Chapter 21

Animals

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Animals are extremely diverse

There are over 1.3 million known animal species. Animals vary greatly in size, habitat, body form, and intelligence.

Chordates
- ~60,000 species
- Notochord, dorsal hollow nerve cord, pharyngeal slits, postanal tail
- Fishes, amphibians, reptiles (including birds), mammals

Echinoderms
- ~ 7000 species
- Five-part symmetry
- Water vascular system
- Sea stars, sea urchins, sand dollars

Arthropods
- › 1,000,000 species
- Jointed appendages; exoskeleton
- Trilobites, spiders and other arachnids, crustaceans, insects, millipedes, centipedes

Roundworms
- ~80,000 species
- Unsegmented, cylindrical worms
- Free-living or parasitic
- Pinworms, hookworms, heartworms

Annelids
- ~15,000 species
- Segmented worms
- Earthworms, polychaetes, leeches

Mollusks
- ~112,000 species
- Mantle secretes shell
- Chitons, bivalves, cephalopods, gastropods

Flatworms
- ~25,000 species
- Flat bodies
- Free-living or parasitic
- Marine flatworms, planarians, flukes, tapeworms

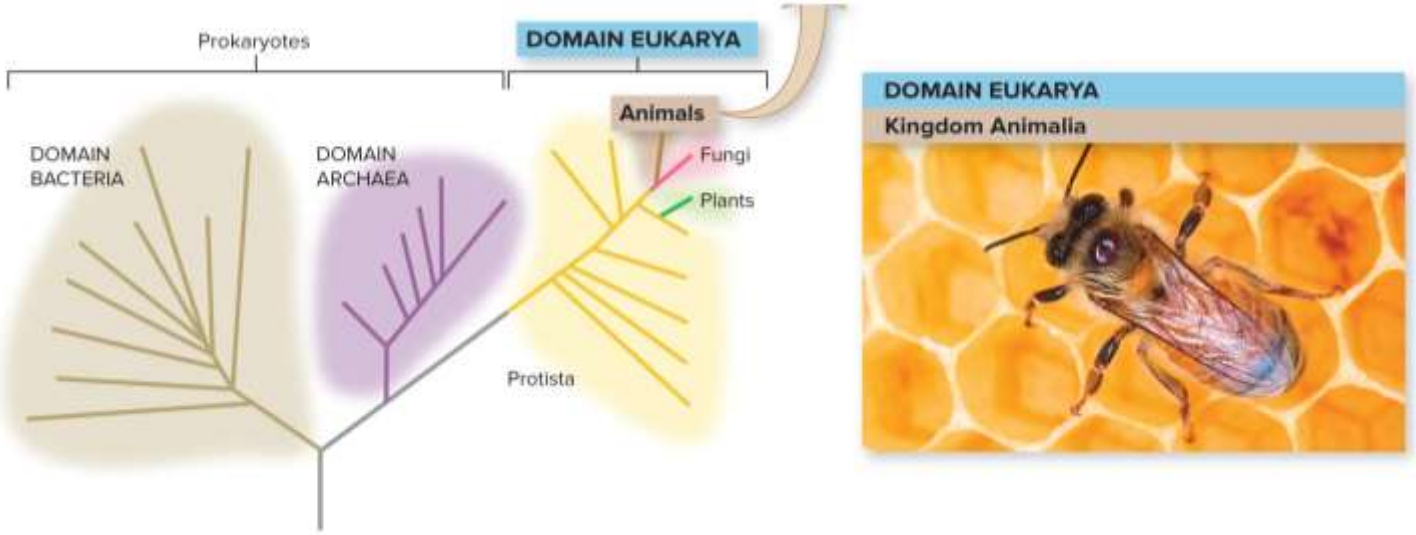
Cnidarians
- ~11,000 species
- Medusa or polyp forms
- Stinging cells
- Hydra, jellyfish, coral

Sponges
- ~5000 species
- Porous bodies
- Filter feeders

What makes it an animal?

Animals all have a specific set of features in common:

- They have eukaryotic cells that lack cell walls.
- Their cells produce an extracellular matrix.
- They have multicellular bodies.
- They go through a blastula stage of development.
- They are heterotrophic, by ingestion.



USDA/ARS/Scott Bauer

Section 21.1

Figure 21.2

There are nine main animal phyla

Most animals are **invertebrates**, which lack backbones. Many fewer animals are **vertebrates**, which have backbones.

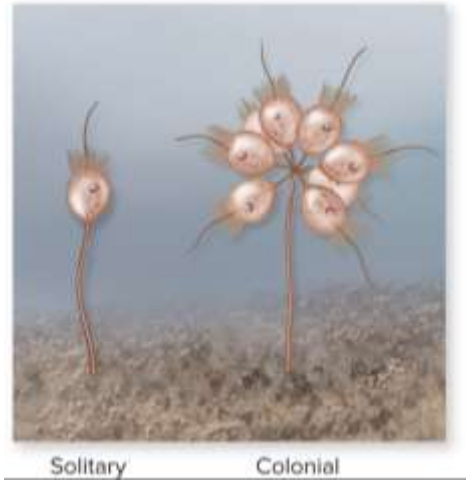
Vertebrates (which include familiar mammals, amphibians, reptiles, and fish) are in phylum Chordata.

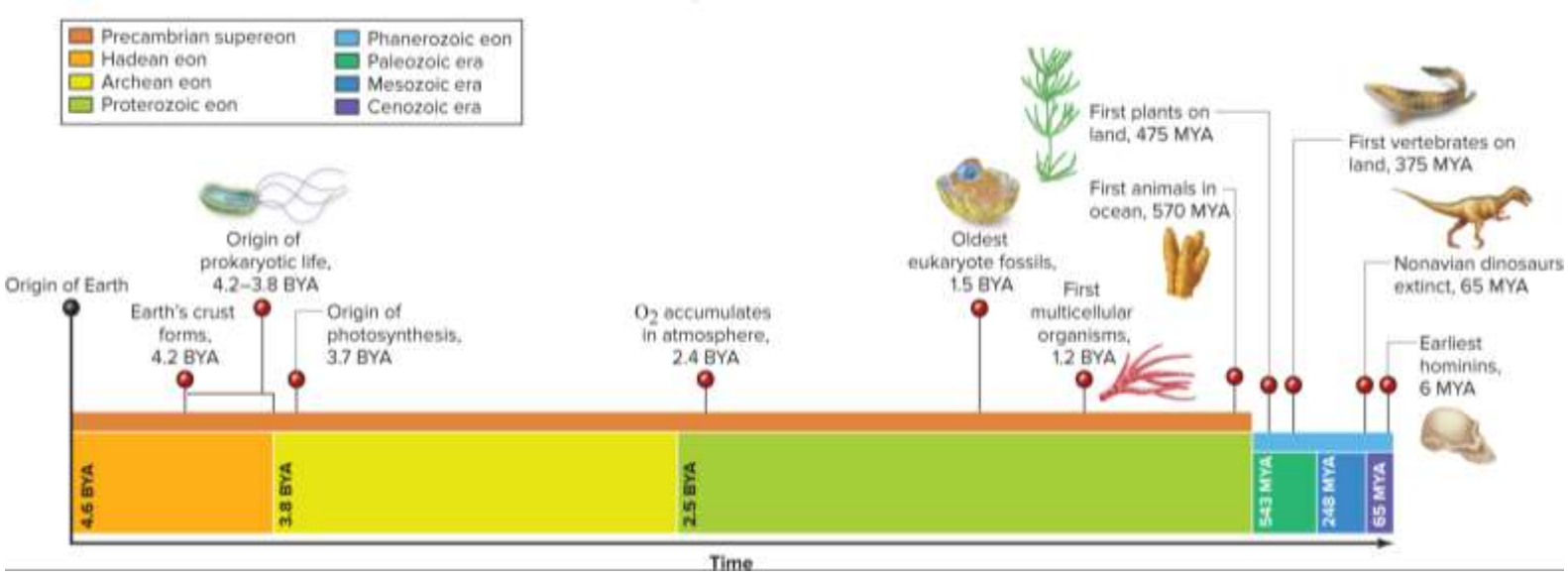
TABLE 21.1 Nine Phyla of Animals

Phylum	Examples	Number of Exiting Species
Porifera	Sponges	5000
Cnidaria	Hydras, jellyfishes, corals, sea, anemones	11,000
Platyhelminthes (flatworms)	*Planaria,* tapeworms, flukes	25,000
Mollusca	Bivalves, chitons, snails, slugs, squids, octopuses	112,000
Annelida	Eartworms, leeches, polychaetes	15,000
Nematoda (roundworms)	Pinworms, hookworms, *C. elegans*	80,000
Arthropoda	Horseshoe crabs, spiders, scorpions, crustaceans, insects	More than 1,000,000
Echinodermata	Sea stars, sea urchins, sand dollars	7000
Chordata	Tunicates, Iancelets, fishes, amphibians, reptiles, mammals	60,000

Animal life began in water

The first animals arose about 570 million years ago. They probably resembled aquatic protists called choanoflagellates.





Clicker question #1

What combination of characteristics do all animals share?

A. multicellular, eukaryotic, heterotrophic
B. unicellular, eukaryotic, heterotrophic
C. multicellular, prokaryotic, autotrophic
D. multicellular, eukaryotic, autotrophic
E. unicellular, prokaryotic, autotrophic

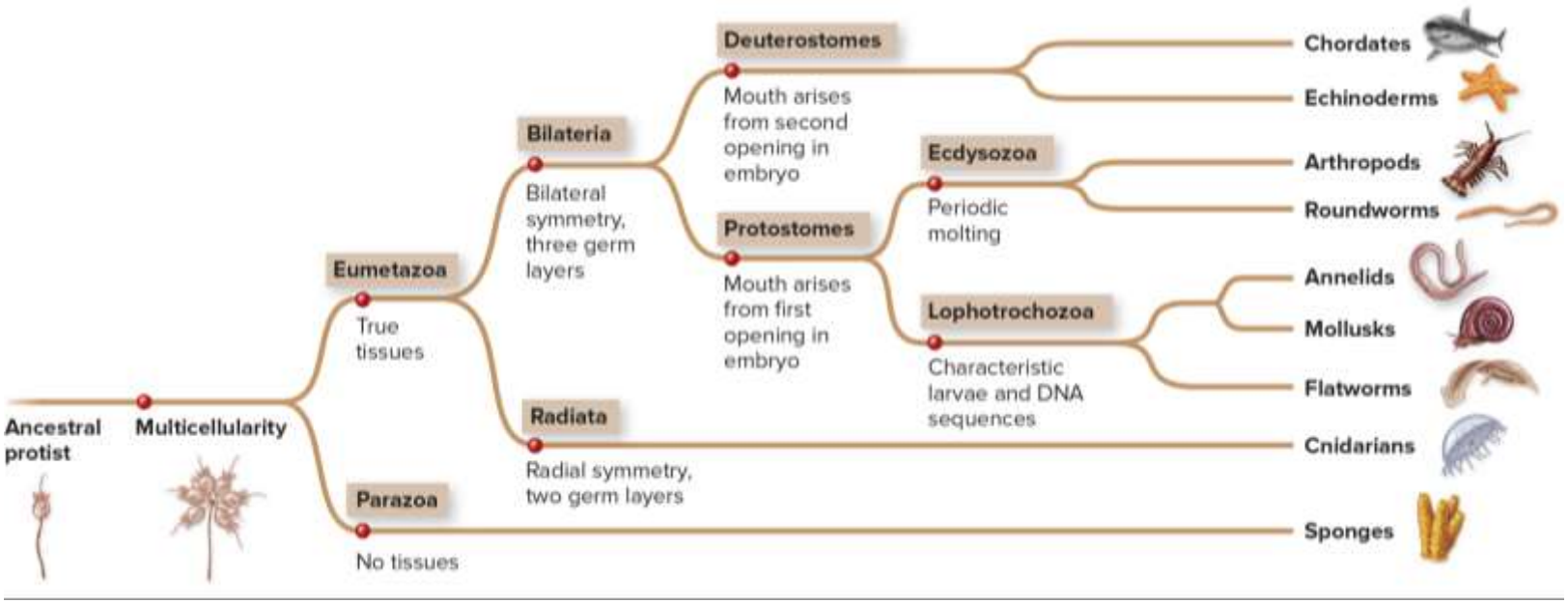
Clicker question #1, solution

What combination of characteristics do all animals share?

A. multicellular, eukaryotic, heterotrophic

Animal features reflect shared ancestry

Animals are grouped by shared features of body form, developmental characteristics, and DNA.

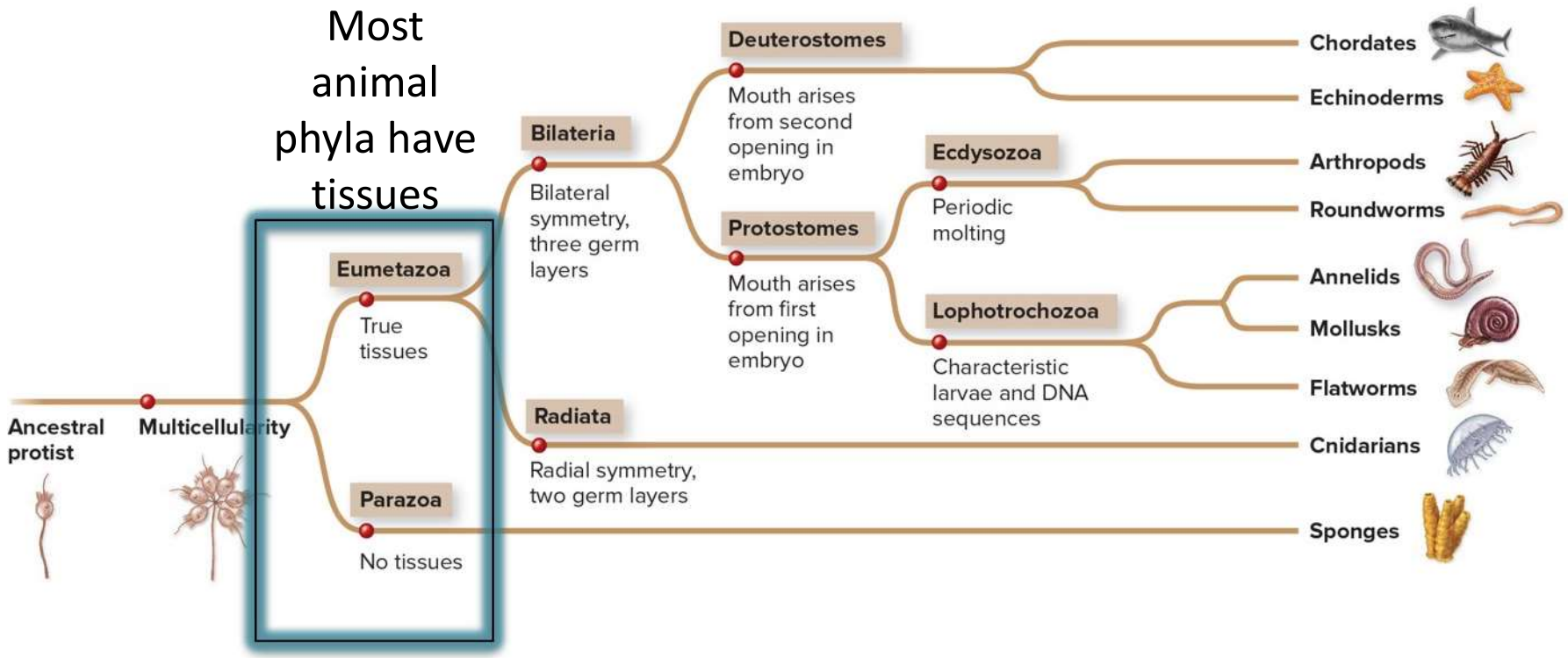


Section 21.1

Figure 21.2

Animals are classified by having tissues

The first branching point in animal taxonomy distinguishes **eumetazoans** (animals with true body tissues) from **parazoans** (animals with no true body tissues).



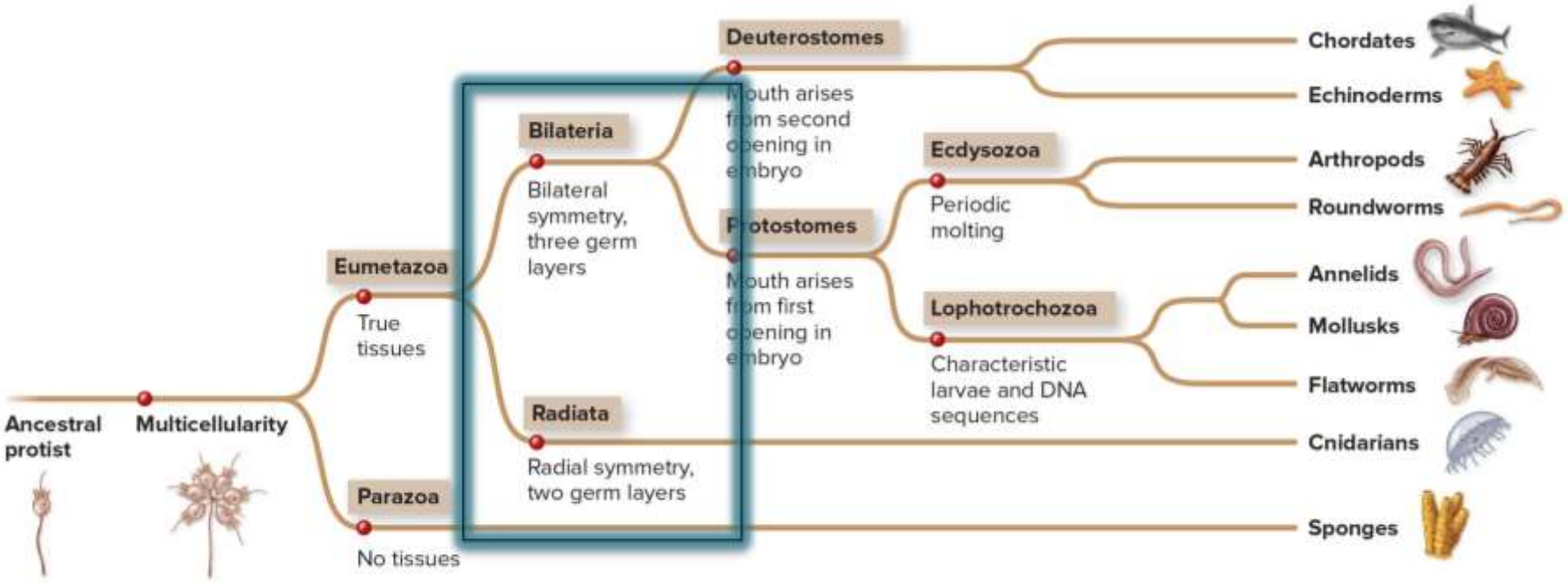
Section 21.1

Figure 21.2

Animals are classified by symmetry

The second branching point distinguishes radially symmetrical from bilaterally symmetrical animals.

Most eumetazoan phyla have bilateral symmetry

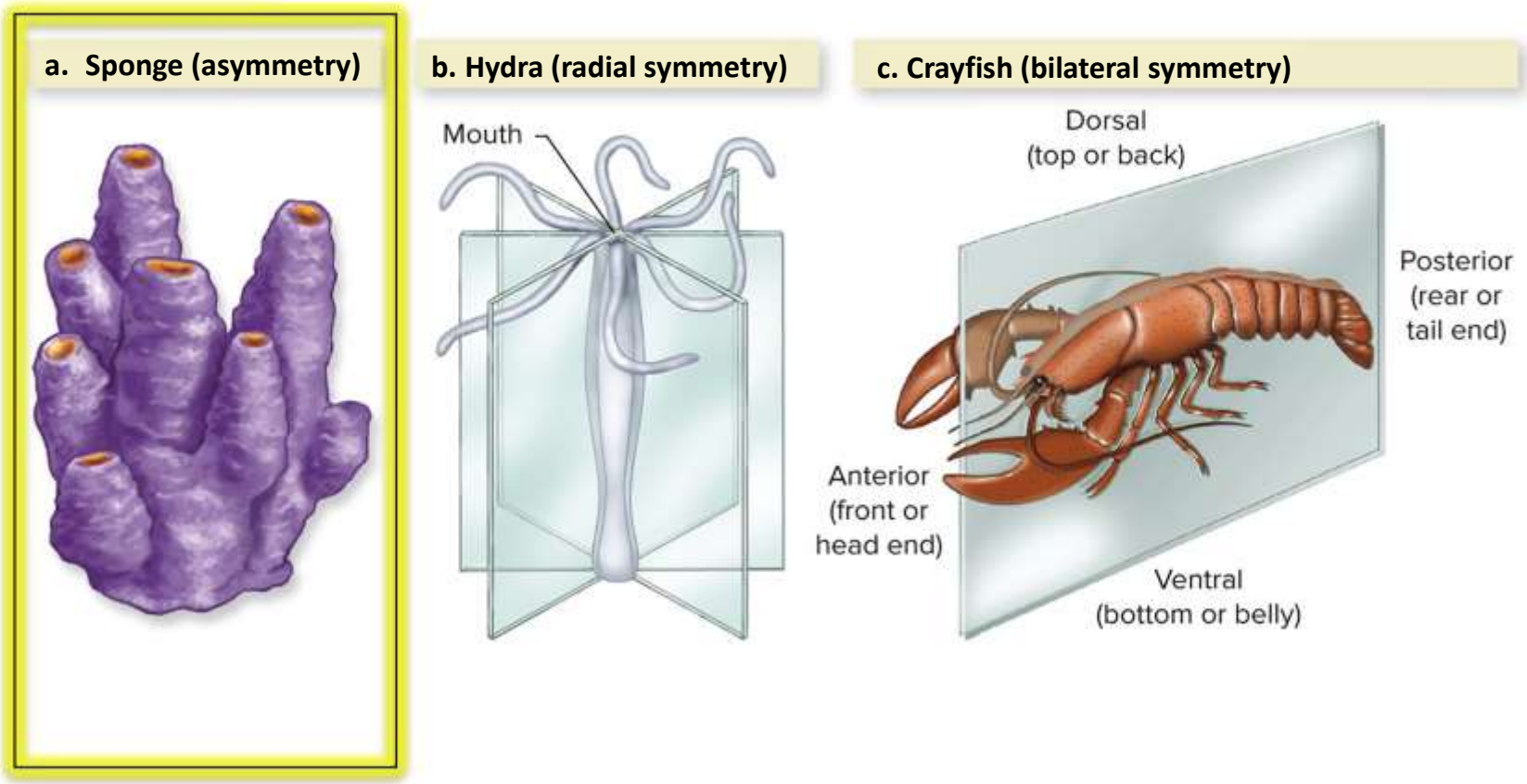


Section 21.1

Figure 21.2

Some animals have no symmetry

Many sponges (phylum Porifera) are asymmetrical.

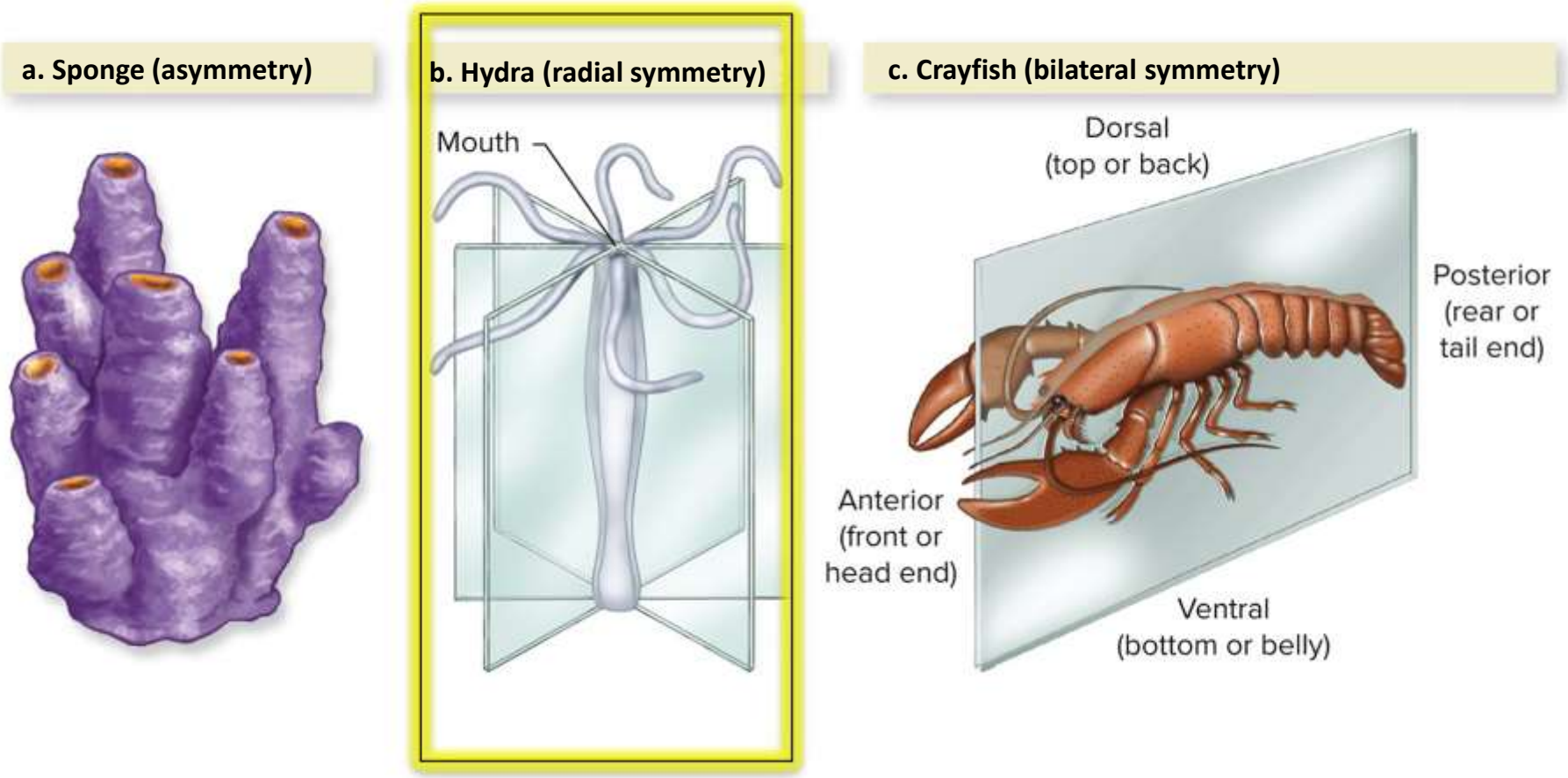


Section 21.1

Figure 21.3

Some animals have radial symmetry

An organism has **radial symmetry** if any plane passing through the body from the mouth to the opposite end creates mirror images.

