Module 5 Study Notes

Introduction

References:

The Honeybee Inside Out	Celia F. Davis
The Honeybee Around and About	Celia F. Davis
Guide to Bees and Honey	Ted Hooper
Beekeeping Study Notes (modules 5,6,7&8)	J.D & B.D. Yates
The Biology of the Honey Bee	Mark L. Winston
The Anatomy of the Honey Bee	R. D. Snodgrass
BBKA website	
MBBKA Study Group	
MBBKA Basic Course Notes	

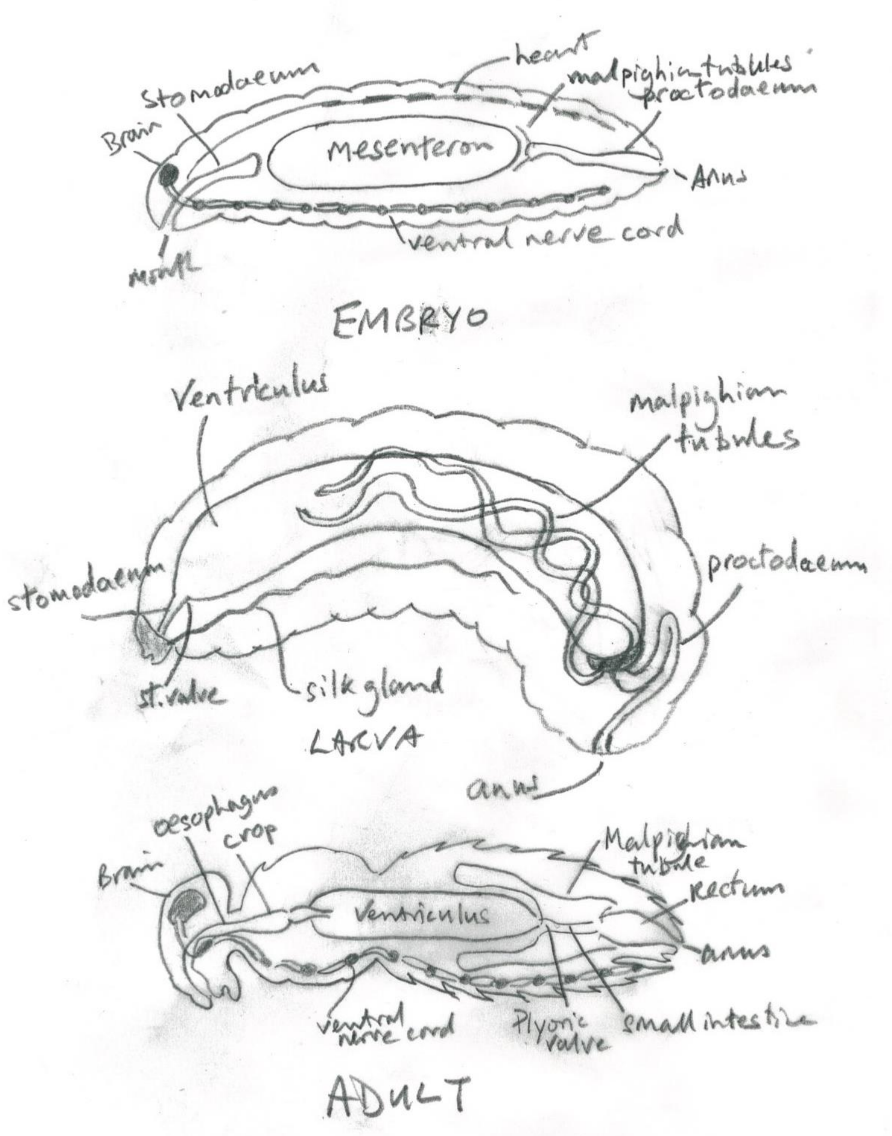
Module 5 Study Notes

Contents

The Candidate shall be able to describe in detail and illustrate where appropriate, referring to histological features as necessary:-

Module 5 Study Notes

5.1 the alimentary system including the process of digestion by enzymes and the absorption and assimilation of products of digestion;



The alimentary system has three distinct phases as it evolves to the final system in the adult bee.

In the embryo the basic elements form but are not initially connected. The stomodaeum (fore gut) and proctodaeum (hind gut) form through invaginations of the ectoderm. The mesenteron (mid gut or ventriculus) forms from the endoderm that initially encompasses the yolk of the egg.

In the larva the stomodaeum is joined to the ventriculus via a basic valve, the proctodaeum is not connected to the mid gut and the 4 malpighian tubules terminate at a membranous thickening between the ventriculus and the proctodaeum.

During the pupa stage the alimentary system is completely remodelled:

- The stocodaeum becomes the pharynx, oesophagus, crop and proventriculus
- The ventriculus is remodelled to include muscles, folds and new lining
- The hind gut (joined to ventriculus at 5th moult) develops small intestine, over 100 malpighian tubules all joined at the pyloric valve, and rectum

Module 5 Study Notes

The function of the alimentary system is to store and filter nectar, remove pollen, digest the pollen and nectar where appropriate. Collect waste from the haemolymth and debris from digestion, recover salt and water before passing on to the rectum.

Key functions of the alimentary system are:

- Ingestion
- Digestion/Absorption
- Assimilation

Ingestion is the process by which food is taken into the alimentary canal. It includes the processes that take place while the food is in the mouth, the lubrication and chemical effects from the salivary and other glands. The swallowing of the food, which sends it onwards in the case of the honeybee to the Ventriculus.

The honeybee adds enzymes to breakdown the sugars within the nectar it collects within the mouth. The enzymes are produced in the salivary gland and hypopharyngeal glands and include sucrase, glucose oxidase and amylase.

The nectar is swallowed through a process known as peristalsis and mixed/stored in the crop of the honey bee. The food is filtered in the crop by the proventriculus and pollen removed from the liquid. The pollen as well as other impurities is passed into the Ventriculus in the form of a bolus.

Digestion is the process by which ingested material is broken down in the Ventriculus into a form that can be absorbed and assimilated into the tissue of the honeybee.

This is primarily performed through enzymes. The process starts in the mouth with the addition of enzymes from the head glands. Most of the chemical digestion processes occur within the Ventriculus where digestive enzymes are generated.

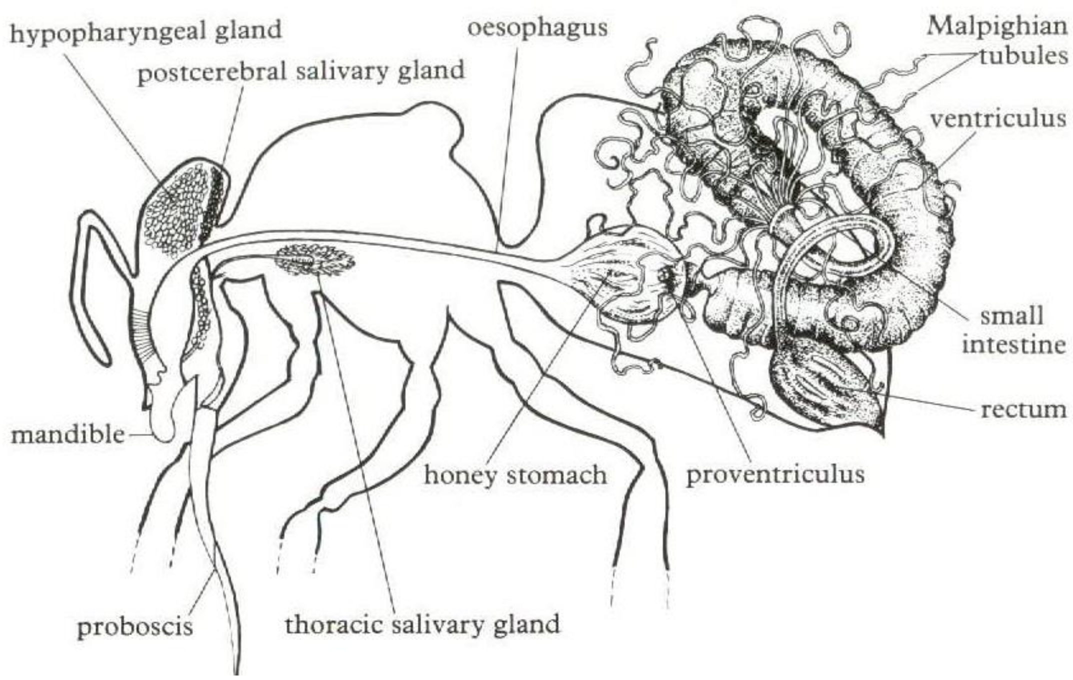
The ingested food bolus is surrounded by a peritrophic membrane which on the one hand protects the fragile epithelium and on the other hand permits the digestive enzymes to access the food. The enzymes enter the pollen through their pores and apertures and split the proteins within into their amino acids. The digested food passes through the peritrophic membrane to the epithelium to be absorbed into the haemolymph.

Assimulation is the absorption of digested food into the haemolymph for transport to the point of need within the body. The digested food include monosacarides, amino acids and lipids. Passive absorption across the epithelium via concentration gradients across the epithelium enterocytes cells.

Some absorption of foods minerals and water is also carried out in the small intestine.

An enzyme is a protein molecule that is a biological catalyst with three main characteristics. First, they increase the rate of a natural chemical reaction. Secondly, they typically only react with one specific substrate or reactant, and thirdly, enzyme activity is regulated and controlled within the cell through several different means, including regulation by inhibitors and activators. It is possible to group enzymes into different categories, including oxidases, transferases, hydrolases, lyaes, isomerases and ligases. In naming enzymes, the "-ase" suffix is often appended to the name of the substrate molecule upon which which the enzyme reacts. For example, the enzyme sucrase catalyzes the transformation of the sugar sucrose in to glucose and fructose. In this case, the "sucr-" suffix represents the molecule upon which the sucrase enzyme reacts. Not all enzymes are named according to this convention.

The salivary or labial glands, procerebral and thoracic, produce salvia which passes to the mouth via the salivarium. The saliva is mixed with incoming food and employed to liquefy dry food. Enzymes from the hypopharyngeal gland, including sucrase and glucose oxidase, are mixed with the food to initiate the breakdown of the sugars.



Foregut

The cells of the foregut are flattened and undifferentiated as they are not involved in absorption or digestion. The cuticular lining is unsclerortized and consists only of endocuticle and epicuticle. The foregut comprises 4 regions:

- The pharynx
- Oesophagus
- Crop
- Proventriculus

The oesophagus is a narrow tube passing through the petiole. It is surrounded by an inner layer of longitudinal muscles and an outer layer of circular muscles, the antagonistic action of these muscles causes the contents to be moved towards the crop, this movement is called peristalsis. The inner wall of the oesophagus is lined with a thick cuticular intima which allows for the expansion caused by peristalsis.

The crop is the extensible part of the foregut.

The proventriculus extends into the crop at its anterior and into the Ventriculus at its posterior end, stomodeal valve. The proventriculus has 4 lips with slender recurved spines that work indepently to filter out pollen from the contents of the crop. The wall of the crop is continually writhes and pulsates vigorously keeping the contents well stirred. The pollen is collected into a bolus before it is passed into the Ventriculus. The proventriculus prevents nectar being passed to the midgut unless required for digestion.

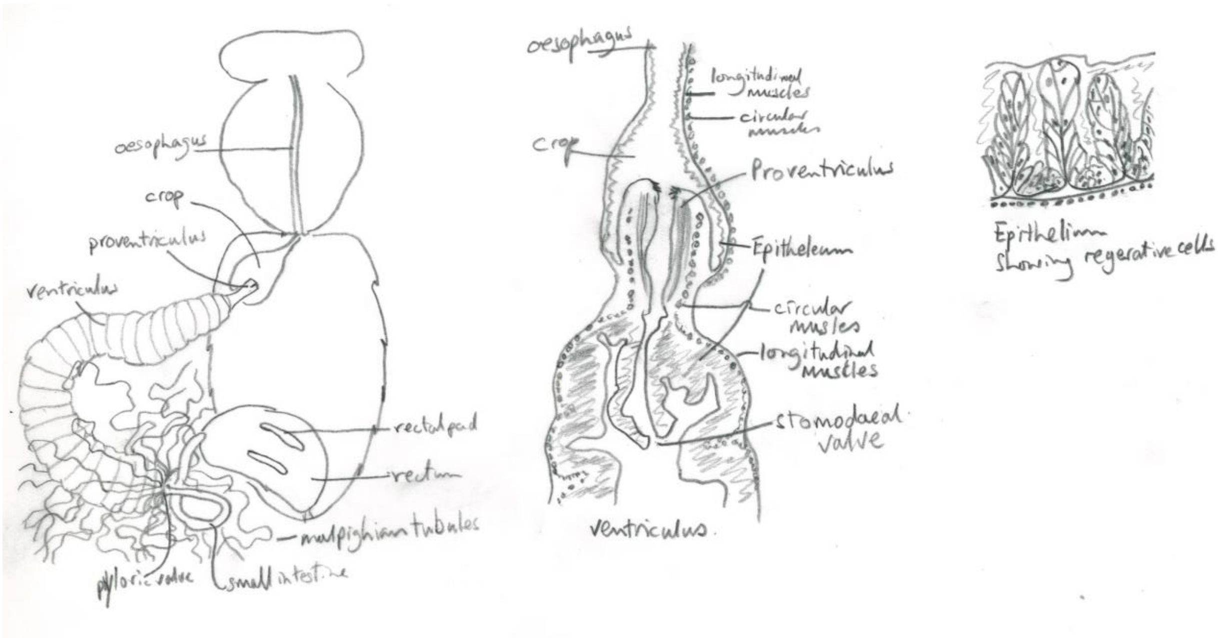
Ventriculus

The Ventriculus is considered the true stomach of the honeybee. It forms a U shape within the abdomen, it has numerous transverse constrictions that form deep internal folds. When dissecting a bee the colour of the Ventriculus can be brown, this is due to the colour of the contents, usually it is pearly white when empty.

The epithelial wall of the Ventriculus is continuous throughout the midgut, it is surrounded by muscles circular surrounded by longitudinal (opposite to oesophagus). The epithelium cells are many and are continually increasing through mitotic division. Cells are cast off and degenerate releasing digestive enzymes and absorption nutrients. Other cells prevalent are enteroendocrine, which secrete hormones which regulate the function of the midgut and intestinal stem cells, from which differentiated cells are derived.

The peritrophic membrane separates the volume of the midgut from the epithelial wall, it comprises proteoglycan gel on a framework of chitin microfibrils. It is produced by the epithelial cells throughout the midgut. It allows passage of digestive enzymes to the ingested food and digested food out to pass through the epithelial to the haemolymph.

The enzymes produced by the epithelial include sucrase (breaks down sugars), amylase (breaks down starch), proteases (breaks down protein in pollen to amino acids), lipases (digest lipids to produce fatty acids and glycerol).



Absorption into the haemolymph is across enterocytes in the epithelial.

Hindgut

The proctodaeum or hindgut is differentiated into two principle regions, the small intestine at the anterior end and the rectum at the posterior. The small intestine is a slender tube, the epithelial has 6 longitudinal folds, the outside is a thick layer of circular muscle (no longitudinal muscles), it joins the ventriculus at the pyloric valve.

The Malpighian tubules open into the pyloric lumen after the ventriculus and before the pyloric valve.

The small intestine opens into the rectum, there is no valve but a constriction of the internal folds reduces the aperture. The rectum is a large thin walled sac, the epithelial is highly folded, surrounded by circular muscles and smaller widely spaced longitudinal muscles. The rectum opens into a small tube to the anus. The structure of the rectum allows it to balloon and hold a volume of faeces.

Thickenings in the rectum wall (6 in total) are called rectal pads, their role is not clearly understood.

5.2 the excretory system and the substances excreted;

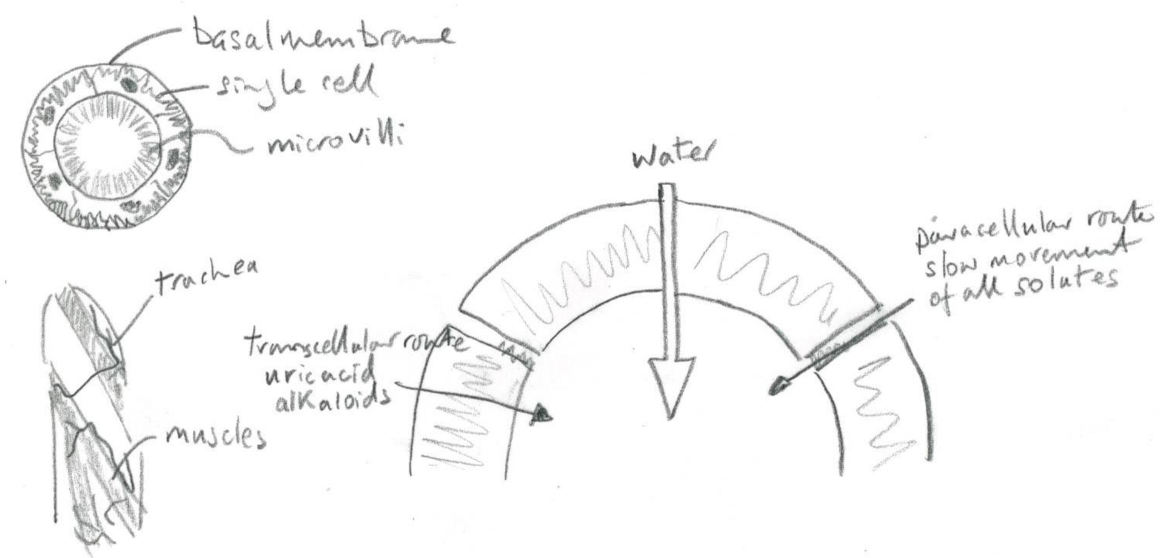
The excretory system acts as a filtration system to both remove and return substances to the haemolymph in order to maintain a balance between water and salts as well as ensure the acidity and osmotic pressure are maintained at the correct levels.

