Anatomy Section Overview

Considered by many to be the most fascinating topic in beekeeping! (Well if not many, certainly by some.) We will explore the internal workings of the honeybee and compare them to our own as well as determine how some diseases change the way internal organs function. What happens when a bee stings and what does the Nasanov gland do?

Class Notes

Pre-Class Preparation

Course Notebook Section

Anatomy of Bees, Pp 1-25

The Honey Bee Chart

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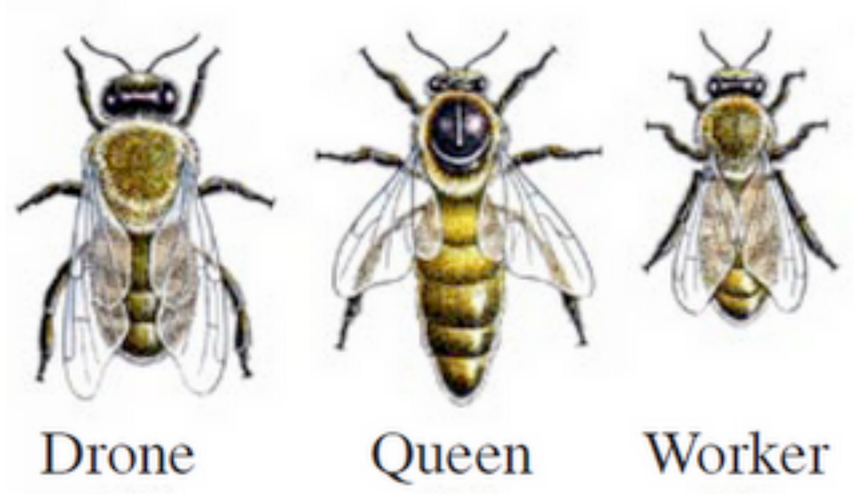
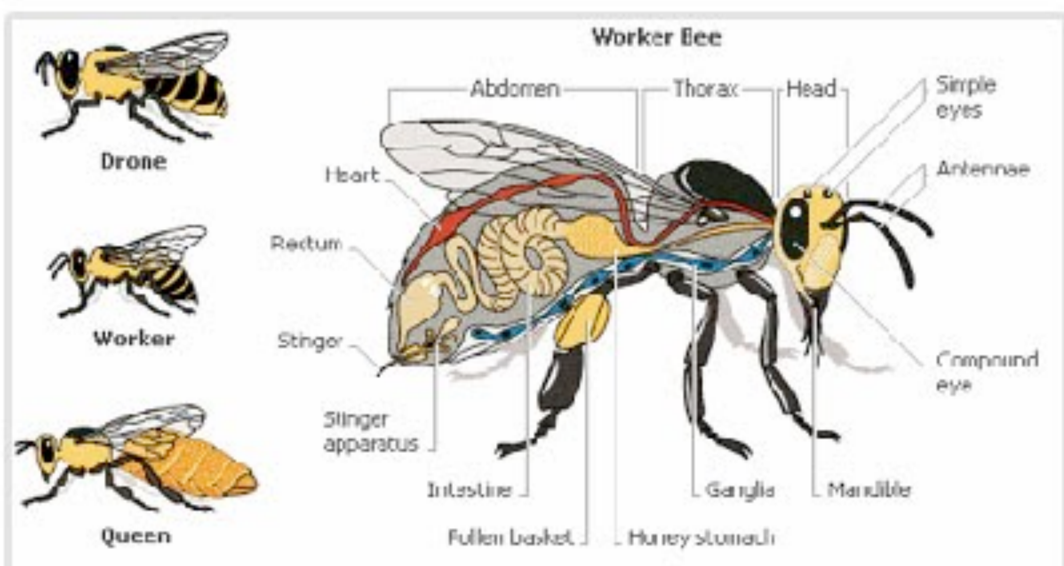
Honey Bees: Anatomy and Life Cycle

Who's Who in the Beehive

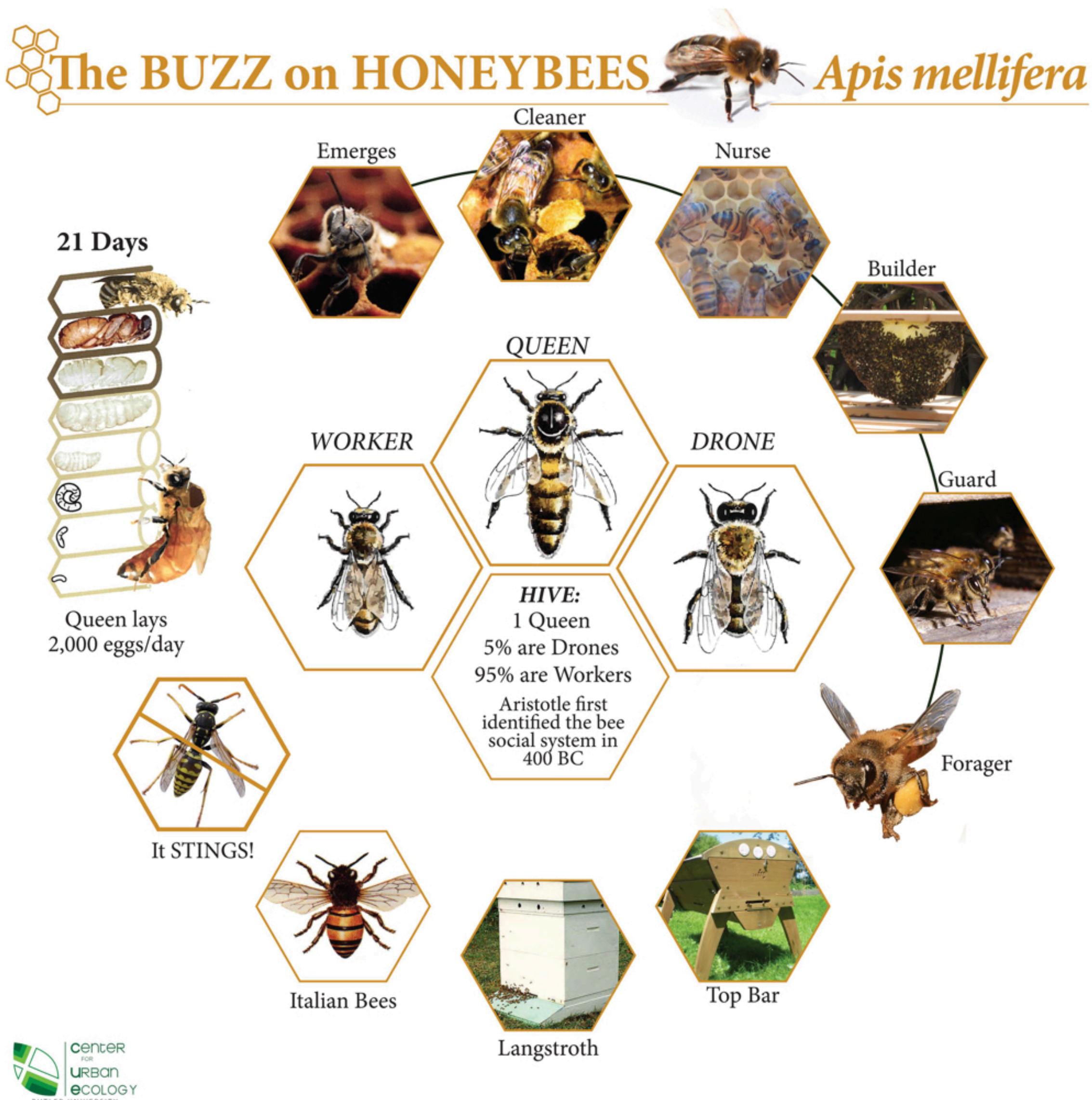


The Drone is male and the Queen and Workers are female

Honey Bee Anatomy



Life-cycle of the Bees



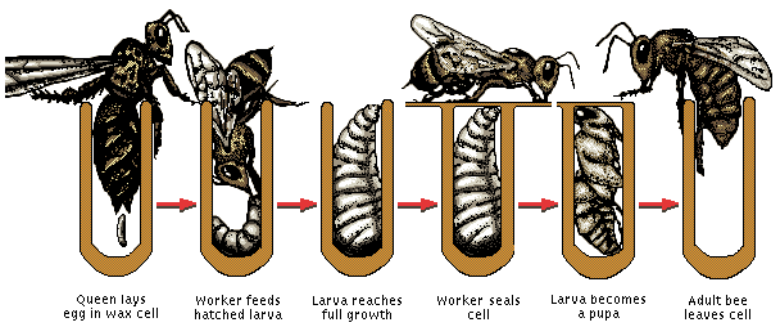
The Life Cycle of a Bee

Khalil Hamdan, Apeldoorn, The Netherlands

The life stages of a honeybee are egg, larva, pupa and adult. Development from egg to adult takes 21 days. The length of these stages is set out in the table below.

