Internal anatomy and physiology

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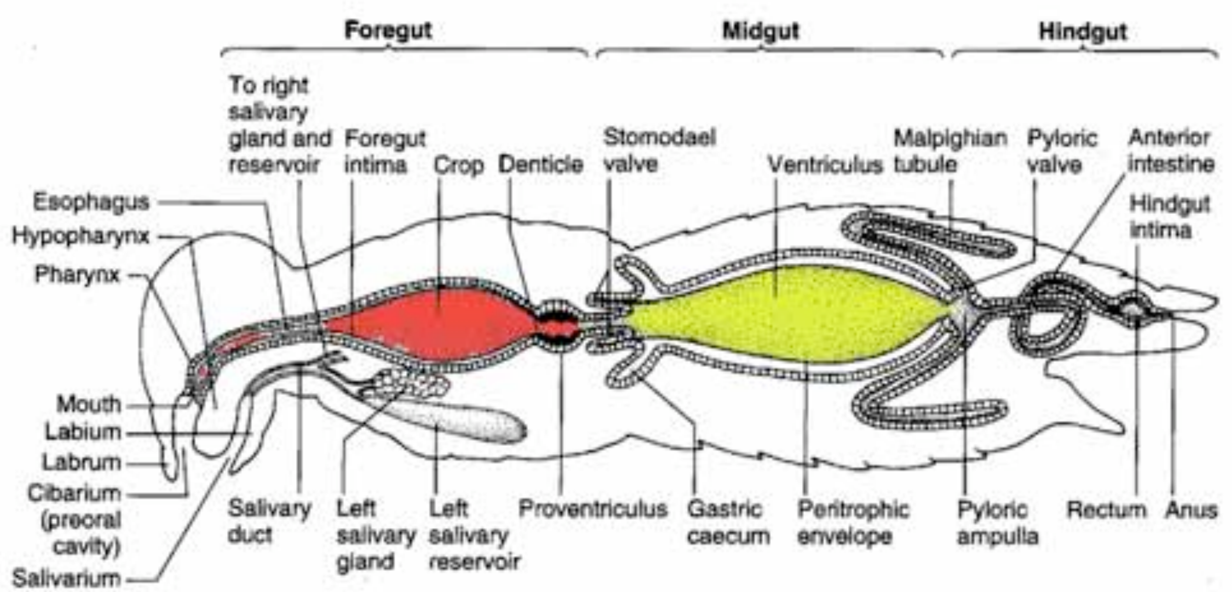
Biology 316 - General Entomology

A. Digestive system



1. **Foregut**
   a. Mouth
   b. The pharynx may be highly modified into a pump seen in sucking insects like Lepidoptera, Hemiptera, and many Diptera.
   c. Posterior to the pharynx is the esophagus that is commonly modified to form a crop, or storage area. Some groups have a modified crop that is distensible (Lepidoptera, Hymenoptera, and Diptera) allowing for additional storage.
   d. Immediately posterior to the crop is the proventriculus, a structure that contains sclerotized teeth-like denticles. The denticles aid in grinding the food.
   e. Some fluid-feeding insects lack a proventriculus.
   f. The stomodael valve (foregut valve) regulates the flow of material from the foregut to the midgut and generally demarks the boundary between the two.
   g. The foregut is lined with chitinous protective layer called the intima. Many plant feeding insects consume leaves with spines and trichomes that could lacerate the lining of the gut.
   h. The intima prohibits absorption of nutrients.
2. **Midgut**
   a. In many insects the foregut valve has associated gastric caecae that produce digestive enzymes and increase surface area.
   b. The midgut is not lined by intima and most of the absorption of nutrients occurs here in the ventriculus.

c. As in other animals, the gut is often highly modified depending upon the type of food eaten.

3. Hindgut

a. The Malpighian tubules attach to the pylorus region of the hindgut. They are part of the excretory system and will be discussed below.

b. Posterior to the Malpighian tubules is the anterior intestine and the highly muscularized rectum that terminates in the anus.

c. The rectum functions in removing water from the fecal material.

d. Water and some small molecules are removed from the gut in the hindgut so that the insect produces very dry excrement.

4. Molting

a. The foregut and the hindgut are lined with a chitinous unsclerotized layer that is shed during molts.

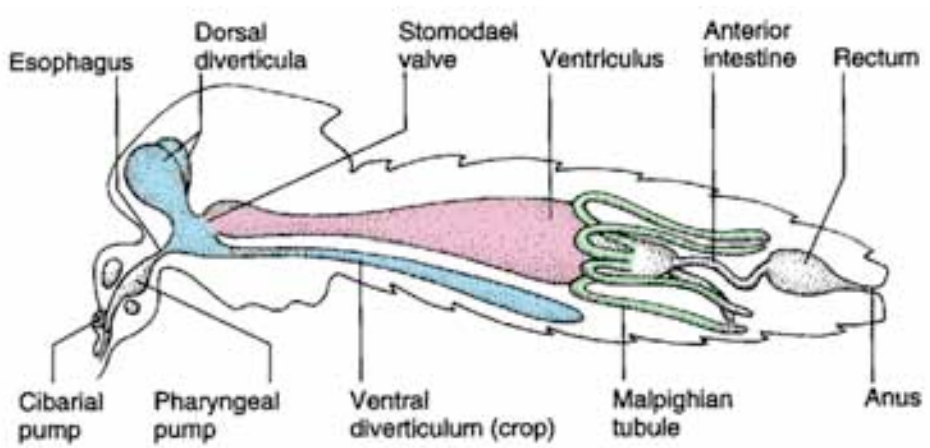
b. The gut epithelial cells are continuous with the epidermal cells.

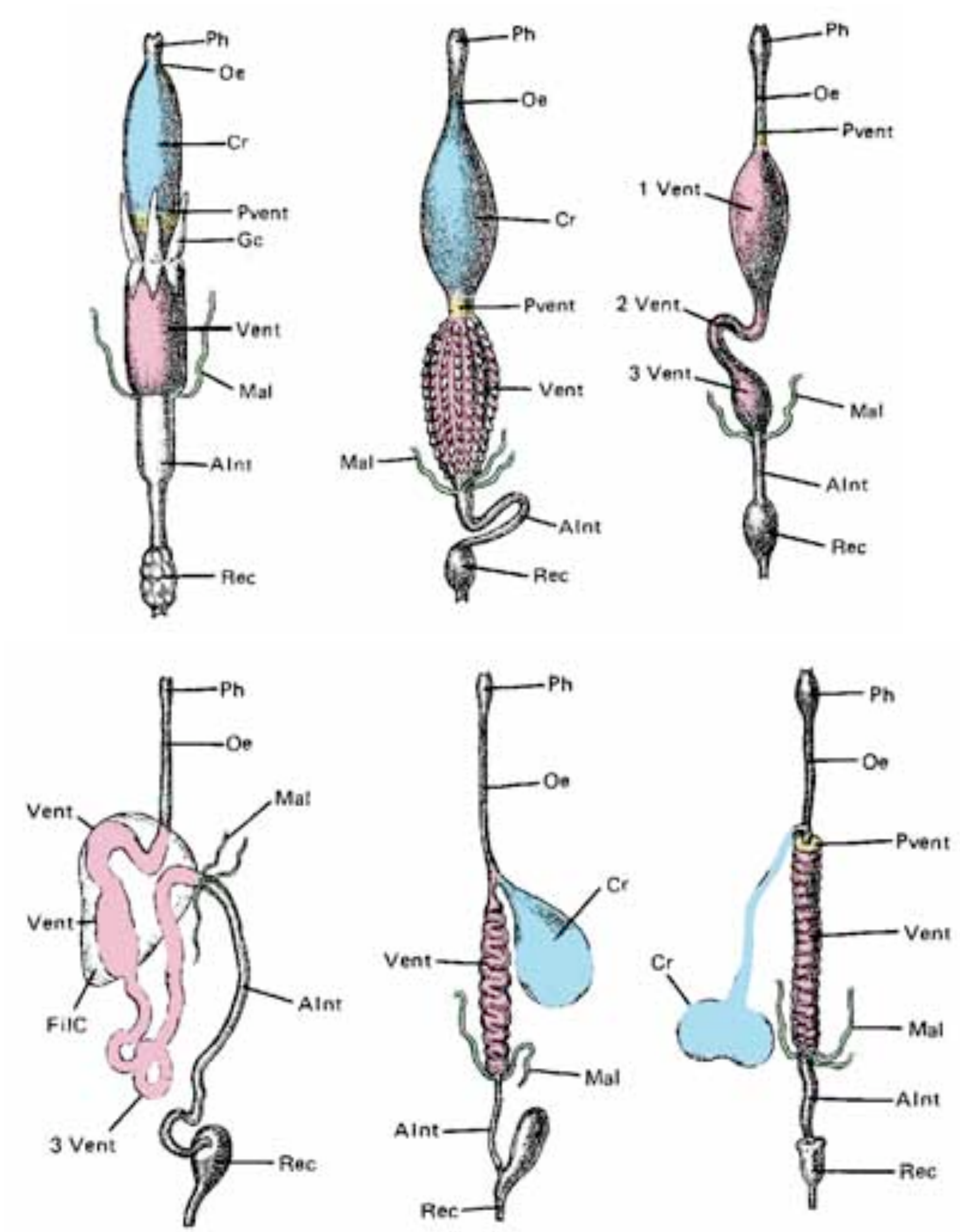
c. Before a molt, the insect takes in air or water into the digestive system to increase its internal hemolymph pressure allowing for the rupture of the cuticle.