There are two types of waste produced by active cells:

- Carbon Dioxide, which is discussed as part of the respiratory system
- Nitrogenous waste

The excretory system includes:

- Filtration through the Malpighian tubules
- Re-absorption
  - Malpighian tubules
  - Small intestine
  - Possibly rectal pads



Excretion of metabolic waste products is carried out via the rectum. First the products are collected from the haemolymph by the Malpighian tubules which wave in the haemolymth extending throughout the abdomen. The tubule has a single cell wall with an inner basal plasma membrane deeply infolded. The lumen of the cell is includes close packed microvilli. The tubule is surrounded by tracheoles and muscles.

The tubule works through both passive filtration and active secretion from the heamolymph. The filtration is through the paracellular route (gaps between cells) and transcellular route (through cells), it is reliant up gradients across the epithelium. The issue with passive filtration is that good substances such as water and salts can be absorbed, these are reabsorbed into the haemolymph towards the base of the tubule.

The open end of the tubule connects between the Ventriculus and the pyloric valve where the uric acid from the tubule joins other waste such as pollen husks from the Ventriculus and passes into the small intestine.

Some further absorption of water and minerals occurs in the small intestine. The excreta is passed on to the rectum where it is stored. The excreta is evacuated via the anus as faeces by the honeybee outside of the hive.

5.3 the respiratory system, including the muscular ventilation of the air sacs, the structure and operation of the spiracles and exchange of respiratory gases: both at rest and during active flight;

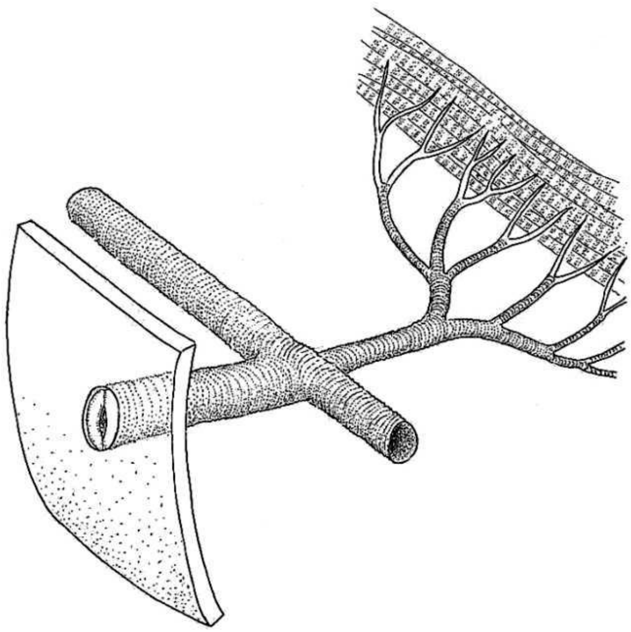
Summary

The bee breathes through tubes called trachea which convey oxygen to where it is required within the body of the insect. In all the higher animals oxygen is transported to the tissues by blood, bit in insects the blood is not involved in the transport of oxygen through the body. The trachea is made of cuticle and is prevented from collapsing by spiral thickening. The trachea start quite large but very rapidly divide many times, getting smaller all the while, until finally they end up as single cells, or a loop. The trachea open to the air through holes in the cuticle called spiracles, and in many cases these are provided with a closing mechanism.

Air enters the tracheal system through spiracles and fills the tubes. When the cells in which the trachea end are using up oxygen, this reduces the pressure of oxygen at that point and molecules of oxygen migrate in to make up the deficiency. It is thus by diffusion that oxygen makes its way via the trachea into the body of the bee. Oxygen is used to oxidize substances such as sugar in the cells to release energy for their use, producing the residue substances, carbon dioxide and water, this is cellular respiration. In the honeybee the main tracheal trunks become large sacs which are ventilated by breathing movements of the abdomen, whereby the abdomen is lengthened and contracted in a telescopic type movement.

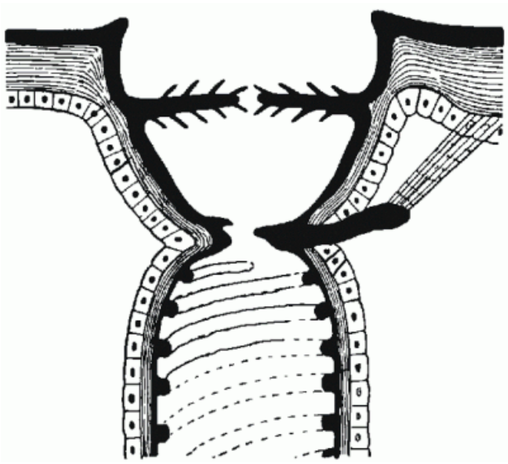
Definitions:

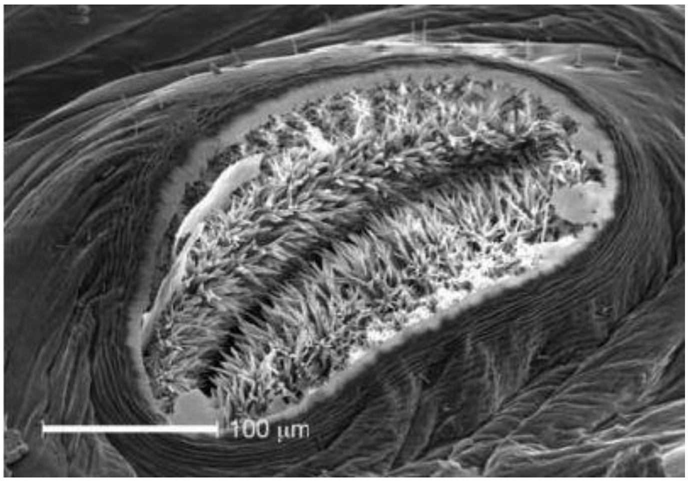
The respiratory system comprises Spiracles (openings), Trachea (large tubes), tracheoles (smaller tubes) and the total surface through which oxygen and carbon dioxide is exchanged is called the respiratory surface. The respiratory surface must be moist for the gases to diffuse, the tracheoles therefore contain fluid.



Spiracles

There are 10 pairs, found on each segment from T2 through A8, There is usually a valve surrounded by hairs on each spiracle, exceptions being the small spiracles on T3 and the “lid” on T2 not being able to fully close. The two spiracles on the propodeum A1 are the largest and all the Abdominal spiracles have a widened entrance called an Atrium. The valves are controlled by small muscles.



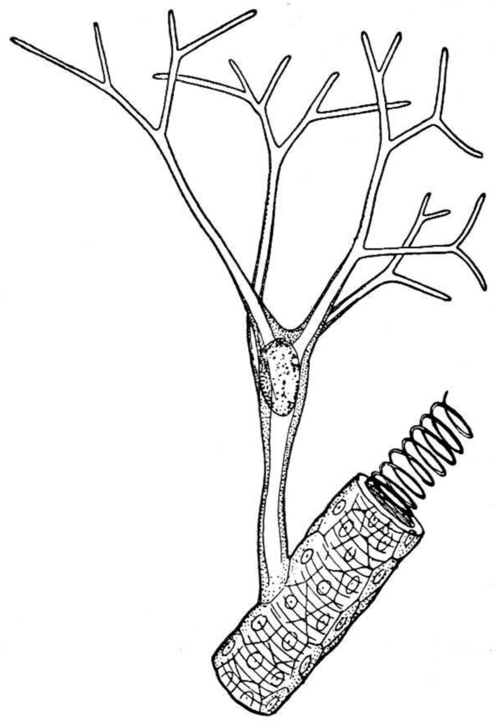


Tracheae

The tracheae are tubes leading from the spiracles and joining together in the body to give two large lateral tracheae (air sacs in adult bee). The tracheae have thicker areas (made of chitin) like a spiral around the tube which prevent it from collapsing in low pressure. The lining of the tracheae is cuticle and is contiguous with the outer cuticle of the bee (implying it sheds with each molt).

Tracheoles

The tracheae split down to smaller tubes (traceoles) which terminate in very small blind endings with fluid for the diffusion of gases. Whether the end is a single cell, disturbs or splits cells is not known, but they will generally terminate where needed such as close to muscle tissue.



Air Sacs

Are present in the head, thorax and abdomen of the bee, they are tracheae with no thickening (taenidia) so have thin walls and can expand and contract. This is enables the bee to breath:

> Build up of carbon dioxide stimulates the nerves in the ganglia which control the muscles that stretch and contract the membrane linking the sternum and tergum. Build up of carbon dioxide contracts the muscles forcing it out via the spiracles, releasing the muscles causes a vacuum allowing fresh air in. A similar action occurs longitudinally in the abdomen as well as in the thorax.

The System

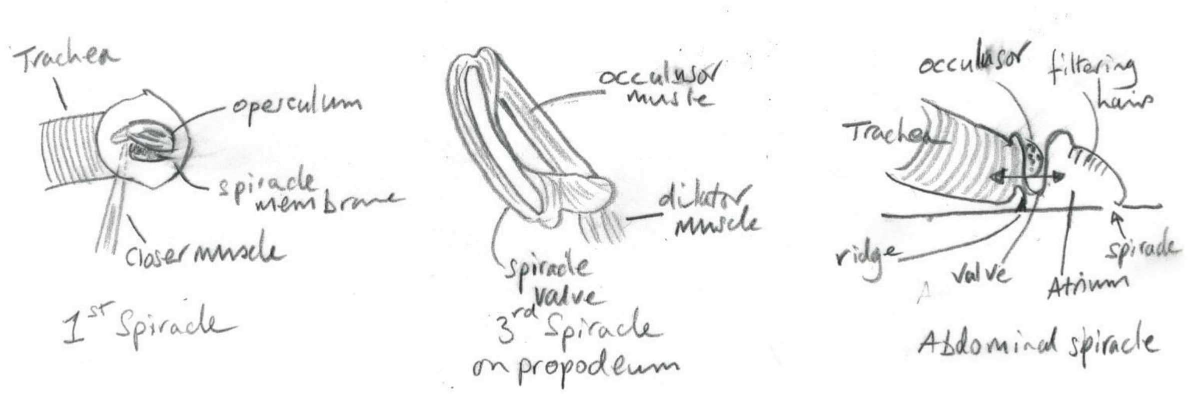
The elements of the respiratory system within a honeybee are:

- Spiracles
- Trachea
- Air Sacs
- Tracheole

Both the larva and the adult bee have 10 pairs of **spiracles**, from T2 – A8. The spiracle is to the anterior end of each plate, all bar T3 have valves that that open and close. T3 is the smallest and A1 on the prodeum is the largest. The spiracle on T1 does not fully close. Spiracle A8 is within the sting chamber.

The opening and closing of the spiracles is controlled by muscles. When is seen to land the contraction and relaxation of the abdomen can be clearly seen, this is the bee drawing in and expelling oxygen and carbon dioxide.

The three types of spiracle are shown in the diagram:



The **first spiracle** on T2 has the trachea connecting directly to the spiracle membrane. The spiracle is hidden under a spiracle lobe which is lined with fine hairs. The spiracle has an external closing mechanism, the operculm, a sclerotized plate that does not fully cover the opening. The operculm is controlled by an occlusor (closing) muscle which connects to a small arm beneath the spiracle membrane. When the muscle contracts the operculm closes over the opening and when it relaxes the operculm opens.

The **second spiracle** is small and permanently open so not discussed here.

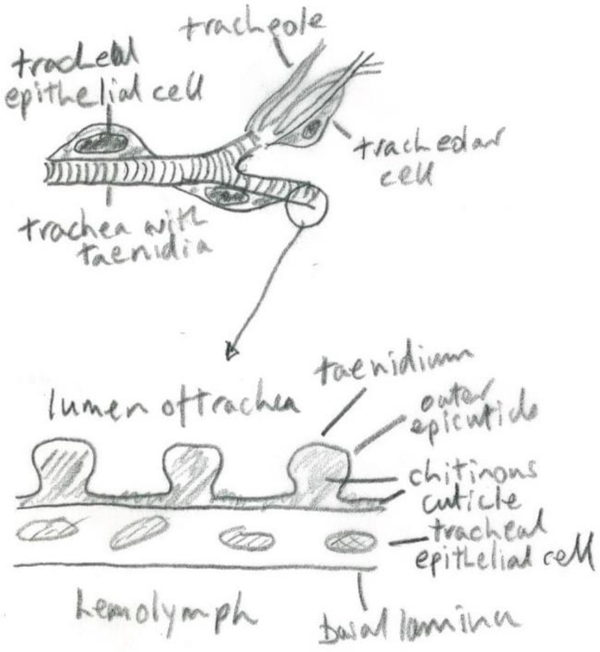
The **3rd spiracle** on A1 (propodeum) has a long aperture of 0.23mm by 0.06mm when open. It is surrounded by an elevated rim creating an external atrium. Within the entrance to the opening is controlled by two muscles connected to a valve made up of a soft integumental fold with a strongly sclerotized margin. The contraction of the occlusor (closing) muscle causes the valve to move forward closing the aperature, the relaxing of the occlusor and contraction of the dilator muscle causes the valve to release and reveal the aperature.

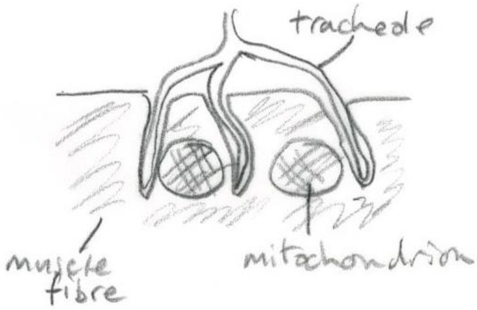
Abdominal spiracle has an internal atrium lined with filtering hairs. A domed shaped valve lies between the atrium and the trachea. Closing muscles move the valve towards the ridge and opening muscles pull the valve away from the ridge thus exposing the trachea.

Trachea are formed from the invaginations of the ectoderm and thus have similar characteristics to the external cuticle of the bee. The trachea consists of an outer epicuticle with sclerotized protein/chitin beneath it, a spiral thickening of the intima runs along the trachea called taenidia. The taenidia contains protein/chitin that is sclerotized giving rise to strengthening mircofibrils.

Along the trachea fine tubes called **tracheoles** arise. Tracheoles are blind-ended, air filled extensions of terminal tracheal cells and are the primary sites of gas exchange within the bee. The tracheoles are usually less than 2µm tapering to 0.3µm. some tracheoles retain their cuticle after moulting unlike trachea. Tracheoles are formed from tracheolar cells, they retain taenidia ridges but they do not contain the protein/chitin sclerotized matrix found in trachea.

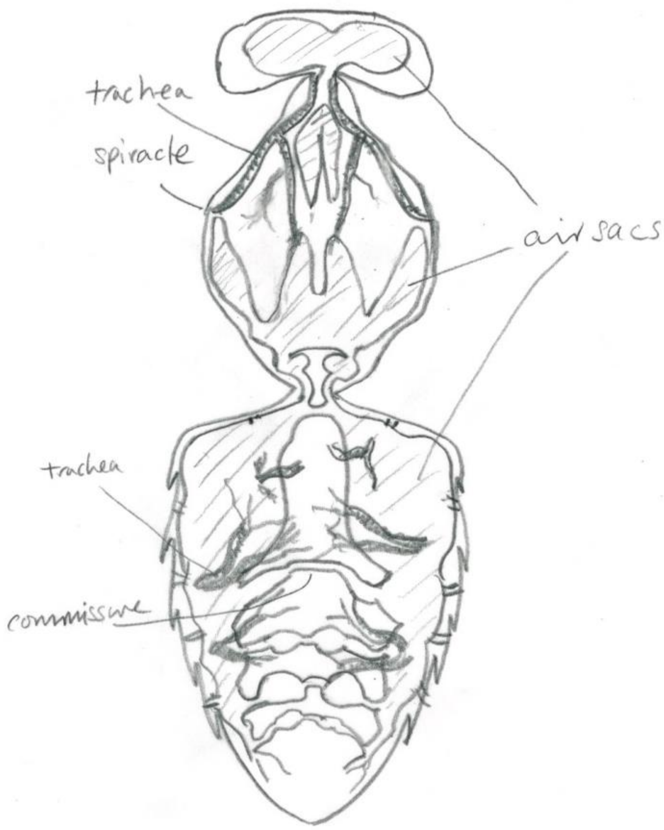
There is a debate whether the tracheoles enter the cells of the receiving material or go between cells. The single cell lining of the tracheoles is very thin 16-20nm which gives a high surface to volume ratio which enables their high diffusion capacity. The diagram shows the tracheoles within invaginations of the flight muscle.





