



SECTION 1 Phylum Arthropoda SECTION 2 Subphylum Crustacea SECTION 3 Subphyla Chelicerata and Myriapoda

# PHYLUM ARTHROPODA

Two-thirds of all animal species belong to the phylum Arthropoda (ahr-THRAHP-uh-duh). This phylum contains a variety of bilaterally symmetrical coelomates, including lobsters, crabs, spiders, and insects. These animals have adapted to almost every environment on Earth.

# CHARACTERISTICS OF ARTHROPODS

The members of the phylum Arthropoda are called **arthropods** (AHR-thruh-PAHDS). Like annelids, arthropods are segmented animals. In arthropods, however, the body segments bear jointed extensions called **appendages**, such as legs and antennae. In fact, *arthropod* means "jointed foot."

Another distinguishing feature of arthropods is their exoskeleton, which provides protection and support. As Figure 36-1 shows, the arthropod exoskeleton is made up of three layers that are secreted by the epidermis, which lies just beneath the layers. The waxy outer layer is composed of a mixture of protein and lipid. It repels water and helps keep terrestrial arthropods from drying out. The middle layer, which provides the primary protection, is made mainly of protein and **chitin**, a tough polysaccharide. In some arthropods, the middle layer is hardened by the addition of calcium carbonate. The inner layer also contains protein and chitin, but its flexibility at the joints allows arthropods to move freely. Muscles that attach to the inner layer on either side of the joints move the body segments.

Arthropods show a high degree of cephalization. Recall that *cephalization* is the concentration of sensory and brain structures at the anterior end. A variety of segmented appendages around the mouth serve as sensors and food handlers. Most arthropods have segmented antennae that are specialized for detecting chemicals. Most arthropods also have **compound eyes**—eyes made of many individual light detectors, each with its own lens. In addition, many arthropods have simpler structures that sense light intensity. These sensory structures on the head send nerve impulses to the brain, which coordinates the animal's actions. As in annelids, impulses travel from the brain along a ventral nerve cord, which links ganglia in the other segments of the body.

All arthropods have open circulatory systems. Recall that in an open circulatory system, the heart pumps circulatory fluid through vessels that empty into spaces in the body.

# **SECTION 1**

# **OBJECTIVES**

- **Describe** the distinguishing characteristics of arthropods.
- Explain the process of molting in an arthropod.
- List the five major subphyla of the phylum Arthropoda.

# **VOCABULARY**

arthropod appendage chitin compound eye molting trilobite tagma mandible chelicera

#### FIGURE 36-1

The arthropod exoskeleton consists of three layers that cover the epidermis. Wax in the outer layer is secreted by wax glands. Sensory hairs projecting from the exoskeleton allow arthropods to respond to vibrations and chemicals in their environment.





#### FIGURE 36-2

This green cicada, *Tibicen superbus*, is in the process of molting. The outer layer of its old exoskeleton appears brown.



#### **Word Roots and Origins**

#### chelicera

from the Greek *chele,* meaning "claw," and *keras,* meaning "horn"

### Molting

A rigid exoskeleton limits the size to which an arthropod can grow. So, each arthropod periodically sheds its exoskeleton and makes a new one in the process of **molting**. An anthropod goes through many cycles of molting during its life. Figure 36-2 shows an insect in the process of molting.

A cycle of molting begins as the tissues of an arthropod gradually swell. When the pressure inside the exoskeleton is very strong, a hormone that triggers molting is produced. In response to this hormone, the cells of the epidermis secrete enzymes that digest the inner layer of the exoskeleton. At the same time, the epidermis begins to make a new exoskeleton by using the digested material. Eventually, the outer layer of the old exoskeleton loosens, breaks apart, and is shed. The new exoskeleton, which is flexible at first, stretches to fit the enlarged animal.

The new exoskeleton takes a few hours to a few days to become as hard as the one that it replaced. During this time, the animal is vulnerable to predators and, if the arthropod is terrestrial, to desiccation. For these reasons, arthropods usually stay in hiding from the time that they begin to molt until their new exoskeleton has hardened. The "soft-shelled crabs" sold in some restaurants are crabs that have been caught immediately after molting.

# **EVOLUTION AND CLASSIFICATION**

Animals having arthropod characteristics first appeared about 545 million years ago. Because all arthropods have a true coelom, an exoskeleton, and jointed appendages, biologists infer that all arthropods evolved from a common ancestor. However, biologists are still uncertain about the order in which subgroups of arthropods evolved and the exact relationships between the subgroups. The phylogenetic diagram in Figure 36-3 shows possible evolutionary relationships between the highly diverse arthropod subgroups.

The similar characteristics of many modern subgroups of arthropods may be the result of convergent evolution. For example, ancient and extinct arthropods, such as **trilobites**, had many body segments and one pair of appendages on each segment. However, most living arthropod species have some segments that lack appendages and some segments that are fused into a larger structure called a **tagma** (plural, *tagmata*). The tagmata tend to be specialized for functions such as feeding, locomotion, and reproduction.

