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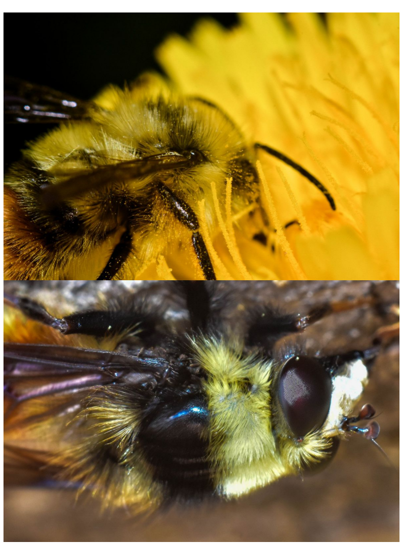
Insect Morphology

Introduction to Insect Structure

The most basic segmentation of insects is that of the *head*, *thorax*, and *abdomen*. All insects have these general structures, although they can vary greatly in individual appearance. All of these parts are sclerotized, or hardened, and the body is divided into plate-like areas, called sclerites.

The head is anterior, and capsulelike. It contains the eyes, antennae, brain, and mouth parts. Typically, insects have both simple eyes (ocelli, ocellus plural) and compound eyes. Ocelli are simple photoreceptors, and detect light. Complex eyes are used to create full images of the environment.

***Osmia lignaria* pictured, with 2 compound eyes and 3 ocelli.**



Antennae of insects vary greatly, and often are a fantastic tool for identification. Bee mimic flies are one example that can easily be differentiated by their antennae. The *Criorhina caudata* pictured on the bottom has antennae typical of a fly, while the bumblebee it mimics has longer, segmented antennae. While other structures differ as well, such as the mouthparts and wings, the antennae are usually easily visible and can be used for quick differentiation.

Insect mouthparts can be quite specialized, however they fall into two major categories: chewing and sucking. Chewing mouthparts have laterally moving mandibles, while sucking mouthparts have been modified into a proboscis, which works similarly to a straw. There are many variations. Bees posses laterally moving mandibles as well as a beak-like tongue for sucking nectar and honey. Piercing insects have small hairs called stylets, which are swordlike in nature. These hairs pierce your kin, and then the proboscis is typically a sheath within the stylets.

Another fundamentally important structure in the head of the insect is its brain. It is primitive in structure, consisting of a body of nerve tissue differentiated into protocerebral (ocular) and duetocerebral (antenullar) regions. Insects lacking antennae do not make the specialization for the deutocerebral region, and it is lacking in those.

The next section is the thorax. It is divided into the prothorax, mesothorax, and metathorax. Each segment usually has a pair of legs attached on the bottom sides. the mesothorax and metathorax typically hold the wings. The wing muscles are attached to the walls of the thorax.

An insects wings, whether they have four, two, or none, are excellent identification tools, and wing venation is often used to identify different vein structures. The four groups of thoracic sclerites include a notum (plural, nota, the dorsal surface), two pleuron (plural, pleura) on each side, and the sternum (plural, sterna, the ventral surface). These can be combined with the prefixes of thoracic segments to identify different positions. For example, the notum of the prothorax is the pronotum.

The final segment of insect bodies is the abdomen. Typically, it contains 11 segments, however the final segment is almost always an appendage. Some insects contain less segmentation, as a result of fusing. Each abdominal segment contains 2 sclerites, the terga (dorsal) and sterna (ventral). Typically the terga extend down the sides and overlap with the sterna. The abdomen also contains much of the organs of the insect, however I will touch upon the details of this in a separate, more detailed posting down the road.

Those are the foundation of insect structures, and while many insects vary greatly in how they present those structures, it is critical to be able to identify them to differentiate between different species, families, and orders. For some, this may be more than enough information for basic insect identification. Understanding the parts of an insect will take you great lengths in beginning identification, and knowing how each order displays these parts differently will ensure you have a good hold on what insects you have around your farm or garden.

Internal Anatomy of Insects

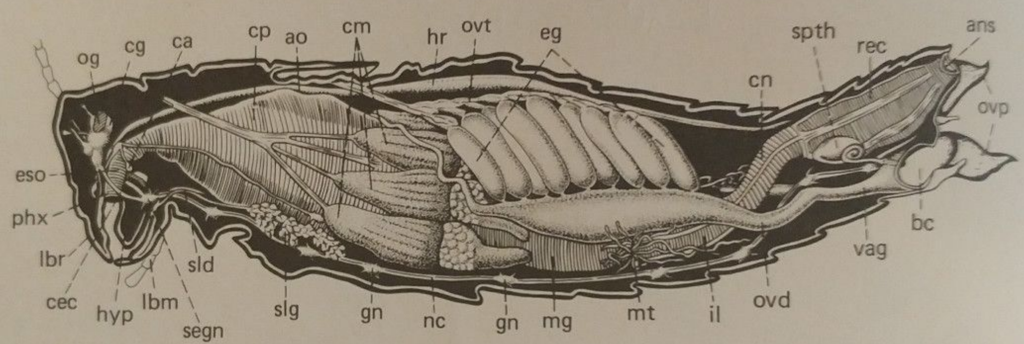


Figure 23. Internal organs of a grasshopper, shown in longitudinal section (somewhat diagrammatic). *ans*, anus; *ao*, dorsal aorta; *bc*, bursa copulatrix; *ca*, corpus allatum; *cec*, circumesophageal connective; *cg*, cerebral ganglion (part of the brain); *cm*, gastric caeca; *cn*, colon; *cp*, crop; *eg*, eggs; *eso*, esophagus; *gn*, ganglia of ventral nerve cord; *hr*, heart; *hyp*, hypopharynx; *il*, ileum; *lbm*, labium; *lbr*, labrum; *mg*, midgut or mesenteron; *mt*, Malpighian tubules; *nc*, ventral nerve cord; *og*, optic ganglion (part of the brain); *ovd*, oviduct; *ovp*, ovipositor; *ovt*, ovarian tubules; *phx*, pharynx; *rec*, rectum; *segn*, subesophageal ganglion; *slg*, salivary gland; *sld*, salivary duct; *spth*, spermatheca; *vag*, vagina. (Redrawn from Matheson, by permission of the Comstock Publishing Co.)

Endoskeleton: While the exoskeleton is the principal structure of the insect body, the endoskeleton still is important. It serves to strengthen the body will, and is another attachment point for muscles. A group of *apophyses* (spinelike or armlike processes) connects the endoskeleton to the head, forming the *tentorium*. This structure is usually H, X, or π shaped.