Throughout the abdomen, thorax and head there are **air sacs** which are trachea without or limited taenidia. This gives them the ability to expand with air and collapse when empty.

Module 5 Study Notes



The air sacs provide a ready supply of oxygen to the brain and the muscles throughout the body. The air sacs in the thorax are supplied by the spiracles 1-3, the air sacs connect to air sacs in the head and abdomen. From the air sacs are short trachea that deliver oxygen to tracheoles close to the point of need.

During flight and high activity air is mainly drawn in through spiracle T2 and exhaled from T3, during periods of inactivity has in drawn in and exhaled via T2. The abdominal spiracles are involved in intake of air during flight but by how much unknown.

Temperature affects the “breathing” activity of the bee. At 12°C there are no abdominal ventilatory movements. 12-15°C the abdomen has intermittent abdominal movements and above 28°C the movement cycles can be 100 per minute.

The purpose of the respiratory system is to deliver oxygen to the points of need and remove CO_2 this is carried out by nerves connecting to the ganglia recognising levels of oxygen and CO_2. When CO_2 is high the ganglia cause the abdominal muscles to contract thus expelling the gas through the spiracles and relaxing the muscles to allow oxygen in.

The ends of the tracheoles are filled with fluid. This end enters into the tissue. The ends of the tracheoles are also devoid of cuticle and therefore the respiratory surface is very thin making the diffusion of oxygen into the cells easy. As respiration occurs in the cell, the products of respiration accumulate in the cell and this forces the fluid in the tracheoles to enter the tissue. The exit of fluid creates low pressure in the tubes and draws in more oxygen to the tissues where it is needed. ???

During cellular respiration, a glucose molecule is gradually broken down into carbon dioxide and water.

The oxygen removed from the tracheal air space is not completely replaced by carbon dioxide, primarily because a large fraction of the carbon dioxide produced dissolves in the tissues and haemolymph (carbon dioxide, in contrast to oxygen, is highly soluble in biological fluids).

The tracheole is partially filled with liquid, energy production causes the fluid to be drawn into the muscle which enables oxygen within the tracheole to pass through the oxygen is replaced by CO_2.

When internal oxygen tensions reach a low threshold, the spiracles begin to open slightly at high frequency (flutter phase), and tracheal pressures rise to near-atmospheric levels. During the flutter phase, high-frequency, but minutely sub-atmospheric, air pressures allow the animal to convectively take in oxygen with minimal emission of carbon dioxide. The spiracles remain sufficiently closed so that internal oxygen levels remain low. Carbon dioxide accumulates throughout the closed and fluttering phases, eventually triggering the spiracular open phase, when tracheal oxygen levels are restored to near-atmospheric partial pressures.

5.4 the circulatory system, including the heart, dorsal and ventral diaphragms and the composition and functions of the haemolymph;

The main functions of the circulatory system are to transport food from the Ventriculus to the body cells and transport waste products to the excretory system. This is achieved through a combination of muscular organs and diaphragms

The elements that control the fluid and effectively comprise the circulatory system are:

- Heart
- Aorta
- Antennal vesticle
- Dorsal diaphragm
- Ventral diaphragm

The heart is tube which is closed at the rear end and has 5 pairs of openings along its length called ostia, haemolymph is drawn into these openings and pumped forward to the aorta. The heart resides within the Dorsal sinus and is connected to the body and the dorsal diaphragm.

The aorta is a narrow tubular extension to the front of the heart which passes through the petiole and opens out at the brain.

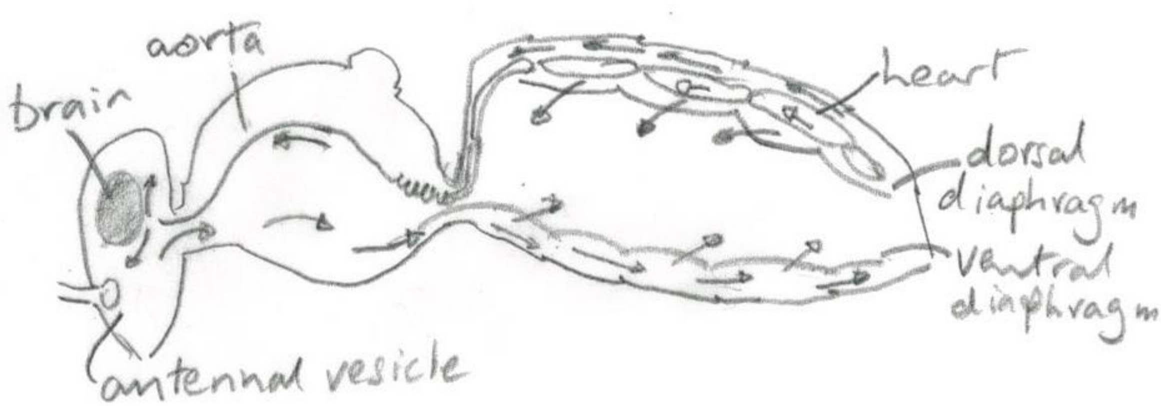
At the base of the antennae there is a structure that draws in haemoplymph when relaxed and pumps it up the antennae when tensioned.

The dorsal diaphragm is connected in places to the upper part of the abdomen, above the diaphragm is a gap (sinus) within which the heart resides. The diaphragm has rhythmic undulations from the rear of the abdomen to the front which causes surrounding fluid to travel forwards.

The ventral diaphragm exists within the thorax and the abdomen and is attached to the sternum, again there is a sinus between the diaphragm and the body of the bee. The rhythmic movement of the ventral diaphragm is front to back, moving fluid from thorax to abdomen within the sinus.

The fluid within the space between the diaphragms swirls.

The circulatory system is an open system, with haemolymph circulated around the body, supporting cells, transporting food and removing the waste products of metabolism, via the movements of the diaphragms. The ventral diaphragm moves the haemolymph from the thorax.



The dorsal diaphragm moves the haemolymph forward within the abdomen. The heart closed at the posterior pumps haemolymph towards the aorta and onwards to the brain. The heart has 5 pairs of ostia which draw in the haemolymph, the valves close when the muscles forming the walls of the heart contract. The contraction drives the haemolymph forward.

Within the head there is the antennal vesicle which circulates haemolymph to the antennae, the vesicle is not muscular, the vesicle is connected by tissue to the muscles of the pharynx. Similar structures exist at the bases of the wings and legs to assist in pumping the haemolymph to the extremities.

Muscles in the mouth are able to increase blood pressure on the glossa, thus inflating it.

The dorsal diaphragm connects at points from terga segments A3 through A6. It is transparent, contains muscle fibres and supports the heart. Above the diaphragm is the dorsal sinus, movements in the diaphragm move the haemolymph forward in the sinus creating the current. A similar structure exists on the ventral side of the abdomen, except the ventral diaphragm starts in the thorax where it is attached to the endosternum of the mesothorax and metathorax and ends as two long prongs connected to the spiracle plates of segment A8.

The aorta is a narrowing of the heart that passes through the petiole, it is coiled as it enters the thorax (coiling is utilised for heat exchange between free flowing haemolymph and that within the aorta) before straightening out and opening near the brain.

The haemolymph comprises; plasma and haemocytes. Plasma is a colourless liquid (90% water) containing several dissolved substances including salts, amino acids, proteins, carbohydrates, uric acid, lipids, fatty acids and organic compounds. The haemocytes are simple cells suspended in the plasma and are instrumental in coagulation and wound healing.

The functions of Haemolymph can be described as:

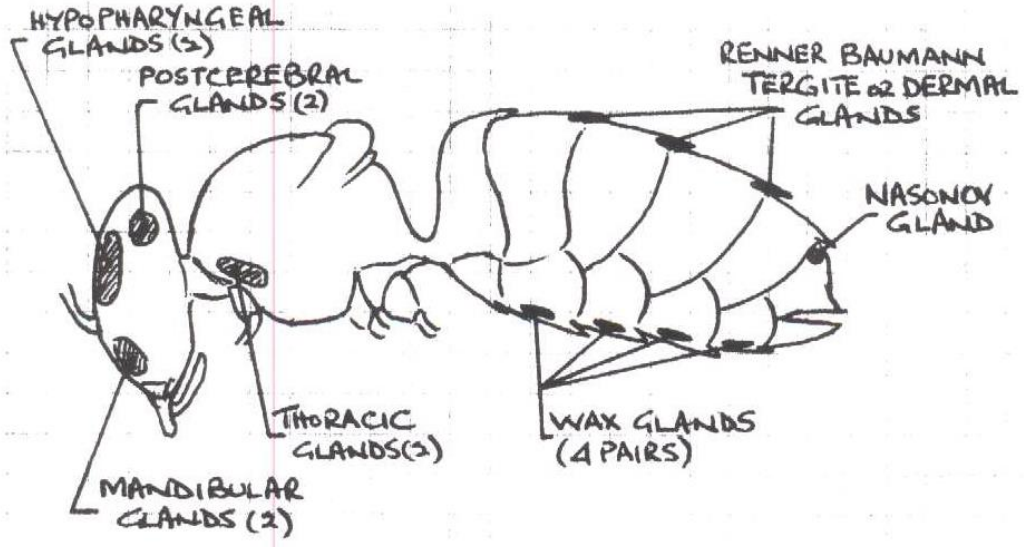
Transport, of food to cells, waste materials after metabolism, hormones from organ source to point of use
Mechanical support, it fills the cavities of the bee
Control of water content of the cells, makes water and dissolved substances available to the cells
Metabolism, chemicals are broken down into simpler ones in the haemolymph, essential for creation of energy
Phagocytosis, some of the haemocytes destroy bacteria and parasites
Wound healing, haemocytes form chain to plug holes until wound repairs.
Immunity, fat body proteins attack invading pathogens

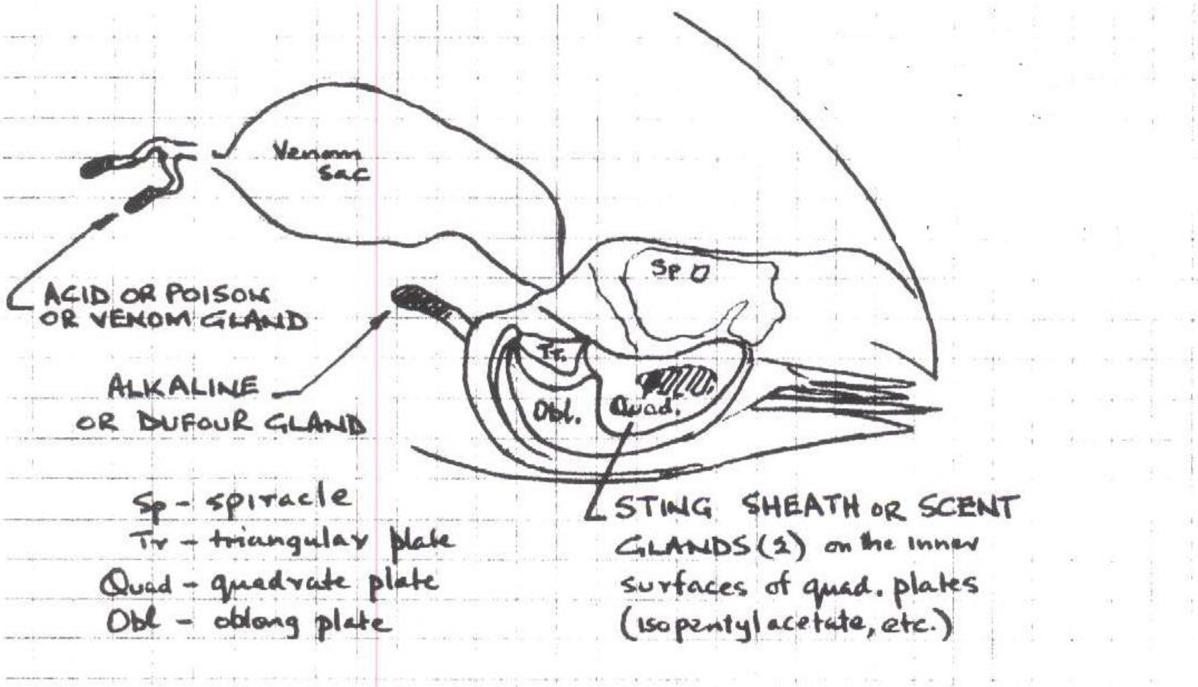
5.5The exocrine glands of all castes and sexes of adult bees and larvae, the functions and main compositions of their secretions including pheromones, (hypopharyngeal, mandibular, tergite glands of the queen (Renner-Baumann); Nasonov, sting, Arnhart post cerebal, thoracic salivary, wax glands and wax production)

Gland	Located	Function	Composition	Caste
Hypopharybgeal	Front of head	Produces element of brood food in younger worker and enzymes in older worker Gorging on pollen can cause gland to revert to food production	Young worker protein in form of clear liquid for making brood food Sucrase and glucose oxidase in older/foraging worker	W
Mandibular	Above mandibles	Young worker, production of brood food and royal jelly Mature worker, alarm pheromone issued by guard bees to ward off robbers and initiate stinging response from other bees Queen, produces pheromones used in mating or part of queen substance	In young worker 10-HDO (10-hydroxydec-2-enoic acid) which is principle fatty acid in brood food and acts as preservative Older worker 2-heptanone which is the alarm pheromone Queen produces : 9-oxodec-2-enoic acid (drone attractant when mating) 9-hydroxydec-2-enoic acid (holds swarm together)	Q W D
Tergite (renner-Baumann)	Edges of abdominal tergites A3-5	Queen recognition, contributes to Queen Substance, emitted through Queen grooming and retenue palpating her abdomen with their antennae	Composition unknown	Q
Nasonov	Tergite A7	Location scent used when flying in swarm to attract other bees, marking the entrance to hive, marking source of water	Terpenic alcohols: Geraniol, Nerol and (E,E)-Farnesol Terpenic aldehydes: (E)-Citral and (Z)-Citral Terpenic acids: Geranic and Nerolic acid	W

Sting scent gland	Quadrate plates	Alarm pheromone, (Z).... attracts bees to sting site and stabilises Isopentyl which along with 2-heptanone elicits stinging response	(Z)-11-Eicosen-1-ol Isopentyl acetate	W
Sting acid (poison or verom gland)	Abdomen	Production of venom to be used in sting	Major ones: Mellitin (50% of dry weight), Phospholipase A, Hyaluronidase, Acid phosphatise, Allergen C	Q W
Sting Alkaline (Dufour)	Sting Chamber	Generally unknown but assumed to: lubricate sting mechanism, neutralise remaining acid and in queen protective coating to eggs or egg adhesive for cell floor	Unknown, white in colour and alkaline in nature	Q W
post cerebal	Behind brain	Salivary, no reservoir, secrete directly into outlet ducts Only vestigial in drone, equal development in Queen and Worker	Water of Alkaline nature	Q W D
Thoracic	In the thorax	Salivary, developed from silk gland in larvae, have resevoir	Water of Alkaline nature	Q W D
Arnhart (tarsal glands)	5th tarsome of each leg	Location (footprint odour) in worker bee Constituent part of Queen Substance, queen emits factor x13 of rate of worker	Unknown except different in the two castes	Q W
Wax glands	Sternites A4-7	Wax production	Downing (1961) 16% hydrocarbons 31% straight-chain monohydric alcohols 3% diols 31% acids 13% hydroxyl acids 6% other substances MBBKA 2009 esters 70% alcohols 1% acids 10% hydrocarbons 13%	W
Wax production	Sternites A4-7	Internally, lying over each gland a large cellular mass composed of oenocytes and fat cells Externally, where the sternites are partly concealed under preceding sternite are two polished surfaces separated by a broad median space. These are the wax mirrors. Wax is discharged as a liquid from gland through the mirrors and rapidly hardens through oxidisation in the pockets between the mirrors and the long under lapping parts of the preceding sternite Wax is removed using hairs on hind legs towards mouth for manipulation.		W

Module 5 Study Notes





5.6 the structure and function of the nervous system and sense organs (including the compound eyes, ocelli, organ of Johnston and the sensilla);

The nervous system comprises:

- The brain and sub-oesophageal ganglion
- 7 ganglia connected together in the ventral sinus and to the brain by nerves
- Sense receptors throughout the body

The brain sits above the oesophagus and is composed of three parts; the protocerebrum, deutocerebrum and the tritocerebrum which is not a distinct division of the brain like the other two parts. Below the oesophagus resides the sub-oesophageal ganglion (really 4 fused ganglia) and is directly attached to the brain causing the pair to operate as one.

The protocerebrum supports two large optic lobes and manages the compound and simple eye, the deutocerebrum supports two large antennal lobes connected to the antennal nerves and the tritocerebrum manages the lower part of the face and the labrum and is connected to the frontal ganglion via nerves. The sub-oesophogus ganglion manages the mandibles, hypopharynx, first and second maxillae (labium is 2^{nd} maxillae).