5. Team Project - B takes notes, A speaks

a. Pick two of the previous insects and predict two specific modifications of the digestive system that you would to expect to see based on the diet of the bug.

6. Modifications to the digestive system

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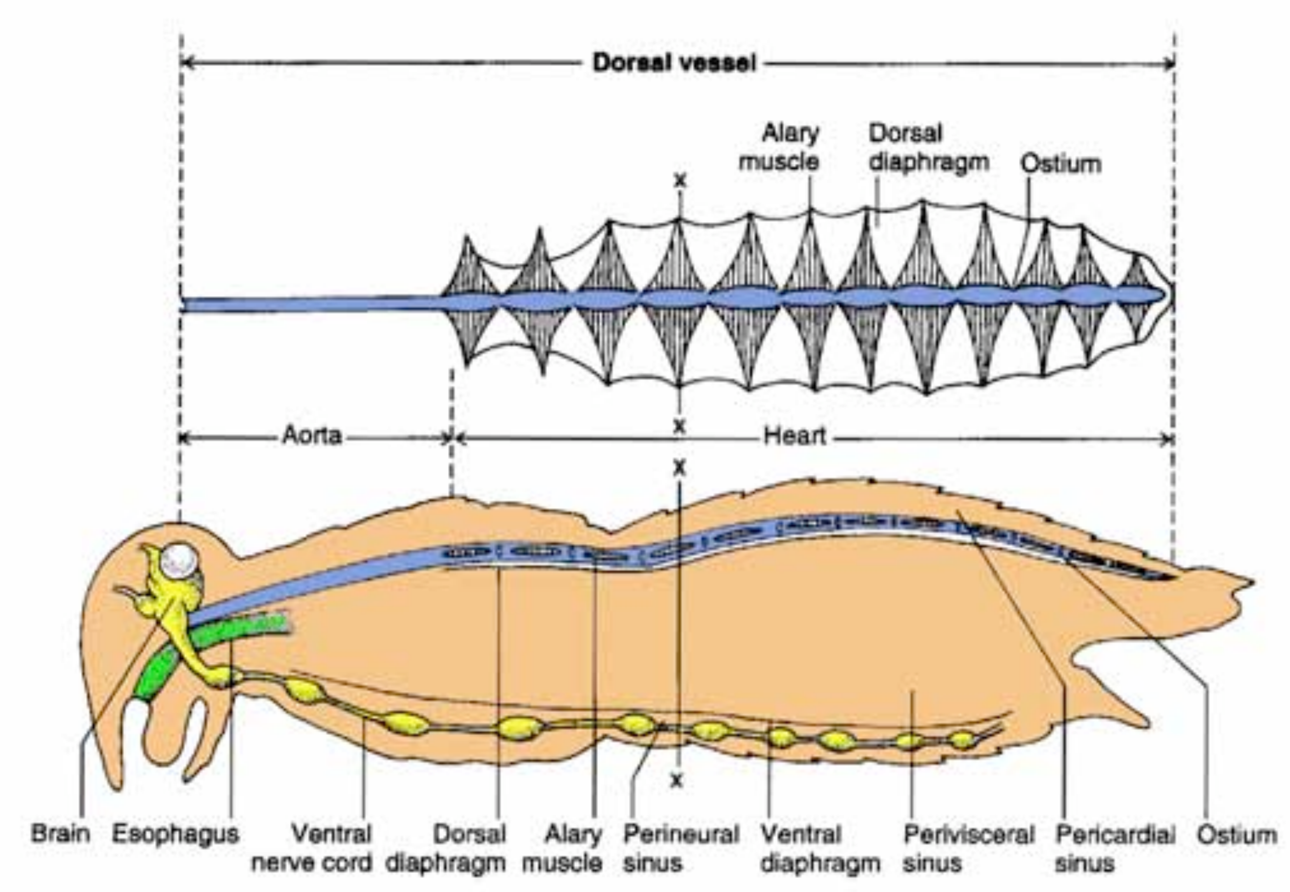
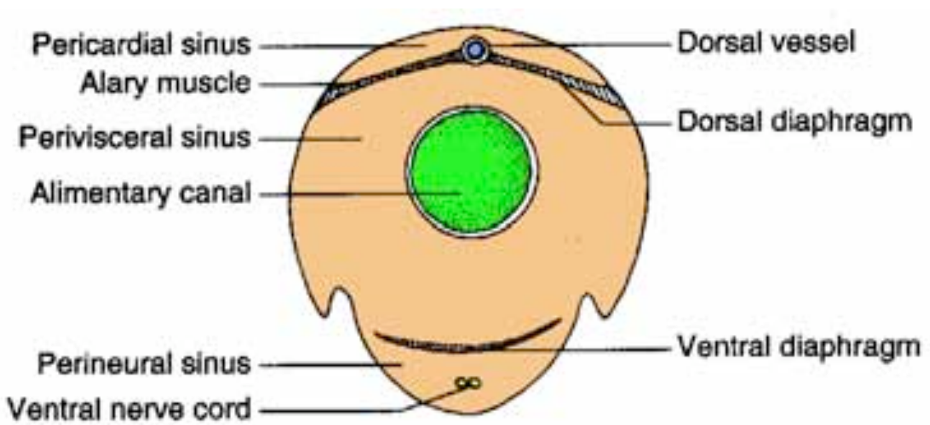
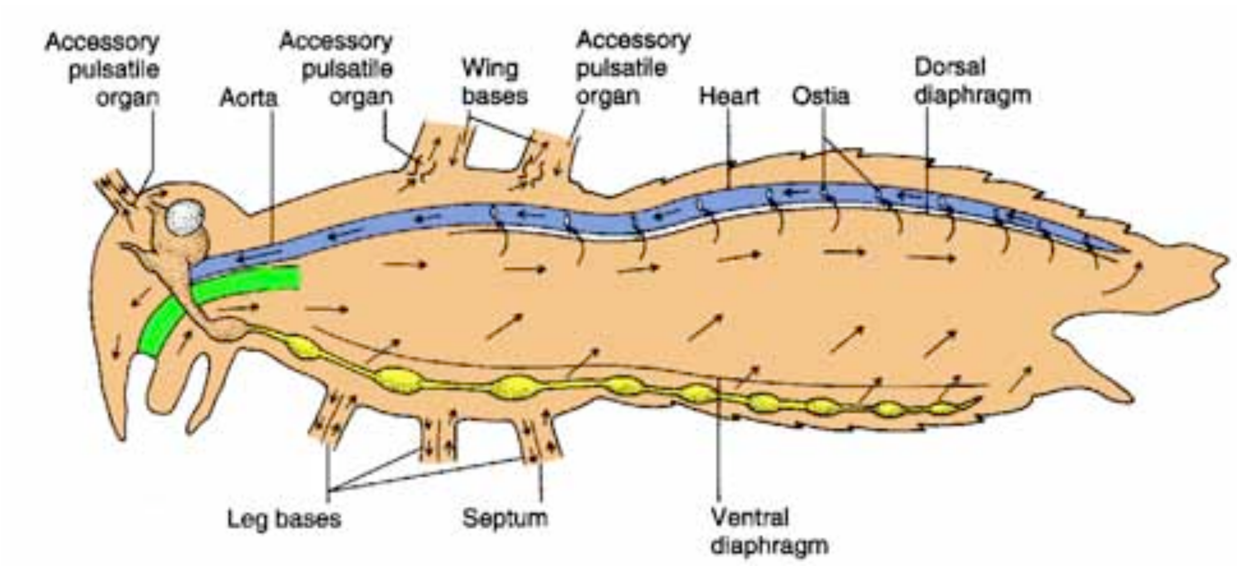
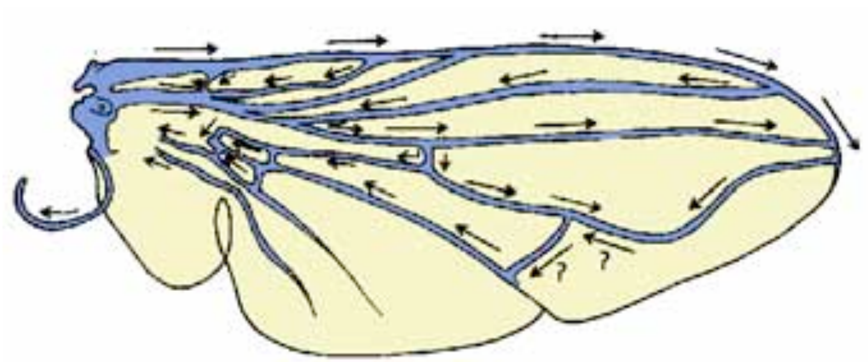
B. Circulatory system





