The Honey Bee

Part One

The honey bee is but one of a remarkable group of animals - the insects. Insects are the most numerous and successful species on the planet with an estimated 2-300 million insects for every man, woman and child. They have been around a long time, fossil records date back some 410 million years (cf. man 0.5 MY)

So what are the defining features that make a creature an insect?

- They have an exoskeleton (rather than the internal skeleton of vertebrates)
- They are typically made up of 3 regions - head, thorax, abdomen
- They usually have 3 pairs of jointed legs, these may be adapted for swimming, jumping, running, clasping, etc
- They are often capable of flight - one or two pairs of wings

The huge group of insects are sub-divided into many families,; bees are to be found, along with wasps and ants, in the family “Hymenoptera” literally “membrane wings”

The hymenoptera have the typical 3 body parts with a very slender waist or petiole between the thorax and abdomen. They have 2 pairs of wings, the front larger than the rear. In flight, the wings are coupled with a row of hooks (hamuli) on the leading edge of the hind wing engaged in a fold to the trailing edge of the front wing. When the bee lands, the wings are folded back and the hooks un-couple.

The hymenoptera are fairly advanced in evolutionary terms, say compared to the very primitive dragonflies, largely unchanged over millions of years (fossils)

The hymenoptera include most of the social insects (apart from the termites) but, having said that, most hymenoptera species are solitary. There are approx 120,000 hymenoptera species worldwide with an unusually high percentage found in the UK - around 6,600 or 5%. They do tend to be insects of temperate zones.

Compare this with the approx 370,000 species of coleptera (beetles) worldwide, 3,700 in the UK.

The exoskeleton

This is a series of thin, hard, light-weight plates with huge variations in thickness and stiffness. They can be fused together to form rigid structures or joined with very flexible membranes. They are very intricately shaped both externally and particularly internally where pegs, ridges and folds provide anchorage points for the internal muscles. A good analogy is the way cars are assembled - they used to be built on a chassis (like vertebrates) but are now made as a monocoque - pressed panels welded together to give strength exactly where it is needed.

The exoskeleton provides protection to the internal organs and its thin, waxy coating is vital in reducing evaporation of body fluids. The flight muscles on bees generate a lot of heat which means that bees run hot! Water-retention is vital to survival in very small creatures which have a lrge surface area compared to their volume.

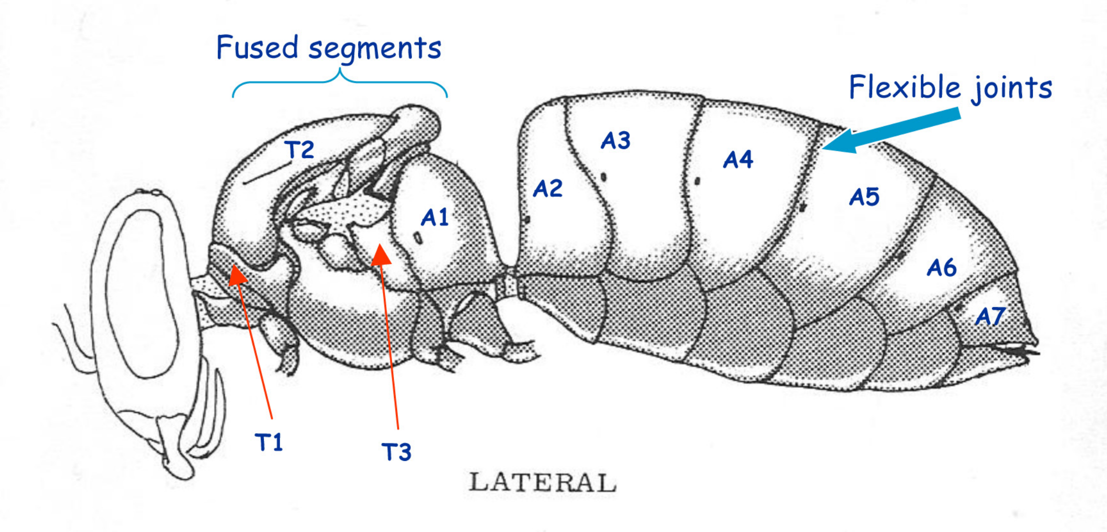
The disadvantage of this outer skeleton is that growth is difficult! Insects overcome this by a process called moulting. Simply put, during moulting, the insect starts to produce a new, larger skin under the existing one. It then exudes a moulting fluid which dissolves most of the old skin which is re-adsorbed, leaving just the very thin outer layer which then splits along lines of weakness. The insect then expands to its new larger state before the new skin starts to harden. This process usually occurs several times from egg to adult.