Arthropods are usually divided into five subphyla on the basis of differences in development and in the structure of appendages, such as mouthparts. The two major types of mouthparts are **mandibles**, which are jawlike, and **chelicerae** (singular, *chelicera*), which are pincerlike. The five main subphyla are Trilobita, Crustacea, Chelicerata, Myriapoda, and Hexapoda, as Figure 36-3 shows.



## **SECTION 1 REVIEW**

- 1. What characteristics do all arthropods share?
- **2.** What is the main function of each layer of an arthropod's exoskeleton?
- 3. What is a compound eye?
- 4. What is molting?
- 5. Identify the difference between chelicerae and mandibles.
- **6.** Identify examples of organisms in each of the five main subphyla of arthropods.

### **CRITICAL THINKING**

- **7. Inferring Relationships** What is the adaptive advantage of having a layered exoskeleton?
- 8. Analyzing Concepts After its old exoskeleton has been shed but before the new one has hardened, an aquatic arthropod absorbs water and swells. How is this behavior adaptive?
- **9. Interpreting Graphics** Study Figure 36-3. Are pill bugs more closely related to centipedes or to barnacles? Explain your answer.

# **SECTION 2**

# **OBJECTIVES**

- Describe the characteristics of crustaceans.
- Compare aquatic crustaceans with terrestrial crustaceans.
- Explain the functions of the appendages on a crayfish.
- Summarize digestion, respiration, circulation, excretion, and neural control in crayfish.

# **VOCABULARY**

nauplius cirrus isopod decapod cephalothorax thorax carapace abdomen antenna antennule cheliped swimmeret telson uropod digestive gland green gland

# SUBPHYLUM CRUSTACEA

The subphylum Crustacea contains about 38,000 known species. Crustaceans are abundant in oceans, lakes, and rivers, and a few species live on land. Some crustaceans are sessile, while others move by walking on legs, swimming with paddle-like appendages, or drifting with the currents.

# **CHARACTERISTICS**

Crustaceans are so diverse that their single defining characteristic is having two pairs of antennae. Also, most crustaceans have a pair of jawlike, chewing mouthparts called mandibles. In most crustaceans, each body segment has a pair of appendages, and at least some of those appendages are branched. Although some crustaceans have 60 or more body segments, most crustaceans have 16 to 20 segments, which are fused into several tagmata.

Some small crustaceans, such as pill bugs, respire through the thin areas of their exoskeleton. Larger crustaceans, such as crayfish and lobsters, use gills to respire. The exoskeletons of aquatic crustaceans, such as lobsters, often contain large amounts of calcium carbonate and thus are extremely hard.

During the development of many crustaceans, the embryo becomes a free-swimming larva called a **nauplius** (NAH-plee-uhs), which looks quite different from an adult of the species. As Figure 36-4 shows, a nauplius has three pairs of appendages and a single eye in the middle of its head. Through a series of molts, the nauplius eventually takes on the adult form.



# **DIVERSITY OF** CRUSTACEANS

Crustaceans exist in a range of sizes, but most are small. For example, copepods (KOH-puh-PAHDZ), as shown in Figure 36-5a, are no larger than the comma in this sentence. At the other end of the size spectrum is the Japanese spider crab, shown in Figure 36-5b. With a leg span of 4 m (13 ft), this crab is the largest living arthropod.

# FIGURE 36-4

early stage in the development of most crustaceans. It has one eye and three pairs of appendages.



(a) Copepod, Cyclops sp.



(b) Japanese spider crab, Macrocheira kaempferi

### **Aquatic Crustaceans**

Copepods are extremely abundant in marine environments and may be the most abundant animals in the world. Copepods are an important part of the ocean's *plankton*, the collection of small organisms that drift or swim weakly near the surface of the water.

In freshwater environments, on the other hand, much of the plankton is composed of crustaceans known as *water fleas*, which are about the size of copepods. A common type of water flea is a member of the genus *Daphnia*.

Barnacles, such as the one shown in Figure 36-5c, are marine crustaceans that are sessile as adults. Free-swimming barnacle larvae attach themselves to rocks, piers, boats, sea turtles, whales, and just about any other surface. They then develop a shell composed of calcium carbonate plates that completely encloses the body in most species. Their swimming appendages develop into six pairs of long legs called **cirri** (SIR-IE) (singular, *cirrus*). The cirri extend through openings in the shell, sweeping small organisms and food particles from the water and directing them to the mouth.

#### **Terrestrial Crustaceans**

Sow bugs and pill bugs are terrestrial members of a group of crustaceans called **isopods**. Terrestrial isopods lack adaptations for conserving water, such as a waxy cuticle, and can lose water quickly through their exoskeleton. Therefore, they live only in moist environments, such as under leaves and rocks, in crevices around garden beds, and in the spaces between house foundations and sidewalks. In addition, pill bugs are capable of rolling into a ball when disturbed or threatened with desiccation, as shown in Figure 36-6. Sow bugs and pill bugs generally feed on decaying vegetation, but they may also eat garden bulbs, vegetables, and fruits that lie on or in the soil.



(c) Goose barnacle, Lepas anatifera

#### FIGURE 36-5

Crustaceans include tiny species, such as the copepod (a), as well as giant species, such as the Japanese spider crab (b). Some aquatic species, such as barnacles (c), attach themselves to submerged marine surfaces.