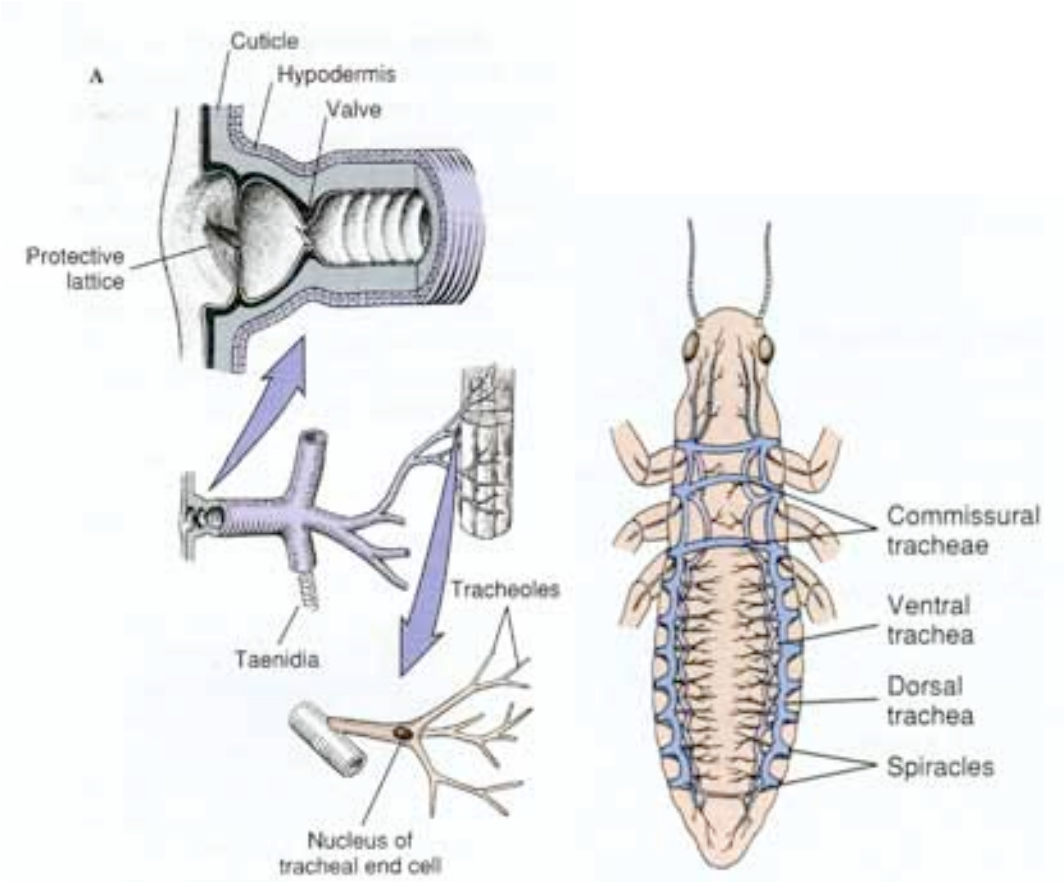




1. **Open circulatory system**
   a. The major portion of the "blood" or hemolymph is not found within vessels.
   b. The hemolymph bathes the organs within the body cavity, the hemocoel.
   c. Insects do not rely on the circulatory system for the transport of oxygen. This instead is done by the tracheal system (see below).
   d. Hemolymph enters the dorsal vessel or heart via small openings called ostia.
   e. The hemolymph is then pumped towards the head where it then returns to the hemocoel.
2. **Functions of hemolymph**
   a. Serves as a lubricant for the movement of internal structures relative to one another.
   b. It is a hydraulic medium for applying pressure for molting, eversible glands are extruded via pressure changes, and some muscular contraction is opposed by hydrostatic pressure within the hemocoel.
   c. Hemolymph transports various substances from one tissue to another.
   d. Specialized cells that phagocytosize or encapsulate foreign particles are found in the hemolymph and are very important in the "immune" system of insects.

C. Tracheal system

1. **Gas exchange system that does not rely on an oxygen transport pigment.**
    a. A few insects have hemoglobin and in some forms hemocyanin plays a role in oxygen transport.
    b. Consists of a system of branching tubes (tracheae) and openings to the outside called spiracles.
    c. Most Collembola, many Protura, and certain endoparasitic wasp larvae lack a tracheal system; gas exchange occurs via the integument.