With the honey bee, the egg hatches to a tiny larva on the 3rd day and, over the next 5 days the larva grows at a phenomenal rate, increasing its weight x1500 and moulting 5 times. To do this, it receives around 1300 visits per day from the nurse bees.

At this stage, the larva fills the cell and the workers cap it over. The fully fed larva lies down in the cell with its head to the capping and spins a cocoon; over the next few days there is a re-arrangement of the external features and, for the first time it starts to look like a bee. This pre-pupa is however largely unchanged from the larva internally. Now comes the really amazing bit - there is an almost complete breakdown of the internal tissues which are then re-assembled to give those of the adult bee - pupation. A final moult provides the finishing touches and the new, fully grown bee emerges from its cell. The whole process is known as metamorphosis. The wings are pumped up and harden - its ready to go!

Segmentation

Typical insects have 6 larval segments fused together to form the head, 3 for the thorax (T1-T3) and 10 or 11 for the abdomen(A1-A10). The honey bee nearly follows this pattern except that it "borrows" the first abdominal segment to increase the size of the thorax (ie T1-T3+A1), the first abdominal segment is actually A2. The last visible segment on the abdomen is A7, A8-A10 are hidden within A7 and their appendages, in highly modified form become the sting and genitalia.



Summary

- The honey bee is a typical insect
- Adapted to a vegetarian diet
- Co-evolved with the flowering plants and vital as a pollinator
- It has the typical head-thorax-abdomen arrangement
- .. with an enlarged thorax and a wispy waist
- The exoskeleton is formed during pupation
- .. combines strength and water-retention with flexibility and lightness.

Part Two

The sense organs, the head and thorax.

The honey bee's environment has two contrasting states - the crowded dark of the hive and the sparsely populated, bright arena where it forages for nectar and pollen. It, and the colony as a whole, needs to be able to recognise nest-mates and "strangers"; they also need a system of communication if they are to exploit the forage efficiently. Thus, the most important senses for an individual bee are a sense of smell/taste and good vision.

The antennae

Bees have antennae that bristle with thousands of receptors and this is where most of the sense of smell is centred. They are very sensitive and selective to a wide range of odours. Other receptors (there are at least 10 different types on the antennae) deal with touch, taste, moisture, CO2 and can sense wind direction/speed - all useful things to have right at the front of the body. The closest things that bees have to ears are also located in a particular point of the antennae - these sense vibrations on the comb, particularly the buzzing associated with waggle dances.

There are 3 parts to the antennae, the scape is ball & socket-jointed to the head allowing movement in all directions. The pedicel is a small segment with an elbow-joint to the scape and the flagellum is the long, sensor-encrusted part to the front. It is fixed to the pedicel and although it appears to be made of segments, there are no internal muscles, it does not move; the segments are properly called annuli. Workers and queens have 10 annuli, drones have 11.

One of the most important types of receptor on the antennae are called pore-plates; there are around 3000 on a worker's antennae and 4500 in the drone, some of which seem to be fine-tuned to queen pheromones. It is evident that drones find the queens, not the other way around!

Compound eyes

Insect vision is quite different in most ways to the way we see. The compound eyes are composed of thousands of separate light-sensing units called ommatidia, each has its own tiny hexagonal lens and light is focussed onto the top of a column of light-sensitive cells with 8 different cells (9 nearer the bottom) comprising a variety of combinations of the 3 wavelength sensitivities - blue, green and UV (cf. in man : blue, green, red) Bees do not see the red of a poppy but they reflect UV which we do not see but bees do. The internal design of the eye allows for increased/decreased sensitivity, depending on whether it is bright or dull, it also has pigments that prevent light in one ommatidium from leaking across to another - this keeps the patterns coherent and allows the bee to build up a picture from the whole eye - a sort of mosaic.

The ability of the bee eye to resolve fine detail is quite limited - at its best it is about 60 times poorer than our most sensitive area but this is compensated by the bee's exceedingly quick response/update time - it processes information about 200 times per second. There can be no doubt that the insect eye is brilliantly adapted to their environment - the next time you try to swat a fly, just remind yourself that it has really poor spacial resolution!!