Worker Bee Life Cycle Timetable	
Hatching of egg:	3 days
Larva stage (Feeding):	5 days
Pupa stage:	13 days
Total:	21 days

Development stages of the bee

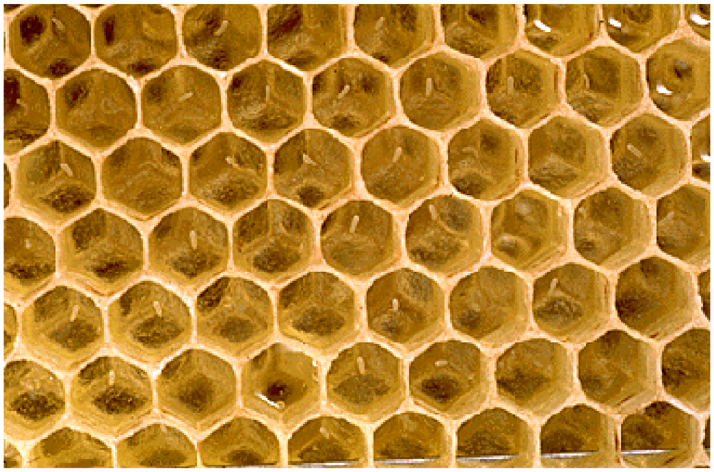


Honey bee life cycle from egg to adult. Photo source: www.ebka.org

Queen bee laying an egg in a cell in brood nest. Photo by P-O- Gustafssen

Egg

The queen bee lays an egg in a cell of the honeycomb. The egg of the honeybee is cylindrical, about 1.6 mm long and 0.4 mm in diameter. When first laid, it stands vertically, on the second day it bends over, on the third day it lays on its side. On the fourth day it hatches into a white legless larva.



Eggs in cells.
Photo source: MAAREC- Mid-Atlantic Apiculture Research and Extension Consortium

Larva

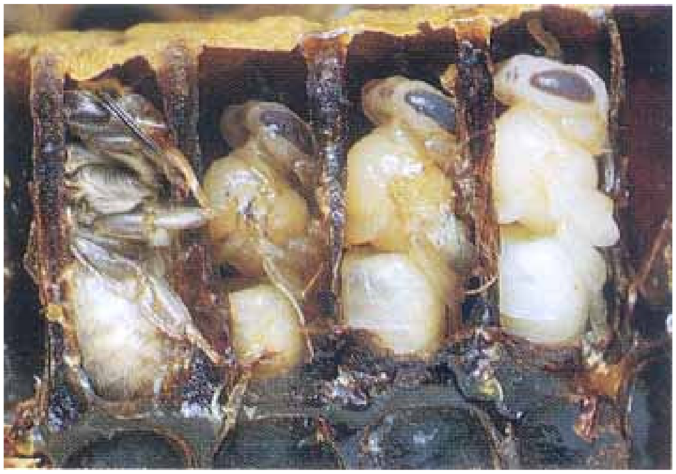
The larva lies coiled on the bottom of the cell. It comprises a head, thoracic and abdominal segments. The larva eats, grows bigger and sheds its skin 5 times between hatching and emerging.

During the first three days the larva is fed by the nurse bees on a diet of royal jelly, a protein-rich whitish milky fluid, produced from the head glands of worker bees. After the third day, the larva is fed beebread, a mixture of honey and pollen prepared by worker bees. Nine days after hatching, the curled-up larva is fully-grown, and can't feed any more. At this stage the cell is sealed over with a porous covering of wax and pollen, and starts to change into a pupa.

Bee larvae in cells. On the lower left are two about to pupate.
Photo source: en.wikipedia.org/wiki/Bees

Pupa

This is the non-feeding stage, during which the larva is transformed into an adult. On the the10th day, the larva spins a cocoon (protective covering) for itself and becomes a pupa. During pupation, gradually the adult body structures forms. First the head and the thorax of the pupa develop and change colour followed by the abdomen, and finally the wings develop before emergence. Once the pupa has transformed into an adult, it is ready to emerge.



Pupal stage.
Photo source: www.bieenkorf.be/volk.htm

Adult

On the twenty-first day from the laying of the egg, the adult bee bites its way out the capping of its cell and emerges, and the pupal envelope remains in the cell. After she is born, she will clean her cell and other cells around. A newly emerged bee is light in colour (greyish coloured).

Young bee hatching out.
Photo by P-O- Gustafssen

The newly hatched bee remains in the hive apart from orientation flights for about 21 days performing various duties, as the table illustrates. When it is 22 days old, the bee becomes a forager (field bee) and will leave the hive to visit flowers.

The life span of an adult worker bee varies with the time of the year. When the colony is active in spring and summer, worker bee may live as long as 5-6 weeks. During the inactive period in winter a worker bee lives five months or more.

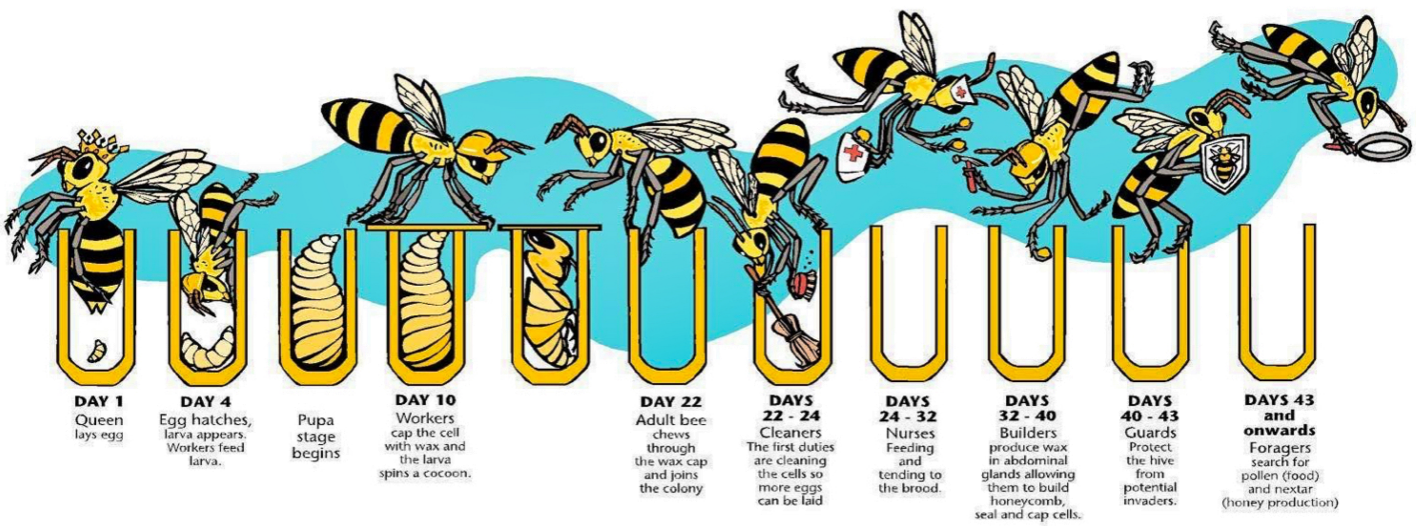
Life span of a worker bee in days after emergence

<u>Period of service as house bee</u>

1 – 2	Cleans cells and warm the brood nest
3 – 5	Feeds older larvae with honey and pollen
6 – 11	Feeds young larvae with royal jelly
12 – 17	Produces wax and constructs comb, ripens honey
18 – 21	Guide the hive entrance and ventilate the hive

<u>Period of service as field bee</u>

22 +	Forage for nectar, pollen, propolis and water



Pages 61-73 *Honey bee anatomy* scanned from **Honey Bee Biology and Beekeeping,** by Dewey M. Caron and Lawrence John Connor, Revised Edition Hardcover June 28, 2013, 368 pages.

