

## Unit 5 of Entomology

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### Unit 5: Insect Maintenance

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In this unit, you'll learn how insects digest their food, breathe oxygen, and circulate their body fluid. In unit four you were introduced to the insect's reproductive system by comparing it with our human system. As you go through this unit, continue this comparison by thinking about how the insect's digestive, respiratory, and circulatory systems compare to our own. As you make these comparisons, keep in mind that insects and mammals are so distantly related that any similarities in these systems must be the product of convergent evolution, and that's the independent evolution of structural or functional similarities. A common example of convergent evolution are the wings of birds and the wings of bats, structures that are very similar but evolved independently. Also, don't forget to refer often to the unit objectives and the study guide.

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By the end of this unit you should be able to describe the embryonic origin of the alimentary canal divisions, draw and label a generalized alimentary canal and describe the function of each component. You should be able to draw and label generalized insect circulatory system and describe the circulation pattern of the insect's hemolymph. You should also be able to describe the tracheal system of insects and define the trachea, tracheoles, and taenidia. And lastly, you should be able to describe how insects maintain the proper body temperature and how they keep from freezing.

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Let's begin with the digestive system. The alimentary canal, or the digestive tract, is very similar to what's found in vertebrates. In fact, by looking at the diagram below, you can probably pick out some of the structures just by the shape and can guess some of the functions. Some of the structures are unique to insects, though, and you won't find them in humans. If you take a look at the alimentary canal, you'll notice that it's divided into three regions: the foregut, the midgut, and the hindgut. These regions also have other names: the stomodeum, the mesenteron, and the proctodeum. You may see these terms as you're going through your textbook and doing the reading for this unit. You'll notice that the digestive system begins at the mouth and ends at the anus. Let's take a look at some of these structures before we move on to the alimentary canal quiz. Let's begin with the foregut. As you know, insects have many different types of mouthparts, and they use these mouthparts to manipulate food into their mouth. Once the food enters the mouth it goes into a buccal cavity, or a buccal chamber. So then the food is sucked through the mouth opening into the pharynx by contractile muscles. So as you can imagine there are strong muscles in an insect's head region. If insects have a piercing-sucking type of mouthpart, they have a cibarial pump, which helps to suck the food up the piercing-sucking mouthpart into this buccal chamber. So from the buccal chamber, the food passes into the pharynx. From the pharynx it goes into the esophagus, and it gets there by means of peristalsis, and this is a rhythmic muscular contraction that moves the food along the digestive system. The esophagus is a simple tube, it's just a connecting tube to connect the pharynx to the crop. And if you're familiar with birds, you know that birds also have a crop, it's just a food storage organ. The food will remain there until it can be processed through the rest of the digestive system. While the food's in the crop, it's already been exposed to enzymes from the salivary glands and sometimes enzymes are actually regurgitated from the midgut to help in digestion while the food is waiting in the crop. On the posterior end of the crop there is a muscular opening called a proventriculus. And this organ contains toothlike denticles that grind up food particles. The proventriculus is very similar to a gizzard in birds. After the food has been crushed by the proventriculus, the food goes through the stomodial valve, which is a sphincter muscle located just behind the proventriculus. It regulates the flow of food from the foregut to the midgut. The midgut, or ventriculus, is where most of the digestion takes place. This is where the enzymes are to digest the food, so that the insect can absorb the nutrients. At the anterior end are fingerlike projections, and these projections are called gastric caeca. And they provide extra surface area for the secretion of enzymes or the absorption of water or other nutrients from the alimentary canal. Inside the ventriculus, there are digestive cells that line the inside wall and these little cells have microscopic projections, called microvillae, that increase

the surface area there for nutrient absorption. And you have all of this food passing through the digestive system so the insect has to protect its delicate membranes and delicate cells from being harmed by this food passing through. So some insects have a peritrophic membrane, and it consists of little chitin fibrils embedded in a protein matrix, and it protects the delicate cells without stopping the absorption of nutrient molecules. So at the very end of the midgut there's another sphincter muscle called the pyloric valve, and it regulates the flow of material, all of this digestive material, from the midgut to the hindgut. The main function of the hindgut is to maintain homeostasis by regulating the absorption of water and also salts from the waste products in the alimentary canal. At the very beginning of the hindgut, there is a series of spaghetti-like structures called malpighian tubules. Sometimes there are just a few dozen, sometimes there are a hundred, and these long structures float throughout the abdominal cavity, and they serve as excretory organs. They remove the nitrogenous waste from the hemolymph, and then convert it to urea through a series of chemical reactions inside the tubules and eventually to uric acid. And once the uric acid is formed, and it's formed as a semisolid, it accumulates and is eventually emptied into the hindgut, and is excreted as part of the fecal pellet in most insects. In some insects, the hindgut is divided into an ileum, a colon, and a rectum. And a neat thing about the rectum in some insects, especially things like termites that have to conserve water, there'll be rectal pads. So on each side of the rectum, there'll be like six pads that actually will absorb water from the fecal pellet right before it's excreted. So some insects have a very unique shape to their feces. OK, now that you've had an overview of some of the structures, be sure to do your textbook reading and continue on with the following quiz.