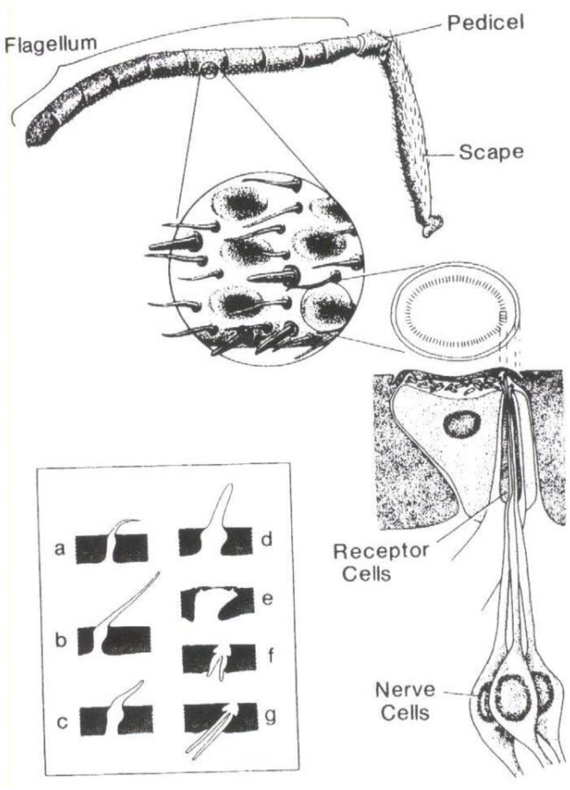
The larva has 11 ganglia (T1-3, A1-7, plus one in A8-10) these fuse during metamorphosis to 7 in the adult bee T1, (T2+T3+A1+A2), A3-6, (A7+A8+A9+A10). The ganglia are in fact fused pairs of ganglia connected via a nerve cord.

The first two ganglia in the Thorax manage the legs and wings as well as the Thorax and propodeum. The ganglia in the Abdomen supply the nerves to the appropriate segments in the abdomen.

The major receptors are called sensilla (sensillum – singular) have a specially constructed cell or group of cells in the cutilcle together with sensory nerve axons connected to an associated synapse. The table summarises the list of major sensilla:

Name	Role	Description	Location
Sensilla trichodea (hair or seta)	Touch	Nerve cell attached to base of a hair	All over body, legs and eyes
S. basiconica (peg or cone)	Taste	Similar to trichodea except stunted hair	Mouthparts, antennae and legs
S. coeloconica (pit)	Carbon Dioxide, temp and humidity	Same as basiconica except peg in pit below surface of exoskeleton	Mainly on antennae
S. campaniformia (bell)	Stress and strain on cuticle	No hair, covered by thin layer of cuticle	Groups in wings, legs and sting
S. placodea (plate)	Taste, permeable to chemicals	Flush with surface of cuticle, elipticle plate, pores allow molecules of gas through	On antennae, used pheromone sensing.
S. scolopophora	Muscle tension and vibration	Subgenual organs and organ of Johnston	Tibia and antennae respectively
Ocelli	Simple eye	See below	3 on top of head, lower in drone
Compound eye	Sight	See below	Side and top of head

Module 5 Study Notes



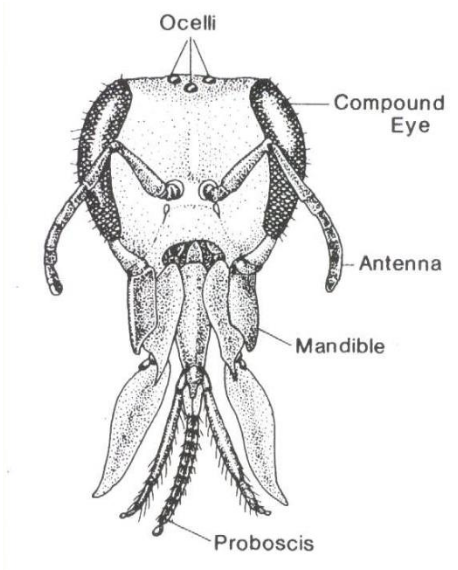
a. Small thick-walled hair S. Trichodeum
b. Thick-walled peg S. Trichodeum
c. Slender thin-walleded peg S. Trichodeum olfactorium
d. Large thin-walled peg S. Basiconicum
e. Pore plate S. Placodeum
f. Pit organ S. Coeloconicum
g. Pit organ S. ampullaceum

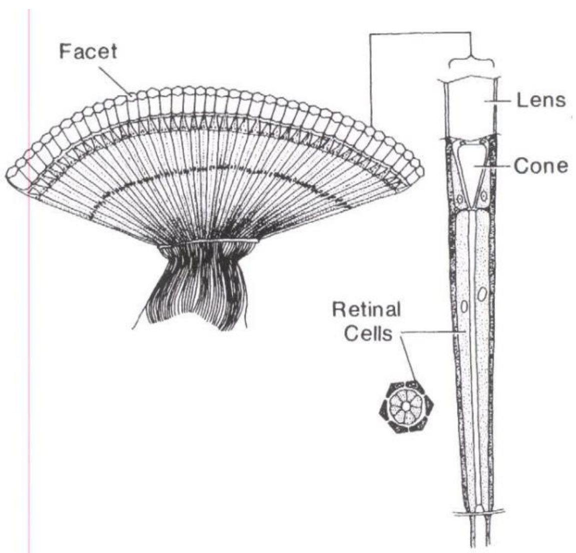
Organ of Johnston

Found at the distel end of the pedicel of the antenna. Some of the dendrites are embedded in the wall of the pedicel and others are connected to the membrane between the pedicel and the first segment of the flagellum. Movement of the flagellum cause nerve impulses.

Its role seems to be a wind speed indicator, for recognising speed of flight, and possibly for detection of airborne vibrations.

Compound Eye





The Compound eye is so-called because they are made up of many parts. Each part is called a ommatidium which operates as a complete eye in itself. The bee creates a picture of its surroundings by joining together all the images.

The ommatidium comprises two parts the lens and the receptor.

Lens

The corneal lens is the surface of the eye, it is transparent, looks hexagonal when eye viewed as a whole and is slightly convex at the sides.

The crystalline cone is behind the lens and is a hard and transparent cone

Two primary pigment cells surround the cone to prevent light entering from adjacent ommatidia

Receptor

The retinula cells are elongated nerve cells, there are 8 long ones and one short one, they are twisted around each other forming a core.

- 2 cells sensitive to green light
- 2 cells sensitive to blue light
- 2 cells sensitive to ultraviolet light
- 2 cells sensitive to green or blue light
- 1 cell sensitive to ultraviolet polarised light

The core is called the rhabdom and is made up of the right angle projections (microvilli) from the retinula cells called rhabdomere and combined they make up the rhabdom.

Operation

The lens and cone concentrate the light striking its surface into a beam directed to travel down the rhabdom.

Light reaches the rhobdomeres and strikes the microvilli, within which there is a photopigment called rhodopsin.

Rhodopsin changes structure based on energy and colour of light, it then changes back

Each retinula cell has a nerve fibre leading from it and impulses are created with each rhobdopsin change.

All nerve fibres lead back to brain where an image is composed.

Image will be a mosaic in nature and between frames of images it will be dark, but frames are at 100 per second.

Ocelli

The ocelli has the same structure as the ommatidium employed in the compound eye but the lens does not focus on the retinula cells, so no image is formed. The ocelli seem to be concerned with the intensity of light, but work in conjunction with the compound eye in a stimulatory effect. Cover the ocelli does not stop the perception of light intensity in the bee but the coverse (cover the compound eye and the bee is blind.

5.7 the endocrine glands and the functions of their secretions particularly the neurosecretary cells, the corpora allata, corpora cardiac and the prothoracic glands;

The endocrine system contains a number of ductless glands producing secretions called hormones which are released directly into the haemolymph and have a profound effect upon growth, development, moulting, caste determination, age polyethism and glandular development.

It works in combination with the nervous system, the latter controlling the rapid minute-by-minute activities of the organism while the hormones are more concerned with slower, long-term effects.

The glands of the endocrine system although quite distinct work together and sometimes hormones from different glands may produce contradictory effects.

There are four major parts to the system

- The neurosecretory cell
- The corpora cardiaca
- The prothoracic gland
- The carpora allata

Neurosecretory cells

Found in groups in the brain and other ganglia. They are special nerve cells, identical in shape to other cells, which have processes to conduct impulses but as a result of stimulation secrete chemicals which can travel down the nerve fibres to various organs or other endocrine glands.

Corpora Cardiaca

These two glands are found behind the brain one on either side of the aorta connected to the brain by the fibres of the neurosecretory cells. The chemicals produced by these cells are stored in the corpora cardiac and when conditions are right they are released into the haemolymph, so the corpora cardiaca acts as a conduit for the chemicals produced by the brain. It also produces its own hormone.

Prothoracic gland

These two glands one found between the pro- and mesa- thorax near the first spiracle and they produce and secrete ecdysone (moulting hormone). The production of ecdysone is essential for moulting but it is only released in response to another hormone produced in the neurosecretory cells, stored in the Corpora Cardiaca and subsequently released by them into the haemolymph. This illustrates well the connection between the nervous and endocrine system because the brain hormone seems to be released as a result of the reception of impulses in the brains possibly related to size and stretching in parts of the cuticle.

The corpora allata

These are found on either side of the oesophagus. Connected to the brain by the fibre of the neurosecretory cells which have come via the corpora cardiaca and also connected to the sub-oesophageal ganglion. They produce the vital hormone called juvenile hormone (JH). (Also known as neotenin). High levels of JH in the larva maintain the larval characteristics and it is only when levels of JH fall and ecdysone is released that moulting occurs and growth and development changes are able to take place. This is one example of the interaction of two quite separate hormones from different glands having an effect on one development process. JH also plays an essential part in the determination of the female caste.

All except the prothoracic gland, which degenerate at pupation, persist in the adult.

How do they work??

Hormones circulate in the haemolymph and are broken down by enzymes. They are not stored in the glands so there must be continuous production where a sustained effect is required. When a hormone reaches a target cell it causes biochemical changes, usually resulting in the production of enzymes which allow specific reactions to take place and/or enable production of particular proteins. One hormone may have different effects on different parts of the insect at different stages of its life.

The endocrine glands work in combination with the nervous system. The neurosecretory cells are part of the nervous system a long processes connect these groups of cells with the corpora cardiaca and the corpora allata. Nerves also connect the corpora cardiac with the thoracic glands and with the corpora allata so there is an intimate connection between the two systems.

5.8 the fat body and its storage of metabolites;

The fat body is not a thing rather a collection of cells distributed in different parts of the body for the storage of food reserves to be used by the bee in different manners at distinct stages of the life cycle.

There are three types of cells within the fact body:

- Trophocytes, these form the major part of the fat body and are present in all stages of the bees life
- Oenocytes (oil cells), again in all stages larva, pupal and adult life, the cells are destroyed at the larval stage and new ones formed in the adult stage. Large concentration are formed over the wax glands in adult bee, peaking at same time as wax production. Cells larger in queen and contribute to the egg yoke.
- Urate (excretory cells), found only in larva and pupa. They store nitrogenous waste in the form of uric acid in larva and pupa, once the Malpighian tubules are formed they disappear.

Fat Body and Larva/Pupa

In the larval stage the fat body, consisting of small polygonal cells, increases in size and number with each stage of development. At time of the cell being sealed the fat body occupies 65% of body weight. During the pupal stage the fat cells release their contents into the haemolymph. The white colour of the larvae is the density and colour of the fat body (occupying the body cavity) pressed against the translucent larva skin.

Fat Body and Adult Bee

The contents of the fat body storage varies by bee age and season:

- Young bee, fat globules (required for food production) and little protein
- Older summer bee, protein and glycogen (rapid breakdown for energy) stored in fat cells
- Winter bees, large amounts of protein, little fat

Module 5 Study Notes

5.9 the reproductive system of queen and drone and the production of sperm and eggs;

Queen Reproductive System

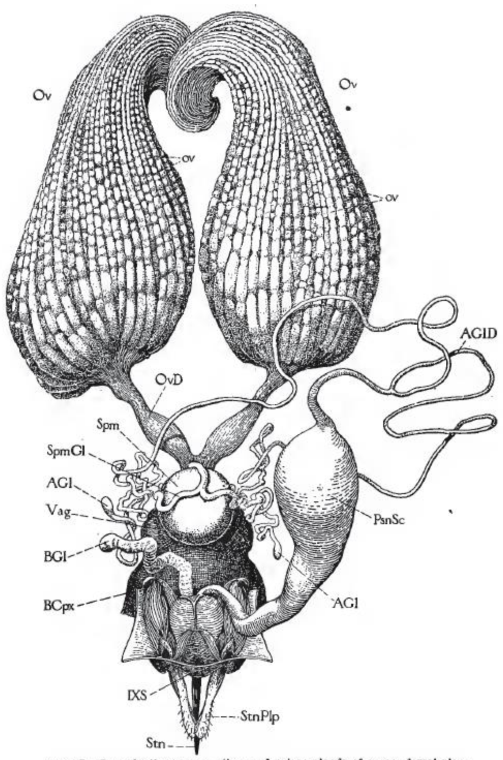
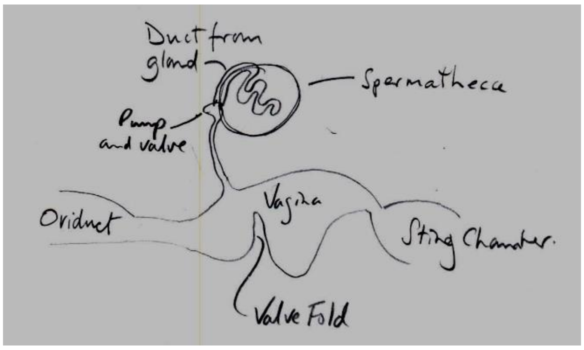


FIG. 57.—Reproductive organs, sting, and poison glands of queen, dorsal view.



The reproductive system of the queen not only produces eggs it stores sperm and unites it with eggs prior to laying.

The key elements of the system are:

- ovaries, there are two ovaries, one on either side of the abdomen and attached to the ventral wall. The each ovary consist of 150-180 egg producing ovarioles (worker 2-12). The ovarioles produce up to a million eggs over the lifetime of the queen.

- oviducts, these are tubes that lead from each ovary to the median oviduct

- vagina, the median oviduct feeds into the vagina along with the spermatheca duct. Within the vagina is the valve fold which coordinated with the pump in the spermatheca duct unites sperm and egg.

- bursa copulatrix, this is the sting chamber from where the egg is laid within a cell

- spermatheca, is a spherical structure above (dorsal side) the vagina, within here the sperm from mating is held. The sperm travels down the spermatheca duct into the vagina. At the entrance to the vagina the valve fold presses an egg to the duct for fertilisation.

Egg Production

At the tip of each ovariole germinal cells divide and produce:

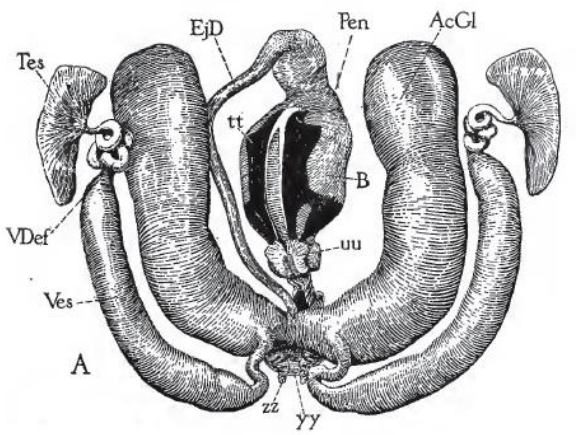
- Oocytes which become the eggs

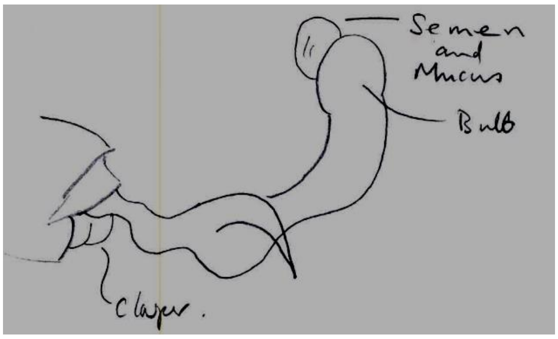
- Trophocytes which provide nourishment to the oocytes, there are 48 trophocytes per oocyte.