Muscular system: Insects can have between several hundred muscles and a few thousand. These are composed of striated muscle cells (marked by stripes, used for skeletal muscles in humans). These muscles are attached to the body wall and move the different parts of the insect. They typically connect to the body via *tonofibrillae*, which are fine connective fibers.

Digestive System: It's important to note that different types of diets require different systems, and a large amount of variation is present. One of the main parts of the digestive system is the *alimentary canal*, a tube that runs from the mouth to the anus. This is visibly in the featured image of this post; it is the long, central tube in the larvae. There are three main regions of the digestive system: the *stomodaeum* (foregut), *mesenteron* (midgut), and the *proctodaeum* (hindgut). Various valves and sphincters regulate the travel of food from each section.

- Stomodaeum (foregut): Usually differentiated into a *pharynx* (inside the mouth), a *esophagus* (a tube extending posteriorly from pharynx), a *crop* (enlargement of the end of the esophagus), and the *proventriculus* (often bears teeth). At the end, the stomodaeal valve regulates transfer of material to the midgut. The foregut is lined by a small layer of cuticle known as the *intima*, which often has short hairs. Another part of the digestive system is the labial glands. Most insects typically have a pair underneath the anterior part of the alimentary canal. These are often called salivary glands, but they don't always secrete saliva; Lepidoptera and Hymenoptera larvae use these glands to secrete silk.
- Mesenteron (midgut): Typically an elongate sac of uniform diameter, but sometimes is differentiated into two parts. It lacks a cuticle, and doesn't have mucus to lubricate food. The lack of mucus also means no protection for *epithelial cells*, which are typically found between the intima and the longitudinal muscles above it. Therefore, these epithelial cells secrete a thin membrane, known as the *peritrophic membrane*. It is permeable, allowing the exchange of digestive enzymes and digested foods that are ready for absorption.
- Proctodaeum (hindgut): Extends from *pyloric valve*, which is between it and the midgut. It is supported posteriorly by muscles that extend to the abdomen wall, and is usually

differentiated into two regions, the anterior intestine and rectum. The malpighian tubules are also located here, and they are how the insect excretes waste.

The final part of the digestive system is the *filter chamber*. Most Homoptera (aphids, etc) posses this. It is a modification of the alimentary canal, where the anterior part of the hindgut and the anterior part of the midgut are connected. These are usually quite distant. The midgut is differentiated into an anterior enlargement behind the stomodaeal valve, which is enclosed in the filter chamber, a croplike sac behind that, and then a long tubular section that turns to reenter the filter chamber. This is used to extract water from the food entering the midgut.

Circulatory System: Compared to a vertebrae, the circulatory system is rather open. The only blood vessel is a tube under the alimentary canal. The posterior part of this is the *heart*. It's divided into many chambers by valves, with each chamber possessing an *ostia* (lateral opening), which is where blood enters. The anterior piece is slender, and is called the *dorsal aorta*. Outside of this vessel, blood simply circulates throughout the body cavity. Pairs of sheetlike muscle bands extend from the bottom of the heart to the lateral portions of the terga, which is known as the *dorsal diaphragm*. This serves to separate the heart from the rest of the body cavity.

Blood of insects is typically clear, sometimes green or yellowish. Cells called *hemocytes* are suspended inside. The blood typically makes up 5-40% of the body weight of an insect, and it bathes the organs and the tissues of the body. It is notable that the blood does little to transport oxygen as it does in our bodies.

Tracheal System: Responsible for the intake and distribution of oxygen, as well as the removal of Carbon Dioxide. This is accomplished through many tubes, known as *tracheae*. These branch throughout the body, breaking off into finer segments called *tracheoles*, >1 micron thick intracellular tubes, which then permeate the tissues with oxygen. There are two types of systems, open and closed. In open systems, present in most insects, the spiracles can open. Closed systems have their spiracles permanently closed, and instead have a network of tracheae under their shell.

Excretory System: Consists of a group of tubes, known as the *Malpighian tubules*, which occur at the anterior end of the hindgut. The number various, however 1-200 of these tubes may be present. Waste is taken from the blood to the tubules, and then passed through the hindgut and anus. Occasionally, glands in the rectum may absorb water and salt.

Reproductive System: Insects primarily reproduce through sexual means, and usually possess distinct sexes. Parthenogenesis, or unfertilized asexual reproduction, does occur in some species, such as eusocial bees or aphids, and some species even have no known males. Gonads are present in the abdomen, with ducts opening to the posterior end of it.

- Female Reproductive System: Females possess a pair of *ovaries*, a system of ducts for transporting the egg, and associated structures. Directly below the ovaries are a group of *ovarioles*, which lead to the oviduct posteriorly, uniting in a suspensory ligament that attaches to the body wall. Usually four to eight ovarioles are present, but 1-200 are possible. Often a *spermatheca* is present, a small sac in which sperm is stored. Adhesive glands for securing eggs may also be present.

- Male Reproductive System: Primarily, there is a pair of *testes*. These are attached to sperm tubes, which then attach to the *Vas Deferens* by stalklike *vas efferens*. There are many variations on this, as well as associated accessory glands.

The Fat Body is an aggregation of cells in the body cavity used for intermediate metabolism and food storage. It is usually best developed in the later instars or larval stages, and may be depleted after metamorphosis occurs.

Nervous System: The brain connects to a *subesophageal ganglion via* two commissures. In the previous post I mentioned that there were two lobes of the brain, however Borror, De Long, and Triplehorn, an updated reference from Snodgrass, mentions three. They are the *protocerebrum* (vision), *deutocerebrum* (antennal), and *tritocerebrum* (innervates labrum and foregut).

Sense Organs are located mainly within the body wall. Most are microscopic in size and are excited by a specific stimulus.

Chemical Senses are taste and smell. These structures are variable, but usually consist of a group of sensory nerve cells whose distal processes form a bundle that extends to the surface of the body. Taste is typically a product of the mouthparts, however some insects have taste organs on their antennae, or even the tarsi of their feet (Lepidoptera and Diptera).