#### FIGURE 36-6

Pill bugs are isopod terrestrial crustaceans that are often found in moist environments with decaying vegetation. Pill bugs and sow bugs look similar, but only pill bugs roll up when disturbed.





#### FIGURE 36-7

(a) Each of the 20 body segments of a crayfish has a pair of appendages, as seen in this ventral view. (b) Some of the appendages of the anterior cephalothorax are visible in this closer ventral view.

# TABLE 36-1Crayfish Appendages

Appendage	Function	
Antennule	touch, taste, and balance	
Antenna	touch and taste	
Mandible	chewing food	
Maxilla	manipulating food and drawing water currents over gills	
Maxilliped	touch, taste, and manipulating food	
Cheliped	capturing food and defense	
Walking leg	locomotion over solid surfaces	
Swimmeret	creating water currents and transferring sperm (males)	

# **THE CRAYFISH**

The crayfish is a freshwater crustacean that is well studied because of its size and abundance. Crayfish are structurally similar to lobsters, which are marine crustaceans. Crayfish, lobsters, crabs, and shrimp are **decapods** (DEK-uh-PAHDZ), or members of the order Decapoda. *Decapoda* means "10 feet," a name used because these crustaceans have five pairs of legs that are used for locomotion.

### **External Structure**

The crayfish's external structure is shown in Figure 36-7. The body is divided into two major sections: the abdomen and the cephalothorax (SEF-uh-loh-THAWR-AKS). The **cephalothorax** consists of two tagmata: the head, which has five segments, and the **thorax**, which has eight segments and lies behind the head. The dorsal exoskeleton over the cephalothorax is a single, tough covering known as the **carapace** (KAR-uh-PAYS). The **abdomen**, the tagma behind the cephalothorax, is divided into six segments.

A pair of appendages is attached to each segment of the crayfish. Several pairs have specialized functions, as summarized in Table 36-1. The two pairs of **antennae** include the branched **antennules**, which serve as feelers sensitive to touch, taste, and balance. The long antennae are also feelers that respond to touch and taste. Crayfish use a pair of *mandibles* to chew food and use two pairs of *maxillae* (maks-IL-ee) and three pairs of *maxillipeds* (maks-IL-i-PEDS) to manipulate food. The posterior pair of maxillae also function in respiration, and the maxillipeds are sensitive to touch and taste. The most anterior pair of walking legs, the **chelipeds** (KEE-luh-PEDS), end in large pincers used for capturing food and for defense. The other four pairs of walking legs carry the crayfish over solid surfaces; two of these pairs end in small pincers that can grasp small objects. The **swimmerets**, which are attached to the five anterior abdominal segments, create water currents and function in reproduction.



At the posterior end of the crayfish is a paddle-like tail made up of the **telson** and the **uropods** (YOOR-oh-PAHDZ), which are attached to the sixth abdominal segment. Powerful abdominal muscles can propel the animal rapidly backward in a movement referred to as a tail flip.

## Digestion

The major parts of the digestive tract of a crayfish are shown in Figure 36-8a. Food passes through the esophagus to the stomach, where teeth made of chitin and calcium carbonate grind the food into a fine paste. After the paste is mixed with enzymes secreted by a digestive gland near the stomach, it enters the intestine for further digestion and absorption. Waste leaves through the anus.

## **Respiration**

Like most crustaceans, crayfish have featherlike gills for respiration. Figure 36-8b shows that the gills extend from the base of each walking leg into a chamber under the carapace. As a crayfish walks, its legs circulate water across its gills. Feathery branches on the posterior pair of maxillae also help direct water over the gills. Each gill is covered by an extension of the exoskeleton that is thin enough to permit gases to diffuse across the gill surface.

## Circulation

The main components of the crayfish's open circulatory system are shown in Figures 36-8a and 36-8b. In this system, the dorsal heart pumps a circulatory fluid called hemolymph into several large vessels that carry the fluid to different regions of the body. The fluid leaves the vessels and enters spaces within the body, where it bathes the various tissues. It then passes through the gills, where it exchanges carbon dioxide with oxygen in the water. From the gills, the fluid returns to the dorsal part of the crayfish and enters the heart.



The major internal organs of a cravfish are seen in this cutaway side view (a) and cross section through the heart region (b).





Observing Crayfish Behavior

**Materials** crayfish in container with water, tapping instrument

Procedure



**CAUTION** Crayfish have powerful pincers that could injure you. Do not place your hand near the crayfish.

- **1.** Gently tap the anterior (head) end of the crayfish, and record your observations.
- **2.** Tap the posterior (tail) end of the crayfish, and record your observations.

**Analysis** Describe each behavioral response you observed when you tapped the crayfish. How does each behavior aid the animal in its survival?

# Excretion

As freshwater organisms, crayfish live in a hypotonic environment. Remember that a *hypotonic environment* is one in which the concentration of solute molecules is lower than that in the organism's cells. Therefore, water constantly enters the tissues of a crayfish by osmosis. This excess water, along with wastes, is eliminated by excretory organs called **green glands**, which are visible in Figure 36-8a. The dilute fluid collected by the green glands leaves the body through a pore at the base of the antennae.

