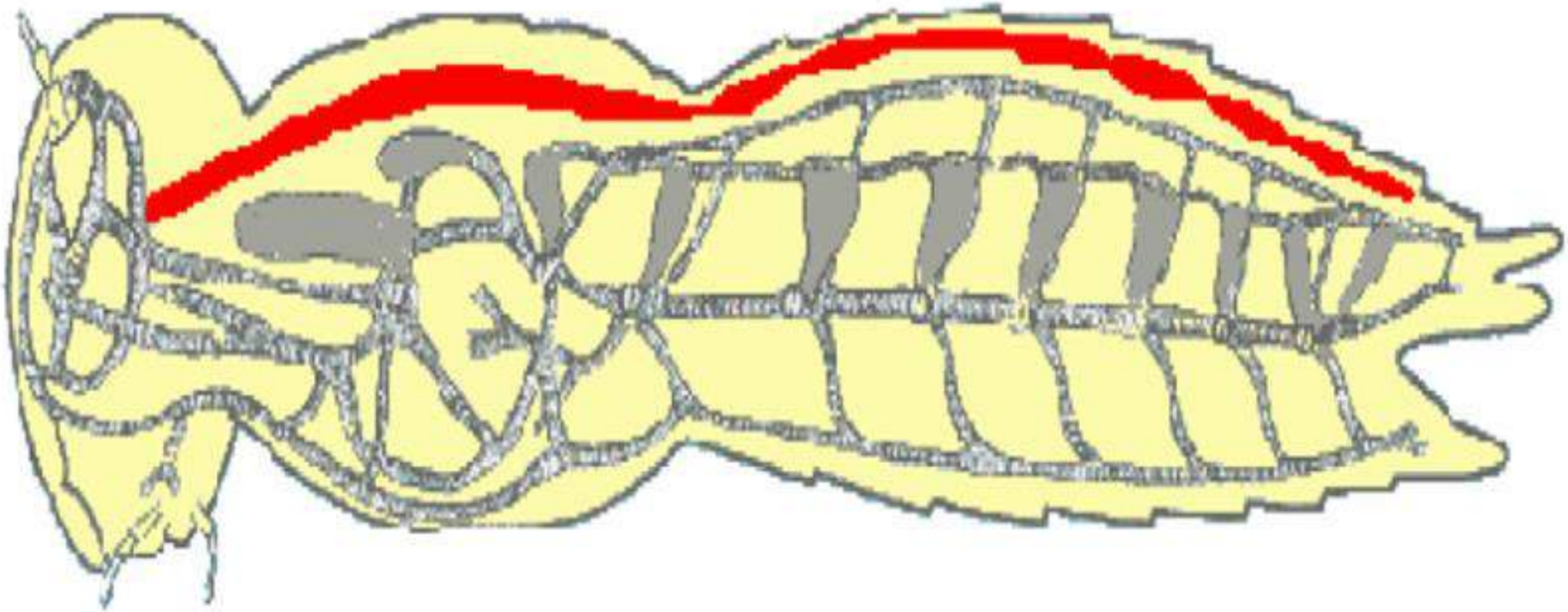
Pericardial sinus
Alary muscle
Perivisceral sinus
Alimentary canal
Perineural sinus
Ventral nerve cord
Dorsal vessel
Dorsal diaphragm
Ventral diaphragm


Dorsal vessel
Alary muscle
Dorsal diaphragm
Ostium
x
x
Aorta
Heart
x
x
Brain
Esophagus
Ventral nerve cord
Dorsal diaphragm
Alary muscle
Perineural sinus
Ventral diaphragm
Perivisceral sinus
Pericardial sinus
Ostium

Organs associated with blood circulation

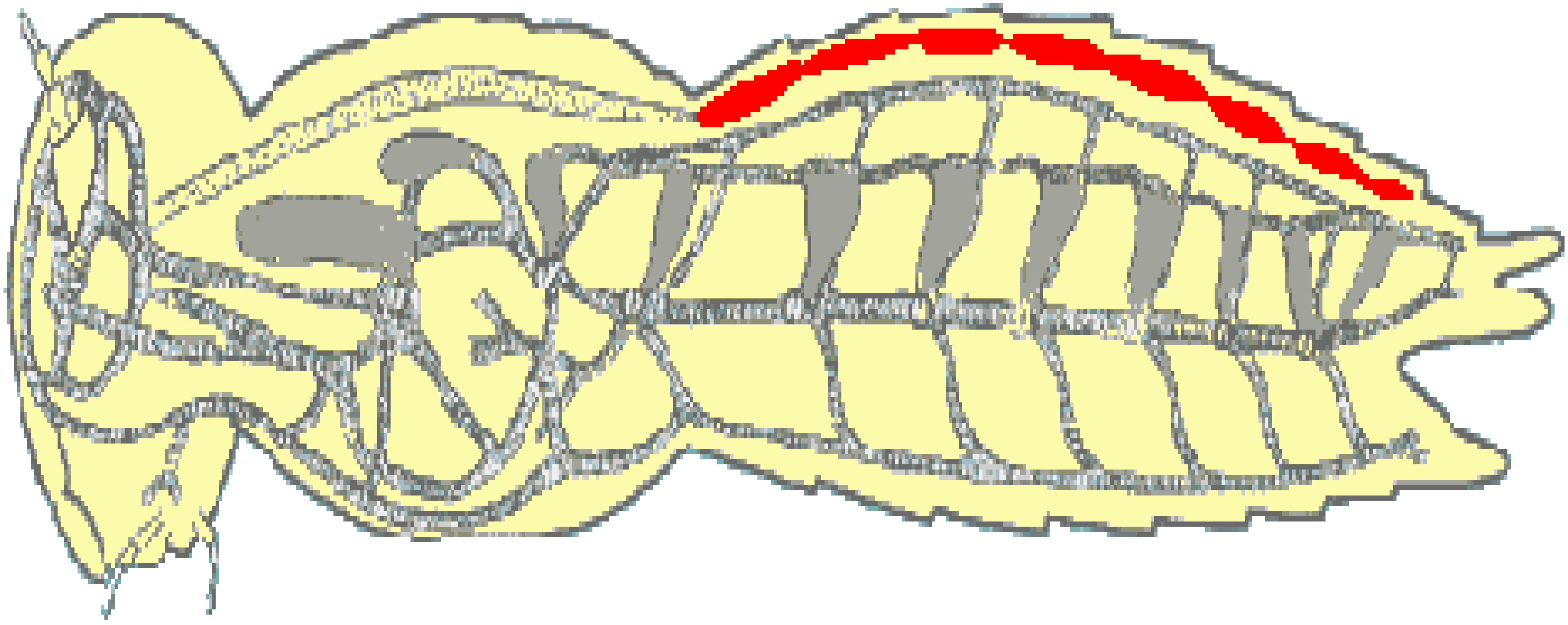
- **Dorsal blood vessel**
- It is the **main organ of circulation** and consists of **anterior aorta and posterior heart.**
- lies along the dorsal midline of the insect body.
- The dorsal vessel is a simple tube closed at its posterior end and bears a number of vulvular openings called as **ostia** (prevents back flow of haemolymph)
- **The number of ostia are**
- 3 pairs –thorax
- 9 pairs -abdomen

Dorsal Vessel



- **Hemocoel**
- The main body cavity of invertebrates, such as insects.
- The compartmentalized structure of this cavity is due to the presence of one or two fibromuscular septa.
- Organs of the insect are suspended in this cavity.

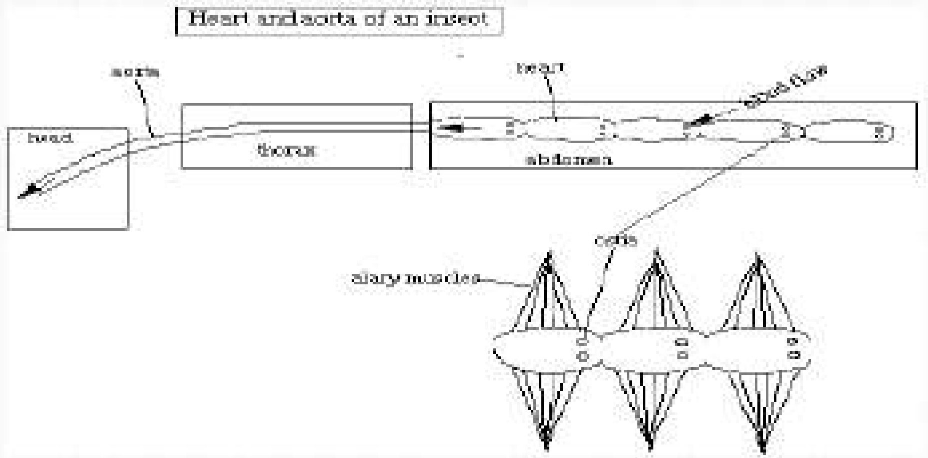
- **Heart**
- In the abdomen, the dorsal vessel is called the heart. It is divided in segments into chambers that are separated by valves (ostia) to ensure one-way flow of hemolymph.
- Usually closed at its posterior end.



- The heart's contraction rate varies considerably from species to species -- typically in the range of 30 to 200 beats per minute.

- The rate tends to fall as ambient temperature drops and rise as temperature (or the insect's level of activity) increases.

- **<u>Alary muscles</u>**
- A pair of alary muscles are attached laterally to the walls of each chamber.
- Fibromuscular innervated structures attached laterally to the body wall and vary in number from 1-13 pairs.
- Contractions of the these muscles force the hemolymph forward from chamber to chamber.

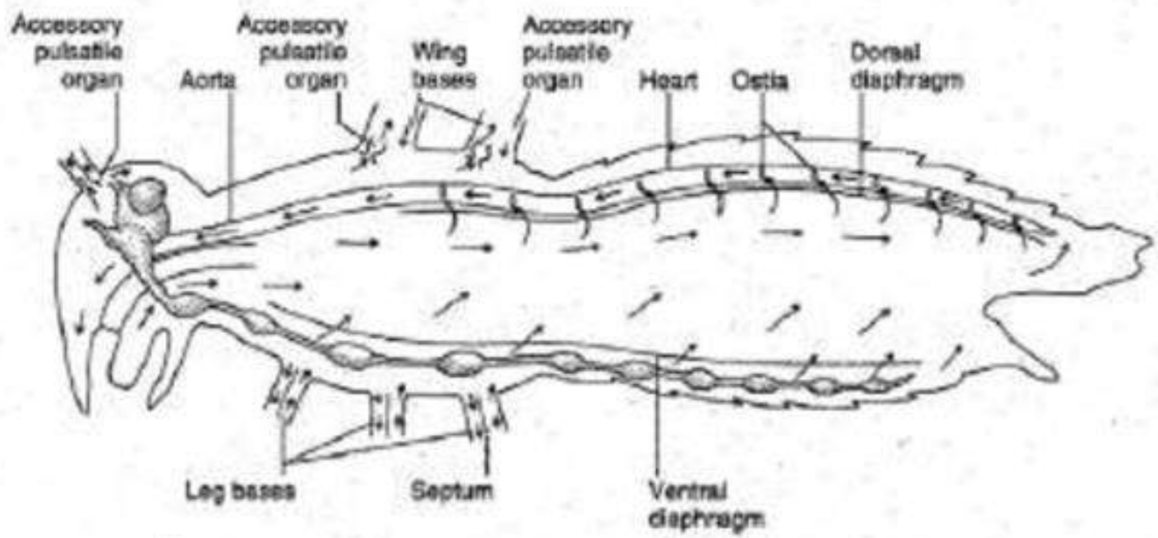


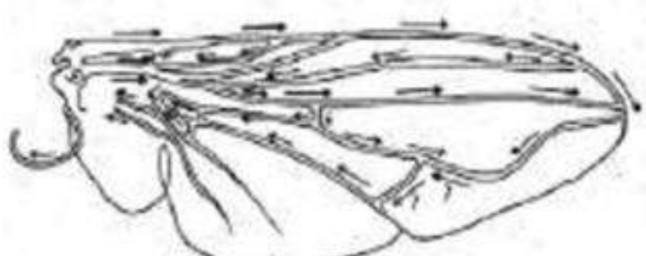
Aorta

- In front of the heart, the dorsal vessel lacks valves or musculature. It is a simple tube (called the aorta) which continues forward to the head and empties near the brain.

- Hemolymph bathes the organs and muscles of the head as it emerges from the aorta, and then haphazardly percolates back over the alimentary canal and through the body until it reaches the abdomen and re-enters the heart.

✓ **Accessory pulsatile organs**: Insects consists of **sac like structures** called **accessory pulsatile organs**, which are present at **the base of the appendages such as wings, legs and antenna**. They pulsate independently and supply adequate blood to the appendages.

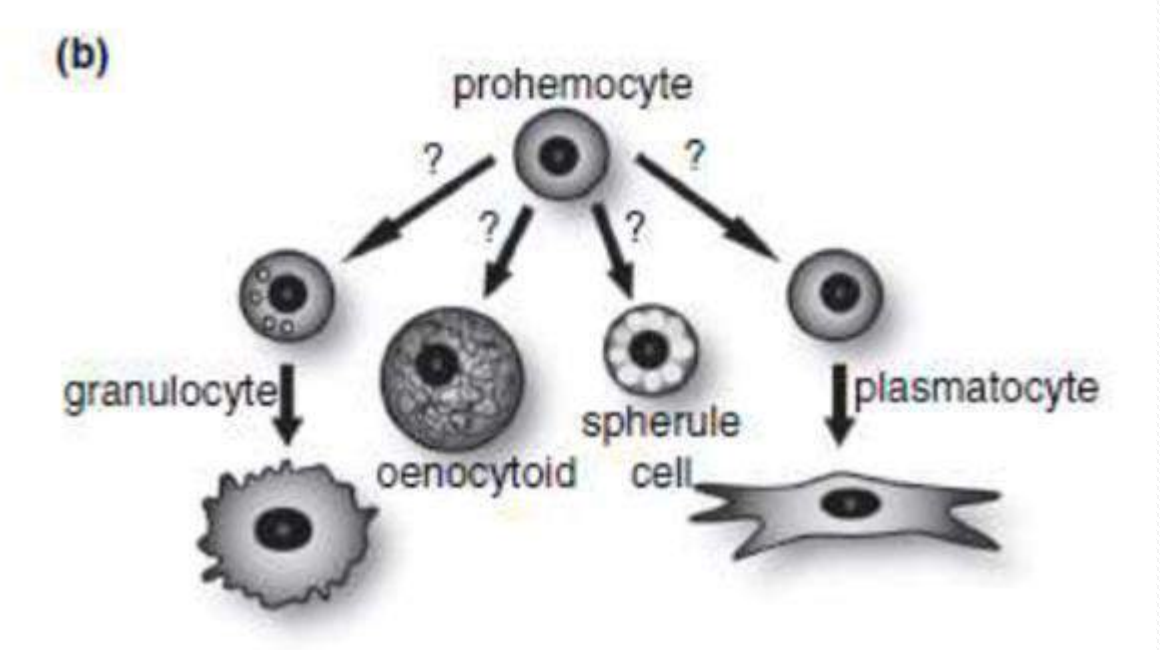


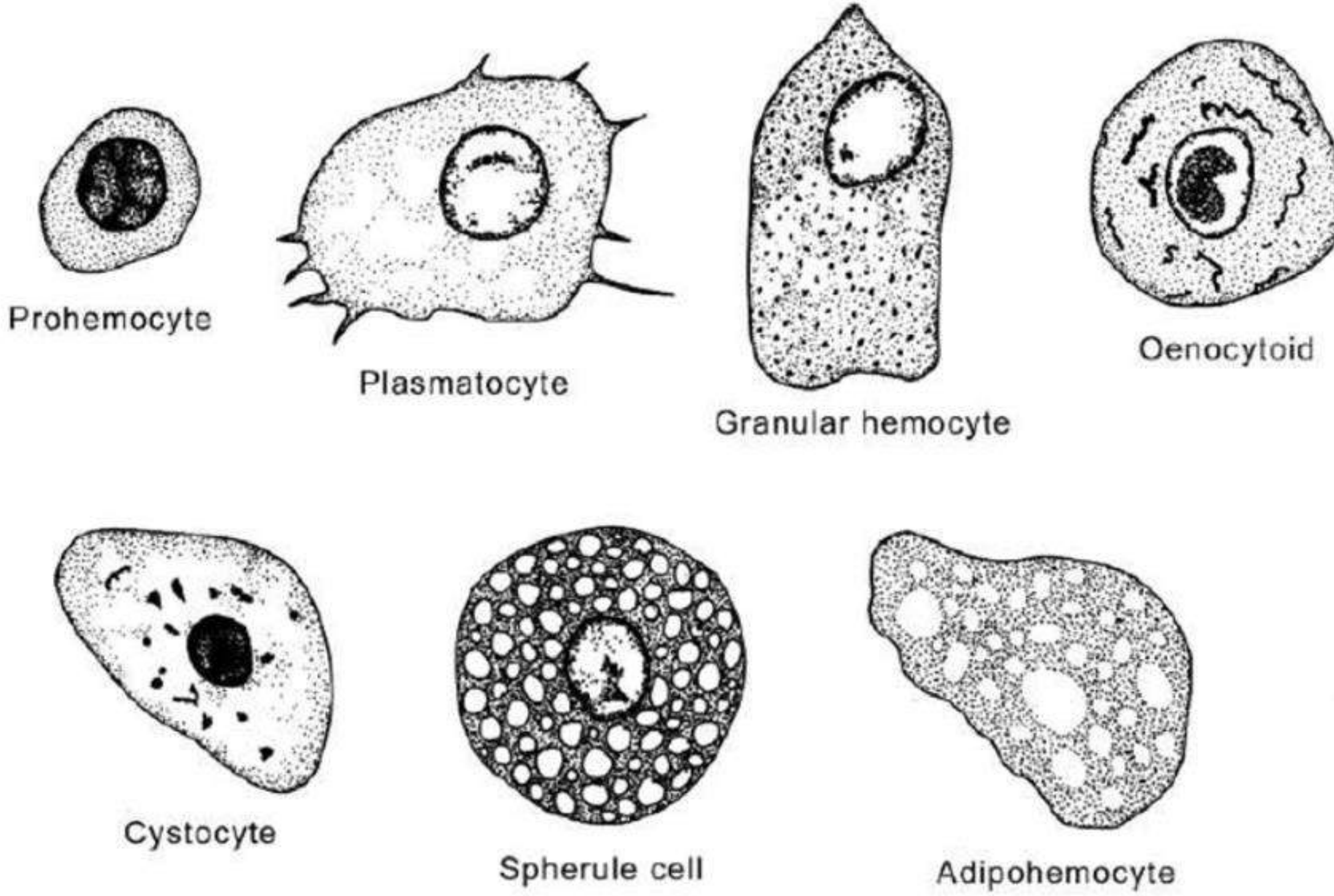


- **Haemolymph**
- Colorless liquid that bathes the insect tissues.
- Lack hemoglobin unlike humans
- Oxygen is delivered by respiratory system
- **Composition of Haemolymph** -contains a **fluid portion** called **plasma and cellular fractions** called **haemocytes.**

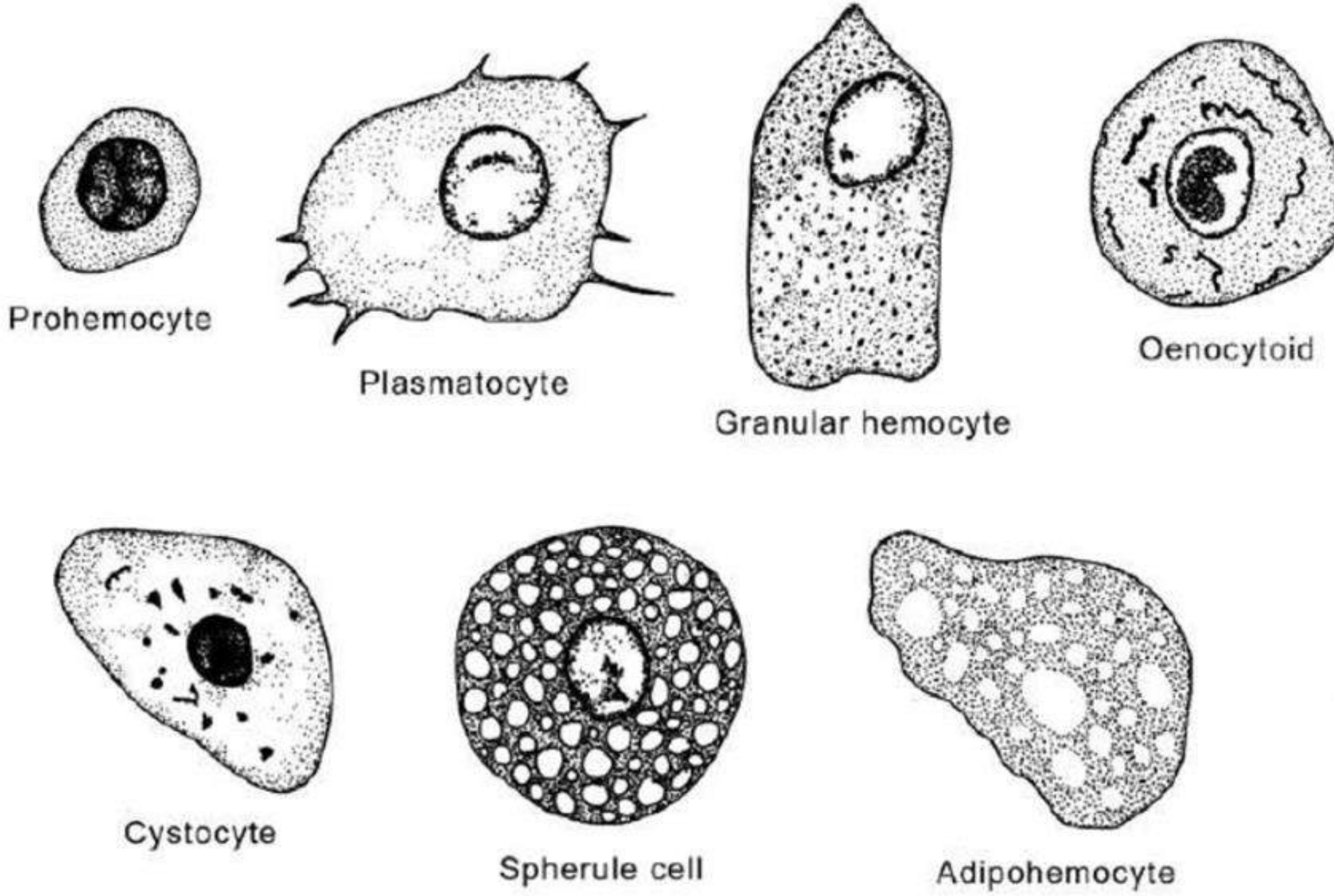
- **1.Plasma:** Plasma is an aqueous solution of inorganic ions, lipids, sugars (mainly trehalose), amino acids, proteins, organic acids and other compounds.
- pH is usually acidic (6-7).
- Density is 1.01 to 1.06.
- Water content is 84-92 per cent.
- Inorganic ions present are `Na' in predators and parasites, `Mg' and `K‘ in phytophagous insects.
- Blood lacks vitamin **‘K’**
- Carbohydrate is in the form of trehalose sugar.
- Major proteins are lipoproteins, glycoproteins and enzymes. Lipids in form of fat particles or lipoproteins.
- Glycerol is present which acts as a anti freezing compound.

- **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




Prohemocyte
Plasmatocyte
Granular hemocyte
Oenocytoid
Cystocyte
Spherule cell
Adipohemocyte

- 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.


Prohemocyte
Plasmatocyte
Granular hemocyte
Oenocytoid
Cystocyte
Spherule cell
Adipohemocyte

Process of blood circulation

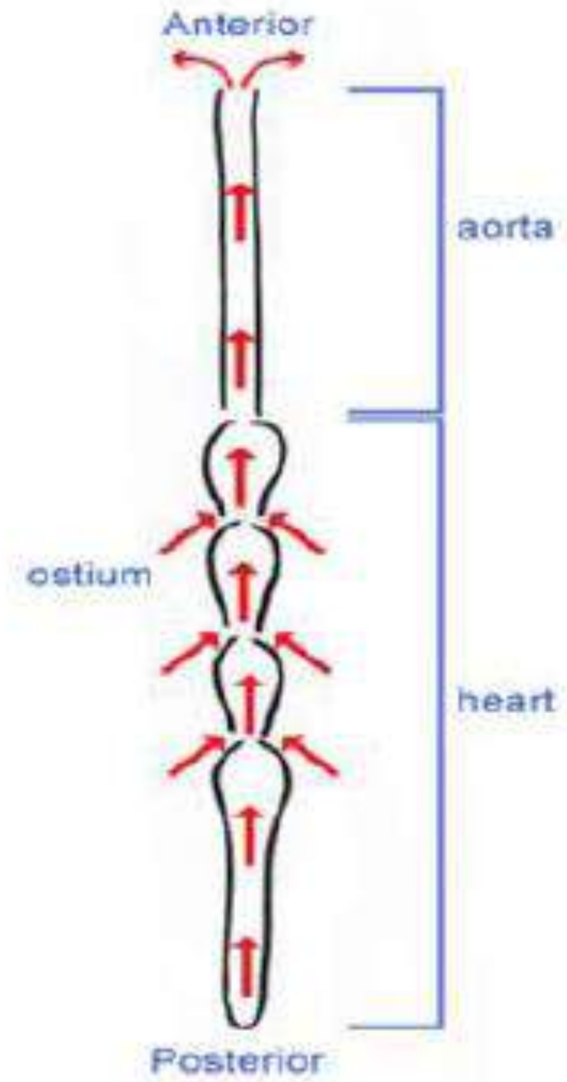
- Heart mainly function as a pulsatile organ whose expansion and contraction leads to blood circulation .
- It takes place generally in **an anti clock manner starting from posterior end to the anterior end in a forward** direction.
- Circulation of blood takes place in two phases due to the action of the alary muscles as well as the muscles of the walls of the heart.
- **<u>The two phases are</u>**
- 1. **Diastole:** During which expansion of heart takes place.
- 2. **Systole :** Contraction of heart takes place**.**

- **1. Diastole: Expansion of heart (diastole)**. It results in **increase of volume of heart and decrease in the area of pericardial sinus.** This creates a pressure on the blood in pericardial sinus forcing the blood to enter into the heart through the incurrent ostia. These incurrent ostia allow only the entry of blood from the sinus in to the heart and prevents its backflow from the heart to the sinus.

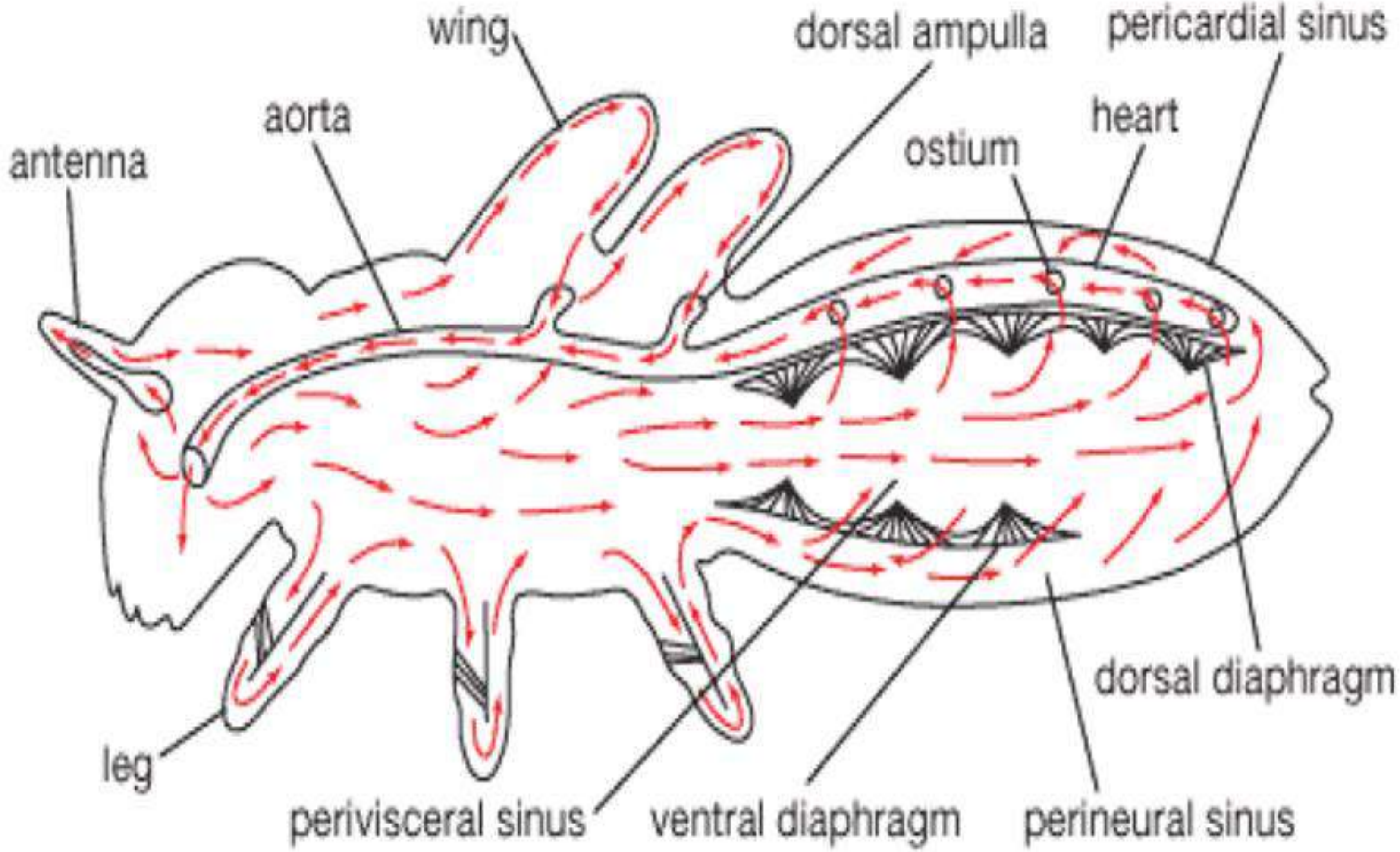
- **2. Systole : Contraction of heart (systole).** This **creates pressure on the blood within the heart leading to its forward movement in to the** aorta. From the aorta blood enters in to the head and flows back bathing the visceral organs in the visceral sinus and neural cord in the perineural sinus.

- In **between diastole and systole** there will be a short period of rest which is known as **diastasis.**

DORSAL VESSEL (HEART) OF INSECT



Heamolymph Flow in Insect



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.