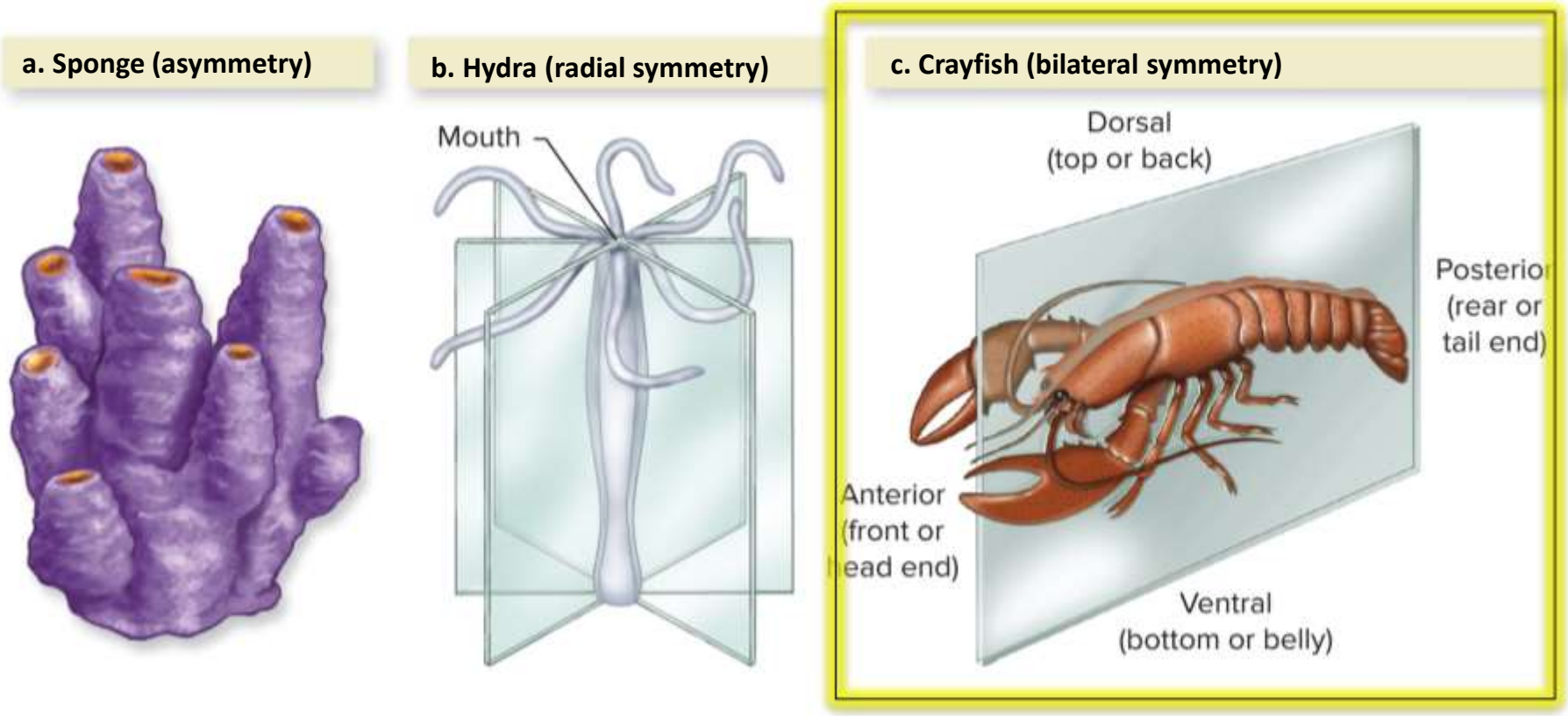


Section 21.1

Figure 21.3

Some animals have bilateral symmetry

An organism has **bilateral symmetry** if only one plane can divide the animal into mirror images.



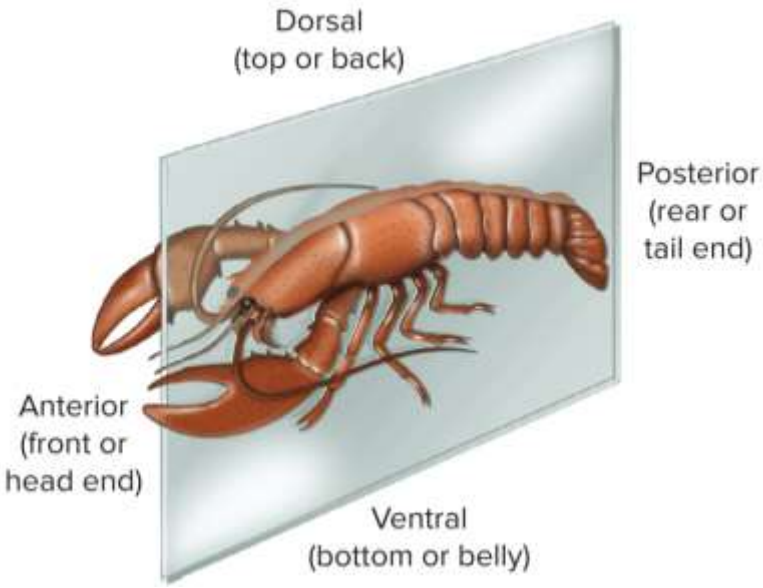
Section 21.1

Figure 21.3

Bilaterally symmetric animals have a head and a tail

This body type correlates with **cephalization**, which is the tendency to concentrate sensory cells and a brain at the animal's head.

Typically this is accompanied by greater sensory complexity.



Clicker question #2

How many of the following animals have bilateral symmetry?

A. one
B. two
C. three
D. four
E. five

Figures 21.45, 21.47

Clicker question #2, solution

How many of the following animals have bilateral symmetry?

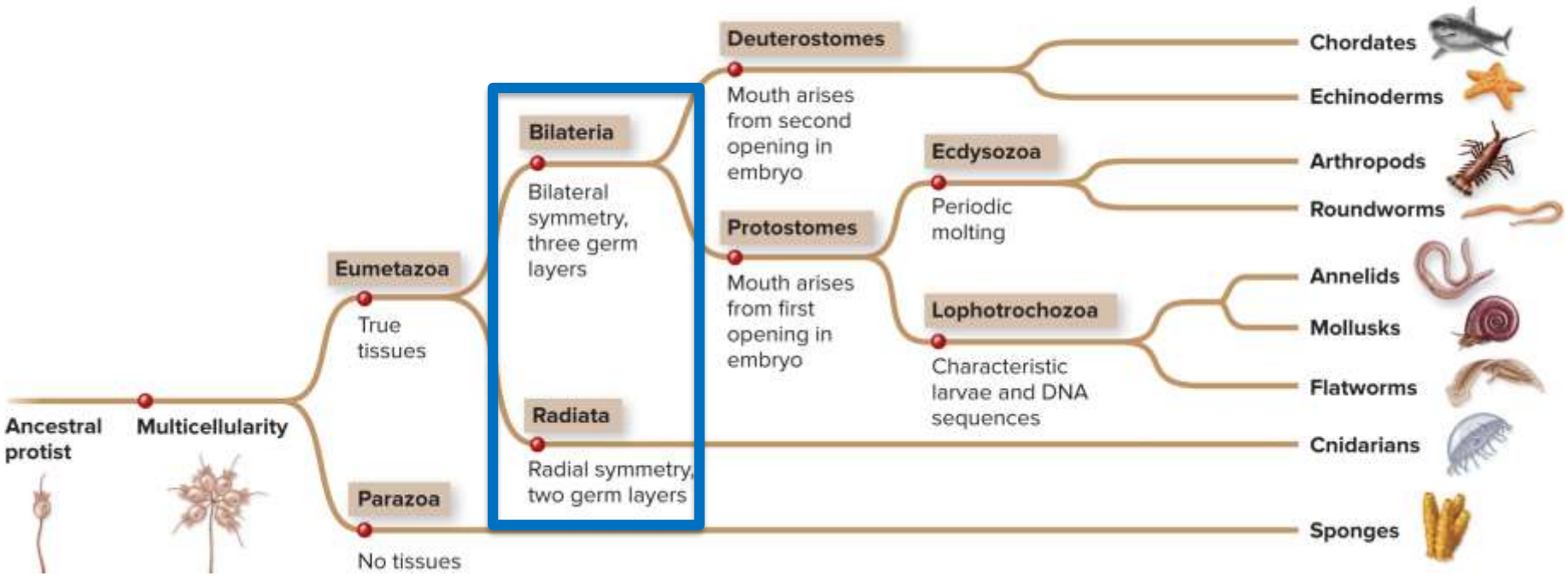
B. two

Figures 21.45, 21.47

Animals are classified by germ layers

The same branching point also distinguishes animals with two embryonic germ layers from animals with three.

Most eumetazoan phyla have 3 germ layers



Section 21.1

Figure 21.2

The gastrula is an early embryonic structure

In eumetazoans, the embryonic ball of cells called a **blastula** folds in on itself, forming a **gastrula**.

©Herve Conge/Phototake

Figure 21.4

Animal embryos develop germ layers

In some animals, the gastrula only develops two tissue layers (endoderm and ectoderm).

In others, a third tissue layer (mesoderm) develops.

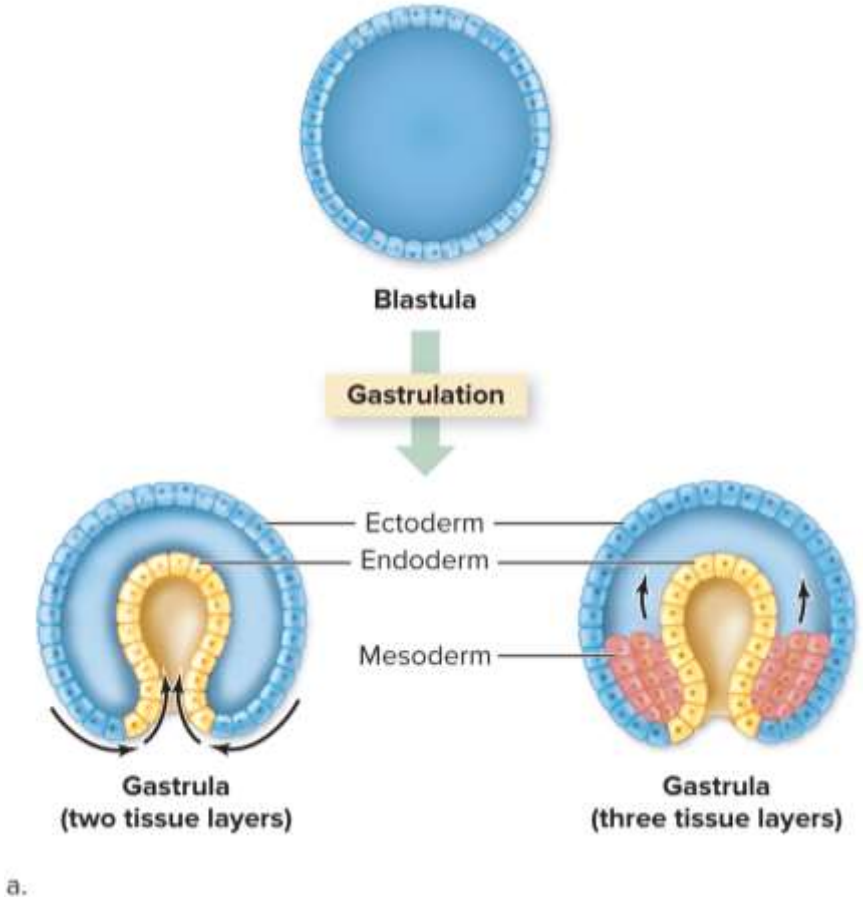


Figure 21.4

The germ layers develop into body parts

Ectoderm develops into the skin and nervous system.

Endoderm becomes the digestive tract.

Mesoderm gives rise to the muscles and circulatory system.

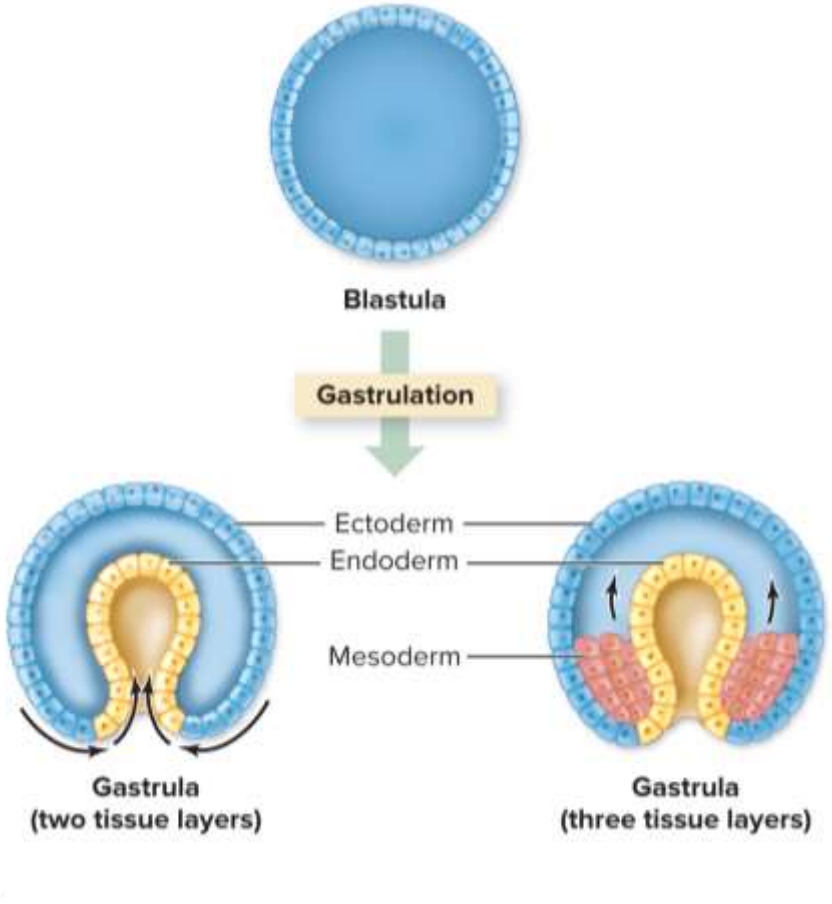
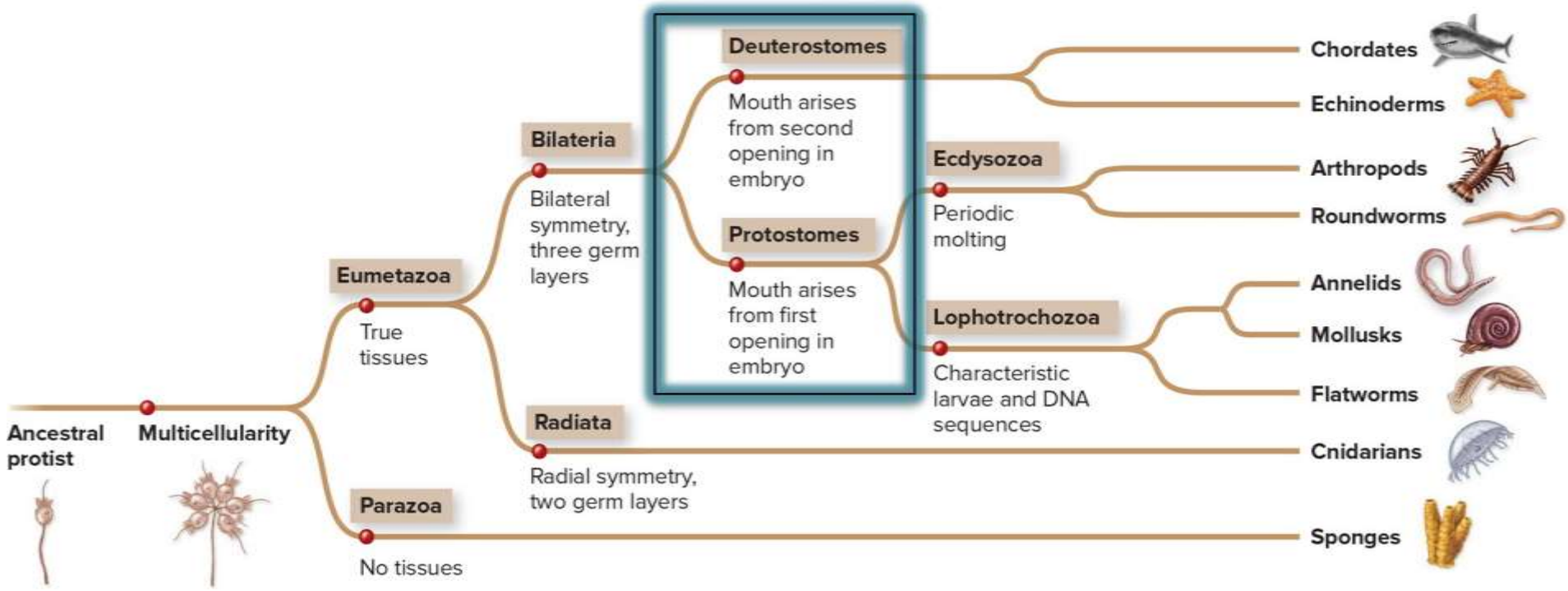


Figure 21.4

Animals are classified by early embryonic development

The third branching point distinguishes animals by how their gastrula develops.



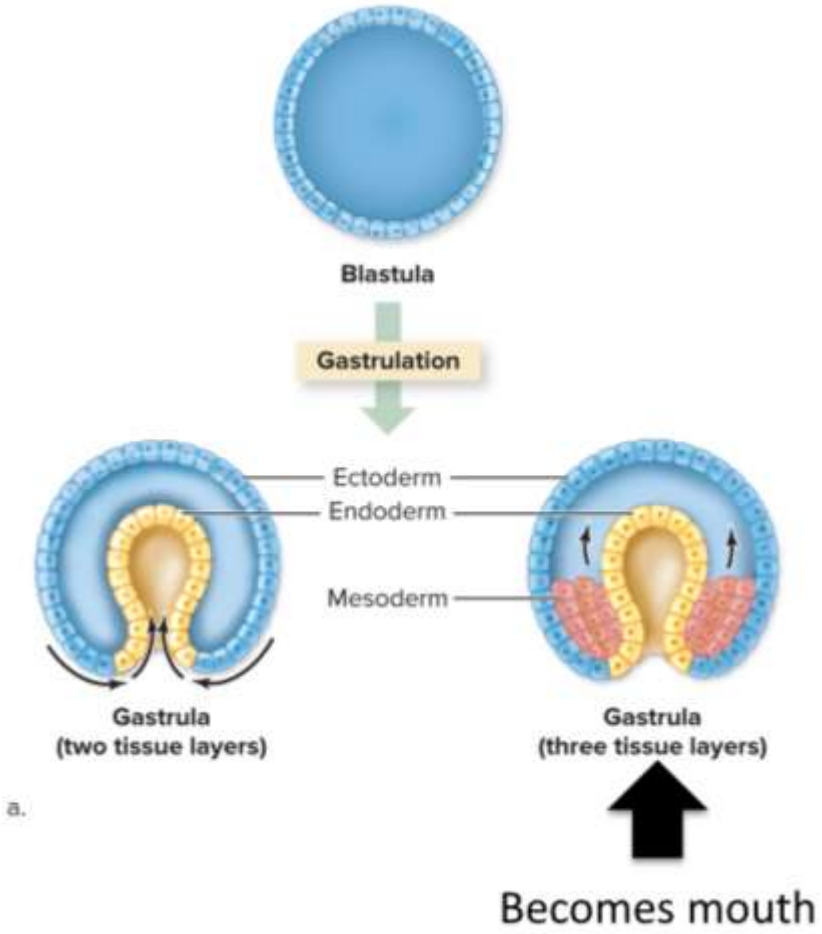
Section 21.1

Figure 21.2

Protostomes are “mouth first”

If the first indention of the gastrula develops into the mouth, the organism is a **protostome**.

The anus will develop from the second opening.



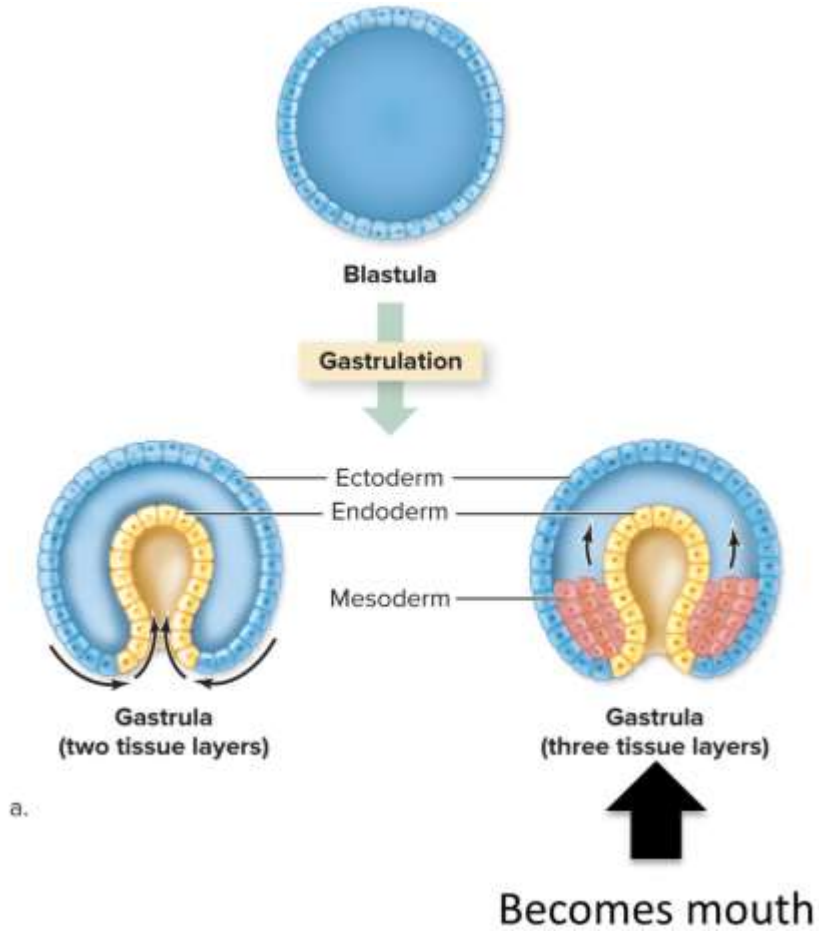
Section 21.1

Figure 21.4

Deuterostomes are “anus first”

If the first indention of the gastrula develops into the anus, the organism is a **deuterostome**.

The mouth will develop from the second opening.