Mechanical Senses are that of touch, pressure, or vibration. There are three types of structures responsible for this. The first type are *hair sensillum*, the simplest tactile receptor. They are simply a seta (hair) with a nerve cell. Next are the *campaniform sensillum*, which lack seta, and instead have the nerve ending in a domelike area beneath the cuticle. The

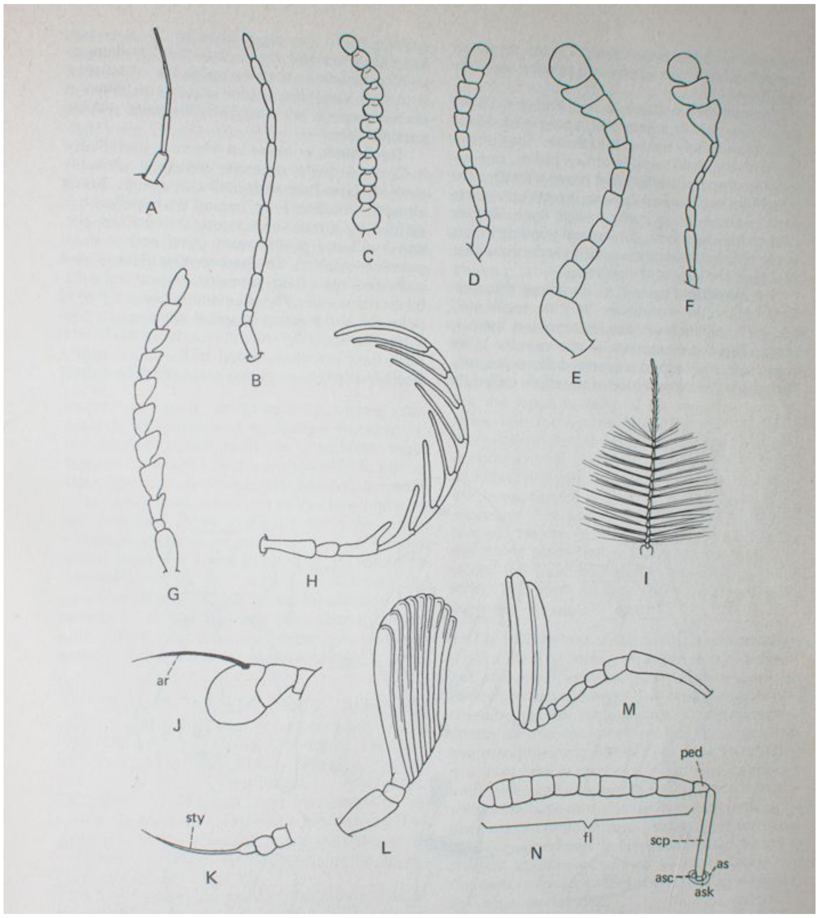
Scolopophorous organs are more complex than the prior two. They are bundles of sensory cells attached to the body wall, and are widely distributed around it. They are sensitive to the movements of the insects body. Some examples of these include subgenual organs, Johnston's organs, and tympanal organs.

Auditory Organs: Hair sensilla and tympanal organs are utilized to detect airborne sounds, however which hairs serve this function is not always clear. Tympanal organs are Scolopophorous organs with the sensory cells attached to tympanic membranes. These membranes contain air on both sides and are quite thin.

Vision Organs: These structures are sensitive to light. As I've noted in prior posts, these structures are the ocelli and compound eyes. Ocelli are composed of a single corneal lens that is elevated or domelike. There are two layers behind this lens, the corneagenous cells and the retina. Compound eyes are composed of many (up to several thousands) of individual ommatidia. They're elongate groups of cells that are capped by a hexagonal cornea lens.

Antennae: There are many different forms of antennae, varying greatly between each order, and often subtle differences between species has to do with antenna appearance. The types of antennae are listed below, with a visual key.

- **Setaceous**: Bristlelike, with the segments becoming thinner distally (towards the top). E.g.: Dragonflies. *Fig A*.
- **Filiform**: Threadlike, with segments uniform in size. Typically cylindrical. E.g.: Ground beetle. *Fig B*.
- **Moniliform**: Similar to a string of beads, with segments having similar size and typically spherical. E.g.: Wrinkled bark beetle. *Fig C*.



- **Serrate**: Sawlike. Segments are more are less triangular, especially in the top 1/2 - 1/3. E.g.: Click beetle. *Fig **G***.
- **Pectinate**: Comblike. Most segments posses long, slender lateral processes. E.g.: Fire colored beetle. *Fig **H**.*
- **Clubbed**: There are four types of clubbed antennae. The segments increase in diameter distally. **Clavate** indicates a gradual increase, a such as *Fig **D*** or ***F***. **Captitate** indicates that they suddenly enlarge, such as *Fig **F***. **Lamellate** posses expanded, laterally forming ovular plate-like lobes, such as *Fig **M**.* Finally, **flabellate** refers to lobes that extend laterally, such as *Fig **L**.*
- **Geniculate**: Elbowed, where the first segment is long and the following segments are smaller, and at an angle. E.g.: Stag beetle. *Fig **N***
- **Plomose**: Feathery. Most segments have whorls of long hair attached. E.g.: male mosquitos. *Fig I*.
- **Aristate**: The final segment is typically enlarged, and has a conspicuous dorsal bristle known as the arista. E.g.: Syrphid fly. *Fig **J***.

- **Stylate**: The last segment has an elongate terminal sty-like or finger-like process, known as the style. E.g. Robber fly. *Fig* ***K***.

These are many of the organs and structures you may find within an insect. Of course, this list is not exhaustive, and I have even left out many terms that seemed too obscure. Structures will vary between different species, family, etc, so it is best to research those individually for a fuller understanding.

Physiology and Function

The Body Wall: The body wall serves a number of functions. It provides the service of an exoskeleton, and protects the insect from outside shock. It also allows reception of external stimuli. As a result of a high body surface to volume ratio, insects lose much more water to evaporation. The epicuticular layer resists water loss, and some insects can further prevent this by closing their spiracles. It's also worth noting that the cuticle is not easily wetted, and sprays often need a wetting agent to stick to the shell. Gasses enter the body via the tracheae, although diffusion can occur through the body. Lipid-solubles generally penetrate the cuticle the best.

The exoskeleton is quite rigid, although less so in insects with chemical defenses or color markings. It is significantly stronger than the endoskeleton, and possesses more attachment sites for muscles. This strength is very important for flying, as it affords insects protection against collision. Smell organs can be located just about anywhere on the body, which is advantageous. There are downsides to this system. Discontinuous growth is necessary, and each molt the exoskeleton must be shed. During this time, an insects soft tissues are what supports it. This is the stipulation that limits the size of insects; an insect the size of a mammal would be crushed during this period.

Digestion and Nutrition: Solid food is broken up by the mouthparts as well as the teeth in the proventriculus, and then is subjected to digestive enzymes. Most insects eat with their mouths, and saliva serves to prevent coagulation of blood, as that would clog the food channel. Some insects inject digestive enzymes into the food before they even begin ingesting it. Aphids, for example, inject amylase into plants, so they can digest the starch inside. The enzymes vary greatly depending on diet, and may be general or specialized. Omnivorous insects typically produce lipases (for fats), carbohydrates (starches & sugar), and proteolytic (protein) enzymes. Most species cannot digest cellulose, however microorganisms that can may be present. Typically these are bacteria or flagellated protozoans, often housed in special organs near the gut.