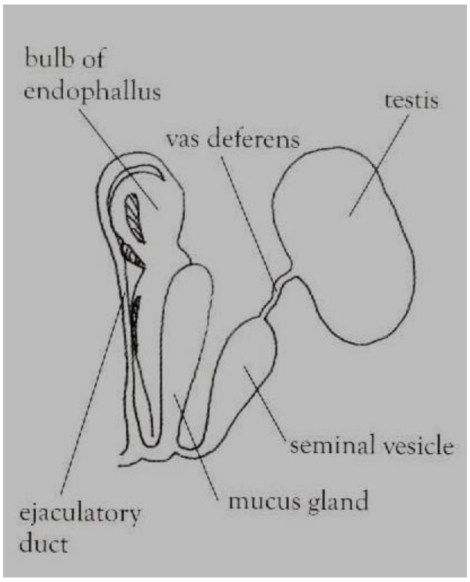
The oocyte passes down the ovariole gaining size through the supply of nourishment from the trophocytes which diminish and finally disappear, yolk is added in the later part of the ovariole, the follicle cells surrounding the egg form the covering (chorion). As the egg leaves the ovariole the final meiotic division occurs.

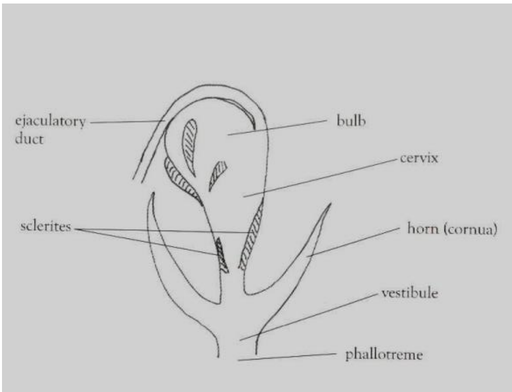
The egg emerges from the oviduct, is pressed to the entrance of the spermatheca duct by the valve fold, if sperm worker egg results, if no sperm drone egg results.

Drone Reproductive System









The drones reproductive system comprises:

- Testes, there are two testis which peak in size prior to drone emerging from cell, they shrink until the drone reaches full maturity at 12 days
- Vasa deferentia, small tubes that lead from each testis and lead to the seminal vesicles
- Seminal vesicles, the sperm reside here and are nourished until they are required

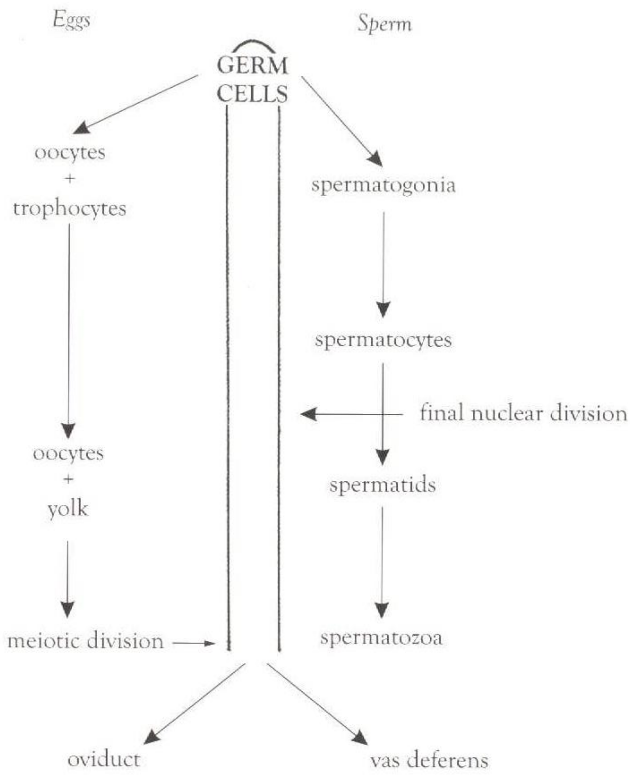
- Mucus glands, two small tubes enter the gland from the seminal vesicles, the mucus produced by the glands is not involved in the production of the semen rather the delivery. The mucus forms a thick mass when in contact with air.
- Ejaculatory duct, runs from the base of the mucus gland, near the entrance from the seminal vesicle to the bulb of the penis
- Penis, the penis (endophallus) resides within the abdomen of the drone, opening to the outside on A9 (the phallotreme) from the vestibule which is connected to the bulb by the cervix. Two horns (cornua) are attached to the phallotreme. The surface of endophallus has several plates (sclerites) on the surface

Sperm Production

The testis comprises a large number of tubes, the tip of which form the sperm cells, as they travel down the tube they divide to form spermatogonia, then form groups called spermatocytes which grow and divide into spermatids and finally change shape to form spermatozoa which emerge into the vas deferens.

The drone mates once and dies, so all sperm (spermatozoa) are released in one explosive moment. After the mounting of the queen the contraction of the abdominal muscles causes the penis to evert (go inside out). The muscle lining of the seminal vesciles and mucus gland causes the sperm and then the mucus to be expelled.

The endophallus breaks off, the drone dies, the sperm remains within the queen until endophallus is removed by next drone or worker on return to colony.



5.10 the structure of the egg, development of the embryo within the egg and the hatching of the larva;

Structure of the egg:

- Chorion, is the outer layer of the egg
- Vitelline membrane, is the egg wall
- Cytoplasm, lining inside vitelline extending to strands throughout the egg
- Yolk, globules entwined throughout the egg with the cyptoplasm strands
- Nucleus, contains all the genes for the development of the bee

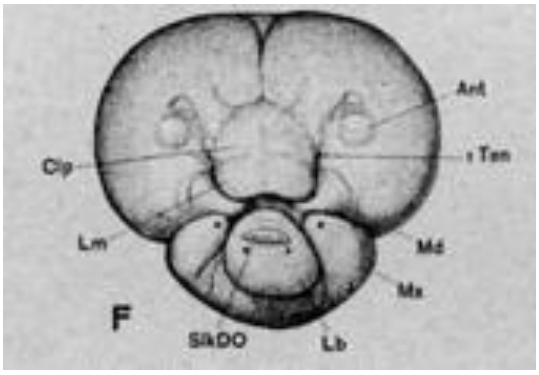
Stages of egg development to the emergence of larva:

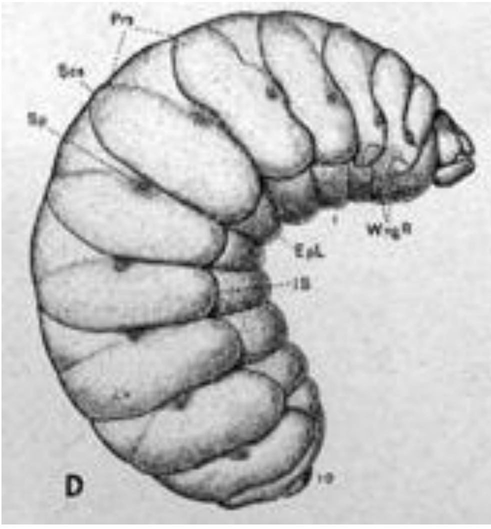
- Cleavage, single nucleus divides forming many cells throughout the yolk
- Blastoderm formation, the cleavage cells form layer inside vitelline membrane
- Formation of germ band (layers of cells), thickening of the blastoderm on ventral side becomes the germ band
- Division of germ band, longitudinal fissures which run the length of egg divide germ band into three areas, two side lateral plates and median plate on ventral side
- Median plate moves inwards towards the yolk to form the mesoderm (which later will develop into muscles, circulatory system, part of reproductive system). The lateral plates grow, enclosing the mesoderm and forming the ectoderm (which will become the cuticle and its appendages, tracheal system, foregut and hindgut, nervous system and sense organs, part of reproductive system, oenocytes)
- The endoderm (evolves into the midgut) form from two ingrowths of the blastoderm, they join enclosing the yolk.
- Pits and ingrowths form on the ectoderm which will mature into physical elements in the larval development.
- After 3 days the larva is complete and enclosed within a membrane which splits to allow the emergence of the larva.

Module 5 Study Notes

5.11 the external and internal structure of the honeybee larva;

External Structure





The body is divided into a head and 13 segments comprising T1-T3 (Thoracic) and A1-A10 (abdominal).

The main body does not have external structures, at one end it has the beginnings of the head with mouth and spinneret and at the other end the anus.

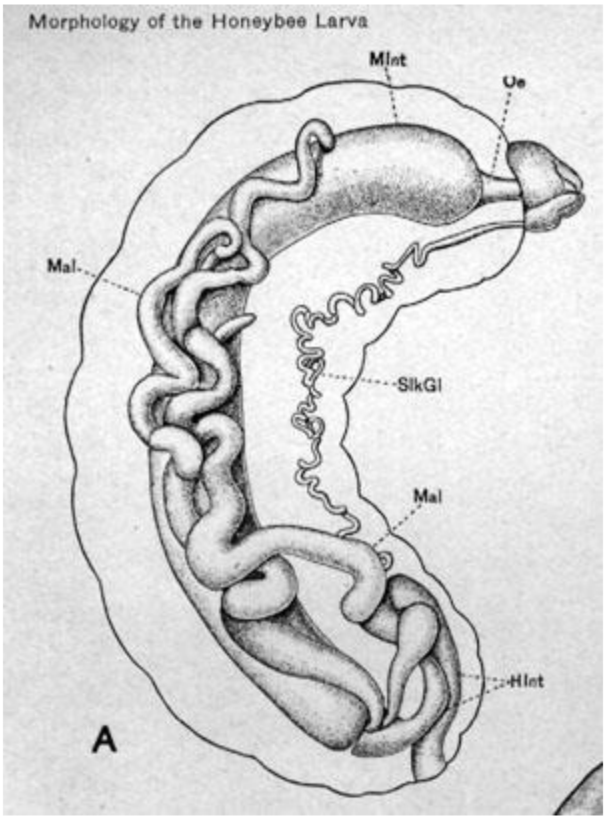
Internal Structure

All the main elements of the mature honeybee exist within the larva:

- **Digestive System**, a large part of the body is occupied by the midgut (ventriculus), at this stage it is not connected to the hindgut. Liquid food is sucked in through the mouth.
- **Excretory System**, the waste products of the body are stored with the malpighian tubules which swell with their contents.
- Respiratory System, there are 10 permanently open pairs of spiracles on segments T2-A8 (reflecting adult bee structure) which connect into tubes that run the length of the body.
- Nervous System, brain, sub-oesophageal ganglion and ganglia associated with each segment are formed, A8-10 are fused.
- Circulatory System, the heart is present from A9 through T2 with 11 chambers and 10 pairs of openings terminating in a short aorta and both Ventral and Dorsal Diaphragms are present.

Module 5 Study Notes

- Fat Body, fills most of the space within the body giving the creamy white colour to the larva. The fat body contains urate cells for further storage of waste.
- Silk Glands, long coiled structures that appear to the outside world at the spinneret on the labium.
- Testes and Ovaries, worker and queen larvae have ovaries (the queens ovaries larger than those of worker) and the testes in drone larger still than queens ovaries, located between A4 and A6.



Key:

Oe – Foregut

MInt – Ventriculus (midgut)

Mal – Malpighian Tubules

SlkGl – Silk Gland

Hlot – Hind Gut

Module 5 Study Notes

5.12 the metamorphosis of the larva with outline accounts of ecdysis, larval defaecation, cocoon spinning, the external anatomy of the pro-pupa, its change to a pupa and then to an imago;

"Ecdysis" correctly is the actual emergence of a new form of the insect from an old cuticle.

The "correct" term for the process of moulting is apolysis (Davis).

There are six instances of moulting between the egg hatching and the emergence of the imago.

General description of moulting

The process is initiated by hormones.

During the stadia (periods between moults), the level of juvenile hormone in the haemolymph is high.

The moult is initiated by a rise in the level of moulting hormone ecdysone, corresponding with a drop in the level of JH.

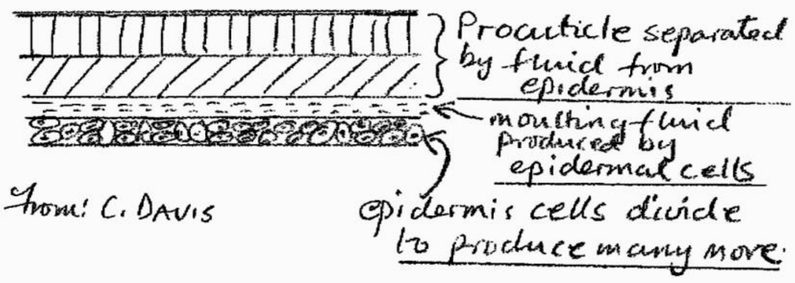
Ecdysone is secreted by the prothoracic glands.

The secretion of ecdysone is initiated by the neurosecretory glands in the brain which give a chemical signal to the corpora cardiaca which in turn signals the prothoracic glands to release ecdysone.

JH is secreted by the corpora allata, also under the control of neurosecretory cells in the brain via the corpora cardiaca.

At the start of the moult the epidermal cells divide and multiply.

- The cuticle separates from the epidermis.
- Epidermal cells secrete ecdysal fluid which fills space between the epidermal cells and the old cuticle.
- Enzymes in the ecdysal fluid digest the old cuticle and a new cuticle grows over the epidermal cells.
- Digestion products assist growth of the new cuticle.
- The larva (or (pro)pupa?) swallows air, expands and ruptures cuticle.
- The old epicuticle and exocuticle are sloughed off.



Propupal Moulting

When the worker larva is six days old (day 9) and fully grown, the cell is capped possibly with some food remaining which it may or may not eat (Winston).

The larva stretches out in the cell on its back, head nearest the capping.

The connection between the hind gut (proctodaeum) and ventriculus is made and the contents of the four Malpighian tubules and the ventriculus is discharged into the cell as larval faeces.

The cocoon is spun with silk originating from the silk glands via the spinneret (the silk glands later become the adult thoracic glands).

The faeces become mixed up with the cocoon silk and possibly reinforce the cocoon.

In the next 24 hours many external features form as the larva changes into a propupa (or prepupa).

Anatomy of Propupa

- Head and mouthparts are remodelled
- Compound eyes develop
- Thoracic segments change shape
- The petiole forms
- Abdominal A8 A9 and A10 are combined into A7.
- Rudimentary wings and legs
- The sting starts to form.
- Also the ventriculus starts to reduce in size.

Almost two days after capping (worker) the 5th moult starts, and lasts about two days during which the propupa changes into the pupa. Completed day 12 -13.

Pupa characteristics

The new pupa is white, not hairy, has small wings and mostly adult appendages.

Many internal changes then take place:

- The alimentary tract develops, the musculature and the reproductive system develops.
- Some nerves die and new nerves form
- Reproductive system changes to adult form
- The drone’s testes shrink as sperm is transferred to the seminal vesicles

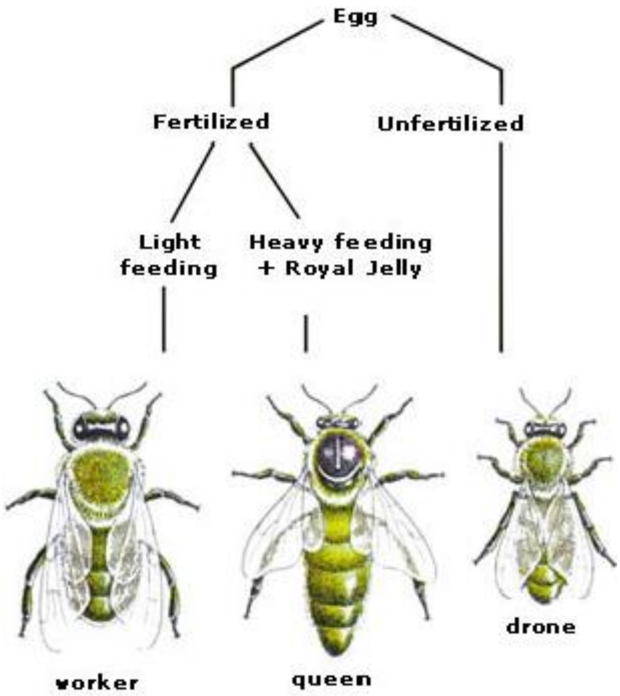
Externally:

- Cuticle hardens.
- External hairs grow.
- Wings develop.
- Exoskeleton colour darkens white to brown
- Eyes change colour pink to purple.

Sixth moult

Final moult occurs (day 20), then after waiting several hours while the cuticle hardens, the imago chews through the wax capping and finally emerges (eclosion).

5.13 the effect of feeding and other factors on caste determination including discussion about the differences between brood food and royal jelly;



The type of feeding of a larva is determined by the type of cell in which a larva resides (worker/drone or queen cell), worker and drone cells will be fed brood food and queen cells copious amounts of royal jelly. Sticking to the differences in feeding and food between worker and queen, there are three elements within brood food and it is the mix of elements as well as the feeding programme that determine the caste.