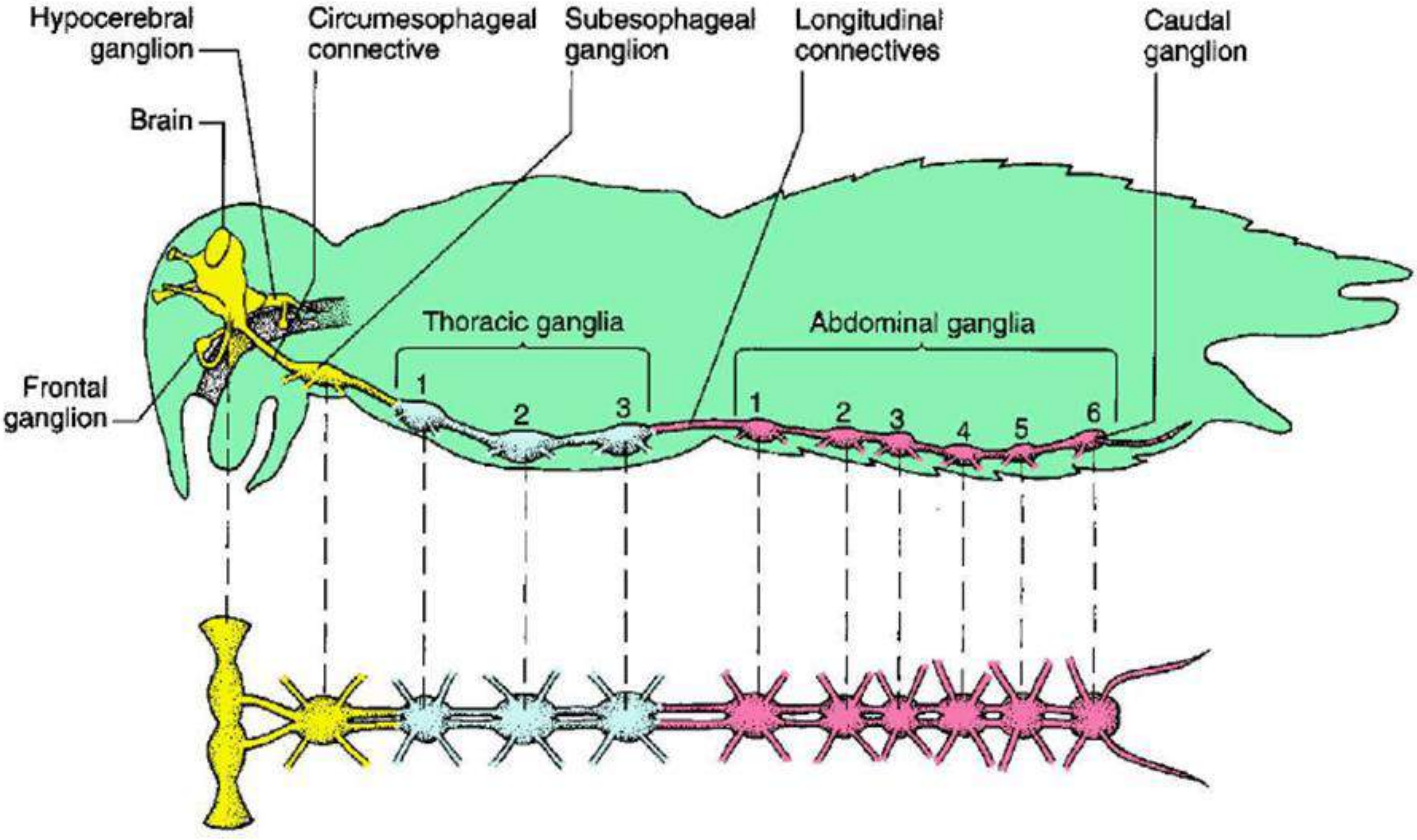
- **7. Reflex bleeding**: Exudation of heamolymph through slit, pore etc. repels natural enemies. e.g. Aphids.

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

Nervous system

- An insect's nervous system is a network of specialized cells called **neurons** that serve as an "information highway" within the body.

- The nervous system of insect functions to **generate and transport electrical impulses**, to integrate information received and to stimulate muscles for movement.



Hypocerebral ganglion
Circumesophageal connective
Subesophageal ganglion
Longitudinal connectives
Caudal ganglion
Brain
Frontal ganglion
Thoracic ganglia
1
2
3
Abdominal ganglia
1
2
3
4
5
6

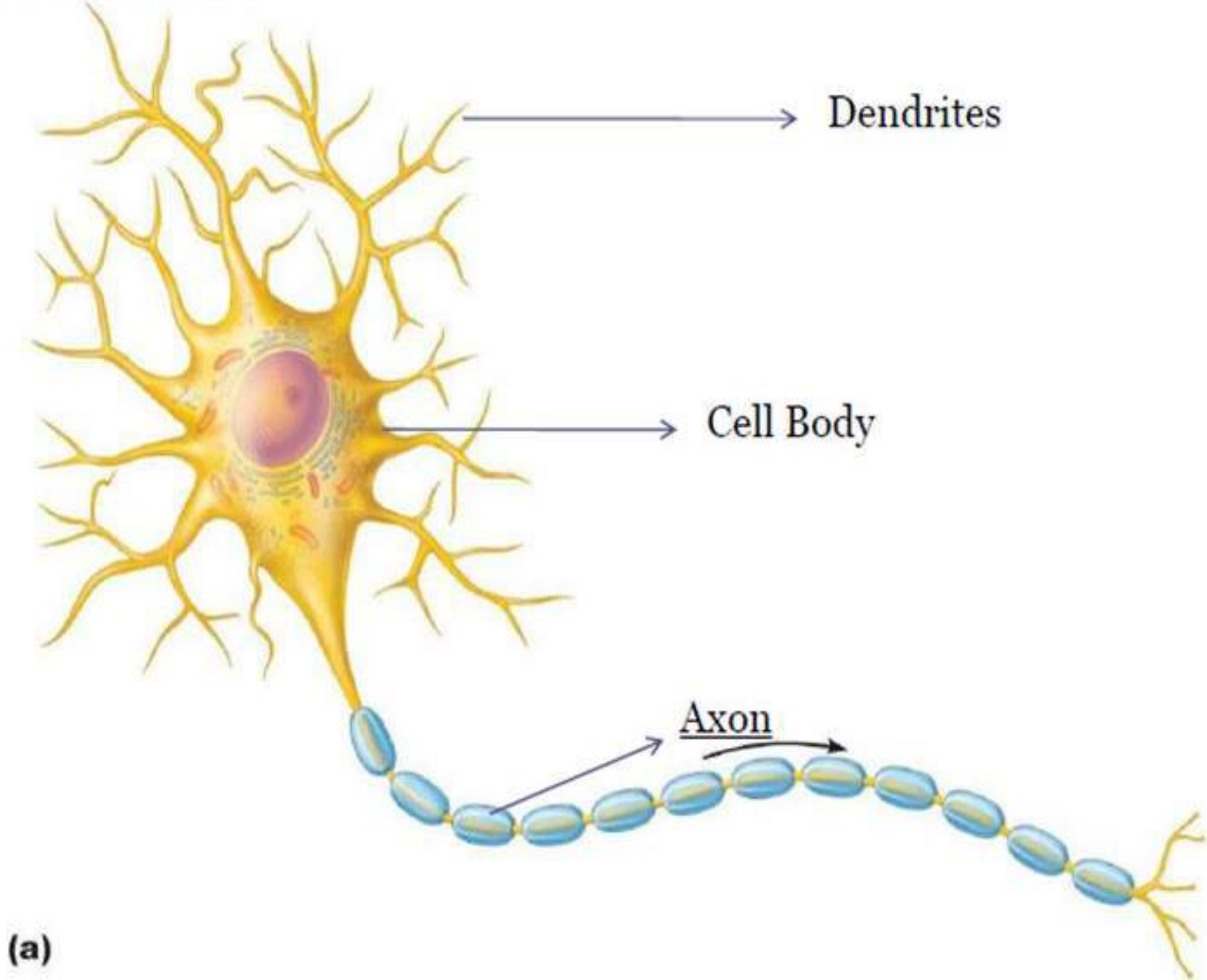
Neuron

- The **basic unit of nervous system** that functions in nerve impulse transmission is the nerve cell or neuron.

- **A neuron is composed of:**

- A cell body where nucleus is found (soma)
- One or more receptor fibrils=Dendrites
- An axon that branches at the tip

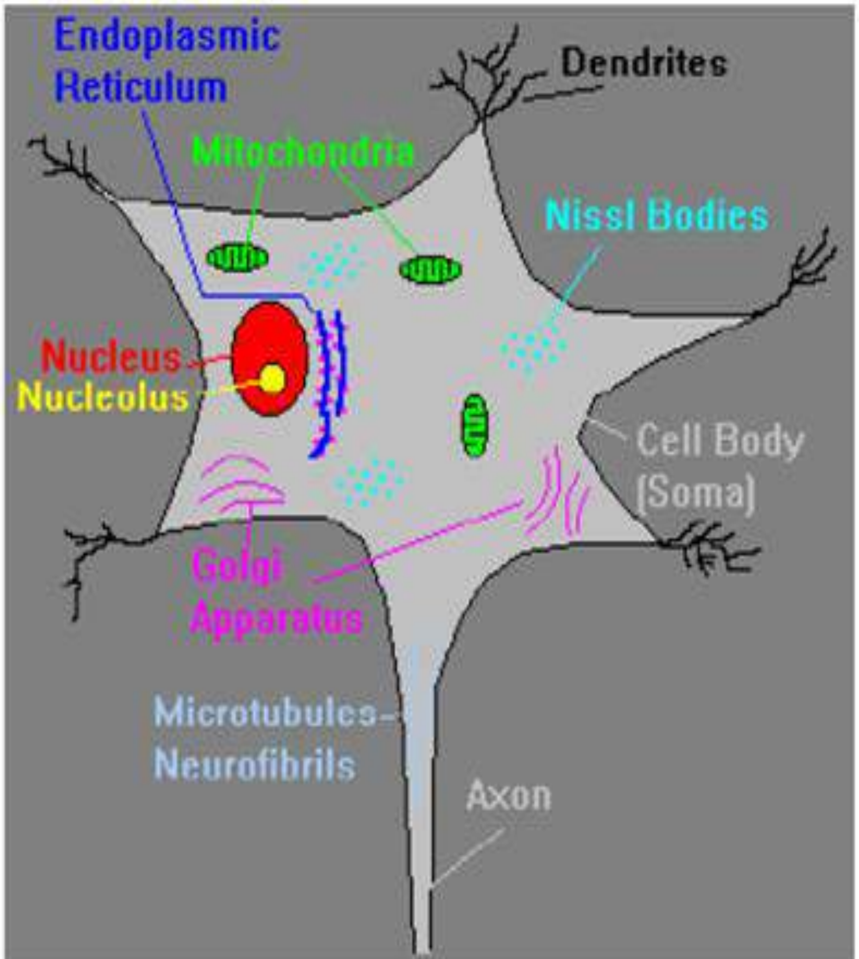
NEURON

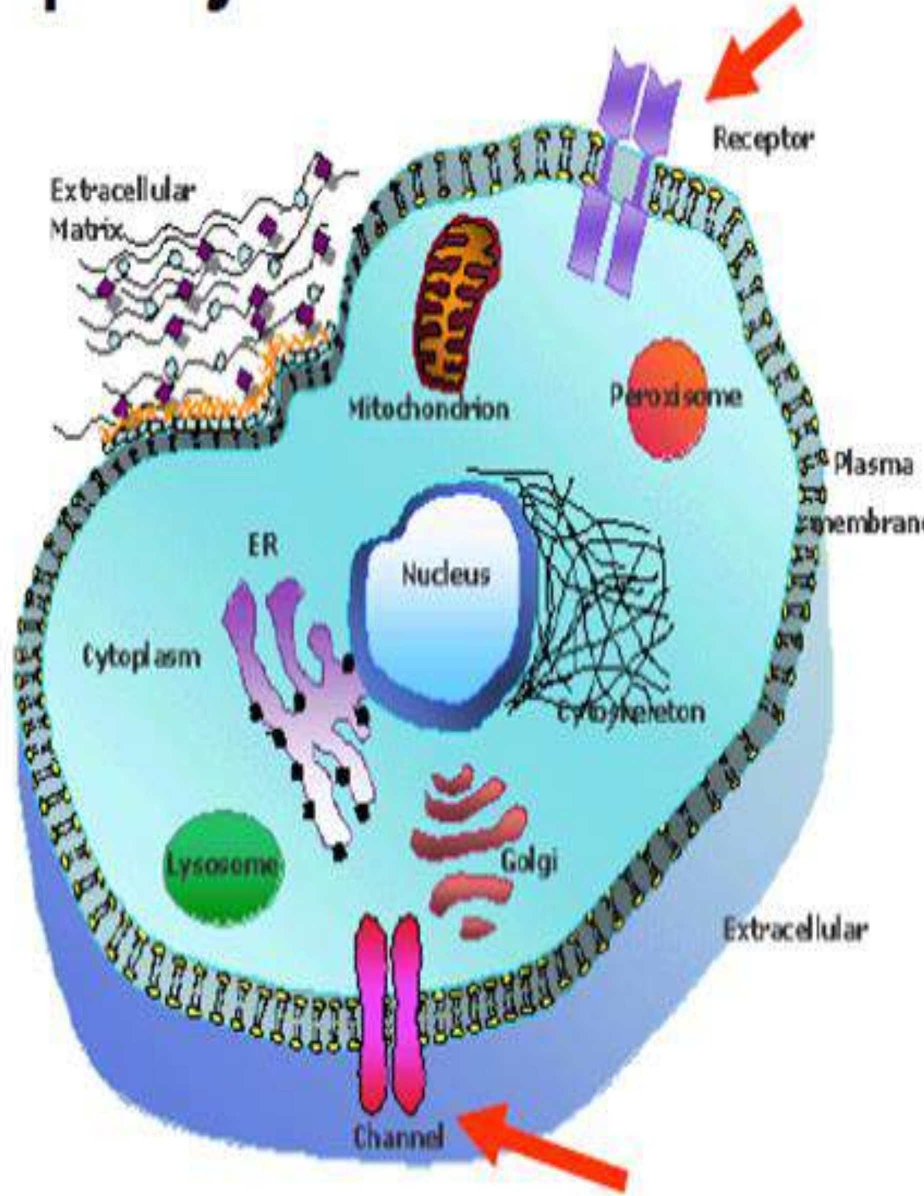


Neuron has projections

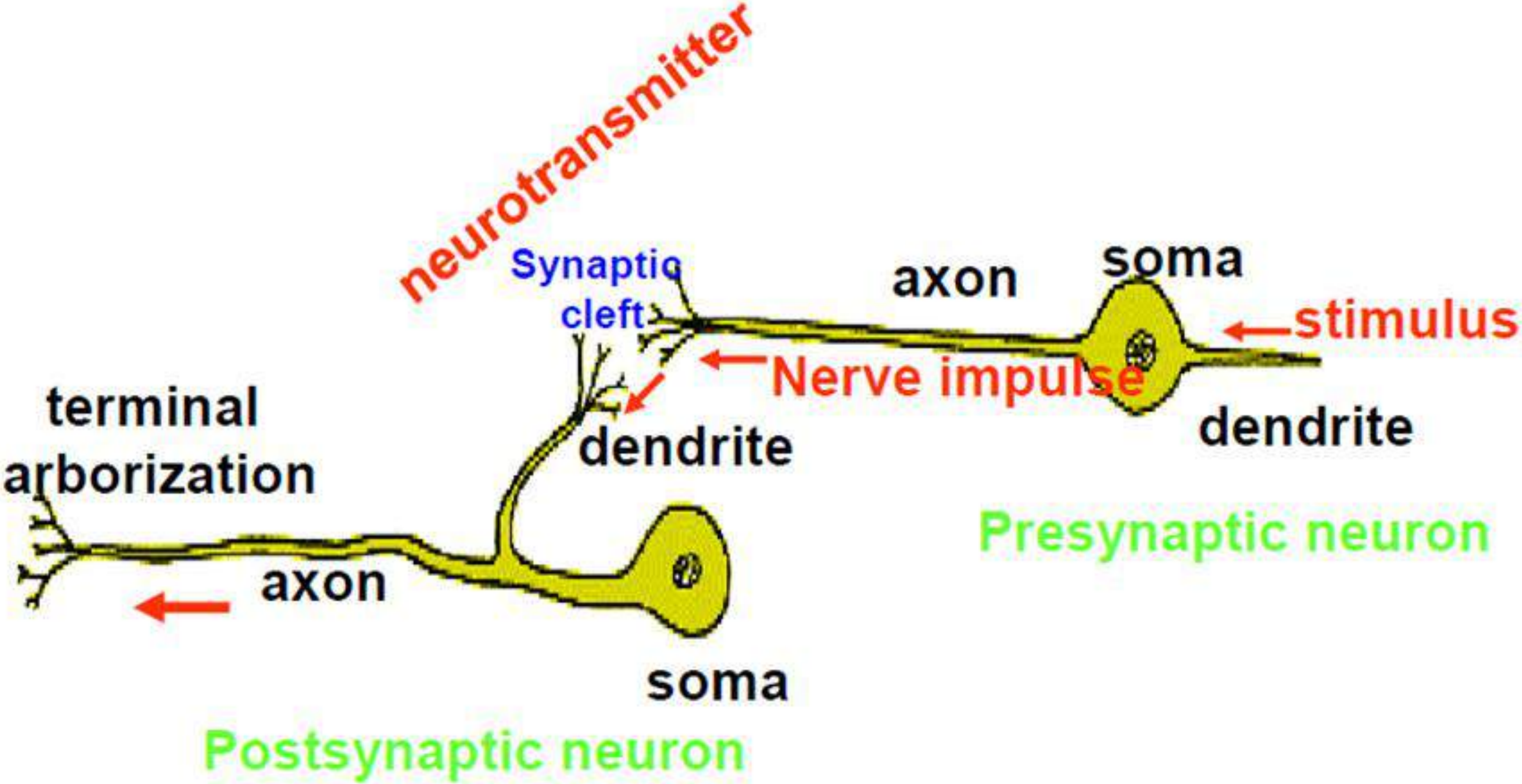
- Neurons similar to other cells, but:
- 1.have specialized extensions called **dendrites** and **axons**. Dendrites bring information to the soma and axons take information away from the soma.
- 2.Neurons communicate with each other through specialized structures called synapses and chemicals (e.g. neurotransmitters).

Neuron has projections





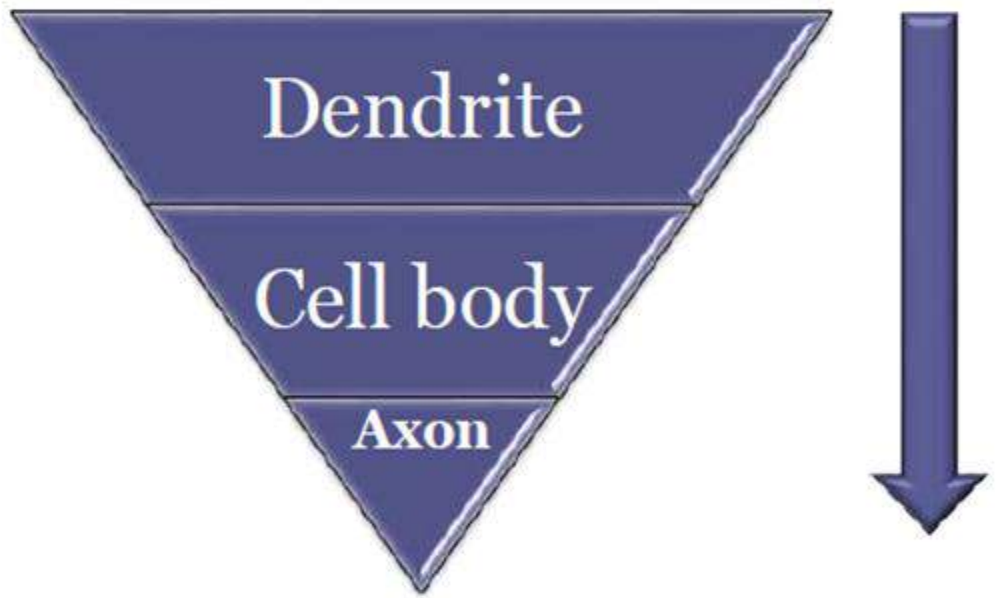
Neuron-neuron junction: synapse



Remember: electric synapse

Signal transmission

- Signal transmission is always **unidirectional**, moving toward the nerve cell body along a dendrite and away from the nerve cell body along an axon.

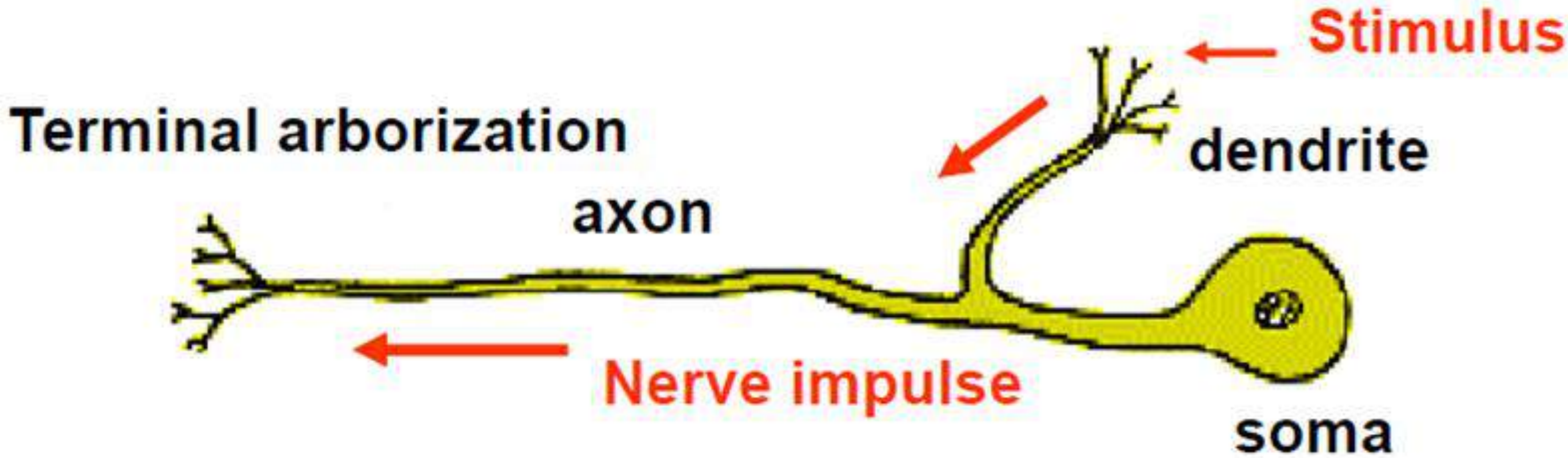


- **A. On structural basis**
- i. **Monopolar**: neuron with a single axon
- ii. **Bipolar**: neuron with a proximal axon and a long distal dendrite.
- iii. **Multipolar**: neuron with a proximal axon and many distal dendrites.

- **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.**

Types of neuron: unipolar

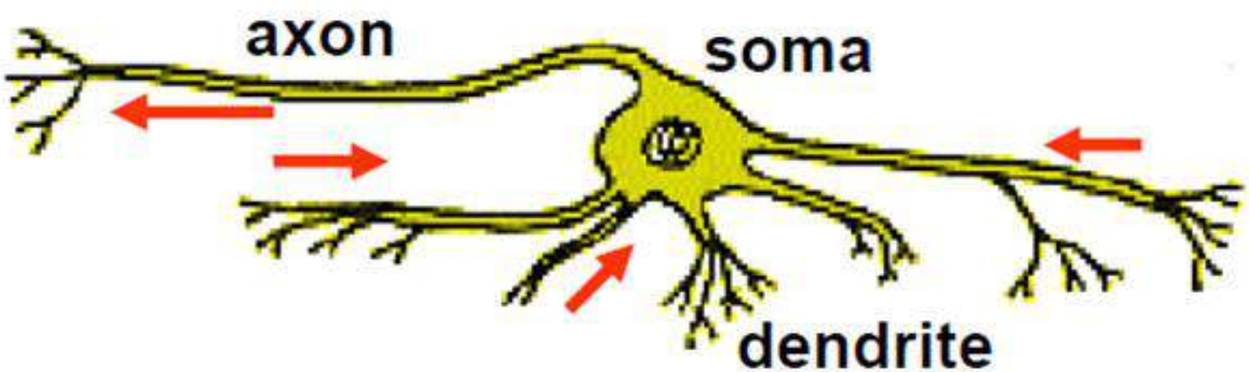
one projection extending from the soma



Types of neuron: bipolar

- Two projections extending from the cell body
- Typical of sensory neuron

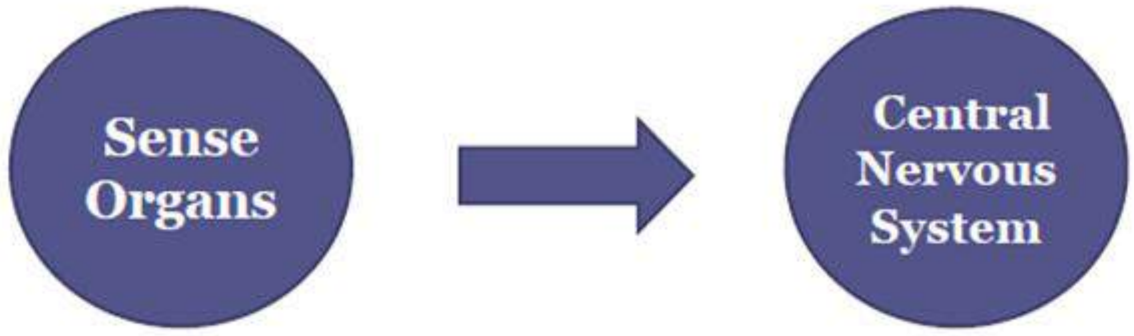
Types of neuron: multipolar



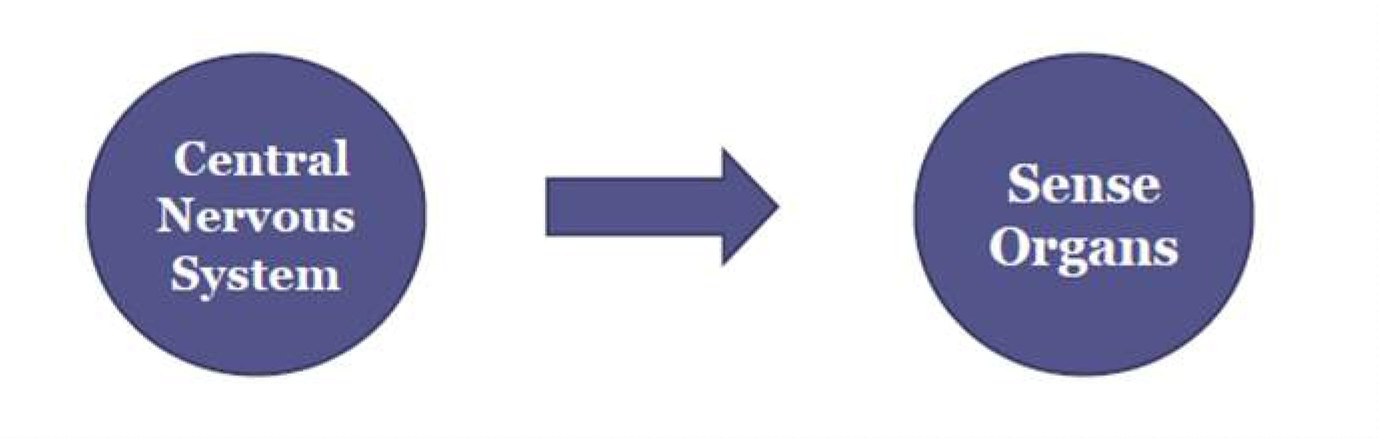
Many projections extending from the soma
But only one axon

- Neurons are usually divided into three categories, **depending on their function** within the nervous
- system:

- **1. SENSORY NEURONS:** These bipolar or multipolar cells have dendrites that are associated with sense organs . They always carry information **toward** the central nervous system.



- **MOTOR NEURONS :** These unipolar cells that conduct signals **away from** the central nervous system and stimulate responses in muscles and glands.



- **INTERNEURON (ASSOCIATION) NEURONS:** These neurons connect sensory and motor neurons that conduct signals **within** the central nervous system.