5

Honey bee anatomy

The anatomy of any animal is the assemblage of structural parts that enables the animal to do the things necessary to maintain its own existence and to perpetuate its kind. The adult honey bee, *Apis mellifera* L., is constructed on the general plan of an insect, but it leads a specialized life. For this reason a bee is equipped with special structures that enable it to live in its particular environment. Both the fundamental insect parts, as well as specialized structures and anatomical modifications, help the honey bee adapt to its manner of living and differentiate it from other insects.

The honey bee has the typical segmented insect body of three regions: head, thorax and abdomen (Figure 5-1). The body appendages (one pair of antennae, two pairs of wings and three pairs of legs) are also segmented. The open circulatory system inside the body circulates blood freely in a large cavity, not within arteries and veins. The alimentary canal is a tube. Paired openings to the respiratory system, the **spiracles**, are evident on two thoracic and seven abdominal segments. The body is bilaterally symmetrical (a single cut through the body length results in two nearly equal halves).

Outside, the honey bee has a hard outer body covering or **exoskeleton**. This protective covering functions as the body skeleton. Internally muscles, connective tissue and all body parts connect and are supported by the exoskeleton. In insects there are no internal 'bones' as in humans. The only structural system is the external exoskeleton. It consists of hardened plates with more flexible membranes between for movement, like a medieval knight's suit of armor.

Body hairs generously cover the exoskeleton of the bee. These are structured something like a feather with a main shaft and numerous side branches (Figure 5-1 inset). Such hairs, a bee exclusive, are termed **plumose hairs**. They give bees a hairy or fuzzy appearance. These hairs protrude from all portions of the exoskeleton even between the facets of the compound eyes. Body hairs have sensory functions, enable the bee to collect and transport pollen, help protect the bee, regulate body temperature and keep the exoskeleton free of dirt and debris.

Head

The head (Figure 5-2) of the honey bee contains the major sense organs. A **sense organ** is a structure that detects some type of stimulus, such as a ray of light or a chemical odor, and transmits what is detected via the nervous system. The major sense organs of the bee head are the **ocelli**, compound eyes, antennae, mouthparts, and body hairs. Each sense organ consists of millions of smaller receiving structures located on the exoskeleton. These are minute and most are not visible except under a microscope. In addition to the regular body hairs, there are smaller hair-like structures, tiny pits, minute protruding pegs and flat smooth disks. All contain specialized sensory structures that serve to inform the bee about its environment.

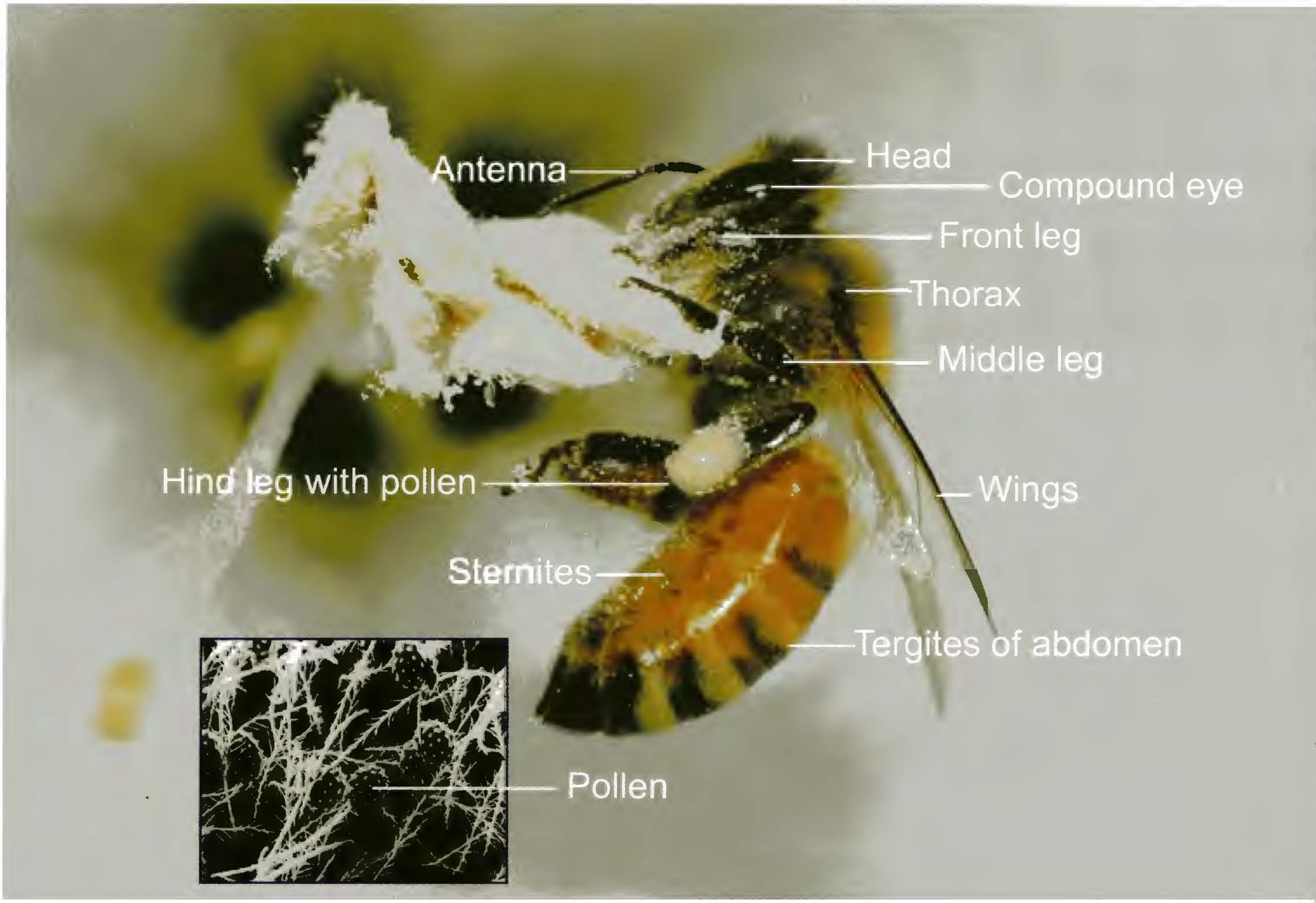


Figure 5-1. Honey bee worker on *Datura*. L. Connor photo. Inset. Branched body hairs holding pollen grains.

Figure 5-2. Magnified bee head. Antennae have hundreds of sensory hairs. Body hairs protrude from between compound eye facets. Ocelli are at top of head. Mouthparts are at lower margin but only mandibles are evident.

Honey bees have three **ocelli** located at the top of the head. They are arranged in a triangle. The exact function of each ocellus is unknown. They respond to and receive light but cannot 'see' since the image formed by the transparent exoskeleton is not directly connected to the nerve area. Ocelli probably help bees respond to light levels. Bees are initially negatively phototactic as adults then become attracted to light. Bee species that fly under low light levels have large, prominent ocelli.

The honey bee has two **compound eyes**, each with 6,900 facets. Each facet is a lens of transparent exoskeleton capable of 'seeing' at a fixed focal length. This compound eye system gives honey bees only fair vision. They actually 'see' by assembly of a mosaic in the large optic lobes of their brain from hundreds of different facets. As the bee moves, and as things around the bee move, the view of each lens changes, improving visual ability. Bees can distinguish between patterns as long as they are sufficiently different in amount of brokenness. If bees could read, this type would need to be some 100 times larger for the bee to distinguish the different letters.

Bees have **trichromatic vision**, meaning that their eyes contain three types of photoreceptors (cone cells) just as ours do. Unlike humans, who have blue, green and red cones, bees have blue, green and ultraviolet photoreceptors,

Figure 5-3. Comparison of silverweed, *Potentilla anserine*. As we see it on the left, and as bees view it on right. B. Roslett photo.

This means that the vision of bees is shifted toward the ultraviolet compared to ours. Bees see in range 300-650 while human range is 400-700 nanometers. A comparison of the color vision of bee and man is shown in Figure 5-3.