### **Neural Control**

The nervous system of the crayfish is illustrated in Figure 36-8a. It is typical of arthropods and is similar to the nervous system of annelids. The crayfish brain consists of a pair of ganglia above the esophagus that receive nerve impulses from the eyes, antennules, and antennae.

Two bundles of nerve fibers extend from the brain and pass around either side of the esophagus to a ganglion that controls the mandibles, maxillae, and maxillipeds. The ventral nerve cord runs posteriorly from this ganglion, connecting a series of ganglia that control the appendages and muscles in the segments of the thorax and abdomen.

## **Sensory Organs**

Crayfish sense vibrations and chemicals in the water with thousands of small sensory hairs that project from the exoskeleton. Sensory hairs are visible in Figure 36-1. These sensory hairs are distributed over the entire body, but they are especially concentrated on the antennules, antennae, mouthparts, chelipeds, and telson.

The compound eyes of a crayfish are set on two short, movable stalks. Each eye has thousands of light-sensitive units, each with its own lens. At the base of the antennules are organs that can detect the animal's orientation with respect to gravity.

# **SECTION 2 REVIEW**

- **1.** What characteristics are shared by most or all crustaceans?
- 2. What is the important role of copepods in marine ecosystems?
- **3.** What are the functions of the mandibles and the chelipeds on a crayfish?
- **4.** What structural adaptations of crayfish promote effective respiration in water?
- 5. Describe the type of circulation found in a crayfish.

#### **CRITICAL THINKING**

- **6. Inferring Relationships** Why are the largest crustaceans found only in aquatic environments?
- 7. Applying Information Barnacles spend most of their adult life attached to a marine surface. What structural adaptations for this lifestyle do barnacles have?
- **8. Inferring Relationships** What is the adaptive advantage of having two pairs of antennae?
- **9. Predicting Results** What problem would a crayfish have if it were born without a green gland?

# SUBPHYLA CHELICERATA AND MYRIAPODA

Unlike crustaceans, nearly all members of the subphyla Chelicerata, Myriapoda, and Hexapoda are terrestrial.

# SUBPHYLUM CHELICERATA

The subphylum Chelicerata, made up of *chelicerates*, includes spiders, scorpions, mites, sea spiders, and horseshoe crabs. Chelicerates lack antennae and typically have six pairs of appendages. The first pair of appendages, the *chelicerae*, are modified into pincers or fangs. The major group in Chelicerata is class Arachnida (uh-RAK-ni-duh), which has more than 70,000 species.

# **Class Arachnida**

Members of the class Arachnida, called **arachnids**, include spiders, scorpions, mites, and ticks. Like crayfish, arachnids have a body that is divided into a cephalothorax and an abdomen. The cephalothorax usually bears six pairs of jointed appendages: one pair of chelicerae; one pair of **pedipalps**, which aid in holding food and chewing; and four pairs of walking legs.

# **Anatomy of a Spider**

Spiders range in length from less than 0.5 mm long to as long as 9 cm (3.5 in.) long in some tropical tarantula species. As Figure 36-9 shows, the body of a spider is very narrow between the cephalothorax and the abdomen.



# **SECTION 3**

# **OBJECTIVES**

- List the characteristics of arachnids, as represented by a spider.
- Explain the adaptations that spiders have for a predatory life on land.
- Identify the unique characteristics of scorpions, mites, and ticks.
- **Compare** the characteristics of millipedes and centipedes.

# V O C A B U L A R Y

arachnid pedipalp spinneret book lung trachea spiracle Malpighian tubule

#### FIGURE 36-9

The major internal organs of a female spider are shown in this cutaway side view. The inset shows a closer view of a book lung, one of the spider's adaptations to life on land.





**Word Roots and Origins** 

#### spiracle

from the Latin *spiraculum,* meaning "air hole"

#### **FIGURE 36-10**

The black widow, *Latrodectus mactans* (a), and the brown recluse, *Loxosceles reclusa* (b), are the only two spiders in the United States whose venom is dangerous to humans. Note the red hourglass-shaped spot on the abdomen of the female black widow and the dark violin-shaped marking on the cephalothorax of the brown recluse.



(a)



The chelicerae of spiders are modified as fangs and are used to inject venom into prey. The venom is produced by poison glands in the cephalothorax and flows through ducts in the chelicerae to the tips of the fangs. Most spiders have eight simple eyes at the anterior end of the cephalothorax. Each simple eye has a single lens.

On the tip of the abdomen of many spiders are three pairs of organs called **spinnerets**, which are visible in Figure 36-9. Each spinneret is composed of hundreds of microscopic tubes that connect to silk glands in the abdomen. A protein-containing fluid produced in the silk glands hardens into threads as it is secreted from the spinnerets. Spiders use their silk threads to spin webs, build nests, and protect eggs. In some species, spider silk also aids in dispersing spiders from one habitat to another. Young spiders move to new habitats when the wind pulls them through the air by their threads.

The nervous, digestive, and circulatory systems of spiders are similar to those of crustaceans. Because spiders are terrestrial, however, their respiratory system is quite different. In some spiders, respiration occurs in **book lungs**, paired sacs in the abdomen with many parallel folds that resemble the pages of a book. The folds in a book lung provide a large surface area for gas exchange. Other spiders have a system of tubes called **tracheae** (TRAY-kee-ee) that carry air directly to the tissues from openings in the exoskeleton known as **spiracles.** Some spiders have both book lungs and tracheae.