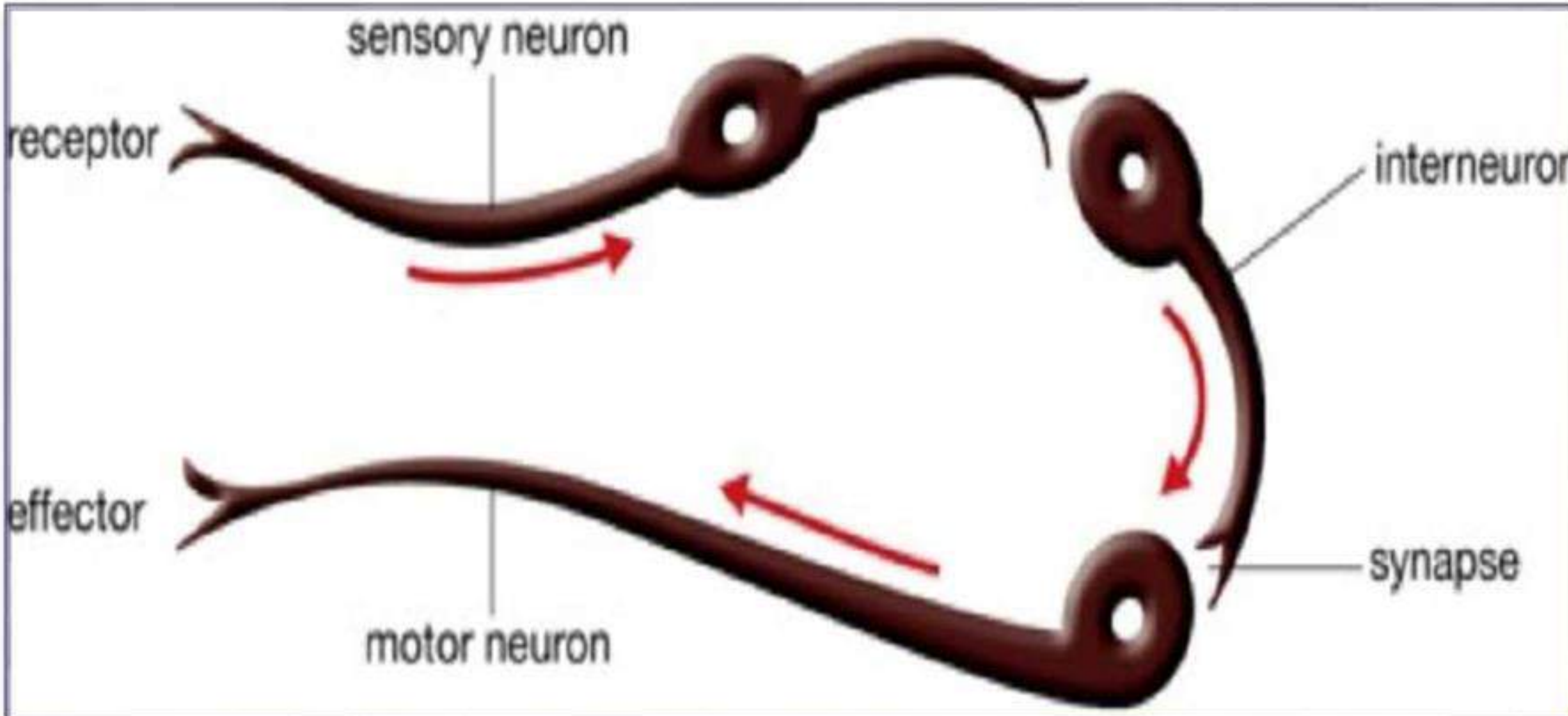
Types of neuron: two ways of classification

By the number of extensions

- unipolar neurons have one projection extending from the soma.
- Bipolar neurons have two projection extending from the soma
- Multipolar neurons have many projections extending from the soma. However, each has only one axon

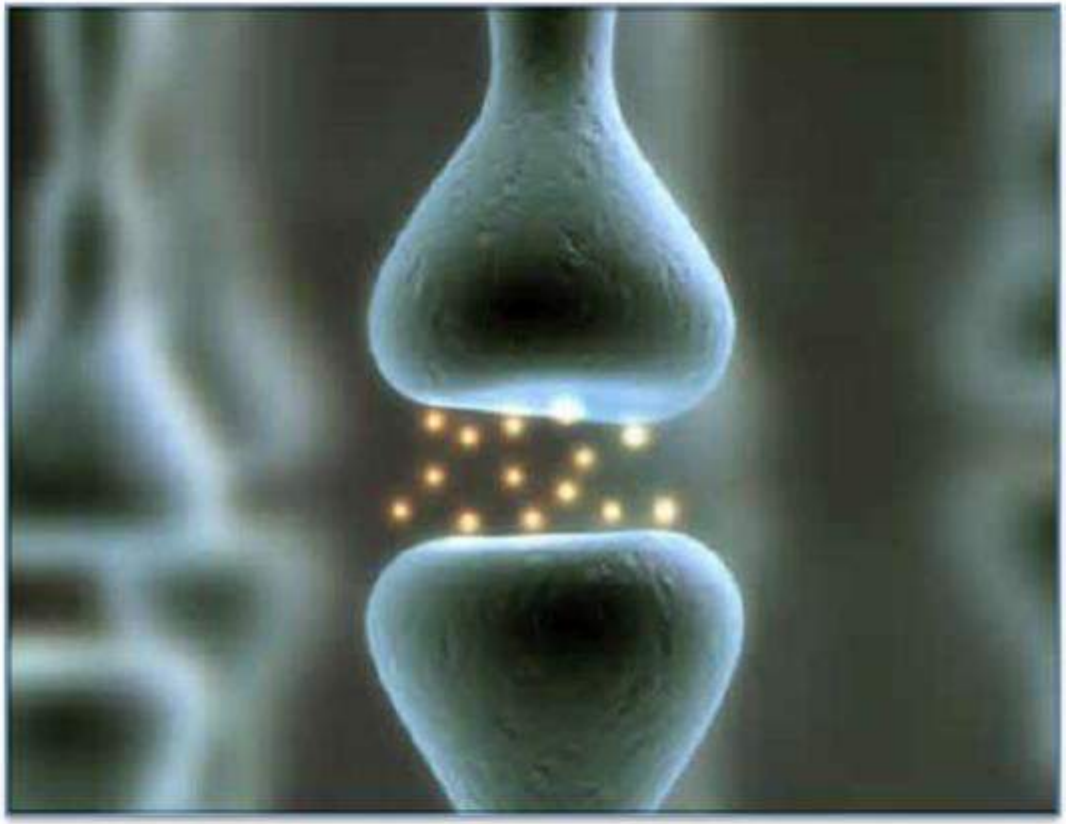
By the direction of information that they send (function)

- **Afferent (sensory) neurons** --bipolar or multipolar cells have dendrites that are associated with sense organs. They carry information **TOWARD** the central nervous system (CNS).
- **Efferent (motor) neurons** -- unipolar cells that conduct signals **AWAY** from CNs and stimulate responses in muscles and glands.
- **Interneuron (association neuron)** -- unipolar cells that form connections between afferent and efferent neurons and conduct signals **WITHIN** CNS.

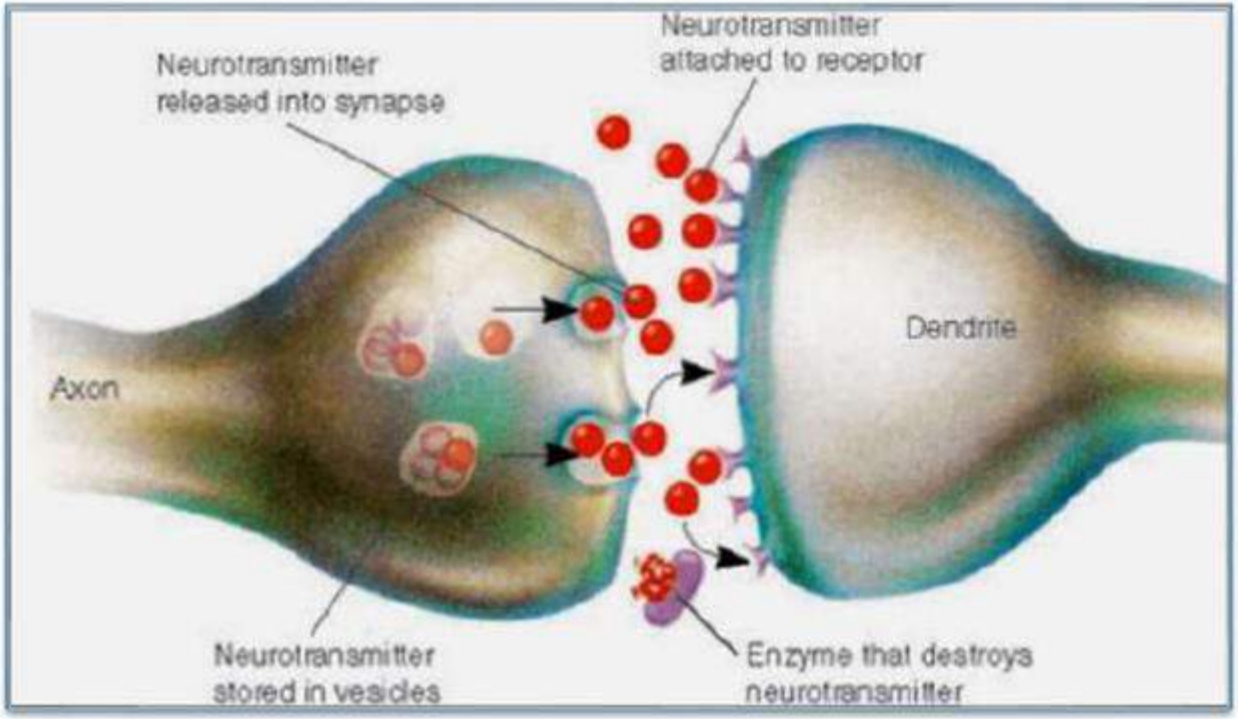


sensory neuron
receptor
interneuron
effector
synapse
motor neuron

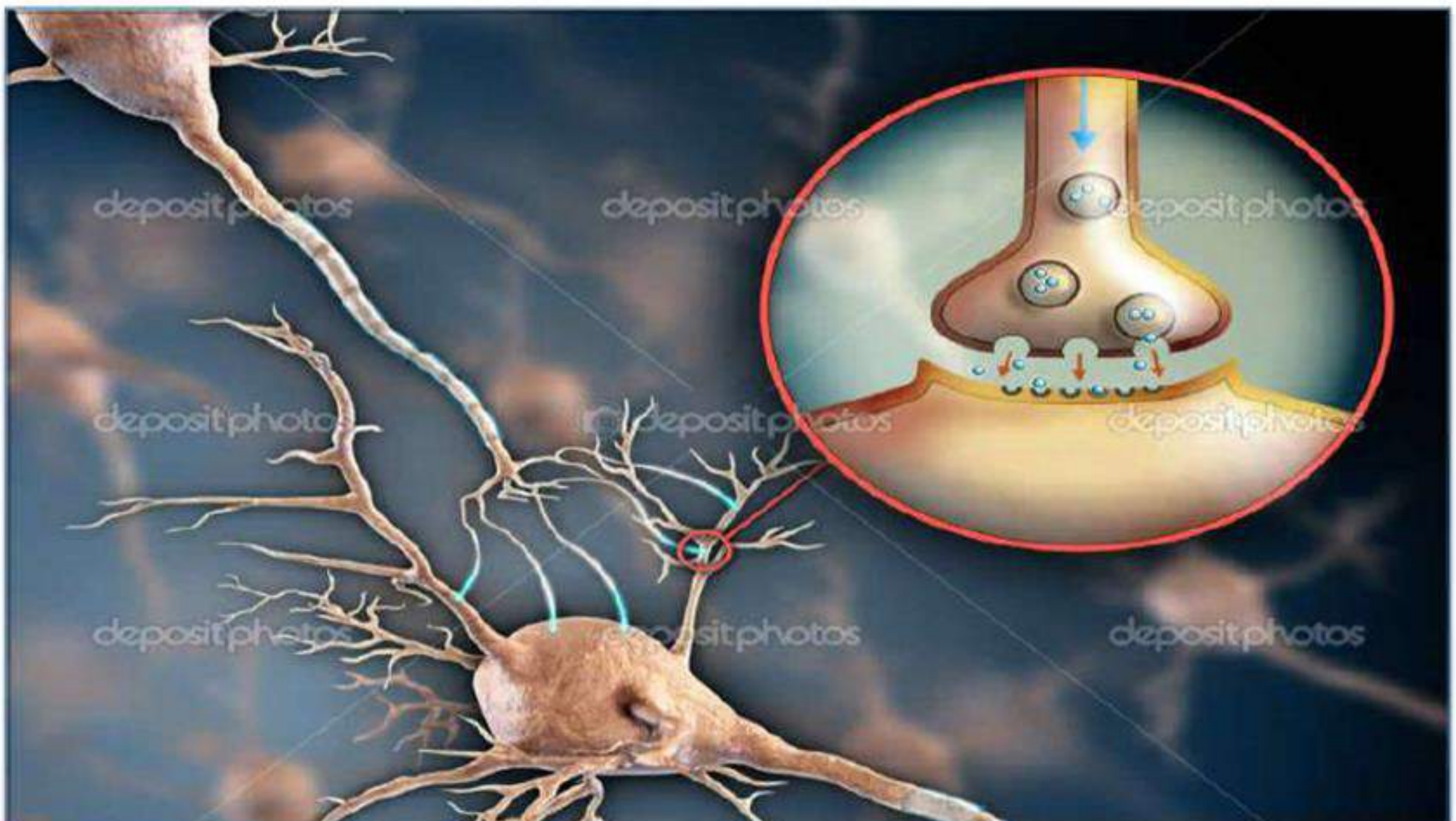
- Individual nerve cells connect with one another through special junctions, called **synapses**.



- When a nerve impulse reaches the synapse, it releases a chemical messenger (**neurotransmitter** substance) that diffuses across the synapse and triggers a new impulse in the dendrite(s) of one or more connecting neurons.

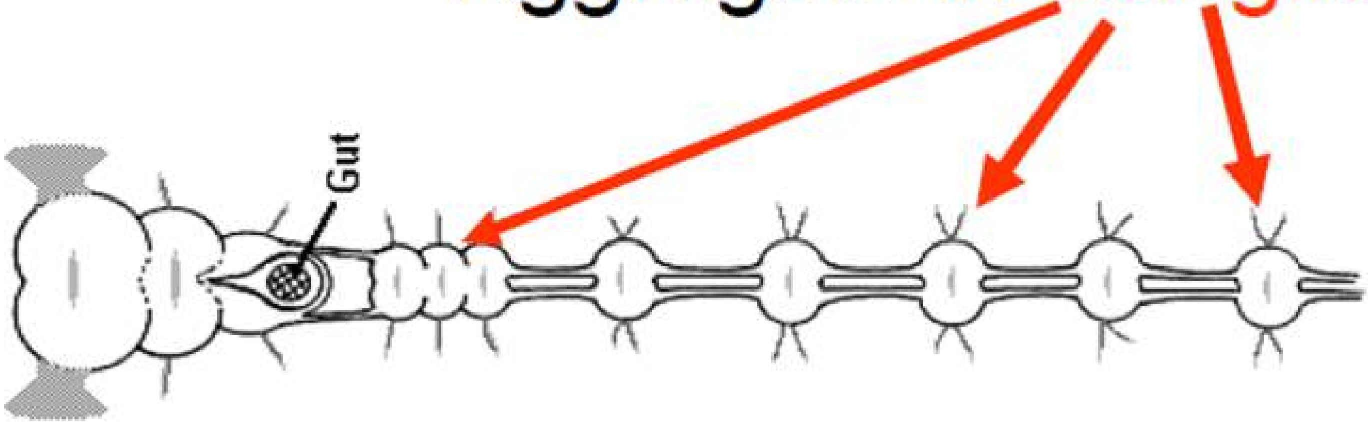


- Acetylcholine, 5-hydroxytryptamine, dopamine, and adrenaline are examples of neurotransmitters found in **both** vertebrate and invertebrate nervous systems.



Where are motor neurons and interneurons?

Aggregate in Ganglion



- Nerve cells are typically found grouped in bundles. A **nerve** is simply **a bundle of dendrites or axons** that serve the same part of the body.

- A **ganglion** is a dense **cluster of interconnected nerves** that process sensory information or control motor outputs.

- 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.
- **1)Protocerebrum:** Large, innervate compound eyes and ocelli.
- **2)Deutocerebrum:** Found beneath protocerebrum, innervate antennae.
- **3)Tritocerebrum:** Bilobed, innervate labrum.
- Brain is the main sensory centre controlling insect behaviour.

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

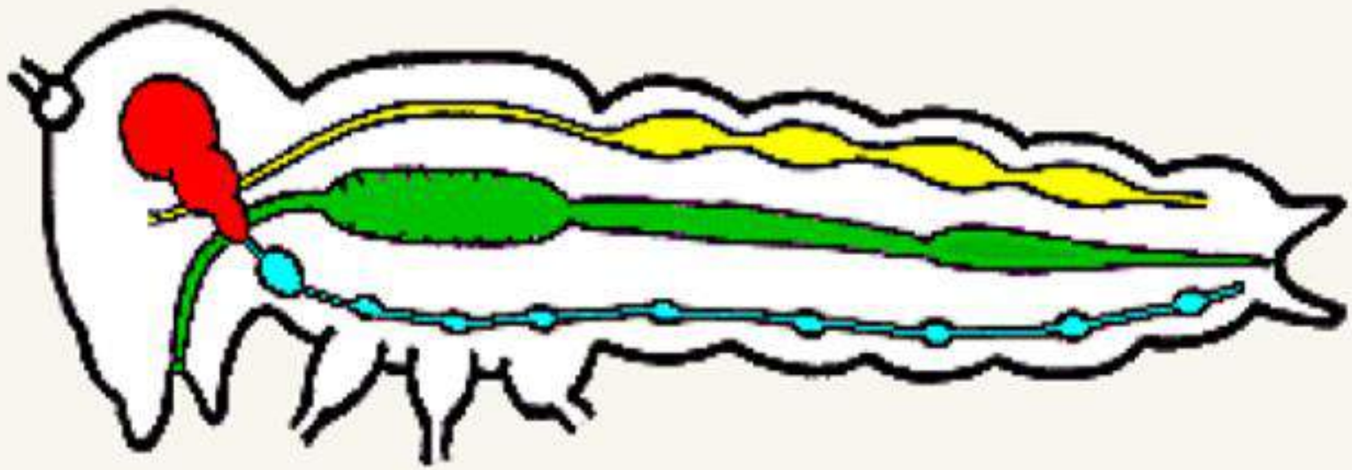
- **c. Sub esophageal ganglia**: Formed by the last three cephalic neuromeres which innervate mandible, maxillae and labium.

- **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.

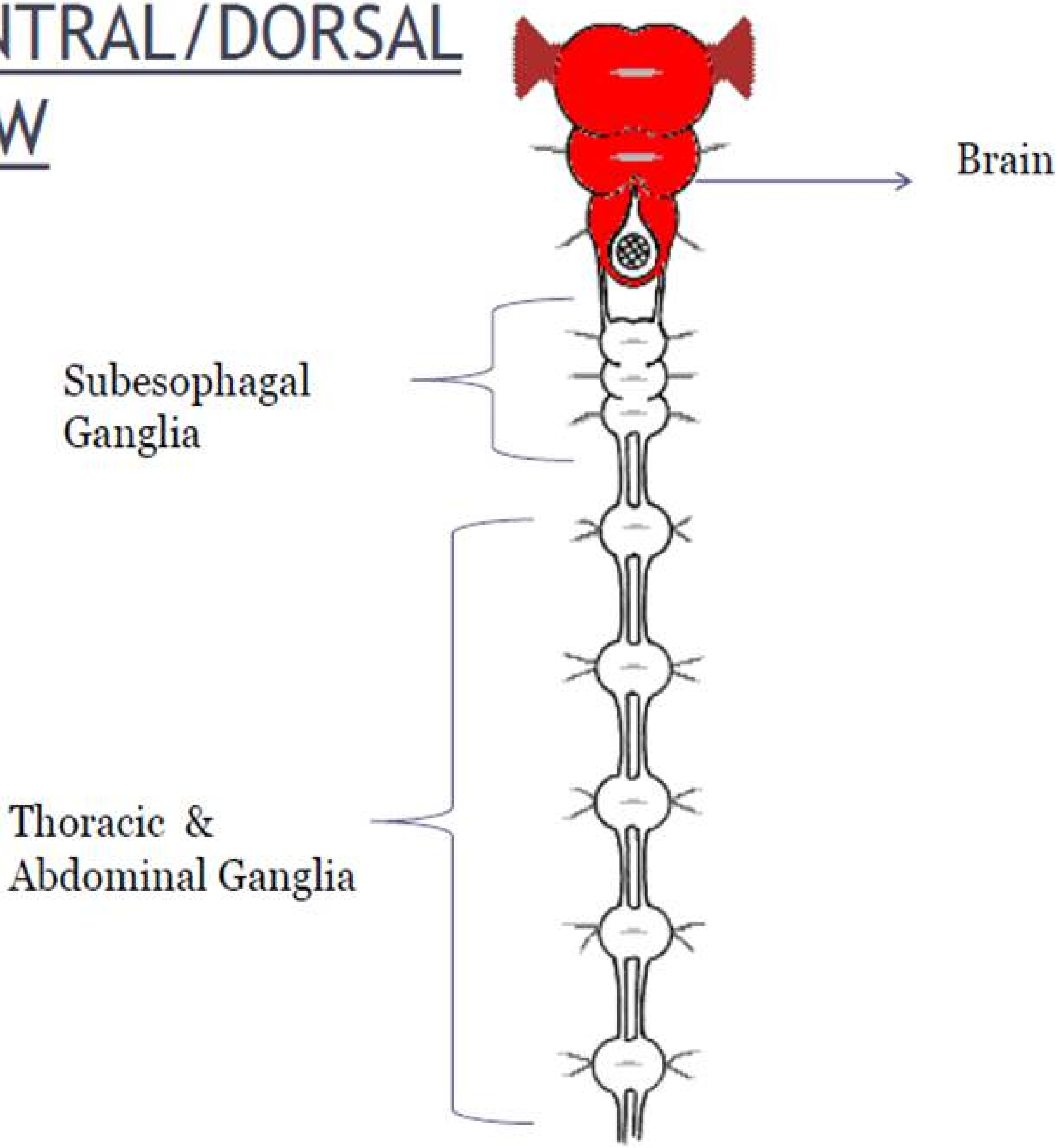
- **f. Thoracico abdominal ganglia :** Thoracic and abdominal ganglia are fused to form a single compound ganglia. Innervate genital organs and cerci.

LATERAL VIEW



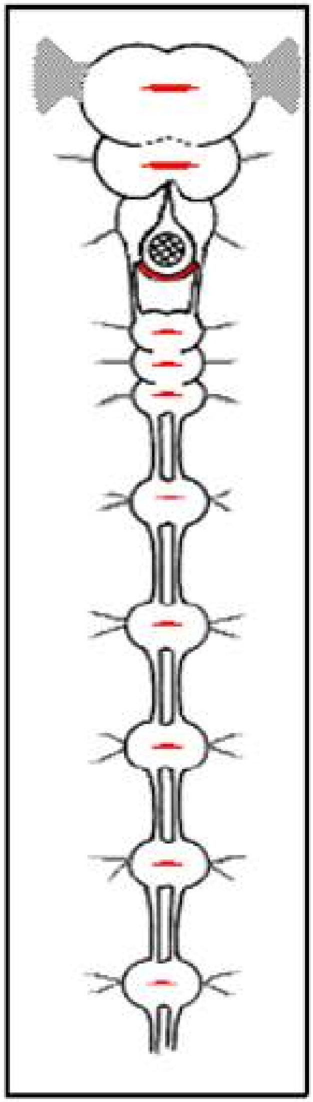
Side view of body showing relative position of circulatory (yellow), digestive (green), and nervous (blue) systems. Brain (Red)

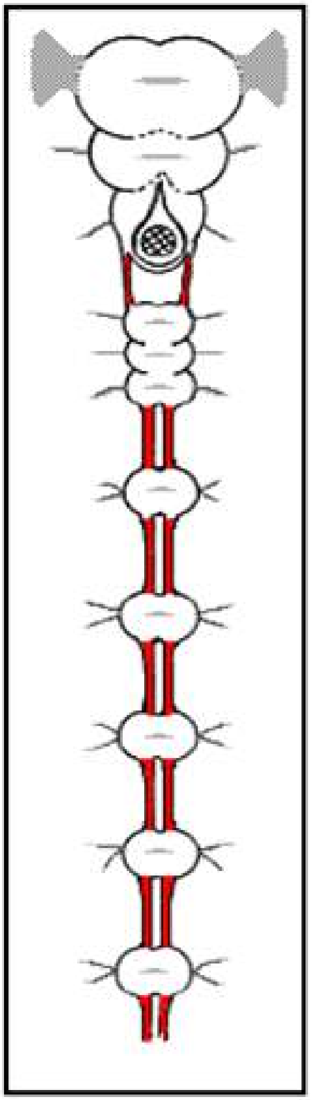
VENTRAL / DORSAL VIEW



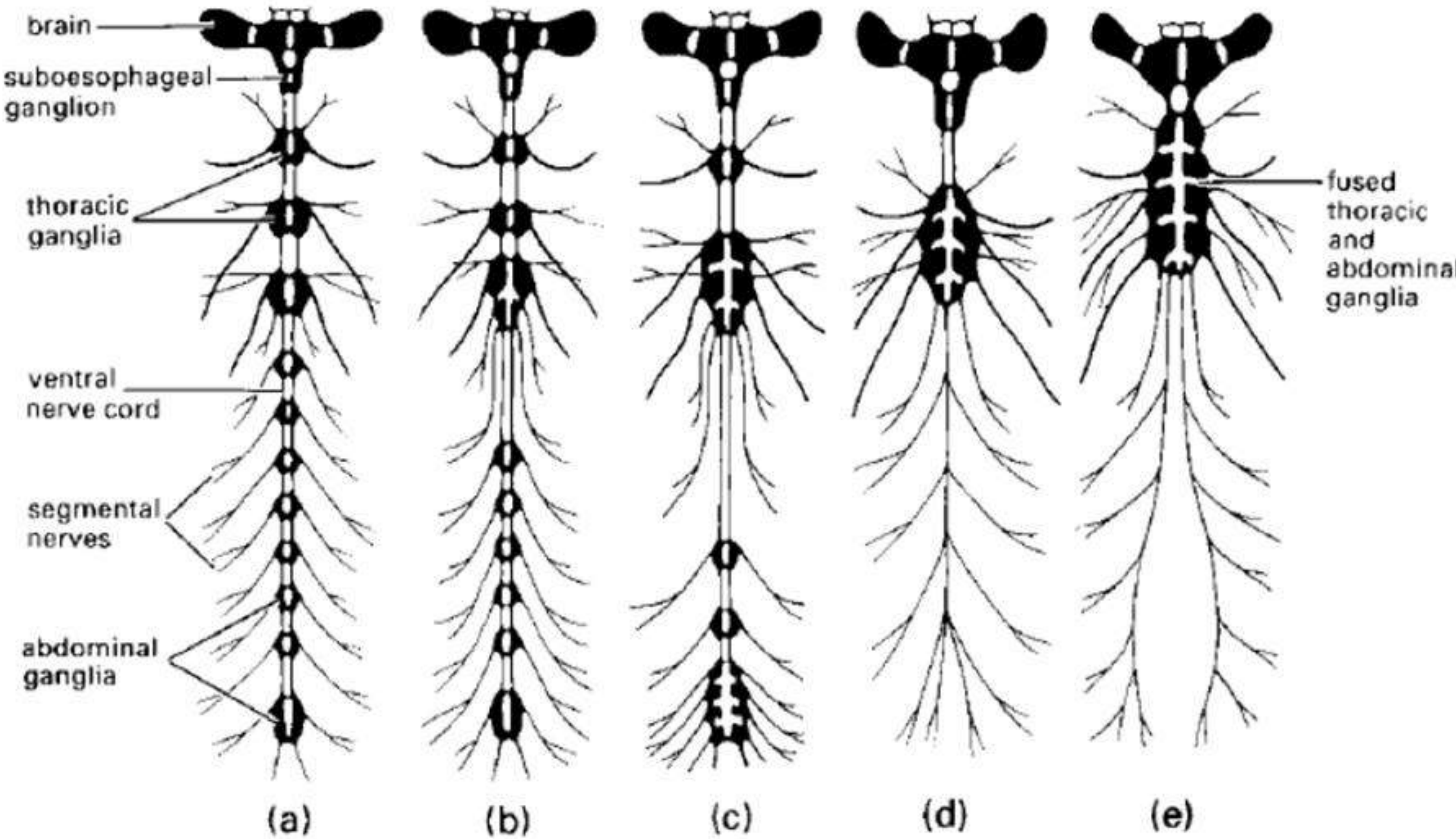
- Ganglia within each segment are linked to one another by a short medial nerve (<u>commissure</u>) and also joined by <u>intersegmental connectives</u> to ganglia in adjacent body segments.

Commissure nerves in red

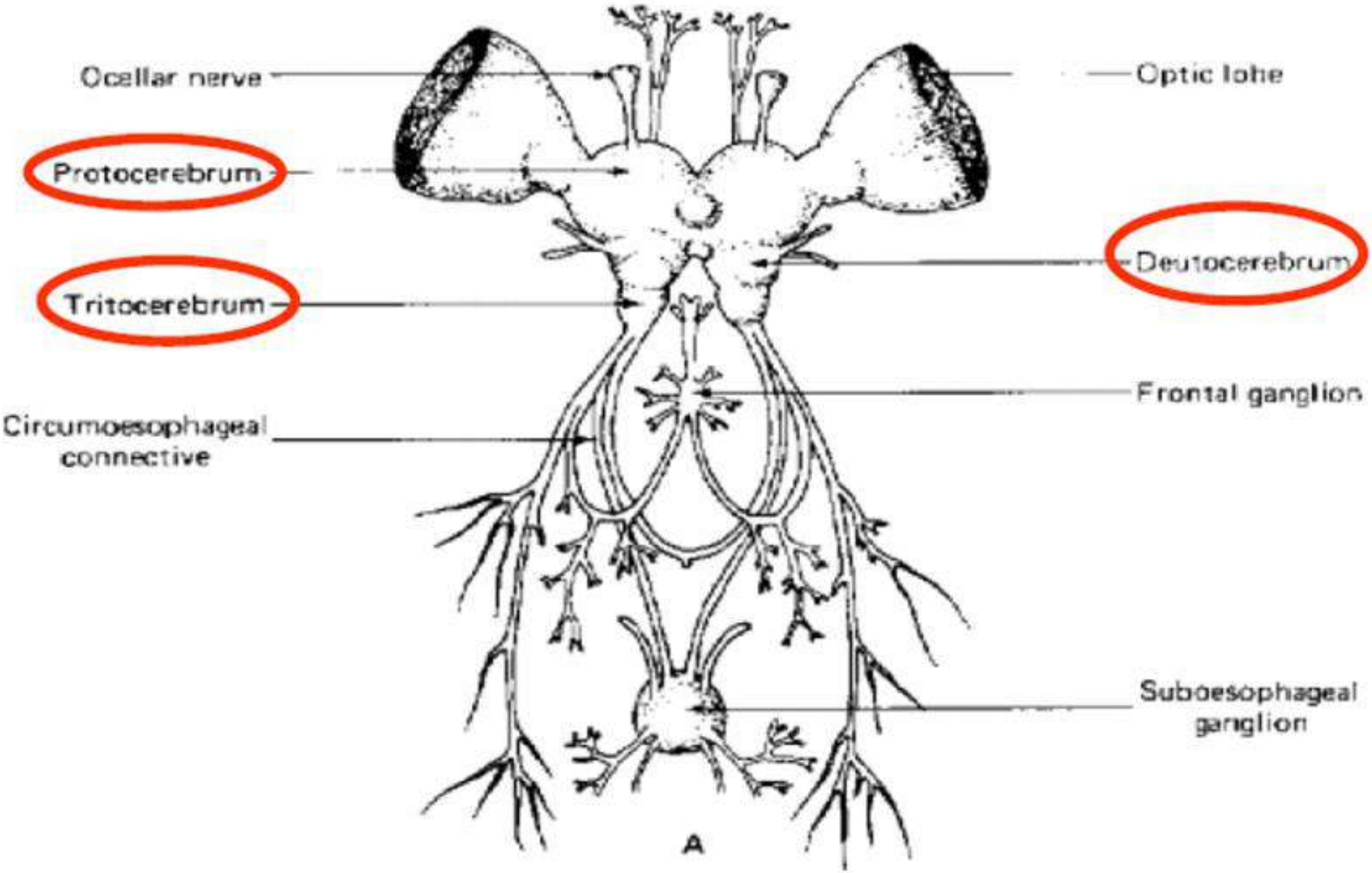




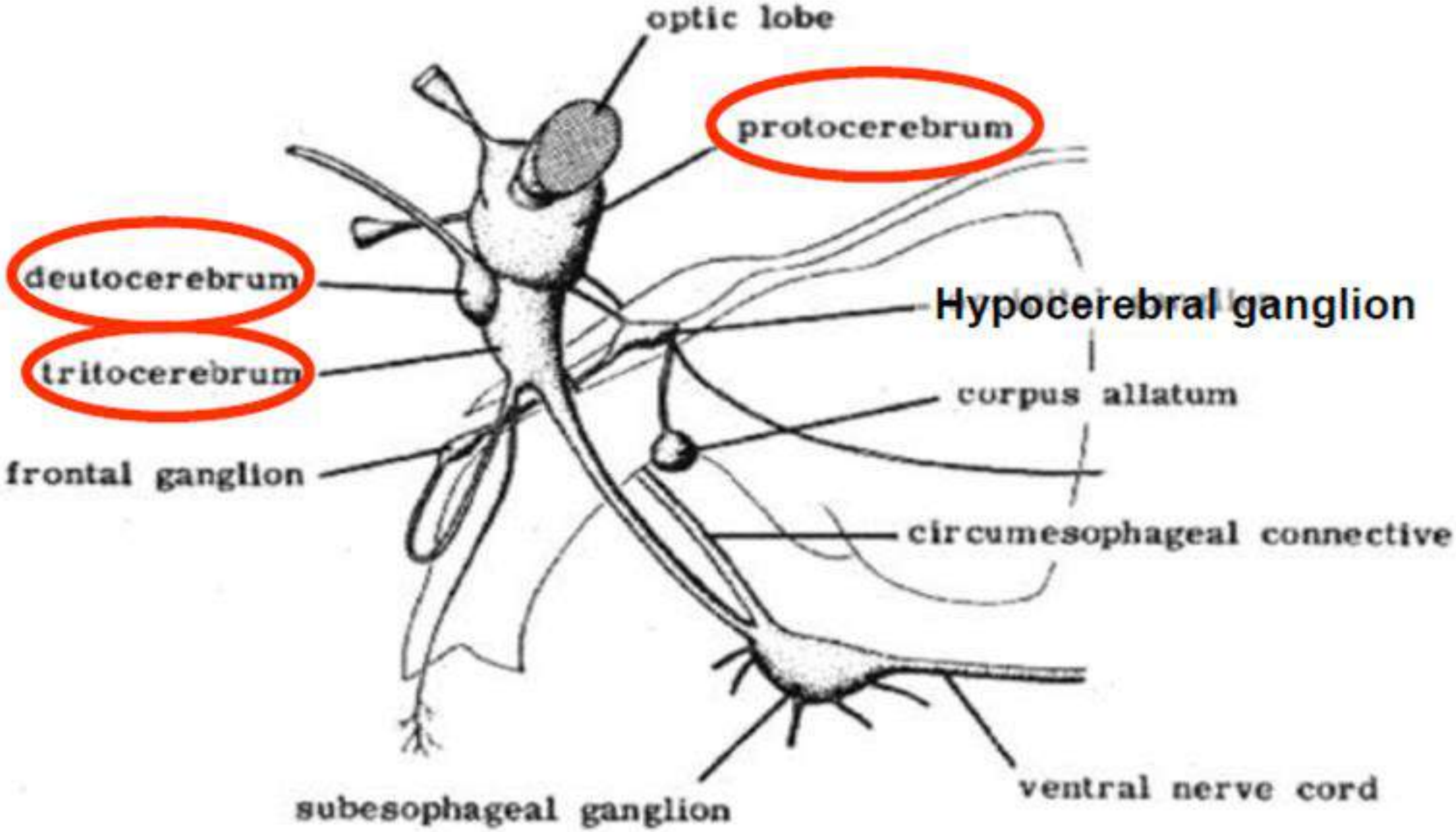
Intersegmental connectives


brain
suboesophageal ganglion
thoracic ganglia
ventral nerve cord
segmental nerves
abdominal ganglia
fused thoracic and abdominal ganglia
(a)
(b)
(c)
(d)
(e)

Brain: proto-, deuto- and tritocerebrum



Brain: another perspective



Components of the insect brain.