Insects require the same ten amino acids that we do: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. They also require various B vitamins, sterols (such as cholesterol or stigmasterol), several minerals, and some nucleic acid derivatives. They are unable to synthesize the amino acids nor the sterol. The quantity and quality of nutrition has a great impact on development.

Respiration: The respiration is carried out entirely by the tracheal system, which was detailed in the previous section.

Blood & Circulation: An insect's blood transports salts, hormones, digested material, and metabolic products throughout the body. There is homeostatic regulation of the water salt ratio in the body. Blood is also very important for inflating the wings, as well as for molting.

An insects blood consists of plasma and hemocytes. There is little oxygen present, and over twenty times as much amino acids compared to mammalian blood. The plasma has a high concentration of uric acid too, comparatively. There are about 50,000 hemocytes per square mm. The functions of these hemocytes varies greatly. Some examples include those that encapsulate foreign bodies inside the blood, migrate to wounds, and conduct phagocytosis (ingestion of bacteria).

Circulation is created by pulsations of the heart, with the help of accessory pulsatile organs. The rate varies from 14 to 160 BPM. There is typically an increase in rate with increased activity. The insect circulatory system is very low pressure, and is sometimes even less than atmospheric pressure. When molting or inflating wings, insects may increase the pressure by holding air in the alimentary canal.

Blood is also responsible for homeostasis, or the maintenance of water content, pH (usually 6.0-7.5), salt content, as well as other factors.

Chemoreception: Involved in many insect behaviors. Feeding, mating, and habitat selection ago hand in hand with behavioral responses to chemicals. These reactions are often very specific, and chemically similar compounds can yield entirely different reactions.

Hearing: Insects are usually sensitive to 200-3000 hertz, although certain moths and Orthoptera can hear into the ultrasonic range, at over 100,000 hertz. Airborne sound is detected by small seta, or hairs. Some insects are not adapted to hear airborne sounds, but may hear sounds through substrate. A honey bee is an excellent example of this.

Vision: There are four types of photoreceptors present in insects: dermal receptors, dorsal ocelli, lateral ocelli, and compound eyes. Many types of larvae that lack ocelli or compound eyes will react to light. Dorsal ocelli react to the intensity of the light, but do not form an image. Lateral ocelli form images on retinal cells, and are likely capable of basic color and form recognition. Compound eyes posses light sensitive elements known as rhabdoms. Each cell has a small visual angle, coming together to form a mosaic view.

An advantage of insect vision is its high flicker fusion frequency, or the point when light appears continuous. Think of a flickering fluorescent light versus a working one; both are flickering, one appears continuous to us. Insects can see up to 250 pulses per second, compared to humans 45-53. This allows them to be very sensitive to motion, and perceive forms while rapidly flying. Some insects also possess depth perception.

The visible waves of light to insects are 2,540-7,000λ, compared to human's 4,000-8,000. This allows them to see ultraviolet, and honeybees even analyze polarized light to find the location of the sun.   Many insects appear to be colorblind, however others can observe colors including UV.

Reproduction: Eggs are developed in the ovarioles inside the ovaries. This is controlled by at least one hormone from the Corpora allata. This has been proven; removing the Corpora allata prevents egg function, and reinserting it makes reproduction begin again. Neurosecretory cells in the brain may produce the hormones that affect the Corpora allata.

Impregnation has a lot to do with external stimuli, such as sounds, scents, and body forms. This supersedes the compatibility of the gonads. Interspecies hybridization is quite rare because of the species specific stipulations involved in mating. Male insects have one X chromosome (XY), while females have two (XX). Eggs posses an X chromosome, while sperm may or may not possess an X (1/2 chance), therefore sex is determined when the eggs are fertilized. Some insects, such as Hymenoptera, have haploid (unfertilized) males, and diploid females, so unfertilized eggs will hatch into males.

Muscle Action: Insect muscles are unique in that they are capable of rapid contraction, with wings often stroking at 100/s, or even as high as over 1000/s. These contractions occur much faster than the nerve impulses reaching them, so these results are properties of the muscles themselves, not the brain. This also means that they must be extremely efficient muscles, with a high energy output.

Energy Sources: Obviously, food is where insects derive their energy. Most of the energy used by muscle contractions comes from carbohydrates. This is apparent, as glycogen stores are depleted after extensive muscle activity, with the products of said activity being water, CO2, and energy.

Body Temperature: Insects are primarily cold blooded, or poikilothermic. It is possible for an insect to raise its body temperature through activity of the thoracic muscles. These are the muscles associated with flying, however they may be contracted without moving the wings. Most flying insects are 5-10°C warmer than their environments, however moths and bumblebees may raise their temperature 20-30°C warmer!

Coordination of Bodily Systems: These systems work together via the Nervous and Endocrine systems.

Nervous System: The central nervous system is responsible for rapid adjustment to environmental changes. The three types of nerve cells are motor, internuncial, and sensory. Internuncial cells connect the CNS together, while sensory and motor cells are self explanatory. The Ganglia of the CNS are coordination centers for the body; these are the brain, subesophageal ganglion, and segmental ganglia of the ventral nerve cord. Most of these are autonomous, to some extent. Some activities require use of the brain, however many can occur with the brain absent.

Endocrine System: The endocrine system is made up of hormone producing glands. Hormones are chemical substances that produce effects on physiological processes. They control reproduction, molting, and metamorphosis, as well as other functions. Molting is caused by prothoracic glands secreting ecdysone (C27H44O6), which initiates growth and development. Interestingly, some plants produce substances similar to ecdysone and other juvenile hormones, making them toxic to insects! Evolution at work.

Pheromones: Pheromones are chemical signals used between the same species. They have slow transmission, but last a long time and are often effective at long ranges, even several miles. Pheromones serve many functions. Some of these include alarm substances, sec attractants, individual group recognition, aggregation formation, trails, and caste determination. Many pheromone compositions are known, and farms can even use them for pest control against specific species. Some of these pheromones are specific chemicals, while others are specific quantities of many chemicals. Oftentimes, similar species use the same chemicals in different concentrations.