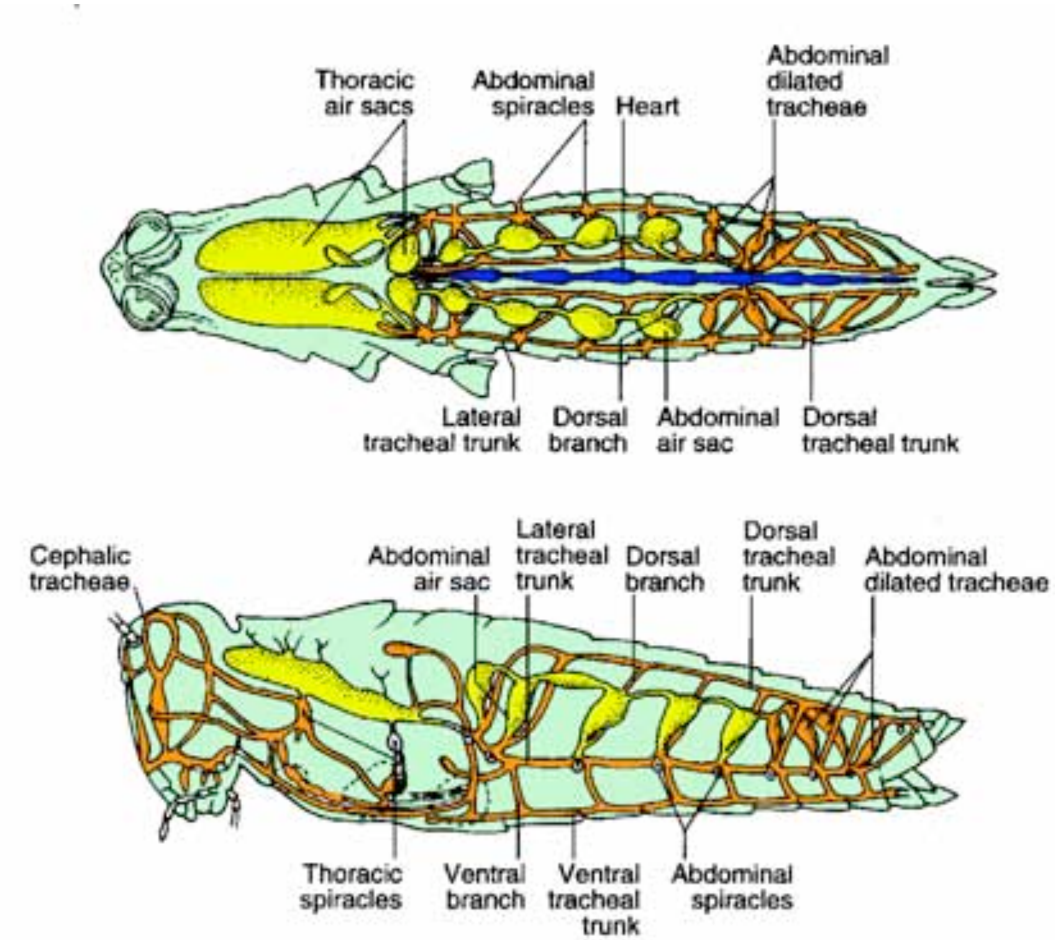


2. **Spiracles**
    a. Simple spiracles are merely openings to the outside.
    b. Atriate spiracles have mechanisms that allow the insect to close the opening.
        i Prevents water loss
        ii Prevents the entry of pathogens and parasites
3. **Tracheae**
    a. Tubes that begin rather large and branch to become successively smaller and smaller as they penetrate deep within the tissues of the insect.
    b. They are also lined with intima that is shed during each molt.
    c. Chitin is lacking in the smaller tracheae.

4. Air sacs

a. Air sacs are found mainly in flying insects.

b. Many potential functions, all rather speculative, including increasing the volume of air in the body for exchange, lowering the specific gravity for flight, and providing room for the growth of internal organs.



5. Tracheoles

a. The smallest branches of the tracheae are the tracheoles.

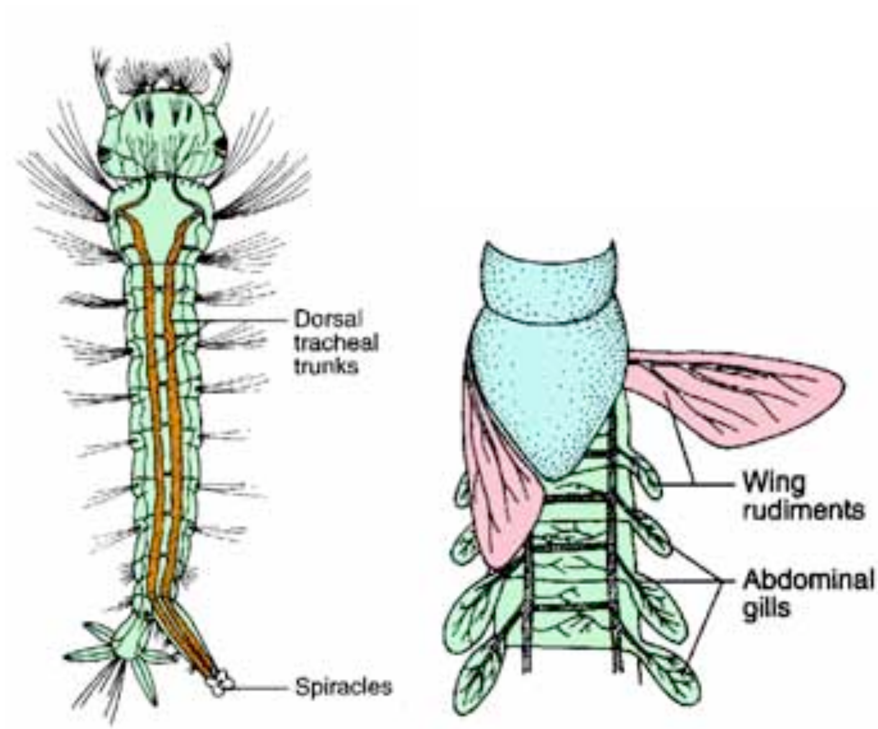
b. Gaseous exchange occurs here.

c. Provide for a tremendous amount of surface area (there are 1.5 million tracheoles in a large silkworm larva).

6. Two types

a. Open systems are found in most terrestrial insects and many aquatic forms. One or more pairs of spiracles are present. Usually the first pair is found on the mesothorax.

b. Closed systems are found in many aquatic insects and the larvae of endoparasitic species. Closed systems lack spiracles and gaseous exchange between the tracheal system and the environment occurs directly through the integument.



7. Two types of ventilation - passive and active ventilation

a. In passive ventilation the insect employs no pumping or other movements to aid the passage of gases into and out of the tracheae.

   i The insect may control the flow by opening and closing the spiracles.

   ii Generally effective for smaller insects and those with well-ventilated air sacs.

b. In active ventilation, the insect increases air movement by pumping movements of the abdomen, thorax, and even protraction and retraction of the head.

   i In many larger bodied and/or active insects requiring large volumes of gas for exchange, the movements of the body are coordinated with opening and closing of the spiracles to produce a unidirectional flow of gases through the body. Air moves into the animal via the thoracic spiracles and out of the body via the abdominal spiracles.

8. Ventilation in aquatic insects

a. Immature aquatic insects with closed tracheal systems rely entirely on passive diffusion of gases through the integument into and out of the tracheae.

   i In smaller bodied immatures, passive diffusion is adequate with the use of the tracheal system.

   ii Many larger bodied aquatic insects posses tracheal gills, integumental evaginations covered by a very thin cuticle and well supplied with tracheae and tracheoles.

   iii Other larger bodied insects may have spiracular gills or cuticular gills.

b. Aquatic insects with open tracheal systems obtain oxygen in a variety of ways.

   i Some surface periodically.

ii All require a hydrofuge structure that functions in breaking the surface film of the water thereby exposing the spiracles to the atmospherere.

iii Hydrofuge structures are usually made of "hairs" that are resistant to wetting causing the water near the surface to be repelled from the hydrofuge areas.

