Unit 4 in Entomology

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Unit 4 Integument, Development and Reproduction.

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Have you ever watched a butterfly emerge from its cocoon? How does it go from being a little worm like caterpillar in to a beautiful butterfly with scaled wings and a different type of mouth part and different legs? Well, if you've ever watched this amazing process, you may have wondered how it happens. In this unit you will study the molting process, including all of the hormones involved. First, you'll need to learn about some of the structures and the composition of the exoskeleton. In the final portion of this unit, you learned about the insect reproductive system and how insects propagate their kind.

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There are five objectives in this unit, by the end of this unit you should be able to: describe the layers of the integument, tell me why tell me why having an exoskeleton would be advantageous and disadvantageous. You should be able to use the proper terms for the structures involved in molting and explain all the steps in the molting process. You should explain the role of some of the chemicals, juvenile hormone and ecdysone, tell me where they come from and how they're used together during molting. Should also, be able to identify the internal and external reproductive structures of insects and describe what they do or what they're used for.

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In unit one, you learned that arthropods have an outer exoskeleton made up of chitin and proteins. Well, it’s a little more complex than that. The exoskeleton is also called the cuticle and is made up of three distinct layers: the epicuticle, exocuticle and endocuticle. The top layer is extremely thin, it's the epicuticle, and it's the protective waterproof layer made up of fats and polyphenols. The exocuticle is the hardened layer, it consists of a chitin-protein matrix made of microfibers linked together that forms like a plastic kind of material. The innermost layer of the cuticle is flexible, it's the endocuticle. It's also made of chitins and protein but they're not linked together to form a hard layer, it remains flexible. The cuticle is only made of chitin and proteins, it's not made up of cellular material. Directly below the cuticle is the cellular layer called the epidermis. The epidermis is very important because those cells are the source of the proteins, chitins, lipids, and all the other products contained in the exoskeleton in other words, the epidermal layer, the cellular layer supplies all the materials needed for the Endo, exo, and epicuticle. When an insect molts these cells play a critical role, because they have to replace all of those ingredients needed to form the exoskeleton.

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The cuticle and epidermis make up what we call the insect's integument. Below the integument is a basement membrane. Scientists aren't really clear what makes up this layer but we do know that this layer separates the epidermal cells from the insect's blood, the hemolymph. The membrane has pores large enough to allow proteins and other molecules in the blood to pass through the membrane and on to the epidermal cells. If you take a look at the picture on your lower right, you can see a cross section of a cockroach cuticle. The arrows will show you on the diagram which part of the cuticle you are looking at in the cockroach cross section. Here you can see with the true photograph, the differences between the layers of the epi, the exo, and the endocuticle.

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Now let's take a look at some of the advantages of having an exoskeleton. First the exoskeleton acts as a physical barrier protecting the insect from everything from thorns to bacteria. It also acts as a waterproof barrier keeping in body moisture in dry habitats and keeping water out in wet habitats, it is much like our skin. Besides protection and keeping moisture in, the cuticle provides a place for muscles to attach, since insects have no internal skeleton. In humans our muscles attach to the bones, in insects the muscles actually attach to the skin or the exoskeleton. In the diagram below, you can see how the insect muscles would have to attach to the exoskeleton. Notice in the head region, the major muscles that have to control the mandibles and the thorax, there's lots of muscles to control the leg and wings

movements and in the abdomen, there are muscles there to hold in all of the gut material.

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Let's further compare the skeletal structure of humans and insects. Human internal skeletons and insect exoskeletons serve another purpose besides just muscle attachment. They provide the body's form and structure. Imagine a human without any bones, it would just be a blob of tissue. Insects would be much the same way without their exoskeleton. It is interesting to note that insect’s cuticle serves not only as its skin but also as its skeleton. Human skin provides many of the same protective functions as the cuticle but we still need our inner skeleton to provide muscle attachment and support for our body structures. Insects have efficiently combined all of these functions into just one organ.

