What You’ll Learn
■ You will compare and contrast the adaptations of echinoderms.
■ You will distinguish the features of chordates by examining invertebrate chordates.

Why It’s Important
By studying how echinoderms and invertebrate chordates function, you will enhance your understanding of the beginnings of vertebrate evolution.

Understanding the Photo
Echinoderms obtain food by a variety of methods. They can be carnivores, herbivores, scavengers, or filter feeders. These sea stars are carnivorous echinoderms. They extend the stomach from the mouth and engulf mussels, filter-feeding mollusks.

Biology Online
Visit ca.bdel.glencoe.com to
• study the entire chapter online
• access Web Links for more information and activities on echinoderms and invertebrate chordates
• review content with the Interactive Tutor and self-check quizzes
What is an echinoderm?

Members of the phylum Echinodermata have a number of unusual characteristics that easily distinguish them from members of any other animal phylum. Echinoderms move by means of hundreds of hydraulic, suction-cup-tipped appendages and have skin covered with tiny, jawlike pincers. Echinoderms (ih KI nuh durmz) are found in all the oceans of the world.

Echinoderms have endoskeletons

If you were to examine the skin of several different echinoderms, you would find that they all have a hard, spiny, or bumpy endoskeleton covered by a thin epidermis. The long, pointed spines on a sea urchin are obvious. Sea stars, sometimes called starfishes, may not appear spiny at first glance, but a close look reveals that their long, tapering arms, called rays, are covered with short, rounded spines. The spiny skin of a sea cucumber consists of soft tissue embedded with small, platelike structures that barely resemble spines. The endoskeleton of all echinoderms is made primarily of calcium carbonate, the compound that makes up limestone. Some of the spines found on sea stars and sea urchins have become modified into pincerlike appendages called pedicellariae (PEH dih sih LAHR ee ay). An echinoderm uses its jawlike pedicellariae for protection and for cleaning the surface of its body. You can examine these structures in the MiniLab on the following page.
Echinoderms have radial symmetry

You may remember that radial symmetry is an advantage to animals that are stationary or move slowly. Radial symmetry enables these animals to sense potential food, predators, and other aspects of their environment from all directions. Observe the radial symmetry, as well as the various sizes and shapes of spines, of each echinoderm pictured in Figure 29.1.

The water vascular system

Another characteristic unique to echinoderms is the water vascular system that enables them to move, exchange gases, capture food, and excrete wastes. The water vascular system is a hydraulic system that operates under water pressure. Water enters and leaves the water vascular system of a sea star through the madreporite (mah druh POHR ite), a sievelike, disk-shaped opening on the upper surface of the echinoderm’s body. This disk functions like the strainer that fits into a sink drain and keeps large particles out of the pipes.

Echinoderms have radial symmetry

All echinoderms have radial symmetry as adults and an endoskeleton composed primarily of calcium carbonate. Explain How does radial symmetry benefit an animal that cannot move fast?

A living sand dollar has an endoskeleton composed of flattened plates that are fused into a rigid framework.

A sea lily’s feathery rays are composed of calcified skeletal plates covered with an epidermis.
Look at the close-up of the underside of a sea star in Figure 29.2. You can see that tube feet run along a groove on the underside of each ray. Tube feet are hollow, thin-walled tubes that end in a suction cup. Tube feet look somewhat like miniature droppers. The end of a tube foot works like a tiny suction cup. You can find out how tube feet help a sea star eat by looking at Figure 29.4 on the next page. Each tube foot works independently of the others, and the animal moves along slowly by alternately pushing out and pulling in its tube feet. You can learn more about the operation of the water vascular system in the Connection to Physics at the end of this chapter.

Tube feet also function in gas exchange and excretion. Gases are exchanged and wastes are eliminated by diffusion through the thin walls of the tube feet.

Echinoderms have varied nutrition

All echinoderms have a mouth, stomach, and intestines, but their methods of obtaining food vary. Sea stars are carnivorous and prey on worms or on mollusks such as clams. Most sea urchins are herbivores and graze on algae. Brittle stars, sea lilies, and sea cucumbers feed on dead and decaying matter that drifts down to the ocean floor.

Echinoderms have a simple nervous system

Echinoderms have no head or brain, but they do have a central nerve ring that surrounds the mouth. Nerves extend from the nerve ring down each ray. Each radial nerve then branches into a nerve net that provides sensory information to the animal. Echinoderms have cells that detect light and touch, but most do not have sensory organs. Sea stars are an exception. A sea star’s body consists of long, tapering rays that extend from the animal’s central disk. A sensory organ known as an eyespot and consisting of a cluster of light-detecting cells is located at the tip of each arm, on the underside. Eyespots enable sea stars to detect the intensity of light. Most sea stars move toward light. Sea stars also have chemical receptors on their tube feet. When a sea star detects a chemical signal from a prey animal, it moves in the direction of the arm receiving the strongest signal.

Echinoderms have bilaterally symmetrical larvae

If you examine the larval stages of echinoderms, you will find that they have bilateral symmetry. The ciliated larva that develops from the fertilized egg of an echinoderm is shown in Figure 29.3. Through metamorphosis, the free-swimming larvae make dramatic changes in both body parts and in symmetry.