Over the top rim of the compound eyes is a region, the POL region, of only 2-3 ommatidia wide, where the eyes are modified to be able to detect and analyse the polarisation of light in the sky. A small patch of blue sky anywhere in the sky immediately provides the bee with all of the information it needs to know where the sun is, and which is the way home.

Simple eyes

Pub Quiz question - how many eyes does a bee have? Answer = 5. 2 compound eyes and 3 simple eyes or ocelli. These are arranged in an inverted triangle on the head of the worker bee but are pushed down to a more forward-pointing place in the drone because the huge compound eyes meet over the top. The exact function of these simple eyes was a mystery for many years because it is clear they do not focus an image on the retina - they are simply very sensitive light-detectors. Modern thinking is that they are part of the in-flight stability system as some of the nerves from these ocelli run straight through the brain to the nerve-centres controlling the wing muscles.

Mouthparts

Insect mouthparts are possibly the most diverse aspect of the basic insect design. There are many parts and they have become adapted exquisitely to the particular feeding habits of the particular insect. The mouthparts of the bee are completely different to those of its close relative the wasp, which is not hugely different to those of a primitive, non-specialised insect such as the cockroach. Diet is far more important than family in this respect.

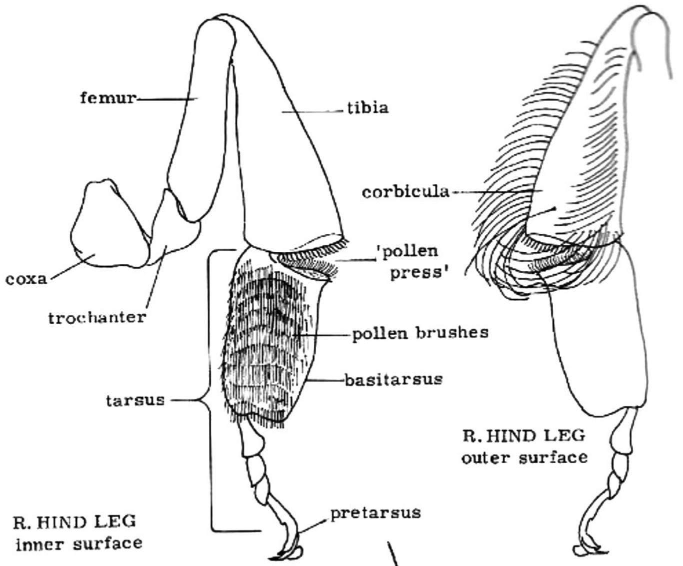
Bees have upper and lower sets of mouthparts - basically the chewing/biting/wax-manipulating top set are called the mandibles while the lower set together form the proboscis, used to suck up liquids. The proboscis is NOT a sealed tube (forget any thoughts of elephants) but a collection of at least 5 parts which normally fold away separately under the bees head. When the bee wants to use its proboscis, these parts are swung forward and up and brought together to produce a tube within a tube; they are locked in place by the mandibles and the mouth opening is sealed around the top of the structure, enabling liquids to be sucked up.

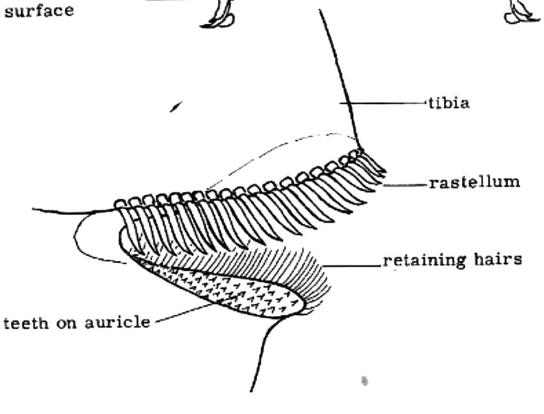
Internal parts of the head

There is a small brain between the compound eyes and two sets of important glands. The hypopharyngeal glands in the front of the head are the source, in young nurse bees, of the brood food and royal jelly used to raise the next generation. The post-cerebral glands are one of two sets of salivary glands, the second set sits low in the thorax.