Protostomes and deuterostomes are fundamentally different

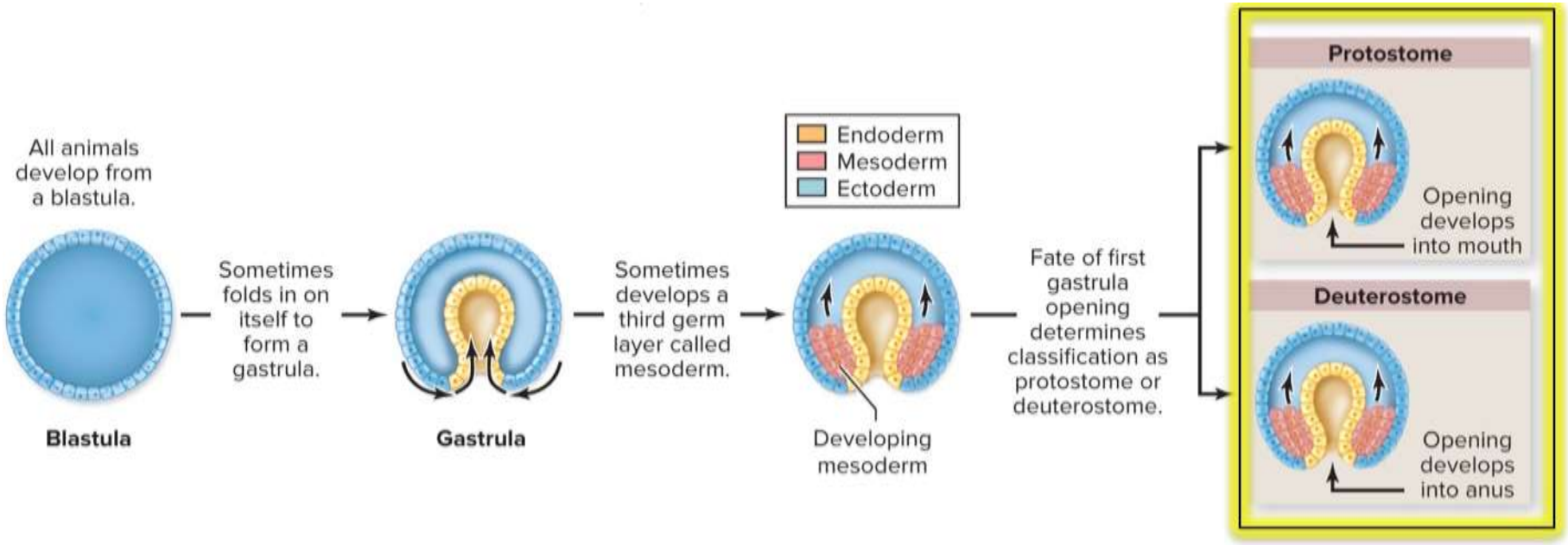
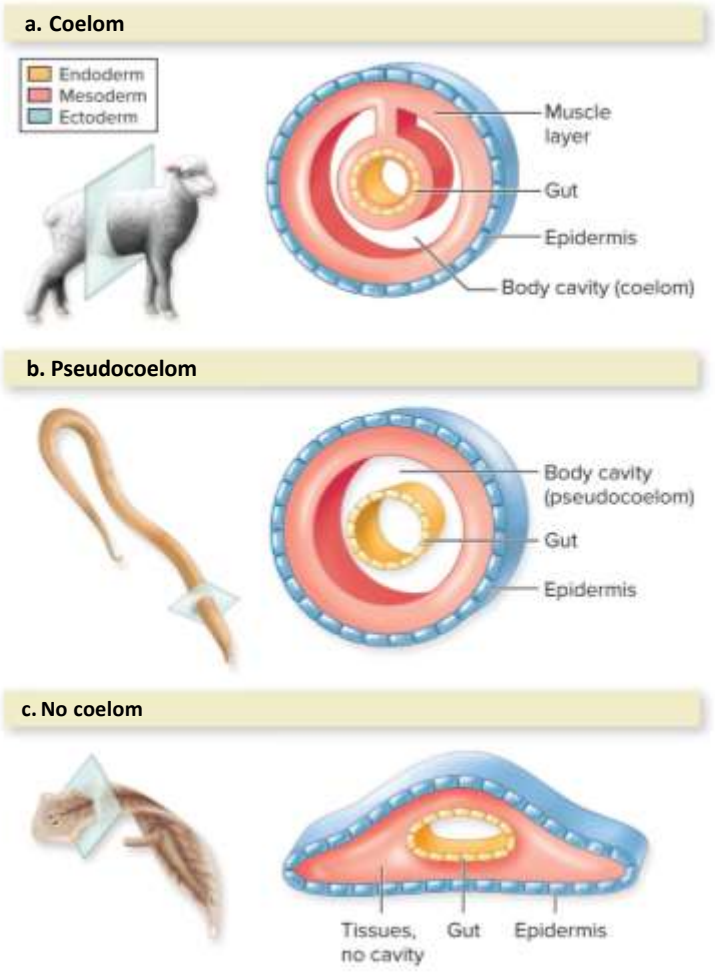


Figure 21.46

Animals are classified by body cavity



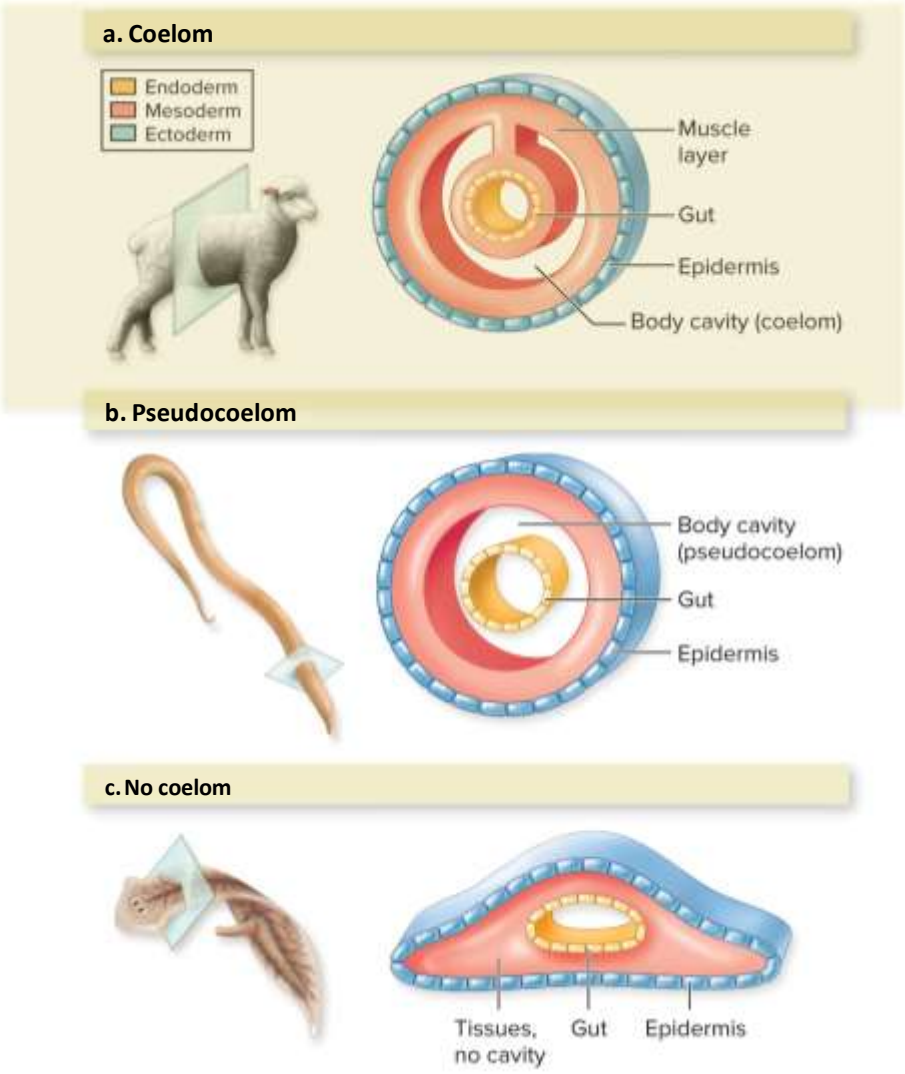
A **coelom** is a body cavity surrounded on all sides by mesoderm.

Bilaterally symmetrical animals have different types of body cavities.

Section 21.1

Figure 21.5

Some animals have a true coelom



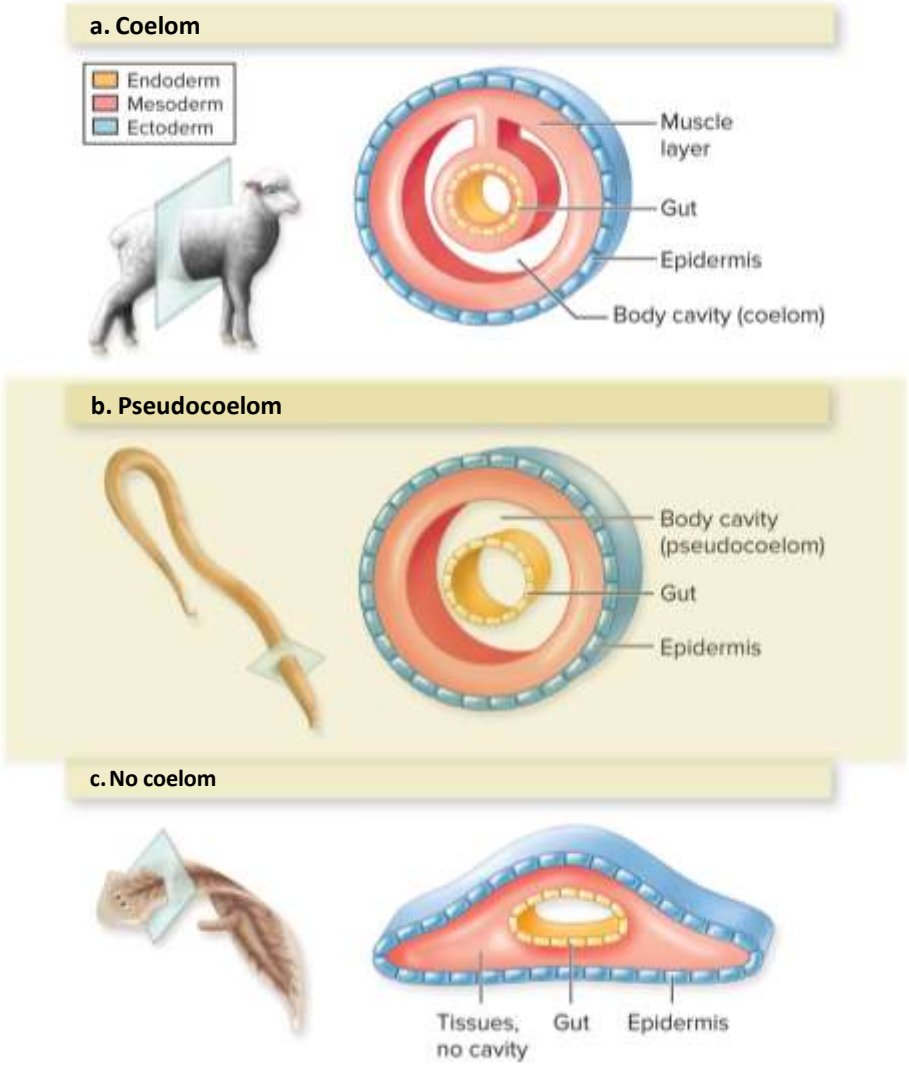
This sheep's body cavity is fully surrounded by mesoderm.

This is where the internal organs will grow.

Section 21.1

Figure 21.5

Some animals have a **pseudocoelom**

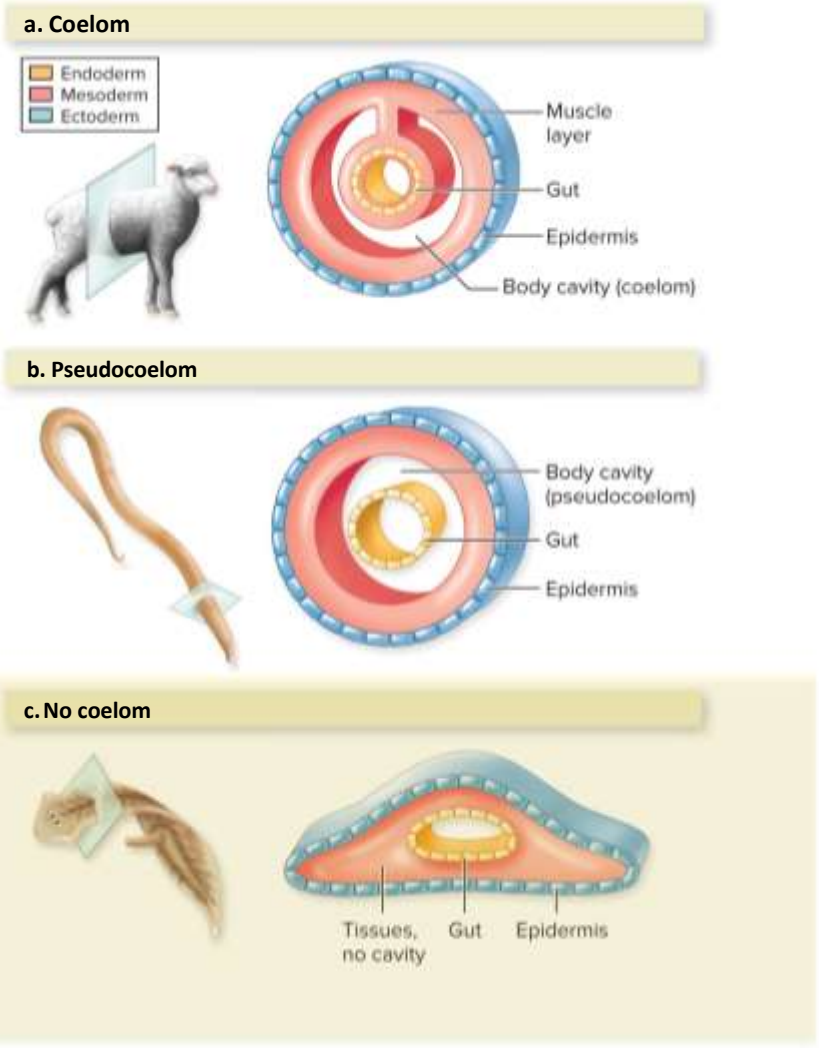


This roundworm's body cavity is surrounded by mesoderm on one side and ectoderm on the other side.

Section 21.1

Figure 21.5

Some animals have no coelom



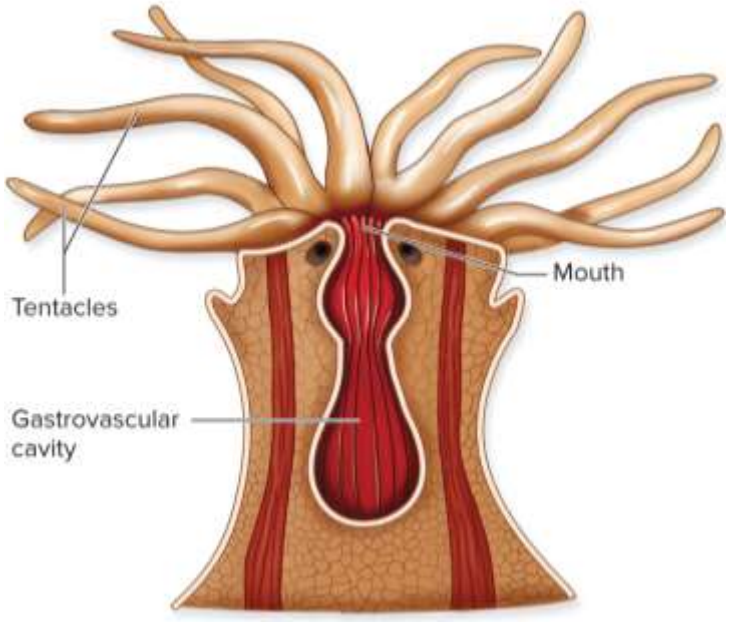
This flatworm lacks a body cavity.

Section 21.1

Figure 21.5

Animals are classified by digestive tract

Animals have an
incomplete digestive tract
if the mouth both takes in food
and ejects wastes.



Animals have a
complete digestive tract
if food passes in one direction
from mouth to anus.

Figures 21.6, 32.13

Section 21.1

Animals are classified by segmentation

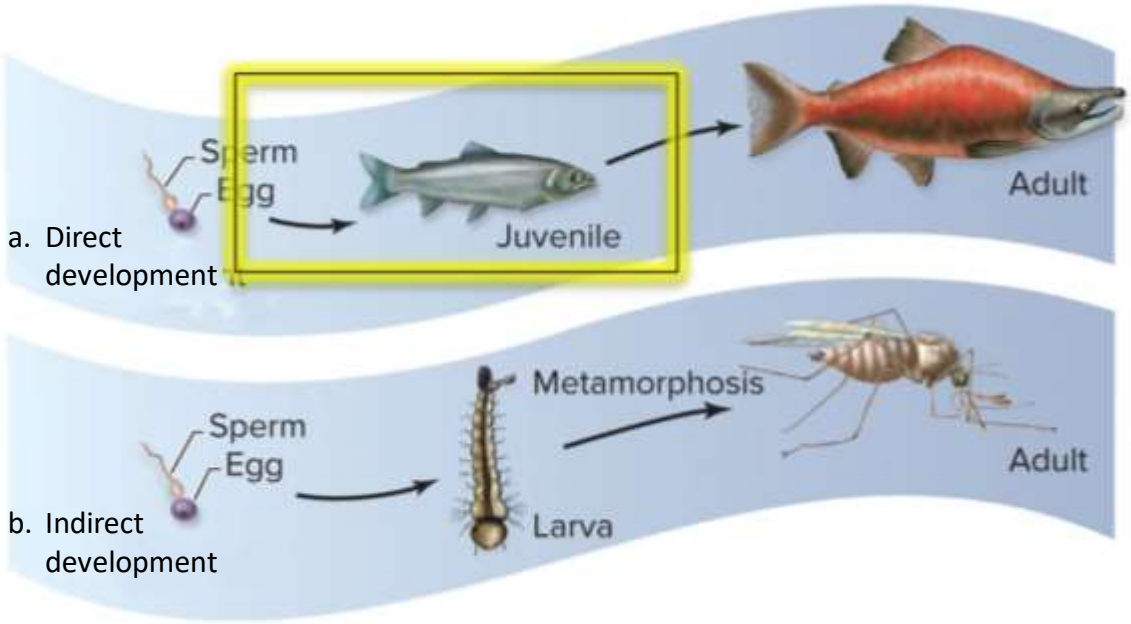
This millipede's body is **segmented**: it is divided into repeated parts.

©Don Farrall/Getty Images RF

Segmented bodies are more flexible and have more potential for developing specialized body parts than unsegmented bodies.

Animals are classified by reproduction and development

Animals with **direct development** resemble adults in their juvenile stage. The baby fish looks like a smaller version of the adult fish.

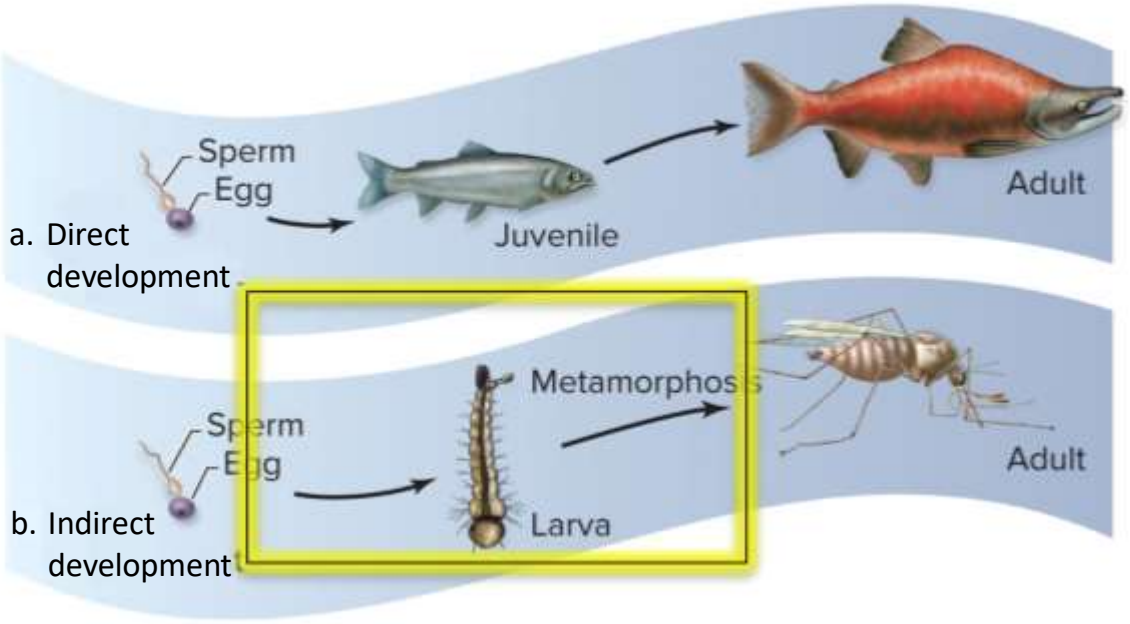


Section 21.1

Figure 21.8

Some animals reproduce larvae

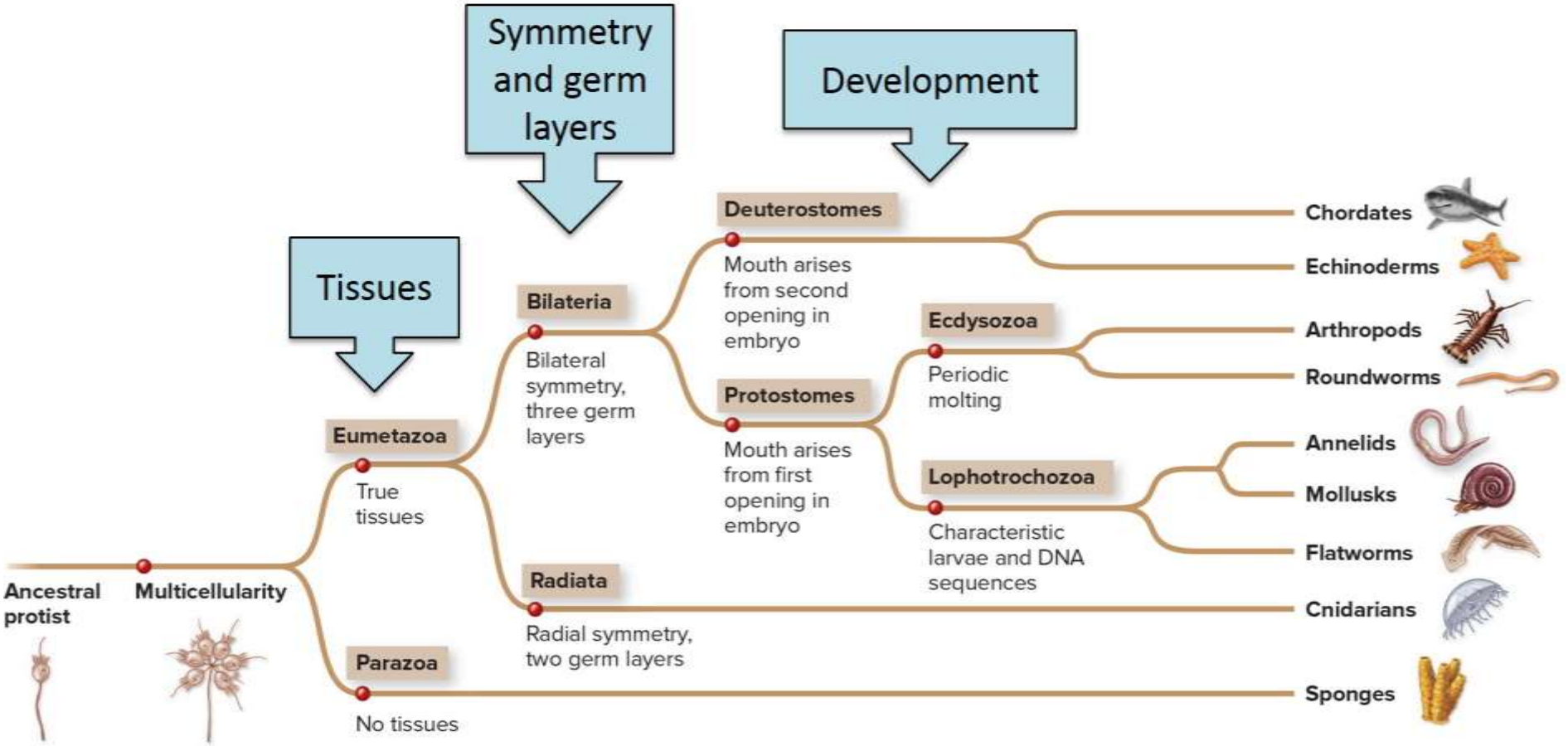
Animals with **indirect development** have a larval stage that does not resemble the adult form. The larva undergoes **metamorphosis** as it matures into an adult.



Section 21.1

Figure 21.8

Each animal phylum has a unique combination of features



Section 21.1

Figure 21.2

Clicker question #3

Which type of animal does NOT go through this sequence in its early development?

A. sea star
B. shark
C. snail
D. sponge
E. flatworm

Figure 21.4

Clicker question #3, solution

Which type of animal does NOT go through this sequence in its early development?

D. sponge

Figure 21.4

21.1 Mastering concepts

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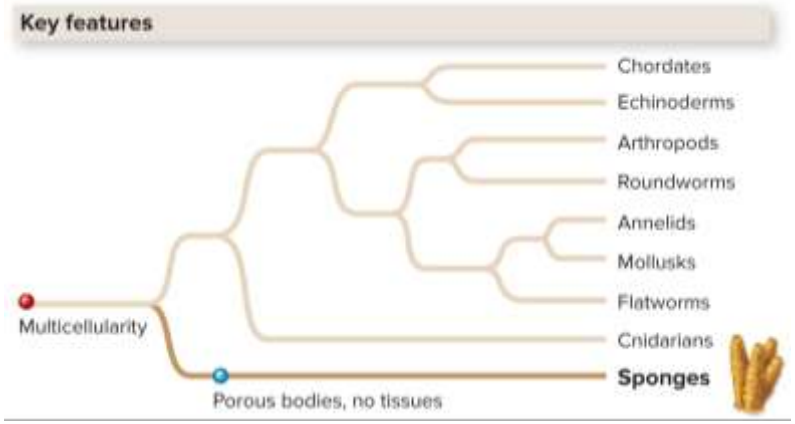
What features were used to build the animal phylogenetic tree?

Sponges (Porifera) are simple animals

Sponges are aquatic and sessile (anchored to a surface). They do not have true tissues.



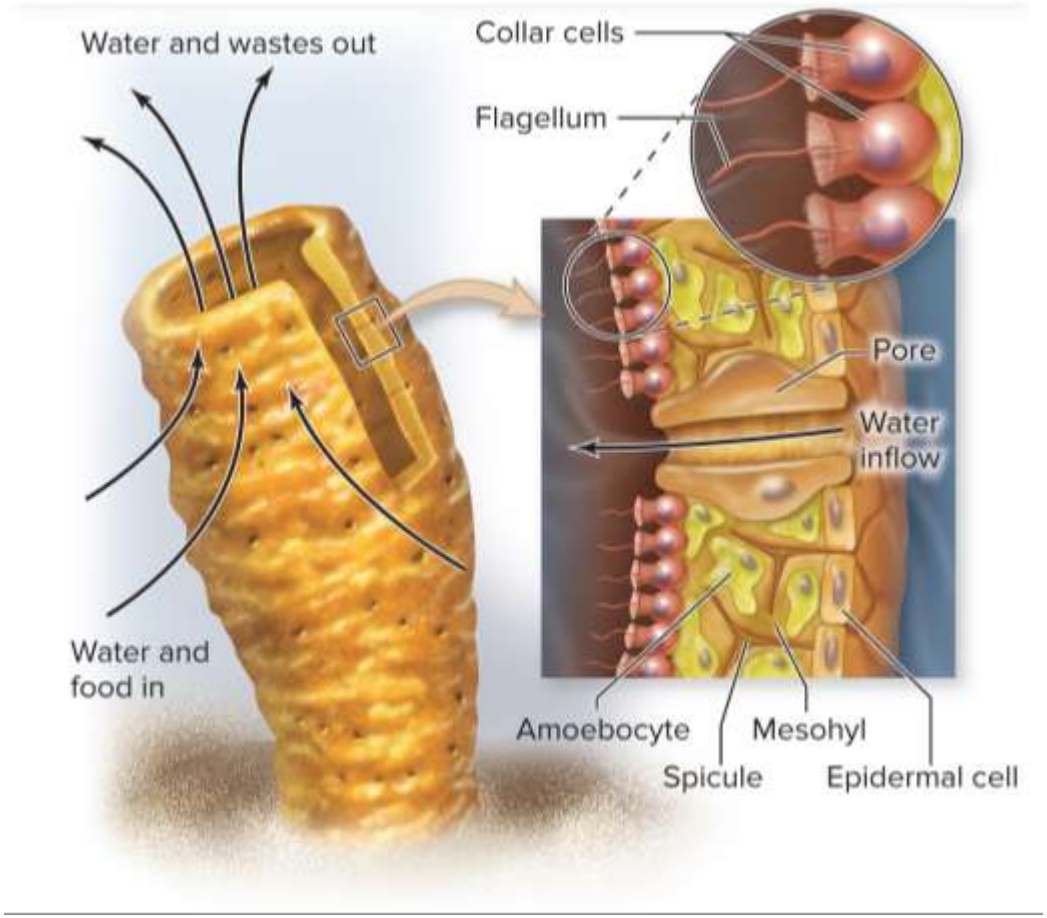
They have hollow bodies that are either asymmetric or radially symmetric.