BRAIN

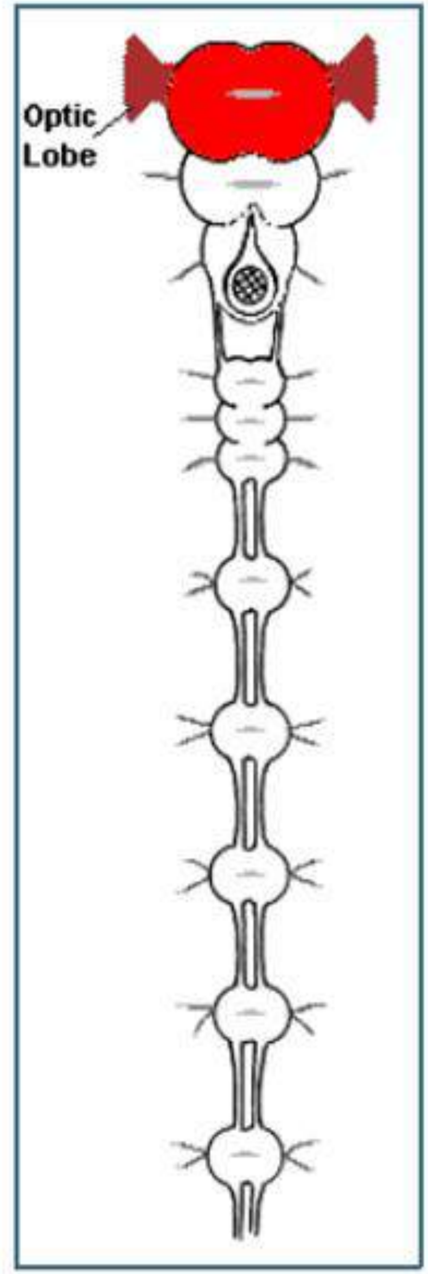
- An insect's **brain** is a complex of six fused ganglia (three pairs) located dorsally within the head capsule.

- Each part of the brain controls (innervates:supply) a limited spectrum of activities in the insect's body:

1. Protocerebrum
2. Deutocerebrum
3. Tritocerebrum

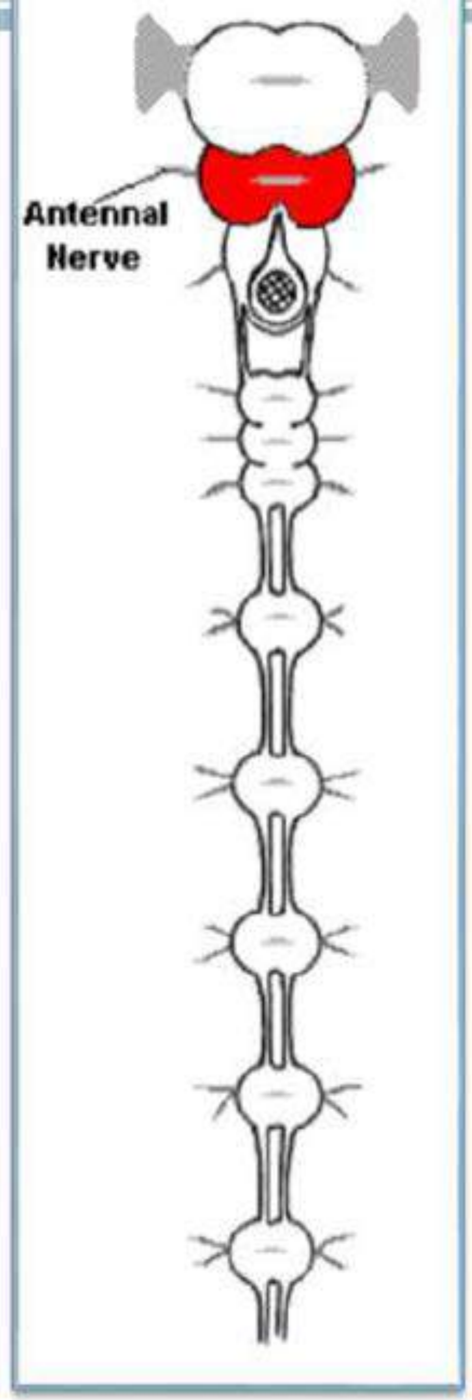
Protocerebrum

- The first pair of ganglia are largely associated with vision; they innervate the compound eyes and ocelli.



Deutocerebrum:

- The second pair of ganglia process sensory information collected by the antennae.

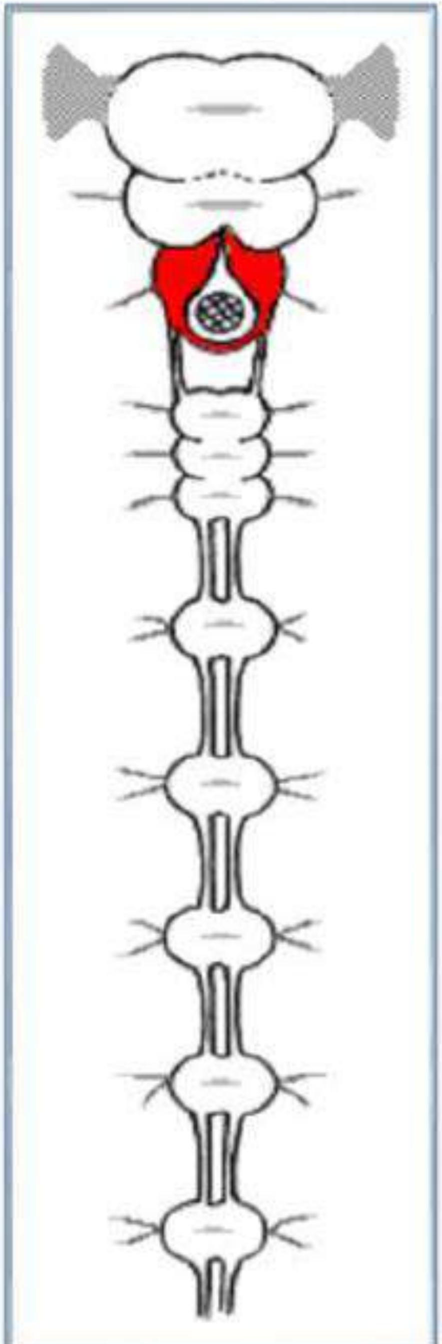


Tritocerebrum:

- The third pair of ganglia innervate the labrum and integrate sensory inputs from proto- and deutocerebrums.

- They also link the brain with the rest of the ventral nerve cord and the **stomodaeal nervous system**, that controls the internal organs.

- The commissure for the tritocerebrum loops around the digestive system.



SUBESOPHAGEAL GANGLION

- Located ventrally in the head capsule (just below the brain and esophagus) is another complex of fused ganglia (jointly called the **subesophageal ganglion**).

- The subesophageal ganglion innervates not only mandibles, maxillae, and labium, but also the hypopharynx, salivary glands, and neck muscles.

VENTRAL NERVE CORD

- In the thorax, three pairs of **thoracic ganglia** (sometimes fused) **control locomotion** by innervating the legs and wings.

- Thoracic muscles and sensory receptors are also associated with these ganglia.

- Similarly, **abdominal ganglia** control movements of abdominal muscles.

- Spiracles in both the thorax and abdomen are controlled by a pair of lateral nerves that arise from each segmental ganglion.

- A pair of abdominal ganglia usually fused to form a large **caudal ganglion,** innervates the excretory system, reproductive organs, and sensory receptors (such as cerci) located on the insect's back end.

THE STOMODAEAL NERVOUS SYSTEM

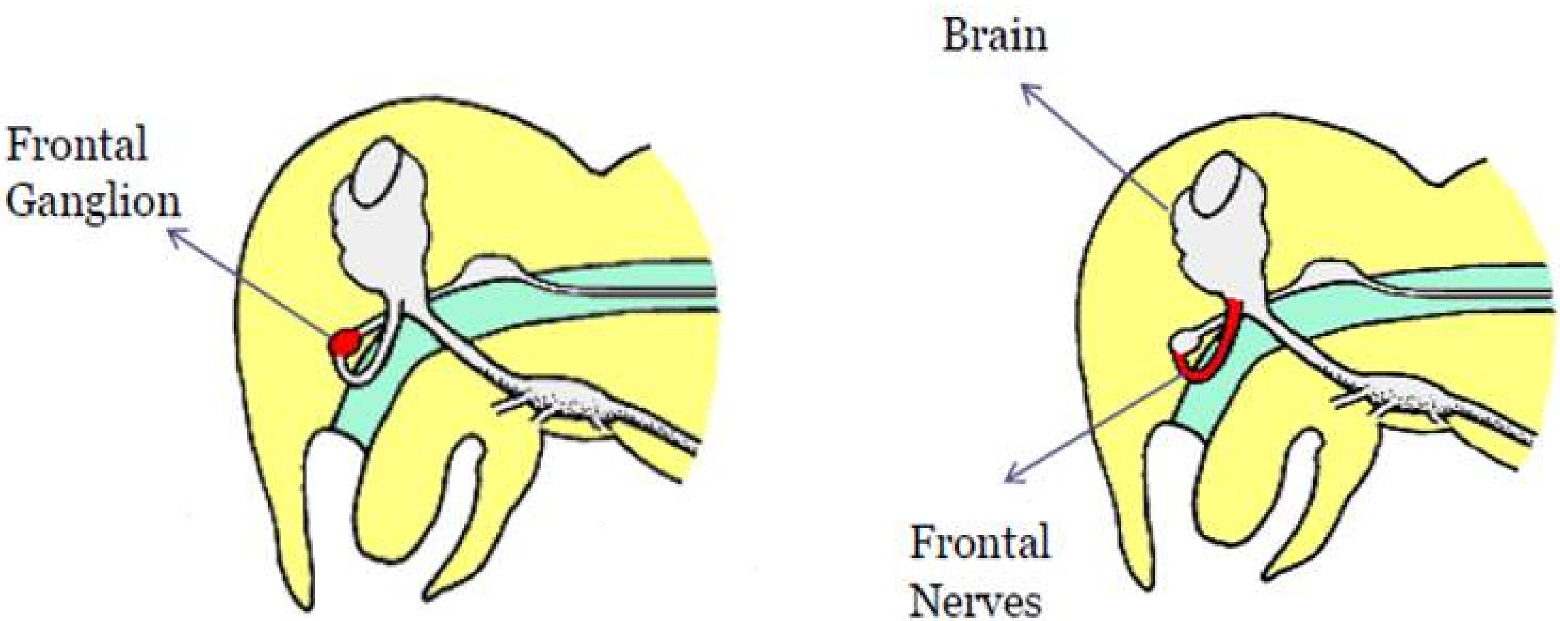
- An insect's internal organs are largely innervated by a stomodeal (or stomatogastric) nervous system.

- The stomodeal nervous system controls activities of the gut and circulatory system

- II. **Visceral nervous system**: The visceral (sympathetic) nervous system consists of three separate systems as follows:
- (1) stomodeal/stomatogastric which includes the frontal ganglion and associated with the brain, aorta and foregut;
- (2) Ventral visceral, associated with the ventral nerve cord
- (3) Caudal visceral, associated with the posterior segments of abdomen.
- Together the nerves and ganglia of these subsystems innervate the anterior and posterior gut, several endocrine organs (Corpora cardiaca and Corpora allata), the reproductive organs, and the tracheal system including the spiracles.

- IV. **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.

• A pair of <u>frontal nerves</u> arising near the base of the tritocerebrum link the brain with a <u>frontal ganglion</u>(unpaired).

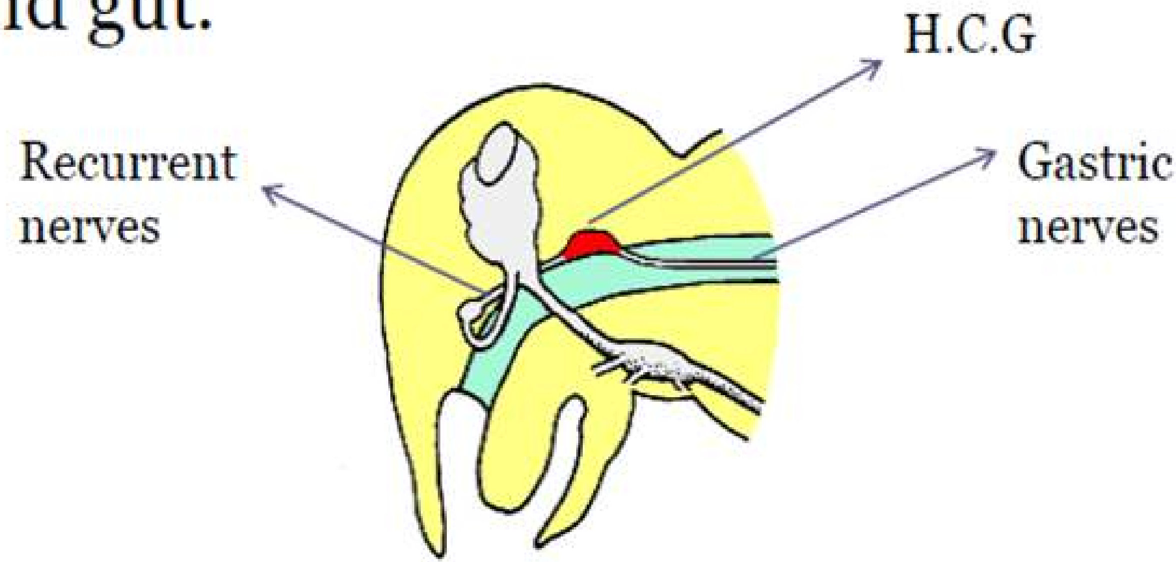


• This ganglion innervates the pharynx and muscles associated with swallowing.

- A Recurrent nerve from the frontal ganglion arises that leads to Hypocerebral ganglion.

- Hypocerebral ganglion innervates the heart, corpora cardiaca, and portions of the foregut.

- From H.C.G, Gastric nerves arise that innervate the hind gut.



- • In comparison to vertebrates, an insect's nervous system is far more de-centralized.

- Most overt behavior (*e.g.* feeding, locomotion, mating, etc.) is integrated and controlled by segmental ganglia instead of the brain.

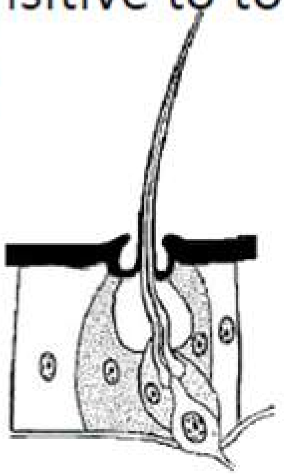
- In some cases, the brain may stimulate or inhibit activity in segmental ganglia but these signals are not essential for survival.

- Indeed, a headless insect may survive for days or weeks (until it dies of starvation or dehydration) as long as the neck is sealed to prevent loss of blood!

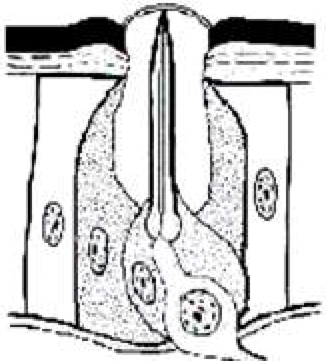
Sensory organs in insects

- 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).**

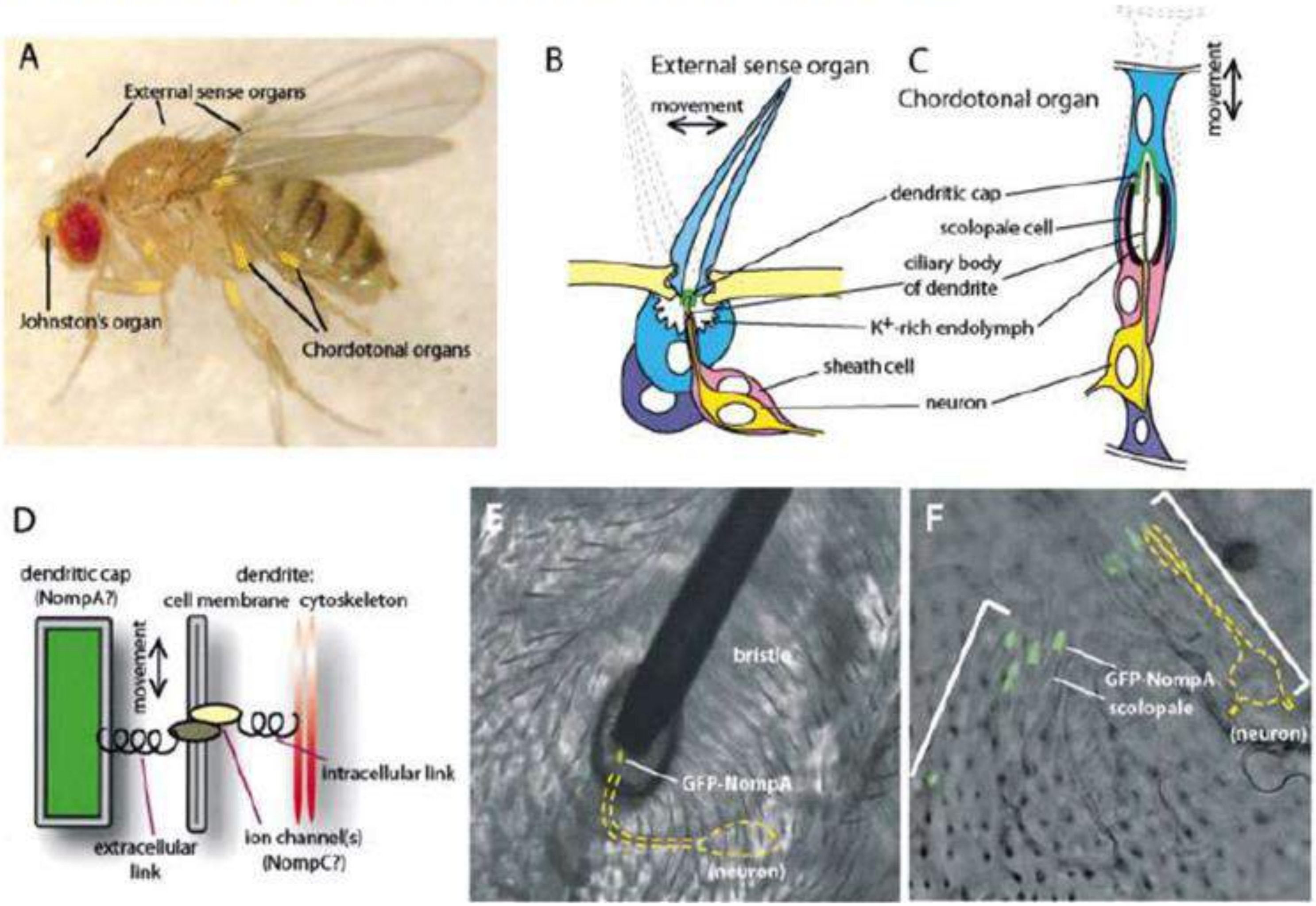


- ii. **Campaniform sensilla** (Dome sensilla): Terminal end of these sensilla is rod like and inserted into dome shaped cuticula. These cells are sensitive to pressure and **located in leg joints and wing bases.**



Campaniform sensillum

- 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 :**

- 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.**

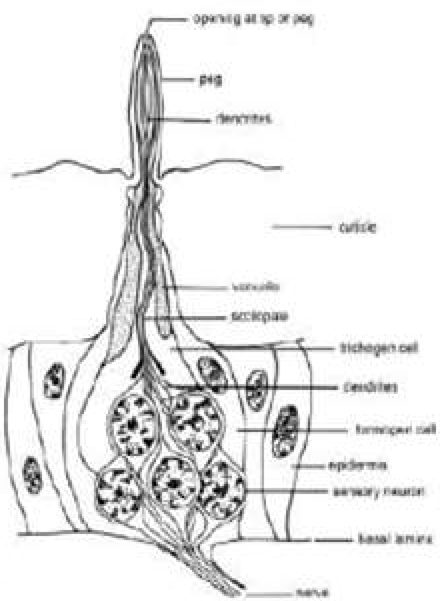
- iv. Subgenual organ: Chordotonal organ **located in the proximal tibia of each leg, used to detect substrate vibration**. Subgenual organs are found in most insects, **except in Coleoptera and Diptera.**

- **2. Auditory receptors (detect sound waves)**
- **i. Delicate tactile hairs**: Present in plumose antenna of male mosquito.

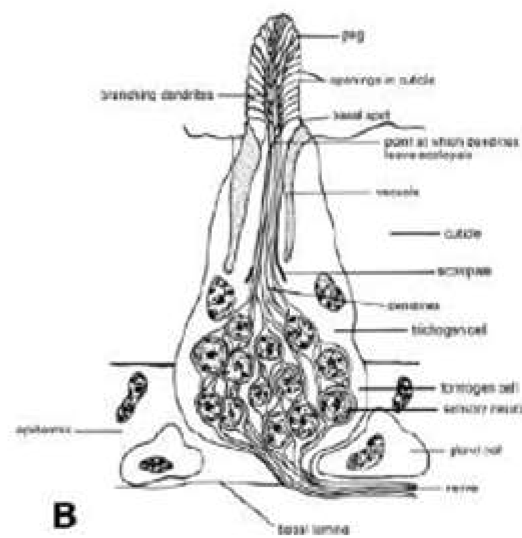
- **ii. Tympanum**: This is a membrane stretched across tympanic cavity responds to sounds produced at some distance, transmitted by airborne vibration. Tympanal membranes are linked to chordotonal organs that enhance sound reception.
- Tympanal organs are located
- * Between the metathoracic legs of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


A1
A2
A3
Tympanum
Spiracle
Spiracle

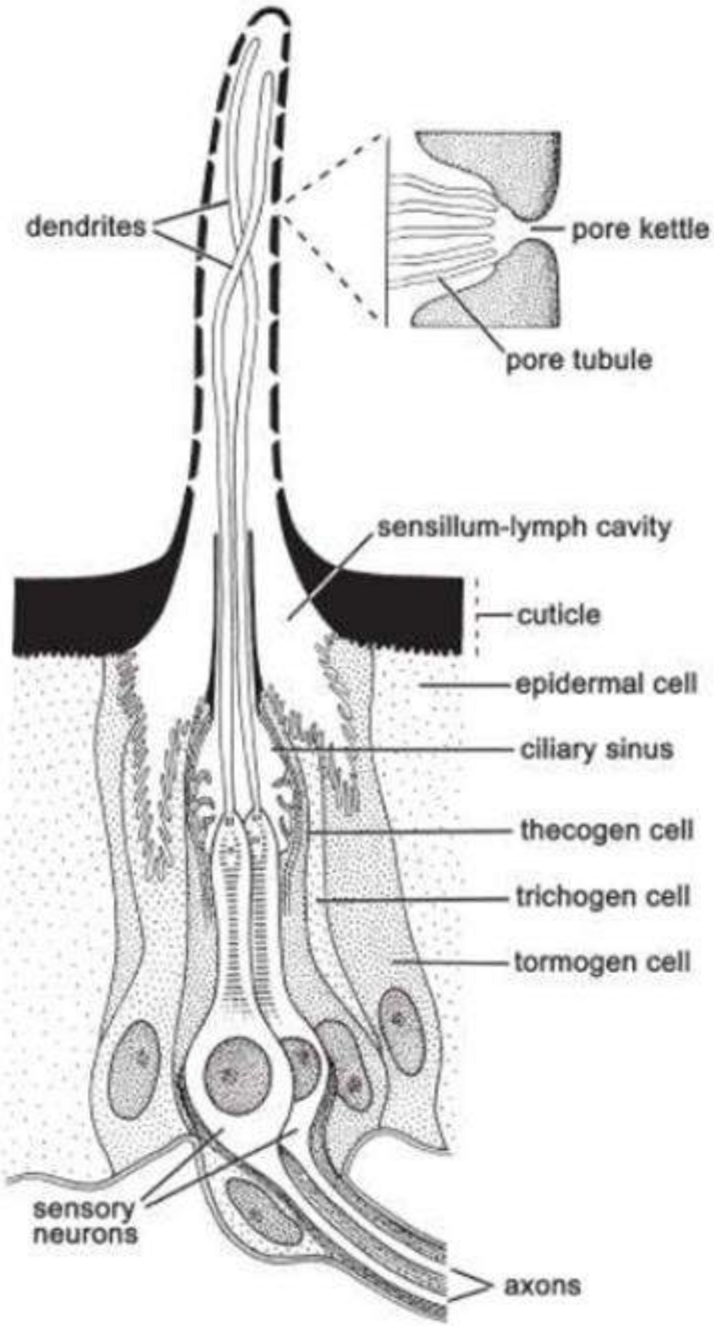
- **3. Chemoreceptors** (detect smell and taste)
- Detect chemical energy. Insect chemoreceptors are sensilla with one pore (uniporous) or more pores (multiporous).
- **Uniporous chemorceptors** mostly detect chemicals of solid and liquid form **by contact** and are called as **gustatory receptor.**
- Many sensory neurons located in antenna are of this type.
- **Multiporous chemoreceptors** detect chemicals in **vapour form**, at distant by smell and are called as **olfactory receptor**.
- Few sensory neurons located in trophi and tarsi are of this type.