The Thorax

This is the centre of movement - 3 pairs of legs are attached and two pairs of wings. The legs are simply a series of hollow, jointed tubes. The joints allow movement in one direction only but all of the joints are at slightly different angles so there is considerable freedom of movement overall. Starting at the body end, the parts are called the coxa, trochanter, femur, tibia and tarsus. The tarsus is itself made up of several parts, a large important piece (basitarsus) followed by 4 smaller parts and finally the foot. The foot has 2 claws which can grasp any rough surface and a soft pad between them when the surface is smooth.





TIBIO-TARSAL JOINT ('pollen press')

How does a bee walk or run? At very low speeds, the bee moves L1,L2,L3,R1,R2.R3 etc but soon changes as it speeds up to a system of standing on a tripod of L1,R2,L3 while simultaneously moving forward R1,L2,R3; then standing on those while the others move forward. It's difficult to see!

Apart from their use in moving, the bee's legs play a vital role in pollen collection

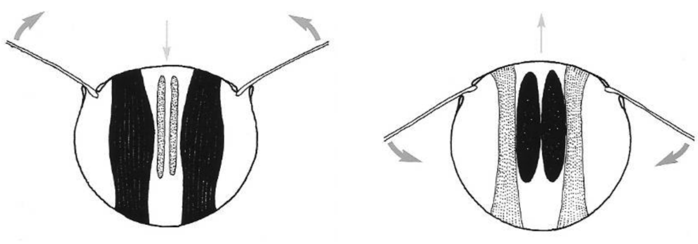
The front legs have an antenna cleaner between the tibia and basitarsus, this brushes pollen off the antennae onto stiff pollen brushes on the inner surface of the basitarsus; these also sweep pollen off the rest of the head. The middle legs sweep pollen off the thorax and transfer pollen from the front legs to the middle, then the back legs. The back legs are where the clever bits happen. The pollen brushes on the inside of the basitarsus (which is very wide and flattened) are very pronounced and can hold a good amount of pollen grains. There is a line of stiff bristles, the pollen rake or rastellum, along the bottom edge of the tibia and these are used by the bee, in flight, to rake the pollen off the opposite leg. The pollen falls into the gap between the basitarsus and tibia, on to a sort of shelf called the auricle. The joint between these two parts is on the front edges so the gap between them can be opened, to receive a load of pollen, or closed, when the trapped pollen is compressed and forced through the gap, emerging on the outside of the joint and is forced up into the concave area on the outside of the tibia - the "pollen basket" or corbicula. Stiff hairs fringe this area and retain the packed pollen which is further shaped and compacted with the middle legs. This whole apparatus is known as the pollen press.

Pollen brushed from the right hand side of the bee is raked off and transferred to the left hand pollen basket, and vice versa.

Wings and flight

The thorax is a semi-rigid box formed of the usual 3 thoracic segments T1-T3, with the addition of the first abdominal segment, A1. It is semi-rigid in that it has a fold area in the structure with two definite stable states - the dome of the thorax has a raised position and a lowered one, it does not like being between these states. The wings are attached to the thorax in such a way that these movements of the thorax are enough to drive the wings; thus the principal muscles that allow the bee to fly are not directly attached to the wings - they are called indirect flight muscles. The interior of the thorax is dominated by two very large pairs of muscles. Two large muscles running from top to bottom of the thorax pull the thorax down, which raises the wings. Immediately, two other large muscles running front to back, pop the thorax back up again, lowering the wings and creating lift. This cycle continues many times per second.

The precise way in which the wings attach to the thorax also twists the wings and changes the angle of attack; the wing tip describes a sort of figure-8, so much of the flight is semi-automatic. There are however a number of smaller muscles which bear directly on the wings and exert control over pitch, roll and yaw. The main thing to remember is that the wings are powered by indirect flight muscles.



Summary

The head is a great place to have most of one's sensory organs - the bee has its antennae, compound eyes and ocelli all at the front where they can best sense the immediate surroundings

The mouthparts are in two parts, the upper mandibles which allow the bee to bite and manipulate wax, and the proboscis, made up of several separate parts which are brought together, swung up into place as needed and secured by the mandibles.

The thorax carries the 3 pairs of legs and 2 pairs of wings. The legs are used, not solely for movement, but also as an efficient system for the collection, compaction and transportation of pollen back to the hive.

The wings are attached to the thorax in such a way that they act as levers when the thorax is subject to controlled deformation; indirect flight muscles alternately lower and raise the roof.