The excretory system of spiders is also modified for life on land. The main excretory organs, called **Malpighian** (mal-PIG-ee-uhn) **tubules,** are hollow projections of the digestive tract that collect body fluids and wastes and carry them to the intestine. After most of the water is reabsorbed, the wastes leave the body in a nearly solid form with the feces. Thus, the Malpighian tubules help spiders conserve water in terrestrial environments.

### Life of a Spider

Spiders feed mainly on insects, although some can catch fish, frogs, and even birds. Different species of spiders are adapted to capture their prey in different ways. Some chase after prey, some hide beneath trapdoors waiting for prey to approach, and some snare prey in webs spun from silk. When an insect becomes trapped in the sticky web, the spider emerges from its hiding place near the edge of the web and paralyzes the insect with its venom. Many spiders also immobilize their prey by wrapping them in silk. They can then consume the body fluids of the prey at a later time.

Spider venom is usually harmless to humans, and most spiders bite only when threatened. There are, however, two kinds of spiders in the United States whose bites can be dangerous to humans. They are the black widow and the brown recluse, shown in Figure 36-10. The female black widow has a bright red or orange mark shaped like an hourglass on the ventral surface of its abdomen. The venom attacks the nervous system.



The brown recluse has a violin-shaped mark on the dorsal surface of its cephalothorax. Therefore, it is sometimes called the "violin spider." The venom of the brown recluse kills and digests the tissues surrounding the bite.

A male spider is usually smaller than a female of the same species. When the male is mature, he transfers sperm to special sacs in the tips of his pedipalps. The sperm are then placed in the seminal receptacle of the female during mating. As soon as mating has occurred, the male darts away. If he is not quick enough, he may be eaten by the female. Eggs are fertilized as they pass out of the female into a silken case that she has spun. The female may carry the egg case with her or attach it to a web or plant. The young spiders hatch in about two weeks and undergo their first molt before leaving the case.

### **Scorpions**

Scorpions, such as the one shown in Figure 36-11, differ from spiders in two ways. Scorpions have large, pincerlike pedipalps, which they hold in a forward position. They also have a segmented abdomen with a large stinger on the last segment, which can be curled over the body. Scorpions usually hide during the day and hunt at night, mostly for insects and spiders. They seize prey with their pedipalps and inject venom into the prey with their stinger. Only a few species of scorpions have venom that can be fatal to humans. Most scorpions live in tropical or semitropical areas, but some are found in dry temperate or desert regions.

### **Mites and Ticks**

Mites and ticks are the most abundant and most specialized arachnids. About 30,000 species have been identified, but the actual number of species may be much larger than that. Unlike spiders and scorpions, mites and ticks have a completely fused cephalothorax and abdomen, with no sign of separation between them.

Most mites are less than a millimeter in length, and some are small enough to live on particles of dust. They can be found in freshwater, marine, and terrestrial habitats. Many mites are entirely free living, while others are parasites during at least part of their life cycle. Spider mites parasitize fruit trees and many other agricultural crops by sucking the fluid from their leaves. The larvae of harvest mites also known as chiggers—attach themselves to the skin of vertebrates, including humans. They break the skin with their chelicerae and feed on blood, causing swelling and itching. Other species of mites live on the bodies of chickens, dogs, cattle, humans, and other animals, where they feed on sloughing skin, hair, and feathers.

Ticks, such as the one shown in Figure 36-12, are parasites that feed on their hosts by piercing the flesh and sucking on the blood. Many species of ticks carry bacteria and other microorganisms in their guts that may cause diseases in the host. While the tick feeds, the microorganisms are transmitted to the new host. Rocky Mountain spotted fever and Lyme disease are transmitted in this way. Ticks range in length from a few millimeters to 3 cm (about 1 in.).



Scorpions, such as *Paruroctonus mesaensis*, have pincerlike pedipalps and a venomous stinger at the end of their segmented abdomen.

#### **FIGURE 36-12**

The lone star tick, *Amblyomma americanum*, is an arachnid that parasitizes humans and other mammals.





(a) Millipede, Narceus americanus



(b) Giant centipede, Scolopendra sp.

#### **FIGURE 36-13**

(a) Millipedes have a rounded body and two pairs of legs on each body segment except the last two. (b) Centipedes have a flattened body and one pair of legs on each body segment except the first and the last two.

# SUBPHYLUM MYRIAPODA

The subphylum Myriapoda (MIR-ee-AHP-uh-duh), includes the class Diplopoda (duh-PLAH-puh-duh), which consists of millipedes, and the class Chilopoda (KIE-LAHP-uh-duh), which consists of centipedes. *Myriapoda* means "many feet," and is so named because myriapods have many body segments, most of which have one or two pairs of legs each. Unlike crustaceans, myriapods have one pair of unbranched antennae. They are terrestrial but lack a waxy exoskeleton. They avoid drying out by living in damp areas.

