UNIT

8

INVERTEBRATES

CHAPTERS

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References to *Scientific American* project ideas are located throughout this unit.

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National Science Teachers Association *sci*LINKS Internet resources are located throughout this unit.

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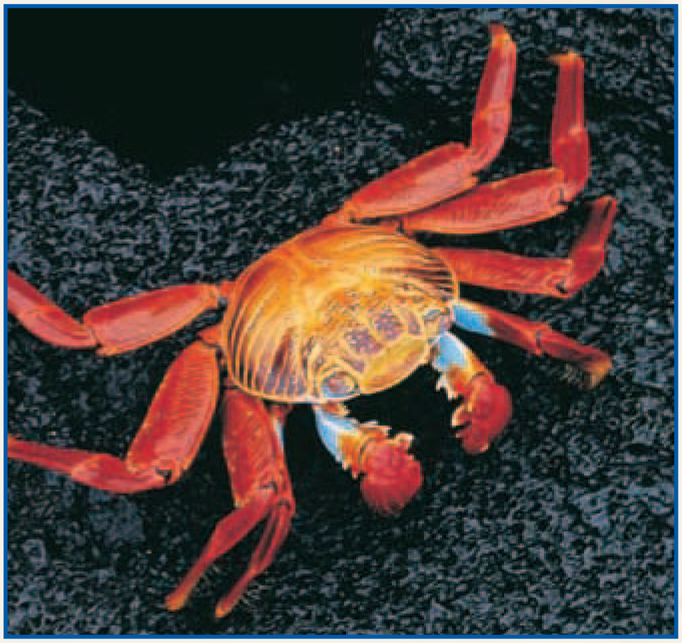
“*It has taken biologists some 230 years to identify and describe three quarters of a million insects; if there are indeed at least thirty million, as Erwin (Terry Erwin, The Smithsonian Institution) estimates, then, working as they have in the past, insect taxonomists have ten thousand years of employment ahead of them.*”

From “Endless Forms Most Beautiful,” from *The Sixth Extinction: Patterns of Life and the Future of Humankind,* by Richard Leakey and Roger Lewin. Copyright © 1995 by Sherma B. V. Reprinted by permission of *Doubleday, a division of Bantam Doubleday Dell Publishing Group, Inc.*

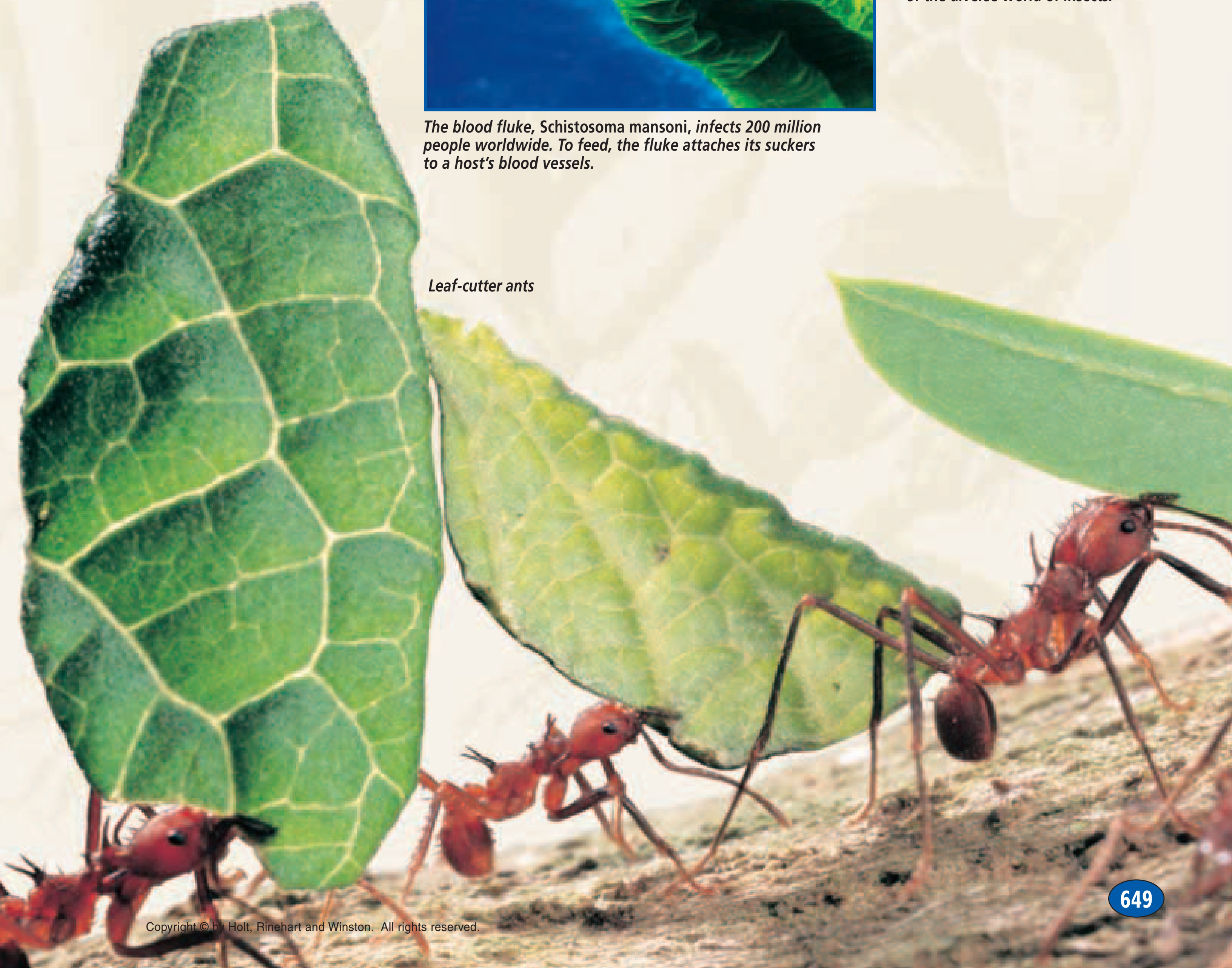


This Sally lightfoot crab lives on bare volcanic rock on the Galápagos Islands.

This sea star clearly demonstrates pentamerous radial symmetry.

The leaf-footed bug, Diactor bilineatus, *is a colorful member of the diverse world of insects.*

The blood fluke, Schistosoma mansoni, *infects 200 million people worldwide. To feed, the fluke attaches its suckers to a host's blood vessels.*



Leaf-cutter ants

CHAPTER 32

INTRODUCTION TO ANIMALS

The diversity of animal life is staggering. Animals have adapted to Earth's lushest environments and to its harshest environments. This Sally Lightfoot crab, *Grapsus grapsus,* lives on the bare volcanic rock of the geologically young Galápagos Islands.

SECTION 1 *The Nature of Animals*

SECTION 2 *Invertebrates and Vertebrates*

SECTION 3 *Fertilization and Development*

SECTION 1

THE NATURE OF ANIMALS

If you are asked to name an animal, you might respond with the name of a familiar large-bodied animal, such as a horse, a shark, or an eagle. But the kingdom Animalia is much more diverse than many people realize.

OBJECTIVES

- **Identify** four important characteristics of animals.
- **List** two kinds of tissues found only in animals.
- **Explain** how the first animals may have evolved from unicellular organisms.
- **Identify** four features found only in chordates.
- **Identify** two functions of the body cavity.
- **List** the structural features that taxonomists use to classify animals.

VOCABULARY

animal
vertebrate
invertebrate
specialization
ingestion
zygote
differentiation
chordate
notochord
dorsal nerve cord
pharyngeal pouch
symmetry
radial symmetry
dorsal
ventral
anterior
posterior
bilateral symmetry
cephalization
germ layer

CHARACTERISTICS

Animals are multicellular heterotrophic organisms that lack cell walls. Some animals, called **vertebrates,** have a backbone. Other animals, called **invertebrates,** do not have a backbone. Invertebrates account for more than 95 percent of all animal species alive today. Most members of the animal kingdom share other important characteristics, including sexual reproduction and movement.

Multicellular Organization

The bodies of animals are multicellular. Some animals contain large numbers of cells. For example, some scientists estimate that the body of an adult human contains 50 trillion to 100 trillion cells. Unlike the cells of unicellular organisms, the cells of multicellular organisms do not lead independent lives. Each cell depends on the presence and functioning of other cells.

In all but the simplest animal phyla, there is a division of labor among cells. **Specialization** is the evolutionary adaptation of a cell for a particular function. Just as a general contractor makes use of carpenters, electricians, and plumbers to build a house, a multicellular organism makes use of specialized cells to perform particular functions, such as digesting food, removing wastes, or reproducing.

A *tissue* is a group of similar cells that perform a common function. Most animal bodies are composed of combinations of different kinds of tissues. The formation of tissue from many individual cells is made possible by *cell junctions,* connections between cells that hold the cells together as a unit. The members of most animal phyla have *organs,* body structures that are composed of more than one type of tissue and that are specialized for a certain function.

Without multicellularity, the enormous variety found in the animal kingdom would not exist. The size of unicellular organisms is limited. Moreover, all of their functions, such as reproduction and digestion, must be handled within a single cell. Multicellularity and cell specialization have enabled organisms to evolve and adapt to many environments.