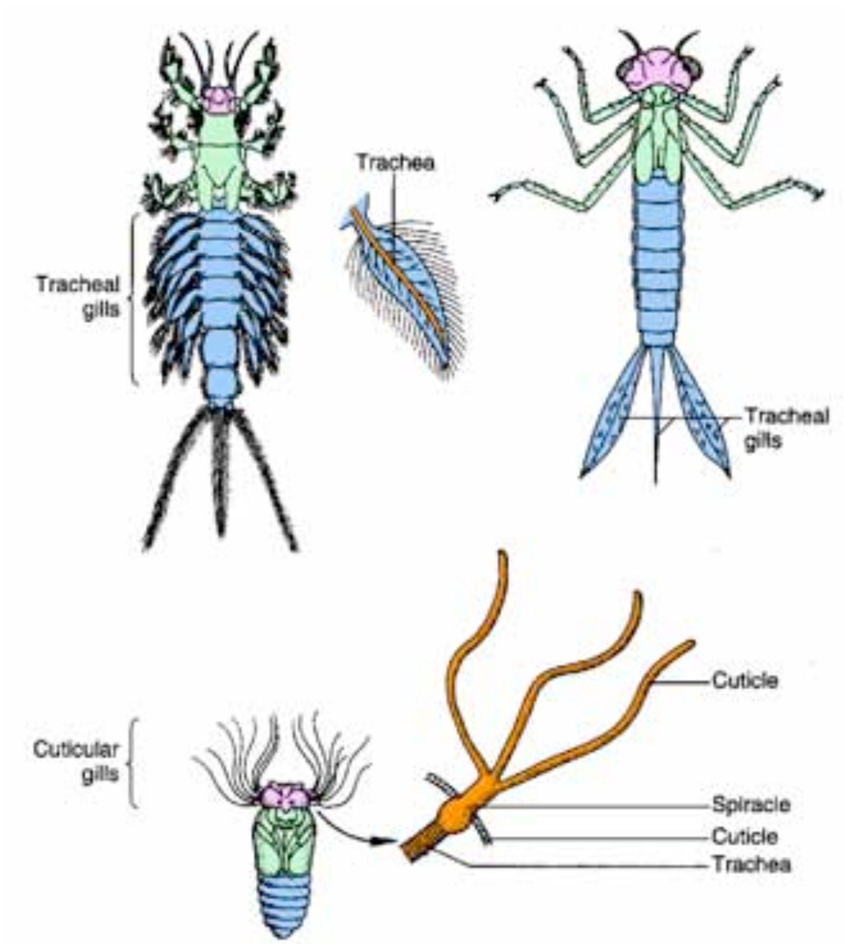
iv Many aquatic Hemiptera and Coleoptera carry air stores in the form of bubbles. These bubbles are held in place by hydrofuge hairs and/or the shape of the body forms a storage area.

v Many insects carry stores of air and are able to replenish the oxygen without surfacing.

vi Stores of oxygen act as a "physical gill" where the partial pressure differential of the oxygen between the gill and the water results in oxygen diffusing into the gill from its dissolved state. Nitrogen in the air store does not readily diffuse into the water and thus prevents the air store from collapsing.

vii A plastron is a very thin layer of gas held firmly in place by tiny hydrofuge hairs. The spiracles open directly into this thin layer.

viii Other insects tap directly into aquatic plants to obtain oxygen.



9. Team Project - C takes notes, B speaks

a. Which state of the tracheal system, open or closed, is ancestral to the Hexapoda? Why?

D. Excretory system

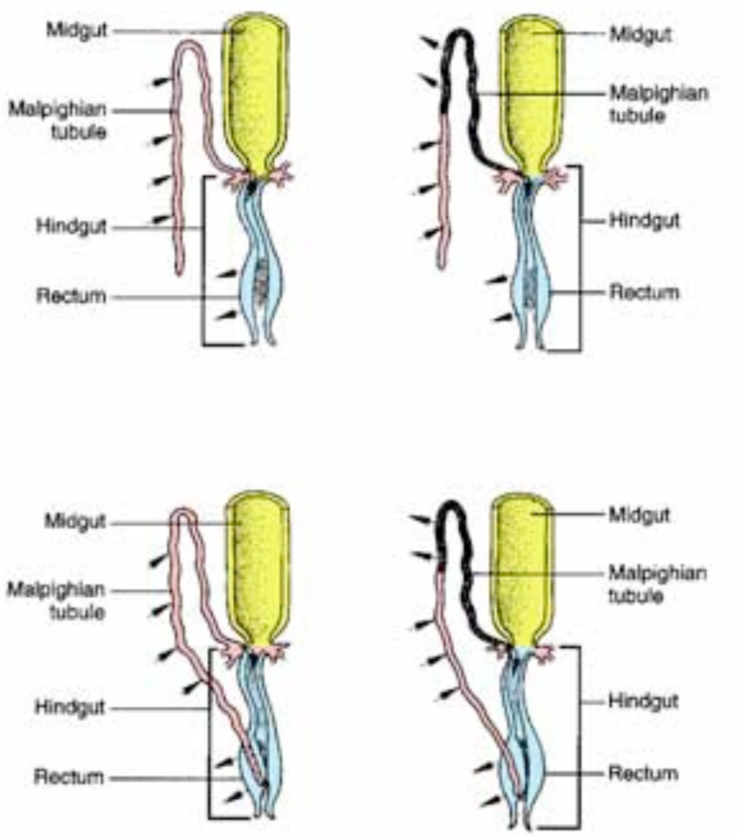
1. The function of the excretory system is to maintain chemical homeostasis.

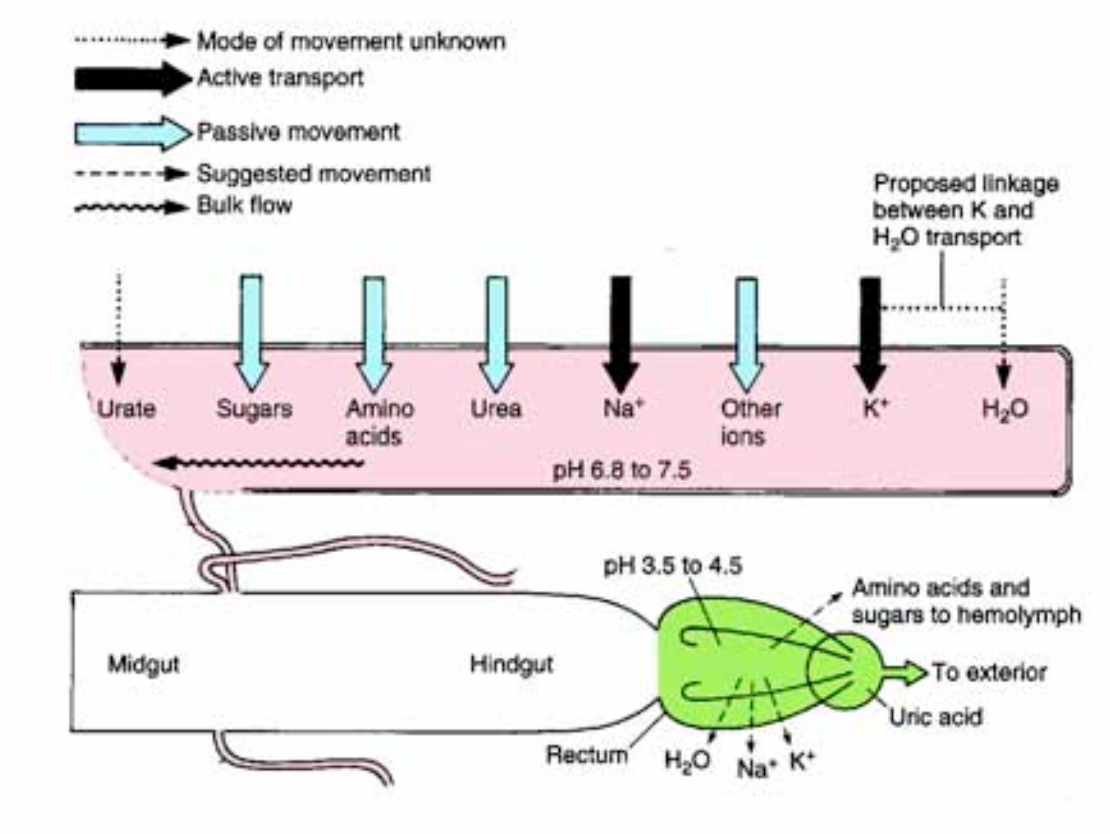
a. The hemolymph is cleansed of metabolic wastes, usually nitrogenous, and toxins, and the concentration of salt and water are regulated.

b. The Malpighian tubules and the hindgut comprise the excretory system.