Echinoderms are deuterostomes

Recall that most invertebrates show protostome development. Echinoderms are deuterostomes. This pattern of development indicates a close relationship to chordates, which are also deuterostomes.
A Sea Star

Figure 29.4
If you ever tried to pull a sea star from a rock where it is attached, you would be impressed by how unyielding and rigid the animal seems to be. Yet at other times, the animal shows great flexibility, such as when it rights itself after being turned upside down. The rigidity or flexibility of a sea star is due to its endoskeleton.

Critical Thinking How is radial symmetry useful to a sea star?

A Endoskeleton A sea star can quickly change from a rigid structure to a flexible one because it has an endoskeleton in the form of calcium carbonate plates just under its epidermis. The plates are connected by bands of soft tissue and muscle. When the muscles are contracted, the body becomes firm and rigid. When the muscles are relaxed, the body becomes flexible.

B Madreporite Water flows in and out of the water vascular system through the madreporite.

C Tube feet The total suction action of tube feet, caused by the contraction and relaxation of the ampullae, is so strong that the sea star's muscles can open a clam or oyster shell.

D Eyespots Echinoderm eyespots distinguish between light and dark but do not form images.

E Digestive gland The digestive gland releases enzymes involved in digestion.

F Stomach To eat, a sea star pushes its stomach out of its mouth and spreads the stomach over the food. Powerful enzymes secreted by the digestive gland turn solid food into a soupy liquid that the stomach can easily absorb. Then the sea star pulls the stomach back into its body.

G Anus Waste products of digestion are eliminated through the anus.

H Pedicellariae The pincerlike pedicellariae on the rays of the sea star keep the surface of its body clean.

Blood sea star
Diversity of Echinoderms

Approximately 6000 species of echinoderms exist today. About one-fourth of these species are in the class Asteroidea (AS tuh ROY dee uh), to which the sea stars belong. The five other classes of living echinoderms are Ophiuroidea (OH fee uh ROY dee uh), the brittle stars; Echinoidea (eh kihn OY dee uh), the sea urchins and sand dollars; Holothuroidea (HOH loh thuh ROY dee uh), the sea cucumbers; Crinoidea (cry NOY dee uh), the sea lilies and feather stars; and Concentricycloidea (kon sen tri sy CLOY dee uh), the sea daisies. You can compare different echinoderms in the BioLab at the end of this chapter.

Sea stars

Sea stars may be the most familiar echinoderms. Most species of sea stars have five rays, but some have more. Some species may have more than 40 rays. You have already read about the characteristics of sea stars that make them a typical example of echinoderms.

Brittle stars

As their name implies, brittle stars are extremely fragile, Figure 29.5. If you try to pick up a brittle star, parts of its rays will break off in your hand. This adaptation helps the brittle star survive an attack by a predator. While the predator is busy with the broken-off ray, the brittle star can escape. A new ray will regenerate.

Brittle stars do not use their tube feet for locomotion. Instead, they propel themselves with the snake-like, slithering motion of their flexible rays. They use their tube feet to pass particles of food along the rays and into the mouth in the central disk.

Sea urchins and sand dollars

Sea urchins and sand dollars are globe- or disk-shaped animals covered with spines, as Figure 29.5 shows. They do not have rays. The circular, flat skeletons of sand dollars have a five-petaled flower pattern on the surface. A living sand dollar is covered with minute, hair-like spines that are lost when the animal dies. A sand dollar has tube feet that protrude from the petal-like markings on its upper surface. These tube feet are modified into gills and are used for respiration. Tube feet on the animal’s bottom surface aid in bringing food particles to the mouth.
Sea urchins look like living pin-cushions, bristling with long, usually pointed spines. The sea urchin’s spines protect it from predators. Sea urchins have long, slender tube feet that, along with the spines, aid the animal in locomotion.

**Explain the functions of the spines of a sea urchin.**

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**Sea cucumbers**

Sea cucumbers are so called because of their vegetablelike appearance, shown in Figure 29.6A. Their leathery covering allows them flexibility as they move along the ocean floor. When sea cucumbers are threatened, they may expel a tangled, sticky mass of tubes through the anus, or they may rupture, releasing some internal organs that are regenerated in a few weeks. These actions confuse their predators, giving the sea cucumber an opportunity to move away. Sea cucumbers reproduce by shedding eggs and sperm into the water, where fertilization occurs. You can find out more about sea cucumber reproduction in the Problem-Solving Lab on this page.

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**Sea lilies and feather stars**

Sea lilies and feather stars resemble plants in some ways, as shown in Figure 29.6B. Sea lilies are the only sessile echinoderms. Feather stars are sessile only in larval form. The adult feather star uses its feathery arms to swim from place to place.

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**Sea daisies**

Two species of sea daisies were discovered in 1986 in deep waters off New Zealand. They are flat, disk-shaped animals less than 1 cm in diameter. Their tube feet are located around the edge of the disk rather than along radial lines, as in other echinoderms.
Origins of Echinoderms

The earliest echinoderms may have been bilaterally symmetrical as adults, and probably were attached to the ocean floor by stalks. Another view of the earliest echinoderms is that they were bilateral and free-swimming. Most invertebrates show protostome development, whereas deuterostome development appears mainly in chordates. The echinoderms represent the only major group of deuterostome invertebrates. This pattern of development is one piece of evidence biologists have for placing echinoderms as the closest invertebrate relatives of the chordates.

Because the endoskeletons of echinoderms easily fossilize, there is a good record of this phylum. Echinoderms, as a group, date from the Paleozoic Era, as shown in Figure 29.7. More than 13,000 fossil species have been identified.