A



B


dendrites
pore kettle
pore tubule
sensillum-lymph cavity
cuticle
epidermal cell
ciliary sinus
thecogen cell
trichogen cell
tormogen cell
sensory neurons
axons

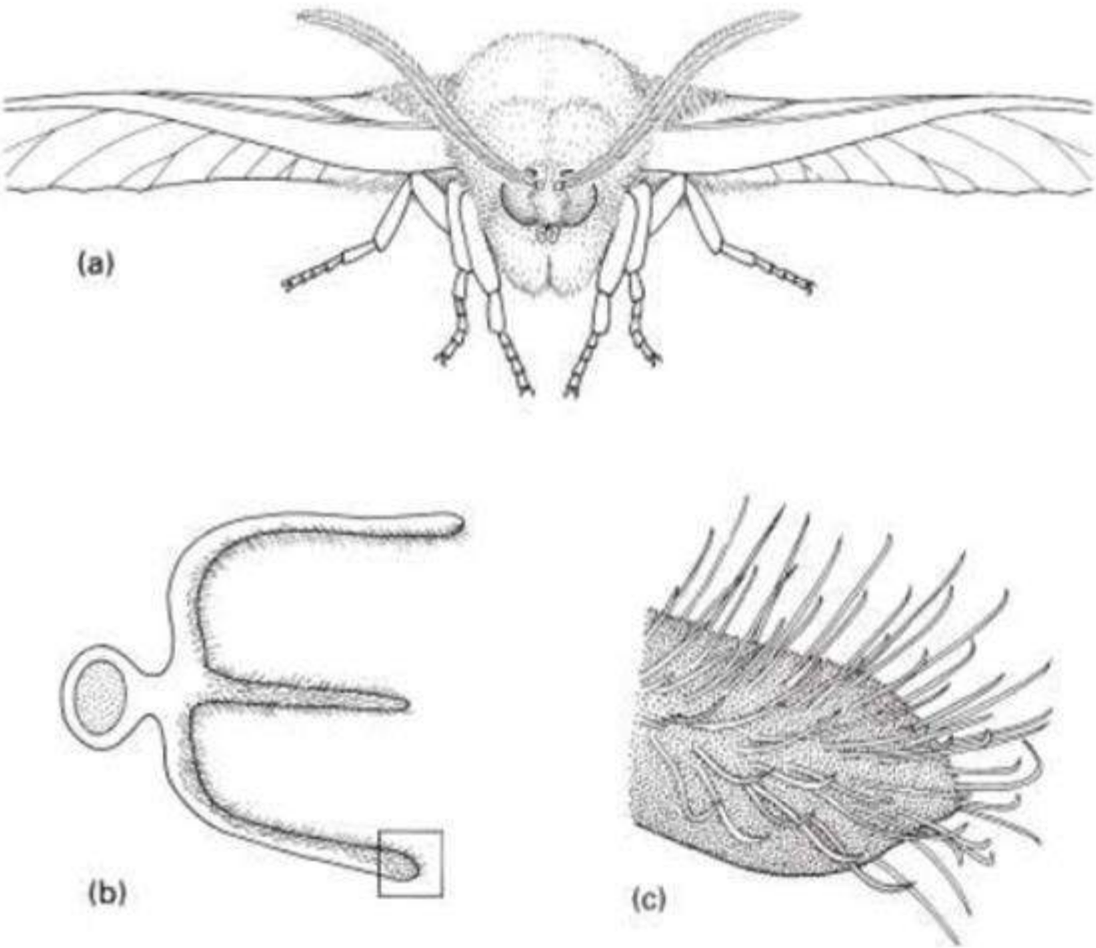
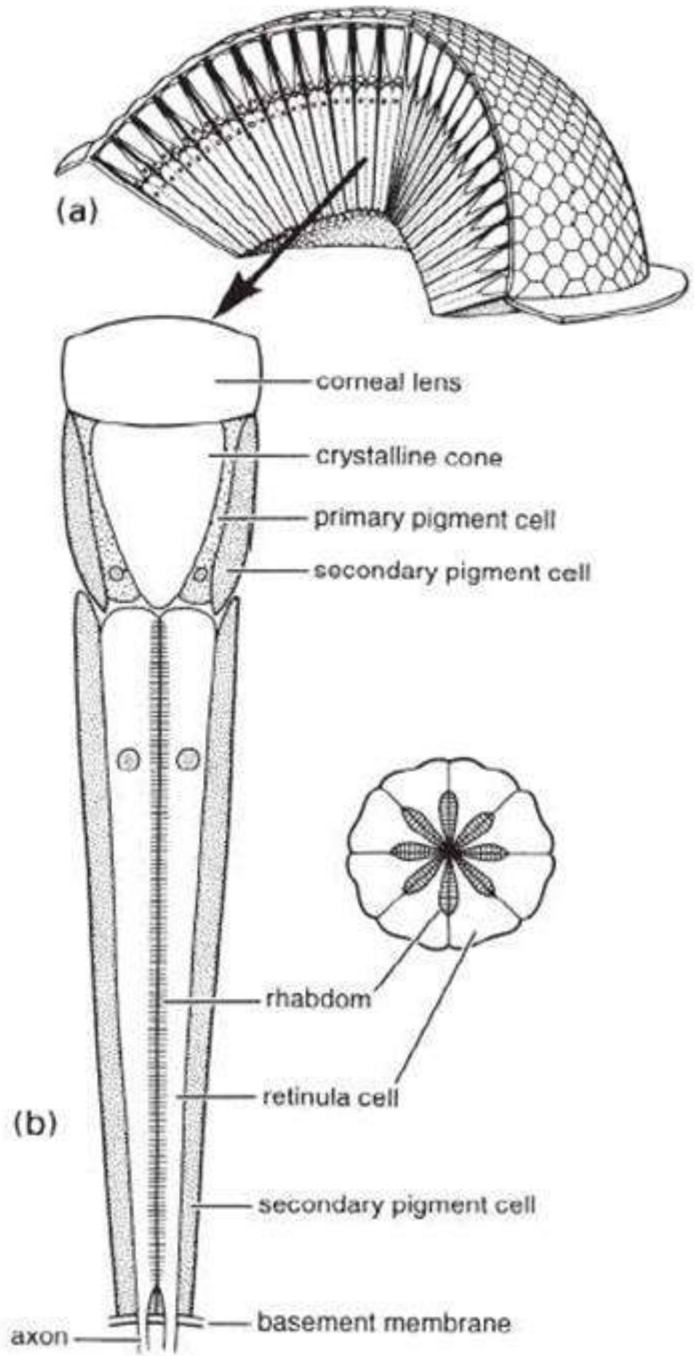


Fig. 4.6 The antennae of a male moth of *Trictena atripalpis* (Lepidoptera: Hepialidae): (a) anterior view of head showing tripectinate antennae of this species; (b) cross-section through the antenna showing the three branches; (c) enlargement of tip of outer branch of one pectination showing olfactory sensilla.

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.

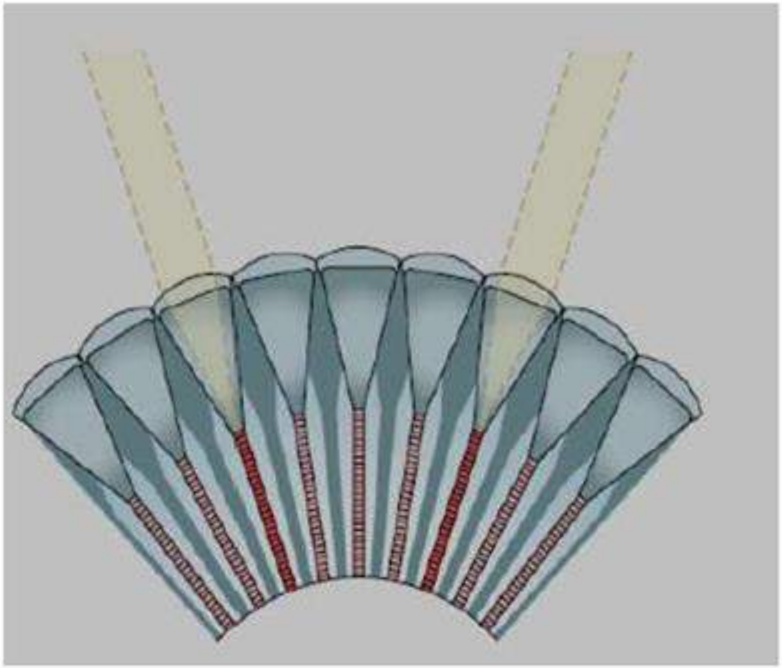
- **5. Photoreceptors (detect light energy)**
- **a. Compound eyes:** The compound eye is based on many individual units called **ommatidia.**
- Each ommatidium is **marked externally** by a **hexagonal area** called **facet.**
- Compound eye is made up **of two parts** called **optic part and sensory part.**
- Optic part contains a cuticular lens called **corneal lens** secreted by **corneagenous cells and crystalline cone** covered by primary pigment cells. Function 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


(a)
corneal lens
crystalline cone
primary pigment cell
secondary pigment cell
rhabdom
retinula cell
(b)
secondary pigment cell
basement membrane
axon

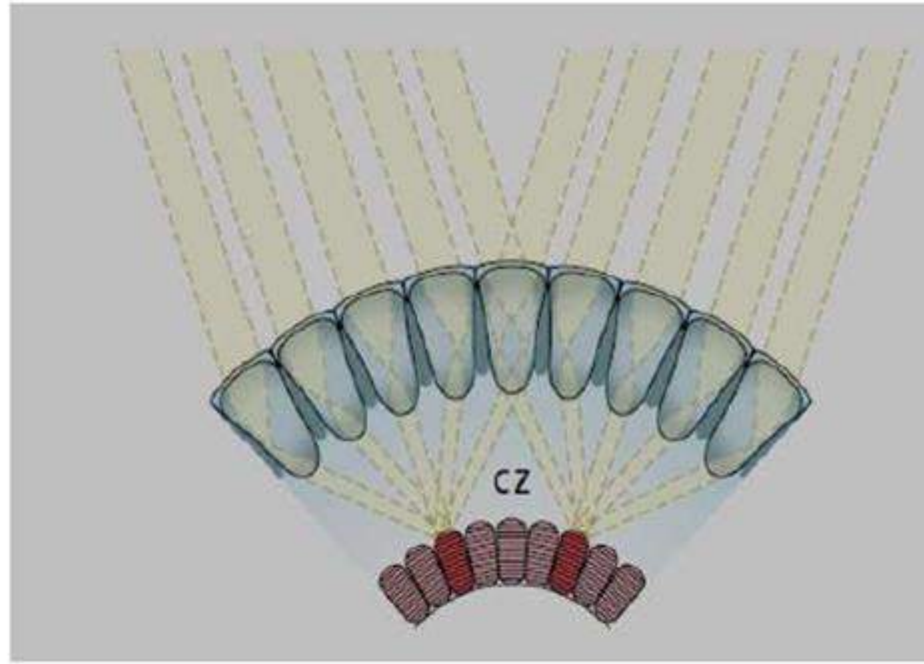
- **Types of ommatidia**
- i. **Apposition type** (light tight): Due to the **presence of primary pigment cells** light cannot enter the adjacent cells. The mosaic image formed is very distinct. The image formed by the compound eye is of a series of opposed points of light of different intensities. This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

Types of compound eyes



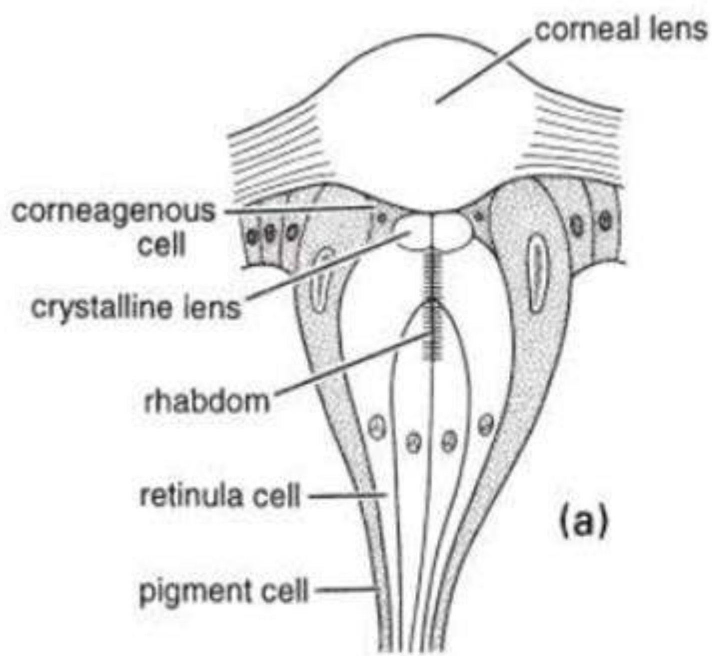
Apposition Eyes



Superposition Eyes

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**



Glandular system in insects

Exocrine glands

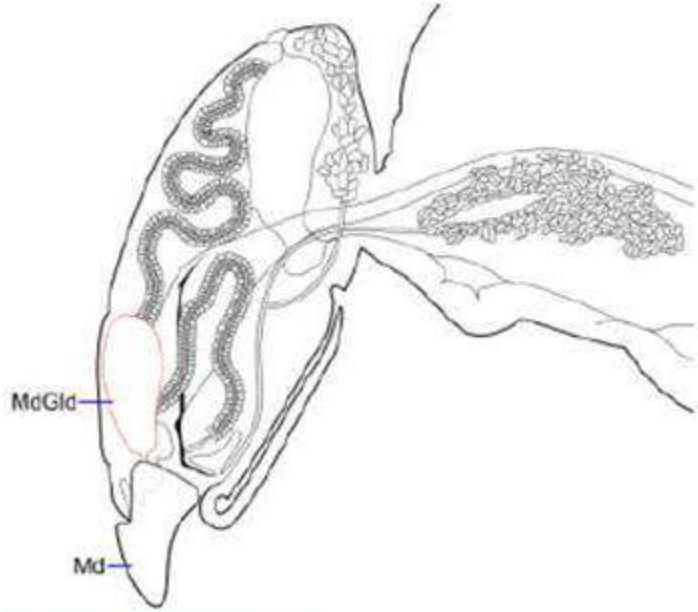
A. Chepalic glands
B. Dermal glands
C. Milk glands
D. Silk glands

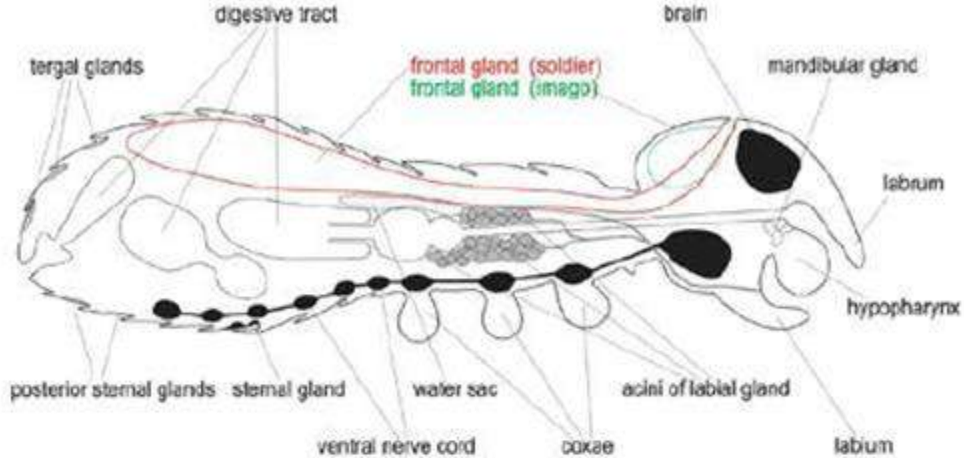
Endocrine glands

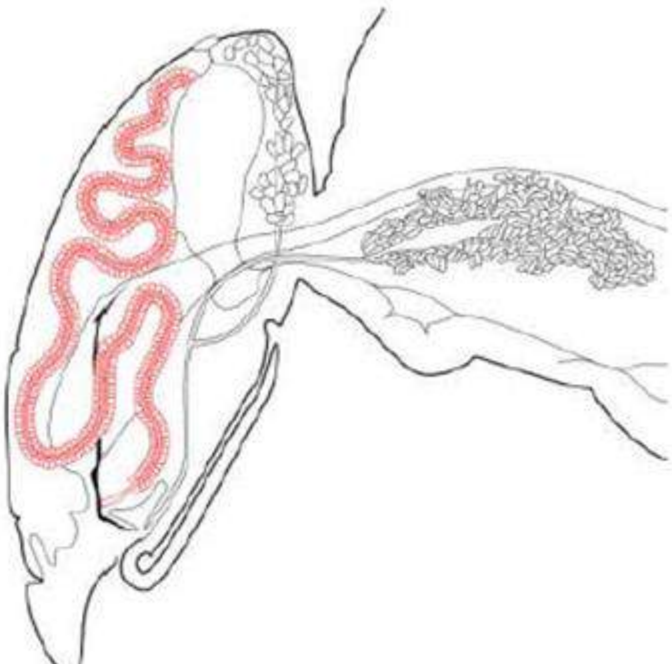
A. Nuerosecretory cells
B. Carpora cardiaca
C. Carpora allata
D. Prothoracic glands
E. Weisman’s ring

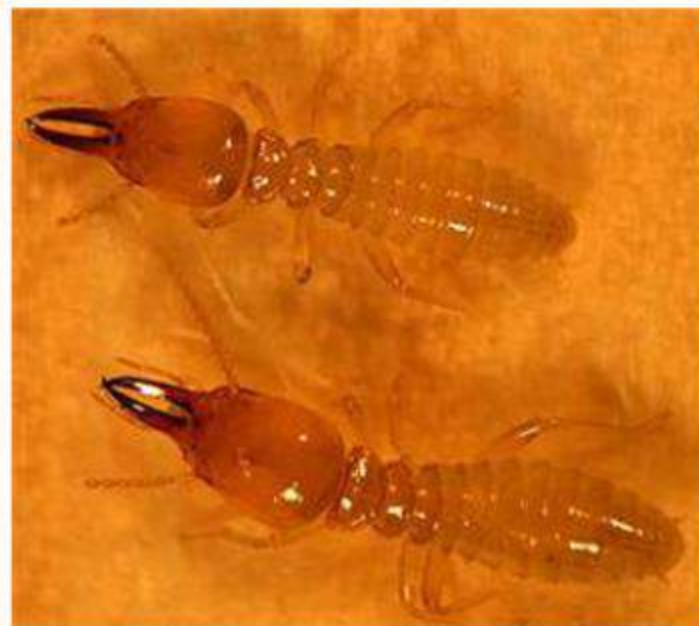
Glandular system

- Glandular system is otherwise called as **secretary system** and is divided in to two major groups **based on the presence or absence of ducts.**
- I. **Exocrine glands (glands with duct)**
- 1. **Salivary glands**: Salivary glands are modified labial glands which secrete saliva and open beneath hypopharynx.
- 2. **Mandibular glands**: Secrete saliva in caterpillars when salivary glands are modified into silk glands. In queen bee it secretes queen substance.
- 3. **Maxillary glands**: Secretions are useful to **lubricate mouth parts**.
- 4. **Pharyngeal glands**: Secrete bee milk or royal jelly in nurse bee.
- 5. **Frontal glands**: Secrete sticky defensive fluid in nasute termites.

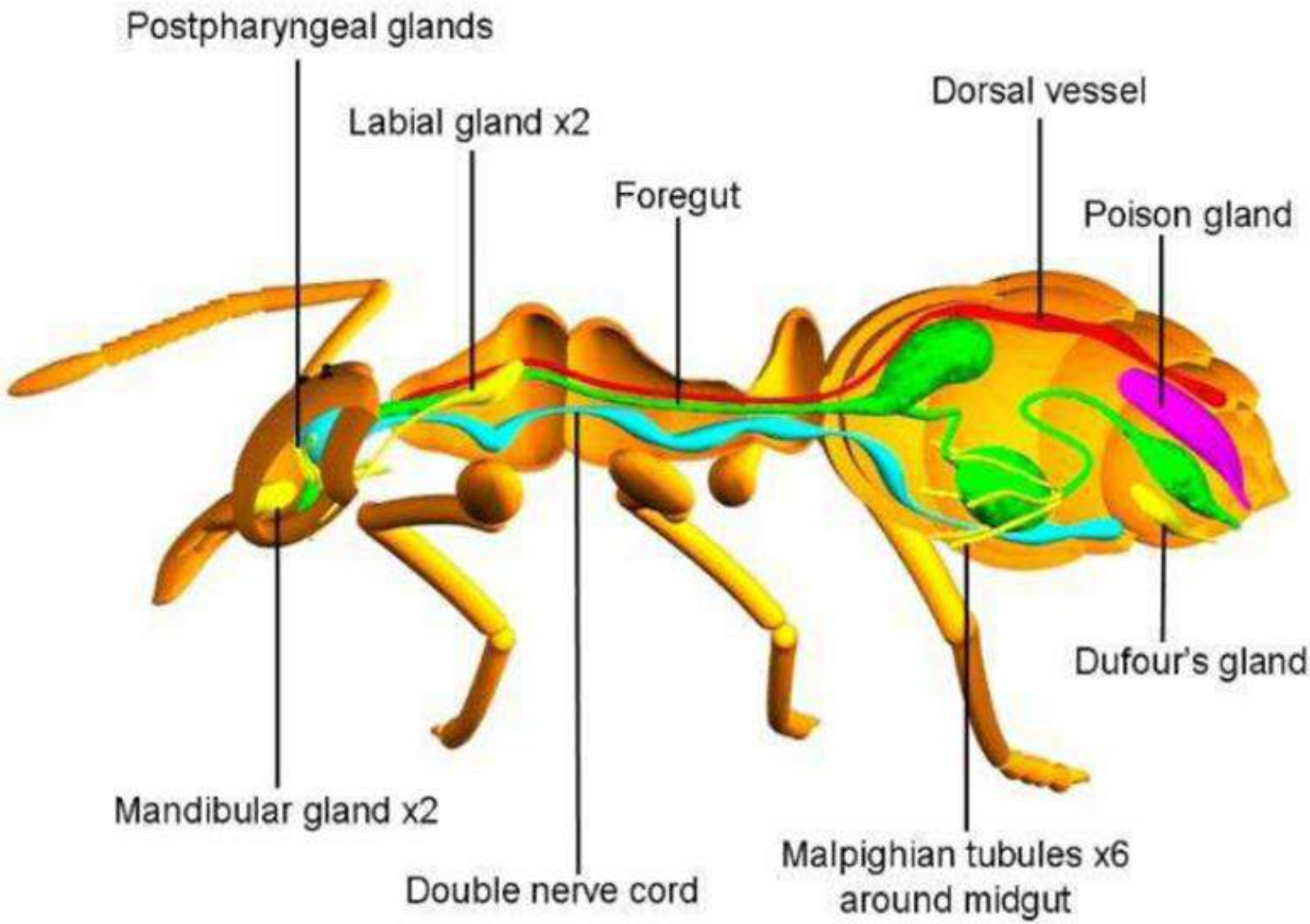

MdGld
Md


digestive tract
brain
tergal glands
frontal gland (soldier)
frontal gland (imago)
mandibular gland
labrum
hypopharynx
posterior sternal glands
sternal gland
water sac
acini of labial gland
ventral nerve cord
coxae
labium





Cutaway of an ant showing some of the major glands and other structures



✓Dermal glands

- **Wax glands**: Dermal glands producing wax in bees and mealy bugs.
- **Lac glands**: Dermal glands secreting resinous substances in lac insect.
- **Stink glands** (Repugnatorial glands): Secrete **bad smelling** substance. e.g. Stink bugs, bed bugs.
- **Pheromone glands**: Found in abdominal terminalia of one sex and its secretions are released outside to attract opposite sex of the same species.
- **Poison glands**
- 1. **Sting glands**: Modified accessory glands secreting venom in worker bees and wasps.
- 2. **Setal glands**: Glandular seta (Scoli) **secrete irritant flu**id in hairy/slug caterpillar.



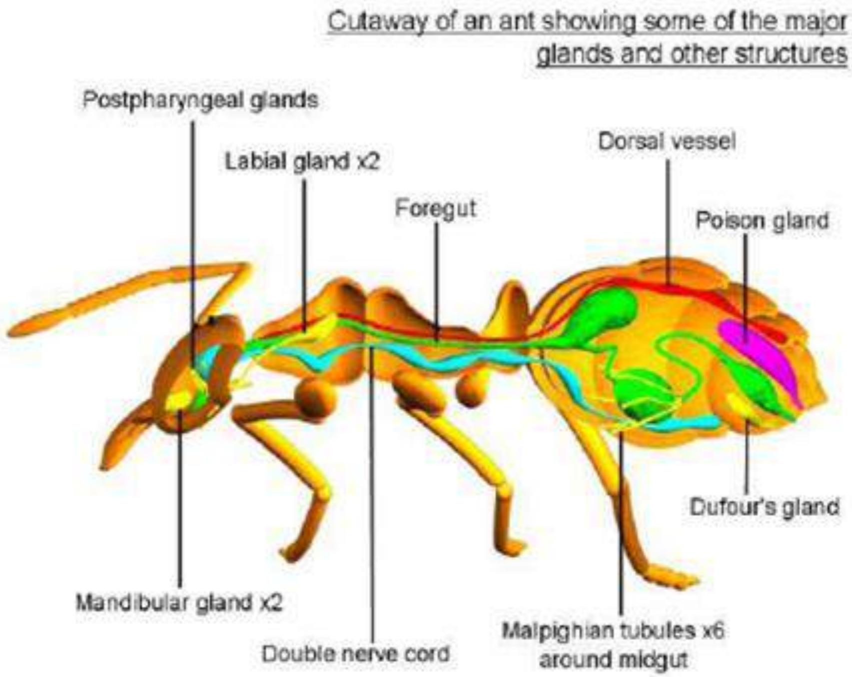
- **Tenant hairs**: Secrete sticky **fluid found in pulvilli of legs** and helps in ceiling walking in house flies.
- **Moulting glands**: Modified glandular epidermal cells, secrete moulting fluid necessary for moulting
- **Dufours glands** : present at the back of the abdomen in ants and produce trail marking pheromones

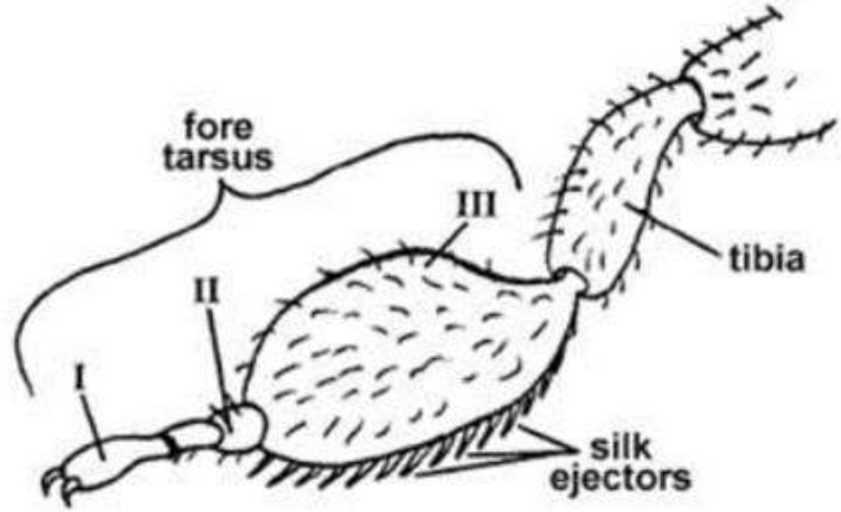
✓ **Milk glands**: Modified accessory gland nourishing larva developing in uterus.

✓ **Silk glands** : modified labial glands found in caterpillars of lepidoptera

Dermal glands in embioptera

• **Osmeteria** (Forked gland): Eversible gland in the thorax of papilionid larva with defense function. e.g. **Citrus butterfly larva**.


Cutaway of an ant showing some of the major glands and other structures
Postpharyngeal glands
Labial gland x2
Dorsal vessel
Foregut
Poison gland
Dufour's gland
Mandibular gland x2
Double nerve cord
Malpighian tubules x6 around midgut


fore tarsus
III
II
I
tibia
silk ejectors

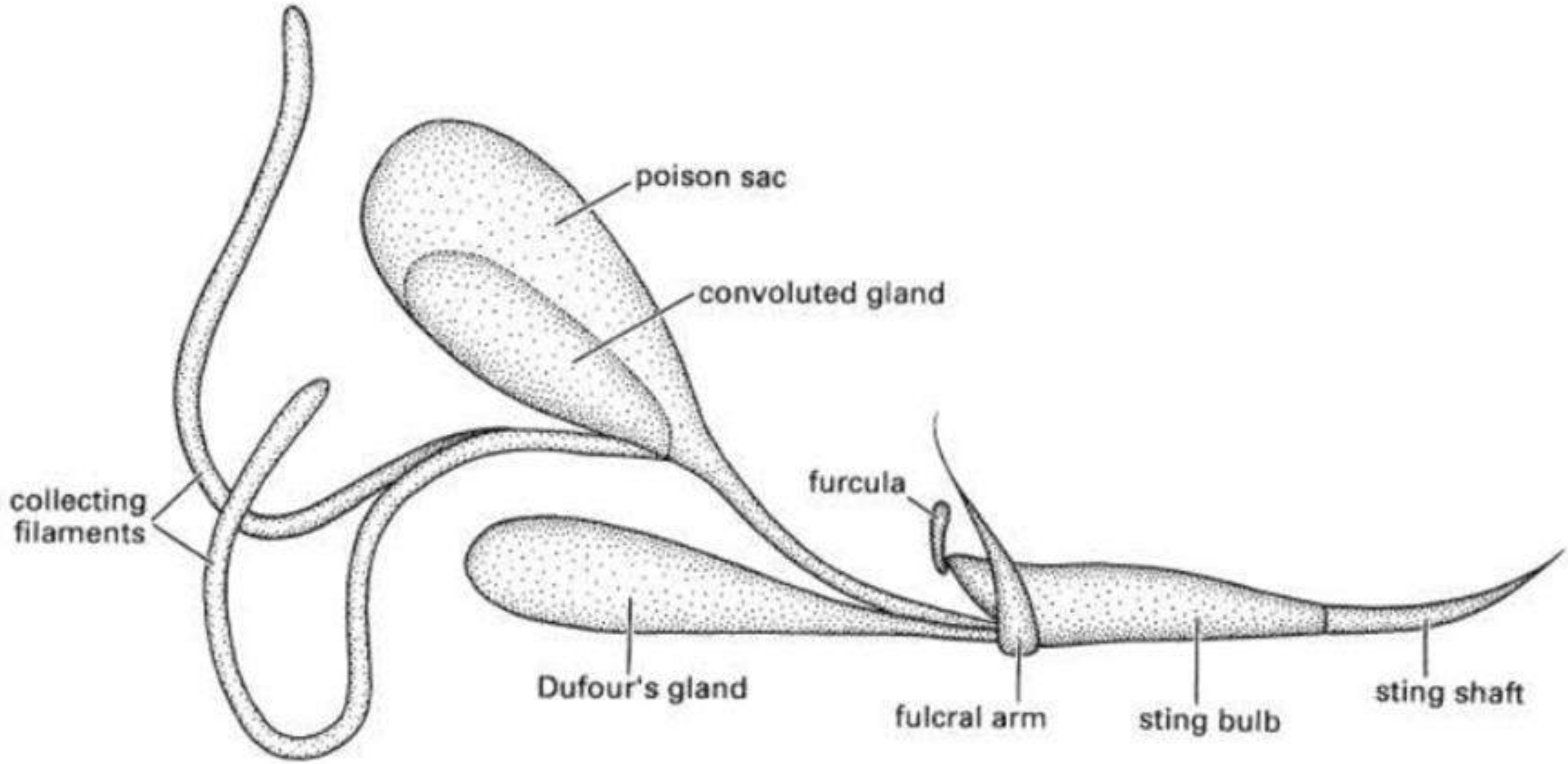
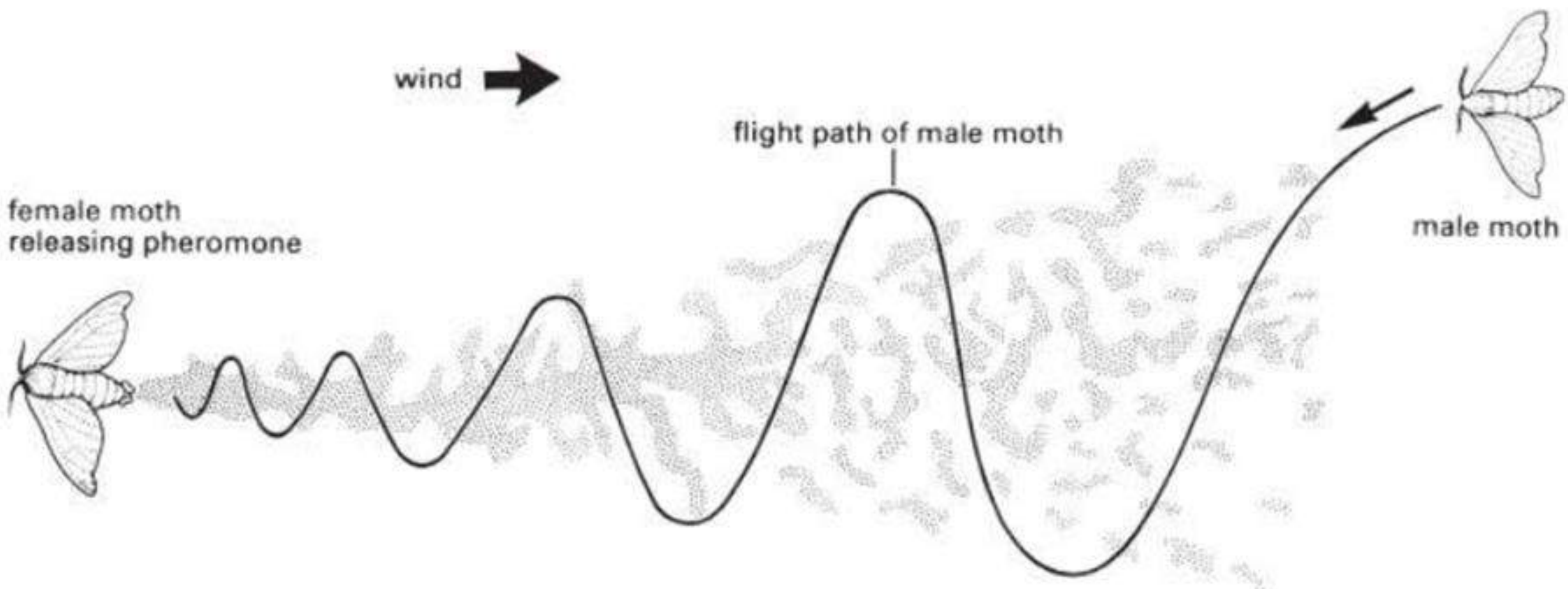