Each **antenna** (plural: antennae) consists of 12 segments. The first segment (scape) is the longest and the most flexible. It is positioned midway on the head, fitting into a ball-and-socket joint. The pedicel is a flexing elbow joint. The last 10 distal segments (flagellum) are of nearly equal size (Figure 5-4). Each antennae is completely covered with hairs (Box 7, Figure 5-13), pore plates, pits, pegs and other sensory structures that perceive stimuli. The antennae of bees are very mobile and in constant movement. Antennae smell, taste (Figure 5-14), perceive humidity and temperature, feel, monitor gravity and flight speed and even detect sound waves (vibrations) to help guide the bee in her daily activities.

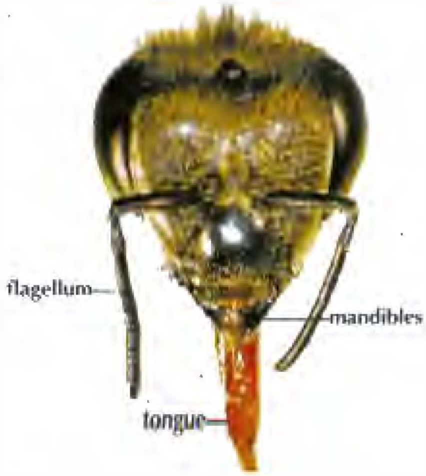


Figure 5-4. Worker head. From I. Stell, *Understanding Bee Anatomy*.

The **mouthparts** of the bee are complex structures located on the bottom margin of the head (Figures 5-4, 5-5). Bees have chewing-lapping mouthparts, which means they can manipulate solids and lap up liquids (Figure 5-7). Basically, the mouthparts consist of four parts. The **labrum** is the front-most portion. It serves as a protective shield closing the mouth cavity, something like the upper lip of humans. The **mandibles**, one to a side, are the 'jaws.' They move laterally and are mainly used to manipulate wax. They have sharp edges but lack muscles strong enough to chew through or bite anything. They are spoon-shaped, looking like cement trowels, better suited to smooth and carry rather than chew or cut.

Figure 5-5. Queen head. From I. Stell, *Understanding Bee Anatomy*.

The remaining mouthparts, the **maxilla** and **labium**, consist of several distinct parts. All the pieces fold together to form the **tongue** or **proboscis**. The proboscis is a sucking tube with an inner and outer chamber ending in the spoon-shaped **flabellum** (Figure 5-8). The labium has paired segmented palpi (singular: palpus) that resemble antennae but only have three small segments. Palpi and the hairy glossa have many taste, smell and touch sense organs. When not in use the proboscis folds into an area beneath the head so the mouthparts are not visible.

Figure 5-6. Drone head. From I. Stell, *Understanding Bee Anatomy*.

Internally, most of the head cavity is occupied by gland systems, muscles of the antennae and mouthparts, plus the bee brain (Figure 5-15). In the center, the proboscis ends in a muscular pharynx that sucks fluid up into the mouth and digestive tract. The various glands of the head discharge their contents via small ducts into the mouth cavity just before the pharynx. Major head glands are the **mandibular, hypopharyngeal, postcerebral** and **thoracic (salivary) glands**, the last pair extending into the thorax.

Figure 5-7. Honey bee worker using proboscis to collect a drop of honey. R. Williamson photo.

Figure 5-8. Spoon-shaped flabellum at the tip of the tongue. From I. Stell, *Understanding Bee Anatomy*.

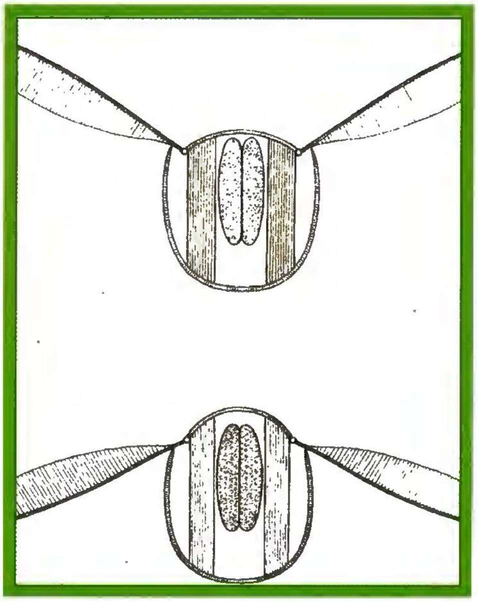


Figure 5-9. Diagram of indirect wing muscles. R. Elzinga drawing.

Queen and drone head

The head of the queen (Figure 5-5) is similar to that of the worker (Figure 5-4), but a little rounder in shape when viewed from the front and with fewer eye facets. The mandibles of the queen are toothed and not spoon-shaped. The drone head (Figure 5-6) is larger and their compound eyes are twice as large as the worker's with more (8,600) and larger facets. The **ocelli** are displaced downward to allow the compound eyes to meet at the top of the head. Drone antennae are one segment longer and slightly thicker than in the worker. Drone mandibles are smaller, not spoon-shaped and have teeth on the outer margin.

Thorax

The thorax (middle body region) is the **locomotor** section of the honey bee body (Figure 5-1). The thorax consists of 3 body segments, although on close examination it appears that bees have four segments. Anatomically the 4th segment is actually the first abdominal segment. The segments are labeled the pro-, meso- and metathorax. Attached to the meso- and metathoracic segments are the two pairs of wings. Each segment has a pair of legs, the norm in insects. The exoskeleton of the thorax, shaped like a box, consists of many plates or **sclerites** that overlap and serve as attachment points internally for numerous internal muscles.

The wings of the honey bee are paired, with the first pair being the largest. Each wing has numerous hollow lines or 'veins' on its surface carrying nerves and through which blood circulates into the wing. The veins define a network of 'cells' and provide support and a framework to the wing. When the bee is in flight, the wings are joined by a tiny set of hooks, **hamuli**, extending forward from the back wing. Joining the wings means flight surface is increased, helping give bees their great flight agility.

Bee flight is accomplished by indirect wing muscles. Flight muscles do not attach directly to the wing itself, as one might expect, because wing attachment points are very narrow. Rather, the flight muscles are located in the thoracic segments and occur as complimentary pairs, one pair running front to back and the other top to bottom (Figure 5-9). Small direct muscles fold wings over the abdomen.

To fly, the muscles that extend from top to bottom contract while the front to back set of muscles relaxes. This results in the thorax being pulled from top to bottom and pushed out at the ends, causing the wings to be pulled upwards at their attachment points. Then the other set of muscles (those front to back) contracts and the top to bottom set relaxes. The thorax is now pulled from the ends, and the top and bottom of the thorax pops outward so the wings go down. By alternating contraction and relaxation of the muscles, wing flapping and flight result. The wings have a hardened anterior edge and are flexible posteriorly. They flex, roll and vary their surface exposure as they are moved up and down in a figure eight pattern.

The honey bee, like all insects, has three pairs of **legs.** A pair of legs is attached to each of the three segments of the thorax. Legs obviously serve for locomotion, but they also contain sensory structures to taste, smell and feel. Although six legs may seem awkward for walking, they are coordinated by the nervous system to operate as a pair of triangles. The first and third leg of one side work with the middle leg of the opposite side.

Each leg consists of five major segments, coxa, trocanter, femur, tibia and tarsus—with further segmentation of the most distal tarsus section. Legs end in a pair of claws with central arolium, a softer, pad-like structure. Legs have body hairs modified to groom the bee body. The forelegs have the antenna cleaner, indented areas with special stiff hairs of the indentation that clean the antennae of debris when they are drawn through the hairs (Figure 5-10). The middle pair of legs have a stout spine which is used to spear wax scales from abdominal wax glands to pass to the mouthparts (Figure 5-11).

Figure 5-10. The front leg of a worker. From I. Stell, *Understanding Bee Anatomy*.

The hind legs of workers are highly modified with body hairs arranged in special patterns to aid the bee in collecting pollen. On the outside of the tibia (the fourth most distal segment), body hairs line the edge. The structure formed is called the **corbicula** or **pollen basket** (Figure 5-12). Pollen is carried in this structure from flower to hive. On the inner surface of the next distal segment, the basitarsus, the body hairs are arranged in compact rows (combs). These hairs collect and accumulate pollen grains. Other hairs located at the top margin, the rake and auricle (the pollen press), push and pack pollen from the inner metatarsus to outer corbicula.