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www.scilinks.org
Topic: Multicellular Organisms
Keyword: HM61002

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Heterotrophy

Plants and some unicellular organisms are autotrophic. They make food using simple molecules from their environment and an energy source, such as the sun. Animals, on the other hand, are heterotrophic. They must obtain complex organic molecules from other sources. Most animals accomplish this by ingestion. During **ingestion,** an animal takes in organic material or food, usually in the form of other living things. Digestion then occurs within the animal's body, and carbohydrates, lipids, amino acids, and other organic molecules are extracted from the material or cells the animal has ingested.

Word Roots and Origins

ingestion

from the Latin *ingestus,* meaning "carry in"

Sexual Reproduction and Development

Most animals can reproduce sexually, and some can also reproduce asexually. In sexual reproduction, two haploid gametes fuse. The **zygote,** the diploid cell that results from the fusion of the gametes, then undergoes repeated mitotic divisions. Mitotic division of a cell produces two identical offspring cells. How does an adult animal, with its many different organs, tissues, and cell types, arise from a single cell? In the process called *development,* the enlarging mass of dividing cells undergoes differentiation. During **differentiation** (DIF-uhr-EN-shee-AY-shuhn), cells become specialized and therefore different from each other. For example, some cells may become blood cells, and others may become bone cells. The process of differentiation is the path to cell specialization.

Movement

Although some animals, such as barnacles, spend most of their lives attached to a surface, most animals move about in their environment. The ability to move results from the interrelationship of two types of tissue found only in animals: nervous tissue and muscle tissue. Nervous tissue allows an animal to detect stimuli in its environment and within its own body. Cells of nervous tissue, called *neurons,* conduct electrical signals throughout an animal's body. Multiple neurons work together to take in information, transmit and process it, and initiate an appropriate response. Often, this response involves muscle tissue, which can contract and exert a force to move specific parts of the animal's body. The bat shown in Figure 32-1 continuously processes information about its position in space and the position of its prey. It can adjust its muscular responses so rapidly that it can intercept insects in flight.

FIGURE 32-1

Capturing fast-moving prey requires exquisitely timed coordination between the nervous tissue and muscle tissue in the body of this heart-nosed bat, *Cardioderma cor.*

ORIGIN AND CLASSIFICATION

The first animals probably arose in the sea. The structural characteristics of invertebrates suggest that they were the first multicellular animals and that they evolved from protists. Because protists are both heterotrophic and eukaryotic, scientists have inferred that multicellular invertebrates may have developed from colonies of loosely connected, flagellated protists, such as the one shown in Figure 32-2.

What path did cell specialization take in these early organisms? Colonial protists may have lost their flagella over the course of evolution as individual cells in the colony grew more specialized. They may have been similar to modern colonial protists that do show some degree of cell specialization, such as some species of algae. In these species, the gametes are distinct from nonreproductive cells. A similar division of labor in early colonial protists may have been the first step toward multicellularity.

Scientists often use a type of branching diagram called a *phylogenetic diagram,* such as the one in Figure 32-3, to show how animals are related through evolution. Taxonomists have grouped animals into several phyla (singular, *phylum*) by comparing animals' fossils, body symmetry, patterns of embryo development, and ribosomal RNA (rRNA) and other macromolecules. Taxonomy is an ever-changing branch of science; therefore, it should not be surprising that the actual number and names of animal phyla continue to change and be debated. Many taxonomists recognize 30 or more different animal phyla, though some phyla contain a very small number of species.

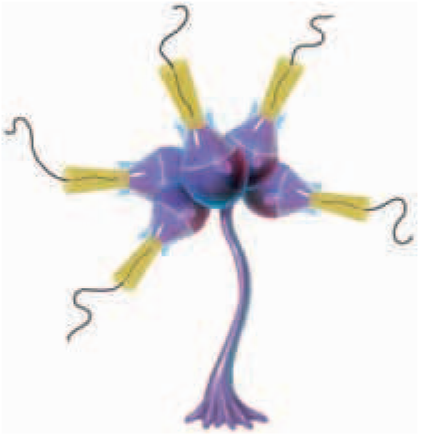

FIGURE 32-2

The first animals may have evolved from colonial protists similar to the one shown in this drawing.

FIGURE 32-3

This phylogenetic diagram represents a hypothesis for the relationship among members of the animal kingdom based on rRNA analysis. Notice on the diagram the locations of similarities in body tissues, body symmetry, and embryo development. For updates on phylogenetic information, visit **go.hrw.com.** Enter the keyword **HM6 Phylo.**

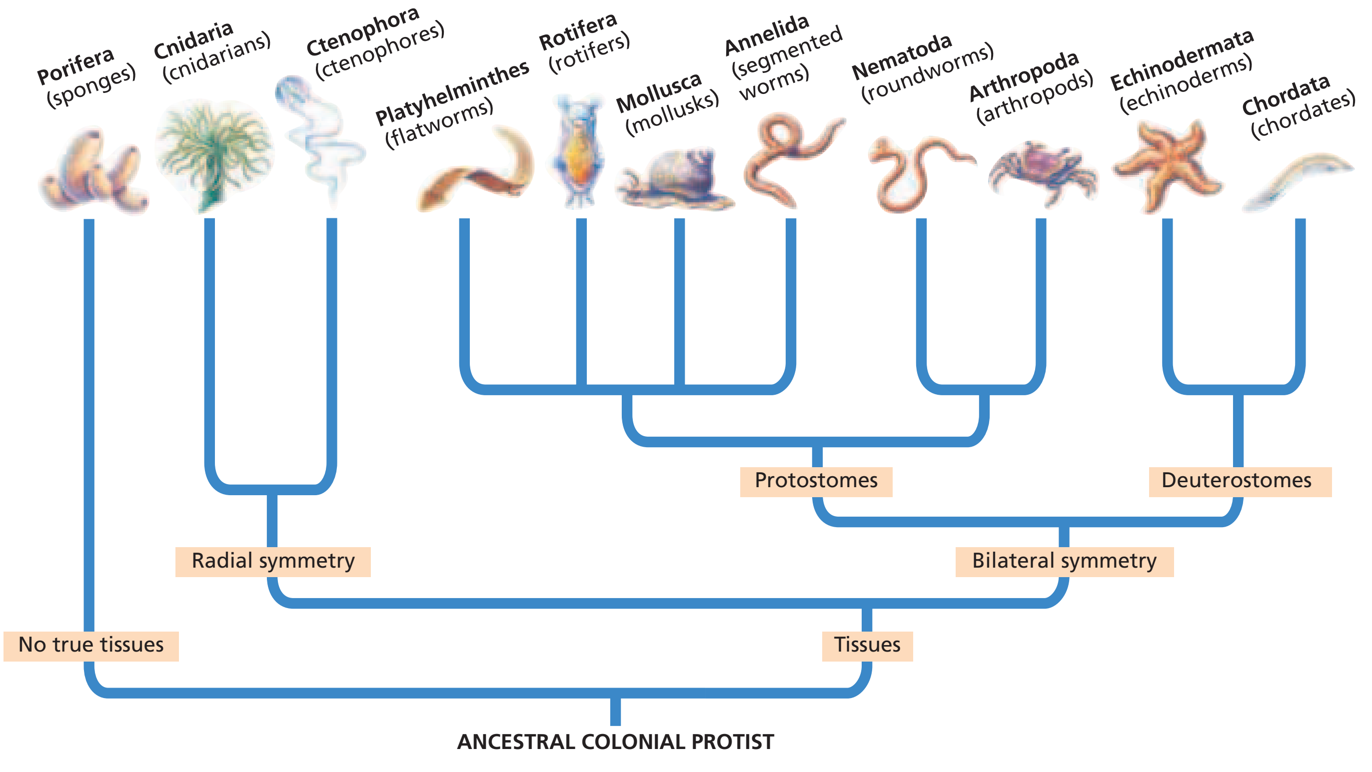

FIGURE 32-4

The palm spider, *Nephila* sp., is an arthropod, with a segmented body and body parts specialized for trapping, killing, and eating its prey.

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Topic: Vertebrates

Keyword: HM61602

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Invertebrates

Invertebrate body plans range from the absence of body symmetry and true tissues, as is found in sponges, to bilateral symmetry and specialized body parts found in arthropods, such as the spider shown in Figure 32-4. Invertebrates do not have a backbone. Invertebrates make up the greatest number of animal species.

Chordates

The name **chordate** (KAWR-DAYT) refers to animals with a **notochord,** a firm, flexible rod of tissue located in the dorsal part of the body. At some stage in development, all chordates have a notochord, a dorsal nerve cord, pharyngeal pouches, and a postanal tail. The **dorsal nerve cord** is a hollow tube above the notochord. **Pharyngeal** (fuh-RIN-jee-uhl) **pouches** are small outpockets of the anterior digestive tract. The postanal tail consists of muscle tissue and lies behind the posterior opening of the digestive tract. A few chordates retain their early chordate characteristics all their lives. In most vertebrates, a subphylum of the chordates, the dorsal nerve cord develops into the brain and the spinal cord, and the notochord is replaced by the backbone. In aquatic vertebrates, the pharyngeal pouches have evolved into gills for breathing.

Although vertebrates are only one small subphylum of animals, they merit discussion from a human perspective. Humans are vertebrates, and the ecology of humans includes extensive interaction with other vertebrate species.

Careers in BIOLOGY

Veterinarian

Job Description Veterinarians are doctors who are trained to protect the health of animals, such as pets and livestock. Some veterinarians also protect animals and people from the diseases that they each carry.