Behavior

Insects display a wide variety of behavior, some of which is very unique. Their responses are largely hereditary and automatic, and usually they aren't learned. They respond to light; some are attracted, while others may be repelled. This often has to do with other pieces of their behavior. For example, an insect living inside of bark may avoid light, while a moth may fly to a flame (more on that later). Insects are very responsive to certain chemicals, as they may lead them to food, a mate, or an oviposition site (a place to lay eggs). These responses may change as environmental conditions change. A honeybee will have a positive reaction to light when it's warm, but may have a negative reaction to light when the temperature is lower, likely a reaction to light reaching inside the hive.

The stimuli are sometimes quite specific. Moths are known for flying to candlelight. It turns out, males do this significantly more than females, because the flickering flame is similar to infrared signals emitted from the thorax of female moths. Moths have even been observed trying to mate with candle flames!

Complex Behaviors

Although many insect behaviors appear well thought out, almost all of them are mechanical in nature. They are mostly automatic, and are performed the same way by all members of the species. The first time an insect does something will be just as well as the last time, there is no need for practice. These behaviors typically persist because they are evolutionary advantageous.

Insects possess a circadian rhythm. Some wake during the day, others the night, or both. These appear to be controlled mostly by environmental factors, such as the lower temperature and light values, however some insects do possess some form of internal rhythm, and show diurnal activity despite being placed in continuous light or darkness.

Are insects intelligent? That's an abstract question, and certainly depends on your definition of intelligent. If it is defined as the capacity to modify behavior through experience, most insects have limited capacity to learn. Borror, De Long, and Triplehorn state there is little or no evidence to suggest they can think. Insect brains are capable of action-target selection, processing sensory information, and executing command functions over the body. I would certainly argue that this is a form of intelligence, but you can make your own distinctions.

Locomotion: Leg joints may be dicondylic or monocondylic, meaning they have either one or two points of articulation. Dicondylic joints typically move through one plane while mono joints have more varied movements (think ball and socket). Legless larvae and caterpillars move by pushing their prolegs forward, with a wave passing through the body. Usually two or three segments are involved in this motion. Jumping insects are usually propelled by the hindlegs, except in springtails.

Flight: Flying is one of the most distinctive features of insects, and is one of the major reasons they are so distributed and widespread. The wing structures are deflated when they first appear after molting, and have heavily sclerotized veins that provide support. They are hollow, and contain blood, tracheae, and nerves. The base of the wings are membranous, with several articular sclerites. There are usually five paired muscle groups, the tergosternal, dorsal longitudinal, phragmata, basalar, and axillary muscles. During movement, the fore and hindwings may be connected, or not. These movements are typically complex, and often move on many axes. They may fold, twist, or buckle, and often move in a figure eight motion. Forward flight is similar to a propeller; each wing draws air backwards, forming a low pressure zone above the insect, and a high pressure zone behind it. This creates lift and forward movement. The stroke rate may vary wildly. A butterfly could move at a few strokes per second while a fly (such as the *Bombylius major* pictured below) may move its wings as much as 400 times per second. Flight speed is widely variable, with the upper limit usually being about 35 mph. Considering the relative body size, this is pretty incredible, and allows insects to quickly move many times the lengths of their own bodies.

Migrations: Usually, these are one way trips, with the next generation making the opposite migration. Monarchs are notorious for their trips, and have been observed flying as many as 1,870 miles, from Ontario to San Luis Potosi, Mexico. In the US, you can expect North to South migrations, with breeding typically occurring in the Southern areas.

Feeding Behaviors: Insects are generally phytophagus (herbivorous) or zoophagus (carnivorous), however there is certainly overlap within some species.

Phytophagous Insects eat plants, and almost all agriculture pests fall under this category. There are several approaches to this. Chewing mouthparts lead to holes or skeletonized leaves, and with a large enough population can lead to defoliage. Grasshoppers, sawflies, caterpillars, and beetles eat like this. Sucking insects usually cause a browning or spotting on leaves, or curling and wilting. Think of aphids, froghoppers, and true bugs. Some feed between plant tissues, tunneling between two surfaces in the leaf; these are the leaf miners. Each species possess a different pattern, and many of these have been documented. Stem borers are typically larvae, and they bore into the stems, roots, or tubers of a plant.

There are some interesting, unique feeding behaviors as well. Certain ants, ambrosia beetles, and termites will use fungus to help digest their food. In these ant colonies, leaves are cut, then ‘seeded’ with fungus, which breaks down the leaves into something edible to the insect. When new queens leave to create colonies, they take a small amount of this fungus before leaving the colony. This is certainly food for thought when considering insect intelligence. Galls are another plant related behavior that I'm going to throw in here. A chemical is injected into the plant that makes it grow abnormally, producing a gall. Each species will have a different gall form. Typically the feeding larvae injects the chemical, however sometimes it is the ovipositing female.

Zoophagous Insects are usually insect feeders, but not always. In agriculture, these are generally considered beneficial insects. It's not always that simple, but usually if it eats pests and doesn't bother plants, it's good. There are two categories that usually have limited overlap: predators and parasites. Predators usually eat insects smaller than them, and typically consume them all at once. These are usually powerful, active insects. Parasites live inside or on a host, and live with them continually for at least some of their life cycle. If it is an insect parasite, it is generally known as a parasitoid. These generally do end up killing and consuming their hosts, unlike a flea or a tick that simply lives off of it.

Saprophagous insects are also notable, and these feed on dead or decaying plant and animal matter. This can include carrion, dung, leaf litter, dead logs, etc. Dermestid beetles are a good example of this, and are often used in forensic entomology. Sometimes the insects don't feed on the matter, but rather the microorganisms living in it.

Defensive Behavior: A wide variety of defensive behaviors are displayed in insects. Some are passive, such as when a caterpillar plays dead when something encounters it. I have observed Noctuids (larvae and adult) displaying this very behavior. Other insects stay protected by hiding in shelters. Often they will burrow into plant and animal tissues, or underneath rocks, soil, or litter.

Camouflage is another viable strategy for many insects. By mimicking the colors and textures of their host plants, they can remain undetected to predators. Batesian mimicry is also common in insects. This is when patterns that are negatively reinforced by another toxic or distasteful insect are copied.

While this is sometimes effective, many parasitoids have specialized ovipositors that can pierce through surfaces, into the insects underneath. The snakefly pictured is a fantastic example of this, and pierces into insects inside downed logs. Some species defend themselves by constructing cases, Lepidoptera especially. Many Hymenoptera make homes for their larvae, usually enclosed with a food source (often paralyzed insects).

That leads us into chemical defenses. Many insects simply are distasteful, or even toxic, to ingest. Monarch butterflies are a great example of this, and they are known for making unknowing birds vomit them up. This is not a mistake most animals will make twice, especially given the bright orange markings. There are often very specialized defenses; for example, Tobacco Hornworms (Manduca sexta) can spray nicotine on predators.