Figure 5-11. The middle leg of a worker. From I. Stell, *Understanding Bee Anatomy*.

The esophagus (oesophagus) of the digestive tract and aorta of the circulatory system are thin tubes passing through the thorax. The ventral nerve cord consists of one large ganglion and a second smaller ganglion that receive sensory neurons from the wings and legs and send impulses via motor neurons to wing muscles and legs to coordinate movement of the bee.

Abdomen

A prominent feature of the honey bee body is the narrow segment, termed a **wasp-waist**. It does not represent separation of thorax and abdomen but rather it separates the first and second segments of the abdomen. Thus three thoracic and one abdominal segment are anterior to this 'waist,' followed by continuation of the segments of the abdomen termed the **gaster**. The reason for this or the significance of such a body narrowing is not known.

Virtually all hymenopterans have a thin wasp waist. In some hymenopterans, such as mud daubers, the restricted portion is very long, reaching 1/2 inch (1 cm) or more in length (Chapter 3, Figure 3-9). Portions of the internal systems that must fit through this narrowing are the nerve cord, the esophagus and the aorta, which for unknown reasons, is coiled at this point.

The abdomen lacks external attachments. When closely viewed, the seven visible (three are hidden) abdominal segments consist of overlapping top (**tergites**) and bottom (**sternites**) plates (Figure 5-1). Each segment has a pair of **spiracles**, the openings of the respiratory system connected internally with three on the thorax. The abdomen is continually moving due to flexible membrane joints between segments. Movement is side-to-side (during waggling), up-and-down, and in-and-out (telescoping). Such movement aids breathing, digestion, excretion and circulatory functions.

Figure 5-12. The hind leg of a worker. From I. Stell, *Understanding Bee Anatomy*.

Box 7
Bee sense of touch

Vision and chemical senses of smell and taste are important to honey bees. Touch or mechanoreception is also important. Bees have touch sensors on antennae, mouthparts, tarsi and elsewhere on the exoskeleton. They also have internal sensors. Mechanoreceptors perceive and transport mechanical energy to the nervous system (via nerve impulses). They can be very general, such as body hairs (setae) for touch, or very specific, such as proprioreceptors, that provide information on the relative position of parts of the body. These sense cells stretch from one body region to another or one body part to the next and respond to pressure or changes in stress.

Special mechanoreceptors are used for measuring distances. On the antennae, specific hairs respond to wind as both air speed and air current indicators (Figure 5-13). As a bee flies, these hairs, and perhaps other sense cells responding to energy use, provide the bee with a measure of flight distance. Bees also can measure distance by walking, which they use in measuring the internal dimensions of a potential cavity for a new nest site.

As the bee moves, hairs on different body regions change contact with hairs (called bristle fields) on an opposing body region. Bees use this touch information to detect gravity. Bees need excellent gravity-detection ability so they can transform the sun angle to a gravity angle in bee dancing within their dark hive. Other uses of gravity information are not certain. A small colony of 3,400 bees and a queen were able to construct comb and survive without apparent ill effects for seven days without gravity in space.

Other specialized mechanoreceptors on the bee's body detect vibrations which pass through a substrate. This is how bees hear. We now know they are capable of perceiving airborne sound waves just as insects like grasshoppers, crickets, mosquitoes and some moths can do. Specialized hairs in the pedicel of the antennae (Johnston's organ) can detect air pressure oscillations over a very short distance. It is thought this is how bees gather information from dancing bees. The bees 'hear' bee waggling in the wagtail dance and can measure how long it lasts. Bees perceive substrate vibration very well. Most beekeepers know they need to avoid jarring or bumping movements when working around bees to help reduce the chances of alerting bees and being stung.

The sense of time is not well understood in bees. It is an internal mechanism of some sort. Bees accurately time the waggling of dancing bees. They know sun passage time, for they can return to an experimental feeding station at the same time each day to collect sugar syrup fed only at that time. Remarkably, if bees are imprisoned on their way back from a foraging trip, they accurately compensate for the passage of time, giving the correct sun time in their dance, even if not allowed to see the sun's new position when released to dance.

Two of the newest discoveries in bee senses are realization of their ability to detect magnetic and electrical fields. They have special iron deposits in their fat bodies that perceive magnetic force fields and pass this information on to the nervous system. This sense may be used in flight (by birds at least); bees probably use it to align their parallel beeswax combs. How they detect or use electrical field information is poorly understood.

Figure 5-13. Close-up of sensory hairs and oval plates on bee antenna.

Figure 5-14. Worker bee gathering water at a plastic birdbath. Note the antennae are 'tasting' the water. A. Connor photo.

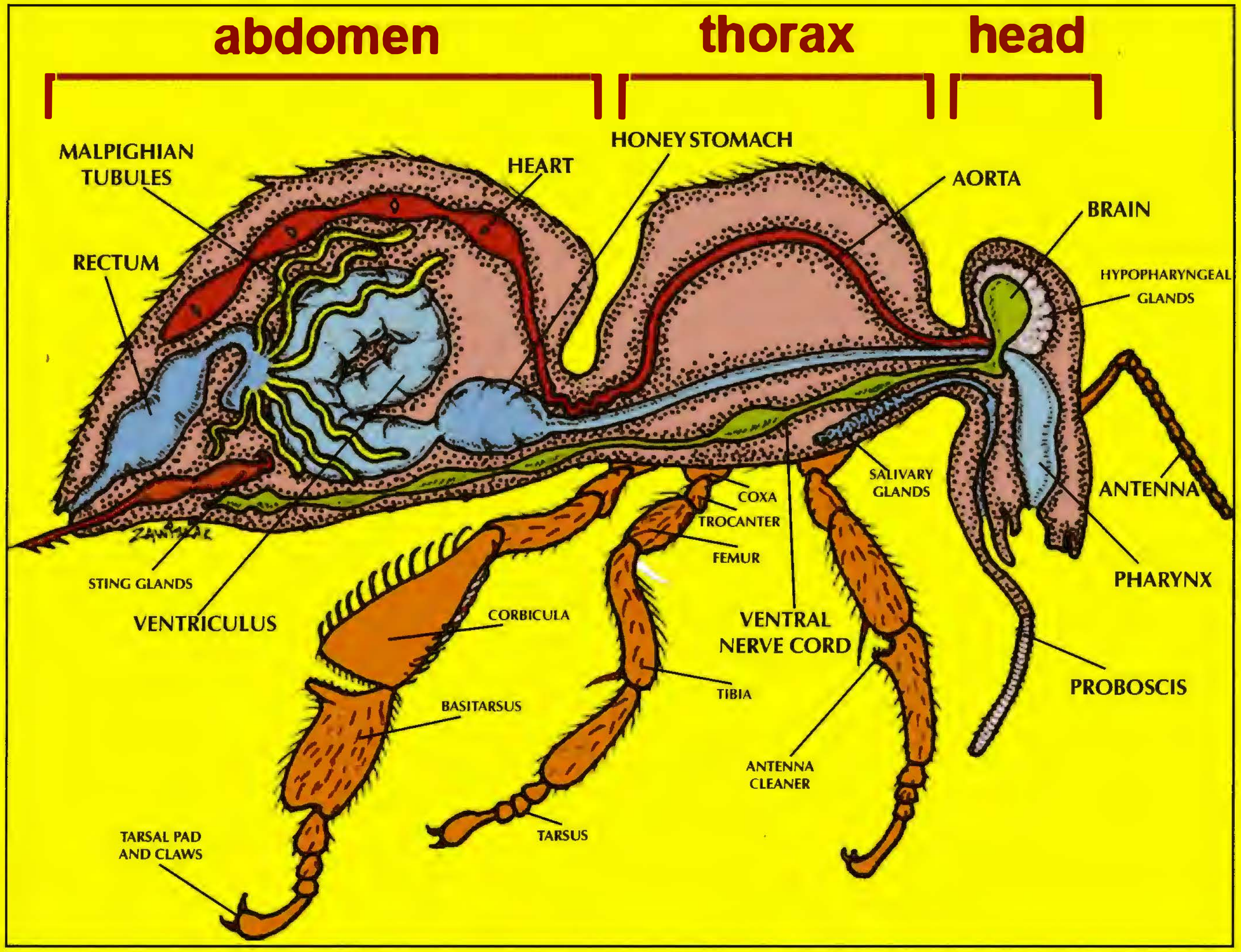


Figure 5-15. Section of honey bee worker showing major internal organs. J. Zawislak drawing.