**Understanding Main Ideas**

1. How does a sea star move? Explain in terms of the water vascular system of echinoderms.
2. Describe the differences in symmetry between larval echinoderms and adult echinoderms.
3. How are sea cucumbers different from other echinoderms?
4. What evidence suggests that echinoderms are closely related to chordates?

**Thinking Critically**

5. How do the various defense mechanisms among the echinoderm classes help deter predators?

**SKILL REVIEW**

6. Get the Big Picture Prepare a dichotomous key that distinguishes among classes of echinoderms. Include information on features you may find significant. For more help, refer to Get the Big Picture in the Skill Handbook.
Invertebrate Chordates

How is a sea squirt your relative?

Finding Main Ideas  On a piece of paper, construct an outline about invertebrate chordates. Use the red and blue titles in this section as a guideline. As you read the paragraphs that follow the titles, add important information and vocabulary words to your outline.

Example:
I. What is an invertebrate chordate?
   A. All chordates have a notochord.
   B. All chordates have a dorsal hollow nerve cord.

Use your outline to help you answer questions in the Section Assessment on page 775. For more help, refer to Outline in the Skill Handbook.

What is an invertebrate chordate?

The chordates most familiar to you are the vertebrate chordates—chordates that have backbones, such as birds, fishes, and mammals, including humans. But the phylum Chordata (kor DAI tub) includes three subphyla: Urochordata, the tunicates (sea squirts); Cephalochordata, the lancelets; and Vertebrata, the vertebrates. In this section you will examine the tunicates and lancelets—invertebrate chordates that have no backbones. You will study the vertebrate chordates in the next unit.

Invertebrate chordates may not look much like fishes, reptiles, or humans, but like all other chordates, they have a notochord, a dorsal hollow nerve cord, pharyngeal pouches, and a postanal tail at some time during their development. In addition, all chordates have bilateral symmetry, a well-developed coelom, and segmentation. The features shared by invertebrate and vertebrate chordates are illustrated in Figure 29.8. You can observe these features in invertebrate chordates in the Problem-Solving Lab later in this section.
All chordates have a notochord

The embryos of all chordates have a notochord \((\text{NOH tuh kord})\)—a long, semirigid, rodlike structure located between the digestive system and the dorsal hollow nerve cord. The notochord is made up of large, fluid-filled cells held within stiff, fibrous tissues. In invertebrate chordates, the notochord may be retained into adulthood. But in vertebrate chordates, this structure is replaced by a backbone. Invertebrate chordates do not develop a backbone.

The notochord develops just after the formation of a gastrula from mesoderm on what will be the dorsal side of the embryo. The notochord anchors internal muscles and enables invertebrate chordates to make rapid movements of the body. These movements propel the animal through the water at a great speed.

All chordates have a dorsal hollow nerve cord

The dorsal hollow nerve cord in chordates develops from a plate of ectoderm that rolls into a hollow tube. The sequence of development of the dorsal hollow nerve cord is illustrated in Figure 29.9. This tube is composed of cells surrounding a fluid-filled canal that lies above the notochord. In most adult chordates, the cells in the posterior portion of the dorsal hollow nerve cord develop into the spinal cord. The cells in the anterior portion develop into a brain. A pair of nerves connects the nerve cord to each block of muscles.

---

**Figure 29.9**

After gastrulation, organs begin to form in a chordate embryo.

- **A** The notochord is formed from mesoderm on the dorsal side of a developing embryo.
- **B** The dorsal hollow nerve cord originates as a plate of dorsal ectoderm just above the developing notochord.
- **C** The edges of this plate of ectoderm fold inward, eventually meeting to form a hollow tube surrounded by cells. The dorsal hollow nerve cord pinches off from the ectoderm and develops into the central nervous system of the animal.
- **D** Cells migrate from the meeting margins of the neural tube and eventually form other organs, including bones and muscles.
All chordate embryos have pharyngeal pouches

The pharyngeal pouches of a chordate embryo are paired structures located in the pharyngeal region, behind the mouth. Many chordates have pharyngeal pouches only during embryonic development. In aquatic chordates, pharyngeal pouches develop openings called gill slits. Food is filtered out and gas exchange occurs as water flows through gill slits. In terrestrial chordates, pharyngeal pouches develop into other structures, such as the jaw, inner ear, and tonsils.

All chordates have a postanal tail

At some point in development, all chordates have a postanal tail. As you know, humans are chordates, and during the early development of the human embryo, there is a postanal tail that disappears as development continues. In most animals that have tails, the digestive system extends to the tip of the tail, where the anus is located. Chordates, however, usually have a tail that extends beyond the anus.

Muscle blocks aid in movement of the tail. Muscle blocks are modified body segments that consist of stacked muscle layers. Muscle blocks are anchored by the notochord, which gives the muscles a firm structure to pull against. As a result, chordates tend to be more muscular than members of other phyla. You can observe many of the chordate traits in a lancelet in the MiniLab on the next page.

Homeotic genes control development

Homeotic genes specify body organization and direct the development of tissues and organs in an embryo. Studies of chordate homeotic genes have helped scientists understand the process of development and the relationship of invertebrate chordates to vertebrate chordates.

Diversity of Invertebrate Chordates

The invertebrate chordates belong to two subphyla of the phylum chordata: subphylum Urochordata, the tunicates (TÉW nuh kaytz), also called sea squirts, and subphylum Cephalochordata, the lancelets.