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Okay, so those were the advantages, what about the disadvantages? If the cuticle does so much for the insect, what could possibly be wrong with it? Consider that insects never get to be the size of a whale, they are not as big as a rhinoceros, they are not even as big as a cat. Well maybe in science fiction movies, but not in real life. The exoskeleton does not allow for the insect to grow very big at all. The exoskeleton does not grow. Once it is formed, it stays its original size, remember that is very hard have like plastic. An insect muscles and organs grow inside the exoskeleton and causes pressure from the internal growing structures that will eventually break the cuticle open. The exoskeleton must be shed for growth to continue, for example a caterpillar will have to shed its skeleton approximately 5 times and then pupate in order to become a butterfly. So every time the internal organs get too large, the insect must molt into a larger exoskeleton. Let's look at this a little more closely.

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Right after the insect has shed its cuticle and the new one is being made, the insect has to wait for it to harden. During this time the insect cannot move which means it can't run from predators or seek covering if it begins to rain. Also while the insect is waiting for the exoskeleton to harden, it's vulnerable to high amounts of water loss because the exoskeleton is not waterproof until it hardens properly. If you take a look at the cockroach picture to the right, the far left cockroach has just molted and will stand until its exoskeleton darkens and hardens many times people call this an albino cockroach, when in reality it's just a newly molted cockroach that is yet to harden. The tanning process continues over several minutes to sometimes hours and the cuticle continues to darken as time goes on. Once the cuticle is hard enough, the insect will begin to move about, but very guardedly. The far right cockroach has a hardened cuticle and is ready to move and go about his normal routine. Remember the muscles are attached to the exoskeleton, so this is a very complex process as the muscles have to reattach as the new cuticle is formed.

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Once the internal organs of an insect grow too large, it's time for the insect to discard the old exoskeleton by molting and it does this in a series of steps. First, is apolysis, the outer cuticle separates from the epidermal cells. Second, the epidermal cells secrete a molting fluid. This molting fluid contains enzymes that break down the old cuticle. Material from the broken down exoskeleton will be recycled to form part of the new cuticle. Thirdly, epidermal cells secrete the foundation for a new cuticle and recycle parts of the digested old cuticle. The new cuticle is continually added to, and this causes the old cuticle to be shoved up and away. Eventually the old cuticle will break from the pressure and this leads us to the fourth step, ecdysis. The insect will wriggle and move its way out of the old cuticle. The old exoskeleton is left by the wayside. The insect, vulnerable to the environment, will need to remain still until the new cuticle hardens. If you've ever collected locust shells in the side of a tree or a fence post, you can see how the exoskeleton split right across the thorax and the newly emerged cicada or locust came out of exoskeleton and flew away as an adult. Take a look at the diagram below and you can see how this process takes place.

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Before we go on with our discussion of the molting process, let's review some of the vocabulary terms. Many of these we have already mentioned in the previous units, but let's take a minute to review them. Instar. Instar is a stage in between two successive molts. So if an insect is in the fourth instar, it's

molted four times and is waiting for the fifth molt, so each time an insect molts, it begins a new instar. What about the term larvae or larva in singular? Larvae refers to the immature stage of a holometabolous insect. Caterpillars, fly maggots and beetle grubs are all larvae. Nymph. Nymph refers to the immature stages of non-holometabolous insects; so immature grasshoppers, cockroaches, silverfish—they're not called larvae, they are called nymphs. Holometabolous insect larvae turns into a pupa. Pupa is the singular term. Pupae is the plural, before it molts into an adult. When a last instar larva is ready to grow into an adult, it will first undergo a pupal or growing stage, in a caterpillar, this is where it spins a cocoon around itself, within a cocoon, the pupa begins to slowly form the adult structures of the butterfly many moths, maggots and grubs spend their pupal stage in a pupal case underground.

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All right, let's try to bring some of this together. Take a look at the diagram below. We have ametabolous, hemimetablous, and holometabolous. We have an example insect for each group. The silverfish is under the ametabolous category so remember the juveniles look very similar to the adults. And silverfish are interesting because they continue to molt their entire life. So during the fourth molt of a silverfish, ecdysone will form the adult cuticle. They'll be able to reproduce and have all the functions of an adult. That's an ametabolous. Let's look at hemimetabolous where we have the grasshopper. You can see there's a first molt juvenile all the way up to a fifth molt juvenile, but during the sixth molt, the ecdysone will form the adult cuticle so the juvenile looks very similar to the adult between the fifth and sixth molt--the wings will fully develop and the reproductive organs will develop. In holometabolous, things work a little bit differently. So you have the egg, then you have the larval stages, first through the fourth molt, but during the fifth molt ecdysone does not form the adult, it forms the pupal cuticle, so you have the pupal stage which is a growing stage and then after the pupal stage will become the adult.