Of course, simply biting or stinging can be an excellent defense. Typically insects don't inject venom via their mandibles, so bites are generally just severe pinching. Stingers can inject venom, and piercing mouthparts often are similar to hypodermic injections. Whether or not a piercing insect will cause irritation depends on the insect and the individual. It is also notable that other arthropods, such as spiders, ticks, and centipedes, can inject venom when biting.

Acoustic Behaviors: Many insects make noise, most of which we cannot hear. They are often too soft in volume or too high pitched for the human ear. The CNS discriminates rhythms, and what causes behavior varies from each species. There are often different pulse rates in different groupings. Song can occur semi-continuously, or only at night or day. Individuals in the same species often synchronize their songs, regardless of if another species is singing near them. Interestingly, the rhythm often depends on temperature, and a female may not to react to a singing male if she is a different temperature than him.

Sound behaviors are used for a variety of reasons. Some Noctuid moths have highly developed ears so they can avoid bats using their echolocation. It is believed that insects that make noise when they are caught do so to try and scare away their captor, or perhaps to alert other insects nearby. Field cricket males have been observed using their songs to mark territory, changing to an ‘aggression song’ when another male enters their area. Song can help bring mating pairs together as well, although other stimuli is used to initiate mating.

Social Behaviors: Aggregations of insects may occur as the result of a mutual positive reaction between a large group of individuals of the same species, such as a gathering on a dead animal or at a light. Hibernation and sleeping aggregations are common as well, such as when monarchs migrate. Perhaps the most interesting social behavior is insect society- which will be discussed below.

Insect Society: Social insects live in a family group, with the older members coexisting and caring for the young. Often these societies function as a singular unit, and are comparable to individuals. Each member is autonomous, but serves the society. Polymorphism is often present, with different members separating into castes and performing different functions.

Hymenoptera, for example, have queens, drones and workers. These are some of the most interesting species of insects; often the individuals will respond differently to conditions as the situations change. Honeybees (Apis mellifera) are the penultimate example of this, and change which functions they perform as they age. These societies can be incredibly complex, and often the way they work varies.

Development & Metamorphosis

Insects develop in a number of different ways, and some change considerably between their larval and adult forms; butterflies are the typical example of this. This post will cover the basics of these processes, as well as descriptions of many larval forms.

Eggs: Insect eggs vary greatly in appearance. They're usually spherical, oval, or elongate, and are covered in a shell of varying thickness, color, and shape. Sometimes these eggs have spines or other protrusions, and eggs can often appear quite strange. Lacewing eggs have a small stalk that they hang off of plants from, a good example of an odd egg. Usually the eggs are laid directly onto the host of the larvae, so it can find food without too much travel, something critical to an insects survival. It is for this reason that crop rotation can be such an effective tool in pest control, as a travelling insect is at much higher risk than a stationary one. Parasitic insects often lay their eggs inside or on the body of their host, and many wasps will even paralyze prey and trap them, so the larvae has a safe space to develop and eat.

Metamorphosis: There are two types of metamorphosis, simple and complete. In the former, the wings develop externally during the immature phase, and there is no resting phase before completion of the last molt. Shield bugs are good examples of this, as they develop continuously from nymphs into their final adult form, without pupation.

Complete metamorphosis has the wings developing internally during the immature stage, and then has a pupal stage before the final molt. This change is controlled by a brain hormone, a molting hormone (ecdysone), and a juvenile hormone. Many internal structures change during complete metamorphosis. The heart, nervous system, and tracheae usually remain intact, but elements such as the blood, fat body, and larvae muscles may be repurposed. The processes involved in this are called histolysis and histogenesis. In histolysis, larval structures are broken down into material usable for creation of adult structures. Histogenesis is the creation of those structures using said materials.

Types of Larvae:

Eruciform: Caterpillarlike, with a cylindrical body, and a well developed head with short antennae. They possess both the thoracic legs and abdominal prolegs. Examples of this include Lepidoptera, Mecoptera, and some Hymenoptera.

Scarabaeiform: Grublike, and usually somewhat curved. The head is well developed, and thoracic legs are present, while abdominal prolegs are absent. The larvae will appear inactive and somewhat sluggish. Many Coleoptera are examples of this.

Campodeiform: Resembling diplurans in the genus Campodea. Their bodies are elongate, somewhat flattened, with well developed cerci and antennae. Thoracic legs are developed, and the larvae is usually active. Examples can be found in Neuroptera, Trichoptera, many Coleoptera.

Elateriform: Wireworm-like, with elongate, cylindrical bodies. They are hard shelled with short legs, and some reduced body bristles.

Vermiform: Maggot-like, with elongate bodies similar to worms. They have no legs, and may or may not have a developed head. Many Diptera, Siphonaptera, most Hymenoptera, some Coleoptera, and some Lepidoptera.

Types of Pupae: There is a lot of variety into pupae, but they fall into three main categories.

Obtect pupa have their appendages more or less glued to their body. Lepidoptera, as well as some Diptera, pupate this way. Additionally, many Lepidoptera will make themselves a silk cocoon.

Exarate pupa have freed appendages, and often look like a pale, mummified versions of the adult. This is typical in Diptera and other non Lepidoptera larvae. The final kind is **coarctate**, which is similar to exarate, except the pupae is covered by a hardened skin from the second to last larval instar, known as a puparium. This is typical in higher Diptera.

Hypermetamorphosis: This occurs when different larval instars are not the same kind. Typically, the first larvae is active and campodeiform, while subsequent forms are vermiform or scarabaeiform. This cycle is more common in parasitic insects, where the first larvae may have to enter the host, then can molt and become less active.

Caste Determination: Oftentimes, workers are separated from the queen by not being able to reproduce. In honeybees, caste very much has to do with this, and sex. Male bees are drones, and only reproduce. Queens have developed reproductive structures, while workers do not. This likely has to do with a pheromone the queen excretes that inhibits ovary development and queen production. When the queen is missing, ovaries in workers may develop.

Dormancy: Most insects in temperate regions have a heterodynamic life cycle, meaning the adults appear for a limited time during a season, while one part of the life cycle stays dormant throughout the winter. It's notable that this can be any part of the life cycle: the egg, larvae, pupae, or adult may go dormant. Other insects may be homodynamic, with continuous development and no regular dormancy period. This is more common in tropical environments. Most insects in the US have one generation per year, and some large beetles or moths may even have development times of two or more years. Other insects may have multiple generations per year, and continue producing as long as weather permits. Most agricultural pests are this way, aphids being a prime example.