2. Malpighian tubules

a. Attached to the gut, they float freely within the hemocoel and are bathed in hemolymph.





b. They vary in number from two to 250 or more.
c. They also vary with respect to the distal ends and the location and direction of the flow of substances into and out of the tubule lumen.
d. The Malpighian tubules function in removing toxins, nitrogenous wastes, and ions to maintain ionic concentrations within the hemolymph.

3. Rectum of the hindgut

a. Water and other small ions are removed from the gut by the rectum.

4. Diet and environment

a. The ionic composition of an insect's diet is very often very different from that in the hemolymph requiring the active transport of some ions either into the gut for excretion or from the gut into the hemolymph.

Table 4.4 The Ionic Composition of the Diet in Relation to That of the Hemolymph in Some Terrestrial Insects

Diet and insect	M.equiv./l. or /kg. wet weight				
	Na	K	Ca	Mg	
human blood	87·0	51·1	3·0	2·5	
Rhodnius	164·0	6·0	—	—	Assassin bug
horse blood	84·8	31·4	1·7	3·3	
Gasterophilus larva	175·0	11·5	5·7	32·0	Bot fly
lettuce leaves	13·0	86·2	—	—	
Periplaneta	113·0	25·6	—	—	Cockroach
privet leaves	46·4	152·1	824·5	39·9	
Carausius	8·7	27·5	16·2	142·0	Walking stick
carrot leaves	25·6	176·9	214·5	35·6	
Papilio larva	13·6	45·3	33·4	59·8	Swallowtail b-fly
potato leaves	trace	144·5	128·6	85·9	
Leptinotarsa	3·5	65·1	47·5	188·3	Potato beetle
Ribes leaves	trace	249·1	271·2	53·6	
Pteronidea larva	1·6	43·4	17·5	60·5	

Source: Data from various sources.

b. Similarly, the abiotic conditions of the environment influence whether an insect must conserve or excrete water or salt.
   - i Freshwater insects must constantly excrete water that enters the body passively through the integument.
   - ii Many terrestrial insects tend to lose water via evaporation while exchanging gases, while some plant sap feeders ingest so much water that they are challenged with excreting excess water and concentrating nutrients.
   - iii Saltwater insects tend to lose water via passive diffusion through the integument.

5. Nitrogenous excretion

a. Most aquatic insects excrete ammonia.
   - i Ammonia is highly toxic but soluble in water.
   - ii Only insects that have access to lots of water can excrete ammonia.

b. Terrestrial forms or those species that are water-limited excrete uric acid.
   - i Uric acid is insoluble in water and relatively non-toxic.
   - ii The ability to form uric acid is often cited as one of the reasons members of the Arthropoda have been so successful on land relative to other invertebrates.
   - iii Cockroaches store their uric acid. It is thought that during the Carboniferous period (about 345 million years ago) when cockroaches first evolved, there was an extreme shortage of nitrogen. Cockroaches that could store and reuse their nitrogenous wastes had greater fitness than those that could not. Cockroaches also have a symbiotic relationship with bacteria that produce uricase, the enzyme necessary to convert uric acid into a useable form.

E. "Fat" bodies

1. Synthesis and secretion

a. Larval-specific storage proteins (e.g. calliphorin)
b. Vitellogenin (female-specific hemolymph protein)
c. Lipoprotein and lipophorin (transport molecules)
d. Juvenile hormone carrier proteins
e. Juvenile hormone esterases
f. Hemoglobin in Chironomus larvae (molecule is considered a storage protein)
g. Diapause proteins
h. Production of mixed-function oxidases (MFOs)

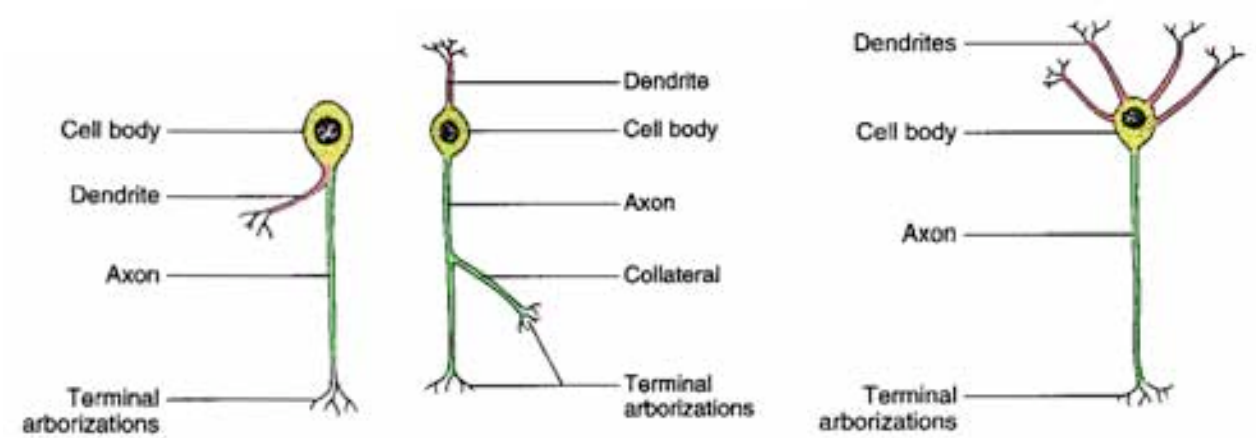
2. Mobilization and storage of reserves to be used as precursors for metabolism in other tissues