Tunicates are sea squirts

Members of the subphylum Urochordata are commonly called tunicates, or sea squirts. Although adult tunicates do not appear to have any shared chordate features, the larval stage, as shown in Figure 29.10, has a tail that makes it look similar to a tadpole. Tunicate larvae do not feed and are free swimming after hatching. They soon settle and attach themselves with a sucker to boats, rocks, and the ocean bottom. Many adult tunicates secrete a tunic, a tough sac made of cellulose, around their bodies. Colonies of tunicates sometimes secrete just one big tunic that has a common opening to the outside. You can find out how tunicates eat in Figure 29.12 on page 774.
Only the gill slits in adult tunicates indicate their chordate relationship. Adult tunicates are small, tubular animals that range in size from microscopic to several centimeters long. If you remove a tunicate from its sea home, it might squirt out a jet of water—hence the name sea squirt.

**Reading Check** Describe which chordate features are present in larval and adult tunicates.

**Lancelets are similar to fishes**

Lancelets belong to the subphylum Cephalochordata. They are small, streamlined, and common marine animals, usually about 5 cm long, as Figure 29.11 shows. They spend most of their time buried in the sand with only their heads sticking out. Like tunicates, lancelets are filter feeders. Unlike tunicates, however, lancelets retain all their chordate features throughout life.

**Figure 29.11**

Lancelets usually spend most of their time buried in the sand with only their heads sticking out so they can filter tiny morsels of food from the water (A). The lancelet’s body looks very much like a typical chordate embryo (B). Describe What chordate features are present in an adult lancelet?

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**MiniLab 29.2**

**Observe**

**Examining a Lancelet** Branchiostoma californiensis is a small, sea-dwelling lancelet. At first glance, it appears to be a fish. However, its structural parts and appearance are quite different.

**Procedure**

1. Place the lancelet onto a glass slide. **CAUTION:** Wear disposable protective gloves and handle preserved material with forceps.
2. Use a dissecting microscope to examine the animal. **CAUTION:** Use care when working with a microscope and slides.
3. Prepare a data table that will allow you to record the following: General body shape, Length in mm, Head region present, Fins and tail present, Nature of body covering, Sense organs such as eyes present, Habitat, Segmented body.
4. Indicate on your data table if the following can easily be observed: gill slits, notochord, dorsal hollow nerve cord.

**Analysis**

1. **Compare and Contrast** How does Branchiostoma differ structurally from a fish? How are its general appearance and habitat similar to those of a fish?
2. **Explain** Why weren’t you able to see gills, a notochord, and a dorsal hollow nerve cord?
3. **Infer** Using its scientific name as a guide, where might the habitat of this species be located?
A Tunicate

Figure 29.12

Tunicates, or sea squirts, are a group of about 3000 species that live in the ocean. They may live near the shore or at great depths. They may live individually, or several animals may share a tunic to form a colony. **Critical Thinking** In what ways are sponges and tunicates alike?

---

**Excurrent siphon** Water leaves the body of the animal through the excurrent siphon on the side of its body. When a tunicate is disturbed, it may forcefully spout water from its siphons.

**Inccurrent siphon** Water enters the animal at the top of the body through the inccurrent siphon, the animal’s mouth.

**Pharynx** The pharynx is lined with cilia and has gill slits. The beating of the cilia causes a current of water to move through the animal. Food is filtered out, and dissolved oxygen is removed from the water in the pharynx.

**Ciliated groove** During filter feeding, food is trapped by mucus secreted in a ciliated groove. The food and mucus are digested in the animal’s intestine.

**Heart** The heart of the tunicate is unusual because it pumps blood in one direction for several minutes and then reverses direction.

**Tunic** Tunicates are covered with a layer of tissue called a tunic. Some tunics are thick and tough, and others are thin and translucent. All protect the animal from predators.
Although lancelets look somewhat similar to fishes, they have only one layer of skin, with no pigment and no scales. Lancelets do not have a distinct head, but they do have light sensitive cells on the anterior end. They also have a hood that covers the mouth and the sensory tentacles surrounding it. The tentacles direct the water current and food particles toward the animal's mouth.

Origins of Invertebrate Chordates

Because sea squirts and lancelets have no bones, shells, or other hard parts, their fossil record is incomplete. Biologists are not sure where sea squirts and lancelets fit in the phylogeny of chordates. According to one hypothesis, echinoderms, invertebrate chordates, and vertebrates all arose from ancestral sessile animals that fed by capturing food in tentacles. Modern vertebrates probably arose from the free-swimming larval stages of ancestral invertebrate chordates. Recent discoveries of fossil forms of organisms that are similar to living lancelets in rocks 550 million years old show that invertebrate chordates probably existed before vertebrate chordates.

**Understanding Main Ideas**

1. List the four features that are characteristic of chordates.

2. How are invertebrate chordates, such as lancelets, different from vertebrates, such as fishes and mammals?

3. Compare and contrast the physical features of sea squirts and lancelets.

4. How do sea squirts and lancelets protect themselves?

**Thinking Critically**

5. What features of chordates suggest that you are more closely related to invertebrate chordates than to echinoderms?

6. Experiment You have found some tadpolelike animals in the water near the seashore and you raise them in a laboratory. Design an experiment in which you will determine whether the animals are larvae or adults. For more help, refer to Experiment in the Skill Handbook.
Observing and Comparing Echinoderms

**Before You Begin**
Do all echinoderms have the same symmetry, shape, and body features? One way to answer this question is to examine a variety of echinoderms and note their similarities and differences. In this lab, you will make observations of a sea star, a sea urchin, a sea cucumber, and a sand dollar.