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See if you can answer the following questions. If you have any trouble, refer to your study guide or to your textbook readings to find the answers.

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Now let's review some of the functions of the insect digestive system. Make sure that you have table 1 and diagram 1 on your study guide properly filled out. The mouth opens into the pre-oral cavity, which grinds and receives the food as it first enters the body. The first region of the foregut, which is heavily muscled to help in swallowing, is the pharynx. The esophagus continues to swallow food and dumps it into the crop. It's basically just a connective tube. The salivary gland secretes fluid to lubricate food as it passes out of the pharynx and down to the esophagus, and then into the crop. The salivary glands secrete digestive enzymes. The crop stores food while the midgut enzymes are allowed to enter through the proventriculus to digest food. And the proventriculus acts as a valve between the crop and the midgut and often contains heavy denticles for further grinding of the food.

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Now the midgut. The midgut secretes digestive enzymes in the peritrophic membrane. It absorbs nutrients from food broken down by the digestive enzymes. So this is where the insect gets most of its nutrients. The gastric caeca are fingerlike pouches off of the midgut. They're known to house symbiotic bacteria, also to aid in digestion. The malpighian tubules filter harmful substances and nitrogenous wastes from the hemolymph, and eventually secrete it into the hindgut for expulsion. The peritrophic membrane is secreted by midgut cells, and it protects the cells of the midgut and the hindgut. It encloses the food but is still permeable to the enzymes, and permits the digestive products to leave and be further digested or absorbed by the midgut cells. Now we're going to enter into the hindgut. The ileum is the first part of the hindgut; it's larger than colon. The colon is just the narrower portion of the hindgut. The rectum is the posterior part of the hindgut. It dehydrates the waste and compresses it into small pellets. And the anus is the muscular area that expels compressed waste out of the insect's body.

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How the gut is formed in an insect is a very fascinating topic. As an insect egg develops, there are two layers of cells within the egg: an inner layer called the endoderm, and an outer layer called the ectoderm. While the egg matures, the ectoderm layer begins to turn inward on both ends, the anterior and posterior ends. If you look in diagram A, you can see how it begins to move in, just like a finger was pushed through. Well, at the same time the endoderm layer begins to form the midgut. As the ectoderm layers are turning inward toward the developing midgut, the two layers eventually fuse together and form

a completed alimentary canal. In letter C you can see that fusion. Since the foregut and the hindgut develop from the ectoderm, they have a cuticular lining similar to the outer cuticle that makes up the exoskeleton. So there is cuticle inside the gut. Just as the exoskeleton is made up of chitin and proteins, so is the cuticular lining in the digestive tract. So when an insect molts, this lining from the foregut and the hindgut is shed along with the exoskeleton. This also helps you to remember why the peritrophic membrane is needed in the midgut. Because that area is more sensitive, it needs to be protected more. The insect has a cuticle in the foregut and hindgut.

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Well, that will do it for the digestive system for now. So now let's begin our introduction into the respiratory system, which is known as the tracheal system. I have a thought question for you. Have you ever thought about how insects breathe? Have you ever seen them inhale and exhale like we do? Do they have lungs? Well, they don't. Insects don't have lungs. They have a very interesting way of getting air into their bodies. Instead of lungs located in their chest as humans and other animals do, they have a unique tubular network throughout their body. Air enters the body through tiny holes in the insects' cuticle called spiracles. They control how much air is allowed to enter the body. They have muscles that can open and close the spiracles and regulate the airflow. The spiracles open up into tubes called trachea, which in turn branch out into tinier tracheoles. This branching gets the tracheoles within a few cell diameters of each cell. This is important because each cell needs to have oxygen available on demand. When cells need more oxygen, the spiracles open and air rushes in. So they have an exchange of gases through these tracheoles. If you take a look at this picture from a fly, you can see there are lots of tracheoles in the muscular areas so that they have oxygen to help them be able to fly. Or in insects that run, they need to have larger tracheoles next to the legs to provide the muscles oxygen. If you notice, these tracheoles look a lot like vacuum cleaner hoses. And they go throughout the body. If you do an insect dissection, they'll be a shiny white color as you do the dissection. So take time to do your textbook reading, to read about these tracheoles in further detail.

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The trachea are marvelously flexible and can bend with the insect because of thickened bands called taenidia. Remember how I said that they look like a vacuum cleaner hose? Well, these bands are very similar to the thickened ridges on a vacuum hose that allow it to be flexible enough to bend and move, but rigid enough not to collapse and become closed. Imagine what would happen to an insect's tracheal system if it wasn't able to bend with the insect as it's flying, jumping, or digging in the ground. The trachea have an inner lining similar to the outer cuticle of the insect's integument. At each molt, portions of this lining are routinely removed and replaced as the cuticle is made. So when an insect molts, it actually molts part of its respiratory system as well. If you take a look at the picture on the right, you can see this caterpillar. And through its skin, you can see the tracheal tubes going throughout the system. Speaking of a caterpillar's respiratory system, take a few minutes to watch the video segment titled "Trachea Animation". This video will take you inside of a caterpillar's tracheal system.