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Before we get to the video, let me cover a few more terms you may come across as you do your textbook readings. One of these is pharate. An insect that is actively constructing a new exoskeleton is said to be in the pharate condition. And this may take days or weeks, but when ecdysis occurs, it happens very quickly. And like I said, a newly molted insect is very soft and is usually unpigmented. It's white or ivory in color and that is said to be in a teneral condition. So a teneral is kind of vulnerable or weak and it is in that condition until the tanning process is completed; and what happens during the tanning process is the sclerites in the exoskeleton will darken as the quinone forms cross length linkages in the exocuticle. So this process is called tanning or sclerotization and it gives the exoskeleton its final texture and appearance. So some terms you may come across are pharate, teneral and sclerotization. As you watch this video clip titled "New Skin", you'll see a caterpillar as it struggles to molt. Keep in mind that a caterpillar needs to molt to have a larger exoskeleton for its internal organs. See if you can catch how the caterpillar goes about making extra room in its new cuticle to take into account its growth in the future.

[14] (Video – New Skin)
"But the problem is, it can't stretch and grow and the caterpillar's life is dedicated to growing. These have to increase their size by 20,000 times between hatching and turning into moths. So when they get too big for their casing, they molt. A new, soft skeleton is ready underneath. All the caterpillar has to do is loosen the old one and step outside. The new casing is soft at first, so it can be inflated, then hardened, giving the caterpillar a bit more room to grow. Not only is this casing waterproof, it is airtight."

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Now that you've seen an example of how molting takes place, let's take a look at some of the chemicals involved. Let's look at some of the molting hormones. First off, a hormone is a chemical messenger, is a chemical signal sent from one part of an organism to have an effect on another part of an organism. Two of the molting hormones we'll discuss are juvenile hormone, also called J. H., and ecdysone. Juvenile hormone is secreted from a part of an insect brain called the corpora allata. It's located in the head region of the insect. If you take a look at the diagram, you'll see it on the top left-hand side of the insect brain. Ecdysone is produced from a tiny pair of glands located near the first thoracic spiracles. Now remember, thoracic refers to the thorax region where the legs and the wings are and spiracles are respiratory tubes. They're little air holes in the thorax area. These glands are called prothoracic glands. These prothoracic glands are often just a loose cluster of cells that are widely scattered throughout the

prothorax so they're not something to be easily dissected out. They're pretty scattered in there. And it's neat to note these prothoracic glands, produce ecdysteroids. They're a group of steroid hormones that stimulate molting. Now does an adult insect need to molt? They don't. So as an insect goes from its juvenile stages to the adult stage the prothoracic glands atrophy, they actually wither away so the insect will never need to molt again. Now these molting hormones are not just randomly produced; they have to be stimulated and there's another hormone called the prothoracicotropic hormone or PTTH. And this is secreted by the corpora cardiac, which is located just behind the brain and PTTH stimulates the prothoracic glands to begin production of ecdysone, so you can see there's a complex chemical mixture that occurs to initiate molting.

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So let's look at some of the function of these molting hormones. First, Ecdysone. When an insect grows too big for its cuticle and is ready to molt, ecdysone is released from the prothoracic glands. It travels to the epidermal cells. Remember this is the cellular layer where it stimulates the epidermal cells to secrete molting fluid. This fluid will digest the old cuticle. Once the old cuticle is broken away from the epidermal cells, the epidermal cells then begin to lay down the new exoskeleton. Juvenile Hormone. The corpora allata continuously secretes JH throughout each molt, except during the last molt. Somehow the juvenile hormone keeps the new cuticle looking young. When the corpora allata stops secreting juvenile hormone, ecdysone is all by itself. Once ecdyson is by itself, it stimulates the epidermis to form the adult cuticle. In the diagram below you can see the epidermal layer, the old cuticle being digested, the new cuticle being laid down, and then ecdysis and the new cuticle hardening.