**Problem**
How are sea stars, sea urchins, sea cucumbers, and sand dollars alike? How are they different from each other?

**Objectives**
*In this BioLab, you will:*
- **Observe, compare, and contrast** various echinoderms.
- **Draw** representative echinoderms.
- **List** the traits of four different echinoderms.
- **Infer** adaptations for life functions of echinoderms.

**Materials**
preserved specimens of sea star, sea urchin, sand dollar, sea cucumber
forceps
culture or petri dish
toothpicks

**Safety Precautions**
*CAUTION: Specimens are preserved and will be reused, so they must be kept intact. Wear disposable protective gloves and use forceps when handling preserved materials. Always wear goggles in the lab.*

**Skill Handbook**
If you need help with this lab, refer to the Skill Handbook.

**Data Table**

<table>
<thead>
<tr>
<th></th>
<th>Sea Star</th>
<th>Sea Urchin</th>
<th>Sand Dollar</th>
<th>Sea Cucumber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer covering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tube feet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of body openings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of symmetry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PROCEDURE**

1. Copy the data table.
2. Examine the sand dollar, sea cucumber, sea star, and sea urchin and fill in the data table by describing the features listed.

3. Draw each of your specimens and label the external features you can see.

4. **Cleanup and Disposal** Clean all equipment as instructed by your teacher, and return everything to its proper place for reuse. Wash your hands with soap and water after handling preserved specimens.

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**ANALYZE AND CONCLUDE**

1. **Observe and Infer** Using your observations, compare the outer coverings of sea stars, sea urchins, sand dollars, and sea cucumbers. Explain how the coverings benefit the animals.

2. **Analyze** In what way are the echinoderms you examined alike externally? Explain how this adaptation benefits these animals.

3. **Infer** Tube feet are not visible on all the specimens you observed. Why not?

4. **Infer** The sea cucumber appears to be less like the other specimens you studied. Why is it classified as an echinoderm?

5. **Infer** Which of the echinoderms you studied may move the fastest? Explain.

6. **Error Analysis** Preserved animal specimens may differ from living animals due to the preservation technique. Soft, fragile parts may not be preserved as well as hard, sturdy parts. Analyze your data table to see where errors may have occurred due to these differences.

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**Apply Your Skill**

**Project** Obtain and view multimedia technology that shows live echinoderms. Summarize what you learned about echinoderms by watching them live as opposed to observing preserved specimens.

**Web Links** To find out more about echinoderms, visit ca.bdol.glencoe.com/echinoderms
Many organisms use hydraulic systems to supply food and oxygen to, and remove wastes from, cells lying deep within the body. Hydraulics is a branch of science that is concerned with the practical applications of liquids in motion. In living systems, hydraulics is usually concerned with the use of water to operate systems that help organisms find food and move from place to place.

The sea star uses a unique hydraulic mechanism called the water vascular system for movement and for obtaining food. The water vascular system provides the water pressure that operates the tube feet of sea stars and other echinoderms.

The water vascular system
On the upper surface of a sea star is a sievelike disk, the madreporite, which opens into a fluid-filled ring. Extending from the ring are long radial canals running along a groove on the underside of each of the sea star’s rays. Many small lateral canals branch off from the sides of the radial canals. Each lateral canal ends in a hollow tube foot, as shown in Figure 29.4 on page 766. The tube foot has a small muscular bulb at one end, the ampulla, and a short, thin-walled tube at the other end that is usually flattened into a sucker. Each ray of the sea star has many tube feet arranged in two or four rows on the bottom side of the ray. The tube feet are extended or retracted by hydraulic pressure in the water vascular system.

Mechanics of the water vascular system
The entire water vascular system is filled with water and acts as a hydraulic system, allowing the sea star to move. The muscular ampulla contracts and relaxes with an action similar to the squeezing of a dropper bulb. When the muscles in the wall of the ampulla contract, a valve between the lateral canal and the ampulla closes so that water does not flow backwards into the radial canal. The pressure from the walls of the ampulla acts on the water, forcing it into the tube foot’s sucker end, causing it to extend.

When the extended tube foot touches a rock or a mollusk shell, the center of the foot is retracted slightly. This creates a vacuum, enabling the tube foot to adhere to the rock or shell. The tip of the tube foot also secretes a sticky substance that helps it adhere. To move forward, muscles in the ampulla relax, and muscles in the tube foot wall contract. These actions shorten the tube foot and pull the sea star forward. Water is forced back into the relaxed ampulla. When the muscles in the ampulla contract, the tube foot extends again. This pattern of extension and retraction of tube feet results in continuous movement. It is the coordinated movement of many tube feet that enable the sea star to move slowly along the ocean floor.

Research
Echinoderms are not the only animals to use water pressure for movement. Research to find out how scallops and earthworms also use hydraulic pressure for locomotion.

To find out more about hydraulic pressure systems, visit ca.bdol.glencoe.com/physics
Section 29.1

**Echinoderms**

- Echinoderms have spines or bumps on their endoskeletons, radial symmetry, and water vascular systems. Most move by means of the suction action of tube feet.
- Echinoderms can be carnivorous, herbivorous, scavengers, or filter feeders.
- Echinoderms include sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, sea lilies, feather stars, and sea daisies.
- Deuterostome development is an indicator of the close phylogenetic relationship between echinoderms and chordates.
- A good fossil record of this phylum exists because the endoskeleton of echinoderms fossilizes easily.