(diversity green): ©Getty Images RF; (diversity pink): ©Laurence F Tapper/YAY Micro/age fotostock RF

Sponges are filter feeders

Water moves into a sponge's body through pores in its sides, then out through a hole at the top.

This allows the sponge to trap food and eliminate waste.



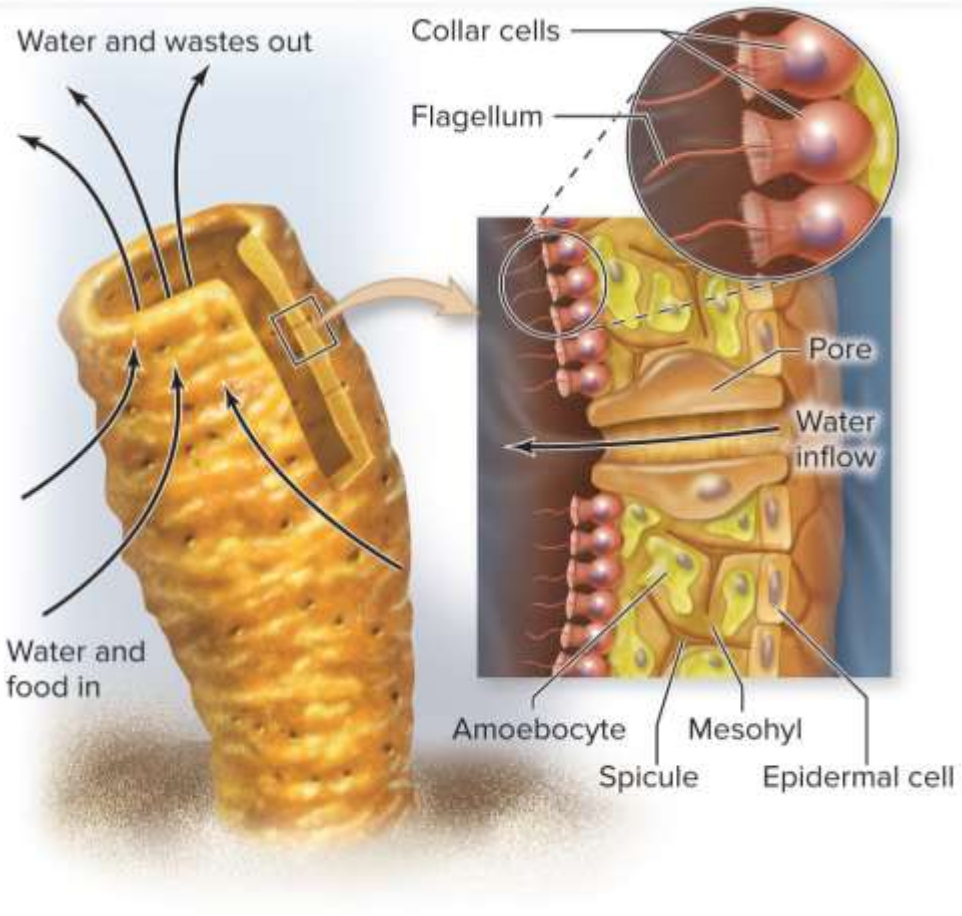
Section 21.2

Figure 21.9

Sponges have specialized cells

Collar cells trap food and start to digest it.

Amoebocytes digest food and distribute it to other parts of the body.



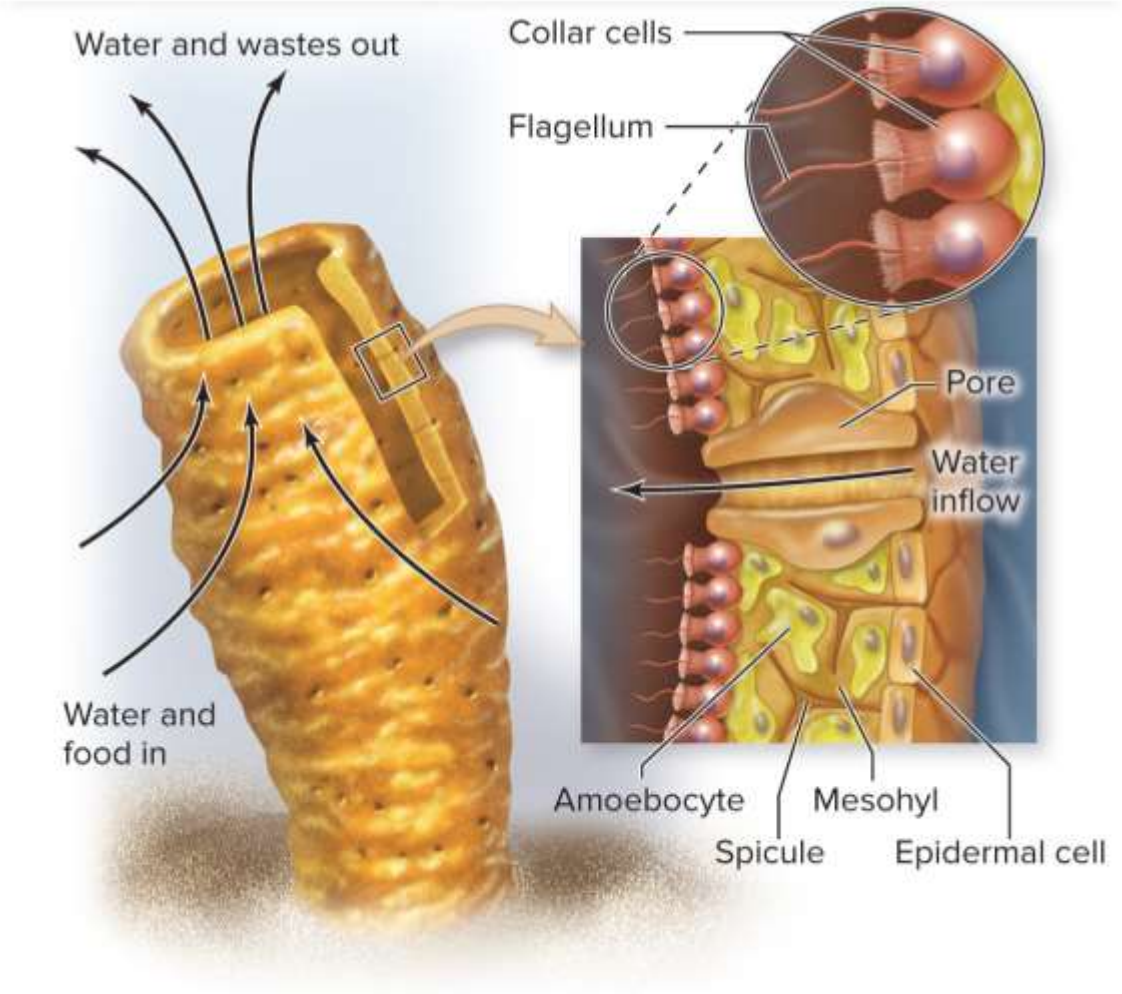
Section 21.2

Figure 21.9

Sponges are hermaphrodites

Reproduction can be asexual (by budding) or sexual.

Sperm are released into the water and fertilize eggs retained in the body of the sponge.

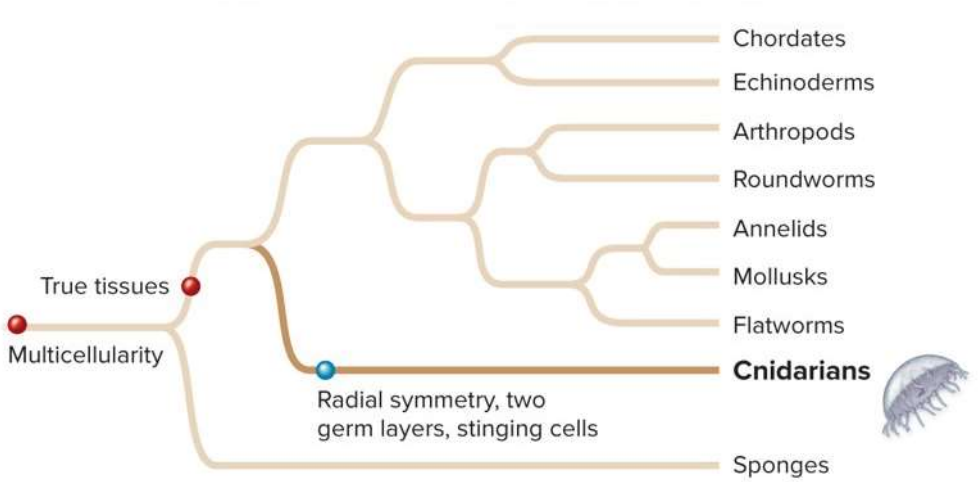


Section 21.2

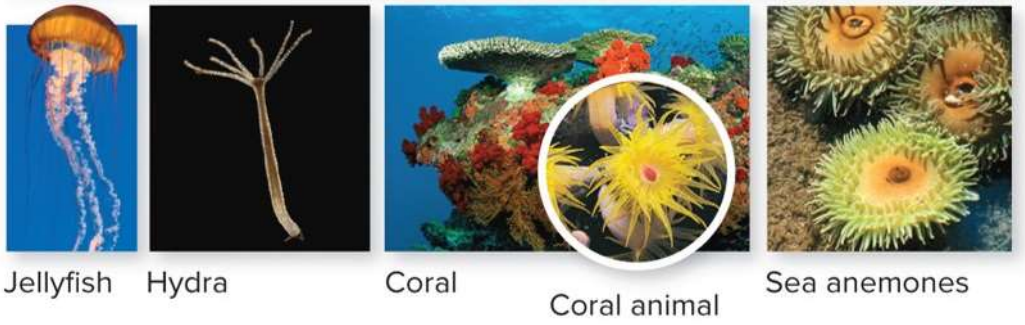
Figure 21.9

Cnidarians are simple eumetazoans

Cnidarians are aquatic and radially symmetric, with 2 germ layers.

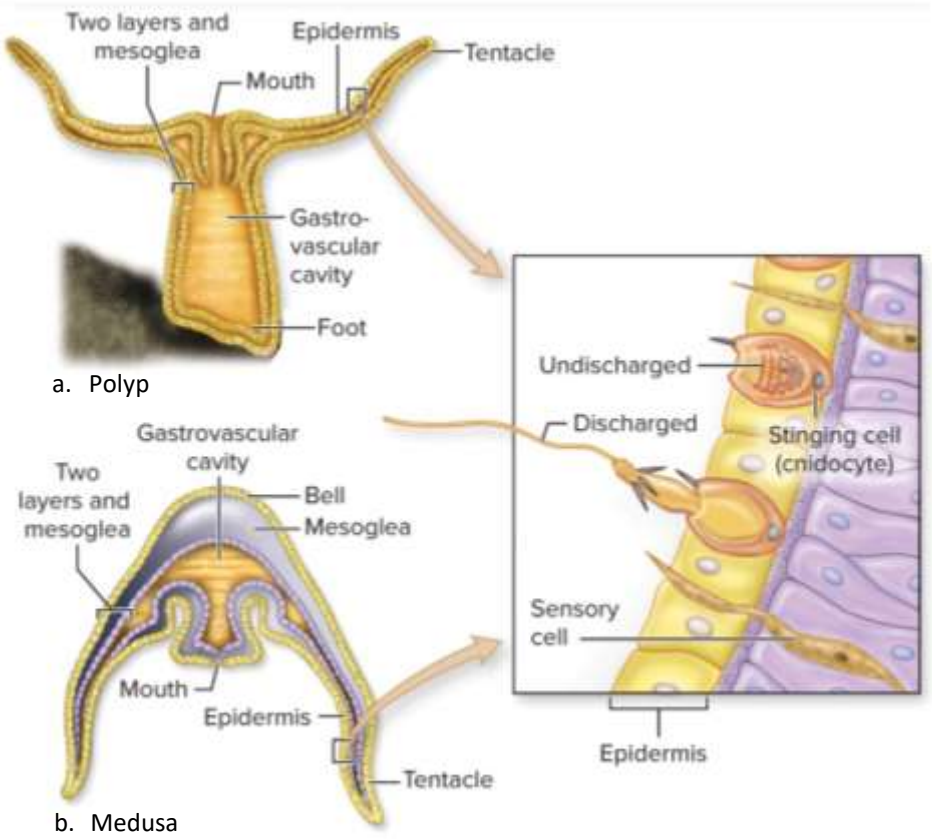


The 4 groups of cnidarians are jellyfish, hydra, coral, and sea anemones.



(jellyfish): ©Kevin Schafer/Alamy RF; (hydra): ©Ted Kinsman/Science Source; (coral): ©Comstock Images/PictureQuest RF; (coral animal): ©Leslie Newman & Andrew Flowers/Science Source; (anemone): ©Russell Ilig/Getty Images RF

Cnidarians' unique feature is mesoglea

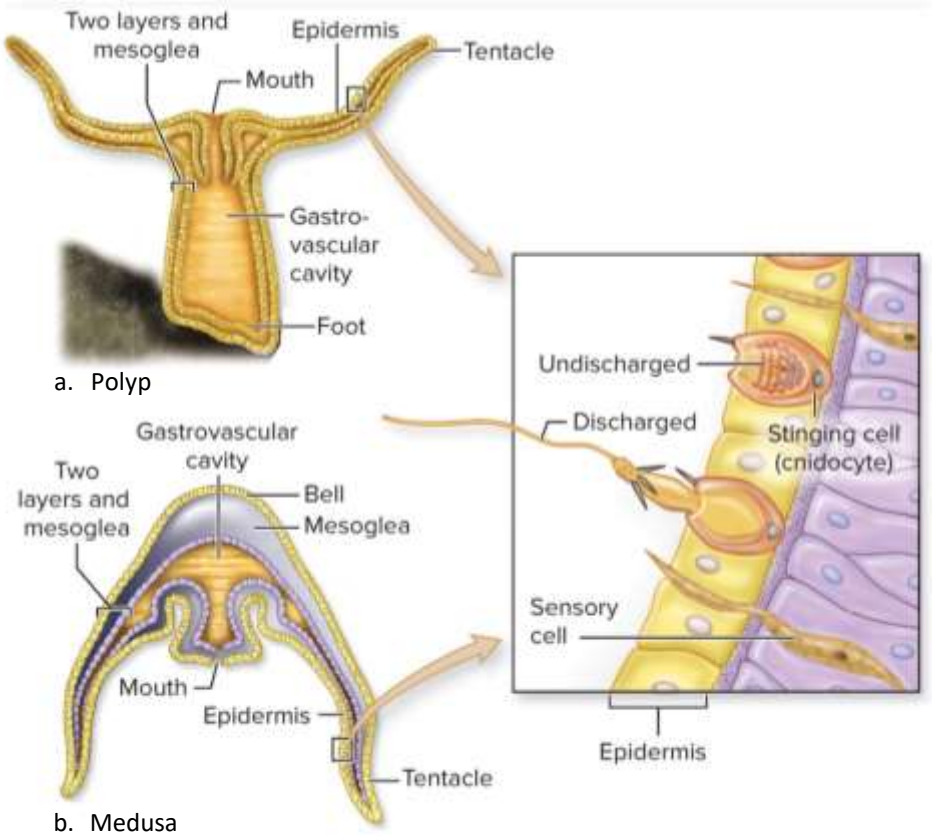


Mesoglea is a jellylike, noncellular substance found between the 2 cell layers that make up a cnidarian's body

Section 21.3

Figure 21.10

Cnidarians have stinging cells



In the outer body layer there are cells called **cnidocytes**, which contain tiny sharp harpoons used to sting predators or prey.

The sting can irritate, paralyze or kill other animals.

Cnidarians reproduce sexually and asexually

Adults release sperm or eggs into the water. When they meet up fertilization occurs to form a zygote.

The zygote develops into a larva and then a **polyp**, which can form a colony and release new **medusae**.

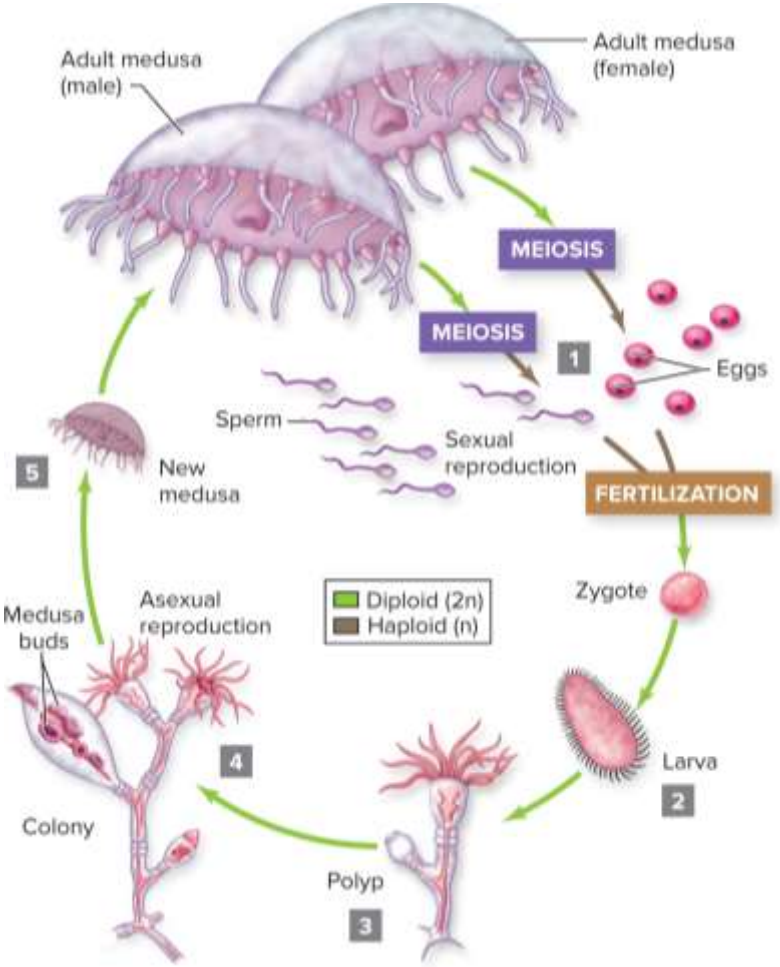
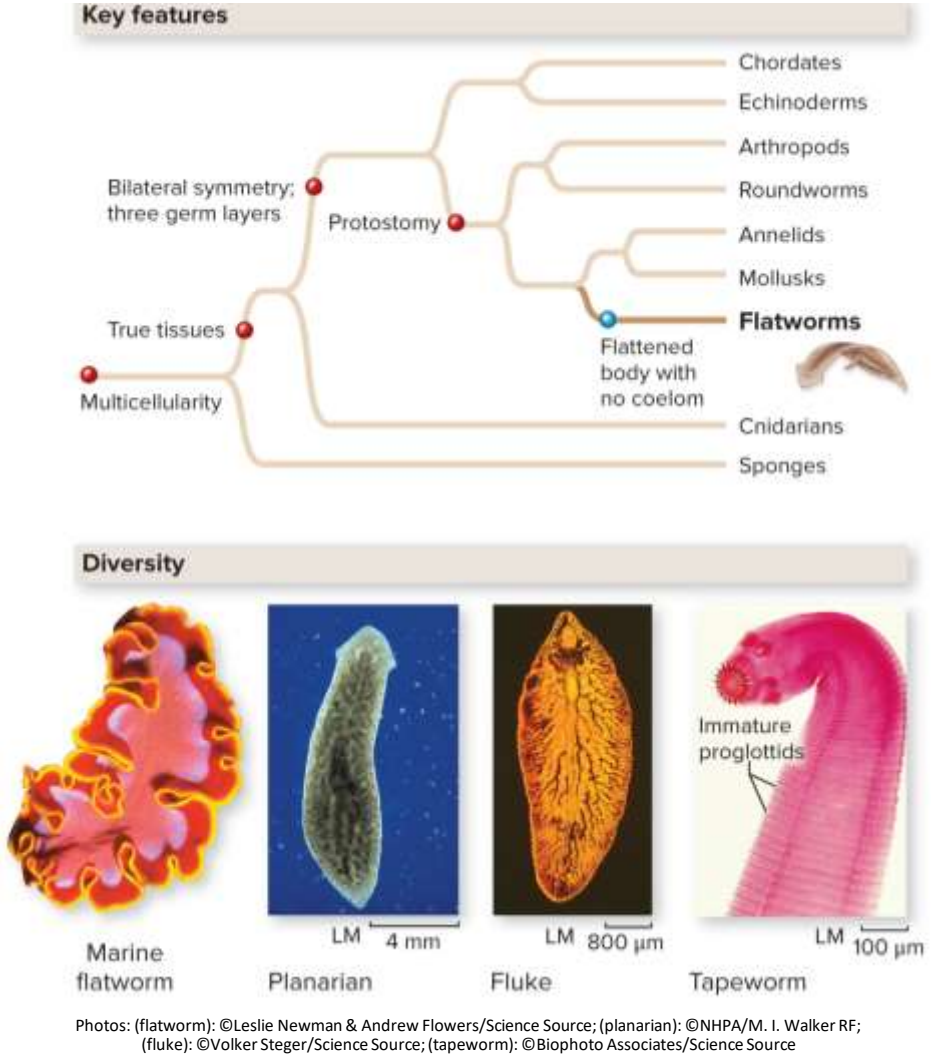


Figure 21.11

Flatworms are simple protostomes

Flatworms (phylum Platyhelminthes) are bilaterally symmetric, with three germ layers.

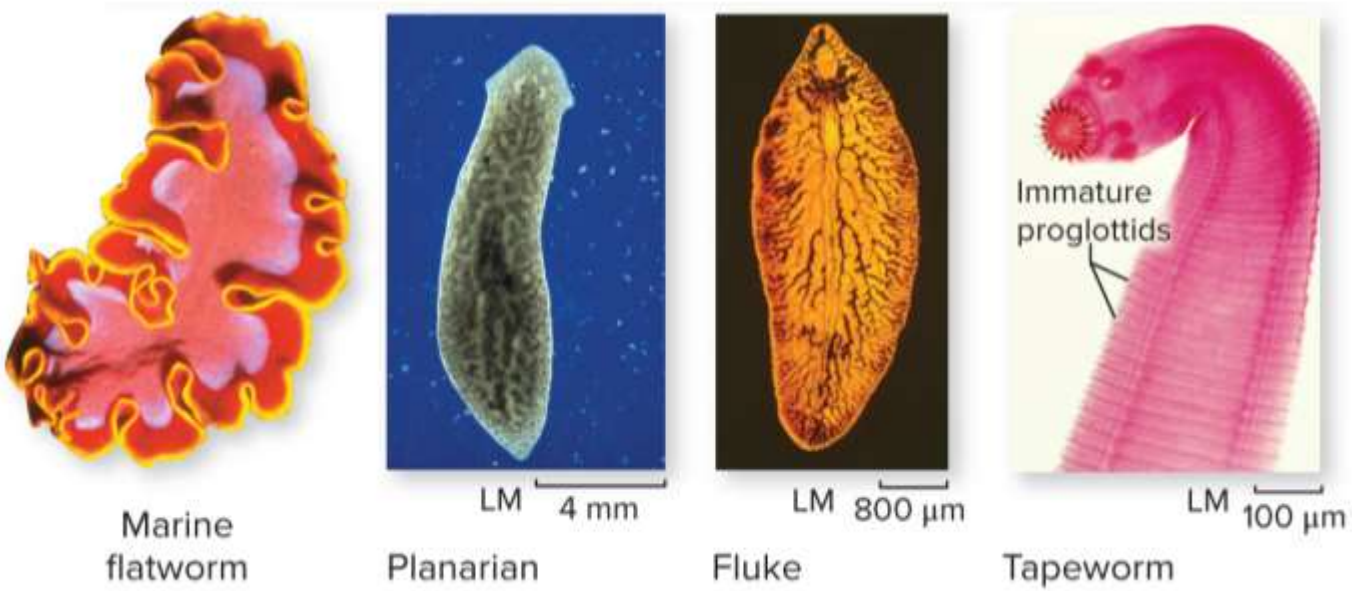
Planarians, flukes, and tapeworms are three groups of flatworms.



Photos: (flatworm): ©Leslie Newman & Andrew Flowers/Science Source; (planarian): ©NHPA/M. I. Walker RF; (fluke): ©Volker Steger/Science Source; (tapeworm): ©Biophoto Associates/Science Source

Flatworms have no coelom

The flat body shape increases surface area and allows for efficient gas exchange in the absence of a coelom and without a specialized respiratory or circulatory system.