The hidden segments of the narrow posterior tip form the honey bee sting in the female and drone mating genitalia. Contrary to common illustration (Figure 5-15) neither protrude from the insect abdomen until actually used.

Digestive and excretory systems

The major internal body systems of the bee are located in the abdomen. The digestive and excretory systems are shown in Figure 5-15. After food enters the body at the mouth, pulled inward by a muscular pharynx, it passes through the thorax and wasp waist within the esophagus. The first section in the abdomen is the **honey stomach**. It is not a true stomach since no digestion occurs there. The honey stomach is actually a crop. It is used to hold nectar collected from flowers before it is converted into honey. Nectar stored here can be returned (regurgitated) back into the mouth then given to another bee in the hive. This return action has earned the name 'bee spit' for honey but there is no consumption, the honey stomach simply stores and transports nectar collected at flowers. The actual eating of food is a different behavior completely separate from the collecting of the food.

The honey stomach is closed by a muscular valve called the **proventriculus**. When the bee eats food (versus when it collects nectar from a flower), the valve is opened and the food (honey or pollen) passes immediately to the mid-portion—the **ventriculus** or stomach. Digestion, the process of breaking complex foods down into their simpler components, occurs in the ventriculus. The ventriculus is coiled and averages about twice the length of the bee body (Figure 5-15).

The digestive tract expands with the posterior intestine, **rectum**. The rectum reclaims reusable products and reabsorbs water to make a semisolid excretion. Rectal pads aid in reclaiming and recycling water. The digestive tract tube ends at the anus through which semi-solid wastes are excreted. Bees usually void wastes outside their hive while in flight.

Connected to the digestive tract, and located between ventriculus and intestine, are numerous **Malpighian tubules**. These are the main excretory organs. They are long, tube-like structures that are suspended in the body cavity to take waste matter from the blood. Wastes are accumulated in each tubule and then dumped into the digestive tract as uric acid. These wastes then pass into the rectum where any valuable ions, minerals and water are reabsorbed before excretion. Box 8 discusses bee nutrition.

Nervous system

The nervous system includes a two-part **brain**, with optic and antennal lobes in the head and a series of seven ventral **ganglia** in the thorax and abdomen. The honey bee has a large brain and ganglia relative to its body size. The brain coordinates overall functions and has nerve centers for vision, smell, taste and touch perception

Nerves from each **ganglion** extend to the major organs of the respective body segment to regulate their activities. As in all insects, each ganglion of

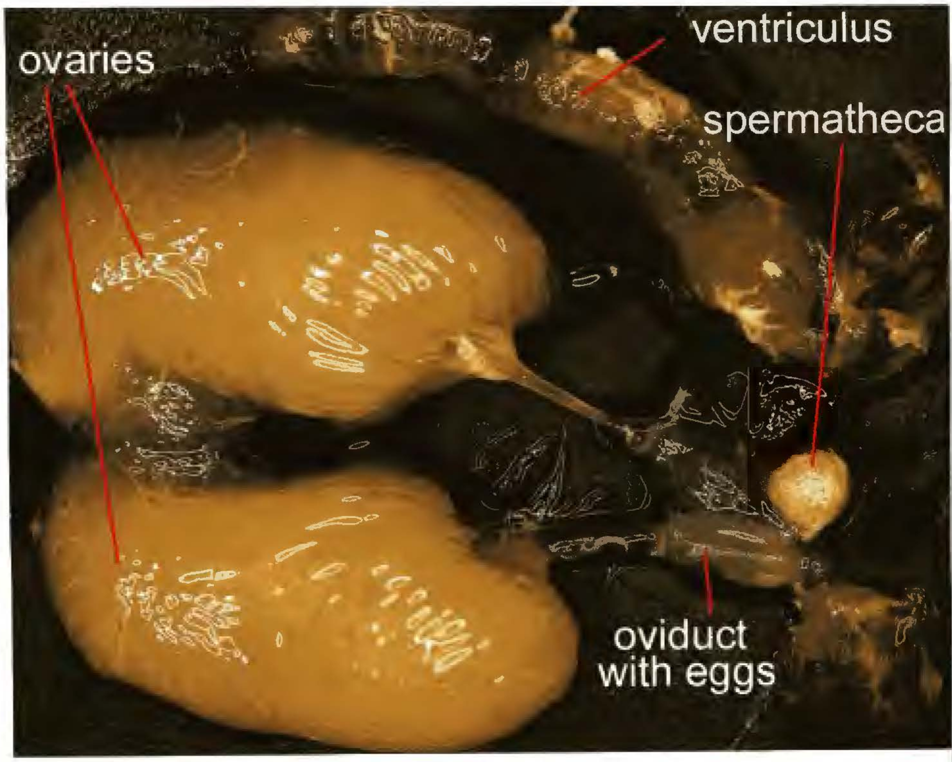


Figure 5-16. Dissection of a laying queen, showing the two large ovaries filled with ovarioles, the oviduct, and spermatheca (sperm storage organ). A. Collins USDA.

the nervous system is capable of coordinating functions for the segment in which it is located, as well as sending information to other ganglia and to the brain to unify the behavior of the whole individual. The last ganglion coordinates the complicated behavior of stinging. Headless bees can still walk and sting although not as well as with intact brain.

Circulation

The circulatory system is very simple in the bee, as in all insects. The major organ is a four-chambered **heart** and a single tube, the **aorta**, that carries blood, hemolymph, forward to the head (Figure 5-15). The heart, positioned dorsally in the abdomen, has a series of muscular chambers each with a pair of openings. When the heart muscle is relaxed, blood enters the four chambers from the abdominal body cavity. These openings close when the heart muscle contracts forcing blood forward through the aorta to the head. Once in the head, the blood is free in the body cavity. It sloshes around percolating backward to the abdomen, aided by breathing and abdominal movements, to be sucked into the heart to repeat the circuit.

Insect blood carries nutrients to the body cells and removes cellular wastes. It also carries hormones, blood cells and other substances. The nutrients enter the blood when absorbed from the digestive tract. Blood contains a large variety of cells but not oxygen-carrying red blood cells. The blood, therefore, is not red, nor must it circulate rapidly. This type of circulatory system, called an **open circulatory system**, serves the needs of the bee even though it is much simpler than the closed human circulatory system with arteries and veins.

Reproduction

The reproductive organs are also located in the abdomen. The worker bee is a female. Her ovaries are undeveloped and appear threadlike under normal colony conditions. In laying workers, ovarioles are evident (Figure 5-17). In the queen, the reproductive organs are very large and occupy a much larger amount of space (Figures 5-16, 5-17). The eggs of mated queens develop in hundreds of thread-like ovarioles in the ovary and pass into the oviduct where they are fertilized by sperm stored in the bulbous spermatheca. The queen places eggs into the cells of the comb. The male drone has testes and a large sperm delivery organ, the **aedeagus**.

A highly modified portion of the reproductive system is the sting (Figures 5-19, 5-20). The sting is anatomically an ovipositor. In most female insects the ovipositor is used to lay eggs. It has lost this egg-laying function in the worker honey bee. The sting glands produce a protein chemical, **venom**, along with an alarm chemical and other substances. Muscles attached to the sting help drive it into the victim (Figure 5-19). Tiny barbs on the three-part sting shaft (Figure 5-20) ensure that it stays in the victim so the alarm chemical remains at the sting site.

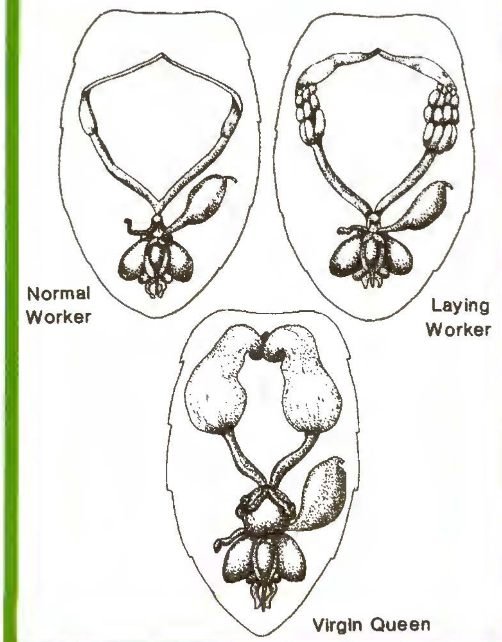


Figure 5-17. Comparison of normal worker, laying worker and virgin queen reproductive tract. From H. Dade *Anatomy & Dissection of the Honeybee*.