**Key Concepts**

**Vocabulary**

- ampulla (p. 765)
- madreporite (p. 764)
- pedicellaria (p. 763)
- ray (p. 763)
- tube foot (p. 765)
- water vascular system (p. 764)

Section 29.2

**Invertebrate Chordates**

- All chordates have a dorsal hollow nerve cord, a notochord, pharyngeal pouches, and a postanal tail at some stage during development.
- All chordates also have bilateral symmetry, a well-developed coelom, and segmentation.
- Sea squirts and lancelets are invertebrate chordates.
- Vertebrate chordates may have evolved from larval stages of ancestral invertebrate chordates.

**Key Concepts**

**Vocabulary**

- dorsal hollow nerve cord (p. 771)
- pharyngeal pouch (p. 772)
- notochord (p. 771)

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To help you review the diversity of echinoderms, use the Organizational Study Fold on page 763.

ca.bdol.glencoe.com/vocabulary_puzzlemaker
Vocabulary Review

Review the Chapter 29 vocabulary words listed in the Study Guide on page 779. Determine if each statement is true or false. If false, replace the underlined word with the correct vocabulary word.

1. **Tube feet** are pincerlike appendages on echinoderms used for protection and cleaning.
2. The **pharyngeal pouches** are the paired openings found behind the mouth of all chordate embryos.
3. The **notochord** is the nerve cord found in all chordates that forms the spinal cord and brain.
4. The round, muscular structure on a tube foot is the **madréporite**.

Understanding Key Concepts

5. The water vascular system operates the tube feet of sea stars and other echinoderms by means of _______.
   A. water pressure  
   B. water exchange  
   C. water pumps  
   D. water filtering
6. When a sea star loses a ray, it is replaced by the process of _______.
   A. regeneration  
   B. reproduction  
   C. metamorphosis  
   D. parthenogenesis
7. The sand dollar in the diagram below exhibits what type of symmetry?
   A. bilateral symmetry  
   B. radial symmetry  
   C. asymmetry  
   D. all of the above

8. Spines on sea stars and sea urchins are modified into pedicellariae used for _______.
   A. feeding  
   B. protection  
   C. breathing  
   D. reproduction

Constructed Response

9. **Open Ended** How does a sessile animal such as a sea squirt protect itself?
10. **Open Ended** How is the ability of echinoderms to regenerate an adaptive advantage to these animals?
11. **Open Ended** In what ways are echinoderms more similar to vertebrates than to other invertebrates?

Thinking Critically

12. **Concept Map** Complete the concept map by using the following vocabulary terms: ampulla, madreporite, tube feet, water vascular system.

13. **Real World Biochallenge** Sea urchins are harvested on the coastlines of many states and imported to countries that consider sea urchin a gourmet food. Sea urchin populations have declined since harvesting began. Visit [ca.bdol.glencoe.com](ca.bdol.glencoe.com) to investigate the controversy over continuing the harvesting. With other class members, stage a debate with assigned roles that will reveal the controversy. Roles should include a person who harvests sea urchins, a consumer, a scientist studying sea urchins, and a person wanting to protect sea urchins and their habitat.
14. **Observe and Infer** Explain why the tube feet of a sand dollar are located on its upper surface as well as on its bottom surface.

15. **Explain** Why is the fossil record incomplete for lancelets?

### Part 1 Multiple Choice
Use the graph below to answer question 16.

**Relationship Between Snake Stars and Sediment Covering Coral**

16. The snake star, a brittle star that looks snake-like, wraps itself around certain corals where it may stay for months. According to the graph, which phrase best describes the relationship between snake stars and the amount of sediment found on coral?

A. There is no relationship between snake stars and sediment.
B. As the number of snake stars increases, the amount of sediment decreases.
C. As the number of snake stars increases, the amount of sediment increases.
D. As the number of snake stars decreases, the amount of sediment decreases.

### Study the diagram below and answer questions 17–19.

17. The dorsal hollow nerve cords are the structures labeled ________.
A. 1 and 4    C. 3 and 6
B. 2 and 5    D. none of the above

18. The structures used for gas exchange are labeled ________.
A. 1 and 4    C. 3 and 6
B. 2 and 5    D. none of the above

19. The notochords are the structures labeled ________.
A. 1 and 4    C. 3 and 6
B. 2 and 5    D. none of the above

### Part 2 Constructed Response/Grid In
Record your answers on your answer document.

20. **Open Ended** What might happen to a marine ecosystem in which fishes that eat sea urchins are overharvested? Explain.

21. **Open Ended** Infer why there are virtually no freshwater echinoderms.
Invertebrates

How are sponges, clams, sea urchins, and beetles alike? All of these animals are invertebrates—animals without backbones. The ancestors of all modern invertebrates had simple body plans. They lived in water and obtained food, oxygen, and other materials directly from their surroundings, just like present-day sponges, jellyfishes, and worms. Some invertebrates have external coverings such as shells and exoskeletons that provide protection and support.

Sponges

Sponges, phylum Porifera, are invertebrates made up of two cell layers. They have no tissues, organs, or organ systems. In general, sponges are asymmetrical. Most adult sponges are sessile—they do not move from place to place.

Sponges are filter feeders. A sponge takes in water through pores in the sides of its body, filters out food, and releases the water through the opening at the top.