Focus on a Veterinarian
Dr. Jack Walther grew up on a ranch, so animals were always part of his life. Today, Dr. Walther practices two days each week in a veterinary practice with another veterinarian. When he arrives each day, animal patients who have experienced overnight injuries or illnesses are already waiting. Dr. Walther handles these emergencies. He also sees patients with appointments for vaccinations, surgical follow-ups, exams, and other routine needs. Dr. Walther emphasizes that a veterinarian's role extends beyond just treating the family pet. "Vets also work to conserve animal resources; for example, they help study and preserve endangered species in Africa." Veterinarians are also at the forefront in protecting animals and people against diseases, such as Lyme disease and West Nile virus. "As a vet, you help not only the animal world, but also humanity."

Education and Skills

- **High school**—three years of science courses and four years of math courses
- **College**—bachelor of science including course work in biology, mathematics, chemistry, and physics; four years of additional schooling to earn doctor of veterinary medicine (D.V.M.) degree
- **Skills**—self-motivation, curiosity, patience, ability to work independently, ability to work with animals

For more about careers, visit go.hrw.com and type in the keyword HM6 Careers.

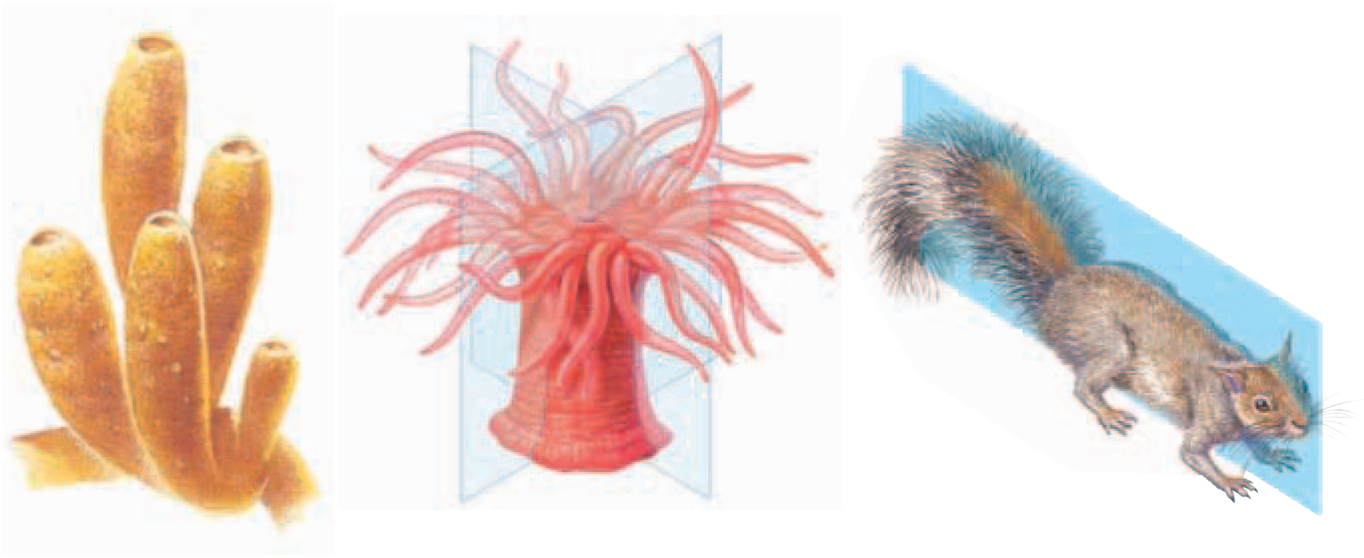

FIGURE 32-5

(a) The sponge lacks a consistent pattern of structure. (b) The sea anemone, an aquatic animal, displays radial symmetry. (c) The squirrel displays bilateral symmetry and cephalization.

BODY STRUCTURE

Animal bodies range from those that lack true tissues and an organized body shape to those that have very organized tissues and a consistent body shape.

Patterns of Symmetry

A *body plan* describes an animal's shape, symmetry, and internal organization. **Symmetry** is a body arrangement in which parts that lie on opposite sides of an axis are identical. An animal's body plan results from the animal's pattern of development. Sponges have the simplest body plan of all animals. Sponges, as shown in Figure 32-5a, are *asymmetrical*—they do not display symmetry. Animals that have a top and bottom side, but no front, back, right, or left end, display **radial symmetry**—a body plan in which the parts are organized in a circle around an axis. Cnidarians, such as the sea anemone in Figure 32-5b, are radially symmetrical.

Most animals have a **dorsal** (back) and **ventral** (abdomen) side, an **anterior** (toward the head) and **posterior** (toward the tail) end, and a right and left side, as shown by the squirrel in Figure 32-5c. Such animals have two similar halves on either side of a central plane and are said to display **bilateral symmetry.** Bilaterally symmetrical animals tend to exhibit **cephalization** (SEF-uh-li-ZAY-shuhn)—the concentration of sensory and brain structures in the anterior end of the animal. As a cephalized animal moves through its environment, the anterior end precedes the rest of the body, sensing the environment.

Word Roots and Origins

cephalization

from the Greek word *kephale,* meaning "head"

Germ Layers

Germ layers are tissue layers in the embryos of all animals except sponges, which have no true tissues. The embryos of cnidarians and ctenophores have two germ layers. All other animals have three germ layers. Every organ and tissue arises from a germ layer.

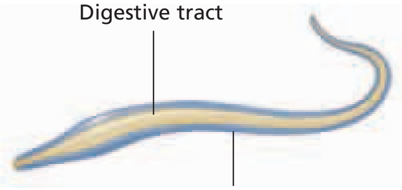

FIGURE 32-6

The body of a roundworm is held erect by its fluid-filled body cavity, which is firm but flexible, like a balloon filled with water.

Body Cavities

Most animals have some type of body cavity, a fluid-filled space that forms between the digestive tract and the outer wall of the body during development. Some animals, such as flatworms, have three germ layers but have a solid body. These animals lack a body cavity.

In the roundworm shown in Figure 32-6, the body cavity aids in movement by providing a firm, fluid-filled structure against which muscles can contract. The body cavity also allows some degree of movement of the exterior of the body with respect to the internal organs, resulting in more freedom of movement for the animal. Finally, the fluid in the body cavity acts as a reservoir and medium of transport for nutrients and wastes, which diffuse into and out of the animal's body cells.

Body Structure and Relatedness

Biologists use similarities in body plans and patterns of development to help them classify animals and hypothesize about the evolutionary history of animals. Biologists use information from extant (living) species and extinct species to develop phylogenetic diagrams, such as the one shown in Figure 32-3. Animal phyla shown on the same branch of the phylogenetic diagram, such as flatworms and rotifers, are thought to be related to each other more closely than they are to other animals and are characterized by similarities in morphology and rRNA sequences. Conversely, animals shown in different parts of the diagram are thought to be more distantly related.

- Multicellularity and a limited degree of cell specialization characterize the sponges. Sponges have no organized body shape and no true tissues.
- True tissues in two layers are found in the cnidarians and the ctenophores.
- True tissues in three layers and bilateral symmetry characterize all of the other animal phyla.

SECTION 1 REVIEW

1. What are the four characteristics common to most animals?
2. Identify how nervous tissue and muscle tissue are interrelated.
3. Summarize how unicellular organisms may have given rise to the first animals.
4. What are the features that all vertebrates share at some point in their development?
5. Identify the body-symmetry type that includes both an anterior end and a posterior end.
6. Name three body features that taxonomists use to help develop phylogenetic trees.

CRITICAL THINKING

7. **Recognizing Relationships** Animals such as sponges lack nervous tissue and muscle tissue. What does this tell you about sponges?
8. **Relating Concepts** In 1994, Western scientists first observed the Vietnamese saola, a hoofed mammal. The saola was shown to be related to wild cattle and buffalo. How do you think scientists identified the saola's closest relatives?
9. **Evaluating Information** How is cephalization advantageous to an animal in finding food?

INVERTEBRATES AND VERTEBRATES

Comparative anatomy, the study of the structure of animal bodies, is one of the oldest disciplines in biology. Some modern scientists work to establish the relationships between different animals, while others try to establish the relationships between the form and function of morphological features of animals and the role of these features in animal ecology.

SECTION 2

OBJECTIVES

- **Compare** symmetry, segmentation, and body support in invertebrates and vertebrates.
- **Describe** the differences in the respiratory and circulatory systems of invertebrates and vertebrates.
- **Compare** the digestive, excretory, and nervous systems of invertebrates and vertebrates.
- **Contrast** reproduction and development in invertebrates and vertebrates.

VOCABULARY

segmentation
exoskeleton
gill
open circulatory system
closed circulatory system
hermaphrodite
larva
endoskeleton
vertebra
integument
lung
kidney

INVERTEBRATE CHARACTERISTICS

Although it may be difficult for us to see many similarities between a clam and an octopus, they are classified in the same phylum. Adult invertebrates show a tremendous amount of morphological diversity.

Symmetry

Most invertebrates display radial or bilateral symmetry. The radial symmetry of a jellyfish, which drifts rather than swims, allows the animal to receive stimuli from all directions. Most invertebrates have bilateral symmetry, which is an adaptation to a more motile lifestyle. Bilateral symmetry allows for cephalization, which is present in varying degrees in different animals. Some bilaterally symmetric invertebrates, such as the sea hare shown in Figure 32-7, are not highly cephalized. Members of *Aplysia* do not have a true brain and are capable of only basic responses to the environment. Other invertebrates, such as squids and octopuses, are highly cephalized and have a distinct head and a nervous system dominated by a well-organized brain.