Part Three

The Abdomen

We come to the last of the three sections of the bee's anatomy - the abdomen which houses several important organs.

Externally, this is the body region where segmentation is most apparent, the plates of the exoskeleton are joined by very flexible membranes, allowing considerable freedom of movement. As noted previously, the first abdominal segment is actually part of the thorax; what we see in the abdomen are segments A2 to A7, with A8-A10 hidden within A7

The digestive tract

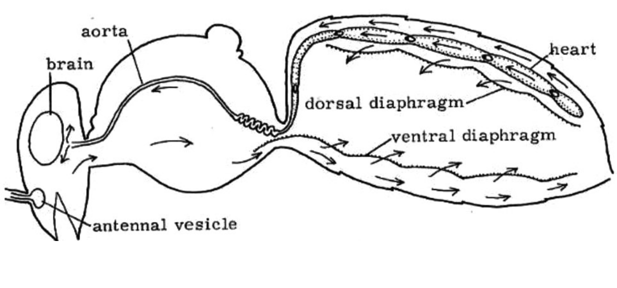
.. starts of course in the head where the proboscis obtains nectar and glandular secretions start the process of splitting the complex sugars into simple sugars, glucose and fructose. The oesophagus runs through the thorax and petiole and expands into a highly elastic sac, the crop, within the abdomen. A very clever valve, the proventriculus, filters pollen out of the nectar and passes it into a concertina-like tube called the ventriculus, where enzymes break down the pollen. A second valve, the pyloric valve, then allows the digested food to enter a thinner tube, the small intestine, where the nutrients are absorbed and passed into the haemolymph (bee blood). Waste products are passed to the rectum and voided in flight. Many thread-like closed tubes float about within the haemolymph in the abdomen and perform a function very like that of our kidneys. These malpighian tubules extract waste products and pass them into the digestive tract, just above the pyloric valve, whence they join pollen husks etc in the rectum. In winter bees, most of the abdomen can be taken up by the hugely extended rectum, a complete contrast to the summer foraging bee where the rectum is small, the crop a significant size.

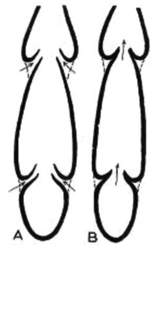
The Circulatory System

As in mammals, the bee's blood or haemolymph, is the means by which food and heat is moved around the body and waste products taken away. Unlike mammals, it is NOT involved in oxygen transfer and, with a couple of exceptions, it is not pumped around in tubes but merely bathes the organs, filling the internal spaces.

The bee's heart is also somewhat different from the discrete muscular mammalian organ, consisting instead of a long tube, closed at the tail end and having 5 pairs of valves (ostia) along its length. Haemolymph enters the ostia from the abdomen and, when the muscular tube contracts, the valves close and the fluid is pumped forward, through the thorax to emerge just behind the brain. The pressure gradient forces haemolymph back from the head to the thorax and then through the petiole, back to the abdomen.

The heart is suspended from the roof of the abdomen and the flow of blood is assisted by diaphragms top and bottom, and by the rhythmic contractions of the abdominal segments. There is a small pulsating organ which pumps haemolymph along the antennae.





The Respiratory System

As discussed when talking about the adult bee parasite "acarine", the respiratory system consists of a number of openings or spiracles along the length of the thorax and abdomen, connected to air sacs and tubes (trachea) which branch repeatedly to finer and finer tubes (tracheoles) which infiltrate all areas of the bee. Gas exchange (oxygen to the muscles, carbon dioxide away) is very largely a matter of simple diffusion over very short distances though, again, the rhythmic contractions of the abdomen assist in ventilating the air reservoirs.

The Wax Glands

.. are four pairs of glands situated under and between segments A4 - A7. The lower segmental plates, properly called sternites, overlap by about 50% and it is on the normally hidden parts that the wax glands are located. The glands are overlaid by the so-called wax mirrors, smooth surfaces where the wax scales actually form. Large quantities of pollen and nectar are consumed by the wax-producers and scales of wax, normally about 0.5mm thick, are removed from the mirrors with the pollen bristles on the rear basitarsus and transferred to the mandibles where they are kneaded, softened and then positioned to build comb, seal cells etc.