Dormant insects have no visible activity, with greatly reduced physiological processes. This state can last a few days to a several months. Hibernation is cold dormancy, while aestivation is dormancy in high temperatures. Although environmental factors play a large role in deciding whether or not to go dormant, genetic factors also play a large role. Many species may go dormant before conditions are unfavorable, and often this can only be broken by lowering the temperature and then raising back to a favorable temp. Photoperiod is also likely to play a role, with the length of the days triggering responses.

Collecting and Preserving Insects

Insect collecting can be done at any time, although they are mainly present during spring, through late fall. Summer is probably the best time, as insects are most abundant. Warm, sunny days will likely have the most insects present, however it would be wise to check throughout different times and weather conditions, as different insects will emerge at different times. At night, street lights and porch lights are a great place to look. Leaf litter and plants are likely to house insects, and there are also many nocturnal insects that stay away from lights.

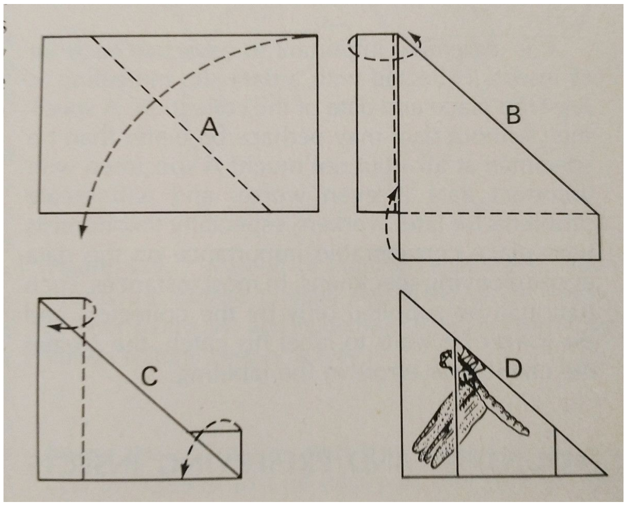
Collecting Equipment:

- **Insect Net –** These can be bought or made. They should be made from netting, which is stitched to a muslin or canvas cloth that wraps around the wire. From there, the insect can be transferred to a jar, either by putting the jar into the net, or by holding the insect by the thorax.

- **Killing Jar –** It is best to have 2-3 jars in many shapes of sizes. Ideally, they are corked, however this may depend. They should be conspicuously labeled “POISON”. Plaster or cotton is added to the jar to hold the killing agent. Borror, Delong, and Triplehorn recommend cyanide, however ethyl acetate can also be used and is significantly safer. Carbon tetrachloride or chloroform can also be used.

- **Pillboxes with tissue**
- **Envelopes, or paper to make them –** Useful for temporary storage. These can be easily constructed in the field and will keep your specimens relatively safe.
- **Vials filled with preservative liquid**
- **Forceps**
- **Hand lens**
- **Aspirator –** These capture small insects into vials using your breath. Typically they have a screen to prevent you from breathing the insect in.
- **Beating umbrella or sheet –** A sheet or umbrella is placed beneath a plant, which is then beaten or shaken so that small insects fall onto the sheet.
- **Sifter –** Leaf litter can be sifted slowly onto white cloth or cardboard, and then insects found can be aspirated.
- **Traps –** There are many types of traps. A Berlese funnel has a funnel with a screen, and a light bulb on top, with alcohol at the bottom. Insects are attracted then fall into the killing jar. A light trap can be effective on some insects, and can be as simple as a light above the killing agent, or a walk in trap where insects settle and can be collected by hand. Pitfall traps can be used on carrion beetles or other non flying insects, and are simply cans with bait at the bottom. Insects fall in then cannot escape. A simple trap could just be a sugar solution spread on a surface.
- **Headlamp**
- **Sheath Knife**

Handling the Catch: Many soft bodied insects can be placed directly into 70-90% isopropyl or ethyl alcohol. This includes larvae and nymphs of many species, as well as some smaller



insects. Hard bodied insects should be put in the killing jar. The length that it takes depends on the insect as well as the killing agent, and may range from a few minutes to a few hours. When the insect is dead, it should be removed as soon as possible to prevent additional discoloration. These can be stored in pill boxes or the paper envelopes pictured.

Relaxing: If you cannot pin and spread a specimen immediately, it will likely dry. When it is in this state, it is quite brittle and will break if you try and arrange it. To fix this, you can either use a relaxing chamber, relaxing fluid, or boil the insect in water (however this may damage it).

Relaxing chambers are containers with wet sand or cloth inside. Ideally, carbolic acid should be added to prevent any molding. After a day or two you should be able to manipulate the specimen again. Relaxing fluid can be made from different mixtures, and usually you leave the insect in it for several minutes. One mixture, often known as Barber's fluid, is listed below:

95% ethyl alcohol	50 cm3
Water	50cm3
Ethyl acetate	20 cm3
Benzene	7 cm3

Another method that can be used is tap water injection. This works on many Lepidoptera. Using a 20-25 gauge needle, inject water into the thorax under the wing until it is completely filled. After 5-20 minutes, your insect should be relaxed.

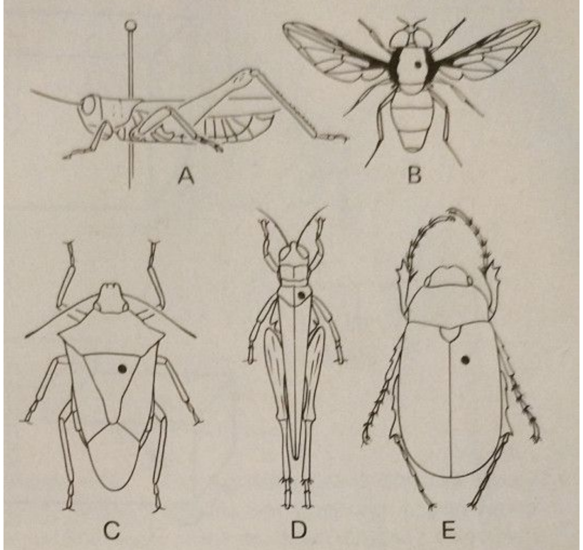


Figure 619. Methods of pinning insects. A, specimen in lateral view showing method of pinning grasshoppers; the black spots in the other figures show the location of the pin in the case of flies (B), bugs (C), grasshoppers (D), and beetles (E). (Courtesy of the Illinois Natural History Survey.)