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Let's take a look at the diagrammatic example of molting. So at the top you can see how juvenile hormone is continuously being secreted and then the large fluctuations of ecdysone as it cycles up and down in the system. So let's consider a butterfly's lifecycle. A caterpillar molts about four times before it becomes an adult. Right before the fifth molt, JH is no longer secreted by the corpora allata. However, ecdysone is still released as usual, so if you look in the pupal stage you can see right before that during the fifth molt, a sudden drop in juvenile hormone but the level of ecdysone still remains. This stimulates the epidermal cells to break down the old cuticle. Then, since juvenile hormone is no longer present, ecdysone stimulates the cells to secrete products that will form a pupal exoskeleton. It's not completely understood why, in the absence of juvenile hormone, ecdysone can make epidermal cells secrete the pupil cuticle. In non-holometabolous insects, in the absence of JH, ecdysone actually forms the adult cuticle since no pupal stage is needed.

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Once the insect is an adult the prothoracic glands, like I mentioned before, usually disintegrate and thus no ecdysone will be released again to stimulate the epidermal cells, so the insect adult will not molt again. There's no need for the insect to molt as an adult because it no longer will be growing. Just like us humans, once we reach a certain age we stop growing. After an insect becomes an adult, the corpora allata begins to secrete juvenile hormone again. Okay, so your next question is, why? As a juvenile, JH kept it looking like a juvenile. But what can JH do for an adult insect? Well, during the adult stage of the lifecycle juvenile hormone aids in egg production in the female and stimulates accessory glands in the male. So these glands secrete necessary products during insect reproduction.

[19] Monarch Emergence Video
We have discussed the cycles of juvenile hormone and ecdysone as an insect goes from molt to molt, and then into a pupal, and then into an adult stage. Let's watch a video now of a monarch butterfly forming its pupal case and then emerging as an adult. The events in the video begin with the caterpillar in the J-formation. This usually happens when the last instar caterpillar finds a substrate on which to pupate. The caterpillar then attached itself to the substrate, hangs down in the J-shape for approximately 14 to 18 hours. During this time, the internal organs all reorganize and then the pupal cuticle is secreted. The larva cuticle splits down its back and the pupal cuticle is formed and the caterpillar will hang straight down. It is usually in the pupal stage for about 10 days for a monarch butterfly, depending on temperature. And then one day, prior to adult emergence, the pupal will become very dark. Once the adult emerges, it only takes about a minute for the adult butterfly to escape the

pupal case. The adult will then rest on some kind of substrate, near the pupal case for several hours. While the hemolymph pumped into the wings to fill them out and the exoskeleton becomes completely hardened. This original video was shot by Dr. Jim Nation, in the department of Entomology here at the University of Florida. The video was originally only 7 to 8 minutes long, but it has been sped up electronically to only last for about 2 and half minutes. Please enjoy as you watch the monarchy emergence.

[20] (Caterpillar Video)

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So now you know, in the absence of juvenile hormone, an insect will molt to the pupal stage or to the adult stage. Can you think of any practical applications for this? Well, because juvenile hormone keeps a larva from becoming an adult, scientists have found that they could use juvenile hormone as an insecticide. The idea is that if a farmer wanted to control caterpillars eating his crop, he would purchase some juvenile hormone and spray it on his field. So even though the corpora allata stops secreting juvenile hormone right before the caterpillar was supposed to pupate, the JH level inside the insect wouldn't drop because of the JH in the environment. Instead of the caterpillar forming a cocoon, it would molt into another caterpillar and another caterpillar and another caterpillar and eventually the caterpillar would just die. Since the caterpillars never became adults, they never had a chance to mate with each other. Therefore, they never had a chance to lay eggs. Eventually the caterpillars start to die off and won't be replaced by new caterpillars, because there wouldn't be any eggs hatching. This is a very simplistic example, but scientists have been able to make man-made juvenile hormone that are called J. H. mimics because they mimic the function of juvenile hormone. They're also called J.H. analogs or insect growth regulators, which are known as IGRs. These are the chemicals are sold commercially to pest control companies.