Segmentation

Segmentation in animals refers to a body composed of a series of repeating similar units. Segmentation is seen in its simplest form in the earthworm, an annelid in which each unit of the body is very similar to the next one. Within the phylum Arthropoda, however, segments may look different and have different functions. In the arthropod shown in Figure 32-8 on the next page, fusion of the anterior segments has resulted in a large structure that includes the animal's head and chest regions.

FIGURE 32-7

The California sea hare, *Aplysia californica,* is a shell-less mollusk that has a simple nervous system.

FIGURE 32-8

In animals such as this crayfish, *Procambarus* sp., segments are fused, producing larger structures. The head and chest structure in this crayfish results from the fusion of several segments. Segments may also give rise to other structures, such as limbs. The crayfish's exoskeleton is also clearly visible.

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Support of the Body

Invertebrate bodies have diverse means of support. Sponges have a simple skeleton that supports their soft tissue; the dried, brown, irregularly shaped "natural sponge" found in stores is this skeleton. The bodies of some other invertebrates, such as roundworms, are supported by the pressure of their fluid-filled body cavity.

An **exoskeleton** is a rigid outer covering that protects the soft tissues of many animals, including arthropods, such as crustaceans, which include crayfish, shown in Figure 32-8. An exoskeleton limits the size and may impede the movement of the organism. Also, an exoskeleton does not grow and must be shed and replaced as the animal grows.

Respiratory and Circulatory Systems

Animals produce carbon dioxide, CO_2, as a byproduct of metabolism. Therefore, carbon dioxide in the blood must be exchanged with oxygen, O_2, from the environment. This process, called *gas exchange,* occurs most efficiently across a moist membrane. In the simplest aquatic invertebrates, gas exchange occurs directly across the body covering. Aquatic arthropods and mollusks, however, have **gills,** organs that consist of blood vessels surrounded by a membrane and are specialized for gas exchange in water.

In most animals, the circulatory system moves blood or a similar fluid through the body to transport oxygen and nutrients to cells. At the same time, carbon dioxide and wastes are transported away from the cells. Sponges and cnidarians have no circulatory system, so nutrients and gases are exchanged directly with the environment by diffusion across cell membranes. Arthropods and some mollusks have an **open circulatory system,** in which circulatory fluid is pumped by the heart through vessels and into the body cavity and is then returned to the vessels. Annelids and other mollusks have a closed circulatory system. In a **closed circulatory system,** blood is pumped by a heart and circulates through the body in vessels that form a closed loop. The exchange of gases, nutrients, and wastes occurs between body cells and very small blood vessels that lie near each cell.

Digestive and Excretory Systems

In sponges, digestion occurs within individual cells. In cnidarians, a central chamber with one opening serves as the digestive system. Most other invertebrates, however, have a digestive tract, or *gut,* running through their body. In these animals, food is broken down in the gut, and the nutrients are absorbed by specialized cells that line the gut.

In simple aquatic invertebrates, wastes are excreted as dissolved ammonia, NH_3. In terrestrial invertebrates, specialized excretory structures filter ammonia and other wastes from the body cavity. The ammonia is then converted to less toxic substances, and water is reabsorbed by the animal before the waste is excreted.

Nervous System

The extraordinary degree of diversity among invertebrates is reflected in their nervous systems. Sponges have no neurons, although individual cells can react to environmental stimuli in much the same way that protozoa can. Neurons evolved in cnidarians, which have a very simple, loosely connected nervous system. Within a single invertebrate phylum, Mollusca, we can trace a stepwise progression of cephalization and the evolution of the brain.

The mollusks have very diverse nervous systems. Recall the sea hare, shown in Figure 32-7. Although its head is not well defined and its nervous system can perform only simple information processing, the sea hare can learn to contract a part of its body in response to certain stimuli. Contrast this simple behavior with that of a highly cephalized mollusk, such as the octopus. The octopus shows very complex decision-making behavior, and it can build a shelter from debris it finds on the ocean floor.

Reproduction and Development

Invertebrates are capable of some form of sexual reproduction, and many can also reproduce asexually. Some invertebrates, such as earthworms, are hermaphrodites. A **hermaphrodite** (huhr-MAF-roh-DIET) is an organism that produces both male and female gametes, allowing a single individual to function as both a male and a female.

Invertebrates may undergo indirect or direct development. Animals that undergo *indirect development* have an intermediate larval stage, as is shown in Figure 32-9. A **larva** (plural, *larvae*) is a free-living, immature form of an organism that is morphologically different from the adult. Larvae often exploit different habitats and food sources than adult organisms do. As a result, organisms in each stage are more likely to survive. Many insects, which constitute a class of arthropods, have indirect development.

In contrast, in *direct development,* the young animal is born or hatched with the same appearance and way of life it will have as an adult; no larval stage occurs. Most invertebrates undergo indirect development. A few, such as grasshoppers, undergo direct development.

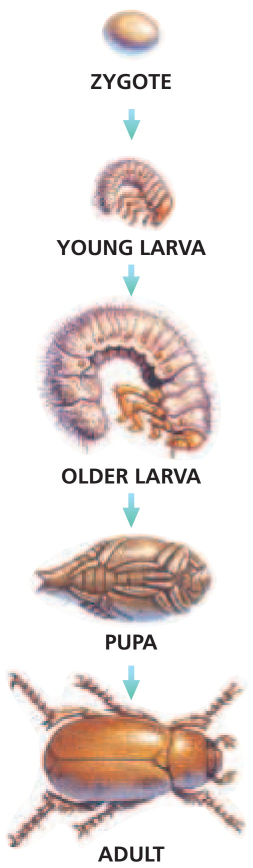

FIGURE 32-9

Animals with indirect development, such as this beetle, have an intermediate, larval stage. A larva is an immature form that exhibits physical traits that are different from those of the adult form.

VERTEBRATE CHARACTERISTICS

Vertebrates are chordates that have a backbone. Classes of vertebrates include fishes, amphibians, reptiles, birds, and mammals. All vertebrate classes except fishes spend part or all of their life on land. Many characteristics of terrestrial vertebrates are adaptations to life on land and fall into two broad categories: support of the body and conservation of water.

Segmentation and Support of the Body

Although it is not immediately apparent, vertebrates are segmented animals. Segmentation is evident in the ribs and the **vertebrae** (vuhr-tuh-bree), the repeating bony units of the backbone. As terrestrial vertebrates evolved from aquatic vertebrates, their limbs and associated muscles evolved to give the animals better support and greater mobility. For example, the legs of amphibians, the first land vertebrates to evolve, are positioned to the side of the body, as shown in Figure 32-10a. However, the legs of mammals, such as the deer shown in Figure 32-10b, are positioned directly beneath the body, allowing the animal to move faster and with a longer stride. Humans show an extreme version of this trait: we are bipedal, and our head is positioned directly over our body.

Vertebrates have an **endoskeleton,** an internal skeleton made of bone and cartilage, which includes the backbone. The endoskeleton grows as the animal grows.

(a)

(b)

FIGURE 32-10

(a) The legs of amphibians, such as this tree frog, *Agalychnis saltator,* are sharply bent and positioned away from the body. (b) The legs of terrestrial mammals, such as this deer, *Odocoileus virginianus,* are straighter than those of amphibians, providing greater mobility and speed.

Body Coverings

The outer covering of an animal is called the **integument** (in-TEG-yoo-muhnt). Although the integuments of fishes and most amphibians are adapted only to moist environments, the integuments of most terrestrial vertebrates are adapted to the dry conditions of a terrestrial environment. All animal bodies are composed of water-filled cells, and if the water content of the cells is reduced appreciably, the animal will die. Thus, the outer covering of terrestrial vertebrates, such as reptiles, birds, and mammals, is largely watertight. Integuments also serve other purposes. The moist skin of an amphibian functions as a respiratory organ for the exchange of gases. The scales of a reptile help protect it from predators. The feathers of birds and the fur of mammals efficiently insulate the body.

Respiratory and Circulatory Systems

Gas exchange occurs in the gills of aquatic vertebrates, including fishes and larval amphibians, but these gills do not function out of water. **Lungs** are organs for gas exchange composed of moist, membranous surfaces deep inside the animal's body. Lungs evolved in terrestrial vertebrates.

Vertebrates have a closed circulatory system with a multichambered heart. In some vertebrates, the multichambered heart separates oxygenated and deoxygenated blood, improving the efficiency of the circulatory system over that found in other vertebrates and many invertebrates.

Digestive and Excretory Systems

Digestion occurs in the gut, which runs from the mouth, at the anterior end, to the anus, at the posterior end. In many vertebrates, the gut is very long and folded, which helps increase the surface area over which nutrients can be absorbed. The human digestive tract is about 7 m (23 ft) long.

Both vertebrates and invertebrates must deal with the very toxic ammonia their bodies produce. Most vertebrates must expel wastes while conserving water. Like invertebrates, most vertebrates convert ammonia to less toxic substances. In most vertebrates, organs called **kidneys** filter wastes from the blood while regulating water levels in the body.

Nervous System

Vertebrates have highly organized brains, and the control of specific functions occurs in specific centers in the brain. The structure and function of the nervous system vary among vertebrate classes. For example, much of a fish's brain processes sensory information. Fishes have limited neural circuitry devoted to decision making. A fish's responses to stimuli in its environment are rigid, that is, they vary little from situation to situation and from fish to fish.