Larval food comprises:

- White, produced by the mandibular gland
- Clear, produced by the hypopharyngeal gland
- Yellow, derived from pollen

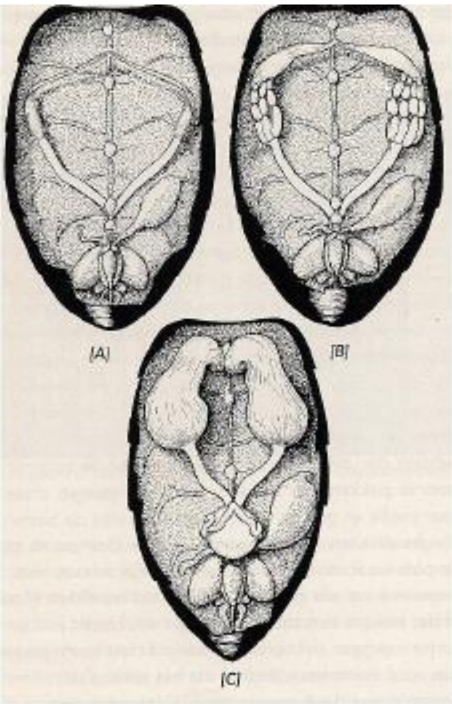
Composition of feed:

- Queen larva (Royal Jelly)
    - First three days mostly white
    - Last two days ratio white to clear 1:1
- Worker (Brood Food)
    - white:clear:yellow in ratio 2:9:3 average

Points to note:

- queen is fed 10 times volume of worker, queen "swims" in royal jelly, worker fed as needed
- larva up to 3 days old transferred between cell types and hence feed change will mature to appropriate caste i.e. queen cell produces queen, worker produces worker.
- Larva transferred 3-4 days old will mature to appropriate caste but may exhibit traits of other caste e.g. pollen baskets on queen.
- Sugar composition in royal jelly is 47% and in brood food 12% for first three days. Brood food rises to 47% after 3 days with addition of honey to mixture. Sugar stimulates to consume more.
- Higher levels of Juvenile Hormone in larva triggers queen development, royal jelly stimulates JH production by the early development of the endocrine system

5.14 the physiological and structural differences between laying workers and normal workers and the role of pheromones in bringing about these differences;



Reproductive organs of a normal worker [A],
A laying worker [B] and a virgin queen [C].

Development of laying worker bees

In a honeybee colony, under normal conditions female worker bees' ovaries are inactive as their development is prevented by brood pheromone (a 10-component mixture of methyl and ethyl fatty esters) and Queen Mandibular Pheromone (9-ODA). However, when a colony loses its queen and there are no fertile eggs or worker larvae of an appropriate age to raise a new queen from, one or more worker bees will partially activate their ovaries and commence to lay eggs as a result of the absence of queen and brood pheromones. The process of developing a laying worker usually takes weeks (3-4 weeks) after the loss of the queen, and by the time all the brood has emerged.

The eggs will be laid in worker cells with several in the same cell and produce eventually undersized drones. Drones produced from laying workers are sexually viable.

The laying workers take the place of the proper queen, they emit a pheromone, which mimics that of the queen scent which along with the brood pheromone inhibit other workers to lay eggs.

	Laying Worker	Normal worker
Ovarioles	10 – 12	Nil or vestigial
Laying rate	50 eggs per day	Nil
Spermatheca	Nil	Nil
Hypopharyngeal gland	Enlarged	Atrophied in older bees
Fat bodies	Increased	Low in summer
Age	Extended	Circa. 6 weeks
Pheromones	Mimic queen substance	Nil
Colony	Disorganised	Orderly
Behaviour	May attract court	Maul laying workers

5.15 the differences between summer and winter worker honeybees;

A key difference between summer and winter bees is their lifespan, the summer bee will survive around 6 weeks whereas the winter bee will survive several months in order for the colony to see through the winter.

The summer bee the employs the hypopharyngeal gland to produce brood food, this gland decreases as the bee becomes older. Going into winter there is less brood and the worker is less likely to be required to produce brood food. Older workers who have not produced brood food when younger can produce brood food after consumption of pollen, this is necessary when the queen begins to lay again in the spring.

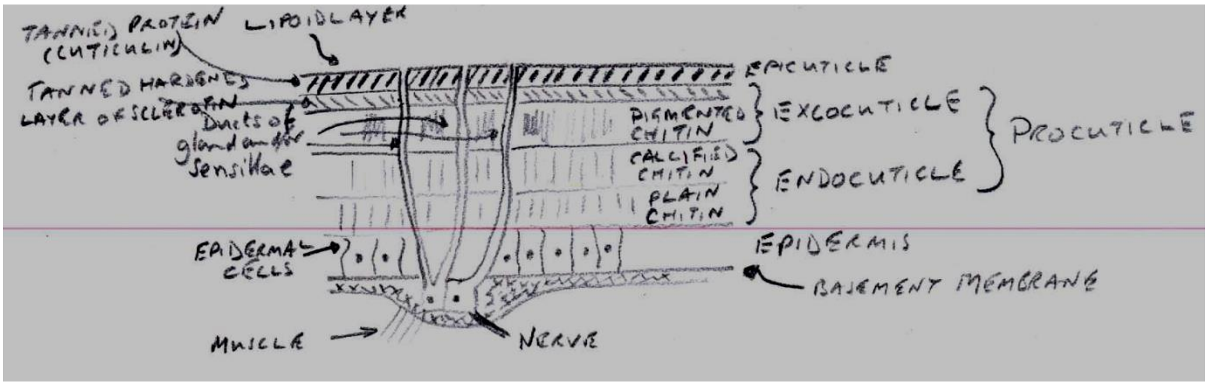
Summer bees lifespan is shorter also because their bodies basically wear out, after approximately 800 km of flying they run out of glycogen which is required for the energy to power the flight muscles.

So key differences are:

- Winter bees contain large amounts of stored glycogen and fat in the fat bodies
- The hypopharyngeal gland is plump and full of brood food in the winter bee
- Metabolic rate of winter worker is lower than summer worker
- Winter bees do less work i.e. no foraging
- The life span of winter worker is months compared with summer worker of circa 6 weeks.

Module 5 Study Notes

5.16 the structure and main constituents of the cuticle with an outline account of its invagination within the body to form linings of the gut and tracheae;



The cuticle comprises the procuticle and the epicuticle. Through the cuticle there are ducts carrying pheromones or sensillae. The functions of the cuticle are:

- Waterproof protective covering
- Provide anchor points for muscles
- Make hard parts
- Provide lining for some internal structures

The cuticle sits on the epidermis, a layer of living cells that secrete substances including:

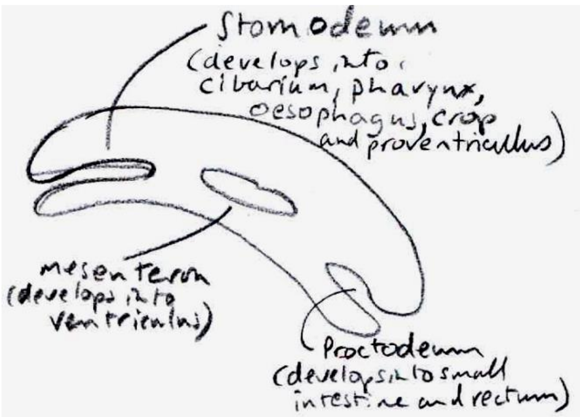
- Chitin, long thread like molecules of nitrogenous polysaccharides
- Arthropodin, protein injected between the chitin threads
- Polyphenols, for tanning the arthopodin and eventually forming sclerotin
- Cuticulin, tanning protein
- Cuticular lipids, paraffin hydrocarbons used for waterproofing the epicuticle

The thickness of the cuticle is circa 0.2µm.

Endocuticle – contains a large amount of chitin which is tough but flexible

Exocuticle – contains a large amount of sclertotin which is hard and dark in colour

Epicuticle – is primarily a thin layer of hard sclerotin and cuticulin but no chitin



Invaginations are internal folds, within the larva they are the stomodeum and proctodeum which are lined with cuticle and develop within the adult bee to become:

Oesophagus – slender tube lined with thick cuticle and surrounded with circular muscles

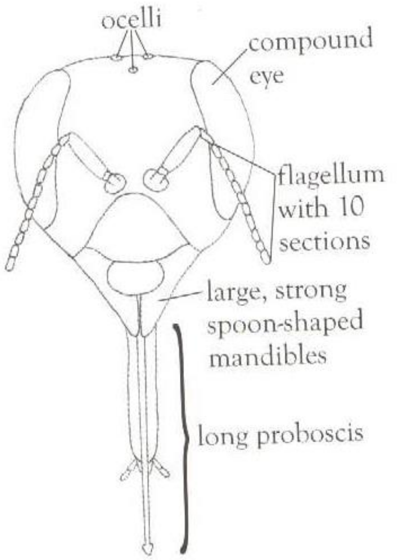
Crop – an extention of the oesophagus which is capable of stretching in order to take a heavy load

Proventriculus – walls are lined with dense cuticular intima

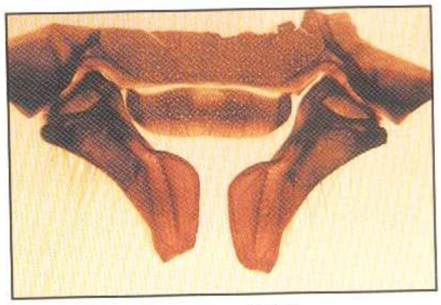
Rectum – has an epithelial wall lined with thin cuticular intima

Trachea – epidermal layer of cells with delicate cuticular intima

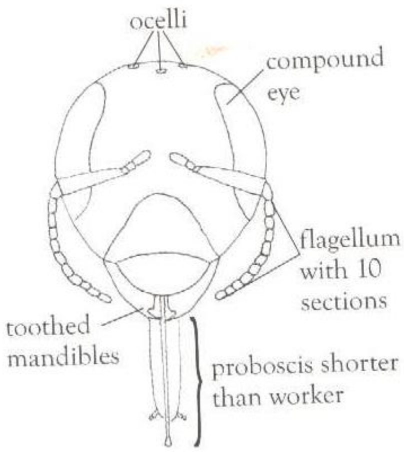
5.17 the external anatomy of the queen, worker and drone;



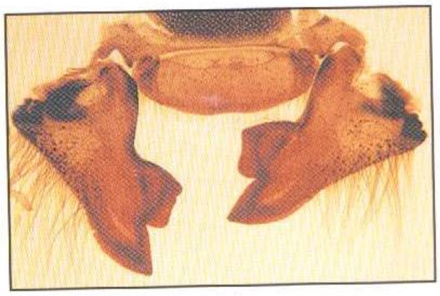
Head of a worker



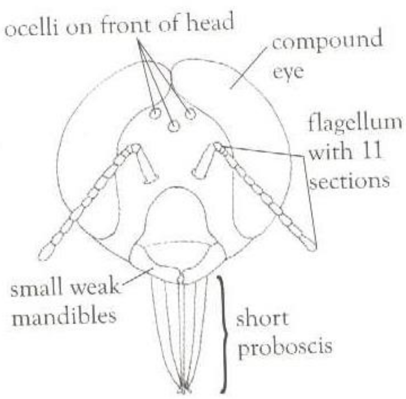
Worker mandibles are spoon~shaped



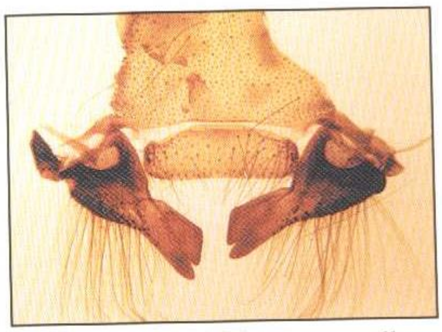
Head of a queen



Queen mandibles are strong and toothed



Head of a drone



Drone mandibles are small and not well co-ordinated

Module 5 Study Notes

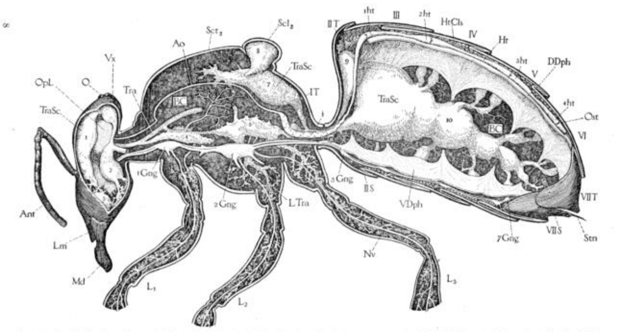


Fig. 1.—Longitudinal, median, vertical section of entire body of worker, showing nervous system (*OpL–7Gng*), tracheal system (*TraSc, 1–10*), dorsal and ventral diaphragms of abdomen (*DDph* and *VDph*), and dorsal vessel consisting of heart (*Ht*) and aorta (*Ao*).

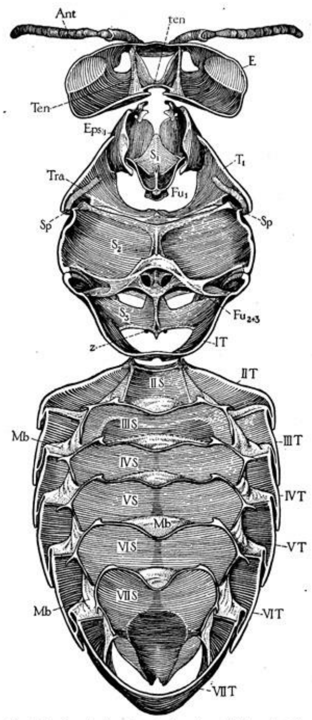


Fig. 20.—Dorsal view of ventral walls and internal skeleton of body of worker.

The honey bee comprises three external elements, Head, Thorax and Abdomen. The above diagrams give an outline to their structure.

The head comprises the eyes, mouthparts and antennae.

The Thorax and Abdomen are covered in a series of plates (tergum and sternum) which are linked via smaller pleuron plates connected via membranes.

The Thorax comprises three main plates:

- prothorax (T1), the first segment behind the head carrying one pair of legs
- mesothorax (T2), middle segment with one pair of legs, pair of wings and a pair of spiracles
- metathorax (T3), rear segment with a pair of legs, pair of wings and a pair of spiracles

There are no Sternum on the Thorax.

There are 10 Abdominal plates although A1/S1 (propodeum) reside on the thorax and linked to the Abdomen via a narrowing of the body called the petiole. Segments A8-A10 are hidden under A7. On the Abdomen there is a sternum associated with each tergum.

The castes differ externally in the following ways:

- Queen has a longer abdomen in order to house her reproductive system
- Drone has larger eyes and a larger rounded Abdomen

Module 5 Study Notes

5.18 the function and structure of the wings, legs, feet, antennae, mouth parts and setae (hairs);

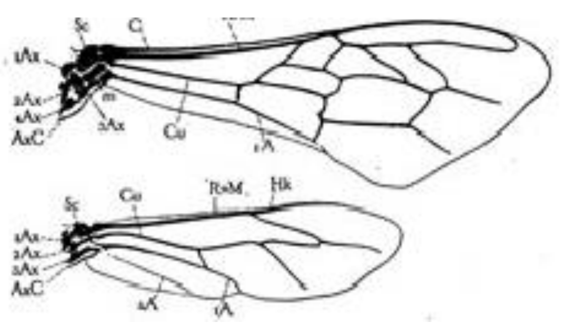
Wings

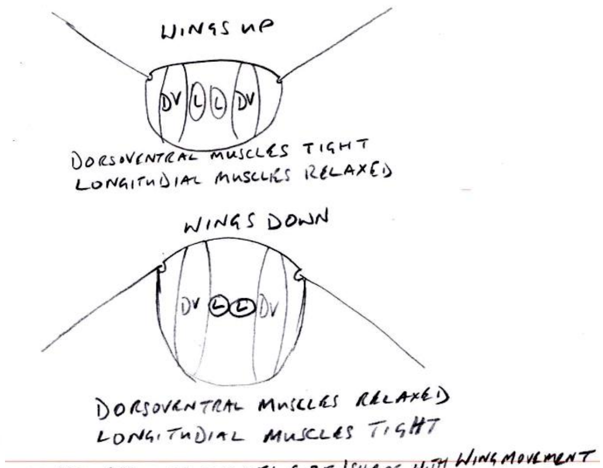
Function:

- to enable the bee to fly
- Used within the hive to fan
- The muscles associated with the wings used to generate heat

Structure:

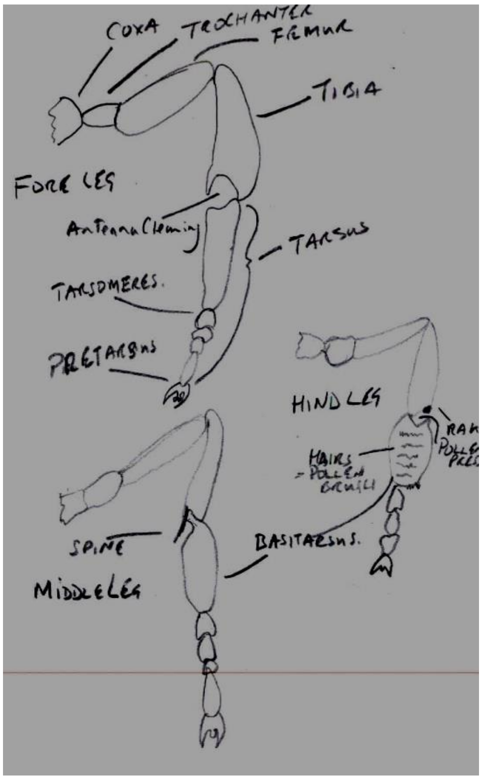
- Two pairs of wings
    - Forewing attached to T2
    - Hindwing attached to T3
- Hind wing has series of hooks (hamuli) along leading edge of wing, in flight they hook into a fold on the trailing edge of the forewing creating a single wing for flight
- There are indirect muscles that act upon the forewing causing the up and down movement of the wing
- There are direct muscles that act upon each wing to
    - To produce rocking and rolling of the wings
    - To trim the wings for yaw, roll and pitch
    - For furling and unfurling the wings
- The flight action is for the leading edge of the wing to make a figure of eight movement
- There are two sets of indirect muscles
    - Longitudinal stretching from the front of T2 to the rear of T3
    - Dorsoventral muscles are connected between the thoracic segment and the scutum
- The wings attach to the appropriate Thoracic segment in a groove called a notum