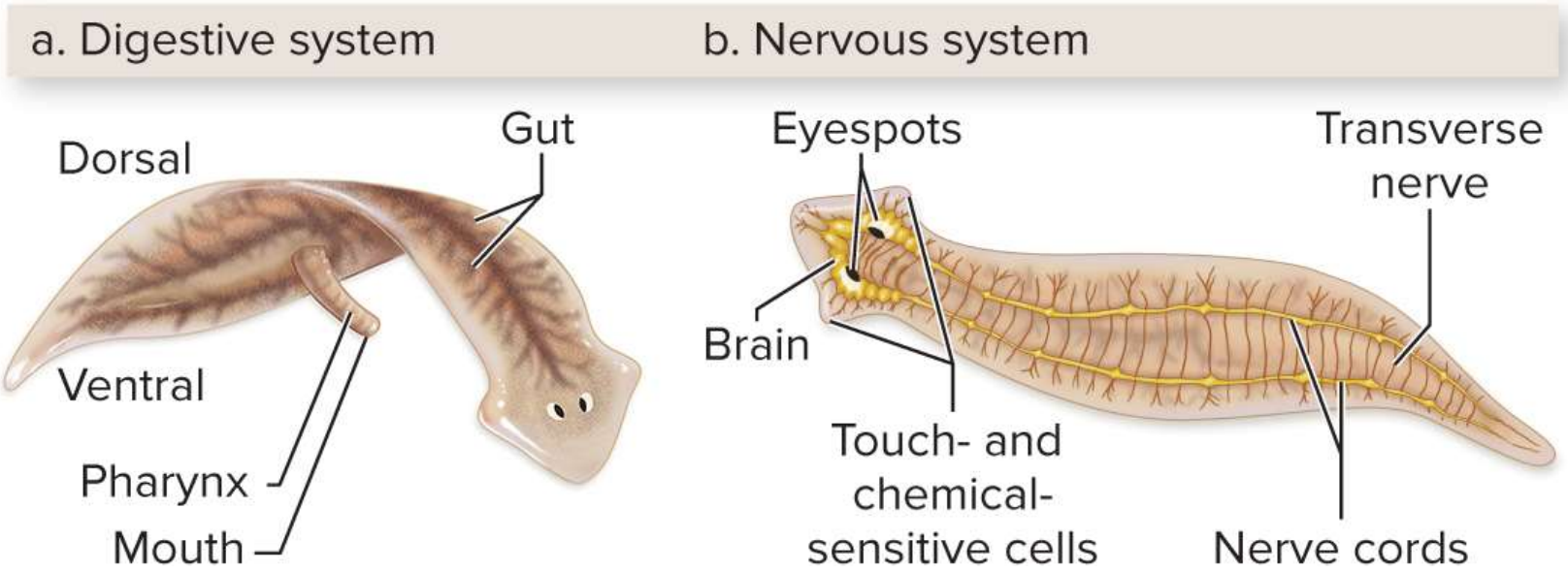


(flatworm): ©Leslie Newman & Andrew Flowers/Science Source; (planarian): ©NHPA/M. I. Walker RF; (fluke): ©Volker Steger/Science Source; (tapeworm): ©Biophoto Associates/Science Source

Planarians are free-living flatworms

A feeding structure called a pharynx brings food into the body and excretes undigested food.

A brain and nerve cords make up the nervous system. It can sense touch, chemicals, and light.

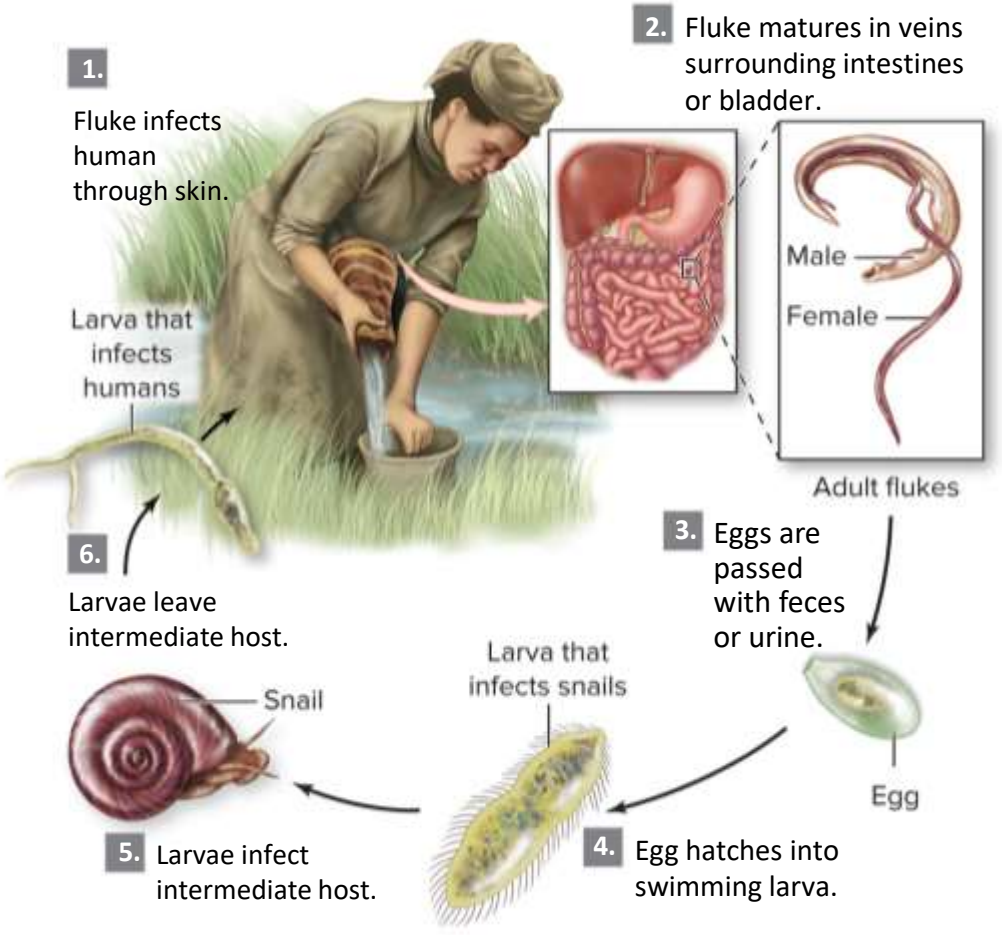


Section 21.4

Figure 21.13

Flukes and tapeworms are parasitic

Some flatworms are parasitic, such as the blood fluke. They reproduce in the human intestine.



Section 21.4

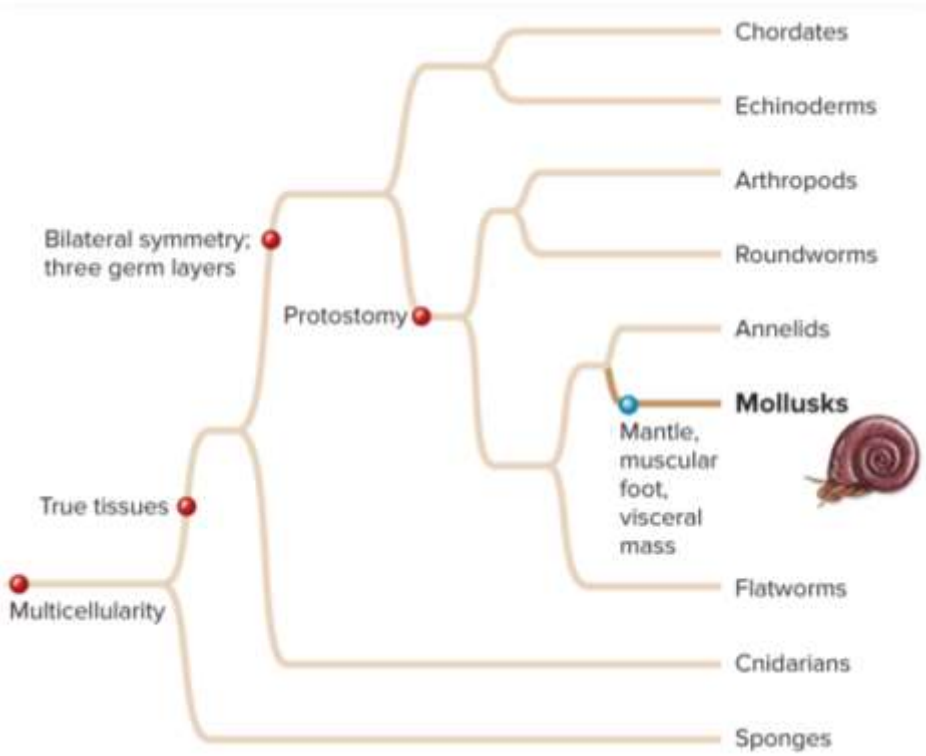
Figure 21.14

Mollusks are soft, unsegmented protostomes

Mollusks are a large, diverse phylum with a true coelom.

Mollusk features:

- A **mantle** that secretes the shell
- A muscular **foot** used for locomotion
- A **visceral mass** where organs are found
- A **radula** for feeding



Section 21.5

Figure 21.15

Mollusks are a diverse group

Chitons have eight overlapping shells.

Bivalves have hinged shells.

Gastropods have spiral shells.

Cephalopods have internal or absent shells.

(chiton): ©Kjell B. Sandved/Science Source; (bivalve): ©Andrew J. Martinez/Science Source; (snail): ©Digital Vision RF; (slug): ©Steven P. Lynch RF; (octopus): ©Rich Carey/Shutterstock RF; (squid): ©Comstock Images/PictureQuest RF

Mollusks have several organ systems

All mollusks have an open circulatory system and reproduce sexually.

Octopus (cephalopod)

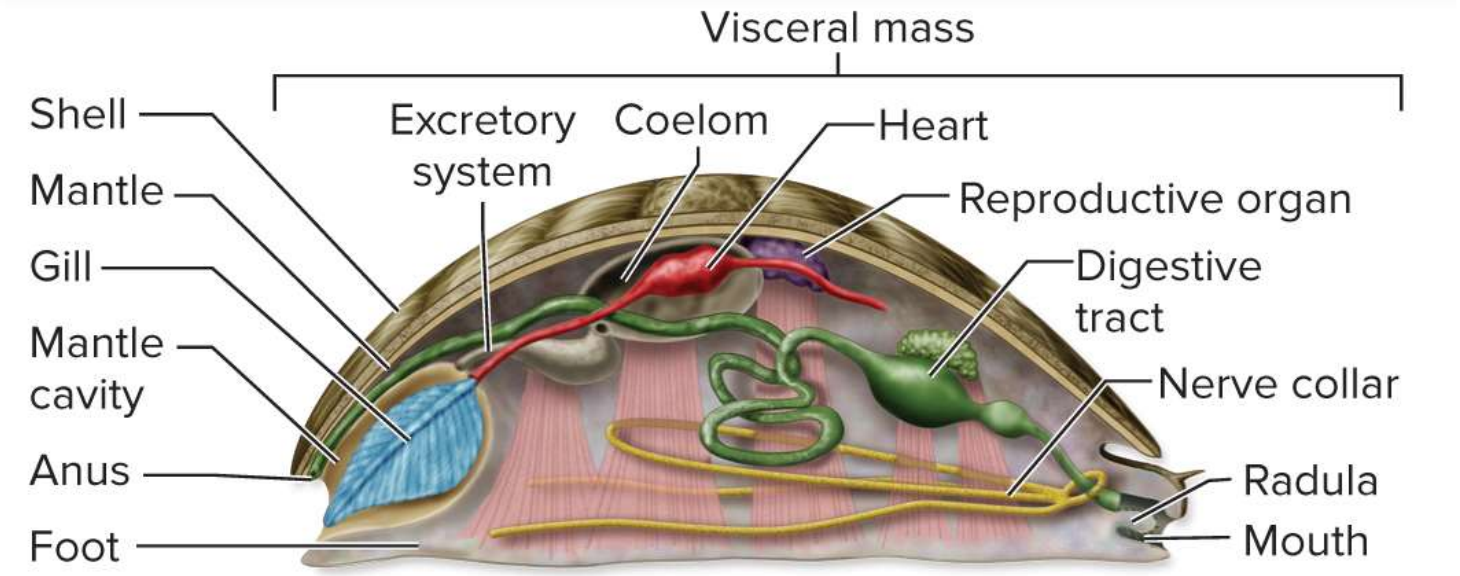
Squid (cephalopod)

(octopus): ©Rich Carey/Shutterstock RF; (squid): ©Comstock Images/PictureQuest RF

Cephalopods have particularly well-developed nervous systems including a large brain, eyes, excellent sense of touch, and impressive problem-solving abilities.

Mollusks have a complete digestive tract

In this bivalve, the radula contains teeth made of chitin. Food moves into the body through the mouth, and excretion occurs through the anus.

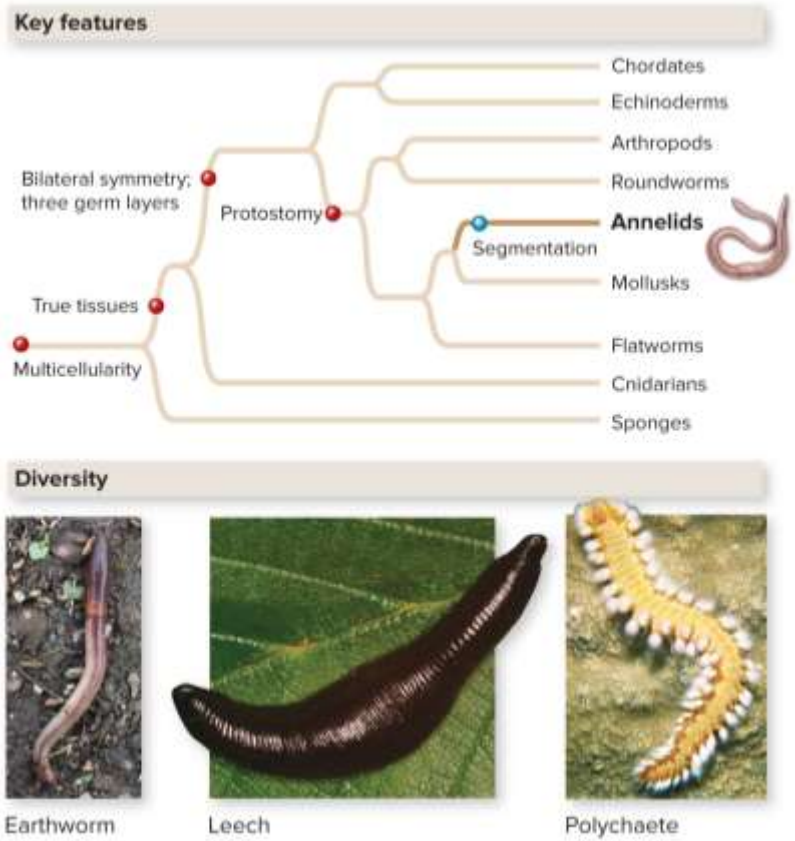


Section 21.5

Figure 21.15

Annelids are segmented worms

Each body segment functions the same as the others



(earthworm): ©David Chapman/Alamy; (leech): ©Edward Kinsman/Science Source; (polychaete): ©L. Newman & A. Flowers/Science Source

Section 21.6

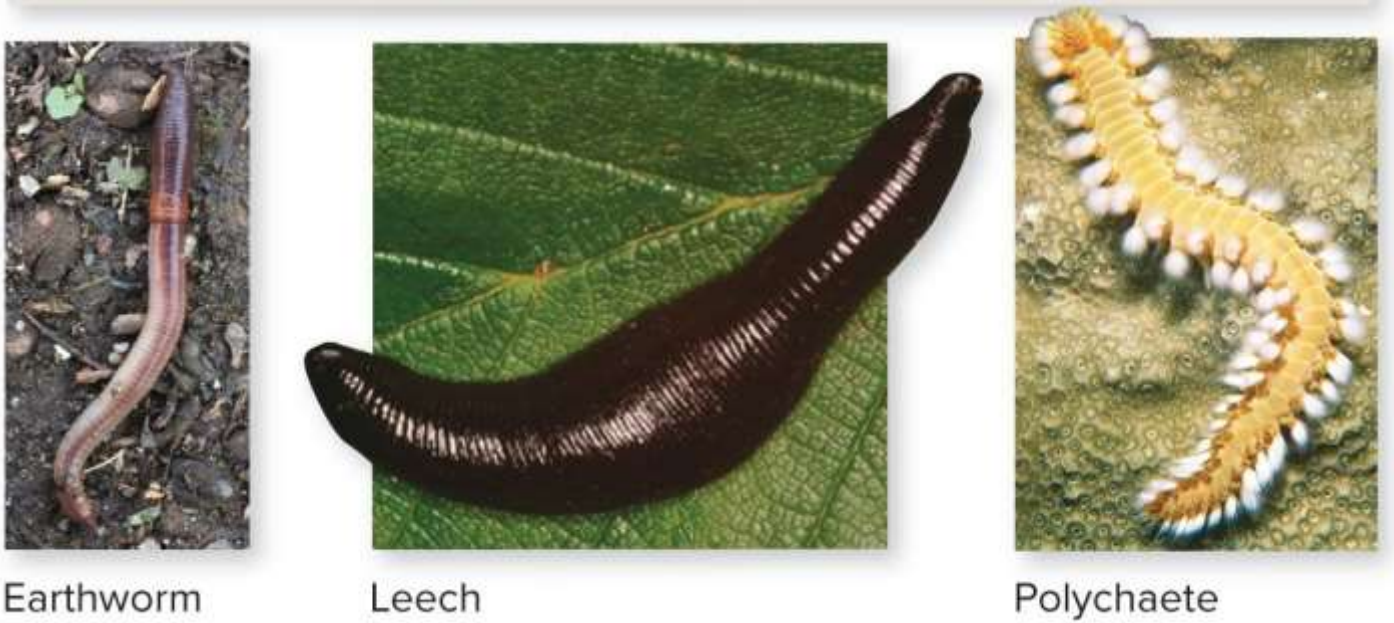
Figure 21.16

Annelids inhabit different environments

Earthworms live in soil, where they are crucial for keeping it aerated.

Leeches live in freshwater. They drink blood and eat small animals.

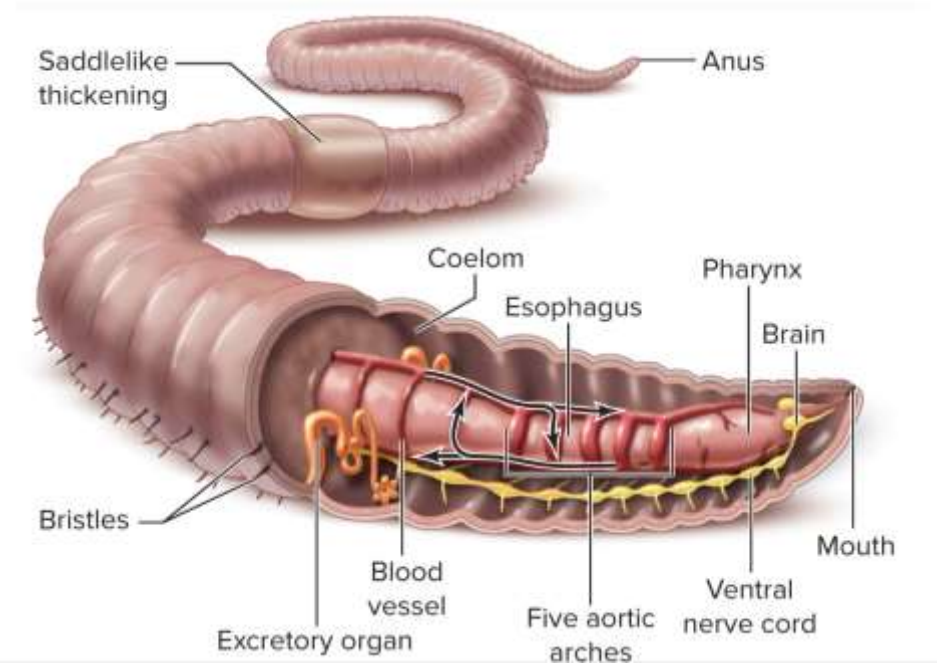
Polychaetes are marine worms.



(earthworm) : ©David Chapman/Alamy; (leech): ©Edward Kinsman/Science Source; (polychaete): ©L. Newman & A. Flowers/Science Source

Annelids have several organ systems

This earthworm has a complete digestive system, a closed circulatory system with aortic arches, and a nervous system that includes a brain and ventral nerve cord.



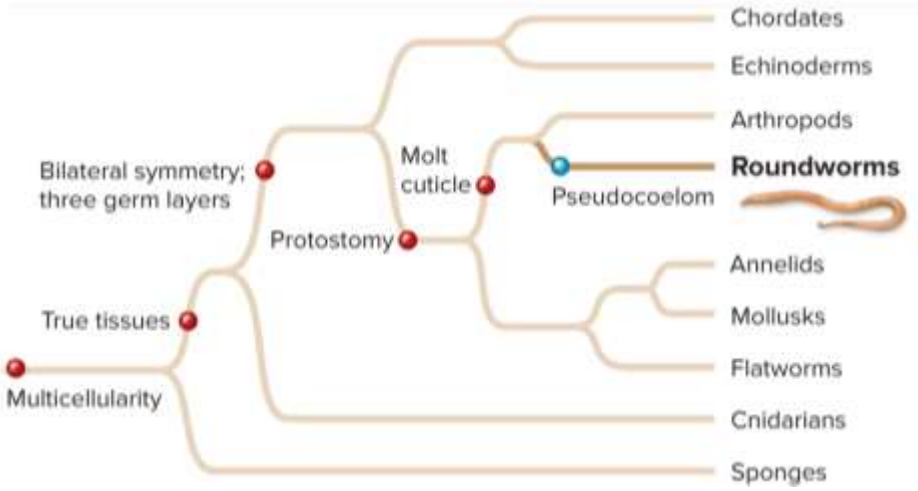
Each body segment contains excretory organs.

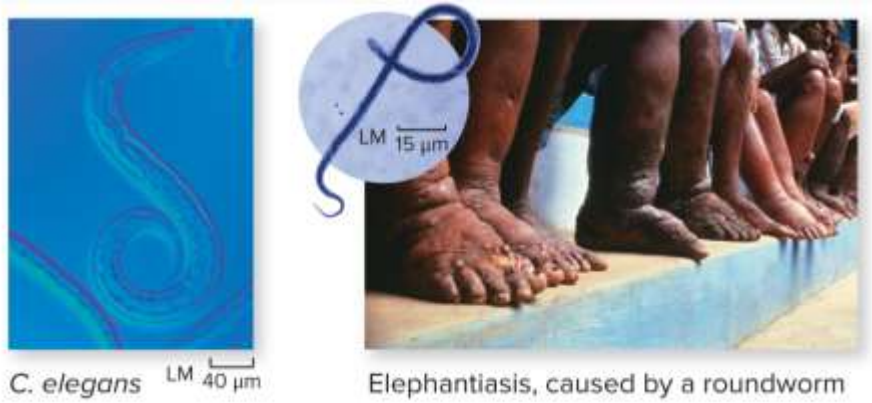
The saddlelike thickening area holds the eggs in a specialized cocoon.

Nematodes are unsegmented worms

Phylum Nematoda is comprised of **roundworms**.

Although they look wormlike, the closest evolutionary relatives of roundworms are the arthropods.

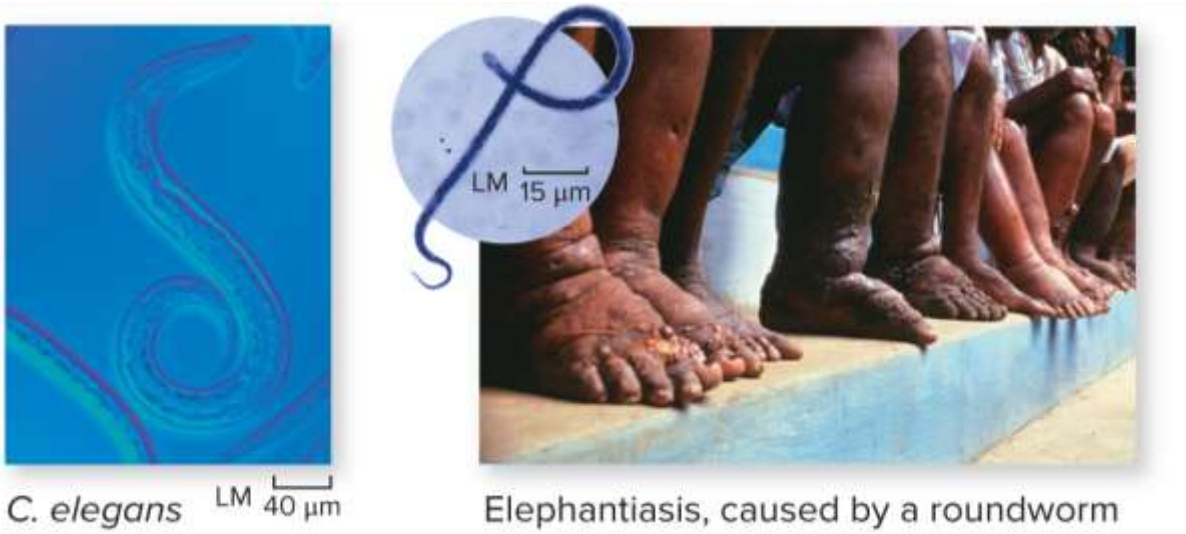




(C. elegans): ©Sinclair Stammers/Science Source; (Wuchereria): CDC/Dr. Mae Melvin; (elephantiasis) ©R. Umesh Chandran, TDR, WHO/Science Source

Some roundworms cause disease

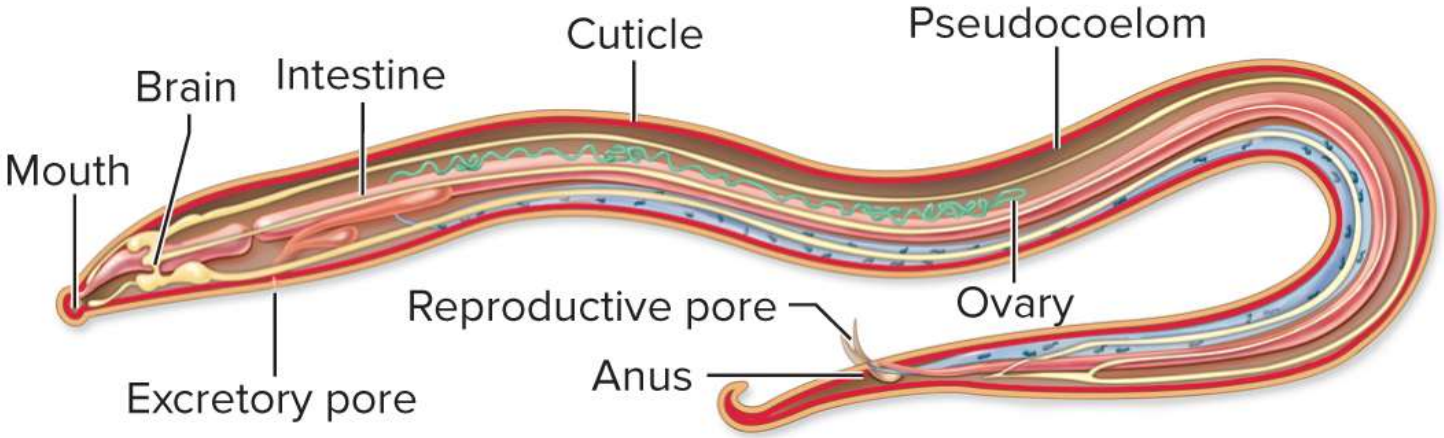
Parasitic roundworms such as pinworms, heartworms, and hookworms infect the intestines, muscles, blood, and lungs of humans and other animals. Others such as *C. elegans* are free-living.