Other animals, such as dogs, display complex and flexible behavior. Much of the tissue in the dog's brain is given over to decision making, and its brain is large with respect to body size.

Reproduction and Development

In most fish and amphibian species, eggs and sperm are released directly into the water, where fertilization takes place. In reptiles, birds, and mammals, the egg and sperm unite within the body of the female, increasing the likelihood that an egg will be fertilized.

The fertilized eggs of many fishes, amphibians, reptiles, and birds develop outside the body. A developing embryo is nourished by the egg yolk and protected by jellylike layers or a shell. The zygotes of some fishes, amphibians, and reptiles remain inside the body of the female, nourished by the yolk until they hatch. In contrast, most mammals give birth to live offspring. Embryos of placental mammals develop in the female's body, nourished by the mother's blood supply until the young are born. With the exception of amphibians and some fishes, vertebrates undergo direct development. So, the young and the adults can share the same resources—an advantage if those resources are plentiful.

Quick Lab

Identifying Animal Characteristics

Materials 3 × 5 in. note cards (20), 5 pictures of vertebrates, 5 pictures of invertebrates

Procedure

1. Working in pairs, one partner will write one different vertebrate characteristic on each of 10 note cards. The other partner will write one different invertebrate characteristic on each of 10 note cards.
2. Place the animal pictures upside down in a stack. One partner (the dealer) will shuffle and deal all the cards and turn over one animal picture.
3. The nondealer plays first by laying down as many cards as possible that describe characteristics of the pictured animal. If no card matches, the play is passed to the other player. When neither partner can play, another picture is turned up and play continues.
4. Play ceases when neither student can play or when no pictures are left.

Analysis What are the disadvantages of using only morphological characteristics to identify an organism?

SECTION 2 REVIEW

1. Identify the primary function for the body covering of terrestrial animals.
2. Compare the structure of exoskeletons and endoskeletons.
3. Compare a closed circulatory system to an open circulatory system.
4. Compare the nervous systems of vertebrates and invertebrates.
5. Describe briefly invertebrate and vertebrate development.

CRITICAL THINKING

6. **Inferring Relationships** How might the segmented bodies of arthropods help them survive?
7. **Recognizing Relationships** How is the structure of the nervous system related to an animal's behavior?
8. **Comparing Concepts** Compare the advantages and disadvantages of the two types of development (direct and indirect development).

MILESTONES IN Developmental Biology

Timeline

1817 Christian Pander identifies germ layers.

1828 Karl Ernst von Baer discovers mammalian eggs and the fate of neural folds and opposes preformation.

1875 Oscar Hertwig observes fertilization.

1883 August Weismann publishes germ plasm theory.

1924 Spemann and Mangold discover the neural organizer.

1950s to present Stem cell research begins and continues.

1969 Lewis Wolpert studies pattern formation and positional information in embryos.

1983 Researchers discover homeotic genes.

1996 Scottish researchers clone Dolly the sheep from a mammary cell.

Present Researchers find stem cells in many types of adult tissues.

People have known only since the the 1800s that eggs and sperm unite at fertilization. In a little more than a century, researchers have come to understand a great deal about how one cell divides repeatedly to form a mass of cells and how a complex multicellular organism develops from that mass of dividing cells. As in many areas of biology, the speed and sophistication of research in developmental biology has been remarkable.

Until the 19th century, biologists believed that embryos grew from very small versions of complete organisms. In 1817, a Russian naturalist named Christian Pander observed developing chicks and described the three embryonic layers now called *ectoderm, mesoderm,* and *endoderm.* In 1828, Karl Ernst von Baer published a paper in which he concluded that the neural fold of an animal embryo gives rise to the animal's nervous system and notochord.

In 1875, German embryologist Oscar Hertwig first observed the union of the nuclei of male and female gametes at fertilization. Soon after, in 1883, another German biologist, August Weismann, laid out his germ plasm theory. This theory states that the body has germ cells, which pass along hereditary traits, and somatic cells, which do not pass along traits to new generations.

In 1924, German embryologists Hans Spemann and Hilde Mangold studied how cells "know" when to divide and what to do in a growing embryo. They hypothesized that one group of cells might "organize" the rest of the cells. Spemann and Mangold discovered that cells that were transplanted from the blastopore region of a blastula to another region of the blastula caused a new nervous system to form. Today, scientists are still searching for the signal these "organizer cells" give. Part of that search has been the study of pattern formation, or how cells respond to signals and form cells and tissues that have particular functions.

In 1969, Lewis Wolpert proposed that morphogens, or pattern-directing substances, diffuse through a body region—a limb bud, for example—and cause fingers or toes to form in a certain order.

In 1983, researchers discovered genes called *homeotic genes* that help control where limbs, such as the legs or antennae, grow on a fruit fly embryo.

Another recent line of research centers on stem cells. Stem cells are undifferentiated cells that are found in embryos and adult tissues and that can give rise to new cells. Researchers have recently discovered that adult stem cells exist in many more types of tissues than were once thought possible. A related line of research led to the birth of Dolly in 1996, the first mammal to be cloned from an adult somatic cell.

Review

1. What does the germ plasm theory state?
2. **Critical Thinking** Why are "organizer cells" important to the growing embryo.
3. **Critical Thinking** How does the production of genetic clones affect the germ plasm theory?

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FERTILIZATION AND DEVELOPMENT

Development of a multicellular animal from an egg cell is a truly remarkable process. Each cell in an animal has the same set of genes that are used to build the animal, yet animals have many different kinds of cells. From the fertilized egg come large numbers of cells—trillions in humans—that consistently give rise to structural features of the animal body.

SECTION 3

OBJECTIVES

- **List** the steps of fertilization and development through gastrulation.
- **List** two body parts formed from each germ layer.
- **Identify** the three different body cavity structures of animals.
- **Name** the categories of animals that undergo spiral cleavage and radial cleavage.
- **Contrast** the two processes of coelom formation.

VOCABULARY

fertilization
cleavage
blastula
gastrulation
gastrula
archenteron
blastopore
ectoderm
endoderm
mesoderm
acoelomate
pseudocoelom
coelom
protostome
deuterostome
schizocoely
enterocoely

FERTILIZATION AND EARLY DEVELOPMENT

In animals, **fertilization** is the union of female and male gametes to form a zygote. Fertilization results in the combination of the haploid sets of chromosomes from two individuals into a single diploid zygote.

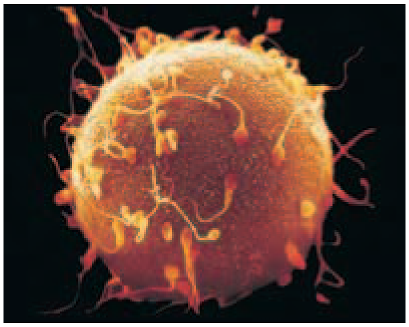
Gametes

In most animal species, the sperm cell, shown in Figure 32-11, is specialized for movement—it is very streamlined and small. The head of the sperm contains chromosomes, and the tail of the sperm is composed of a long flagellum.

The egg, also shown in Figure 32-11, is typically large because it has a large store of cytoplasm and yolk. The size of an egg produced by a given species seems to depend on how long the food supply in the yolk must last. For aquatic animals in which the embryo begins to feed itself early, eggs are small, and there is little yolk. In sharp contrast, the embryos of birds must live on the yolk until they hatch. In these eggs, the yolk volume is very large.

FIGURE 32-11

The small, flagellated sperm is adapted for motility and speed. It must seek out and fertilize the much larger, yolk-filled egg.



Fertilization

At the start of fertilization, the sperm's cell membrane fuses with the egg's cell membrane, and the nucleus of the sperm enters the cytoplasm of the egg. The fusion of the cell membranes of the egg and sperm causes an electrical change in the egg membrane that blocks entry to the egg by other sperm cells. The sperm nucleus merges with the egg nucleus to form the diploid nucleus of the zygote. Once a zygote is formed, replication of DNA begins, and the first cell division soon follows.

Cleavage and Blastula Formation

The series of cell divisions that occurs immediately following fertilization is termed **cleavage.** Figure 32-12, steps 1, 2, and 3 show that as cleavage progresses, the number of cells increases, from 2 to 4, then to 8, and so on. During cleavage, mitotic divisions rapidly increase the number of cells, but the cells do not grow in size. Thus, cleavage yields smaller and smaller individual cells. Cleavage increases the surface area–to-volume ratio of each cell, which enhances gas exchange and other environmental interactions.

In most species, cleavage produces a raspberry-shaped mass of 16 to 64 cells, as shown in step 4. As the number of dividing cells further increases, the mass becomes a hollow ball of cells called a **blastula,** shown in step 5. The central cavity of a blastula is called the *blastocoel* (BLAS-toe-SEEL).