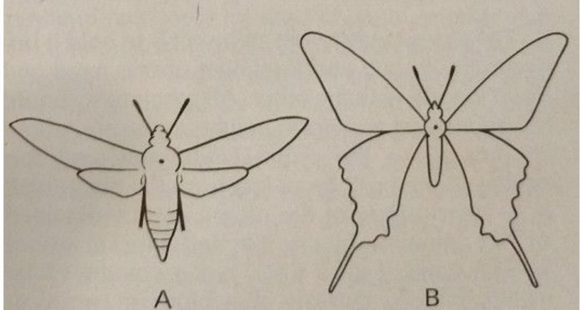


Figure 620. Method of pinning Lepidóptera. These insects are pinned through the center of the thorax, in both moths (A) and butterflies (B). (Courtesy of the Illinois Natural History Survey.)

Preservation in Fluid: This can be used on many soft bodied insects (such as mayflies, stoneflies, caddisflies, etc), which can't be pinned unless they are dried as mentioned above. It's also useful for very small specimens that are going to be studied on microscope slides, and insect larvae and nymphs.
Non-insect arthropods should be preserved this way as well.

Pinning: This is the easiest way to preserve a hard bodied insect. The colors often fade when the insect dries, however this is difficult to avoid. Specialty insect pins should be used, which are longer and do not rust. These are available in sizes 00-7, however the smaller ones may be less applicable. Different orders should be pinned in different areas, which is pictured. Legs should be extended, as well as the wings. Oftentimes bees will have their tongue extended for easier identification. Also, it is best if all species in a collection are pinned to uniform distances. About 25mm above the point is ideal, and uniform distances can easily be attained by using a pinning block, which is simply a block of wood with holes drilled to different depths. Spreading an insect is very much about practice. Using a spreading board makes the task much easier, and having extra pins and paper strips is essential. Pins can be used to move around limbs and wings.

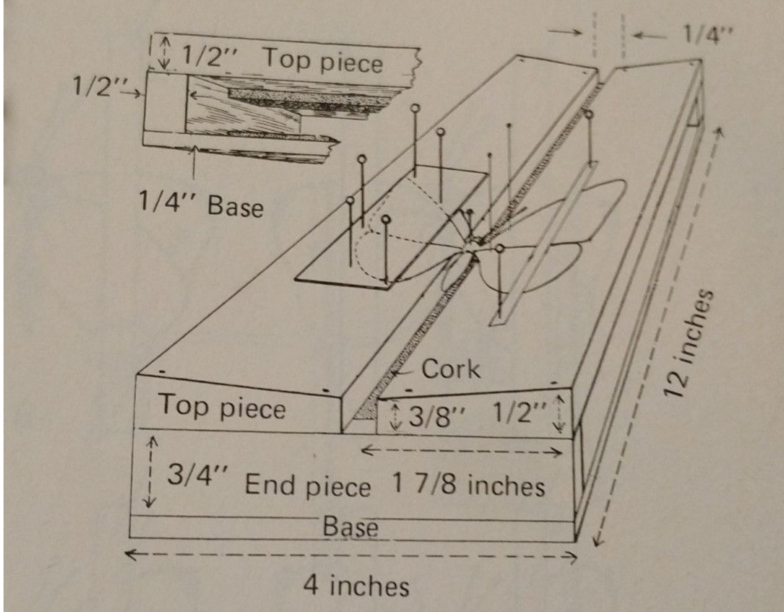


Figure 622. The spreading board, showing dimensions, details of construction (inset), and a spread specimen. The wings of the specimen may be held in place by a single broad strip of paper as shown on the left wings, or by a narrower strip and pins as shown on the right wings. (Courtesy of the Illinois Natural History Survey.)

A spreading board makes positioning an insect much easier. illustration taken from the book.

Typically pressure should be applied to the front marginal wing vein, especially in Lepidoptera. The rear margin of a Lepidoptera's wings should be at a right angle with its thorax, and the hind wings up so there is no gap between them and the forewings, as pictured. It's Important to be very careful, and use forceps to handle the insects. They are very fragile, and often scales and antenna can be easily knocked off. Paper strips and pins can be used to secure wings, and then they will stay in position after they dry. Small insects need some ingenuity to be mounted, and can be glued onto card tips, tiny pins, or microscopic slides. You simply pin the card tip, put a tiny amount of glue onto it, then glue the insect on.

Drying: Many pinned insects can be air dried in a warm, dry location. Larger moths may need a drying chamber with one or multiple light bulbs inside, and some large specimens may even need to have their abdomen organs removed. There is no definitive time it takes a specimen to dry, however this will come with experience.

Soft bodied insects may be freeze or vacuum dried and then pinned, to create a non-fragile, non-discolored specimen. Typically they would shrivel, however this step makes them dry enough to stay on a pin.

Typically an ethyl alcohol solution is used as a killing agent. Some common ones are listed below.

Hood's solution	
70-80% Ethyl Alcohol	5 cm3
Glycerin	5 cm3

Kahle's solution	
95% Ethyl Alcohol	30 cm3
Formaldehyde	12 cm3
Glacial acetic acid	4 cm3
Water	60 cm3

Alcoholic Bouin’s solution	
80% Ethyl Alcohol	150 cm3
Formaldehyde	60 cm3
Glacial acetic acid	15 cm3
Pitric acid	1g

While we are on the topic of solutions, Ethyl acetate can often be ineffective on larvae, so here are killing agents that are sufficient:

KAAD mixture	
95% Ethyl Alcohol	70-100 cm3
Kerosene (reduce for soft body larvae such as maggots)	10 cm3
Glacial acetic acid	20 cm3
Dioxane	10 cm3

XA mixture	
95% Ethyl Acetate	50 cm3
Xylene	50 cm3

Both methods should take 1/2 – 4 hours. All known killing agents remove color, especially greens, allows, and reds. Typically, preserved specimens should be inspected once or twice a year, in case any liquid has evaporated. If so, it should be replaced.

Mounting on Microscope Slides: There are two types of microscope mounts: permanent and temporary. They use different mounting mediums, and temporary mounts usually have their specimens returned to preservative after the mounting, where it may be kept indefinitely. Permanent mounts are mounted once and then can not be removed, however they may last quite a while, even several years.

Many soft body insects can be put straight into mounting medium, however some need to be cleared in a special fluid first. The main solutions used for this are KOH and Nesbitt's solution. This process often involves the insect soaking for several hours to many days when done cold, although it can be done quicker using heat and KOH.

Small specimens can be mounted in a normal slide, while larger ones may need a depression slide or support for the cover glass.

The mediums used for temporary slide mounts include water, alcohol, glycerin, and glycerin jelly. Water and alcohol may only last a few minutes before evaporating, so glycerin is generally used if specimens want to be studied for any extended period of time.