(C. elegans): ©Sinclair Stammers/Science Source; (Wuchereria): CDC/Dr. Mae Melvin; (elephantiasis) ©R. Umesh Chandran, TDR, WHO/Science Source

Nematodes have few organ systems

This roundworm's nervous system includes a brain and nerve cords. Roundworms lack specialized circulatory and respiratory organs.



Fluid in the pseudocoelom distributes nutrients, oxygen, and carbon dioxide.

Clicker question #4

Animals commonly called *worms* are classified into three phyla (flatworms, roundworms, and annelids). What feature distinguishes them?

A. Only flatworms have radial symmetry.
B. Only roundworms have a complete digestive tract.
C. Only annelids are heterotrophic.
D. Only roundworms have a gastrula stage of development.
E. Only annelids are segmented.

Clicker question #4, solution

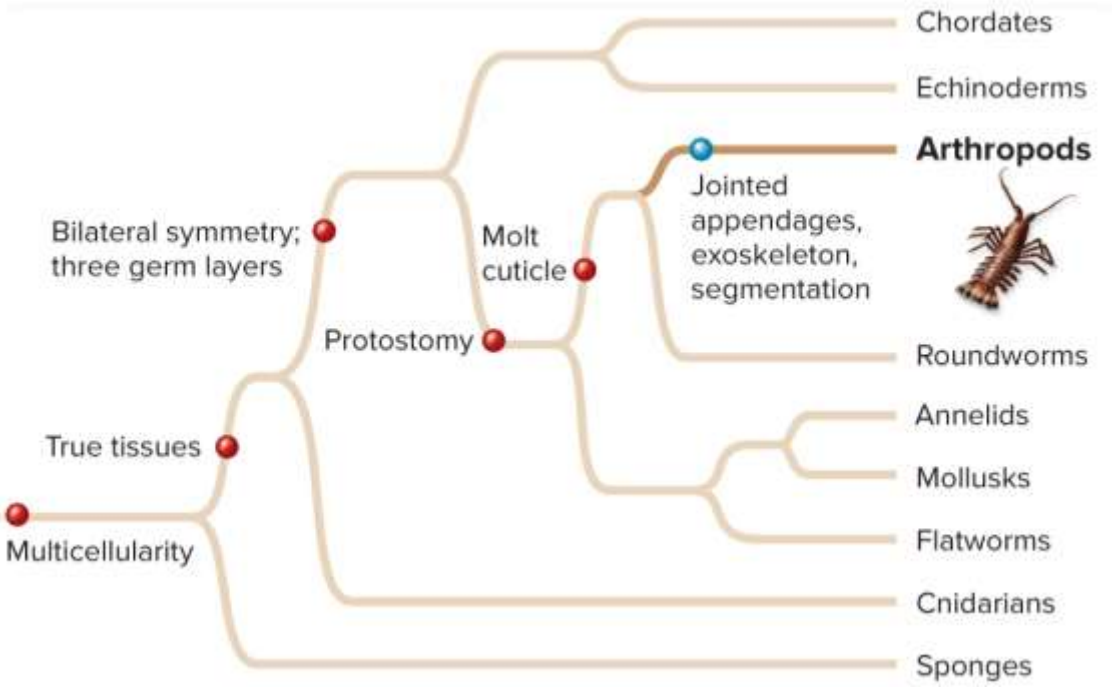
Animals commonly called *worms* are classified into three phyla (flatworms, roundworms, and annelids). What feature distinguishes them?

E. Only annelids are segmented.

Arthropods have jointed appendages

Phylum Arthropoda is the largest, most diverse phylum of animals. Their legs, antennae, mouthparts, and other organs are jointed.

- Trilobites
- Chelicerates
- Myriapods
- Crustaceans
- Insects



Over 1,000,000 species of arthropods exist!

Figure 21.18

Arthropods have an exoskeleton

All arthropods produce a tough outer **exoskeleton** made of chitin that supports and protects the body.

As their bodies grow, they molt and grow a new exoskeleton.

Arthropods have specialized body segments

In many arthropods, the segments group together into three major regions: head, thorax, and abdomen. Segments in each region develop specialized functions.

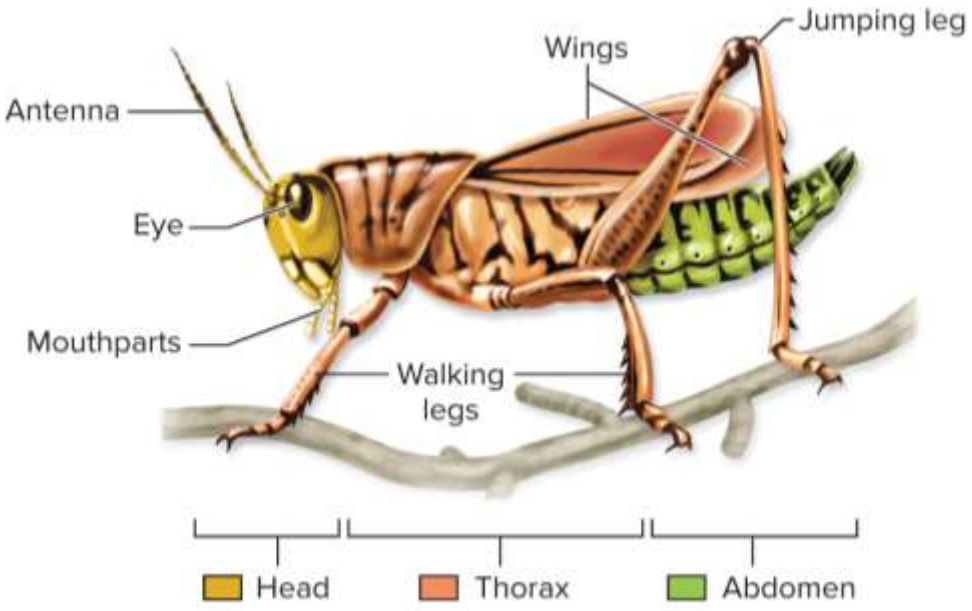
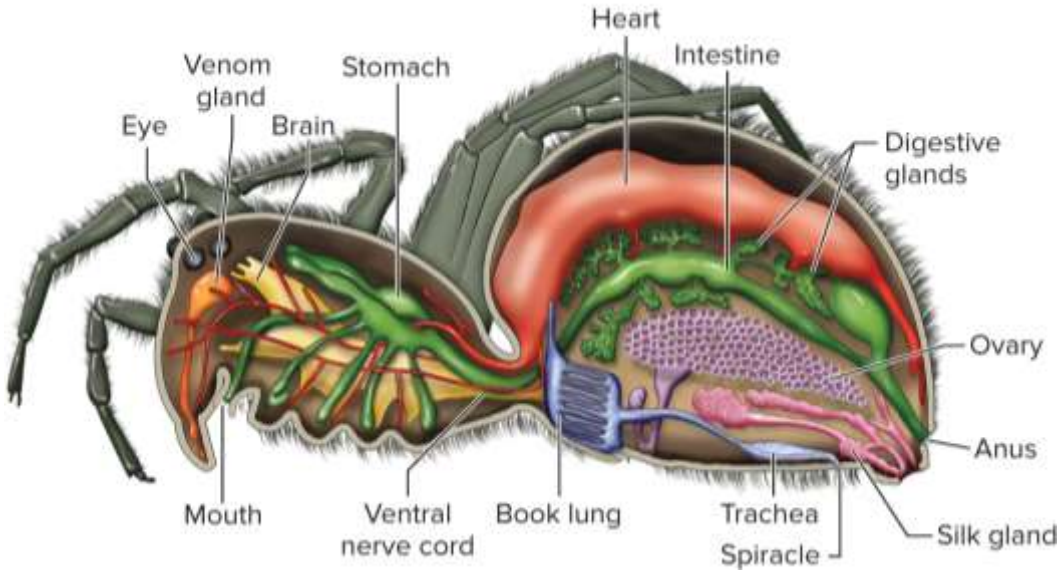


Figure 21.18

Arthropods have complex organ systems

Arthropods have a respiratory system made up of holes called spiracles for letting in air, and tubes called tracheae and book lungs for gas exchange.

The typical arthropod has a well-developed nervous system, open circulatory system, and complete digestive system.



Section 21.8

Figure 21.19

Arthropods are the most diverse animals

Arthropods are divided into five subphyla.

©Francois Gohier/Science Source

These **trilobites** are an extinct marine phylum.

Arthropods are grouped by their mouthparts

The other four subphyla of arthropods are divided into:

- **Chelicerates** with grasping clawlike mouthparts
- **Mandibulates** with chewing, jawlike mouthparts

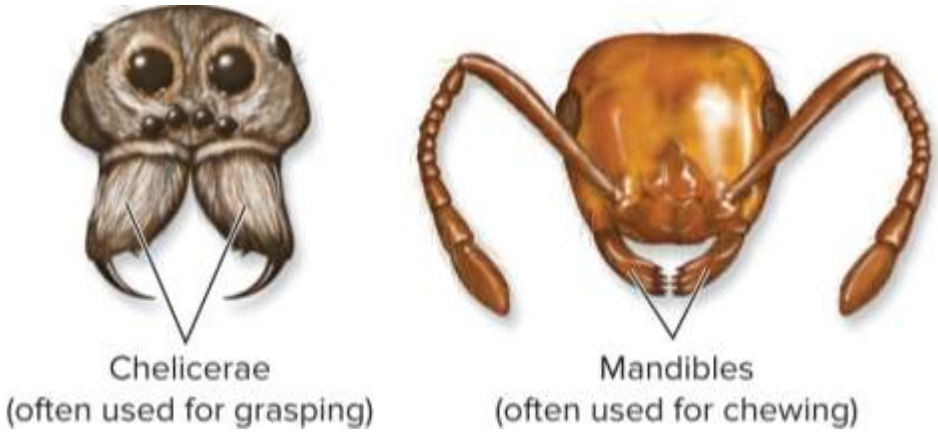
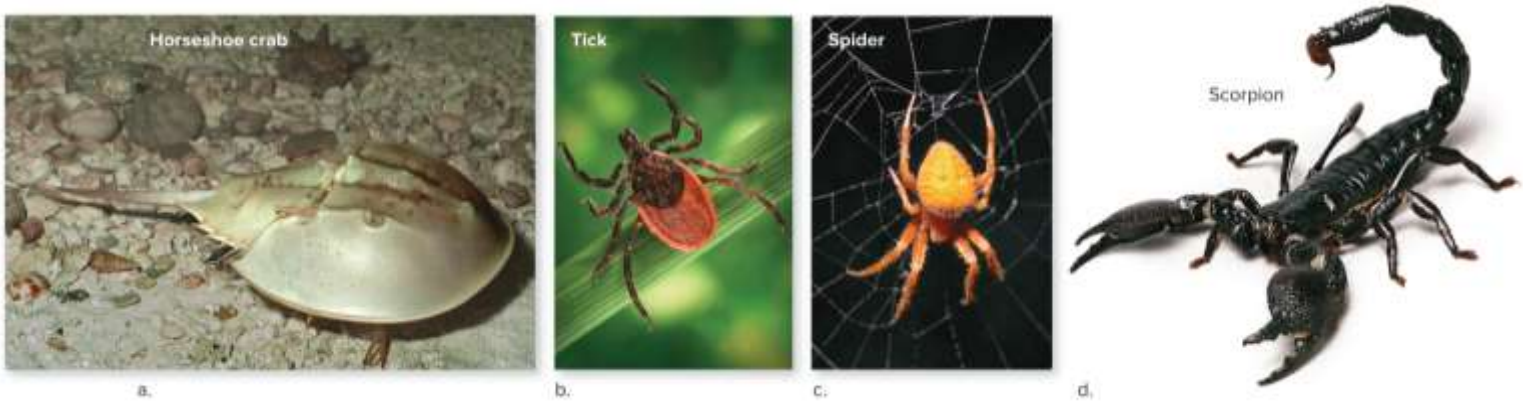


Figure 21.18

Chelicerates are spiders and their relatives

Chelicerates include horseshoe crabs, mites, ticks, spiders, and scorpions.

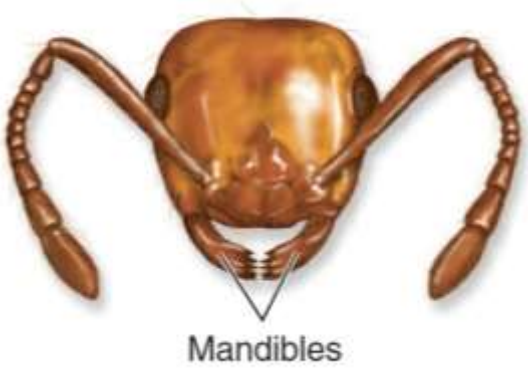
(brow): ©Ingram Publishing RF; (mite): ©Andrew Syred/Science Source



(a): ©Nature's Images/Science Source; (b): CDC/James Gathany; William Nicholson; (c): ©Corbis RF; (d): ©Digital Vision/Punchstock RF

Figs. 21.18 , 21.21, 21.B

Myriapods are mandibulates



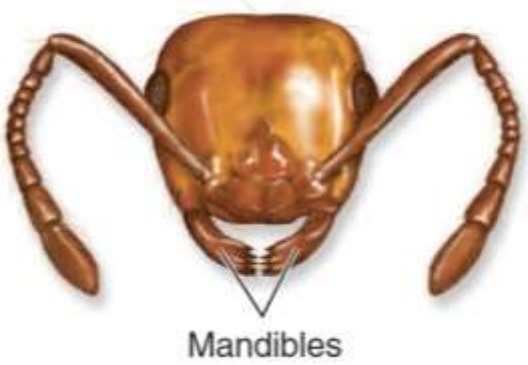
a. Myriapods

Millipedes and **centipedes** (myriapods) make up one group of mandibulates. The head has jaws and antennae; the rest of the body has pairs of legs.

Crustaceans are mandibulates

Crustaceans include crabs, shrimp and lobsters. Their bodies vary, but all have two pairs of antennae

Insects are mandibulates



There are millions of **insect** species. They each have one pair of antennae, six legs, and (usually) two pairs of wings.

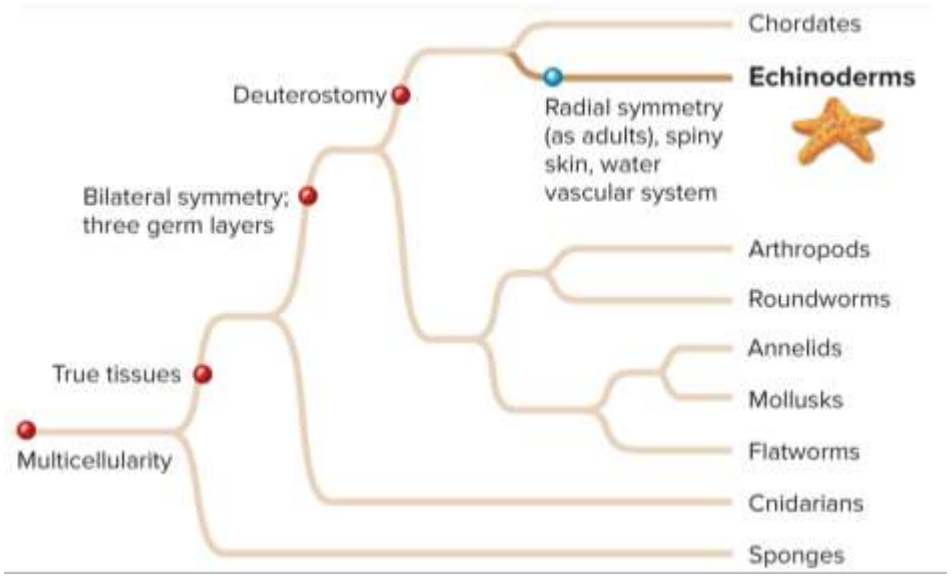
(c, cicada): ©Rob Crandall/Shutterstock RF; (c, dragonfly): ©Thomas Shahan/Flickr/Getty Images

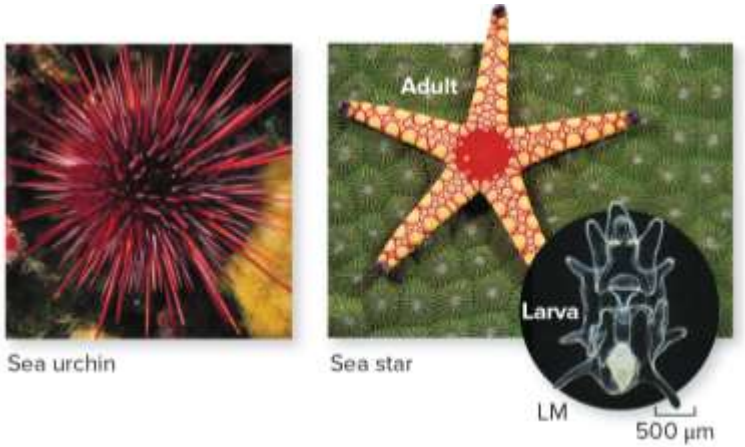
(c, beetle): USDA/Scott Bauer; (c, moth): ©Steven P. Lynch RF

Echinoderms are marine deuterostomes

Echinoderms include sea urchins, sea stars, and sea cucumbers.

They are most closely related to chordates.





Sea urchin Sea star

(sea urchin): ©Andrew J. Martinez/Science Source; (sea star): ©Comstock/Getty Images RF; (larva): ©D P Wilson/age fotostock

Sand dollar Sea cucumber

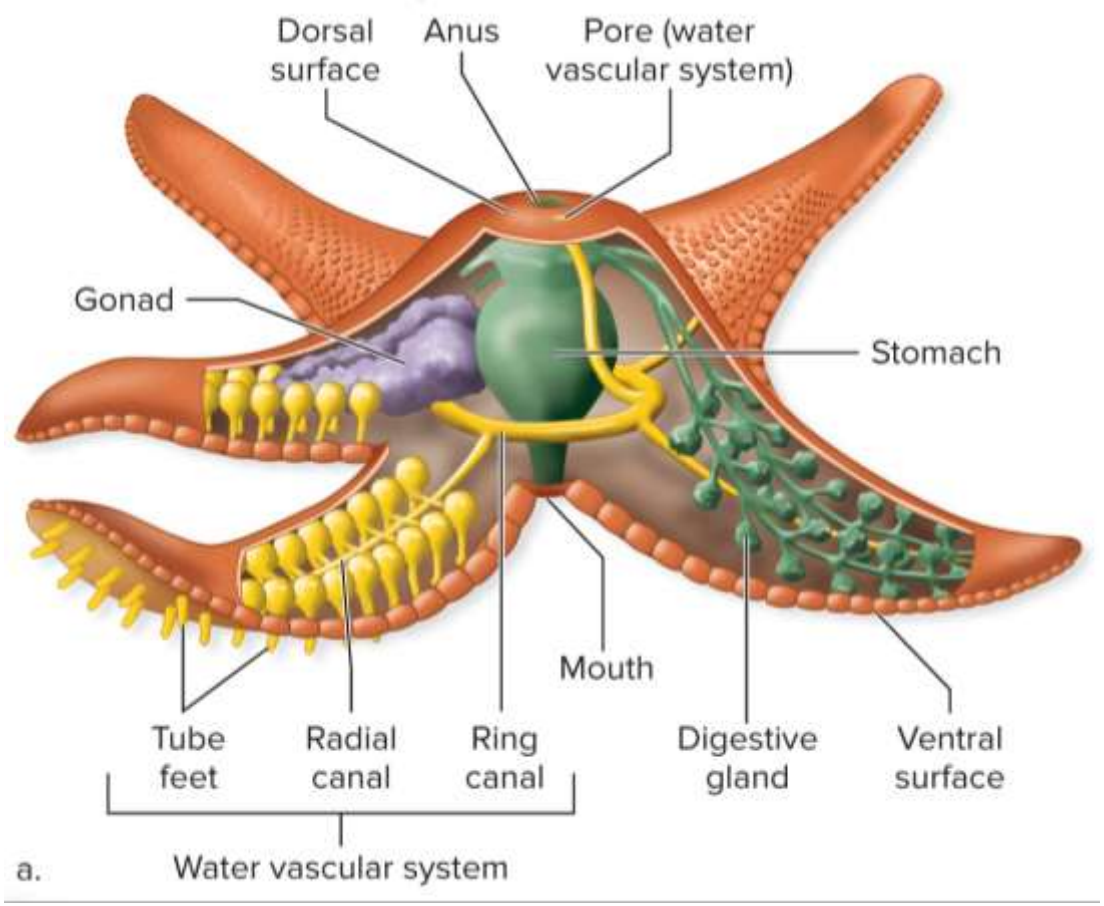
(sand dollar): ©Pat Bonish/Alamy; (sea cucumber): ©Nancy Sefton/Science Source

Echinoderm adults have radial symmetry

Larval echinoderms are bilaterally symmetric.

After metamorphosis, they develop into adults with five-part radial symmetry.

Special features include regeneration and tissues that switch between soft and hard.



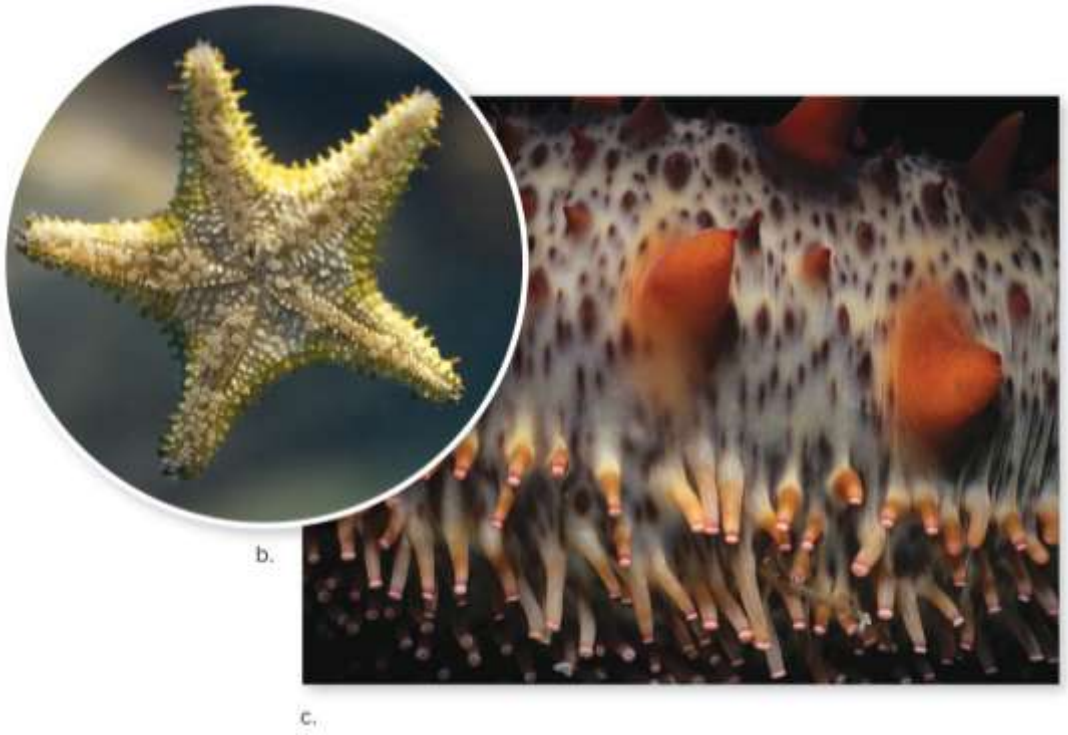
Section 21.9

Figure 21.24

Echinoderms have a water vascular system and tube feet

The **water vascular system** is versatile, fulfilling the functions of a complex circulatory, respiratory, and excretory systems.

Tube feet pump out water and act as locomotion and sensory systems.



(b): ©McGraw-Hill Education; (c): ©Jeff Rotman/Alamy

Chordata is the ninth animal phylum

Phylum Chordata is made up of **chordates**.