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Your next assignment is to find a website that advertises juvenile hormone or an insect growth regulator as an insecticide. You'll want to find the insecticide label and read it and answer the following questions: What is the product? What types of insect does it control? How exactly does it work? Make sure to give some details. Also give me your source-- where did you find the information? Do you consider this product to be safe? What are the safety precautions? Is it toxic? What is it toxic to? Is it toxic to insects? Is it toxic to fish? Is it toxic to birds? Is it toxic to people? Give some details. I am giving you a couple of examples below, but try not to use these examples for your assignment. Find your own website. Just use the examples to get the base information.

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Now we're going to move on to the insect reproductive system. I think you'll find this very fascinating because the reproductive organs of insects are very similar in structure and function to those of vertebrates. So, below I've given you a diagram of the human reproductive system and next to it the insect reproductive system. On your study guide you have a copy of these diagrams. See if you can fill in the structures without looking at the answers on the next slide. See how many you can get correct because they're very similar.

[24]
Okay, were you surprised by the similarities? Insects and humans have developed relatively parallel reproductive systems. When two unrelated organisms evolve the same type of structure for a given purpose, it's called convergent evolution. You may have heard this before. The male reproductive system is on the next slide.

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Most insect species reproduce sexually: one egg from a female, one sperm from a male, and they fuse to produce a diploid zygote. There are also many species which reproduce by parthenogenesis, which is asexual reproduction where there's growth and development of an unfertilized egg. Some species can even alternate between sexual and asexual reproduction.

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Take some time now to read about the insect reproductive systems and fill in the functions of the organs listed on your study guide. Remember the similarities: females have a pair of ovaries that are subdivided into ovarioles. They're a group of germ cells that divide and increase in size that form oocytes. Each oocyte undergoes meosis that results in four cells: one egg and three polar bodies. The polar bodies may be reabsorbed by the female or can actually accompany the egg as nurse cells providing nutrients. As the eggs develop they move down the ovariole and they grow in size. So there will be a linear series of cells with the largest size of the very end going down to younger cells which are smaller. And by the time the egg reaches the base, it has reached full size, which may be a hundred times larger than the original oocyte. Once the eggs are mature, they leave the ovaries through lateral oviducts. Females have accessory glands that provides them lubricants to help the egg to move along. During copulation between a male and a female the male will deposit a spermatophore in the bursa copulatrix in the female, and the female can store the sperm there and can use it for a very long time, so some insect species will actually only mate once and then are able to retrieve sperm for the rest of their lives. During ovulation, the egg will actually pass along the opening to the spermatheca, stimulate the release of the few sperm onto the egg surface, and the eggs will be fertilized, so soon as one of the sperm's nucleus fuses with the egg nucleus, you have fertilization. Then the female will oviposit, which is the laying of eggs soon after fertilization. So after this process is complete and the egg has been oviposited, then the egg is ready to begin embryonic development. In the male system, it contains a pair of testes, usually near the back of the abdomen and the testes is subdivided into follicles where the sperm is produced. Near the end of each follicle there is a layer of germ cells called a spermatagonia and these divide by mitosis to form the spermatacites, and much like the eggs they migrate down and eventually develop into mature spermatozoa. The accessory glands produces some seminal fluid which helps the sperm to move along and then the spermatophores are formed, which are pouch-like structures mostly made of protein that encase the sperm and protect them as they are delivered by copulation to the female’s body.

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So in conclusion, we've covered the integument, the molting process and insect reproduction. The insect cuticle truly is an amazing thing. It provides muscular support, protection from drying out, as well as many other benefits. Even with all of these advantages of having an exoskeleton, an exoskeleton limits insects in other ways. They can only grow to be a few inches because they have to molt their skeleton every time they want to grow. Plus, while they’re molting, they're exposed to harsh environments. Insects are vulnerable to drying out and also vulnerable to predators. Juvenile hormone and ecdysone play critical roles in this molting process. Juvenile hormone levels will keep the insect as an immature. When the insect gets too big for its exoskeleton, ecdysone is released in the absence of juvenile hormone to make the new cuticle underneath the detached cuticle. In the absence of juvenile hormone, while the insect is molting, it becomes an adult. Even though an insect exoskeleton is so different than a human’s exoskeleton, the insect and human reproductive systems are very similar. Imagine a tiny insect reproductive system similar to our own. Biology has such a way of repeating itself. After all, why create a new system when one that already works, exists?

[28] Review Quiz

[29] References