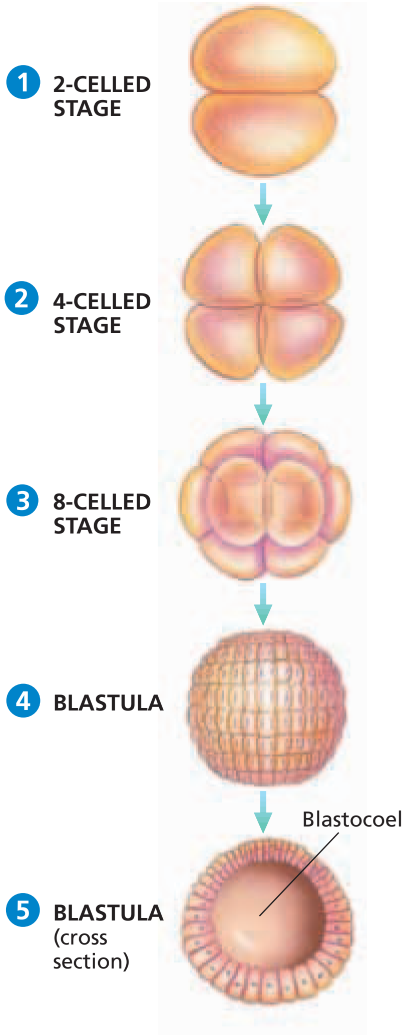


FIGURE 32-12

During cleavage, the zygote divides repeatedly without undergoing cell growth, producing a many-celled hollow blastula.

Gastrulation and Organogenesis

At the start of the next stage of development, shown in Figure 32-13, an area of the blastula begins to collapse inward. As shown in steps 1 and 2, reorganization of the cells of the hollow blastula begins with the inward movement of cells at one end of the blastula. This process, called **gastrulation,** transforms the blastula into a multilayered embryo, called the **gastrula,** shown in step 3. Gastrulation is marked by changes in the shape of cells and the way the cells interact with each other.

As the inward folding continues, the now cup-shaped embryo enlarges, and a deep cavity, called the **archenteron,** or primitive gut, develops. The open end of the archenteron is called the **blastopore.** Forming the outer layer of the gastrula is the outer germ layer, the **ectoderm,** shown in blue in step 3. The inner germ layer, the **endoderm,** is shown in yellow. In most phyla, the gastrula does not remain a two-layer structure. As development progresses, a third layer, the **mesoderm,** forms between the endoderm and the ectoderm.

Each of the germ layers formed during gastrulation develops into certain organs in a process called *organogenesis.* The endoderm forms the lining of the urinary system, the reproductive system, and most of the digestive tract; it also forms the pancreas, liver, lungs, and gills. The ectoderm forms the outer layer of skin, hair, nails, and the nervous system. The mesoderm forms many body parts, including the skeleton, muscles, the inner layer of skin, the circulatory system, and the lining of the body cavity.

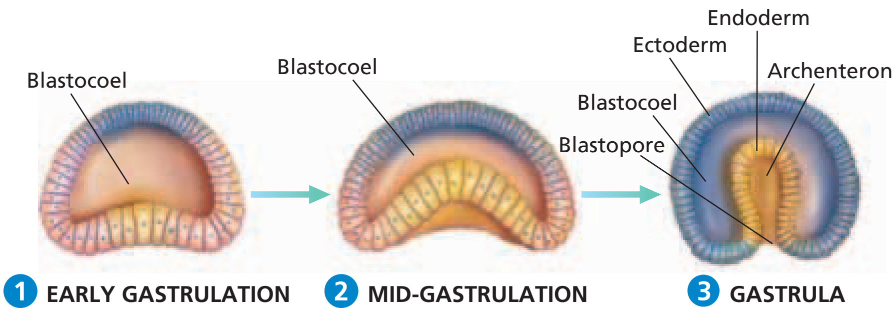


FIGURE 32-13

Echinoderms, such as the sea urchin, undergo the gastrulation process shown here. The blastula reorganizes and forms the cup-shaped gastrula. Other phyla have somewhat different patterns of gastrulation.

PATTERNS OF DEVELOPMENT

The distinct patterns of cleavage and formation of body-plan features found in different animal phyla are clues to the phylogenetic history of the organisms.

Types of Body Cavities

Animals, such as flatworms, that do not have a body cavity are called **acoelomates** (uh-SEE-luh-MAYTS). The interior of the animal is solid, as shown in Figure 32-14a. The endodermic gut, shown in yellow, and the outer covering of the animal, shown in blue, are connected by the solid tissue of the mesoderm.

However, most animal phyla have body cavities that separate their digestive tract from the outer body wall. Within this group, there are differences in how the body cavity develops. In some phyla, including rotifers and roundworms, the mesoderm lines the interior of the coelom but does not surround the exterior of the endodermic gut. A cavity that is not completely lined by mesoderm is called a **pseudocoelom** (SOO-doh-SEE-luhm), which means "false body cavity." Roundworms have pseudocoeloms such as the one shown in Figure 32-14b and are thus called *pseudocoelomates*. In pseudocoelomates, mesoderm lines the fluid-filled body cavity, and the endodermic gut is suspended in this fluid.

A cavity completely lined by mesoderm is called a **coelom** (SEE-luhm), as shown in Figure 32-14c. Animals that have coeloms are called *coelomates* (SEE-luh-MAYTS). In coelomates, mesoderm lines the body cavity and surrounds and supports the endodermic gut. The mesoderm also forms the tissues of attachment for the organs located in the coelom, such as the liver and the lungs. Mollusks, annelids, arthropods, chordates, and echinoderms are coelomates.

Cleavage and Blastopore Fate

Recall from Figure 32-3 that echinoderms and chordates share a branch of the phylogenetic diagram of animals; and mollusks, annelids, and arthropods share another branch. There are two distinct patterns of development in animals with a coelom. In the embryos of mollusks, arthropods, and annelids, the blastopore develops into a mouth, and a second opening forms at the other end of the archenteron, forming an anus. These organisms are called **protostomes** (PROHT-oh-STOHMZ), which means "first mouth."

Many protostomes undergo *spiral cleavage,* in which the cells divide in a spiral arrangement. In the embryos of echinoderms and chordates, the blastopore develops into an anus, and a second opening at the other end of the archenteron becomes the mouth. These organisms are called **deuterostomes** (DOOT-uhr-oh-STOHMZ), which means "second mouth." Most deuterostomes undergo *radial cleavage,* in which the cell divisions are parallel to or at right angles to the axis from one pole of the blastula to the other.

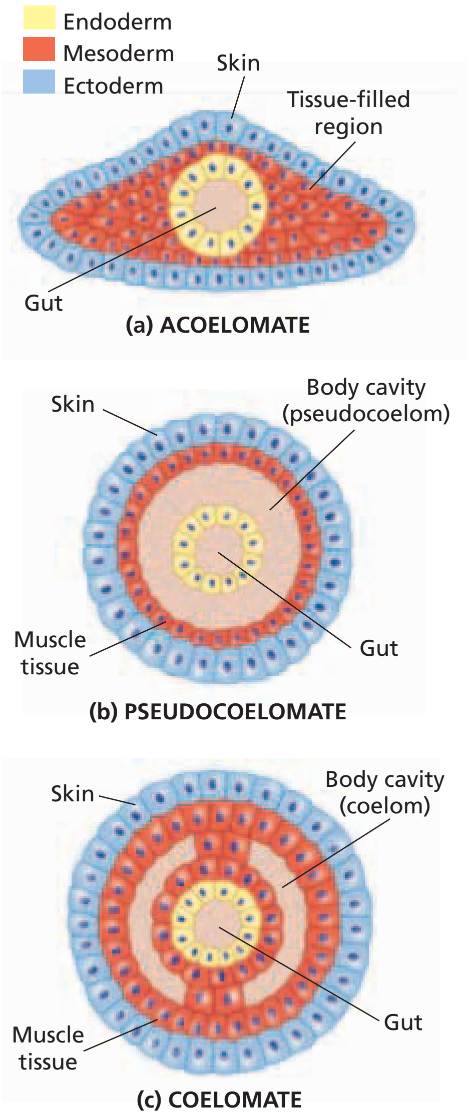


FIGURE 32-14

In three-layered acoelomates (a), the endodermic gut is surrounded by a solid layer of mesoderm. In pseudocoelomates (b), the endodermic gut is suspended in a fluid-filled cavity that is surrounded by mesoderm. In coelomates (c), the endodermic gut is surrounded by and suspended by mesoderm, which also surrounds the coelom, or body cavity.

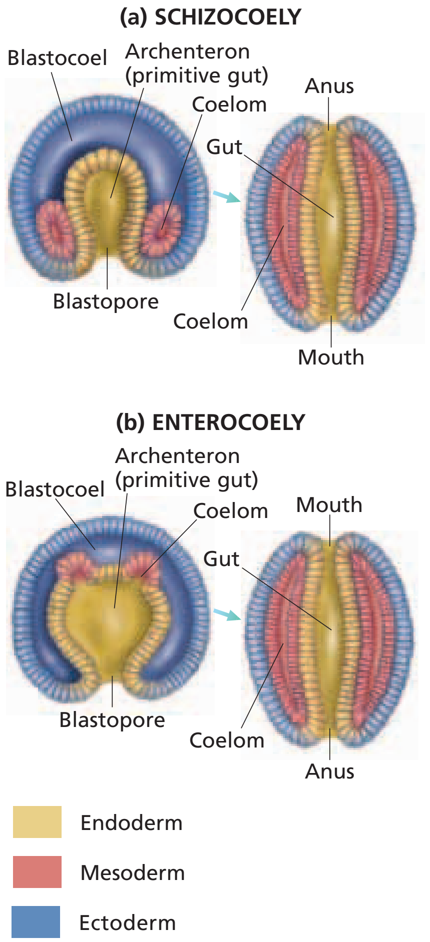


FIGURE 32-15

In protostomes, the coelom arises in a process called schizocoely (a), and the blastopore becomes the mouth. In deuterostomes, the coelom arises by enterocoely (b), and the blastopore becomes the anus.