Cnidarians

Like sponges, cnidarians are made up of two cell layers and have only one body opening. The cell layers of a cnidarian, however, are organized into tissues with different functions. Cnidarians are named for stinging cells that contain nematocysts that are used to capture food. Jellyfishes, corals, sea anemones, and hydras belong to phylum Cnidaria.
**Roundworms**

Roundworms, phylum Nematoda, have a pseudocoelom and a tubelike digestive system with two body openings. Most roundworms are free-living, but many plants and animals are affected by parasitic roundworms.

**Flatworms**

Flatworms, phylum Platyhelminthes, include free-living planarians, parasitic tapeworms, and parasitic flukes. Flatworms are bilaterally symmetrical animals with flattened solid bodies and no body cavities. Flatworms have one body opening through which food enters and wastes leave.

**Focus on Adaptations**

Body Cavities

The type of body cavity an animal has determines how large it can grow and how it takes in food and eliminates wastes. Acoelomate animals, such as planarians, have no body cavity. Water and digested food particles travel through a solid body by the process of diffusion.

Animals such as roundworms have a pseudocoelom (soo duh SEE lum), a fluid-filled body cavity that is partly lined with mesoderm. Mesoderm is a layer of cells between the ectoderm and endoderm that differentiates into muscles, circulatory vessels, and reproductive organs. The pseudocoelom provides support for the attachment of muscles, making movement more efficient. Earthworms have a coelom, a body cavity surrounded by mesoderm in which internal organs are suspended. The coelom acts as a watery skeleton against which muscles can work.
Mollusks

Slugs, snails, clams, squids, and octopuses are members of phylum Mollusca. All mollusks are bilaterally symmetrical and have a coelom, a digestive tract with two openings, a muscular foot for movement, and a mantle, which is a membrane that surrounds the internal organs. In shelled mollusks, the mantle secretes the shell.

Classes of Mollusks

There are three major classes of mollusks. Gastropods have one shell or no shell. Bivalves have two hinged shells called valves. Cephalopods have muscular tentacles and are capable of swimming by jet propulsion. All mollusks, except bivalves, have a rough, tonguelike organ called a radula used for obtaining food.

Segmented Worms

Bristleworms, earthworms, and leeches are members of phylum Annelida, the segmented worms. Segmented worms are bilaterally symmetrical, coelomate animals that have segmented, cylindrical bodies with two body openings. Most annelids have setae, bristlelike hairs that extend from body segments, that help the worms move.

Segmentation is an adaptation that provides these animals with great flexibility. Each segment has its own muscles. Groups of segments have different functions, such as digestion or reproduction.

Classes of Segmented Worms

Phylum Annelida includes three classes: Hirudinae, the leeches; Oligochaeta, the earthworms; and Polychaeta, the bristleworms.
**Arthropods**

Arthropods are bilaterally symmetrical, coelomate invertebrates with tough outer coverings called exoskeletons. Exoskeletons protect and support their soft internal tissues and organs. They have jointed appendages that are used for walking, sensing, feeding, and mating. Jointed appendages allow for powerful and efficient movements.

**Arthropod Diversity**

Two out of three animals on Earth today are arthropods. The success of arthropods can be attributed to adaptations that provide efficient gas exchange, acute senses, and varied types of mouthparts for feeding. Arthropods include organisms such as spiders, crabs, lobsters, shrimps, crayfishes, centipedes, millipedes, and the enormously diverse group of insects.

The evolution of jointed appendages with many different functions probably led to the success of the arthropods as a group.

Like other members of class Arachnida, the black widow spider has four pairs of jointed legs and chelicerae, a pair of biting appendages near the mouth.

Millipedes, class Diplopoda, are herbivores. Millipedes may have more than 100 body segments, and each segment has two pairs of legs.

Members of class Insecta, the insects, such as this luna moth, have three pairs of jointed legs and one pair of antennae for sensing their environments.
**Arthropod Origins**

Arthropods most likely evolved from an ancestor of segmented worms; both groups show segmentation. However, an arthropod’s segments are fused and have a greater complexity of structure than those of segmented worms. Because arthropods have exoskeletons, fossil arthropods are frequently found, and consequently more is known about their origins than about the phylogeny (fy LAH juh nee) of worms.

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**VITAL STATISTICS**

**Arthropods**

**Largest class:** Insecta, with 810,000 known species

**Size ranges:** Largest insects: tropical stick insect, length, 33 cm; Goliath beetle, mass, 100 g

Smallest insect: fairyfly wasp, length, 0.21 mm

**Distribution:** all habitats worldwide

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**Focus on Adaptations**

**Insects**

Insects have many adaptations that have led to their success in the air, on land, in freshwater, and in salt water. For example, insects have complex mouthparts that are well adapted for chewing, sucking, piercing, biting, or lapping. Different species have mouthparts adapted to eating a variety of foods.

If you have ever been bitten by a mosquito, you know that mosquitoes have piercing mouthparts that cut through your skin to suck up blood. In contrast, butterflies and moths have long, coiled tongues that they extend deep into tubular flowers to sip nectar. Grasshoppers and many beetles have hard, sharp mandibles they use to cut off and chew leaves. But the heavy mandibles of staghorn beetles no longer function as jaws; instead, they have become defensive weapons used for competition and mating purposes.