[11] (Video – Trachea Animation)

Like other creatures, insects need oxygen, but they don't have lungs. Instead, down each side, they have a series of holes, which are normally kept tightly sealed. But every now and then, they open, and the air rushes in. The holes lead to a network of tubes made from the same material as the hard casing. Inside the armor, in its liquid interior, the caterpillar's organs—its tubular heart and massive gut—are all connected to a complex branching network of air tubes. Within the tissues, the tubes branch even finer, until they're so minute, they can penetrate individual cells. In fact, each and every cell is plumbed directly into its own oxygen supply. Their elegant breathing system and waterproof armor were the breakthrough that allowed insects to invade dry land. Before that, most life on earth lived in the sea.

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Now let's move on to the insect circulatory system. Have you ever seen a bug hit the windshield, or smash a bug against your leg? What color is that insect's blood? Surprisingly, insect blood is not red. It's usually clear, but it can have a greenish or yellowish tint, depending on what the insect has been eating. Insect blood isn't red because it lacks the red pigment hemoglobin. Hemoglobin not only gives our blood the characteristic crimson color, but it also carries oxygen from our lungs to our cells. As you just

learned, since insects use spiracles and a tracheal system to transport oxygen from outside their body to their cells, they don't need hemoglobin.

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So what exactly is insect blood? Insect blood is called hemolymph, because it's really not blood, but just a body fluid similar to our lymph fluid. In fact, 90% of insect hemolymph is just plasma. The other 10% are hemolymph cells, collectively called hemocytes. And they can have various shapes and functions. Except for transporting oxygen, insect hemolymph serves the same function as human blood. They carry nutrients throughout the body, regulate salts, fight disease, and help to heal wounds. If you take a look at the diagram below, you can see some different hemocyte shapes that are found in insect bodies.

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We as humans have a closed circulatory system; our blood is pumped throughout the body and is contained in vessels that branch to every cell. Since our blood is always contained within the vessels and arteries, we have the closed system. Insects, on the other hand, have an open circulatory system because their hemolymph is not always contained in vessels, but freely sloshes around the insect's body. They only have one dorsal vessel that acts as the heart for the insect. It's closed at one end, in the insect's abdomen, and it's open at the other end, usually near the head. Ostia are tiny openings in the abdominal region of the vessel, and they control how much hemolymph enters the vessel. Once enough blood has entered the portion of the vessel, muscles will contract and push the hemolymph forward, emptying the fluid into the body cavity. So they do have a circulation of sorts. If you look at the diagram below, you can see the tiny arrows showing you the circulation of the hemolymph inside the system.

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Now let's take a closer look at the dorsal vessel. The part of the vessel that has the ostia is called the insect heart, since it does the pumping, and the remainder of the vessel is called the aorta. Once the hemolymph exits the aorta and is sloshing around the insect's body cavity, it's hard to imagine how the blood reaches the various appendages like the antennae, the wings, and the legs. However, hemolymph is helped into the antennae and wings by pulsating organs. They sit at the base of the antenna or the wings and they pump the hemolymph into these appendages. The wing pulsating organ pumps the blood into wing veins. They're not typical veins, but are more like channels that guide the hemolymph throughout the wing. The insect's leg is usually divided by a membrane called the septum. One side of the membrane is for the hemolymph to enter, and the other side for it to exit. The concept talked about here can be a bit confusing, so make sure to read your textbook reading and fill in diagram 2 on your study guide. If you notice in the diagram below you can see some of the wing venation. If you're identifying insects using a key, it may ask you to look at the wing venation, especially with dragonflies, butterflies, and flies. So these wing veins not only help the insect by transporting the hemolymph, but also help us in identifying the insect.

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OK, now we've covered insect digestion, circulation, and respiration. Now let's take a brief look at how insects maintain their body temperature. Insects do not have an insulating layer of fat like mammals. They only have a thin exoskeleton. As you have read, insects can be found living in almost every environment, from frozen snow caps to thermal springs to the desert. They've also adapted ways to regulate their temperature. Read about these adaptations, beginning with the heading "Thermoregulation". Some terms that you'll want to write down are: ectothermic, endothermic, cold hardiness, freezing susceptible, and freezing tolerant. Did you know that some insects can actually become completely frozen, and then defrost in the spring and be just fine? There are insects that actually have anti-freeze as part of their hemolymph. Write down a few of these examples as you do your textbook reading.

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Review Quiz.

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So in conclusion, insects have unique structures to digest their food, breathe air, and circulate their blood. We've briefly discussed each of these systems, along with thermoregulation. Make sure you read the textbook material and answer the questions on the study guide before moving on to the next unit. Just to give you something to think about, what would happen if you held an insect's head underwater? Would it drown? How about if the dorsal organ stopped beating? Would that lead to immediate death? Ponder these questions as you digest the information you have learned.