Figure 5-18. Simplified image of the tracheae and tracheal sacs. From I. Stell, *Understanding Bee Anatomy*.

Figure 5-19. Sting in skin, showing the sting shaft, the glands and muscles which continue to pump venom. Note: hemolymph at top when the sting was separated from the bee's body.

Figure 5-20. Sting showing barbs along two of the three sting shafts.

Respiration

The respiratory system of the bee, like the circulatory system, is considerably different from the human system. Insects have three thoracic and seven abdominal air openings, the **spiracles**, and internally many air sacs that lead to branching tubes or **tracheae** (Figure 5-18). Oxygen moves through trachael sacs and into and out of tracheae with wing and abdominal muscle activity. The tracheal system branches into even finer tubes, the **tracheoles**. A tracheole tube runs alongside each and every living cell of the bee to carry the oxygen to its action site. Waste carbon dioxide returns through the same tubes. Thus oxygen and carbon dioxide travel in the gaseous state to and from the cells rather than being bound in red blood cells as in humans. Cellular metabolic activity in bee and human is otherwise similar.

Gland systems

Glandular activity is extremely important to honey bees. The gland systems of the bee are complex and well developed. **Endocrine** glands secrete hormones that key the functioning of chemical processes. **Exocrine** glands open to the outside and produce pheromones that strongly influence many aspects of bee behavior. Other glands produce products that bees use in their nest while still others regulate various metabolic processes. Bees could not survive without glands. The major glands are shown in Figure 5-21.

The bee head has several important glands. The **hypopharyngeal** (or maxillary) glands are above the pharynx. They secrete a sticky, milky fluid that we call royal jelly or 'bee milk.' The secretion is high in sugar, protein and vitamin content and is a complete food. Worker and drone larvae receive royal jelly the first two to three days of development while developing queens receive it their entire larval life.

As with other gland systems, the hypopharyngeal glands are not completely developed when the adult bee emerges from her brood cell. The glands, which resemble miniature strings of onions, develop after the bees feed on pollen. They secrete royal jelly for a few days and then become less active. These glands only develop in workers; they are absent in drones and rudimentary in queens.

There are two pairs of **labial** (salivary) **glands**. The first pair is sometimes called **postcerebral glands**, referring to their position in the head. They produce a watery saliva that is used to dilute food and hold pollen grains together. Their primary function is in the digestive processes. They secrete **sucrase** (sugar breakdown), **lipase** (fat digestion), **amylase** (starch digestion) and other enzymes. These enzymes convert the carbohydrates of nectar and the fat of pollen into substances useful for the bee.

The **mandibular glands** of queen bees are a major source of the pheromone **queen substance**. This pheromone functions as the major substance that accounts for the social cohesiveness of the bee society. This material is only secreted by queens. In workers, the mandibular gland helps with wax molding and also secretes 2-heptanone, a material used in alarm communication. In drones, these head glands are rudimentary.

Box 8
Honey bee nutrition

We understand a fair amount about honey bee nutrition. Materials that the bee eats, such as the carbohydrates, fats, proteins, etc., are changed chemically in digestion to units small enough to be absorbed from the digestive tract. These materials are transported by the blood to all the cells of the body or to storage in the fat body until needed at a later time.

Carbohydrate intake is in the form of nectar or honey. Enzymes such as sucrase and other amylases break the nectar sugars into the simpler sugars of glucose and fructose. The simple sugars are used directly or converted into fat and glycogen. Honey bees can live on a pure carbohydrate diet for a long time but are unable to continue raising brood or continue gland development without dietary protein.

Vitamins are necessary for the growth and development of bees. Vitamins are especially important in enzyme activity and bees lacking proper vitamins in the diet develop deficiency diseases. Bees obtain most of their vitamins from pollen but nectar supplies some of their vitamin needs as well. Bees require several B-complex vitamins (biotin, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin and thiamin) as well as inositol, and ascorbic acid (vitamin C).

Pollen also supplies the necessary amino acids and minerals bees need. Protein is needed for development of muscles, glands and development of other tissues in the bee. Adult bees begin pollen consumption within two hours of emergence and quickly increase pollen intake to reach a maximum five days after emergence. Pollen consumption is negligible in bees older than ten days of age. Since the pollen is covered with a protein coat, honey bees need special enzymes to break the pollen grains open and digest the protein. Pollen grains are difficult to break apart mechanically. Bees do so enzymatically with four endopeptidases, each different in their cleavage specificities.

Pollens vary widely in their protein content. Some pollens are better nutritionally for bees while some have been shown to lack essential amino acids. Bees require the following amino acids: arginine, histidine, leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophane and valine.

We know relatively little about the fat requirements of bees. Apparently pollen supplies their needs. Fats are mostly stored and deposited in the abdomen and then used in periods of starvation. Bees do need a dietary source of cholesterol, usually as 24-methylene cholesterol, for normal growth.

Minerals bees need in their diet are also obtained from pollen. Pollen has been identified to have 27 trace elements. Phosphorus and potassium are important to the bee and the most common minerals in their bodies. Calcium, magnesium, sodium and iron are also common. Bees need some salt in the diet but they probably retain it by recovering salt before it is excreted. If as little as 0.125% salt is added to sugar water fed to bees, there is a reduction in longevity.

Bees also need water in the diet. During active flight they excrete a semi-solid waste. Water is specifically collected by foragers and nectar, of course, is high in water content. When bees consume honey or sugar sources of 50% sugar content or higher, they dilute the sugar before use so there is a continual need for water in the diet. One estimate puts the annual water collection level at 44 lbs/colony (20 kg).

The main glands in the abdomen are dorsal abdominal tergite glands, ventral wax glands, the scent gland and sting glands (Figures 5-15, 5-21). The wax glands are found on the inner surfaces of four ventral sternites of the bee abdomen (Figure 5-23). Each is paired and secretes wax. The wax forms as scales that protrude from the overlapping sternite of the previous segment. Very young or old bees do not secrete wax. Bees 12 to 16 days of age have the greatest degree of wax gland development. Only worker bees have wax glands. After manipulation with their mandibles, the bees use the wax to make beeswax combs or cap brood or honey-filled cells.

The **scent** or **Nasonov gland** (Figure 5-24) is on the dorsal side of the abdomen connected by a tiny groove to a membranous area. Bees fan the wings and depress the tip of

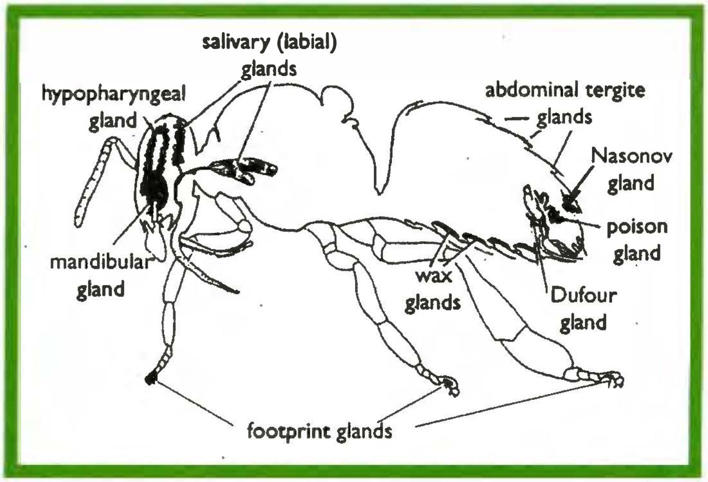


Figure 5-21. Glandular system of the worker bee.

Box 9
Glands and development

The control of growth and development is hormonal with regulation by three main organs. Hormones originate in endocrine glands. Schematically, this is represented in Figure 5-22. Neurosecretory cells in the brain release brain hormone in response to both internal and external stimuli. The hormone travels to small glands, the corpus cardiaca, where it is released into the hemolymph (blood) of the bee. The brain hormone from the corpus cardiaca acts on the prothoracic gland, a small area of glandular tissue in the thorax that is hard to identify. These glands produce ecdysone (molting hormone). This hormone travels in the blood and ends at epidermis cells of the exoskeleton. Ecdysone is the message to begin the process of molting. Another brain gland, the corpus allata, secretes juvenile hormone into the hemolymph. Juvenile hormone also travels in the blood to the epidermis cells of the exoskeleton. It suppresses the expression of adult characteristics.