a. Lipids
b. Glycogen
c. Proteins

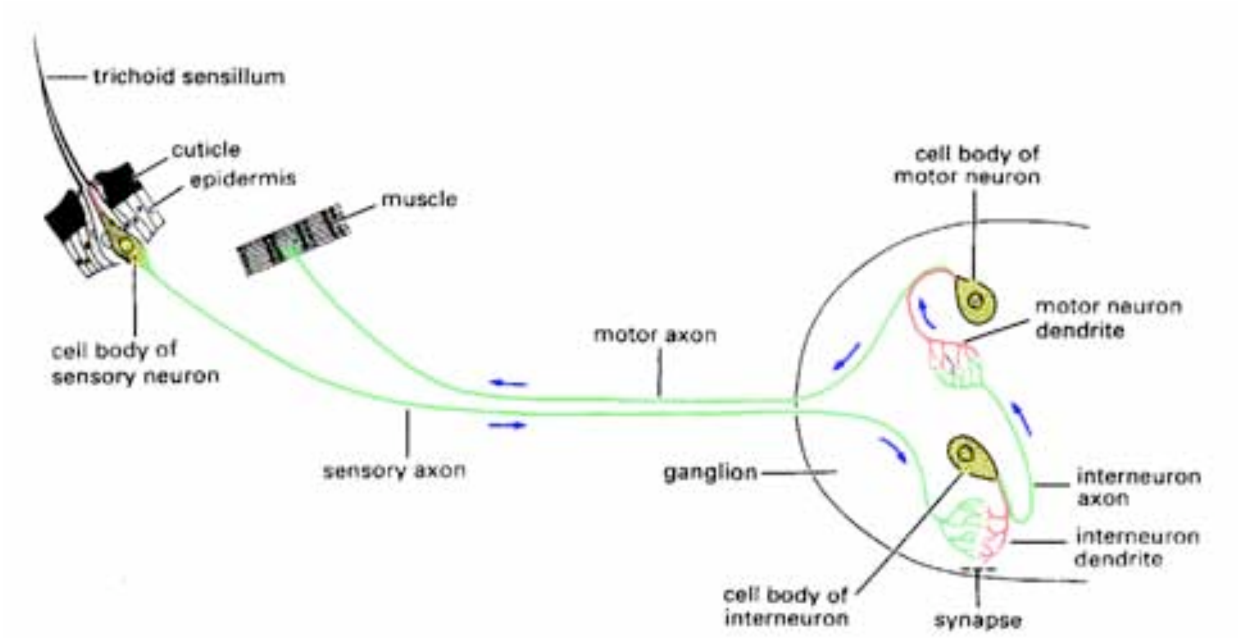
F. Nervous system

1. The neuron

a. The basic functional unit of the nervous system is the nerve cell or neuron.
b. The neuron consists of a cell body, one or more axons, and dendrites.
c. Three general types of neurons
   i Unipolar neurons have a single stalk from the cell body that connects with the axon.
   ii In bipolar neurons, the cell body bears an axon and a single, branched or unbranched dendrite.
   iii Multipolar neurons have an axon and several branched dendrites.

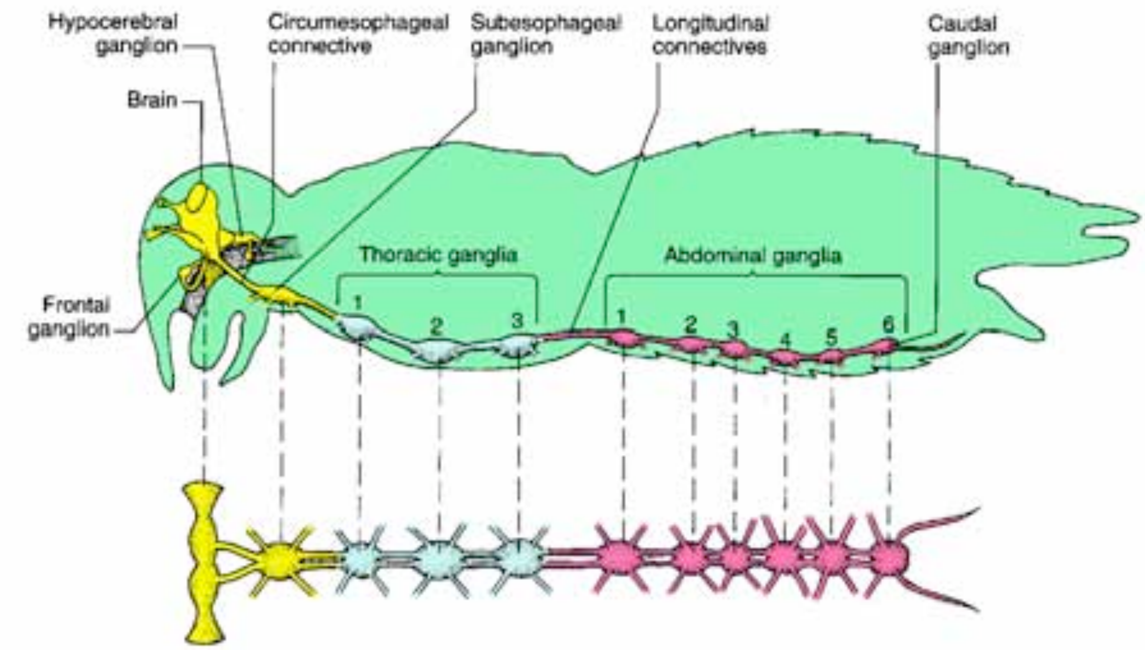


2. **Team Project - A takes notes, B speaks**
   a. Give one potential type of stimulus where a bipolar neuron would be ideal.
   b. Give one potential type of stimulus where a multipolar neuron would be ideal.