Module 5 Study Notes

Legs and feet



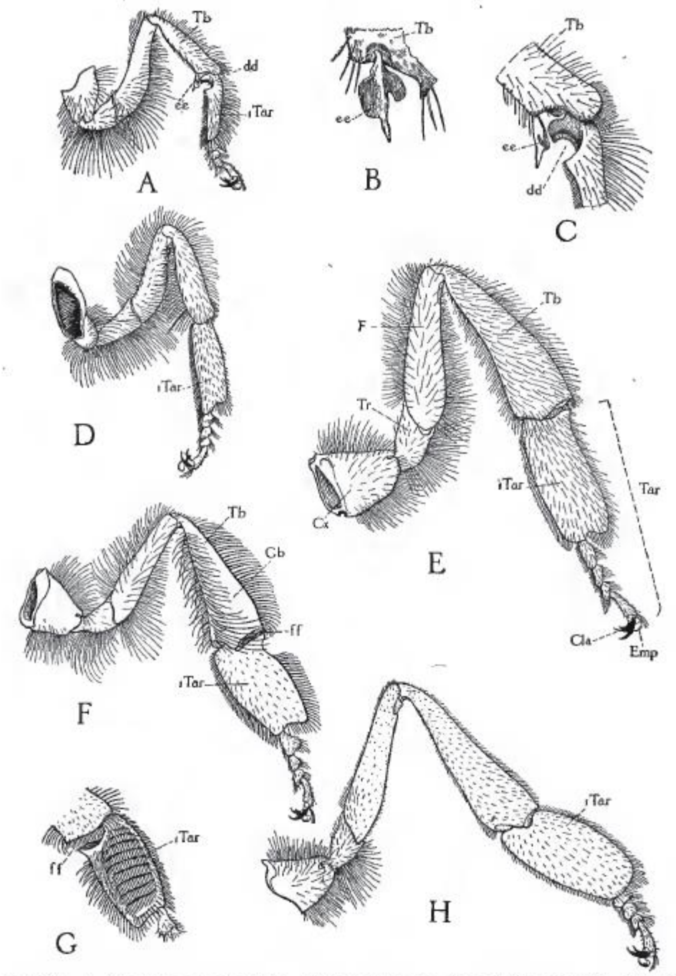


FIG. 29.—A, left front leg of worker, anterior view, showing position of notch (*dd*) of antenna cleaner on base of first tarsal joint (*1Tar*) and of closing spine (*ec*) on end of tibia (*Tb*); B, spine of antenna cleaner (*ee*) in flat view; C, details of antenna cleaner; D, left middle leg of worker, anterior view; E, left hind leg of queen, anterior or outer view; F, left hind leg of worker, anterior or outer view, showing the pollen basket (*Cb*) on outer surface of tibia (*Tb*); G, inner view of first tarsal joint of hind leg of worker showing rows of pollen-gathering hairs and the so-called "wax shears" (*ff*); H, left hind leg of drone, anterior or outer view.

The honey bee has three pairs of legs all attached to the thorax, facts:

- The legs are hollow with a hard outer coating
- Part names; coxa, trochanter, femur, tibia, tarsus (5 tarsomeres), pretarsus
- Function as two tripods when walking at normal speeds (front, rear and opposite middle)
- Fore legs have notch between Tibia and basitarsus which is used for antenna cleaning
- Middle leg has spine which is of unknown use
- Rear leg differs between castes, in worker it is highly developed for pollen collection, in drone and queen it is not
- Foot has claws (ungues) for use on rough surfaces and suction pads (arolium) for smooth surfaces

Module 5 Study Notes

Antennae

The antennae function as highly developed sense detectors as well as playing an integral communication role as part of trophallaxis.

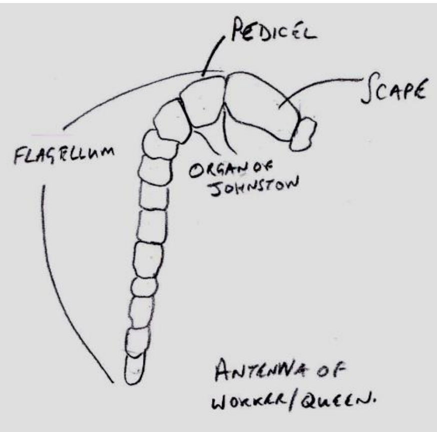
The larval antennae develop in pockets of the epidermis, they complete their development during the propupal stage and are exposed on the pupa after the 5th moult.

There are two antennae attached to the front of the head in a flexible manner so that they can move in all directions. The antennae are the noses of the bee, each consisting of a 10 or 11 segment flagellum attached to a scape via a pedicel.

Each antenna is a hollow tube containing the large antennal nerve, minute extensions of the tracheal system and small muscles which enable the antennae to move in all directions.

The scape is connected is set into a membranous socket and pivoted on a single articulated process, the antennifer, thereby all allowing movement in all directions and controlled by 4 muscles. The proximal segment of the flagellum is the pedicel, it contains the Organ of Johnston, this is employed to determine wind speed and airborne vibrations (sound).

The joint between the pedicel and scape is controlled by 2 muscles facilitating vertical movement. The flagellum on the drone comprises 12 segments and on the worker/queen there are 11 (including the pedicel). Within the



The function of the antennae are as sensory organs, mainly for touch (tactile) and smell (olfactory), they are key elements in the communication within the colony especially with the distribution of queen substance. The sensors within the antennae include:

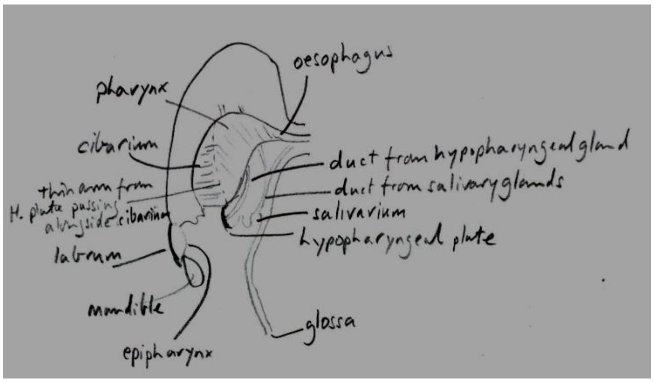
- Olfactory
- Tactile
- Temperature
- Humidity
- Gas (CO_2)
- Vibration
- Muscle tension
- Cuticle strain

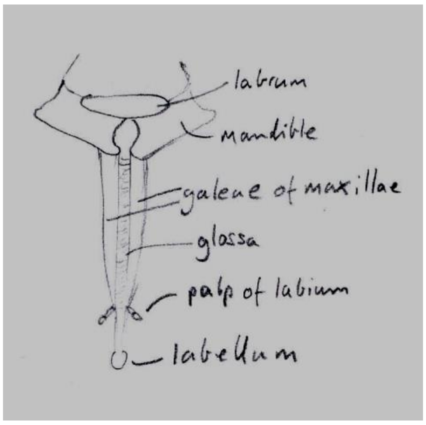
Module 5 Study Notes

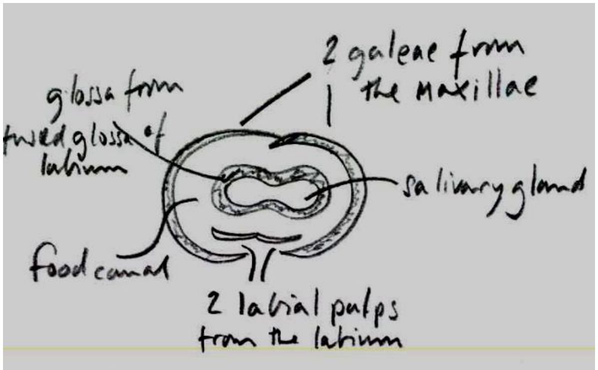
Mouth

The mouth parts are generally common to other insects:

- Labrum, the upper lip is an extension of the face
- Mandibles, the jaws in a worker are spoon shaped and smooth, their uses include
    - Taking in of pollen, shaping and chewing wax, fighting, grooming, dragging out of debris from the nest, brood feeding, gathering and using propolis and to support other mouth parts.
- Proboscis, 5.3-7.2 mm dependent upon race, is basically a tube within a tube, the central tube called the glossa surrounded by another made up from the galeae of maxillae and labial palps (2 of each fused together). It is terminated in the labellum.







The proboscis main function is to ingest liquid (water, nectar and honey) but it also functions in trophallaxis and in the licking of pheromones and exchanging them with other workers. The proboscis can be folded in a Z shape within the mouth when the bee is resting. liquid is sucked up the glossa by the cibrarial pump (the walls of cibarium expanding and contracting). The epipharynx forms an airtight seal at the top of the glossa in order to enable the suction to occur.

The glossa is very hairy and an important use is in the collection of pollen that sticks to the hairs and is removed by the fore legs.

The proboscis is able to protrude and retract and used to:

- Tongue lashing, the worker regurgitates liquid (water or nectar) spreads it on comb or side of hive in a thin layer and repeatedly beats it with her tongue.
- Tongue stropping, hesitant bees when entering the wrong hive and are challenged by a guard, pull their proboscis through their front feet.
- Honey ripening, nectar is regurgitated and held in a fold of proboscis exposing it to air

To liquefy solid foods saliva travels down the glossa tube and the labellum is employed to rub it into the solid food to create a liquid to be drawn up.

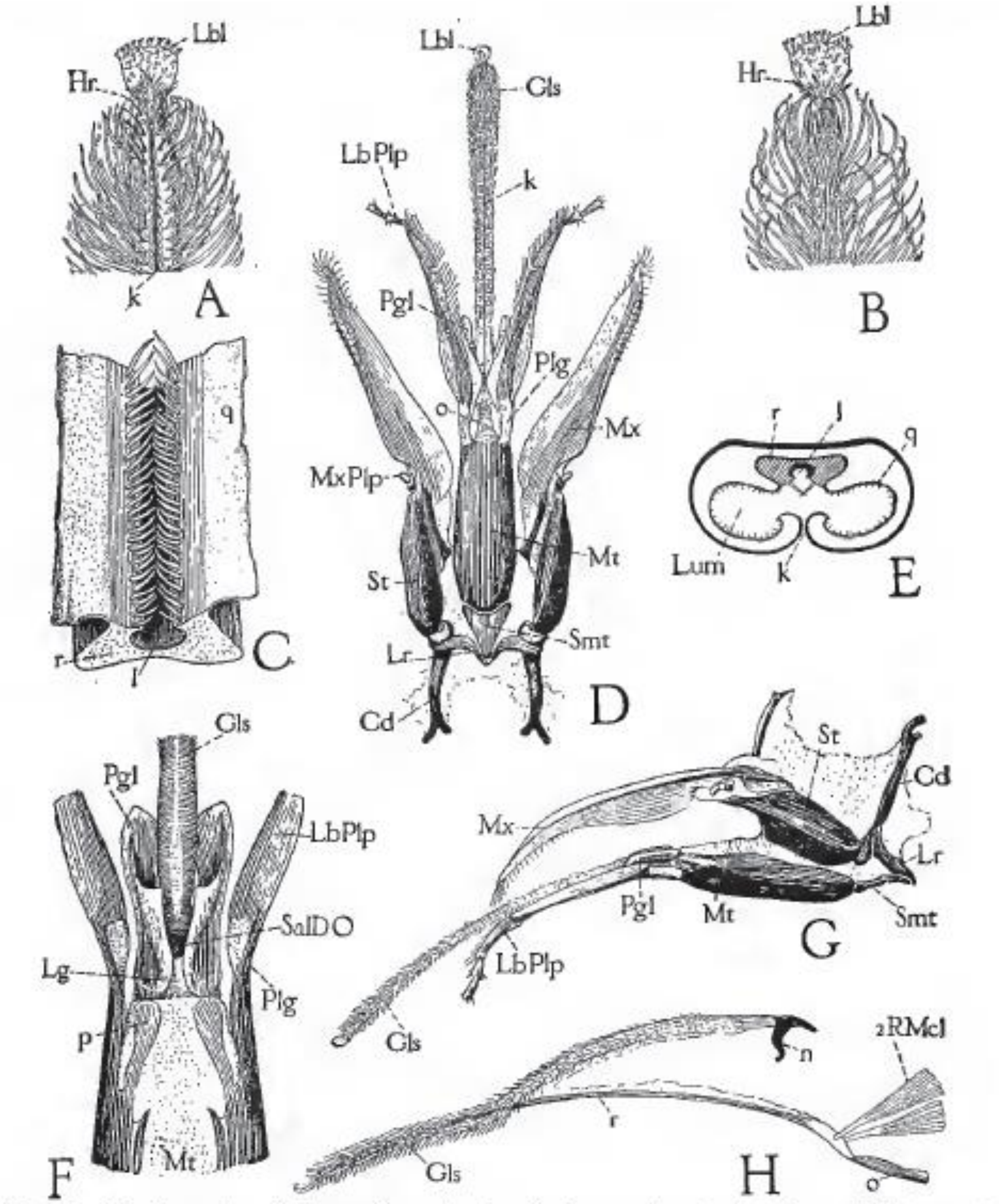
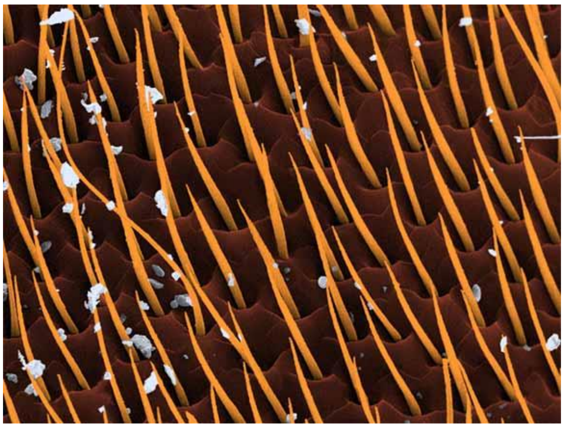
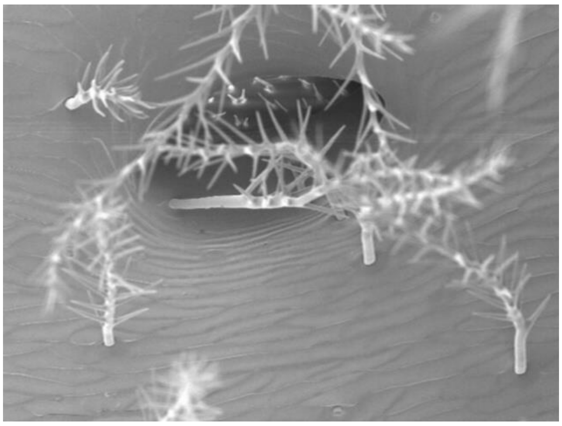


Fig. 15.—Mouth parts of the worker: A, tip of glossa, showing labellum (*Lbl*), guard hairs (*Hr*), and ventral groove (*k*); B, same, from above; C, small piece of glossal rod (*r*) with adjoining parts of walls (*q*) of glossal canal attached, showing ventral channel (*l*) guarded by rows of hairs. D, parts forming the proboscis, labium in middle and maxillæ at sides, flattened out, ventral view; E, cross section of glossa showing its invaginated channel (*Lum*) and position of rod (*r*) along its dorsal wall, and likewise position of channel (*l*) of rod along median line within the glossal channel; F, end of mentum (*Mt*) and bases of ligula (*Lg*) and labial palpi (*LbPlp*), showing opening of salivary duct (*SalDO*), dorsal view; G, lateral view of proboscis showing parts on left side; H, lateral view of glossa (*Gls*) with its rod (*r*) torn away at base showing attachment of retractor muscles (*2RMcl*).