Protostomes and deuterostomes also differ in how early the cells of the embryo specialize. If the cells of some protostome embryos are separated at the four-cell stage of development, each cell will develop into only one-fourth of a complete embryo, and the developing organism will die. Thus, the path of each cell is fixed early in the development of the protostome in a pattern called *determinate cleavage*.

In contrast, if the cells of most four-celled deuterostome embryos are separated, each cell will embark on its own path to become a separate organism. This type of development is called *indeterminate cleavage*. Indeterminate cleavage is responsible for the development of identical twins in humans.

Coelom Formation

The way in which the coelom forms in many protostomes differs from the way it forms in many deuterostomes. Figure 32-15a shows coelom formation in protostomes. Cells located at the junction of the endoderm and ectoderm (at the rim of the cup-shaped embryo) move toward the interior of the gastrula. Rapid division of these cells (shown in pink) in the blastocoel forms the mesoderm. The mesoderm then spreads and splits to form the coelom. This process of coelom formation is called **schizocoely** (SKIZ-oh-SEEL-ee), or "split body cavity."

Figure 32-15b shows coelom formation in deuterostomes. The mesoderm forms when the cells lining the dorsal, or top, part of the archenteron begin dividing rapidly. These rapidly dividing cells (shown in pink) form pouches that become mesoderm. The coelom develops within the mesodermal pouches. This process of coelom formation is called **enterocoely** (EN-tuhr-oh-SEEL-ee), which means "gut body cavity." During both enterocoely and schizocoely, mesodermal cells spread out to completely line the coelom, and the blastocoel disappears. Thus, in both protostomes and deuterostomes, mesoderm lines the interior of the outer body wall and surrounds the gut.

SECTION 3 REVIEW

1. Beginning with fertilization, list the steps of development through mesodermal formation.
2. Name the three germ layers and two body parts that arise from each layer.
3. Compare the development of protostomes and deuterostomes.
4. Identify how the mesoderm is formed in schizocoely, and differentiate it from the process in enterocoely.
5. Identify the type of cleavage that can give rise to identical human twins.

CRITICAL THINKING

6. **Inferring Relationships** Which adaptive advantage is associated with indeterminate cleavage?
7. **Recognizing Relationships** What is the relationship between endoderm formation and coelom formation in echinoderms?
8. **Predicting Patterns** While exploring a tide pool, you find a periwinkle, which is a marine snail. Which kind of development does a periwinkle have? Explain.

CHAPTER HIGHLIGHTS

SECTION 1 The Nature of Animals

- Animals are either invertebrates—lack a backbone—or vertebrates—have a backbone.
- Animals are multicellular organisms that lack cell walls and are heterotrophic. Most animals reproduce sexually and can move.
- Movement and response to the environment are governed by an animal's nervous and muscle tissues.
- The first animals may have evolved from colonial protists.
- At some stage of their lives, chordates have a notochord, dorsal nerve cord, postanal tail, and pharyngeal pouches.
- Most animals have tissues and radial or bilateral symmetry. Bilateral symmetry is associated with cephalization. Most animals have a body cavity that aids movement and the transport of nutrients and wastes.
- Animals are classified by degree of cell specialization, number of tissue layers, type of symmetry, and most recently, by sequencing of rRNA.

Vocabulary

animal (p. 651)
vertebrate (p. 651)
invertebrate (p. 651)
specialization (p. 651)
ingestion (p. 652)
zygote (p. 652)
differentiation (p. 652)
chordate (p. 654)
notochord (p. 654)
dorsal nerve cord (p. 654)
pharyngeal pouch (p. 654)
symmetry (p. 655)
radial symmetry (p. 655)
dorsal (p. 655)
ventral (p. 655)
anterior (p. 655)
posterior (p. 655)
bilateral symmetry (p. 655)
cephalization (p. 655)
germ layer (p. 655)

SECTION 2 Invertebrates and Vertebrates

- Symmetry, segmentation, and type of skeleton are related to the lifestyle of an animal.
- Invertebrates include morphologically diverse phyla, the members of which are mostly radially or bilaterally symmetrical.
- In an open circulatory system, circulatory fluid is pumped by the heart through vessels and into the body cavity and is then returned to the vessels.
- In a closed circulatory system, blood is pumped by a heart and circulates throughout the body in tubelike vessels that form a closed loop.
- Vertebrates have highly organized brains in which specific functions occur in specific centers of the brain. The larger the decision-making portion of the brain is, the more complex and flexible the behavior of the animal.
- Most animals reproduce sexually. Fertilization and development may be external or internal.

Vocabulary

segmentation (p. 657)
exoskeleton (p. 658)
gill (p. 658)
open circulatory system (p. 658)
closed circulatory system (p. 658)
hermaphrodite (p. 659)
larva (p. 659)
endoskeleton (p. 660)
vertebra (p. 660)
integument (p. 660)
lung (p. 660)
kidney (p. 661)

SECTION 3 Fertilization and Development

- Development includes cleavage, blastula formation, gastrulation, and organogenesis. The germ layers include ectoderm, endoderm, and mesoderm.
- Ectoderm forms, among other things, the outer layer of skin; endoderm forms many internal organs; and mesoderm forms the skeleton and muscles.
- Acoelomates are animals without a body cavity. Pseudocoelomates are animals whose body cavity is not completely lined by mesoderm. Coelomates have a body cavity completely lined by mesoderm.
- Protostomes have spiral cleavage and schizocoely. Deuterostomes have radial cleavage and enterocoely.

Vocabulary

fertilization (p. 663)
cleavage (p. 664)
blastula (p. 664)
gastrulation (p. 664)
gastrula (p. 664)
archenteron (p. 664)
blastopore (p. 664)
ectoderm (p. 664)
endoderm (p. 664)
mesoderm (p. 664)
acoelomate (p. 665)
pseudocoelom (p. 665)
coelom (p. 665)
protostome (p. 665)
deuterostome (p. 665)
schizocoely (p. 666)
enterocoely (p. 666)

CHAPTER REVIEW

USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *radial symmetry* and *bilateral symmetry*
   b. *open circulatory system* and *closed circulatory system*
   c. *vertebrate* and *invertebrate*
   d. *spiral cleavage* and *radial cleavage*
2. Explain the relationship between cell specialization and differentiation.
3. Choose the term that does not belong in the following group, and explain why it does not belong: *notochord, cephalization, dorsal nerve cord,* and *radial symmetry*.
4. **Word Roots and Origins** The word *blastopore* comes from the Greek *blastos,* which means “bud,” and *poros,* which means “passage.” Using this information, explain why the term *blastopore* is a good name for the structure it describes.

UNDERSTANDING KEY CONCEPTS

5. **Describe** each of the four characteristics that define animals.
6. **Explain** how neural tissue and muscle tissue work together in an animal’s body to allow the animal to respond to its environment.
7. **Describe** the probable changes that early colonial flagellates underwent as they evolved into the first animals.
8. **List** the four features common to all chordates at some time in their life. What has happened to two of these features in an adult human?
9. **Summarize** what happened to the position of the body with respect to the legs as vertebrates adapted to life on land.
10. **Explain** how having a body cavity aids movement.
11. **Infer** the relationship between two phyla that are represented on the same branch of a phylogenetic tree. Which features are used to determine the relationship?
12. **Identify** the most probable type of movement that an organism with bilateral symmetry would exhibit.
13. **Contrast** segmentation in invertebrates with segmentation in vertebrates.
14. **Sequence** the development of the nervous system from cnidarians to mammals.
15. **Identify** the structure that the archenteron becomes in a developing animal.
16. **Name** two body parts formed by each of the following: endoderm, mesoderm, and ectoderm.
17. **Identify** how a closed circulatory system differs from an open circulatory system.
18. **Compare** schizocoely with enterocoely.
19. **CONCEPT MAPPING** Use the following terms to create a concept map that shows development from blastula to coelom formation in a deuterostome: *blastula, gastrula, archenteron, blastopore, anus, mouth, germ layers, ectoderm, endoderm, mesoderm,* and *coelom*.

CRITICAL THINKING

20. **Recognizing Relationships** Considering that an endoskeleton can support more weight than an exoskeleton, would a large-bodied animal with an exoskeleton be more likely to live in the water or on land? Explain.
21. **Recognizing Relationships** On mammals and birds, the head is positioned higher with respect to the body than it is on amphibians and reptiles. Why might it be helpful to have a head positioned over the body?
22. **Interpreting Graphics** Observe the animal pictured below, and answer the following questions.
    a. Which kind of symmetry does the animal display?
    b. Is this animal cephalized?
    c. How many germ layers does this animal have?
    d. How many openings does this animal’s digestive system have?
    e. Does this animal have neurons?

Standardized Test Preparation

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

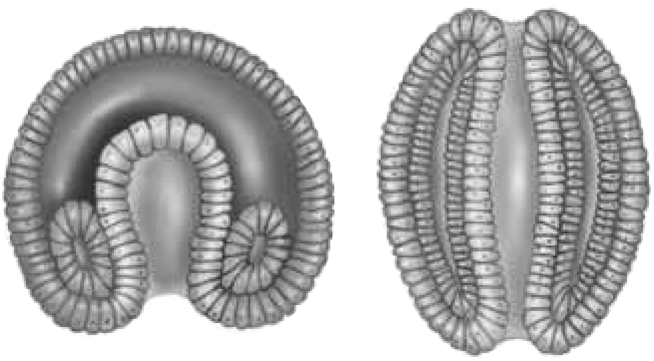
1. What is the name for the process that leads to cell specialization in multicellular organisms?
A. evolution
B. fertilization
C. differentiation
D. asexual reproduction

2. What process takes place as a zygote begins to divide after fertilization?
F. meiosis
G. cleavage
H. gastrulation
J. organogenesis

3. Which animals do not have true tissues?
A. sponges
B. chordates
C. cnidarians
D. ctenophores

4. What are the basic tissue types in an embryo called?
F. coeloms
G. germ layers
H. notochords
J. pharyngeal pouches

INTERPRETING GRAPHICS: The diagrams below illustrate a certain type of body-cavity development. Study the diagrams to answer the questions that follow.