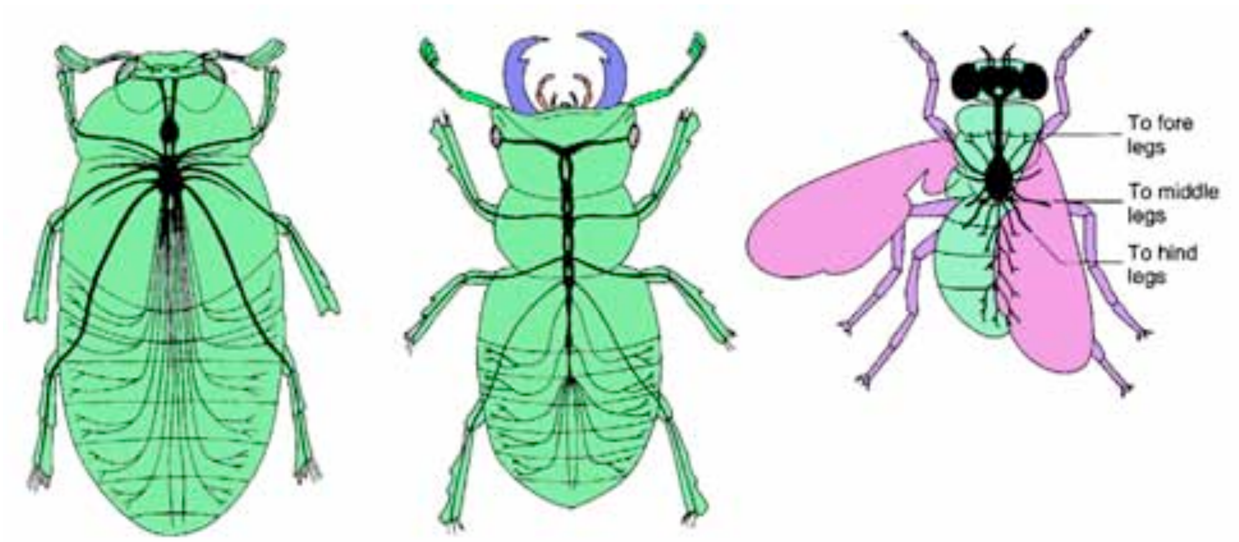


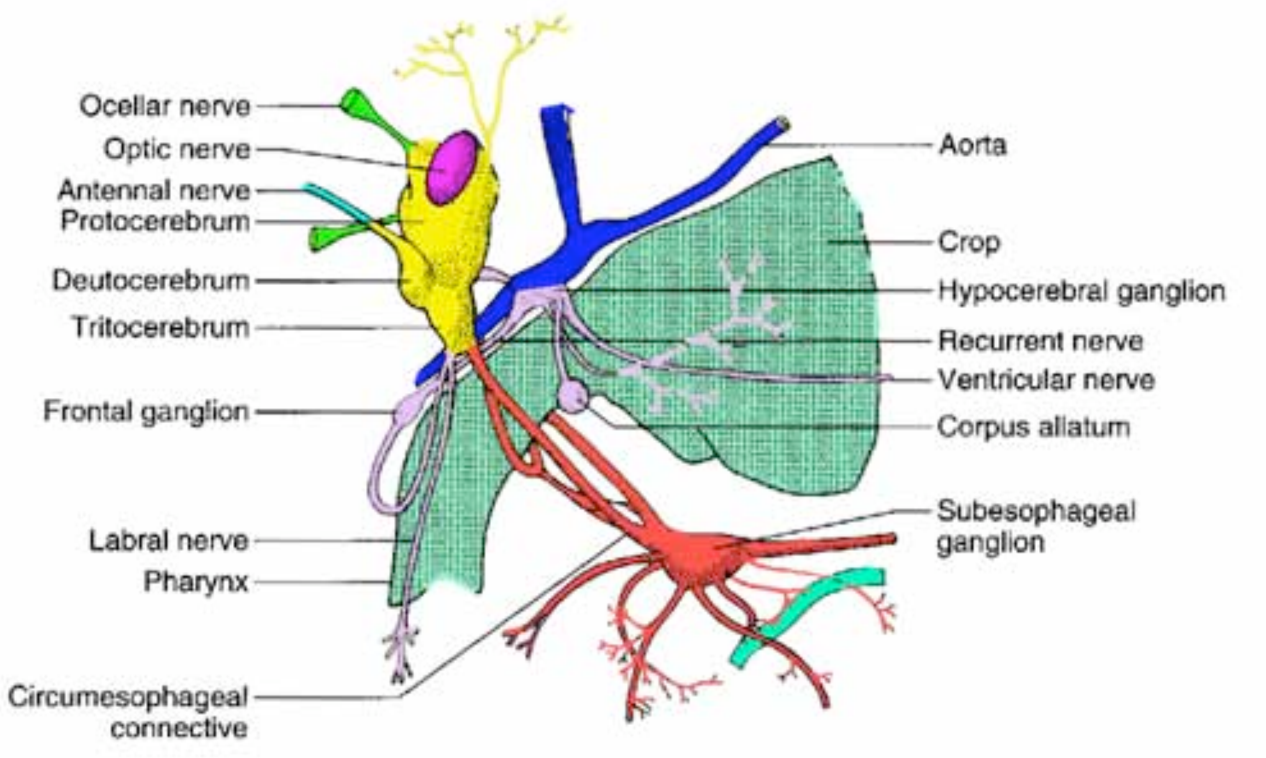
   c. Neurons 'communicate' with one another and with other cells either electrically or chemically via neurotransmitters through small spaces called synapses.
   d. Actions may be either excitatory or inhibitory.
   e. Areas where neurons are concentrated are called ganglia.
   f. Nerves are bundles of axons.

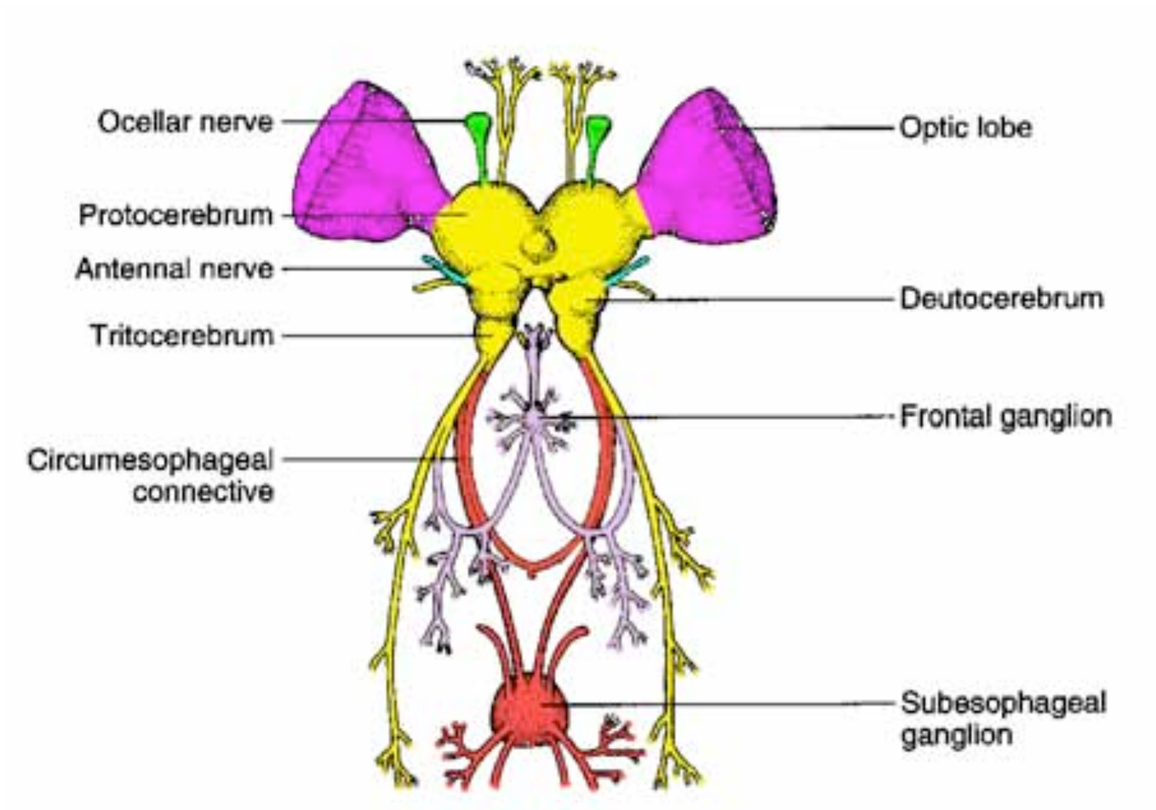
3. Central nervous system



a. The central nervous system is composed of a double chain of ganglia joined by longitudinal connectives.
b. The anterior ganglion is the brain. The brain connects to the ventral chain of ganglia via two connectives that travel around the pharynx. The brain connects to the eyes, ocelli, and antennae.
c. The subesophageal ganglion is highly complex and innervates the sense organs and muscles associated the mouthparts, the salivary glands, and the neck region. In many insects the subesophageal ganglion is also the primary excitatory or inhibitory influence on motor activity of the whole insect.
d. The frontal ganglion connects the brain to the stomatogastric subsystem.
e. The hypocerebral ganglion is associated with two endocrine glands one of which is the corpus allatum that produces JH (juvenile hormone).
f. The thoracic ganglia contain the sensory and motor centers for their respective segments. In some insects these three ganglia are fused into one.
g. In the ancestral state, each abdominal segment possesses a ganglion with the final ganglion associated with the genitalia. More derived taxa show a reduction in the number of abdominal ganglia.


To fore legs
To middle legs
To hind legs


Ocellar nerve
Optic nerve
Antennal nerve
Protocerebrum
Deutocerebrum
Tritocerebrum
Frontal ganglion
Labral nerve
Pharynx
Circumesophageal connective
Aorta
Crop
Hypocerebral ganglion
Recurrent nerve
Ventricular nerve
Corpus allatum
Subesophageal ganglion



4. **Visceral nervous system**
   a. Nerves associated with the brain, salivary glands, and the foregut are the stomatogastric subsystem. These include the frontal ganglion and the hypocerebral ganglion.
   b. The nerves associated with the ventral nerve cord are the ventral viscera subsystem.
   c. The caudal visceral subsystem is associated with the posterior segments of the abdomen (the caudal region) including the reproductive system.
5. **Peripheral nervous system**
   a. All of the nerves with synapses to the central and the visceral nervous systems comprise the peripheral nervous system.
   b. These nerves are associated with sensory structures.

6. An overall view of the interrelationships of the insect nervous system.