### **Class Diplopoda**

Millipedes are members of the class Diplopoda. Most millipedes have two pairs of legs on each body segment except the last two. Millipedes may have up to 100 body segments and thus 200 pair of legs. The legs are well adapted for burrowing through humus and soil, but because the legs are short, millipedes move slowly. As Figure 36-13a shows, the bodies of millipedes are rounded.

Millipedes have short antennae and two groups of simple eyes on their head. They have poor vision but a good sense of smell. Millipedes use their maxillae and mandibles to chew on plants or decaying plant matter in the soil.

### **Class Chilopoda**

Centipedes are members of the class Chilopoda. Centipedes may have as few as 15 or as many as 175 pairs of legs. In tropical regions centipedes reach lengths of 30 cm (12 in.). Their bodies are more flattened than those of millipedes, and their legs are longer relative to their body, as Figure 36-13b shows. Each body segment behind the head, except the first segment and the last two segments, has one pair of jointed legs. The appendages on the first segment are modified into a pair of poison claws. Long antennae and two clusters of simple eyes are located on the head. Centipedes can move quickly in search of earthworms, insects, and other prey. They kill the prey with their poison claws and use their mandibles and maxillae to tear it apart. Most centipedes are not harmful to humans.

## **SECTION 3 REVIEW**

- 1. List the major characteristics of arachnids.
- 2. Describe the functions of pedipalps.
- Describe three ways in which spiders are adapted for catching prey.
- Name two ways in which scorpions differ from spiders.
- 5. How do mites and ticks differ?
- 6. How do millipedes and centipedes differ?

#### **CRITICAL THINKING**

- **7. Making Comparisons** Compare the excretory system of a spider with that of a crayfish.
- 8. Inferring Relationships How might spiders benefit humans?
- **9.** Applying Information A cubic meter of soil may contain thousands of millipedes. What role might millipedes serve in an ecosystem?

# SECTION 1 Phylum Arthropoda

- Arthropods are segmented animals that have jointed appendages, an exoskeleton, a high degree of cephalization, a ventral nerve cord, and an open circulatory system.
- To grow, an arthropod must shed its exoskeleton periodically in a process called molting.

#### Vocabulary

arthropod (p. 723) appendage (p. 723) chitin (p. 723) compound eye (p. 723) molting (p. 724)  The five major subphyla of Arthropoda are Trilobita, Crustacea, Chelicerata, Myriapoda, and Hexapoda. The subphylum Trilobita consists of extinct animals called trilobites.

trilobite (p. 724) tagma (p. 724) mandible (p. 724) chelicera (p. 724)

# SECTION 2 Subphylum Crustacea

- Crustaceans, members of the subphylum Crustacea, have two pairs of antennae. Most crustaceans have a pair of chewing mouthparts called mandibles and one pair of branched appendages on each body segment. The exoskeletons of many crustaceans contain large amounts of calcium carbonate.
- Crustaceans include shrimps, lobsters, crabs, crayfish, barnacles, isopods, copepods, and water fleas. Most crustaceans are aquatic, use gills to respire, and have a larval stage called a nauplius.
- The body of a crayfish is divided into a cephalothorax and an abdomen. The appendages on each body segment are specialized for sensing, feeding, respiration, locomotion, or reproduction.
- Crayfish have a digestive gland that is near the stomach and that secretes enzymes for digestion. Walking circulates water across the gills for respiration. The circulatory system is open. Green glands assist in excretion of excess water that enters the body by osmosis.

#### Vocabulary

nauplius (p. 726) cirrus (p. 727) isopod (p. 727) decapod (p. 728) cephalothorax (p. 728) thorax (p. 728) carapace (p. 728) abdomen (p. 728) antenna (p. 728) antennule (p. 728) cheliped (p. 728) swimmeret (p. 729) telson (p. 729) uropod (p. 729) digestive gland (p. 729) green gland (p. 730)

# **SECTION 3** Subphyla Chelicerata and Myriapoda

- Members of the subphylum Chelicerata lack antennae and have pincerlike mouthparts called chelicerae.
- Arachnids include spiders, scorpions, mites, and ticks. Their bodies are divided into a cephalothorax and an abdomen, and they usually have six pairs of jointed appendages: one pair of chelicerae, one pair of pedipalps, and four pairs of walking legs.
- Spiders have eight simple eyes and chelicerae modified as fangs. Spiders produce silk threads that are used for several functions. Spiders are terrestrial; they respire by means of book lungs, tracheae, or both. Malpighian tubules function to excrete wastes while conserving water.
  - Vocabulary

arachnid (p. 731) pedipalp (p. 731) spinneret (p. 732) book lung (p. 732)

- Scorpions have large, pincerlike pedipalps and a stinger on the last segment of the abdomen.
- Mites and ticks have a completely fused cephalothorax and abdomen. Many species are parasitic, and some spread diseases that affect humans.
- Members of the subphylum Myriapoda have antennae, mandibles, and unbranched appendages.
- Millipedes have rounded bodies and two pairs of jointed legs on each body segment except the last two segments. Centipedes have flattened bodies and one pair of jointed legs on each body segment except the first segment and the last two segments.

trachea (p. 732) spiracle (p. 732) Malpighian tubule (p. 732)

# **CHAPTER REVIEW**

# **USING VOCABULARY**

- **1.** For each pair of terms, explain how the meanings of the terms differ.
  - a. mandible and chelicera
  - b. *isopod* and *decapod*
  - c. cephalothorax and abdomen
  - d. antennae and antennules
  - e. cheliped and telson
  - f. book lung and trachea
- **2.** Explain the relationship between the cephalothorax and the thorax.
- **3.** Choose the term that does not belong in the following group, and explain why it does not belong: *book lung, trachea, spiracle,* and *green gland.*
- **4.** Word Roots and Origins The word *tagma* is derived from the Greek *tassein*, which means "to arrange." Using this information, explain why the term *tagma* is a good name for the structure that the term describes.