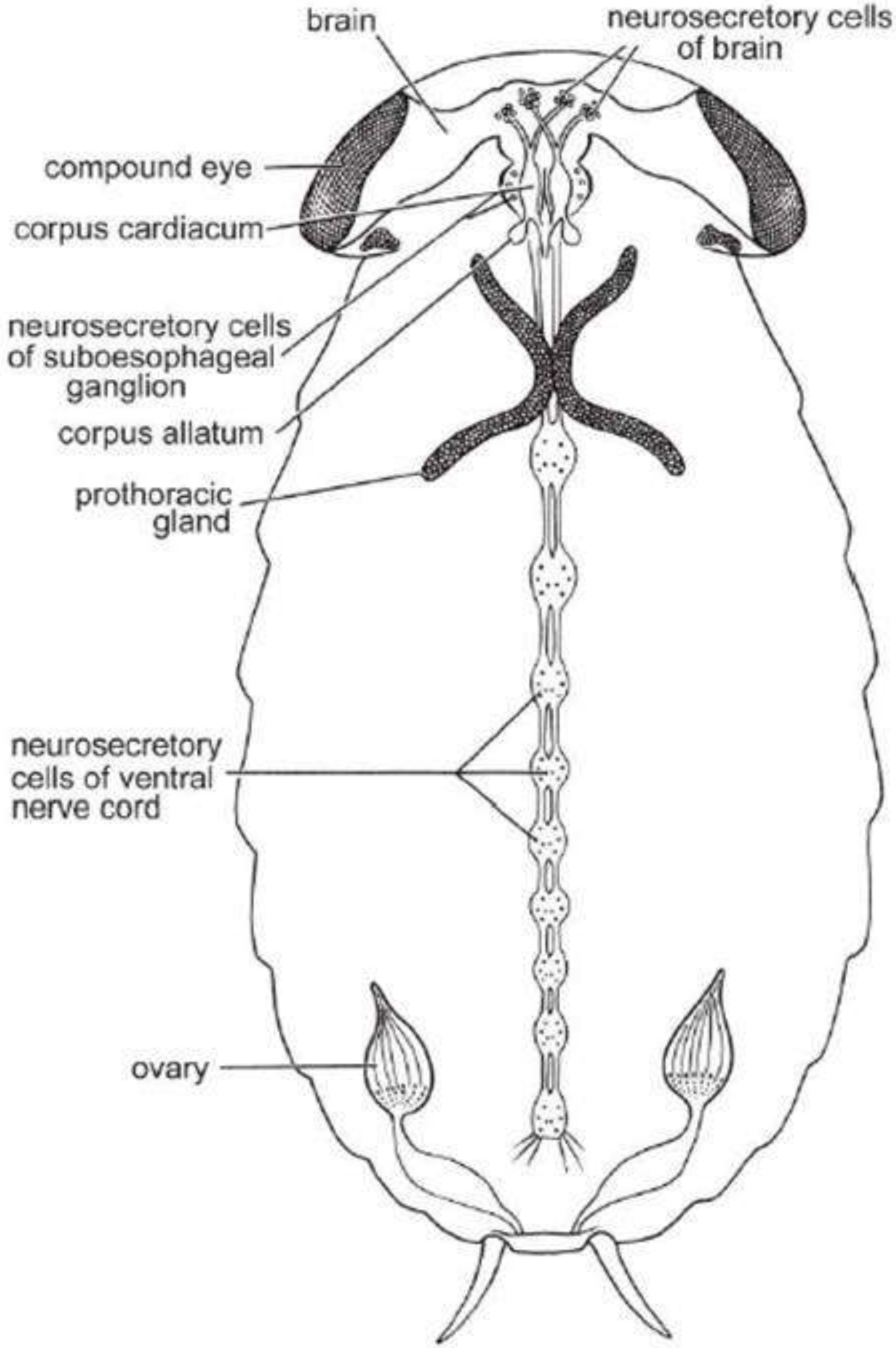
Fig. 14.11 Diagram of the major components of the venom apparatus of a social aculeate wasp. (After Hermann & Blum 1981.)


wind
flight path of male moth
female moth
releasing pheromone
male moth

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

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

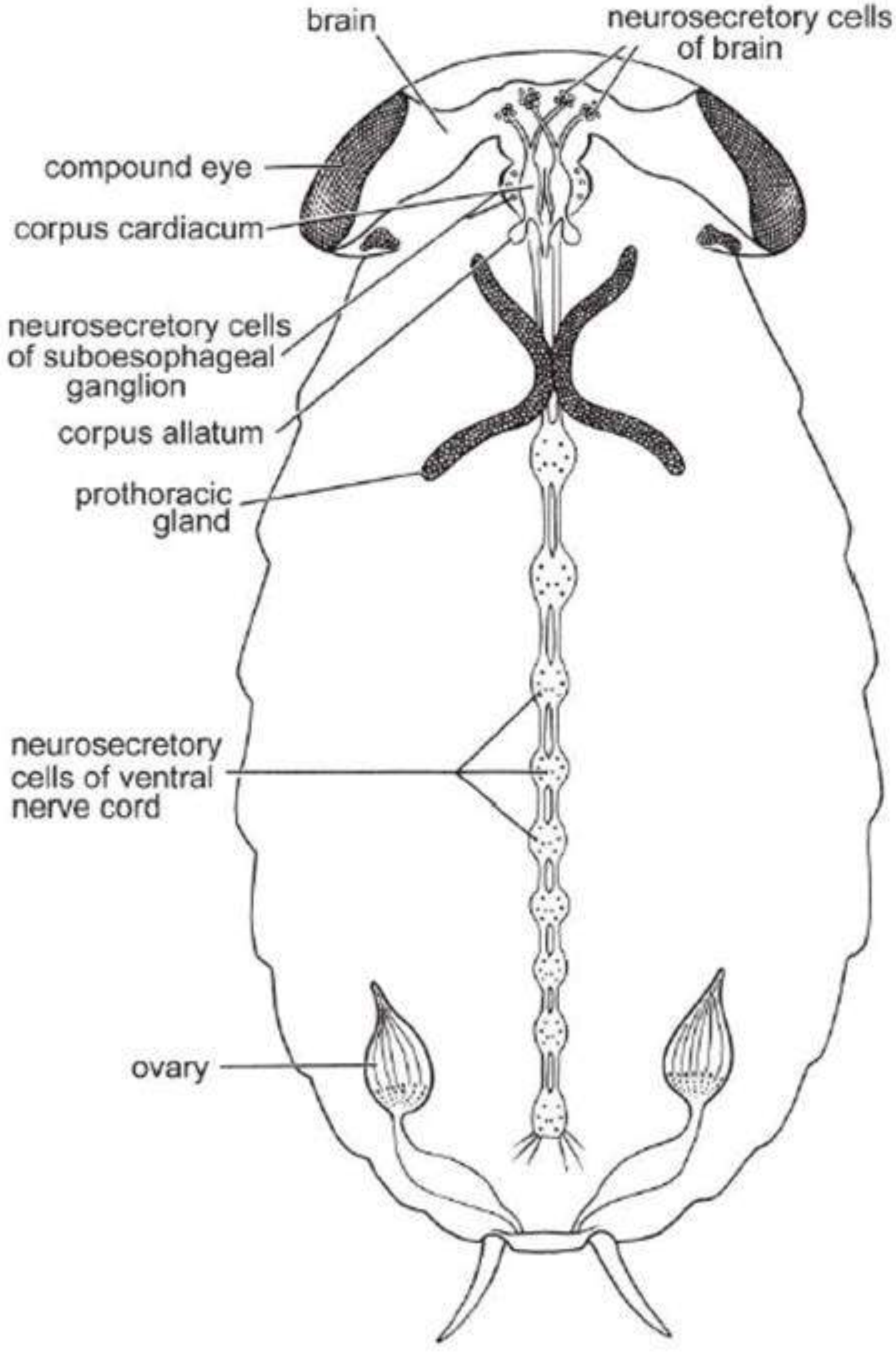
- 2. **Corpora cardiaca**: It consist of paired bodies fused in middle and have both nervous tissues and glandular tissues. It acts as a conventional storage and release organ for neurosecretory cells**. It controls heart beat and regulate trehalose level in haemolymph.**

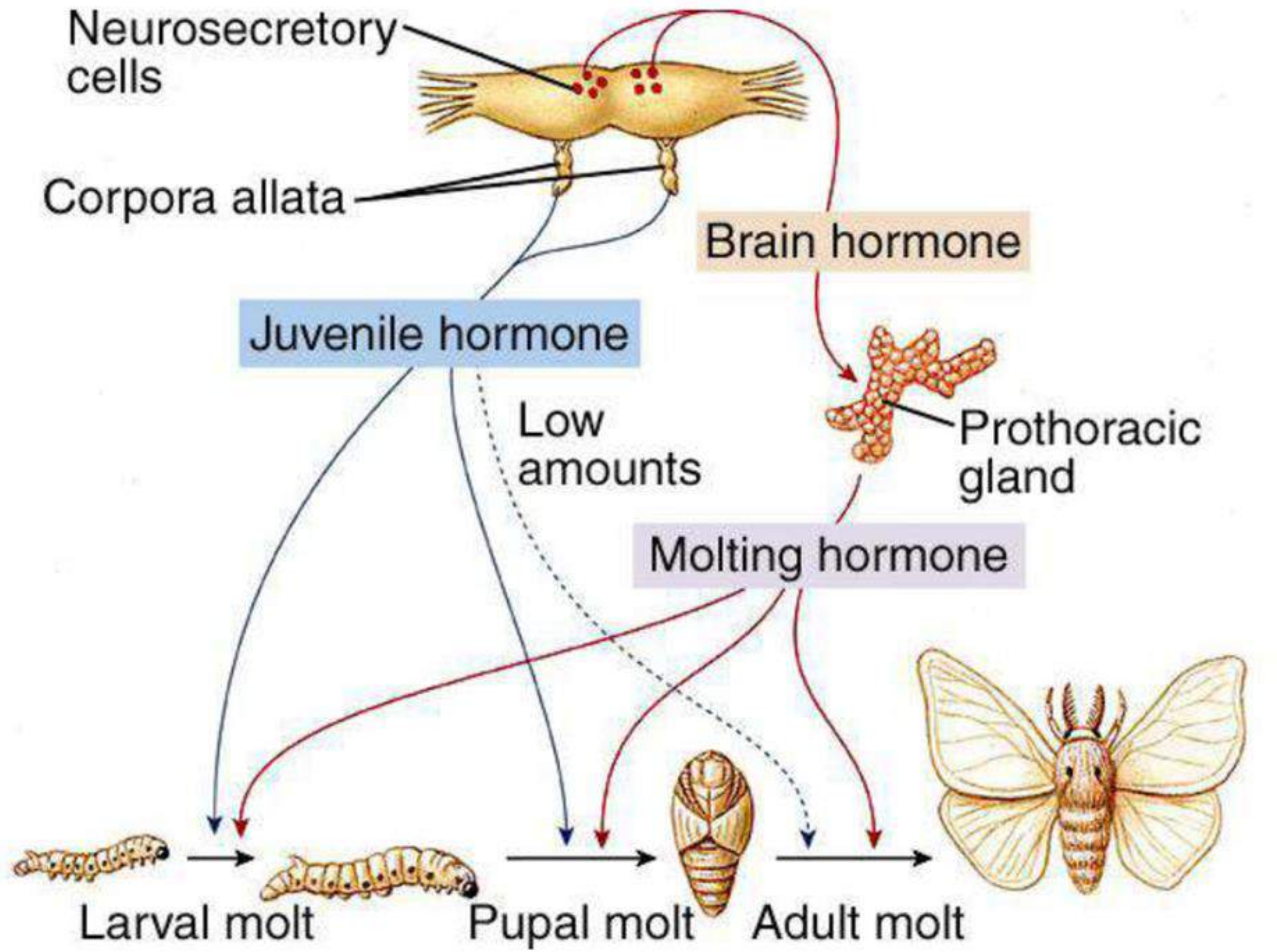

brain
neurosecretory cells
of brain
compound eye
corpus cardiacum
neurosecretory cells
of suboesophageal
ganglion
corpus allatum
prothoracic
gland
neurosecretory
cells of ventral
nerve cord
ovary

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

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

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


brain
neurosecretory cells of brain
compound eye
corpus cardiacum
neurosecretory cells of suboesophageal ganglion
corpus allatum
prothoracic gland
neurosecretory cells of ventral nerve cord
ovary


Neurosecretory cells
Corpora allata
Brain hormone
Juvenile hormone
Low amounts
Prothoracic gland
Molting hormone
Larval molt
Pupal molt
Adult molt

Insect hormones

What is Hormone?

- Hormones are chemicals produced by an organism which circulate in blood to regulate its long term physiological, developmental and behavioral activities.

- Growth and development in insects control by series of hormones which are secreted in predetermine sequences.

- Prothoracicotropic hormone (PTTH) was the first insect hormone to be discovered by early workers such as Stefan Kopec (1922) and Vincent Wigglesworth (1934) as "Brain hormone".

- In insects, virtually all life processes are regulated by neural and endocrine systems.

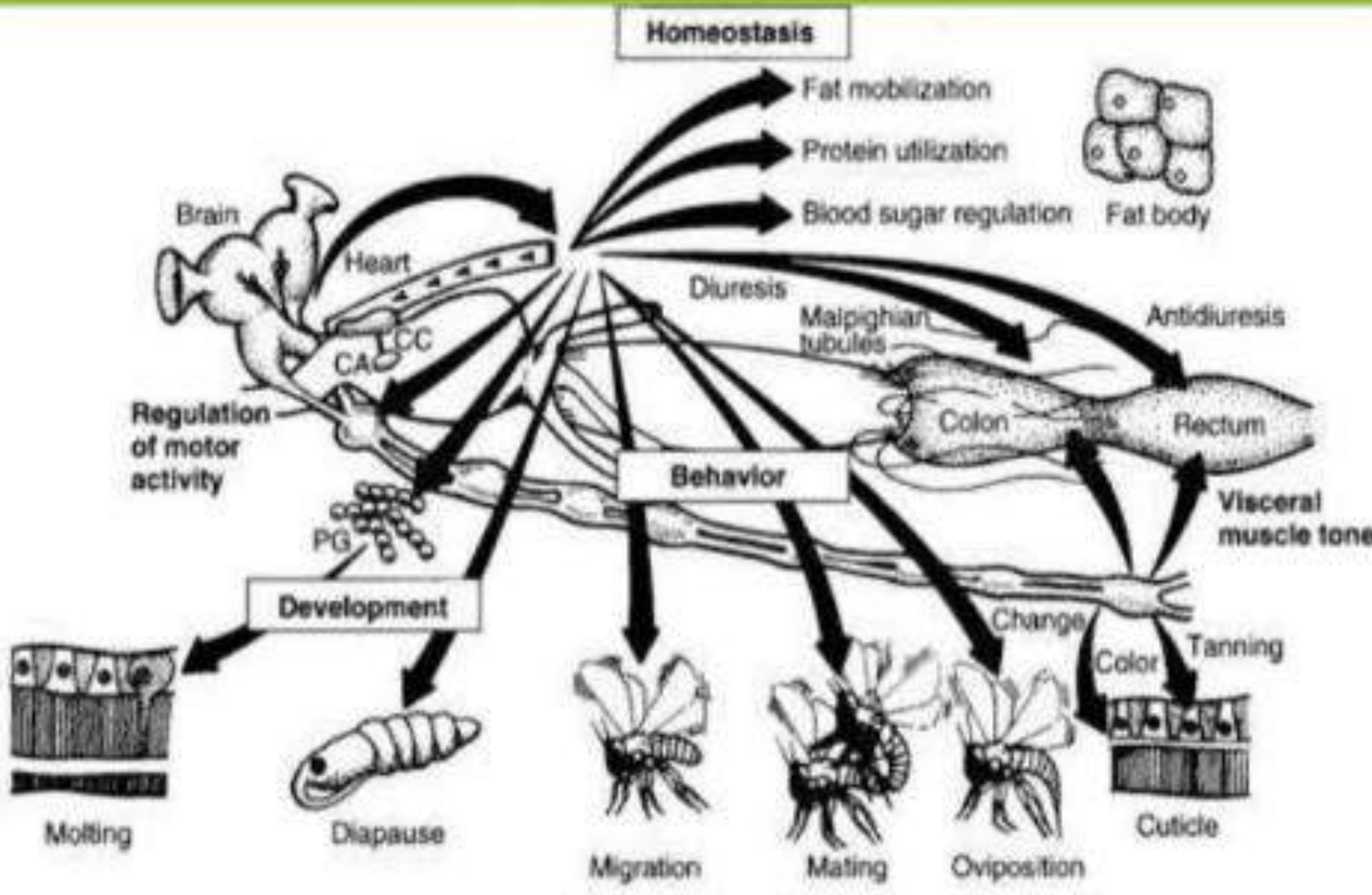
- Basically Three types of hormones
  - a) Brain hormones
  - b) Moulting hormones
  - c) Juvenile hormones

- These hormones are involves in the life processes of insects and regulating insect development , so studying of these can be utilized for insect pest control.

ENDOCRINE GLANDS IN INSECTS

Glands	Secretions
Neurosecretory cells	Produce Neurosecretion
Prothoracic glands	Produce Ecdysone
Corpora allata	Produces JH
Corpora cardiaca	Stores and releases brain hormones
	Also produces and releases some peptides such as Adipokinetic Hormone
Midgut endocrine cells	Produce various peptides
Epitracheal glands	Produce the ecdysis triggering hormone "Eclosion" in Lepidoptera

Major physiological functions regulated by NEUROHORMONES



NEUROSECRETORY HORMONES

BRAIN HORMONE:

- ✓ NSC in dorsal part of protocerebrum produce a hormone called Prothoracicotropic Hormone(PTTH) or BRAIN HORMONE which activates prothoracic glands.
- ✓ Mostly this hormone is constituted of lipid or peptide and water soluble polypeptide or small molecule of protein.

- Hormones exert a critical control over all developmental, reproductive and metabolic activities hence disruption or removal of these lead to mortality of the insects.

- These neuropeptides which are commercially produced used for the pest control.

- But the major problem in commercial exploitation is costly synthesis , inability to penetrate cuticle and photoinstability.

- All the fully sequenced brain hormones are oligopeptides or small protein molecules.

- The important brain hormones are:

  a)Diuretic hormone.

  b)Anti diuretic hormone.

  c) Allatotrophins.

  d)Allatostatins.

  e)PTTH.

  f)Pheromone biosynthesis stimulating hormone.

BURSICON:

- Neurosecretory hormone that controls Tanning or Sclerotization and mechanical properties of the cuticle during and after a moult.
- Found in most ganglia of the CNS.

DIURETIC HORMONE:

- Neurosecretory cells scattered in the ventral nerve cord produce Diuretic hormone.
- It involved in regulation of Insect water balance.

Functional significance of
NEUROSECRETORY HORMONES

- The secretions of the median neurosecretory cells promote the functioning of the prothoracic glands stimulate protein synthesis, probably control water loss and oocyte development activities.

- Neurosecretory hormones have also been associated with behavioural activities, such as, response of the female towards the male, cocoon formation etc.

HORMONES FROM CORPORA CARDIACA

- ✓ Corpora cardiaca found in most insects except Collembola, which lies on each sides of Aorta behind brain.
- ✓ It acts as a Conventional storage and release organ for neurohormones.

Adipokinetic Hormone(s):

- ➢ Adipokinetic hormone (AKH), a decapeptide from the locust has been identified. AKH in CC of locusts regulates lipid metabolism during prolonged flight.

Neurohormone D:

- Material isolated from CC of *Caracius morosus* called Neurohormone D which increasing the frequency of amplitude of Heart beat, stimulating colour change in *Caracius*.

Chloride- Transport stimulating hormone:

- In Desert Locust, rectum of insect is an important organ, which regulates the ionic balance. It is stimulated by the hormone from Corpora cardiaca, the Chloride- Transport stimulating hormone.

JUVENILE HORMONE / NEOTININ

- Corpora allata secretes Juvenile hormone (JH) or Neotinin, there by inhibit metamorphosis. This CA hormone(s) is therefore sometimes also called as "Inhibitory or Status Quo" Hormone.
- Corpora allata glands were discovered by JANET during 1899.
- JH first extracted from the abdomen of *Hyalophora cercopia* (Moth).

Functional significance of **JUVENILE HORMONES**

- ✓ It is needed for egg maturation and function as accessory glands in male.

- ✓ Other activities controlled by this hormone are polymorphism, regeneration, metabolism of fat, water balance, colour changes, imaginal diapause, pheromone production etc.

MOULTING HORMONES:

- Responsible for normal moulting, growth and maturation of insects.
- secreted by Prothorasic glands.

- **Types** of moulting hormones are
  - Ecdysone.
  - Ecdysterone.
  - Ecdysteroids.

- These are steroidal compounds responsible for moulting , growth and maturation of insects.

ECDYSONE / MOULTING HORMONE /ÆCDYSTERIOD

- ✓ Neurosecretory cells activate prothoracic glands to secrete ECDYSONE.

- ✓ First experimental proof about the importance of Prothoracic glands was provided by a Japanese worker, Fukuda in 1940 while working with silkworm.

Functional significance of **ECDYSONE**

- ✓ It initiates the moulting process.
- ✓ It breaks larval and pupal diapauses.
- ✓ Renewals of growth and deposition of new cuticle.
- ✓ MH is interference in principal enzyme system, regulate normal metabolism and growth.

  Ex. Cytochrome oxidase
- ✓ It influences the puffing pattern of giant cell in *Drosophila & Chironomous.*
- ✓ It inhibits the function of Corpora allata.

OTHER HORMONES

PEPTIDE HORMONES:

- It is known to control wide range of physiological, Biochemical and Developmental function including water balance, lipid and carbohydrate metabolism, muscle contraction, reproduction, growth and development.

PROCTOLIN:

- Isolated from Periplanata americana. It acts as an Excitatory Neurotransmitter to modulate Muscle Excitability.

Functions of Endocrine Hormones

- ✓ Regulation of Moulting
- ✓ Determination of form at Metamorphosis
- ✓ Polymorphism
- ✓ Regulation of Diapause
- ✓ Involvement in Reproduction
- ✓ Regulation of Metabolic activities and general body functions
- ✓ Regulation of Behaviour

Insect phermones

INTRODUCTION

- It consists of two greek words Pherein = to carry; and horman = to excite.
- In 1959, the German chemist Karlson and Butenandt gave present name pheromones.
- sex pheromone of silkworm, *Bombyx mori* (Linnaeus) was isolated and characterized by them in 1959.
- Pheromone is intraspecific insect behaviour regulating semiochemical.

What is pheromones ?

- A pheromone is a chemical or a mixture of chemicals released by an organism to the outside that cause a specific reaction in a receiving organism of the same species.

- Pheromones have to permeate the environment quickly which is effective, volatile in nature, serving as chemical means of communication.
- Being exocrine in origin (*i.e.*, secreted outside the body), these chemicals were earlier called ectohormones.

CLASSIFICATION

According to the effects they produce, pheromones are divided into two groups

1. Primer effect pheromones
2. Releaser effect pheromones

1. Primer effect pheromones: operate through gustatory sensila and trigger a chain of physiological changes in the body. In insect they regulate cast determination and reproduction in social insect like ant bees and termites.

2. Releaser effect pheromones: operates through the olfactory sensila and regulate the behavior of insects.

The pheromones of this category are of the following types in insects:

- Sex pheromones
- Aggregation pheromones
- Alarm pheromones,
- Trail pheromones

SEX PHEROMONE

1. Represent diverse assemblage of compounds.
2. Commonly released by females.
3. Out of 150 species, 100 species of females and 50 species of male produces pheromones.
4. Female sex pheromone is important than male.

Sex pheromones	Source
Bombykol	Silkmoth
Gyplure	Gypsy moth
Gossyplure	Pinkworm
Looplure	Cabbage looper
Queen substance	Queen honeybees.

Aggregation pheromones

- Aggregation pheromones - A substance produced by one or both sexes, and bringing both sexes together for feeding and reproduction.
- These pheromones are known mostly in coleopterons,a pentatomid bug.
- Some common names of aggregation pheromones are -: Frontalin, Ipsenol, Periplanone, Dimethyldecanol etc.

Alarm pheromones

- Alarm pheromones-reported in Homoptera, Isoptera, Hymenoptera.
- The pheromones is produced by a variety of organs such as a pair of cornicles near the tip of the abdomen in aphids, cephalic glands in termites and poison glands in ants.

- Alarm pheromones are primarily an antipredator device, warning to members of the same species about presence or absence of an enemy (mostly a predator).
- Chemical nature of some of the alarm pheromones are terpenes (aphids), aldehydes (hemipterans), formic acid (ants) and monoterpene hydrocarbons (termite soldiers).

Trail pheromones

- The trail pheromones are used to find mates, or to utilise food resources more efficiently.
- In case of social or migrating insects, this pheromones also maintains the cohesion and social integration of the colony.

Communication

Pheromone:

Chemical released by an animals that affects the behavior or development of other members of the same species through the sense of smell or taste.

Example: ant trails- following a pheromone.

➢ INTRODUCTION

➢ Muscles power all the movements, external and internal, in insects.

➢All insect muscles are striated, like vertebrate cardiac and skeletal muscle.

➢Insect muscles show high levels of homology to these vertebrate muscles in their structure, protein content, contractility and regulation.

➢Insect muscles are mostly translucent, colourless or grey, though the flight muscles often show a yellowish or brown tinge.

➢In most skeletel muscles, especially those of the appendages, one end of the muscle is attached to a movable part.

➢Cuticular invaginations or apodemes, in the form of cords, bands or plate like structures, may provide the true sites of attachment.

➢ FUNCTIONS OF THE MUSCULAR SYSTEM

1. Support of the body.

2. Helps maintain posture.

3. Movement of the limbs, including ovipositor.

4. Movement of the wings-insects are the only invertebrates that fly.

5. Movement of the viscera.

6. Locomotion.

7. Closure of spiracles.

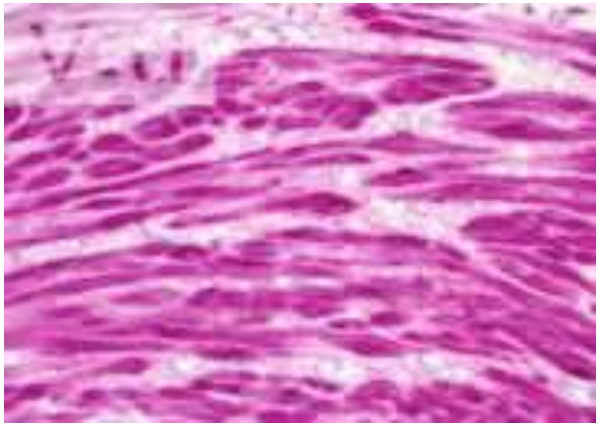
8. Operation of various pumps such as cibarial pump and the pumping of the poison glands.

9. Generation of heat by ‘shivering’.

➢ TYPES OF MUSCLES BASED ON MORPHOLOGY

1. Cardiac muscles :- not found in insects.
2. Smooth muscles :- not found in insects.
3. **Striated muscles :- found in insects.**

Fig :- Smooth Muscle



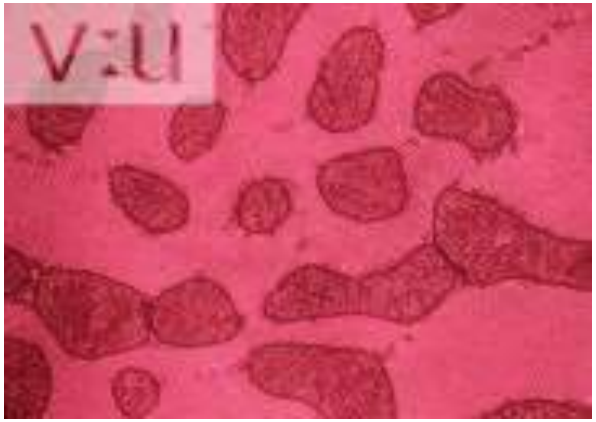
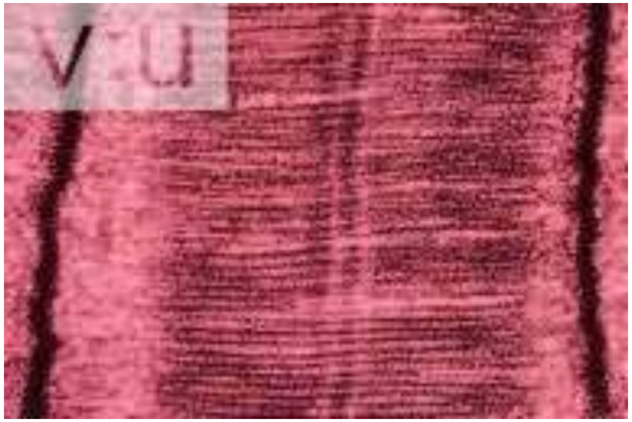


Fig :- Cardiac Muscle

Fig :- Striated Muscle



The only muscle type found in insects is striated muscle. Insects do not have cardiac or smooth muscle types.

➢ TYPES OF MUSCLES BASED ON LOCATION

1. Skeletal muscles :

a. Cephalic Muscles
b. Thoracic Muscles
c. Muscles of Flight
d. Abdominal muscles

2. Visceral muscles :

a. Alary muscle
b. Dorsal blood vessel
c. Accessory pulsatile organs and various diaphragms
d. Alimentary canal, including the crop
e. Reproductive organs and ducts
f. Venom glands
g. Repugnatorial glands
h. Organs of defense
i. Malpighian tubules

3. Cardiac Muscles :

➢ Histology Of The Muscles

➢Each muscle is made up of a number of fibers, which are long, usually multinucleate cells running the length of the muscle.

➢The characteristic feature of muscle fibres is the presence of myofibrils.

➢These are embedded in the cytoplasm i.e Sarcoplasm and extend continuously from one end of the fibre to the other.

➢The fibrils are long serial arrays of contractile units known as Sarcomeres.

➢Each sarcomere is composed of interdigitated molecular filaments, consisting mainly of two proteins : Myosin and Actin.

➢These proteins through their cyclical, ATP dependent interactions generate the contractile forces and movements.