**Different Foods for Different Stages**

Because insects undergo metamorphosis, they often utilize different food sources at different times of the year. For example, monarch butterfly larvae feed on milkweed leaves, whereas the adults feed on milkweed flower nectar. Apple blossom weevil larvae feed on the stamens and pistols of unopened flower buds, but the adult weevils eat apple leaves. Some adult insects, such as mayflies, do not eat at all! Instead, they rely on food stored in the larval stage for energy to mate and lay eggs.
Echinoderms

Echinoderms, phylum Echinodermata, are radially symmetrical, coelomate animals with hard, bumpy, spiny endoskeletons covered by a thin epidermis. The endoskeleton is made primarily of calcium carbonate. Echinoderms move using a unique water vascular system with tiny, suction-cuplike tube feet. Some echinoderms have long spines also used in locomotion.

Echinoderm Diversity

There are six living classes of echinoderms. They include sea stars, brittle stars, sea urchins, sea cucumbers, sand dollars, sea lilies, feather stars, and sea daisies.

Echinoderms have bilaterally symmetrical larvae and are deuterostomes, a feature that suggests a close relationship to the chordates.

Invertebrate Chordates

All chordates have, at one stage of their life cycles, a notochord, a dorsal hollow nerve cord, pharyngeal pouches, and a postanal tail. A notochord is a long, semirigid, rodlike structure along the dorsal side of these animals. The dorsal hollow nerve cord is a fluid-filled canal lying above the notochord. Pharyngeal pouches are paired openings in the pharynx that develop into gill slits in some invertebrate chordates, and are used to strain food from the water and for gas exchange. A muscular postanal tail is present in all chordates at some stage in their development. Muscle blocks aid in movement of the postanal tail. Muscle blocks are modified body segments consisting of stacked muscle layers.

Invertebrate chordates have all of these features at some point in their life cycles. The invertebrate chordates include the lancelets and the tunicates, also known as sea squirts.

Sea cucumbers have a leathery skin which gives them flexibility. Like most echinoderms, they move using tube feet.

The long, thin arms of brittle stars are fragile and break easily, but they grow back. Brittle stars use their arms to move along the ocean bottom.

The lancelet is an invertebrate chordate. The lancelet’s body is shaped like that of a fish even though it is a burrowing filter feeder.
Part 1  Multiple Choice

1. Which of the following is used by segmented worms for movement?
   A. chelicerae  
   B. nematocysts  
   C. setae  
   D. water vascular system

2. An example of an animal with no body cavity is a(n) ________.
   A. sea star  
   B. flatworm  
   C. earthworm  
   D. clam

Use the diagrams below to answer questions 3 and 4. The diagrams represent three different animal body plans.

3. Which body plan would be capable of more complex and powerful movements?
   A. 1  
   B. 2  
   C. 3  
   D. all of these

4. Which type of body plan belongs to pseudocoelomate animals such as roundworms?
   A. 1  
   B. 2  
   C. 3  
   D. all of these

5. An octopus belongs to phylum Mollusca because it has a mantle, bilateral symmetry, a digestive tract with two openings, and ________.
   A. an external shell  
   B. a muscular foot  
   C. a pseudocoelom  
   D. segmentation

Use the diagrams below to answer questions 6–8. The diagram represents the life cycle for a beef tapeworm.

6. Which part of the life cycle for a beef tapeworm is missing?
   A. infection of the cow  
   B. infection of the grass  
   C. infection of the human host  
   D. infection of the tapeworm

7. How do the tapeworm eggs get into the grass?
   A. from rainwater  
   B. from feces of infected humans  
   C. from snails  
   D. from dead cows

8. Beef tapeworm larvae get into human hosts when humans ________.
   A. eat beef  
   B. eat pork  
   C. walk barefoot  
   D. go swimming

9. Which of the following characteristics is unique to echinoderms?
   A. nematocysts  
   B. jointed appendages  
   C. a water vascular system  
   D. filter feeding
10. Asymmetrical organisms are often ________.
   A. free-swimming
   B. sessile
   C. photosynthetic
   D. autotrophic

11. Blood moves through vessels and into open spaces around the body organs in an ________.
    A. closed circulatory system
    B. water vascular system
    C. open circulatory system
    D. tracheal tube

Use the diagram below to answer questions 12–14.
The diagram represents features shared by invertebrate and vertebrate chordates.

12. The structure labeled A in the diagram is the ________.
    A. postanal tail
    B. mouth
    C. dorsal hollow nerve cord
    D. notochord

13. The structure labeled E in the diagram is used for ________.
    A. sensing the environment
    B. moving the tail
    C. support
    D. straining food from water

14. The structure labeled B in the diagram is the ________.
    A. postanal tail
    B. pharyngeal pouch
    C. dorsal hollow nerve cord
    D. notochord

**Part 2** Constructed Response/Grid In

Use the graph to answer questions 15–17. Record your answers or fill in the bubbles on the answer document using the correct place value.

15. **Grid In** How many more minutes does animal A spend in the light than animal B?

16. **Grid In** What is the average amount of time animals A, C, and E spend in the light?

17. **Grid In** What is the average amount of time animals D and E spend in the light?

18. **Open Ended** You are examining a free-living animal that has a thin, solid body with two surfaces. Into what phylum is this organism classified? Explain.

19. **Open Ended** Explain why asymmetrical animals, such as sponges, are often sessile.

20. **Open Ended** In what ways have wings been an adaptive advantage to the success of insects?

21. **Open Ended** Explain why worms are not as well represented in the fossil records as mollusks.