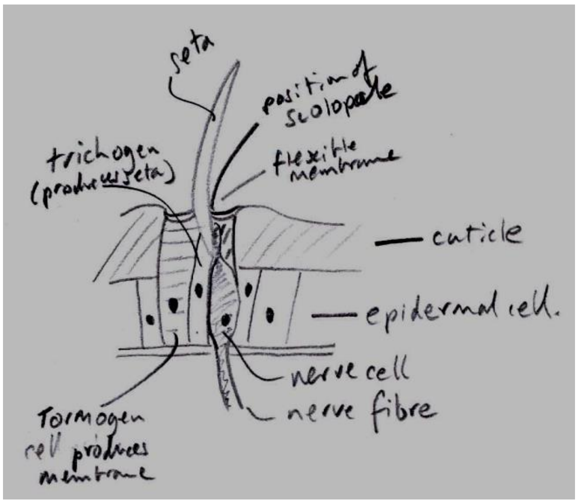
Setae (hairs)





Setae are small hairs that are found all over the body (including on the compound eye) that are used for sensory purposes and the collection of pollen. There are branched hairs and smooth hairs. The branched hairs capture pollen whilst the smooth hairs generally have specific functions:

- The specialised hairs on the legs are used for collection and packing of pollen and include the corbicula, rastellum and pollen brushes
- Interfacetal hairs located in the compound eyes act as mechanoreceptors measuring wind speed and direction
- Tomenta hair on the abdominal tergites whose function is unknown but varies in length, volume and colour on bees of different races.
- Lack of hair is also a sign of age and disease e.g. hairlessness with CBPV
- Sensilla trichodia is a seta providing tacticle information.



The diagram shows a sensillum trichodeum which reacts to touch:

- Seta is the receiving stimuli, when touched it bends within the flexible membrane
- The trichogen cell produces the seta
- The tormogen cell produces the membrane and fills the space beneath it
- The nerve cell produces an impulse when activated
- The scolopale is a thin cap which contains the nerve ends in order to pick up the movement

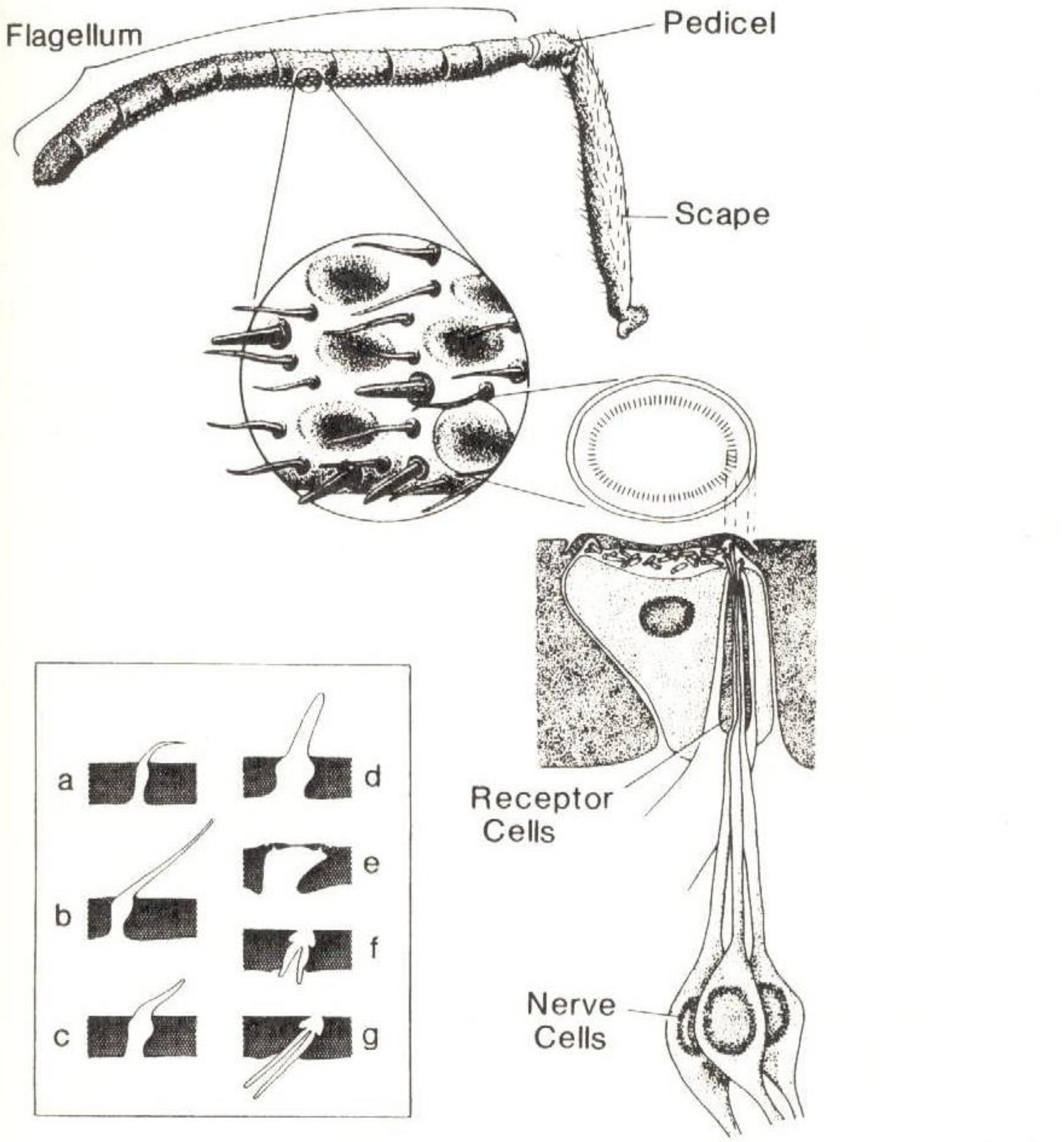


Fig. 3.4

The antenna of a worker bee, with one of the pore plates enlarged to reveal the odorant receptor apparatus. The insert shows the seven types of sensory structures found on antennae: (*a*) small thick-walled hair (sensillum trichodeum), (*b*) thick-walled peg (s. trichodeum), (*c*) slender thin-walled peg (s. trichodeum olfactorium), (*d*) large thin-walled peg (s. basiconicum), (*e*) pore plate or plate organ (s. placodeum), (*f*) pit organ (s. coeloconicum), and (*g*) pit organ (s. ampullaceum). (Nomenclature is from Lacher, 1964. Redrawn from von Frisch, 1967a, based on Lacher, 1964, and Snodgrass, 1956. Copyright © 1956 by Cornell University. Used by permission of Cornell University Press.)

5.19 the structure of the sting mechanism and how this mechanism operates to penetrate human skin and deliver the venom;

The worker sting is a highly modified ovipositor which has evolved for defensive functions. Unlike most stinging insects the bee loses its sting after use, resulting in the bee's death shortly afterwards. The advantage of losing the sting is that the victim is injected with additional venom. The sting chamber is formed by the reduced and modified 8th, 9th and 10th abdominal segments attached to the bee by a thin membrane.

It is this delicate membrane that enables the sting along with the three segments, the poison glands and the terminal end of the alimentary canal to easily become detached once the bee has stung. The sting of the queen is more strongly attached and there are fewer bards on the lancet (see later) meaning the chamber does not become detached after stinging.

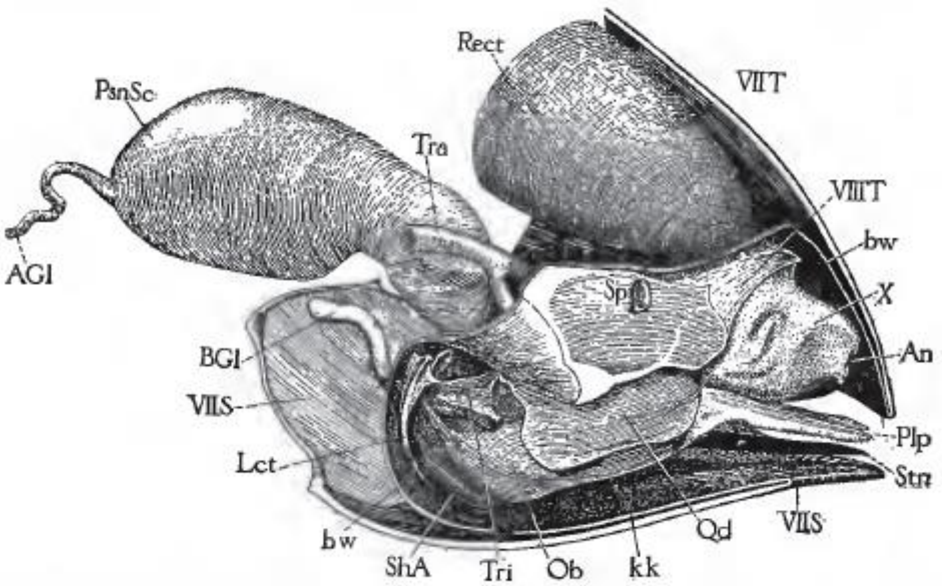


FIG. 41.—Tip of abdomen of worker with left side removed, showing right halves of seventh tergum (*VIIT*) and sternum (*VIIS*), containing the sting chamber (*kk*) cut open along the line *bw*, exposing the eighth tergum (*VIIIT*), the rudimentary tenth segment (*X*) carrying the anus (*An*), and the sting and accessory parts shown by fig. 36.

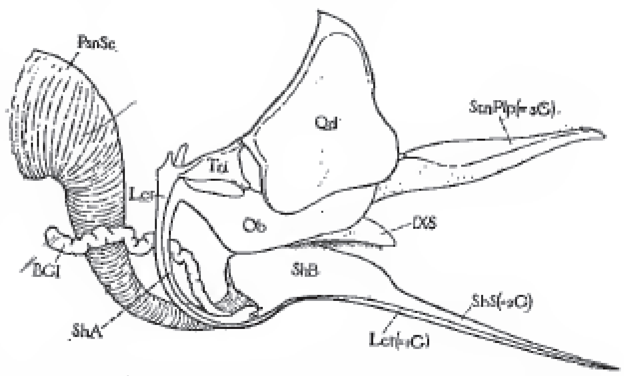


FIG. 36.—Semidiagrammatic view of left side of sting of worker, accessory plates (*Tri*, *Ob*, *Qd*), sting palpus (*StnPlp*), alkaline poison gland (*BGl*), and base of large poison sac (*PsnSc*) of acid gland.

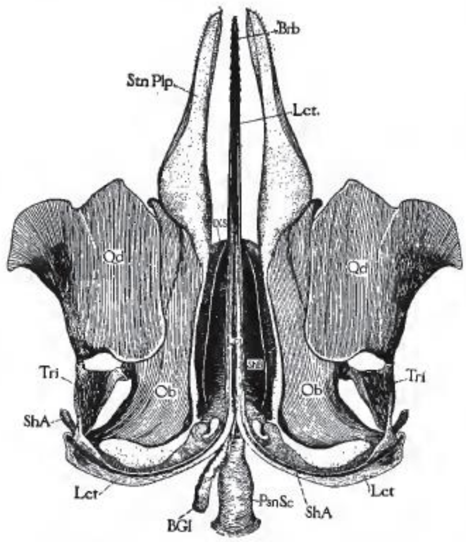


FIG. 37.—Ventral view of sting of worker and accessory parts, flattened out.

Module 5 Study Notes

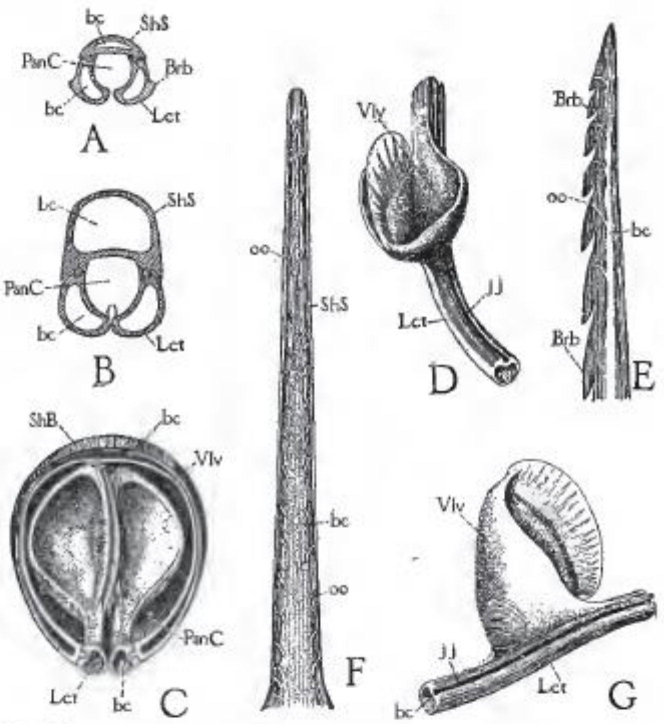


FIG. 40.—Details of sting of worker: A, section through tip of sting showing lancets (*Lct*) and shaft of sheath (*ShS*) surrounding central poison canal (*PsnC*), and each containing a prolongation of the body-cavity (*bc*); B, section of same near base of bulb; C, section of sting through basal bulb, showing poison canal as large invaginated cavity (*PsnC*) in bulb of sheath (*ShB*) containing the two valves (*Vlv*) of lancets (*Lct*); D, part of left lancet carrying valve (*Vlv*), dorsal view; E, tip of lancet showing pores opening on bases of barbs (*oo*) coming from body-cavity (*bc*) of lancet—not from poison canal; F, dorsal view of shaft of sheath showing lateral series of pores (*oo*) from prolongation of body-cavity (*bc*); G, lateral view of left valve and part of lancet.

The elements of the sting are:

- Three plates (per lancet) which along with muscles drive the associated lancet and valve to the bulb
- The shaft comprising the lancets and a stylet which expands into the bulb via an umbrella valve for each lancet, the valve opens when the lancet is extended and closes when it is removed from the victim
- Venom sac which holds the venom and is connected to the bulb
- Poison glands (acid glands) which secrete the venom into the sac
- Dufour gland (alkaline gland) which opens to the sting chamber to lubricate the stylet and to possibly neutralise any leaked venom

Before stinging the bee positions itself perpendicular to the victim by contracting ventral sclerites and extending dorsal sclerites.

The working of the sting mechanism comprises three main elements:

- Sting
- Plates and muscles
- Poison glands and venom sac

The sting is made up of two barbed lancets which slide on the tracks of the stylet or sheath. These open out into a large swelling called the bulb via umbrella valves. The bulb is full of venom from the venom sac and releases it into the poison canal formed by the linking if the lancets and sheath.

When the worker stings the first one lancet is extended by a series of plates and muscles which drive the lancet into the victim as well as opening the valve to the bulb releasing the venom. As the first lancet is withdrawn the second lancet is driven into the victim, this continues until the lancet becomes stuck and the sting is detached. The action of withdrawing the lancet causes a vacuum within the bulb drawing more venom into the bulb. On extending venom is forced into the lancets and sheath causing it to enter the victim via small pores in the lancets and sheath.

The three plates are Oblong, Triangular and Quadrate, there is one set for each lancet and each side functions alternately. The plates drive a Ramus which extends to the lancets and thus the action of thrusting and withdrawal is controlled by muscles connecting the oblong and quadrate plates which connect via joints to the triangular plate. The thrusting action opens the lancet valve within the bulb and venom is poured into the sting.

The poison glands (acid and alkaline) continually produce venom which is stored in the venom sac. The venom sac does not have a muscular wall, rather the flow of the venom is controlled by the expansion and contraction of the bulb. The pulsing of venom after the bee has detached itself is the continued action of the plates.

The Dufour gland releases alkaline solution into the sting chamber at the base of the sting, the purpose of which is not clear, it is thought to lubricate the sting and neutralise any venom that has seeped into the chamber. Snodgrass talks of both acid and alkaline poison elements making up the venom.

Main components of venom are:

- Melittin which makes up 50% of dry weight. It causes the rupture of blood and mast cells and depresses blood pressure and respiration (mast cells release histamine and heparin when ruptured)
- Phospholipase A which causes cell breakdown and pain
- Hyaluronidase acts like a cement holding cells together so as to facilitate better passage of other substances

5.20 the role of the direct and indirect muscles in flight.

The thorax to which the wings are attached at the notum is effectively a box that can change shape. Rather than have muscles directly connected to the wing drive the actions for flight, the wing movements are driven by indirect muscles changing the shape of the Thorax at over 200 cycles per second.

There are two pairs of indirect muscles that occupy the majority of the space within the Thorax:

Dorsoventral muscles, are connected to the lateral parts of the scutum (anterior part of the notum) and to the lower wall of the appropriate thoracic segment. When the muscles contract the notum is pulled downwards which causes the wings to move upwards, the muscles are also known as the elevator muscles. There is are Dorsoventral muscles in the mesothorax (T2) and metathorax (T3) so each pair of wings have their own pair of muscles.

Longitudinal muscles, are attached to the front of the thorax on the curved part of the mesoscutum. The other end is situated in the propodeum on the hind part of the mesothorax. When contracted they cause the wings to be pulled downwards. These muscles are also called depressor muscles. Both pairs of wings are depressed by a single pair of these muscles.

Apart from flight these muscles are employed by workers for other functions, all of which employ the fact that the act of flying creates heat in the muscles:

- Warming the nest, with wings furled the bee is able to exercise its flying muscles to create heat in winter and to maintain the brood temperature in the summer.
- In preparing a swarm next to fly scout bees will heat bees on the outside of the nest by jumping on them and activating their flight muscles to heat the other be in preparation for flight
- A bee must be warm to fly so the muscles are activated before the bee takes off
- Fanning the nest to keep it cool, the wings are flapped whilst the bees are stationary in order to cause air to be circulated