➢Each sarcomere is bounded by electron-dense Z-discs which connect neighbouring sarcomeres.

Contd…….

- From either side of each Z-disc (also called Z-line), so called “thin filaments” extend toward, but do not reach, the center of the sarcomere.

- Each sarcomere comprises of an anisotropic region (the A-band) and two half isotropic regions (I-bands) containing the proximal parts of the thin filaments.

- The dense A-band is further transversed by a lighter H-bands.

- An array of thin I-band actin filaments (each some 5 nm in diameter) extends from the Z-disc to the edge of the H-band.

- While thicker myosin filaments (each about 15 nm in diameter) run throughout the A-band.
- Actin and myosin filaments are linked by temporary cross-bridges, each myosin filament usually being surrounded by 6 actin filaments.

- According to theory of Huxley and Hanson, contraction of the fibril is due to the sliding of the actin and myosin filaments relative to each other

- The actin filaments move further into the A-disk while the myosin filaments thus approach the Z-disks.

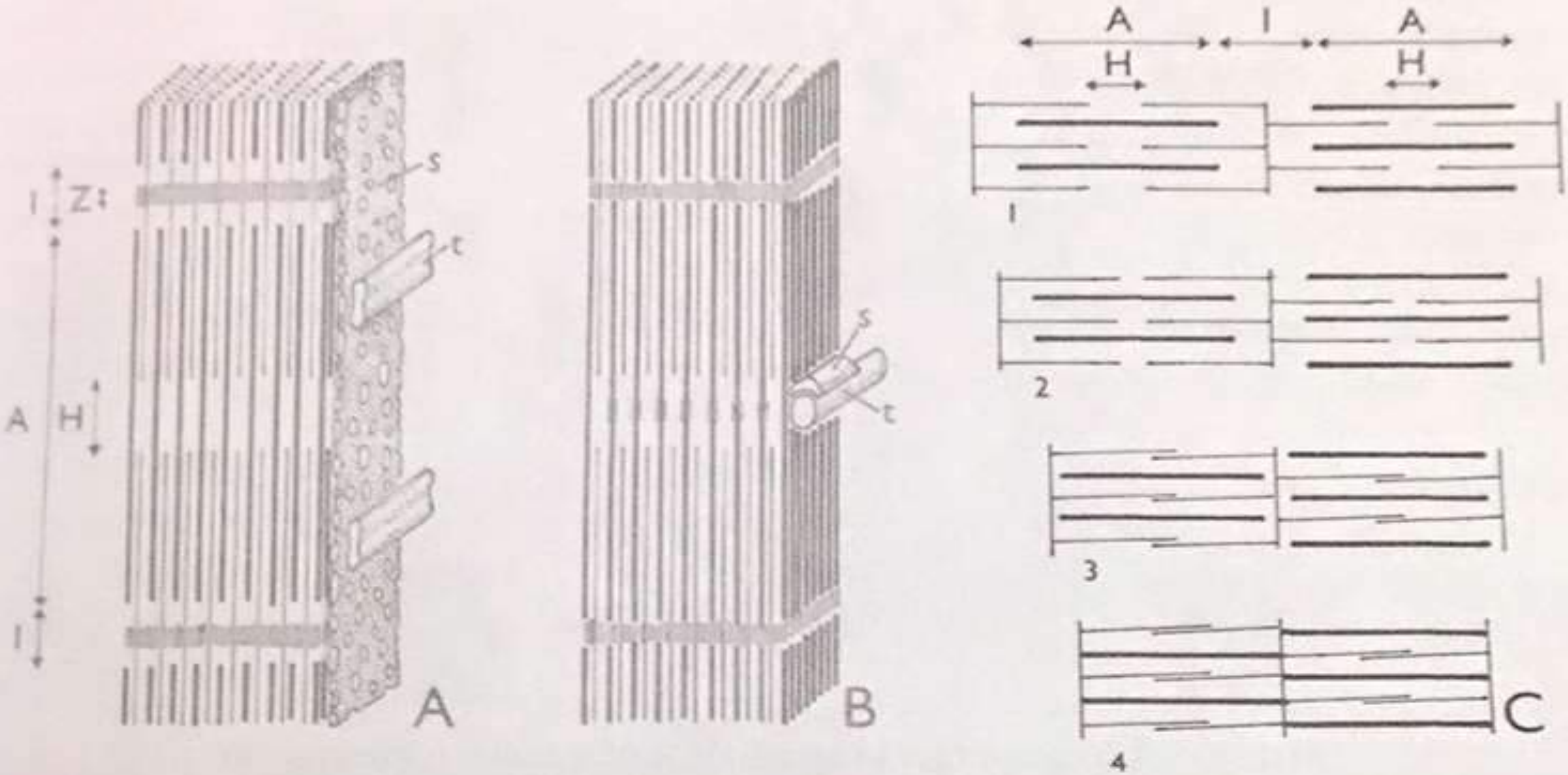


FIG. 53 Ultrastructure of insect muscle (*after* Smith and Huxley). A, synchronous muscle fibril showing extensive sarcoplasmic reticulum and wide I-band. B, asynchronous fibril showing reduced sarcoplasmic reticulum and narrow I-band. C, schematic representation of successive stages in the contraction of two sarcomeres, illustrating changes in the relative positions of the thick and thin filaments (respectively of myosin and actin)

s, sarcoplasmic reticulum; *t*, transverse membrane system (T-system). The relationships of the A, I, H and Z bands to the ultrastructural and molecular constitution of the fibril are indicated at the left and top right.

Contd…..

- The skeletal muscles of insects have a complex structure, which have :

i. The fibrous contractile system
ii. The mitochondria
iii. The tracheal and nervous supply
iv. The membrane systems

- Variations in the histology and ultrastructure of these components are associated with functional differences between different groups of muscles.
- The mitochondria of insect muscle vary greatly in size, shape and distribution. Most extensively developed in the flight muscles, because of high metabolic rate of these contracting structures.
- They may be scattered randomly throughout the sarcoplasm or arranged between fibrils opposite to z-disks.
- The tracheal supply also varies with their activity, visceral muscles being poorly supplied while flight muscles are much more richly tracheated with intracellular tracheoles penetrating the fibrils
- Visceral muscle fibres occur singly or in groups around the gonads, their ducts, diaphragms (in the heart) and gut wall.
- Visceral muscles differ from skeletal muscles having smaller fibers linked by desmosomes (absent in skeletal muscles), poor tracheolar supply, few mitochondria and a poorly developed T- system and sarcoplasmic reticulm.

Contd…..

✓ ***T-SYSTEM :-*** Transverse tubular invaginations arising from sarcolemma (a unit membrane, about 7.5 nm thick).

✓ **Sarcoplasmic reticulm :-** These are longitudinally arranged cisternae of a separate membrane system close to *T-system.*

➢ The T-system may provide a pathway along which the peripheral excitation of a fibre is conducted inward.

➢ While the sarcoplasmic reticulum probably controls the contraction cycle through the activation of myosin ATP-ase by calcium ions.

➢ In skeletal muscles at the junction of muscle and epidermis the cells show regular interdigitation lined with desmosomes.

➢ Within the epidermal cells microtubules connect the desmosomes with cone like depressions of the outer epidermal plasma membrane.

➢ From each cone an electron dense muscle attachment fibre or *tonofibrilla* runs through the procuticle in a pore canal and finally inserts on the epicuticle.

➢ These tonofibrillae slowly dissolved when the old cuticle is digested by moulting fluid. New tonofibrillae become attached to the epicuticle only when it is growing.

Skeletal ... being fully elucidated by ele...

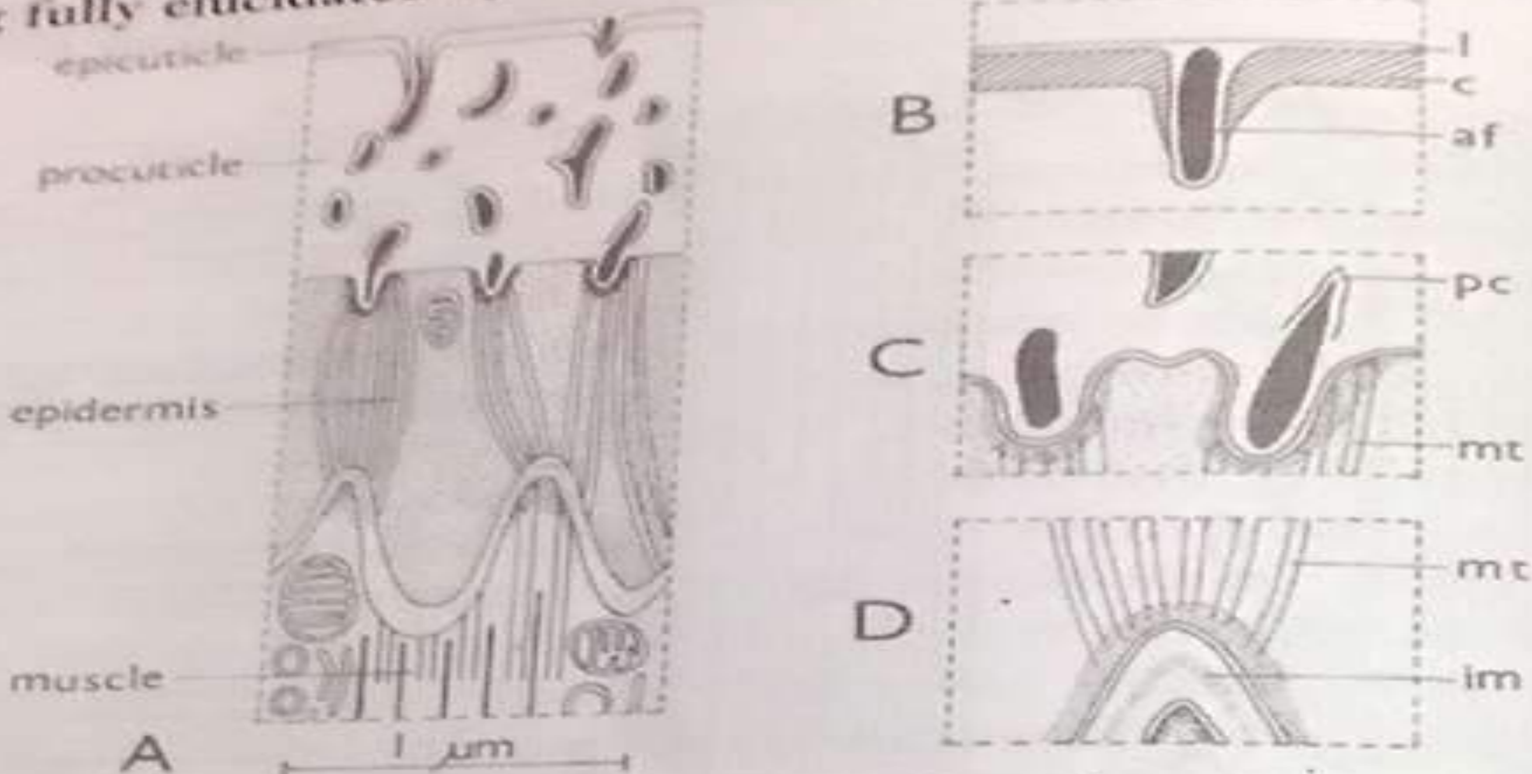


FIG. 54 Ultrastructure of attachment of muscle to integument (*after* Caveney, 1967). A, general diagram; B, relation of attachment fibre to epicuticle; C, junction of procuticle and epidermis, showing two hemidesmosomes; D, junction of epidermis and muscle, showing structure of a desmosome

af, muscle attachment fibre, running in pore canal; *c*, 'cuticulin' layer of epicuticle; *im*, intercellular matrix; *l*, lipid layer of epicuticle; *mt*, microtubules traversing epidermis from hemidesmosome to desmosome; *pc*, pore canal.

➢ Skeletal Muscles (Myology)

❑ Synchronous Skeletal Muscles :- Vast majority of insect muscles are synchronous muscles. Each contraction is driven by a single neural stimulus. The form and arrangement of the myofibrils in synchronous muscles is very variable.

❑ Asynchronous Skeletal Muscles :- In these neural stimulation is asynchronous with respect to contraction. The specialized asynchronous muscles typically have large cylindrical myofibrils, that's why they are sometimes called fibrillar.

A. Cephalic Muscles

✓The principal muscles of head may be divided into :-

1. **Cervical Muscles :-** These control the movement of head and are classified into Levators, Depressors, Retractors and Rotators according to their functions.

- They take their origin from the prothorax and cervix and are inserted into the tentorium and epicranium.

2. **Muscles of the Mouthparts :-** Classified as follows :

a) The Labral Compressors :- Running between the dorsal and ventral surfaces of the labrum.

b) The Posterior Labral Muscles :- Run from the tormal sclerites of the labrum to the wall of the head.

Contd……

c) The Anterior Labral Muscles (Retractors) :- Run from the anterior margin of the labral base to the wall of the head.

d) The Dorsal Abductors :- Originate on the upper lateral part of the epicranium and insert each on an apodeme connected with the inner, basal region of the mandible.

e) The Ventral Abductors :- Present only in the Apterygotes and some lower Pterygotes.

f) Dorsal Basal Muscles :- Arising on the dorsal part of the head and forming the anterior and posterior rotators of the cardo and the cranial flexure of the lacinia.

g) Ventral Basal Muscles :- Inserted on the cardo and stipes and originate on the tentorium in most pterygotes and on the tentorial apodemes in the apterygotes.

i) Stipital Muscles :- Originate on the stipes and include the levator and depressor of the palp, flexor of the galea and the stipital flexor of the lacinia.

j) Extrinsic Labial Muscles :- Arise on the tentorium or cranial wall and insert on the prementum. They correspond to the ventral basal muscles of the maxilla.

k) Median Labial Muscles :- Run from the back of the prementum to the postmentum and have no homologues in the maxilla.

l) Labial Salivary Muscles :- Usually two pairs, arising on the prementum and converging on the labial wall of the salivarium near the opening of the salivary duct.

m) Musles of the endites and palps :- From the prementum there run the levator and depressor muscles of the palps and a flexor of each glossa and paraglossa.

Contd……

n) Intrinsic Palp Muscles :-Inserted on the suspensorium of the hypopharynx.

3. Muscles of Antennae :- Classified as follows :

a) Extrinsic antennal muscles :- A levator and usually two depressors are inserted on the base of the scape.

b) Intrinsic antennal muscles :- Pair of muscles arising in the scape and inserted on the base of the pedicel.

B. Thoracic Muscles

✓ The principal Thoracic Muscles may be divided as follows :-

a) Longitudenal :- Divisible into tergal and sternal groups, the former being important indirect flight muscles.
b) Dorsoventral :- Two main groups here are : tergosternal muscles : principal levators of wing (acting antagonistically to the longitudenal tergals and tergocoxal muscles : act as the tergal promoters and remotors of the leg.
c) Pleural :- Three main groups here are : tergopleural muscles : variable in development and include the axillary muscles, pleurosternal muscles : short fibres linking the pleural and sternal apophyses, pleurocoxal muscles : act as abductors of the coxae.

Contd…..

d) Sternal :- Includes two muscle groups : sternocoxals : are sternal promotors and remotors of the leg, lateral intersegmental : runs from sternum to the pleuron or tergum of the succedding segment and is best developed in larval forms.

e) Intrinsic Leg Muscles :- Lying within the segments of the legs. They include levator and depressor of the trochanter, tibia and tarsus and the levator of the pretarsus.

C. The Abdominal Muscles

a) Longitudenal :- Divided into (a) tergal and (b) sternal longitudenal muscles. In each case they run between the intersegmental folds or antecostae of successive segments. Acting together the groups act as retractors by telescoping the abdomen. Acting alone , the sternal muscles curve the abdomen downwards and the tergals straighten it or bend it upwards.

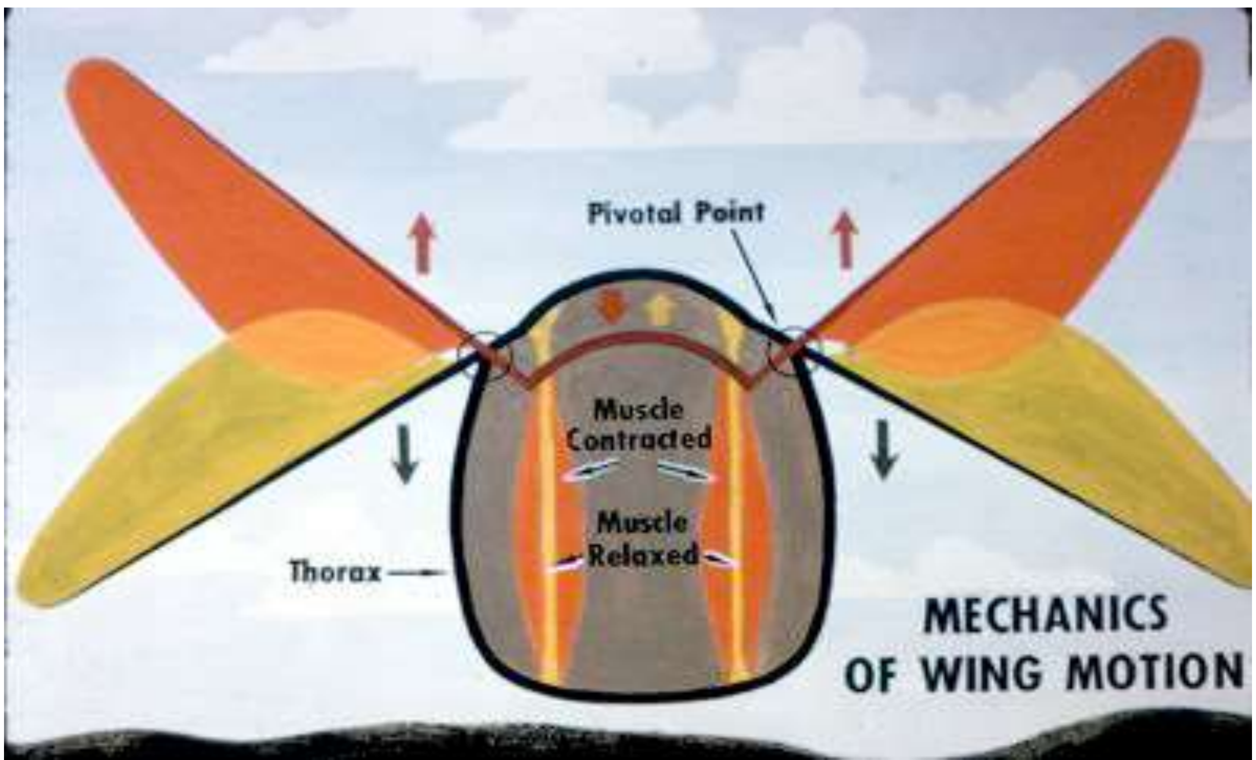
b) Lateral :- Typically run dorsoventrally and are both inter and intrasegmental in position. They are usually tergosternals, but when distinct pleurites are present there may also be tergopleural and sternopleural muscles. By contraction they tend to compress the segment and are therefore important in respiratory movements.

c) Transverse :- Better known as the muscles of the dorsal and ventral diaphragms.

- In addition there are special muscles concerned with movements of the genitalia, cerci and spiracles.

D. Muscles Of Flight

The flight movements are caused by three sets of muscles , the indirect, direct and accessory indirect flight muscles. The indirect muscles are usually the largest in the body and are attached to the thorax and not to the wing base. Wing movement, and most of flight, is controlled by indirect flight muscles**.** They are called this because the longitudinal and dorsoventral muscles do not connect directly to the wing but, control flight by affecting the dorsal surface of the thorax. When the dorsoventral muscles contract, it causes a depression of the tergum, causing the wings to go up. Contraction of the longitudinal muscles causes an arching of the notum and the wings go down. It is a pivotal movement based on the arrangement of the cuticle and wings.



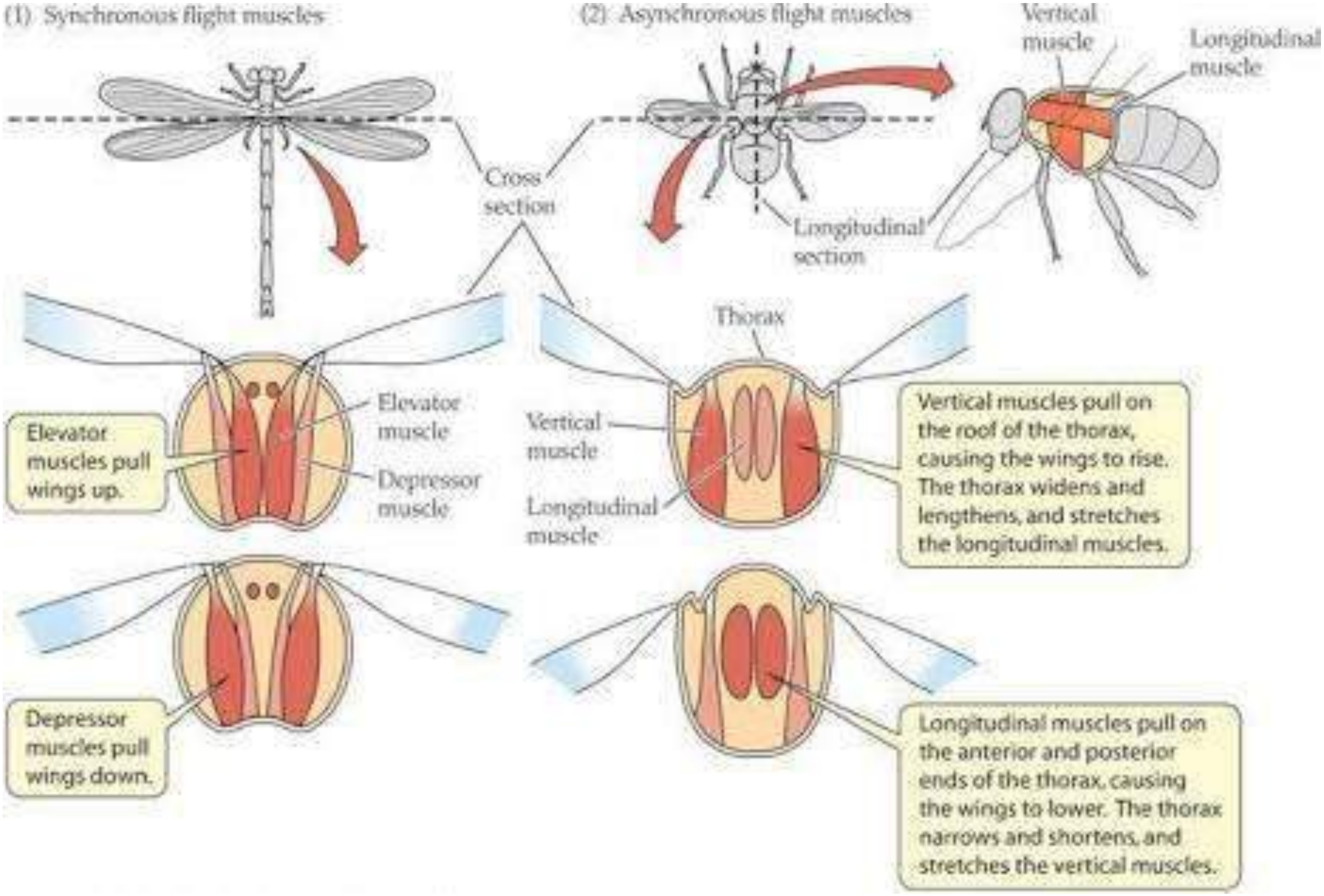


Fig :- Mechanism of working of Flight Muscles

➢ Visceral Muscles

- ✓ These muscles differ in structure from skeletal muscles in severe respects.
- ✓ Adjacent fibers are held together by desmosomes, which are absent from skeletal muscle.
- ✓ The sacroplasmic reticulm is poorly developed, mitochondria are small and often few in number.
- ✓ All insect muscles are striated, s visceral muscle resembles skeletal muscle in contrast to the smooth visceral muscle of vertebrates.
- ✓ Visceral muscles may be innervated from the stomodeal nervous system or from the ganglia of the ventral nerve cord, but are sometimes without innervation as in the heart of *Anopheles spp* larvae.

➢ Cardiac Muscles

- ✓The insect heart usually consists of a simple tube that contains a layer of contractile myocardial cells.
- ✓ These are usually mononucleate cells with straited longitudinal and circular myofibrils.
- ✓ Heart rate is influenced by nerves that innervates the heart in most insects.

➢ Physiology Of Insect Muscles

✓ Properties of insect skeletal muscles such as absolute muscular power and simple contraction do not differ greatly from those of vertebrates.

✓Unlike vertebrates, insect muscles contain relatively few fibres and to achieve smooth contractions they are supplied by multiple nerve endings.

✓ The neuromuscular transmitter substances of insect is probably L-glutamate.

✓ The muscles of legs and abdomen and most flight muscles respond synchronously to the nervous impulses.

✓ In Diptera, Hymenoptera, Coleoptera and Hemiptera there evolved the characteristics fibrillar type of asynchronous indirect flight muscles.

✓ Here the frequency of contraction is not determined by the central nervous system but is directly controlled by the loading on the muscles.

➢ Metabolism of Insect Muscles

✓ The oxygen consumption of an insect may rise a hundred fold when flight begins and if it is to continue for long periods a reserve of oxidizable respiratory material is needed.

✓ In Diptera and Hymenoptera a respiratory quotient of unity during flight indicates that carbohydrates are the main substrate.

✓ In Lepidoptera, Homoptera and Orthoptera on the other hand, R.Q. values of about 0.7 occur and fat reserves are depleted.

✓ Some spp such as locusts and aphids, use glycogen and the disaccharide depletes first then consume fat during prolonged flight.

✓ There are important biochemical differences in the metabolism of different muscles e.g in locust flight muscles lactic dehydrogenase is virtually absent and lectic acid is not an end product of glycolysis, whereas in the leg muscle lactic acid accumulates and is slowly removed by oxidation and conversion to glycogen.

Reproductive system

- Usually Insects are bisexual. But sometimes reproduction also occurs by Parthenogenesis and hermaphroditism.

- The reproductive system is divided in to two parts namely internal genitalia and external genitalia . The internal genitalia serve to the development of germ cells.

- The external genitalia accomplish the union of two sexes and enable the female to deposit eggs.

Female reproductive system

It consists of:

- a pair of ovaries which possess number of ovarioles
- a pair of oviducts, common oviduct / Median oviduct
- spermatheca
- a pair of accessory glands
- Bursa copulatrix or copulatory pouch or genital chamber or vagina

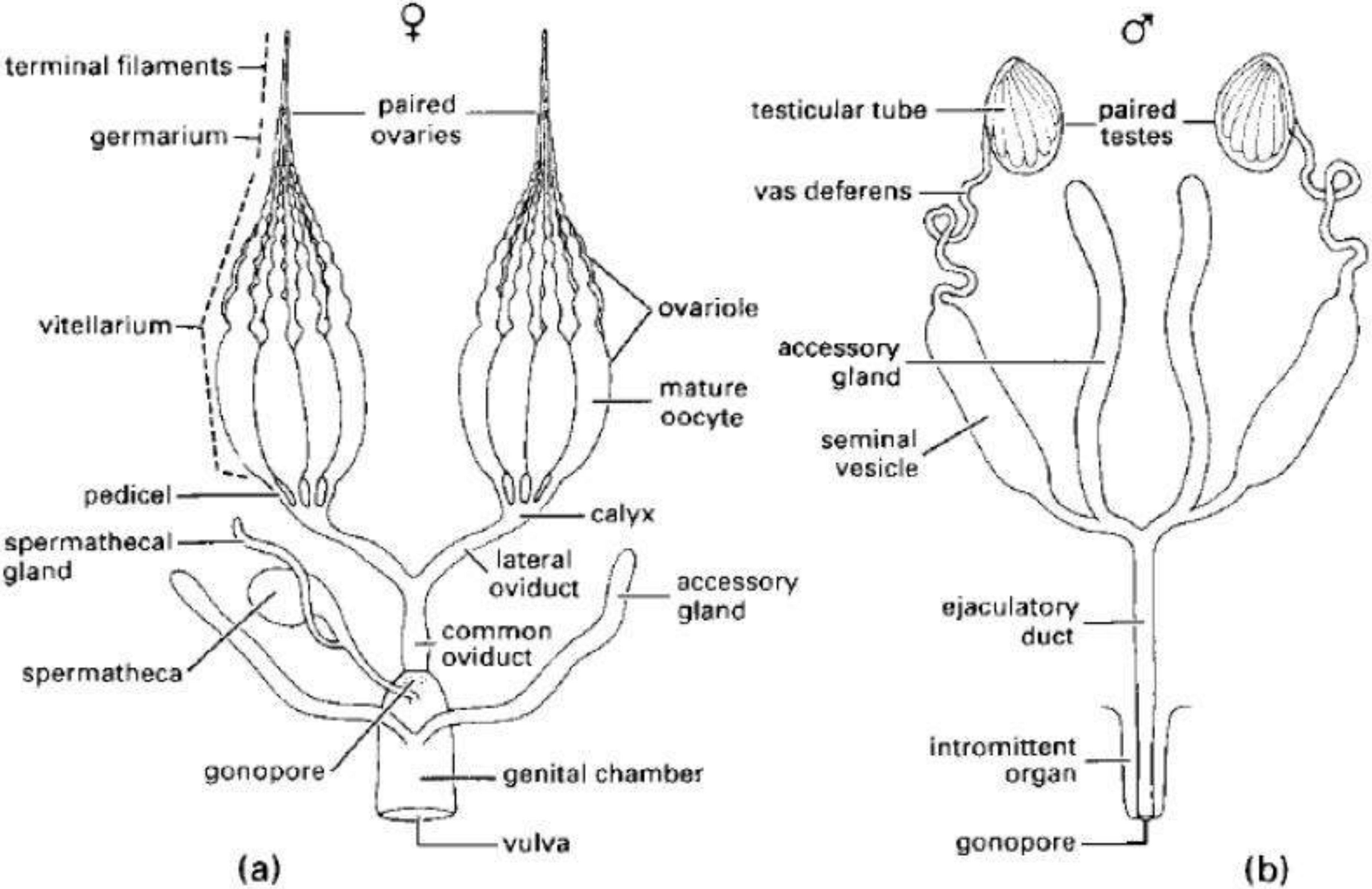
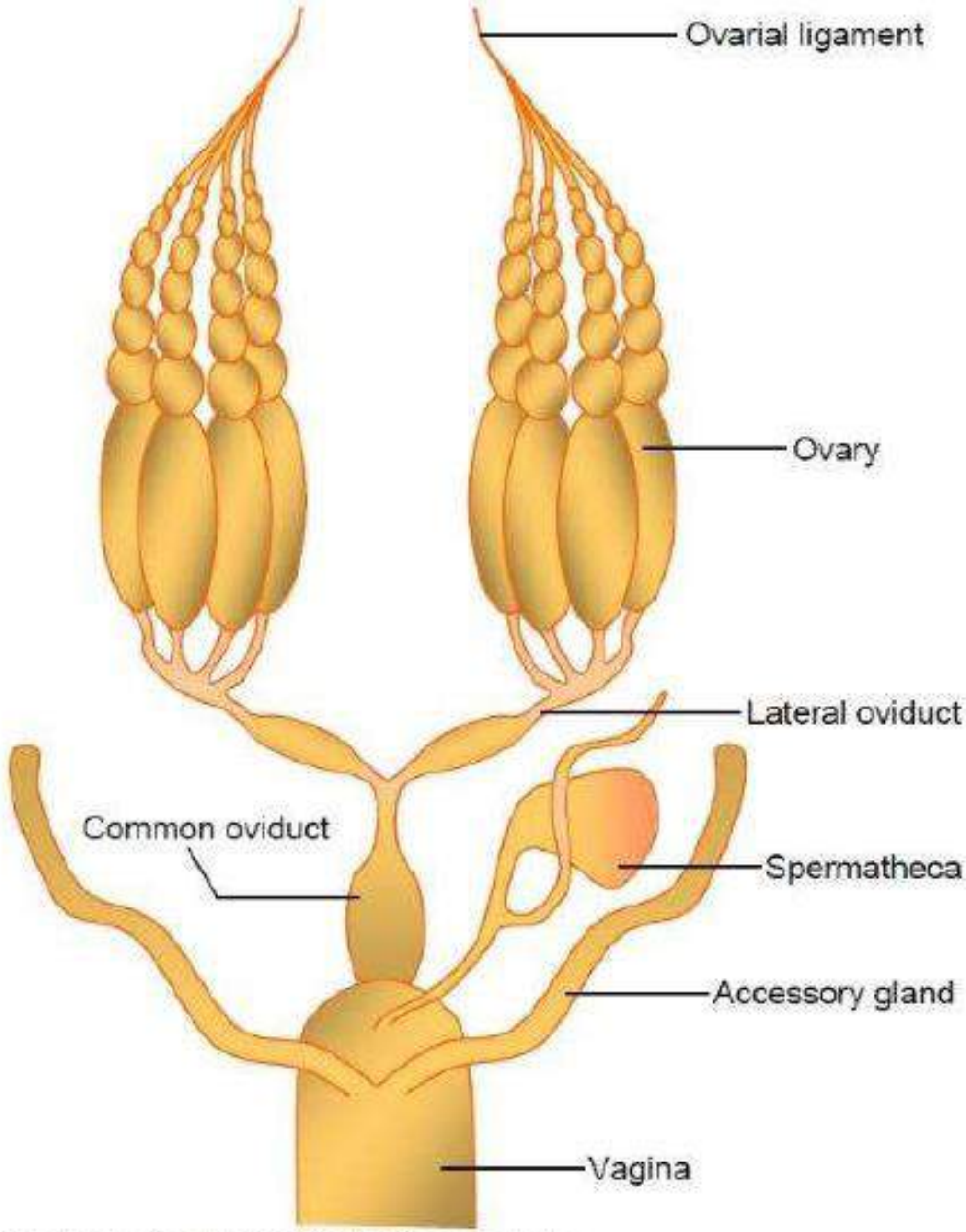


Fig. 3.20 Comparison of generalized (a) female and (b) male reproductive systems. (After Snodgrass 1935.)