The Nasonov Gland

"Come Hither!" This prominent gland is located under the upper part (tergite) of segment A7 and is exposed by the bee depressing the very tip of the abdomen. This is often done with the tail up and wings fanning the air over this scent-gland. A major component of the scent is geraniol and this gland is largely responsible for the smell we associate with honey bees. The primary purpose of the scent is to attract other bees and it plays an important role in marking the entrance to "home" and in keeping a flying swarm together.

The Sting

The worker's sting is a vital instrument in colony defence and is comprised of heavily modified parts of segments A8-A10, normally forming the ovipositor but of course redundant in sterile workers. The actual piercing point is comprised of 3 parts, an upper stylet and 2 barbed lancets which run on tracks in the stylet. The 3 parts fit together to form a canal down the centre through which the venom is pumped. In use, the whole sting assembly is first lowered out of its protective sheath and then pushed into the victim by the abdominal muscles. In mammalian skin, the barbs prevent its withdrawal and the whole sting is pulled from the body, including the poison sac and a small knot (ganglion) of nerve cells that continues to fire muscular contractions. Muscles attached to hinged plates on either side of the mechanism alternately extend and retract the barbed lancets which thus tend to be pulled deeper into the wound. The lancets also run through the poison sac (bulb) and valves on their sides open as they retract, close as they advance, thus forcing the poison down the channel. As well as inflicting a painful sting, the sting emits pheromones which entice other bees to follow suit. Ouch!

The reproductive organs

Most of the bees within the colony, the sterile workers, have only vestiges of reproductive organs whereas the abdomen in the queen is dominated by a huge pair of ovaries. Eggs arise at the very end of long tubes known as ovarioles and mature and grow as they pass along the ovarioles (of which there can be hundreds) into the twin oviducts. The egg then passes a duct leading from the spermatheca - a tiny, spherical sac which stores, and nourishes, the queen's life-time supply of sperm. The queen can at this point fertilise the egg (to give a worker or queen) or not (to give a drone). The egg passes down the ovipositor and is fixed to the cell base by the queen.

In immature drones, the testes similarly dominate the internal spaces of the abdomen. As they mature, drones produce sperm and store this in paired seminal vescicles. Once full, the testes shrink - this is a one-time operation for a drone! The genitalia of the drones are inverted - they are held, inside-out, rather like a three-fingered glove which can be blown up (everted) at the moment of mating, which happens in flight, in drone congregation areas. The 3 "fingers" comprise a pair of horns with the ejaculatory duct between. The exact shape of the male genitalia are different for every species of bee and are important in preventing cross-breeding. The explosive eversion of the genitalia forces the sperm into the genital chamber of the queen; the drone achieves this eversion with a rapid back-flip which wrenches his genitalia from his body; the drone falls to the ground.

The Colony

Everything so far has looked at the biology and anatomy of individual honey bees yet bees ONLY live in a colony so it is appropriate to finish with a few words on the colony itself.

Social insect colonies have been likened to distinct animals; the term "Super-organism" has been used as, in many ways, the whole colony acts as one larger entity. The colony allocates tasks according to age and ability, it stores food when it is plentiful and uses it when scarce. It builds its own environment and closely regulates temperature and humidity within it. Perhaps most significantly, it has communication systems that optimise foraging (dances) and defence (pheromones).

The analogy of the super-organism is most obvious when it comes to reproduction for this goes on at 2 levels - the individual bees but also, by swarming, the whole colony is able to reproduce.

Without human intervention, over millions of years, this reproductive arrangement has been enough to ensure the survival of the species. However, since man has "kept" bees and particularly since Apis mellifera colonies have been moved to all parts of the world where they encounter pests and diseases of closely related species, the ability of bees to survive has been severely challenged. Few feral colonies now exist and the reproductive rate for existing colonies (seldom more than x1 per year) is struggling to maintain the status quo when winter losses amount to 30-40%.

Beekeepers are now increasingly necessary to the future survival of bees.

R M Smith
February 2009

Further reading:

- "The Insects" - R F Chapman
- "Anatomy of the Honey Bee" - R E Snodgrass
- "Anatomy & Dissection of the Honey Bee" - H A Dade
- "Form & Function in the Honey Bee" - Lesley Goodman
- "The Honey Bee Inside Out" - Celia Davis
- "Insects and Flowers - the Biology of a Partnership" - Friedrich G Barth
- "The Buzz about Bees" - Jürgen Tautz