# **UNDERSTANDING KEY CONCEPTS**

- 5. Describe the key characteristics of arthropods.
- 6. Explain how arthropods molt.
- 7. List the five subphyla of arthropods.
- **8. Summarize** the major characteristics of crustaceans.
- 9. Explain how a barnacle feeds.
- **10. Summarize** the function of the major appendages of a crayfish.
- **11. Describe** excretion in a crayfish.
- 12. Compare respiration in crayfish and spiders.
- **13. Identify** the main characteristics of the members of subphylum Chelicerata.
- **14. Compare** the appendages on the cephalothorax of a spider with those of a scorpion.
- 15. List three predatory behaviors of spiders.
- 16. Identify a distinguishing characteristic of mites.
- 17. Explain how parasitic ticks spread diseases.
- **18. Identify** the main characteristics of the members of subphylum Myriapoda.
- **19. Compare** the characteristics of millipedes and centipedes.
- **20. Summarize** how myriapods avoid desiccation in terrestrial environments.

**21. CONCEPT MAPPING** Use the following terms to create a concept map that sequences the process of molting in an arthropod: *exoskeleton, enzymes, inner layer, hormone, molting,* and *epidermis.* 

# **CRITICAL THINKING**

**22. Interpreting Graphics** Identify structures A through F in the diagram below.



- **23. Applying Information** Arthropods first lived on land about 400 million years ago. They have survived several time periods in which other phyla became extinct. What characteristics might have enabled arthropods to survive and adapt?
- **24. Relating Concepts** A water flea of the genus *Daphnia* eats algae. How might this organism acquire its food?
- **25.** Inferring Relationships Barnacles are sessile crustaceans. What adaptation enables them to compete with motile organisms for food? What adaptation protects them from predators?
- **26. Recognizing Relationships** The cephalothorax of a crayfish is covered by the carapace, a fused plate of exoskeleton. What are some advantages and disadvantages of this fused structure?
- **27. Analyzing Patterns** Crayfish have a high concentration of sensory hairs on the telson. What might be the advantage of having so many sensory structures at the posterior end?



# Standardized Test Preparation

**DIRECTIONS:** Choose the letter of the answer choice that best answers the question.

- 1. What do all arthropods have in common?
  - A. spiracles
  - **B.** antennae
  - **C.** a cephalothorax
  - **D.** jointed appendages
- **2.** What is the chitin-containing structure that protects and supports the body of an arthropod?
  - **F.** a tagma
  - **G.** a chelicera
  - $\boldsymbol{\mathsf{H}}\xspace$  an appendage
  - J. an exoskeleton
- **3.** Which of the following statements about compound eyes is true?
  - **A.** Compound eyes have a single lens.
  - **B.** Compound eyes are located on the abdomen of scorpions.
  - **C.** Compound eyes are found in all arthropods except crayfish.
  - **D.** Compound eyes are composed of many individual light detectors.
- **4.** What are the major respiratory organs of crayfish?
  - **F.** gills
  - **G.** lungs
  - **H.** tracheae
  - **J.** book lungs
- 5. How do mites and ticks differ from spiders?
  - A. Mites and ticks have mandibles.
  - **B.** Mites and ticks have two pairs of antennae.
  - **C.** Mites and ticks have a unique respiratory system.
  - **D.** Mites and ticks have a fused cephalothorax and abdomen.

**INTERPRETING GRAPHICS:** The illustration below shows four animals. Use the illustration to answer the question that follows.



- 6. Which animal has a chitinous exoskeleton?
  - F. snail
  - **G.** grasshopper
  - H. hydra
  - J. squid

**DIRECTIONS:** Complete the following analogy.

- 7. mandible : crayfish :: chelicera :
  - **A.** pill bug
  - **B.** scorpion
  - **C.** barnacle
  - **D.** millipede

**INTERPRETING GRAPHICS:** The graph below shows data about molting and two causes of mortality in crabs. Use the graph to answer the questions that follow.

#### **Molting and Mortality Rates**



- **8.** During which months are you most likely to find crabs in molt?
  - **F.** January through March
  - **G.** April through June
  - **H.** July through September
  - J. September through January
- **9.** What is the relationship between molting and mortality?
  - A. Molting increases mortality.
  - **B.** Molting decreases mortality.
  - **C.** Molting has no effect on mortality.
  - **D.** Molting and mortality occur at different times of the year.

### SHORT RESPONSE

Some arthropods are terrestrial and some are aquatic.