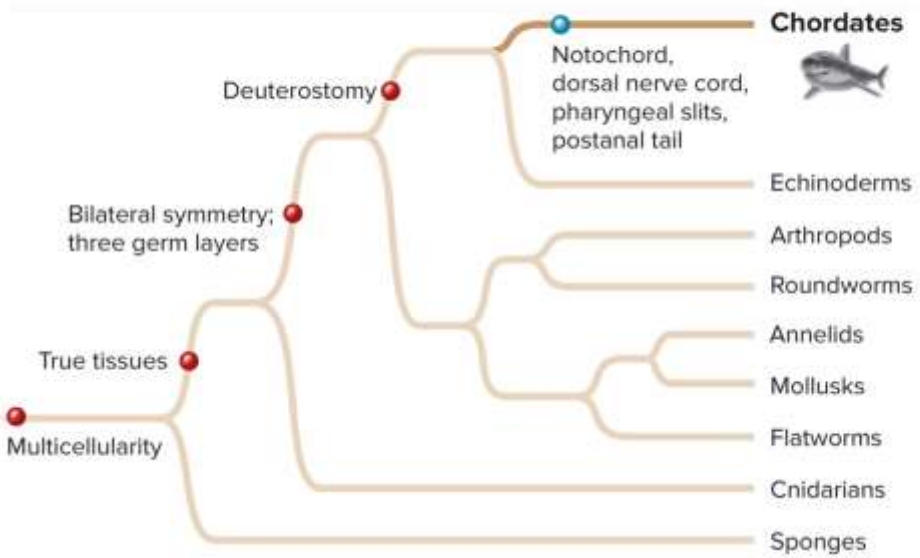


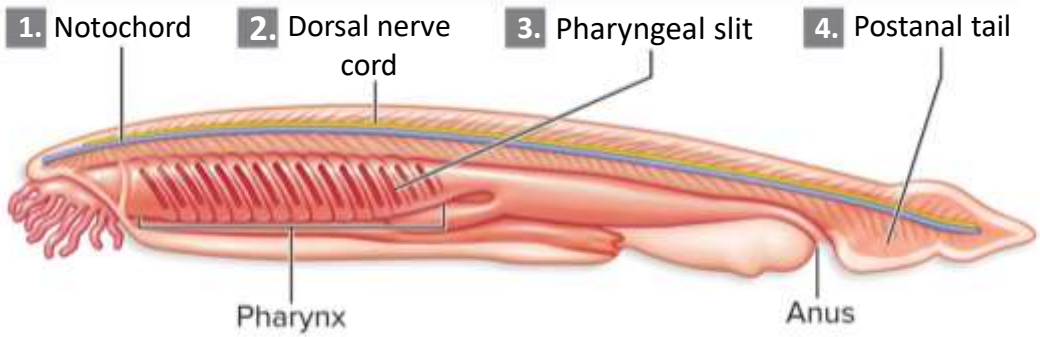
TABLE 21.2 Major Taxonomic Groups in Phylum Chordata

Group	Examples	Approximate Number of Species
Tunicates (subphylum Urochordata)	Sea squirt	3000
Lancelets (subphylum Cephalochordata)	Amphioxus	30
Hagfishes and lampreys (superclass Agnatha)	Slime hag, sea lamprey	70 (hagfishes) 38 (lampreys)
Cartilaginous and bony fishes (superclass Osteichthyes)	Shark, salmon, lungfish, coelacanth	30,000
Amphibians (class Amphibia)	Frog, salamander, caecilian	6000
Reptiles (class Reptilia and class Aves)	Turtle, lizard, snake, tuatara, crocodile, chicken, ostrich	8000 to 10,000 (nonavian reptiles) 9000 to 10,000 (birds)
Mammals (class Mammalia)	Platypus, kangaroo, dog, whale, human	5800

Section 21.10

Figure 21.25
Table 21.2

All chordates share four features



Every chordate expresses each feature at some point during its life, since they are inherited from a common ancestor.

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Some chordates are invertebrates

Tunicates, lancelets, and hagfish are invertebrate chordates.

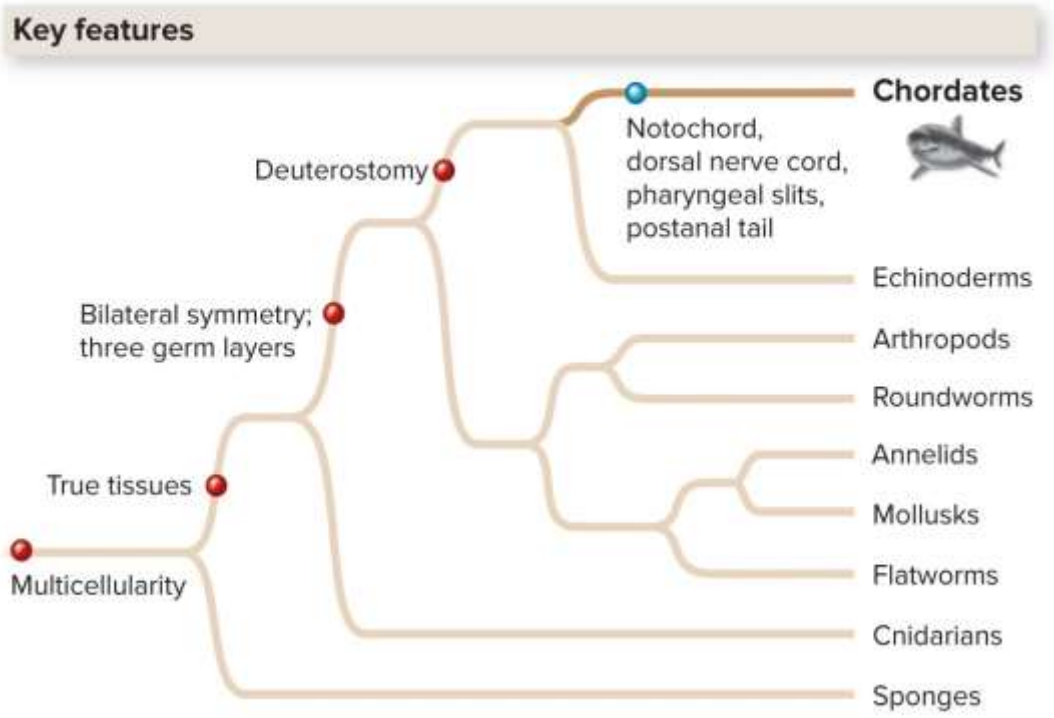

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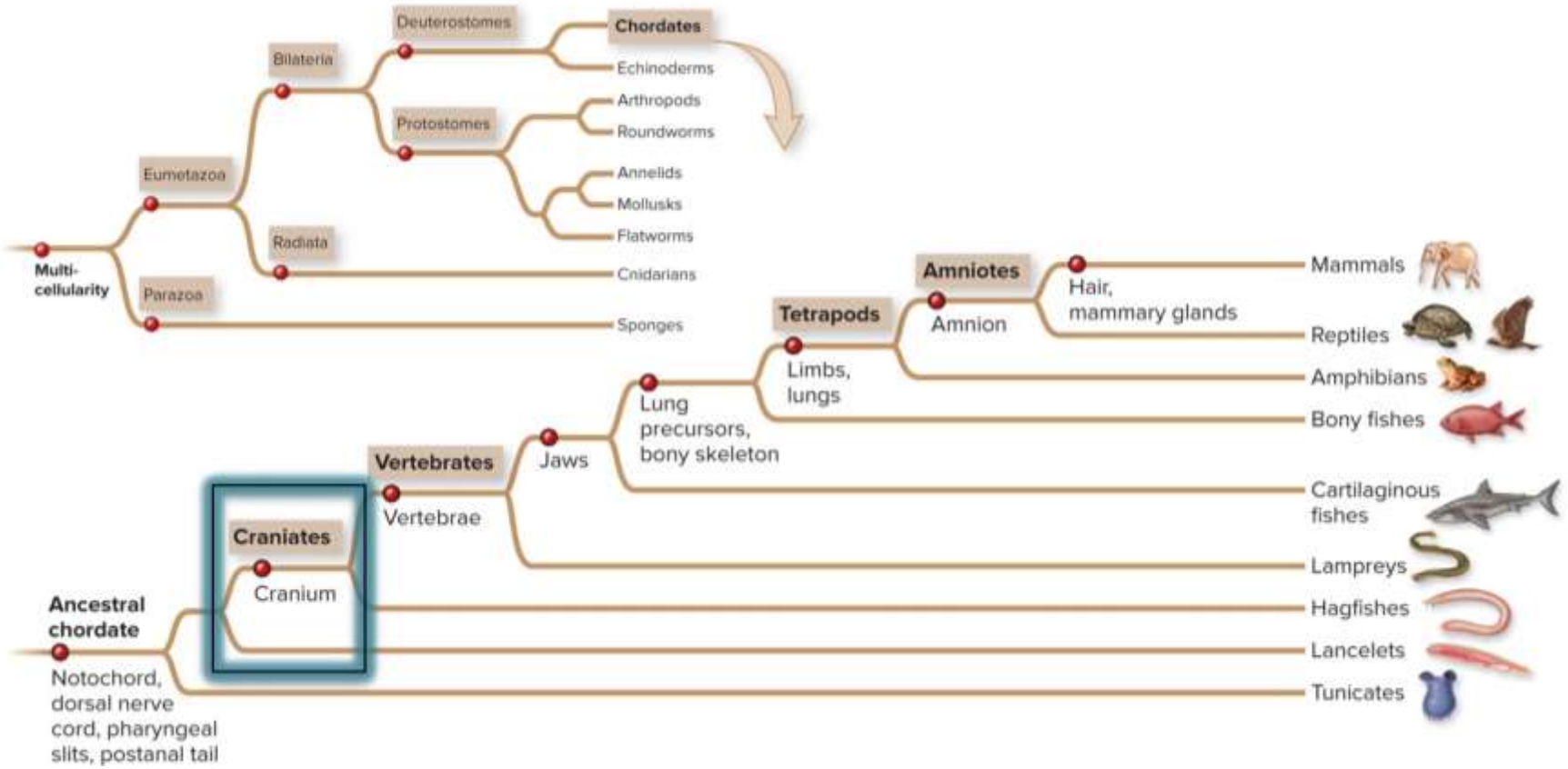
Figure 21.25
Table 21.2

Some chordates have a cranium

Vertebrates and hagfishes have a **cranium**, a bony or cartilage-rich case that protects the brain.

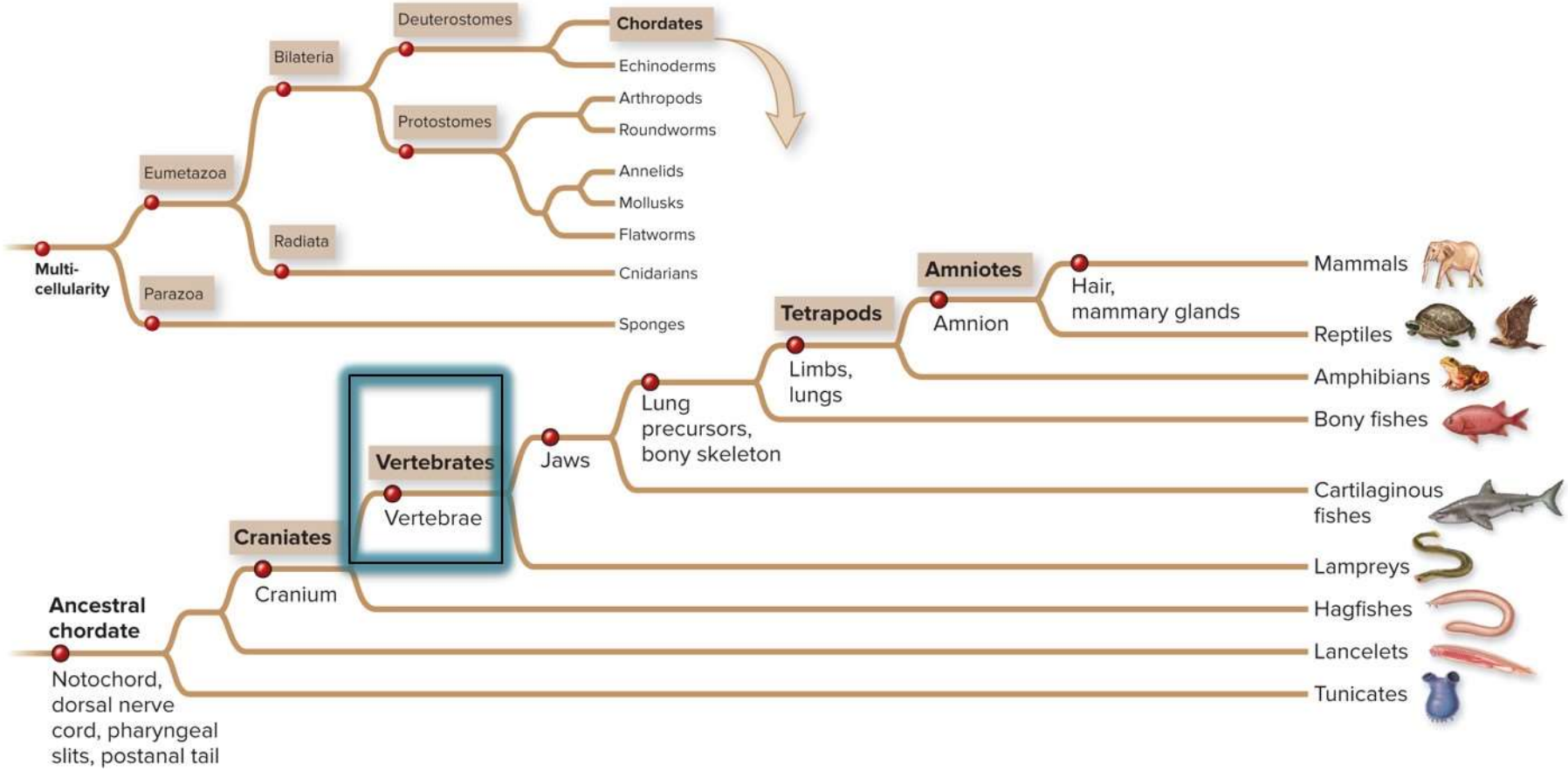


Section 21.10

Figure 21.26

Some chordates have vertebrae

Vertebrates have a series of small structures making up a backbone to protect the spinal column.

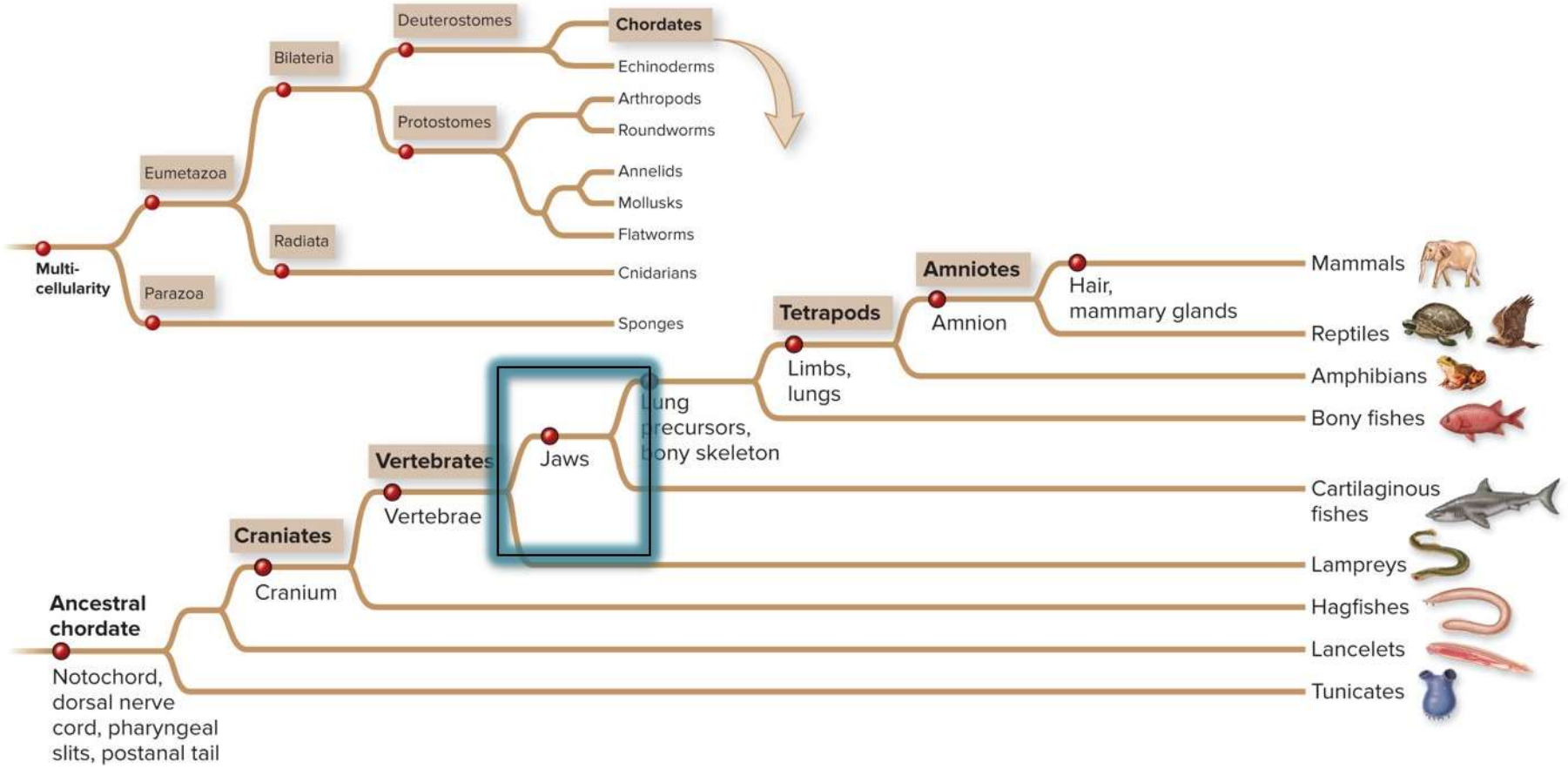


Section 21.10

Figure 21.26

Some chordates have jaws

Fishes, amphibians, reptiles, and mammals have hinged jaws that frame the mouth

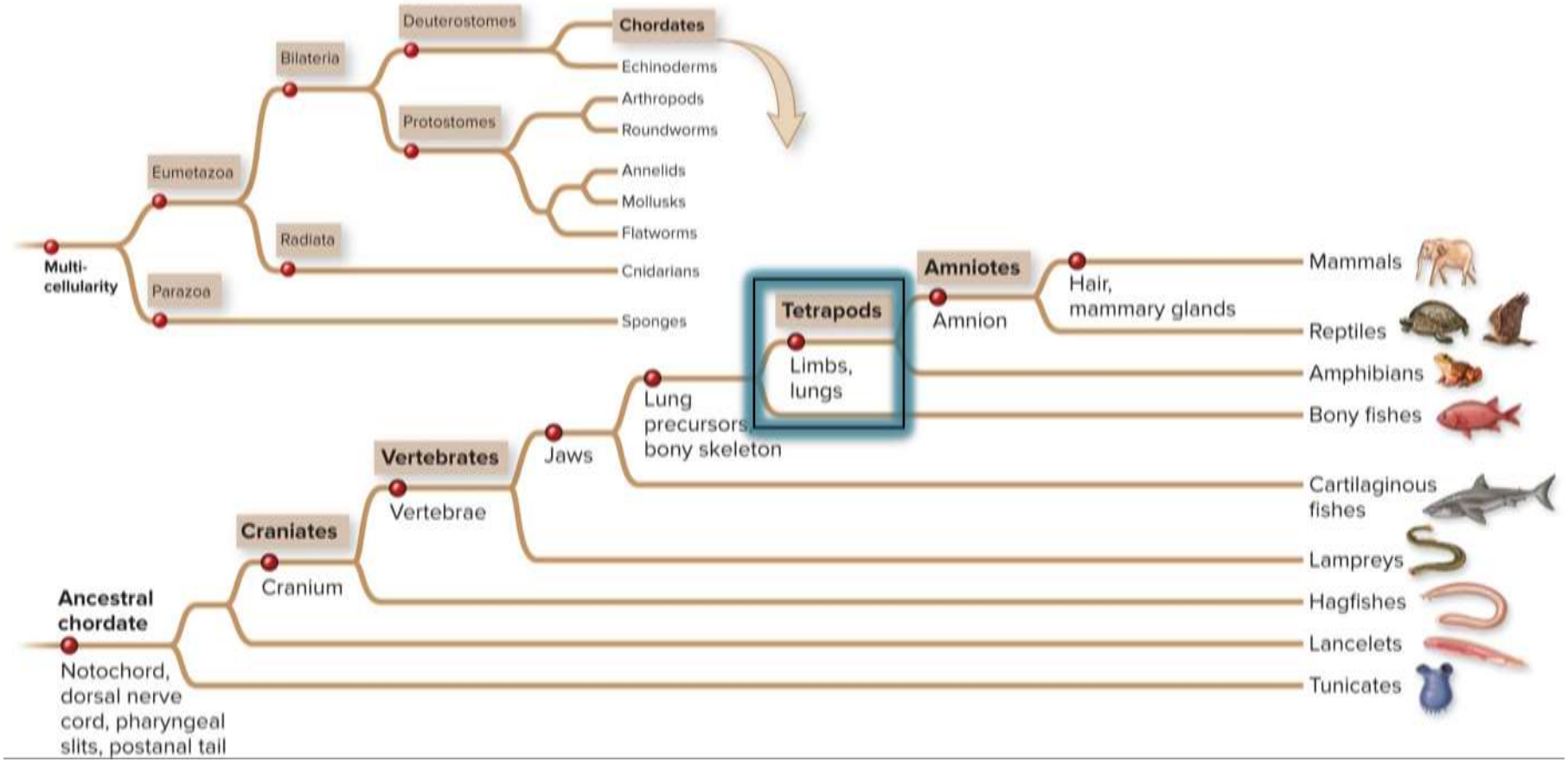


Section 21.10

Figure 21.26

Some chordates have limbs and lungs

Most fishes have gills; amphibians, reptiles, and mammals have lungs for gas exchange.

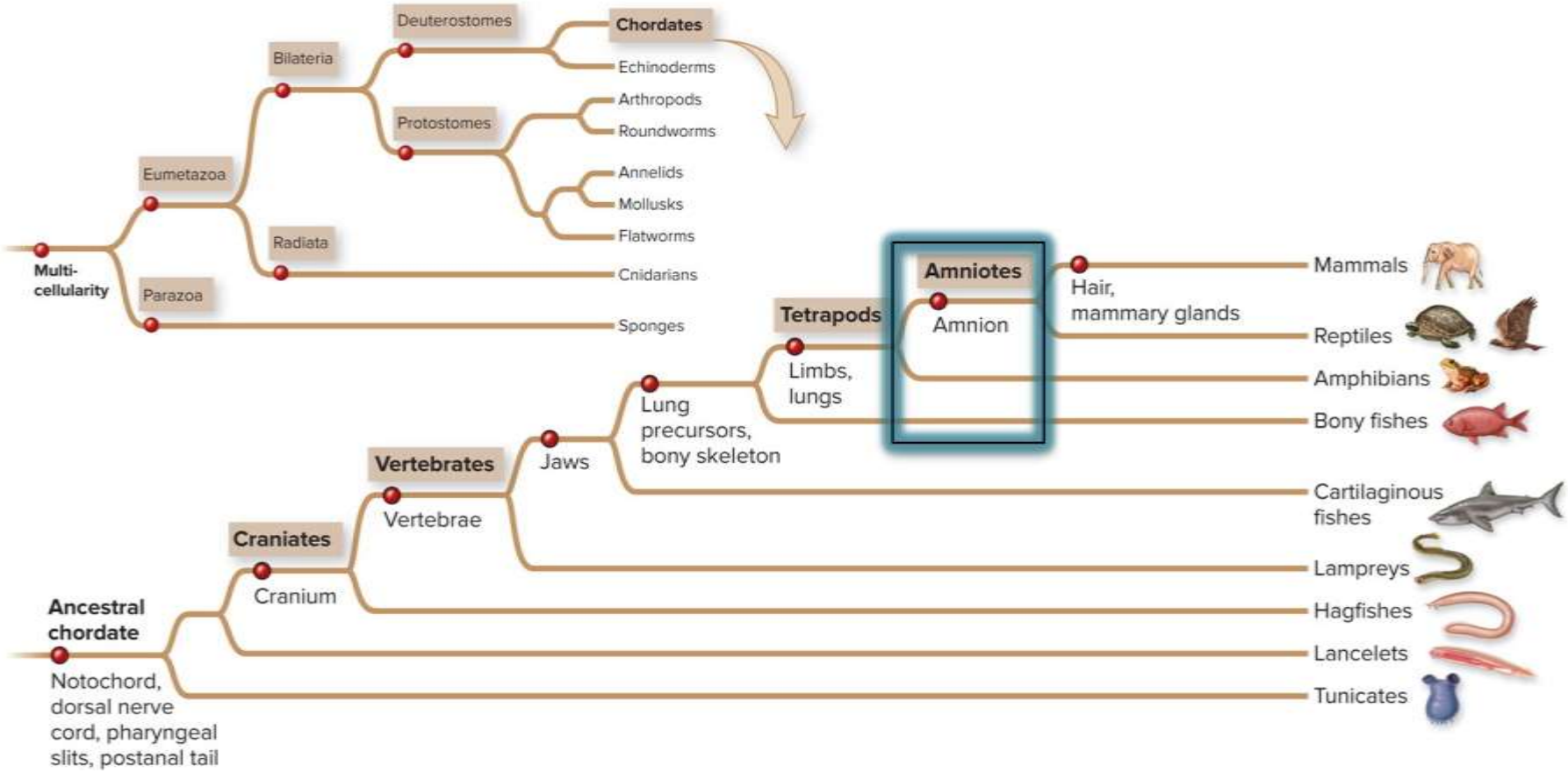


Section 21.10

Figure 21.26

Some chordates have an amnion

Reptiles and mammals have several membranes that surround, protect, and feed their developing embryos

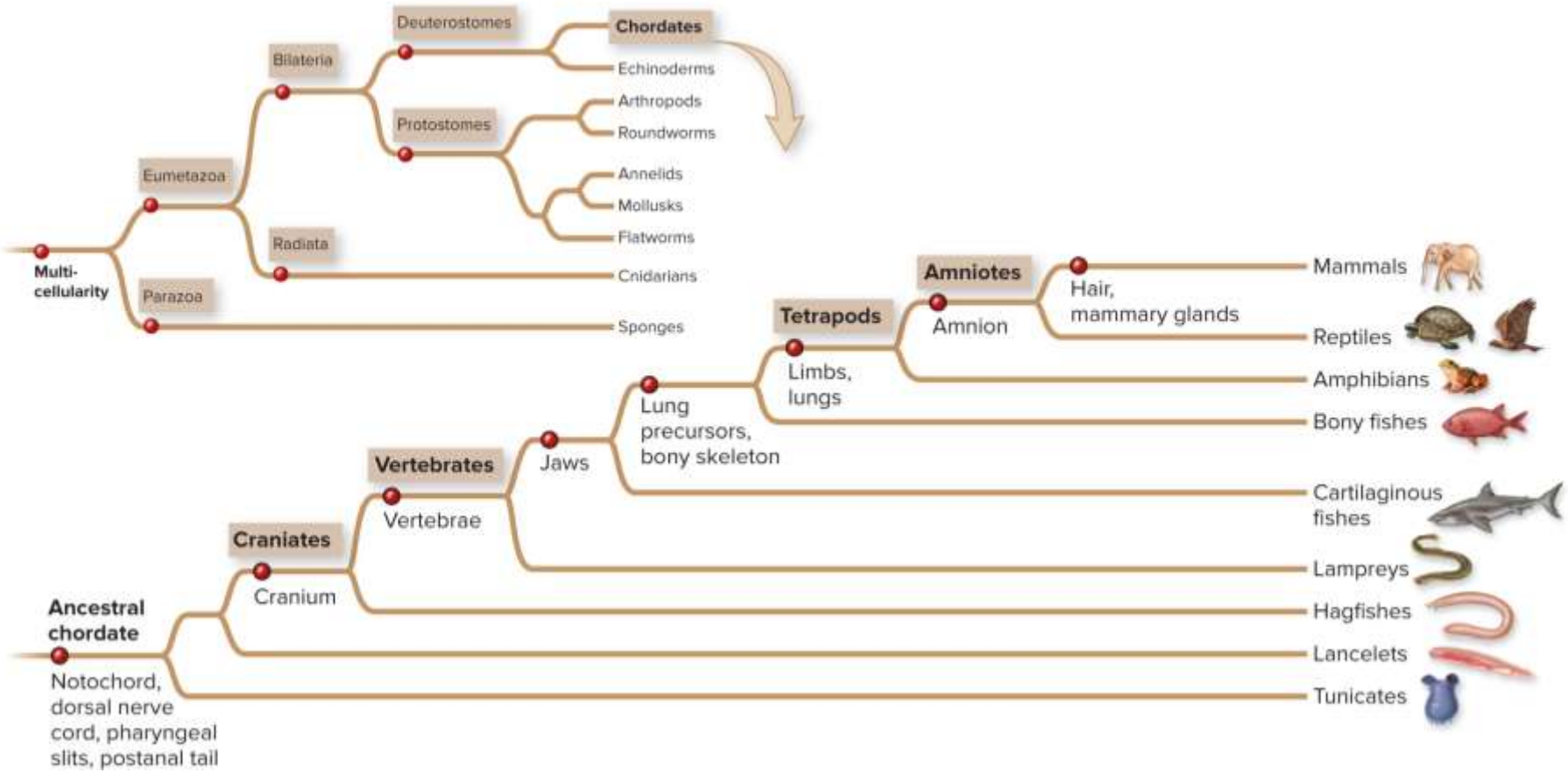


Section 21.10

Figure 21.26

Other features reveal chordate evolution

Body coverings, thermoregulation, and heart chambers are also used to classify chordates.