5. The diagrams represent the development of which of the following animals?
A. fish
B. sponge
C. octopus
D. cnidarian

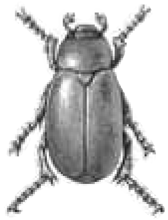
6. With which of the following is the process illustrated above associated?
F. acoelomates
G. deuterostomes
H. spiral cleavage
J. indeterminate cleavage

DIRECTIONS: Complete the following analogy.

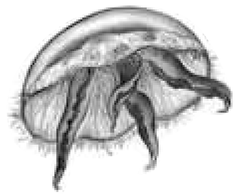
7. Ectoderm : skin :: mesoderm :
A. lungs
B. nerves
C. vertebrae
D. intestines

INTERPRETING GRAPHICS: The diagrams below illustrate different organisms. Study the images to answer the question that follows.

Sponge



Beetle



Jellyfish

8. Which of the organisms has radial symmetry?
F. beetle
G. sponge
H. jellyfish
J. both the beetle and the sponge

SHORT RESPONSE

Ctenophores and cnidarians are considered closely related to one another. Chordates and echinoderms are also considered closely related to one another.

Explain how it was determined that cnidarians are less closely related to chordates and echinoderms than they are to ctenophores.

EXTENDED RESPONSE

Three types of body-cavity organization exist in animals—acoelomate, pseudocoelomate, and coelomate.

Part A Explain how acoelomates and pseudocoelomates differ from coelomates.

Part B Explain how the lining of the body cavity develops in coelomates.

Test TIP If you find particular questions difficult, put a light pencil mark beside them and keep working. (Do not write in this book.) As you answer later questions, you may find information that helps you answer the difficult questions.

Dissecting a Sheep's Heart

OBJECTIVES

- Describe the appearance of the external and internal structures of a sheep's heart.
- Name the structures and functions of a sheep's heart.

PROCESS SKILLS

- observing structures
- identifying
- demonstrating

MATERIALS

- sheep's heart
- dissecting tray
- blunt metal probe
- scissors
- scalpel
- tweezers

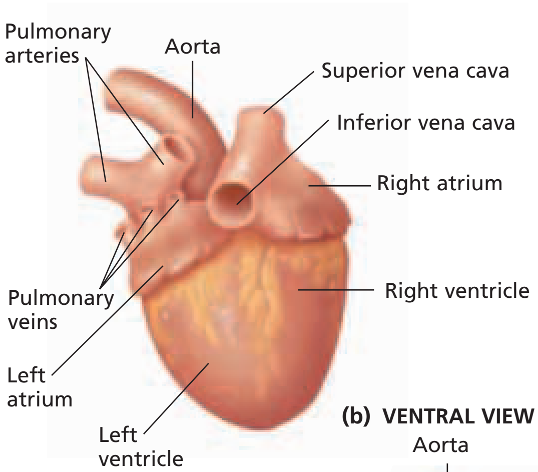
Background

1. The heart has a left and a right side. It has two upper chambers, the left and right atria, and two lower chambers, the left and right ventricles. Why do multiple chambers result in a more efficient heart?
2. Blood enters the heart from the body through the superior or inferior vena cava. The blood then enters the right atrium and flows through valves into the right ventricle. Blood flows from the right ventricle through the pulmonary artery to the lungs. What process occurs in the lungs?
3. Oxygenated blood flows from the lungs through the pulmonary veins to the left atrium. Then, it flows through valves into the thick-walled left ventricle. Blood flows from the left ventricle through the large aorta to the rest of the body.

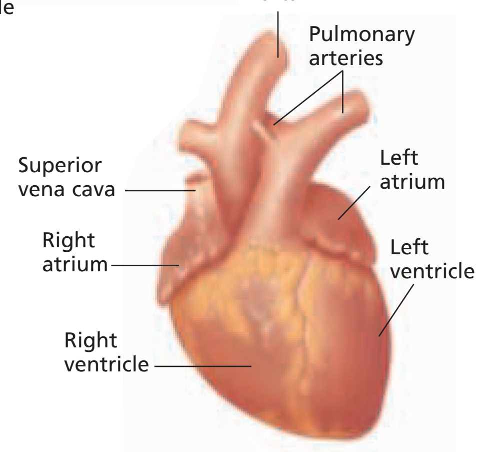
Procedure

1. In this lab, you will observe the external structure of a sheep's four-chambered heart and dissect the heart to study its internal structure.
2.  Put on safety goggles, gloves, and a lab apron.
3. Place a sheep's heart in a dissecting tray. Turn the heart so that the ventral surface is facing you, as shown in the diagram below. Use the diagram of the ventral view to locate the left and right atria, the left and right ventricles, the aorta, the superior and inferior vena cava, and the pulmonary arteries. Turn the heart over. Use the diagram of the dorsal view to locate once again the structures just named, as well as the pulmonary veins.
4. Use a blunt metal probe to explore the blood vessels that lead into and out of the chambers of the heart.
5. Locate a diagonal deposit of fat along the lower two-thirds of the heart. This serves as a guideline to mark the wall between the two ventricles. Use this fatty deposit to guide your incision into the heart.

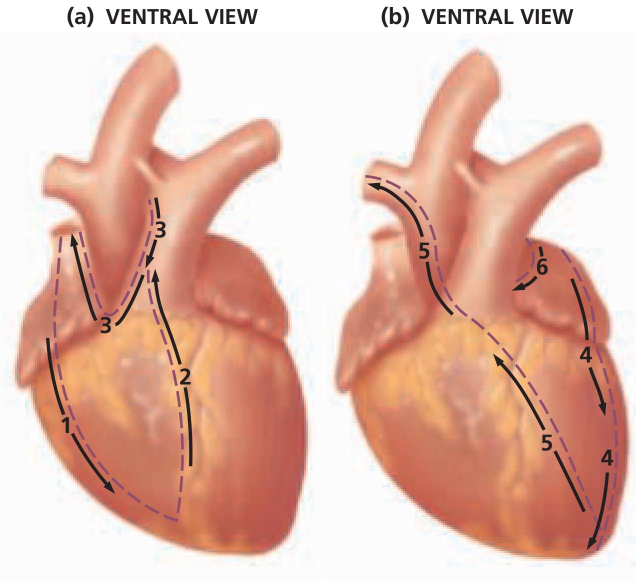
(a) DORSAL VIEW



(b) VENTRAL VIEW



6. Follow the cutting diagram below very carefully to study the anatomy of the right side of the heart.
7. Again, turn the heart with the ventral surface facing you and the apex pointing downward. Use scissors to cut along line 1. **CAUTION Always cut in a direction away from your face and body.** Cut just deep enough to go through the atrial wall. Continue the cut into the right ventricle. With a probe, push open the heart at the cut, and examine the internal structure.



8. Cut along line 2, and extend the cut upward toward the pulmonary artery. Cut just deep enough to go through the ventricle wall. Complete the cut on line 3. Cut downward along the pulmonary artery, around through the wall of the right atrium, and upward along the right superior vena cava.
9. With tweezers, carefully lift the resulting flap to expose the structures underneath.
10. Follow the cutting diagram above very carefully to study the anatomy of the *left* side of the heart.
11. Start to cut on line 4 at the top of the left atrium, and continue into the left ventricle. Cut just deep enough to go through the ventricle wall.
12. Cut on line 5 across the middle of the left ventricle into the aorta. Leave a small margin between this cut and the cut previously made for line 2. Begin to cut on line 6 on the left atrium where cut 4 began. Extend this cut around and through the pulmonary artery upward on the aorta to the right of cut 5.
13. With tweezers, carefully lift up the resulting flap to expose the structure underneath.
14. Observe the thick septum dividing the left and right ventricles. Also, note the greater thickness of the walls of the left ventricle.
15. Locate the tricuspid valve between the right atrium and ventricle. Locate the mitral valve between the left atrium and ventricles. Observe that the valves are connected by fibers to the inner surface of the ventricle. Use a probe to explore the openings in the valves.
16. With a scalpel, cut across a section of the aorta and a section of the vena cava. Compare the thickness of their walls.
17. Dispose of your materials according to the directions from your teacher.
18. Clean up your work area, and wash your hands before leaving the lab.

Analysis and Conclusions

1. Trace the path of blood from the right atrium to the aorta.
2. Pulmonary circulation carries blood between the heart and the lungs. Systemic circulation carries blood to the rest of the body. In which chambers of the heart does pulmonary circulation begin and end? In which chambers does systemic circulation begin and end?
3. What is the function of the septum separating the left and right ventricles?
4. What is the function of the mitral and tricuspid valves?
5. Why are the walls of the left ventricle thicker than the walls of the right ventricle?

Further Inquiry

The heartbeat originates in a small bundle of tissue in the right atrium. This bundle is the sinoatrial, or S-A, node. Read about the S-A node. What does it do? Why is the S-A node known as the pacemaker?