Juvenile hormone and ecdysone together control growth and development. Whether the larva molts to a larger larva or proceeds to the pupal stage depends on the balance between ecdysone and juvenile hormone. Prior to the molt to pupa, juvenile hormone production ceases so its level in the blood goes down and the next molt produces the adult bee from the pupa. Juvenile hormone production returns during the adult stage when it serves additional functions such as regulating egg development and worker duties as well as queen aging.

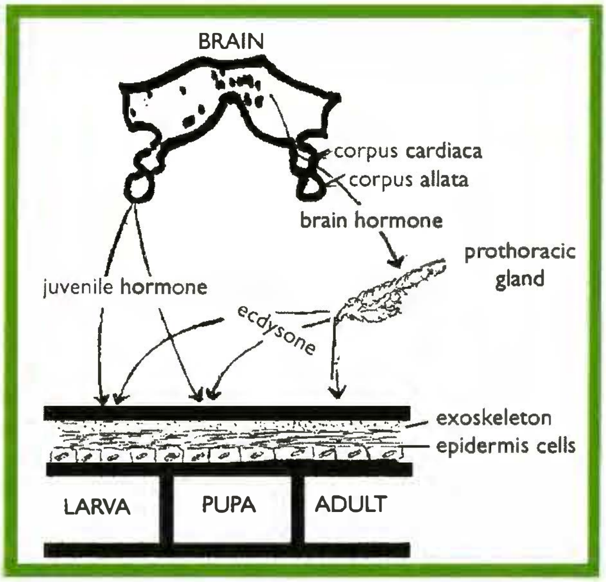


Figure 5-22. Endocrine gland hormones and larval development.

Above: Figure 5-23. Wax glands. Below: Figure 5-24. Scenting with Nasonov gland at tip of abdomen. R. Williamson photos.

the abdomen to disperse the scent when they release the pheromone. The secretion is a mixture of terpenoids; two of the chemicals, citral and geranic acid, are most attractive to bees. Newly-emerged bees have little to secrete; maximum levels are reached in foraging-age bees. In winter, the level of secretion is also low.

The scent-gland pheromone is used to attract workers to food and to help lost and/or disoriented bees locate home or food. It is released most frequently at water sources, around a hive (especially in disorderly or confusing conditions), during swarm movement and at the swarm settling site. New nest sites are also marked with the pheromone. It may be released at flowers but apparently this is not frequently done.

The worker has a series of **glands** associated with the sting (Figures 5-15, 5-21). Two are individually termed **Dufour's** and **Koschevnikov glands**. A pheromone is released when a bee stings a hive intruder (Figure 5-19). When the hive is opened on a cold day, workers elevate the tip of the abdomen and protrude the sting with a droplet of venom towards the disturbance. The pheromone that causes alarm behavior is isopentyl acetate. Young bees have little of this material while older bees have 1-5 □g.

The venom or acid gland is the largest of the four sting glands. It produces a mixture of enzymes and proteins that result in the release of histamine in a victim and, in allergic individuals, a more serious allergic response. Other glands have unknown functions, perhaps connected with egg laying or sting lubrication. Queens have sting glands but produce no alarm pheromone and their venom gland contents are different from the workers.

Bees have glandular tissue on the thorax, lower tip of the abdomen and probably elsewhere on their bodies. One pheromone chemical bees utilize is called footprint substance. It is from the **Arnhart** (or **arolium**) gland of the tarsi of the ultimate segment of each leg, deposited as the bee walks and moves about. This pheromone is attractive to other bees which smell and perhaps also taste it. It is used to mark home and food sources.

There are undoubtedly other pheromone-producing glands. Internally, other neurosecretory and endocrine glands produce hormones to regulate physiological, developmental, and behavioral events in honey bees. Enzyme-producing glands connected with the epidermal cells and internal systems function in digestion, development and detoxification.

Queen and drone

The queen and drone bee differ somewhat in body details. Figures 5-4 through 5-6 show the differences in head shapes and compound eye variations. The queen has a longer abdomen due to the large ovaries and the drone has a large barrel-shaped abdomen to house his reproductive organs. The queen has a long, curved sting lacking the tiny barbs on her sting that the worker sting possesses. The drone has eyes twice the size of worker's, so large that they meet at the top of the head and crowd the ocelli.

Both drone and queen lack the specialized body hairs on the legs since neither collects pollen. Their mouthparts do not work as well as those of the worker and they have smaller honey stomachs. They take their food from workers in the hive and do not need the well-developed food collecting hairs or mouthparts of the worker.

Drone and queen differ internally as well. Both lack wax and scent glands. The head glands differ and, in the queen, the differences are important. The queen's mandibular glands are very critical as they produce a complex series of chemicals that serve to coordinate and organize the colony. In the queen, the hypopharyngeal glands are not important as the queen does not feed the developing young. In drones, mandibular and hypopharyngeal glands are not developed.

Larval stage

The immature larval stage has virtually no external and few internal features (Figure 5-25). The body of the larva is a series of folds. The digestive tract has only the single mouth opening. The digestive tract does not complete development into a tube until just before the larva changes to the pupa. Thus there is no waste discharge in the larva. Eyes, antennae and other features are lacking. Internally, all the systems that will occur in the adult bee are a series of disks of cells. These will divide and differentiate many times in the pupal stage to produce the adult structures.

The pupa of the bee gradually assumes the features of the adult through cell division and differentiation. The early pupa does not resemble the adult while the late pupa clearly has all the adult features. The transformation from simple egg to complex adult requires 21 days in the worker, 24 days with drones and 16 days for the queen.

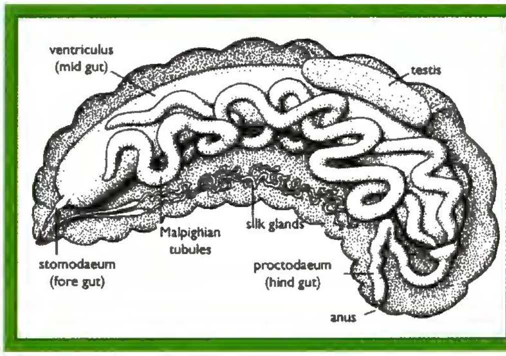


Figure 5-25. Drone bee larva internal anatomy. From H. Dade *Anatomy & Dissection of the Honeybee.*

Anatomy Resource Listing

Books

Honey Bee Biology and Beekeeping - Dewey M. Caron, Available from Wicwas Press, www.wicwas.com
Honey Bee Biology and Beekeeping explains bee biology, what bees do, and provides the tools which make it possible for an individual to successfully manage bee colonies. The author has concentrated on the "why" aspects of bee biology so that the reader understands "when" and "how" certain things must be done to colonies. Bees and beekeeping are explained in a manner meaningful to a person who lacks an extensive background or knowledge of biology. Yet the author has not oversimplified bee biology to the point where it is meaningless to the serious beekeeper or informed biologist.

The Biology of the Honey Bee - Mark L. Winston, ISBN: 0674074092
The Biology of the Honey Bee not only reviews the basic aspects of social behavior, ecology, anatomy, physiology, and genetics, it also summarizes major controversies in contemporary honey bee research, such as the importance of kin recognition in the evolution of social behavior and the role of the well-known dance language in honey bee communication. Thorough, well-illustrated, and lucidly written, this book will for many years be a valuable resource for scholars, students, and beekeepers alike.

Online Resources

Anatomy and Morphology Photos
http://cyberbee.net/gallery2/main.php/v/anatomy_0/

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Anatomy Class Review

Please rate the level with which you agree with the following statements:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
This class was interesting and stimulated my interest in the subject matter	○	○	○	○	○
The instructor answers questions carefully and completely	○	○	○	○	○
The class materials reflected the subject matter	○	○	○	○	○
The quality of the visual aids were good and appropriate to the subject matter	○	○	○	○	○
I was able to follow along and keep up with the subject matter	○	○	○	○	○
This class met my expectations	○	○	○	○	○

What did you like about this class?

What didn't you like about this class?

What topics should have been covered and were not?

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