Female insect reproductive system

- **Ovaries** :are the prominent visceral organs present on the either side of alimentary canal. Anteriorly the ovaries get connected with the body wall by means of thread like suspensory ligaments. The ovaries are covered with fat body and are richly covered with trachea. Each ovary consists of a no. of ovarioles or egg tubes.
- **Ovarioles**: Each ovariole is enveloped by a double layered cellular wall. The outer wall is called ovarial sheath which has an abundant supply of tracheae.
- The eggs are discharged in to the lateral oviducts .

- **Lateral oviducts**: Proximal end of the ovarioles of each ovary join to form a lateral oviduct on each side .The wall of oviduct is glandular and muscular.
- **Median Oviduct**: Two lateral oviducts combine to form a median oviduct
- **Vagina**: In most of the insects median oviduct does not open directly to outside. It opens in to a tubular genital chamber or vagina formed by invagination of body wall from VIII segment . The vagina opens outside and the opening is called vulva.
- **Vulva** serves both purposes of receiving the sperms and discharging the eggs.

- **Bursa Copulatrix**: In some insects the genital chamber or vagina develops a separate pouch called Bursa Copulatrix in to which insects have two reproductive openings .
- One is vulva for receiving the sperms open on VIII sternum and another one is ovipore or gonopore on IX segment for discharging eggs.
- Eg: Lepidoptera and water beetles

- **Spermathea**: It is a sac like structure consisting of a spermathecal gland and opens in to vagina through spermathecal duct. This is mainly used for storing the sperms.
- It also produces some fluids responsible for longevity of cells for several hours.
- **Accessory glands**: These are a pair of collateral glands which open in to the distal portion of vagina and secrete the substance responsible for the formation of ootheca of cockroach, preying mantid and poisonous secretions in case of Hymenoptera.
- This sticky substances are useful for attachment of egg to the substrate on which they are laid.

- Each ovariole in insects consists of a group of tapering units called ovarioles.
- The number of ovarioles in an ovary varies greatly in different insects , usually 4 to 8.
- In Isoptera more than 2000
- Typical ovariole or egg tube consists of 3 parts namely
- 1.Terminal filament
- 2.Egg tube
- 3.Supporting stalk or pedicel

- **Types of ovarioles :**
- Based on the presence or absence of nutritive cells and their location ovarioles are categorized in to two .

1. **Panoistic ovarioles: In these, the nutritive cells are absent and the** development of oocytes takes place with the help of follicular epithelial cells

e.g.: Odonata, Dictyoptera, Orthoptera and Ephemeroptera

2. **Meriostic ovarioles: They contain trophocytes / nutritive cells which vary in** their position.

- Based on the position of trophocytes **Meriostic ovarioles are classified into**

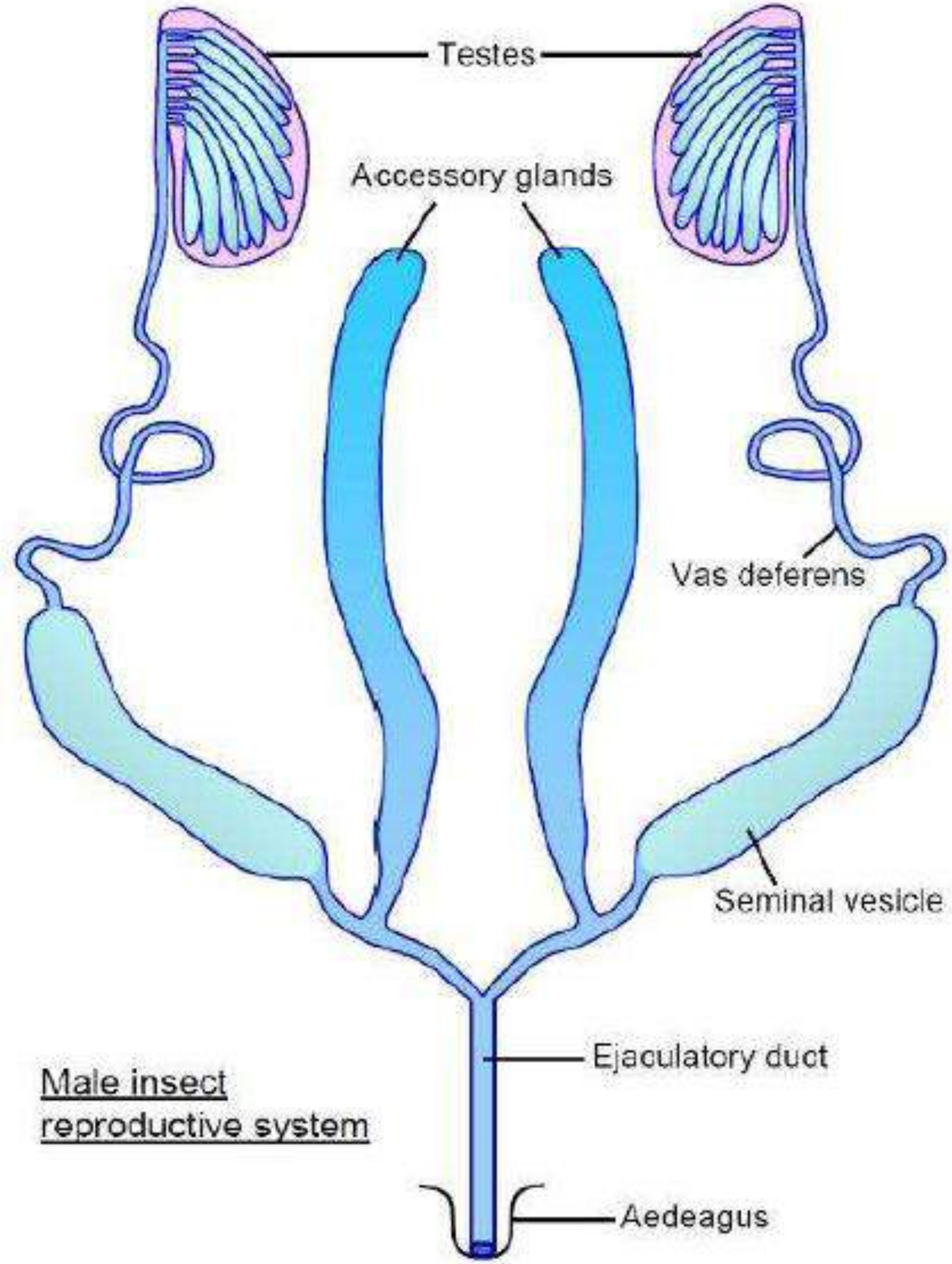
(i) **Polytrophic ovarioles: where developing oocyte and trophocytes arranged** alternatively within the vitellarium. e.g.: Mecoptera, Dermaptera, Psocoptera

(ii) **Acrotrophic ovarioles: Also called teletrophic ovarioles where the** trophocytes are present in the germarium (apex) and are connected with the growing or developing oocytes by cytoplasmic strands. e.g.: Hemiptera and Coleoptera

Male reproductive system

Internal male reproductive organs consists of

- A pair of testis
- A pair of vasa deferens,
- Seminal vesicle
- Ejaculatory duct
- Genitalia


Testes
Accessory glands
Vas deferens
Seminal vesicle
Ejaculatory duct
Aedeagus
Male insect
reproductive system

- **1. Testis : The size of testis is practically same as that of ovaries in Apterygota and** very much smaller in Pterygota . They lie in visceral cavity above the alimentary canal and are connected to the body wall through translucent ducts and are well supplied with trachea and fat body tissues. Each testis consists of number of oval shaped structures known as **follicles or sperm tubes.**

- **2. Vasa deferens : These are the long tubes formed by the union of vasa efferens** which receives the sperms from testis and allow their transport to the ejaculatory Duct.

- **3. Seminal vesicles: Each vasa deferens become enlarged posteriorly to form a sac** like structure called seminal vesicle for **storage of spermatozoa for some time.**

- **4. Ejaculatory duct: Both the vasa deferens of the two testis unite posteriorly to** form a common median ejaculatory duct. The terminal section of ejaculatory duct is enclosed in a finger like evagination of body wall , male copulatory organ or aedeagus or penis.

- **5. Accessory glands: These are 1-3 pairs of glands which open in to the ejaculatory** duct. In most cases their secretion mix with spermatozoa. These glands are called **mushroom glands in cockroaches and mantids because of their appearance as** mushrooms. This secretions facilitates sperm transmission from male to female.

Physiology of reproduction

Spermatogenesis
(occurs inside sperm tube)

Spermatogonia

Mitosis ↓

Primary Spermatocytes (2n)

Meiosis ↓

Secondary Spermatocytes (n)

Mitosis ↓

Spermatids (n)

Spermiogenesis ↓

Sperms (n)

Oogenesis
(occurs inside egg tube)

Oogonia

↓ Mitosis

Primary oocytes (2n)

↓ Meiosis

Secondary oocytes (n)

↓ Mitosis

Oocytes (n)

↓ Vitellogenesis

Ovum (n)

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. **<u>Ovoviviparity:</u>** 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. **<u>Pseudoplacental viviparity:</u>** 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.*

Immunity

- Immunity is the capability of the body to resist harmful microbes from entering it.
- Defense against infection is divided into two main forms termed innate immunity and adaptive immunity.

- **Innate defense mechanisms** are present in different forms in all multi-cellular organisms.

- **Adaptive defense mechanisms** have evolved more recently in vertebrates.

- **Innate (natural) immunity:** This is a first-line defense system of multi-cellular organisms (both vertebrates and invertebrates) mounted in response to various microbial invaders.

- It relies on genetically encoded factors that recognize conserved microbial features (e.g. lipopolysaccharide from Gram-negative bacteria, peptidoglycan from Gram-positive bacteria and glucans from fungi).

- These interactions activate immediate defense responses such as phagocytosis and the production of antimicrobial peptides.

- **Acquired (adaptive) immunity:** This immune response is restricted to vertebrates and uses somatic gene rearrangements to generate lymphocytes expressing random, unique antigen receptors.

- Recognition of an antigen prompts the lymphocyte to divide and mature into cells that defend by secreting antibodies, activating macrophages and killing virally infected cells.

- Insect innate immune responses include cellular and humoral responses.
- **The cellular arm** involves haemolymph coagulation, melanization, phagocytosis and encapsulation processes resulting from co-operating haemocyte types.
- **The humoural arm** includes constitutive and inducible antimicrobial peptides (AMPs).

- These responses are based on the recognition of the pathogen, the induction of suitable genes and biochemical pathways and these leads to fast and massive production of a low molecular weight AMPs to rapidly eliminate invading pathogens.

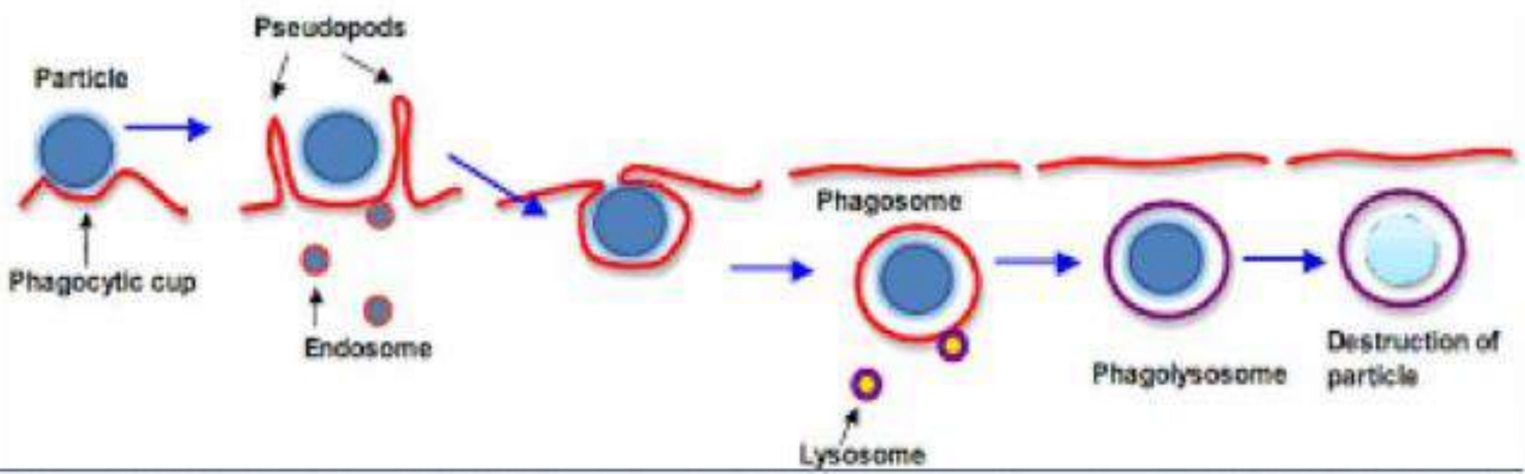
The immune system of insects

- Insects exhibit a particular resistance to infections. This resistance is due to the cuticle that forms a mechanical barrier effectively safeguarding against microbial invasion and to the innate immune reactions.
- The innate immune system of insects consists of organs composed of different types of cells plus a variety of cells circulating free in the hemolymph.
- all the components of the insect immune system (the fat body, the lymph gland and the hemocytes) originate from the mesoderm.

- The fat body: is made up of adipose tissue attached to the internal surface of the cuticle and distributed in all segments of the insect. It is a large biosynthetic organ, functional analogue of the mammalian liver and responsible for the synthesis of antimicrobial peptides.
- The lymph gland: is composed of a few paired pericardial lobules, lying on the anterior end of the dorsal vessel and it is supposed to form hemocytes during larval and adult life.
- The hemocytes: are actively trafficking cells and thought to be involved in all defense mechanisms. The insect hemocytes have been classified by morphological criteria but there is increasing number of reports to characterize them by serological means.

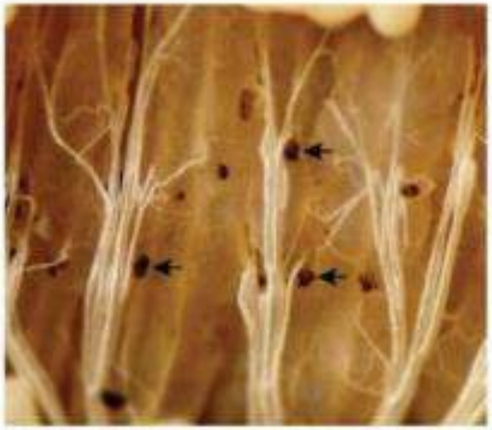
. Cellular reactions

- **1. Phagocytosis**
- Cells with phagocytic activity usually represent a subpopulation of insect hemocytes. Both granular cells and plasmatocytes are supposed to be primarily responsible for phagocytosis. The cell surface molecules described on phagocytic hemocytes exhibit striking similarities to the receptors found on mammalian phagocytic cells. This similarity suggests that phagocytic cell types arise from a common ancestor with a strict conservation of important molecules.

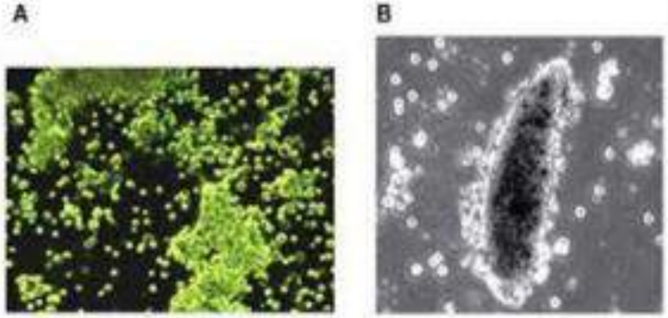


Cellular reactions

- **2. Nodule formation**
- During nodule formation insect hemocytes aggregate to entrap bacteria. Nodules can attach to tissues or may be encapsulated. An insect lectin, named scolexin was found to be involved in the formation of nodules in the tobacco hornworm (*Manduca sexta*). Scolexin is produced by epidermal and midgut cells upon wounding or bacterial infection. In *Ceratitis capitata*, a protein with molecular mass of 47 kDa is secreted by hemocytes against *E. coli* cells by the presence of tyrosine and tyrosinase.



Cellular reactions



- <u>3. Encapsulation</u>
- Encapsulation is a multicellular defense mechanism where a capsule of overlapping layers of hemocytes is formed around protozoans, nematodes and eggs or larvae of parasitic insects. Encapsulation does not induce the expression of antimicrobial genes but it may associate with melanization which contributes to the killing of the invader.
- It is still unclear whether the reaction is mediated by a given subset of hemocytes or through an interaction between different subpopulations of immune cells.
- In both cases adhesion molecules are essential to the capsule formation.
- Parasites have developed various mechanisms to resist the encapsulation reaction of host insect.
- During oviposition endoparasitic wasps inject secretions which suppress the immune system of the host, thus ensuring successful development of the immature endoparasite.

Antimicrobial peptides (AMPs)

- AMPs are defined as critical defense molecules that can protect the host from the invasion of bacteria, viruses or fungi.

- AMPs served as natural first-line of defense system for the majority of living organisms.

- In many cases, they are secreted from secretory glands into internal body fluids or onto mucosal epithelia.

AMPs have the common characteristics

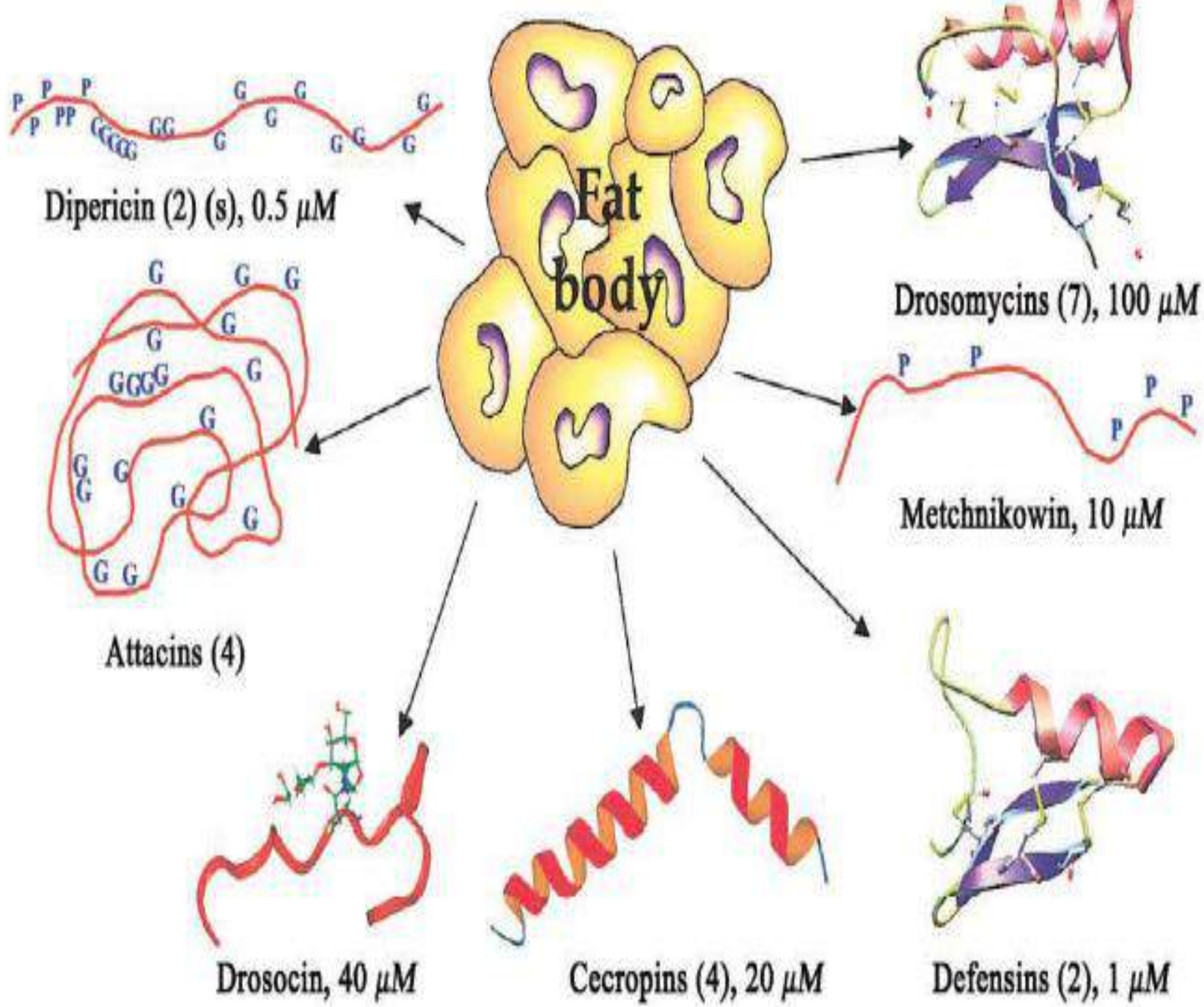
>100 amino acid residues

Heat-stable (100 °C , 15 min)

No effect on eukaryotic cell

Broad activity at low concentration

- There are seven inducible antimicrobial peptides in *Drosophila*.
- They are transcribed in the fat body within hours of an immune challenge and are secreted into the blood.
- Drosomycin, Metchnikowin and Cecropin are active against fungi, Defensin and Metchnikowin against Gram-positive bacteria and Attacin, Cecropin, Diptericin and Drosocin against Gram-negative bacteria.
- These peptides are small and structurally diverse molecules that work in combination to block the growth of invaders by disrupting their membranes.


Fat body
Dipericin (2) (s), 0.5 μM
Attacins (4)
Drosomycins (7), 100 μM
Metchnikowin, 10 μM
Drosocin, 40 μM
Cecropins (4), 20 μM
Defensins (2), 1 μM

Signaling pathways activating genes that encode antimicrobial peptides

- The humoral immune responses mainly involve the release of AMPs by the fat-body, via the Toll , the immune deficiency (Imd), and the JAK-STAT pathways.

- Gram-positive bacteria and fungi predominantly induce the Toll signaling pathway, whereas Gram-negative bacteria activate the Imd pathway.

- **Classification of antimicrobial peptides**
- AMPs are classified according to many factors such as biological activity, sequence and molecular weight and three dimensional structures as following:
- **1) Biological activity:**
- AMPs display multifunctional properties with implications as potential therapeutic agents.
- They exhibit rapid killing, often within minutes in vitro, and a broad spectrum of activity against Gram-positive and Gram-negative bacteria, fungi, parasites, enveloped viruses and tumor cells. In these several years, they have been termed “natural antibiotics”, because they are active against a large spectrum of microorganisms including bacteria, filamentous fungi, protozoan and metazoan parasites.
- So the functions of AMPs can be divided into antibacterial, antiviral, anticancer, antifungal and antiparasitic.

- **2) Sequence and Molecular weight:**
- These peptides are classified into four major groups based on their amino acid sequences and molecular weight.
- **a) Small (2-3 kDa) proline-rich peptides**
- **b) Cecropins or (sarcotoxin) (4 kDa)**
- **c) Insect defensins or (sapecins) (4 kDa)**
- **d)Large (10-30 kDa) glycine-rich peptides/polypeptides**

3) Three dimensional structure:

- **a) *α-Helical* antimicrobial peptides**
- **b) Cysteine rich antimicrobial peptides**
- **c) *β-Sheet* antimicrobial peptides**
- **d) Antimicrobial peptides rich in regular amino acids**
- **e) Antimicrobial peptides with rare modified amino acids**

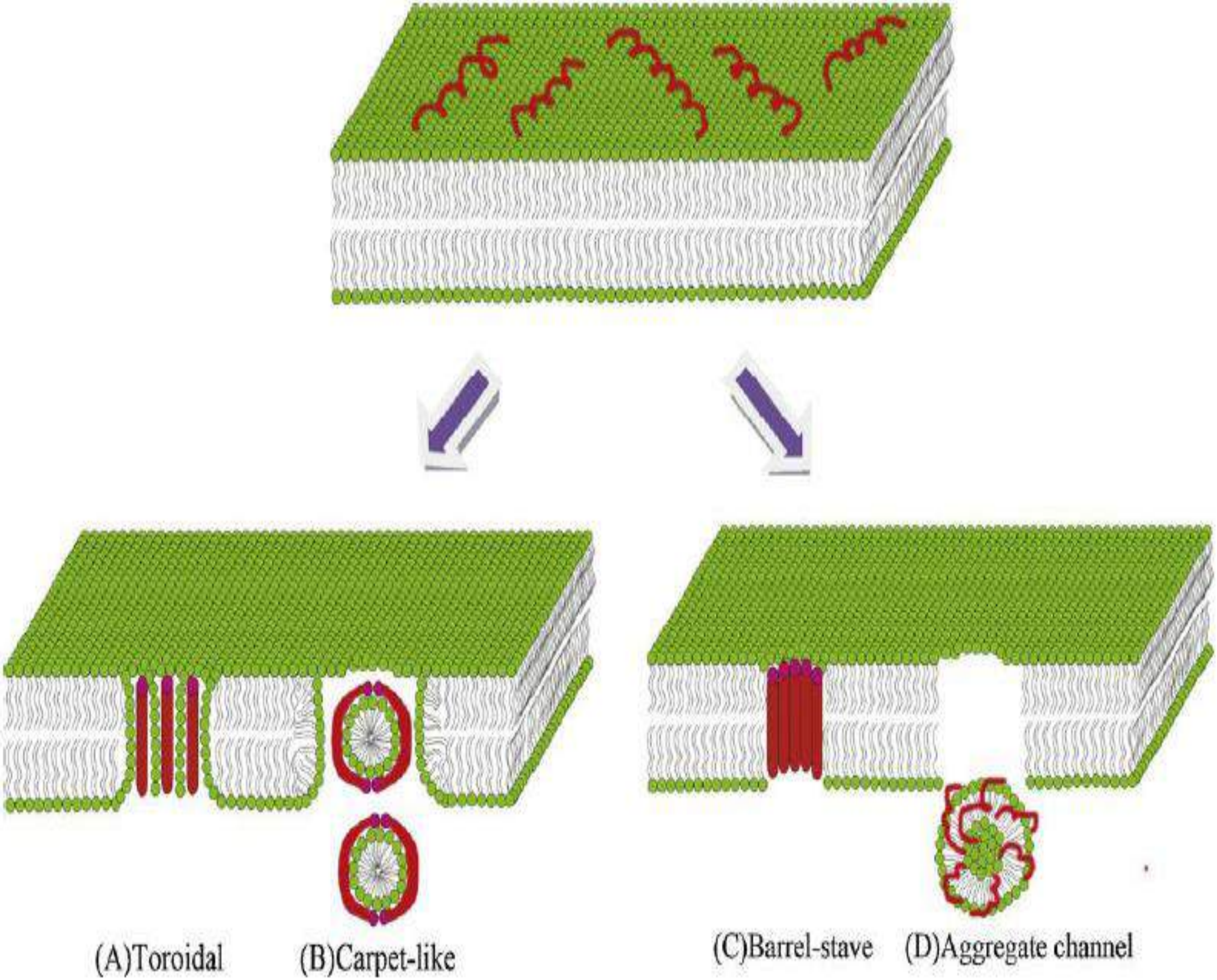
Mode of action of antibacterial peptides

- The precise mechanism of action is currently not completely known for all AMPs.

- The mechanism of the antibacterial activities of antibacterial peptides has been studied for some selected peptides.

- The mode of action of these peptides can be divided into membrane interaction which can lead to the formation of transient pores to transport peptides inside the cell and membrane-disruptive resulting in cell lysis.

- **Pore formation:**
- Killing of bacteria via pore formation in the bacterial membrane requires three principal steps: binding to the bacterial membrane, aggregation within the membrane, and formation of channels.
- The channel formation leads to leakage of internal cell contents and cell death.
- An antibacterial peptide must cross the negatively charged outer wall of Gram-negative bacteria, which contains LPS, or the outer cell wall of Gram-positive bacteria, which contains acidic polysaccharides.
- Currently, there are at least four different commonly used models.


(A)Toroidal
(B)Carpet-like
(C)Barrel-stave
(D)Aggregate channel

References

- **Gillott, C. (2005). Entomology. Springer Science & Business Media.**

- **Nation Sr, J. L. (2015). Insect physiology and biochemistry. CRC press.**