Give examples and describe the distinguishing characteristics of each type of arthropod.

### **EXTENDED RESPONSE**

All arthropods undergo many cycles of molting throughout their lifetime.

*Part A* Describe the process of molting in arthropods.

*Part B* Explain how the anatomical structure of an arthropod relates to the function of molting.

**Test TIP** For questions involving graphs, be sure to study the graph's title, axes, and labels carefully before choosing a final answer.

# **INQUIRY LAB**

# **Investigating Pill Bug Behavior**

### **OBJECTIVES**

- Review characteristics of the phylum Arthropoda and the subphylum Crustacea.
- Observe the external anatomy of a living terrestrial isopod.
- Investigate the behavior of terrestrial isopods.

### PROCESS SKILLS

- observing
- hypothesizing
- experimenting

### MATERIALS

- **5** live pill bugs for each pair of students
- 1 plastic medicine dropper
- water
- potato
- 3 sheets of filter paper cut to fit a Petri dish
- Petri dish with cover
- aluminum foil
- bright lamp or flashlight
- 4 fabrics of different texture
- cellophane tape
- scissors



## Background

- **1.** What are the major characteristics of arthropods and crustaceans?
- 2. Where would you expect to find pill bugs?
- **3.** How are pill bugs different from most other crustaceans?

### **PART A** Response to Light

- Put several drops of water on a piece of filter paper until the paper becomes slightly moist. Place the filter paper in the bottom of a Petri dish. Cover half the bottom of the Petri dish with aluminum foil.
- **2.** Check the lighting in the room. The light must be low and even during this part of the investigation.
- 3. CAUTION You will be working with live animals. Be sure to treat them gently and to follow directions carefully. Place five pill bugs in the center of the filter paper. Shine a lamp directly over the Petri dish so that half the filter paper is brightly illuminated and the other half is in darkness, shaded by the foil.
- **4.** Based on your knowledge of the natural habitat of pill bugs, can you predict where they will go? Make a data table like the one shown, and record your prediction as well as the actual responses of the pill bugs.

## **PART B** Response to Moisture

- 5. CAUTION Sharp or pointed objects can cause injury. Handle scissors carefully. Cut a piece of filter paper in half. Moisten one of the halves with water and place it in the bottom of a Petri dish. Make sure that drops of water do not leak onto the bottom of the dish.
- **6.** Place the dry half of the filter paper in the bottom of the Petri dish, leaving a 2 mm gap between it and the damp filter paper.
- **7.** Place five pill bugs along the boundary between the wet and dry areas. Place the top on the dish.
- 8. To which side do you predict the pill bugs will move? Write your prediction in your data table. Observe the pill bugs for 3 to 5 minutes, and record your observations in your data table. Do your observations agree with your predictions?

### **PART C** Response to Food

- **9.** Again dampen a piece of filter paper and place it in the bottom of a Petri dish. Next place a thin slice of potato near the edge of the dish.
- **10.** Place five pill bugs in the Petri dish opposite the potato slice, and place the lid on the dish.
- **11.** Where do you predict the pill bugs will go? Write your prediction in your data table. Observe the pill bugs for 3 to 5 minutes, and record your observations in your data table. Do your observations agree with your predictions?

### **PART D** Response to Surface Texture

- **12.** Trace the outline of the bottom of a Petri dish on one of the fabrics. Cut the circle out of the fabric and fold it in half. Then cut along the fold to produce two half-circles.
- **13.** Repeat step 12 using the other three fabrics. You should now have eight half-circles.
- **14.** Tape together two half-circles, each of a different fabric. Place the full circle in the bottom of a Petri dish, tape side down, as shown in the figure below.
- **15.** On a sheet of paper, draw the fabric circle and label the two types of fabric that make up the circle.



- **16.** Place a pill bug in the center of the circle and observe its movements. One student should keep track of the amount of time the animal spends on each fabric. On the drawing that was made in step 15, the other student should draw the path the pill bug travels in the circle. After 5 minutes, stop your observations and record the amount of time the pill bug spent on each fabric.
- **17.** Repeat steps 14–16 for two other pairs of fabrics.
- **18.** Return the pill bugs to their container. Clean up your materials and wash your hands before leaving the lab.

### **Analysis and Conclusions**

- **1.** In Part A, why was the entire filter paper moistened?
- **2.** In Part B, why was there a slight separation between the wet and dry halves of the filter paper?
- **3.** In Part C, why was the entire filter paper moistened?
- **4.** In Part D, which fabric did the pill bugs prefer? Describe the texture of that fabric.
- **5.** How do the responses of pill bugs to light, moisture, and food in these experiments reflect adaptations to their natural surroundings?
- **6.** How is being able to detect surface texture a good adaptation for pill bugs in their natural habitat?

### **Further Inquiry**

- **1.** Design an experiment to investigate the response of pill bugs to temperature. Think carefully about how you will construct your apparatus. Seek approval from your teacher before you actually conduct this experiment. How do you think the pill bugs will respond?
- **2.** Design an experiment to investigate whether pill bugs have preferences for certain types of food.

Stimulus	Prediction	Observation
Light		
Moisture		
Food		

#### **OBSERVATIONS OF PILL-BUG BEHAVIOR**