Section 21.10

Figure 21.26

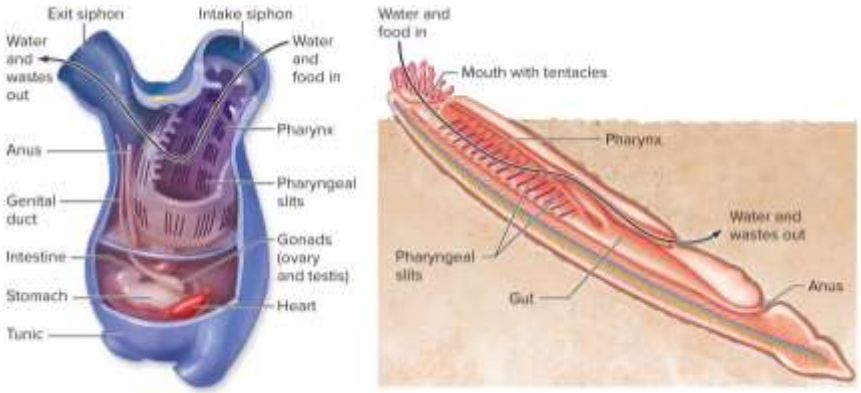
21.2 to 21.10 Mastering concepts

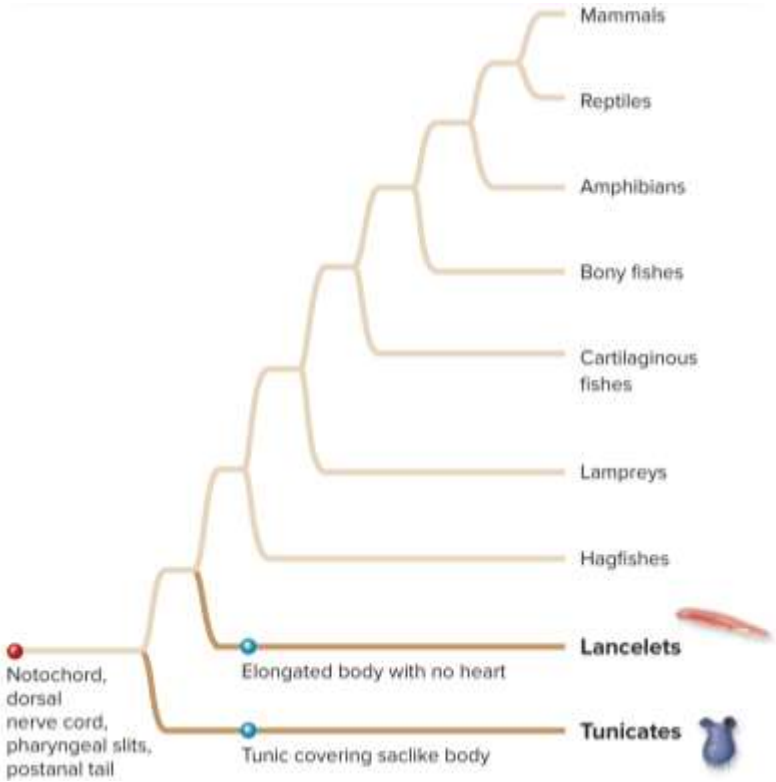
©Michael DeFreitas/robertharding/Getty Images

Make a table comparing the features of each animal phylum.

Tunicates and lancelets resemble ancestral chordates

Tunicates and **lancelets** are chordate subphyla that lack a cranium and vertebrae.



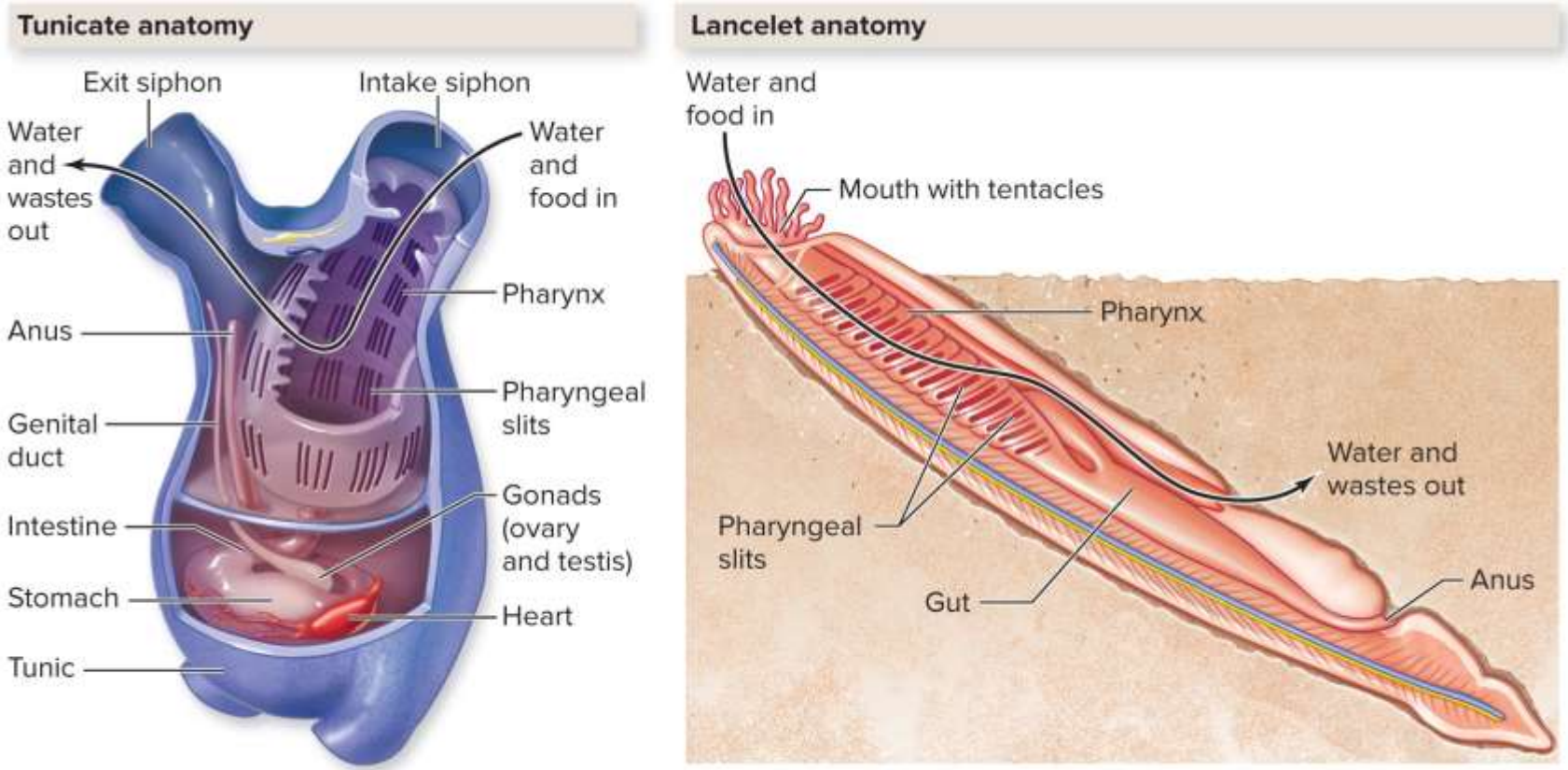


Section 21.11

Figure 21.31

Tunicate and lancelet anatomy is distinct

Tunicate larvae are free swimming; adults are sessile.
Lancelets filter-feed with their tails buried in the sediment.



(blue tunicate): ©Nancy Sefton/Science Source; (orange tunicates): ©Janna Nichols; (lancelet): ©Natural Visions/Alamy

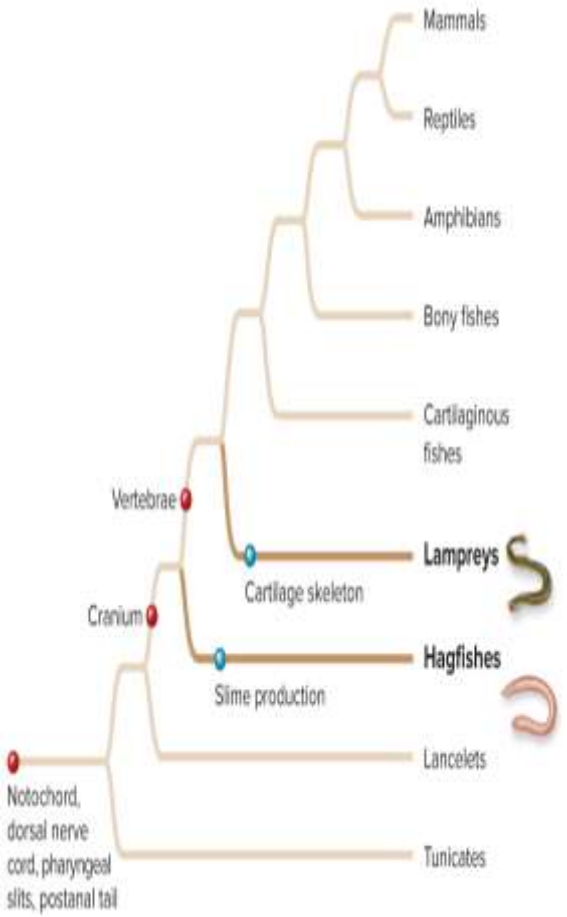
Section 21.11

Figure 21.31

Hagfishes and lampreys are craniates without jaws

A **hagfish** is a marine invertebrate with a cranium. Hagfishes secrete sticky slime, which helps them slide their bodies out of danger.

Lampreys have cartilage around their nerve cord, so they are the first animals to evolve vertebrae.



Section 21.12

Figure 21.32

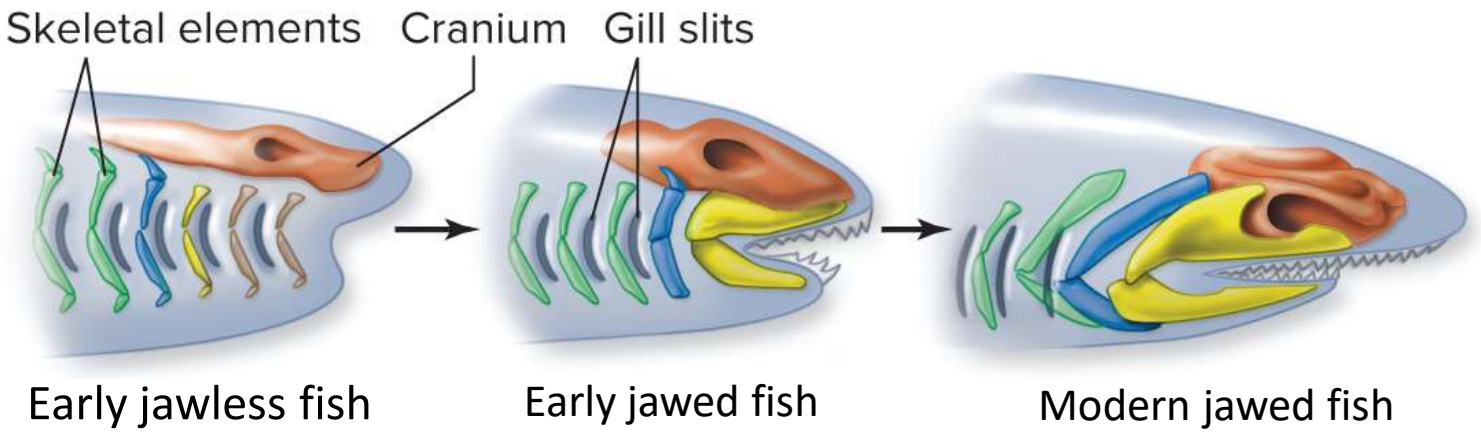
Hagfishes and lampreys have long, slender bodies

Hagfish have cartilage surrounding the brain but not the nerve cord.

Some lampreys use mouth suckers to attach themselves to the sides of fish and drink the blood.

(hagfish mouth): ©Steven Senne/AP Images; (hagfish): ©Mark Conlin/Alamy; (lamprey): ©David Hosking/Alamy; (lamprey mouth): ©Russ Kinne/Science Source

How did jaws develop?

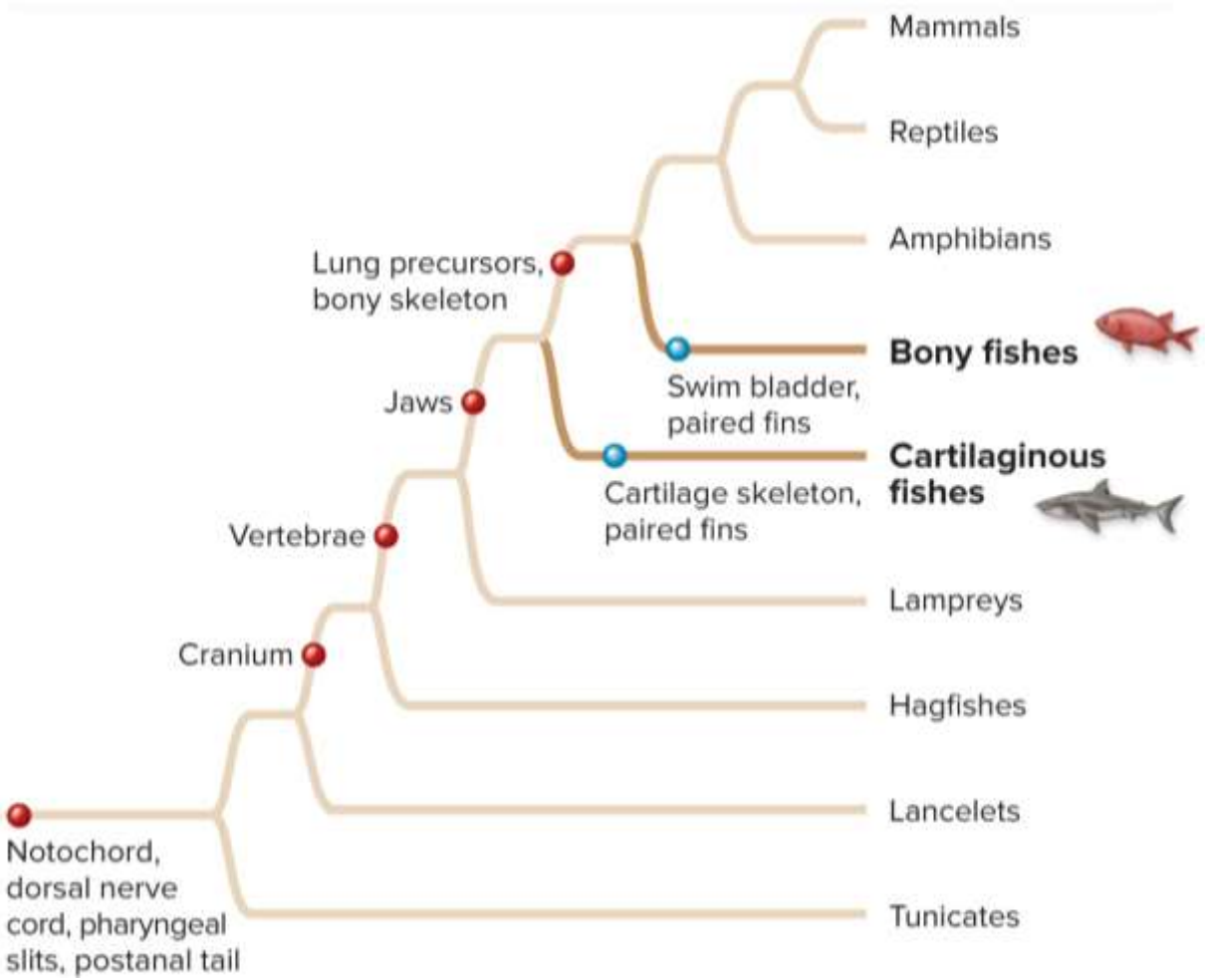


Jaws can include teeth or a beak, and greatly expand the ways vertebrates can eat. In very early fishes, the skeletal elements that supported gill slits near the mouth may have developed into jaws.

Fishes are aquatic vertebrates with jaws

Fishes originated about 500 MYA from an ancestor that had jaws, gills, and paired fins.

Fishes are the most diverse and abundant vertebrates.



Section 21.13

Figure 21.33

Some fishes are cartilaginous

The most ancient fishes have skeletons made of cartilage. Sharks, rays, and skates are examples.

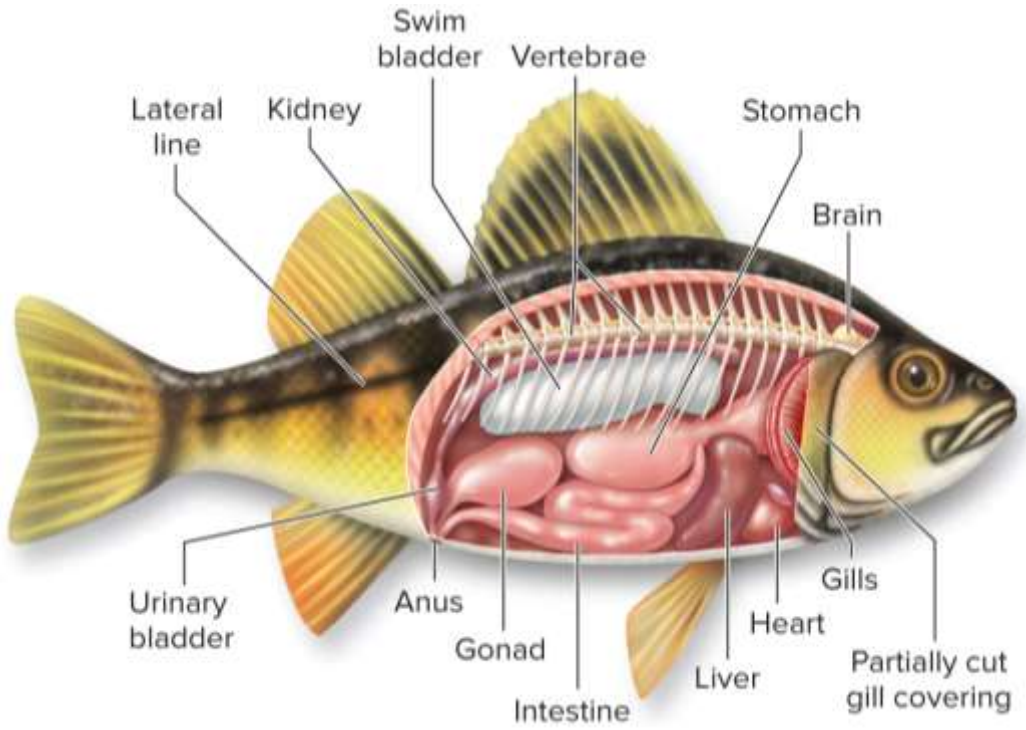
Stingray (cartilaginous fish)

Shark (cartilaginous fish)

(shark): ©Michele Westmorland/Getty Images RF: (snappers): ©Corbis RF

Along their sides, they have sense organs called **lateral lines** for detecting vibrations.

Bony fishes have skeletons of bony tissue



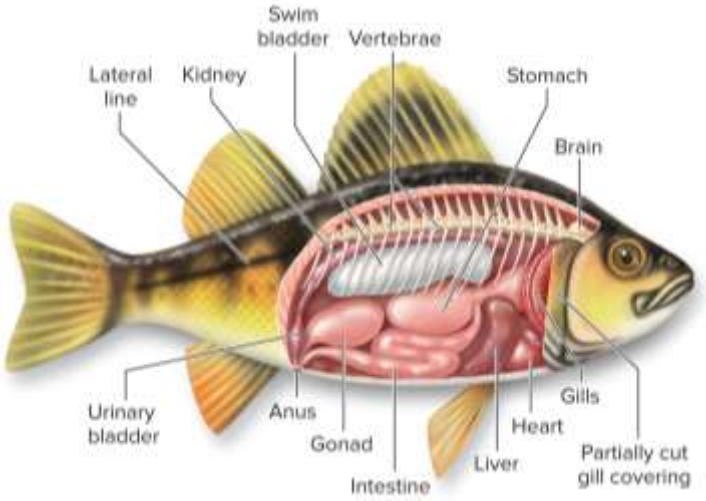
Unique features of bony fishes include hinged gill coverings and a swim bladder they use to adjust their buoyancy.

Like cartilaginous fishes, bony fishes have a lateral line system.

Section 21.13

Figure 21.34

Bony fishes include two main lineages



Ray-finned fishes are the most familiar fishes – trout, tuna, eels, etc.

Lobe-finned fishes are most closely related to tetrapods (animals with four limbs).

Ray-finned fish (bony fish)

Lungfish (bony fish)

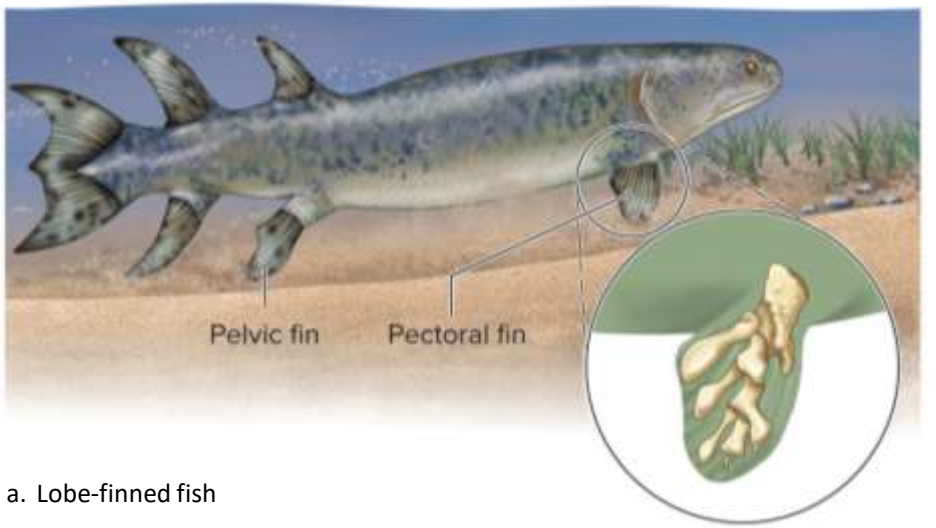
Coelacanth (bony fish)

(ray): ©MedioImages /SuperStock RF; (lungfish): ©Peter E. Smith/Natural Sciences Images Library; (coelacanth): ©Peter Scoones/Planet Earth Pictures/Getty Images

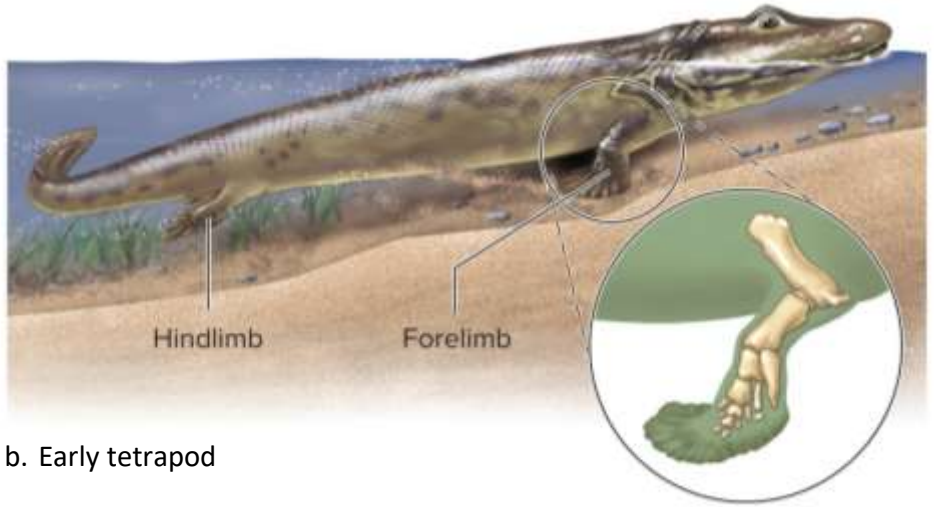
Fishes changed vertebrate evolution

Adaptations for surviving on land first arose in lobe-finned fishes.

- Lungs developed from the swim bladder in a few species known as lungfish.
- Strong pectoral and pelvic fin bones are the precursors for limb bones.



a. Lobe-finned fish

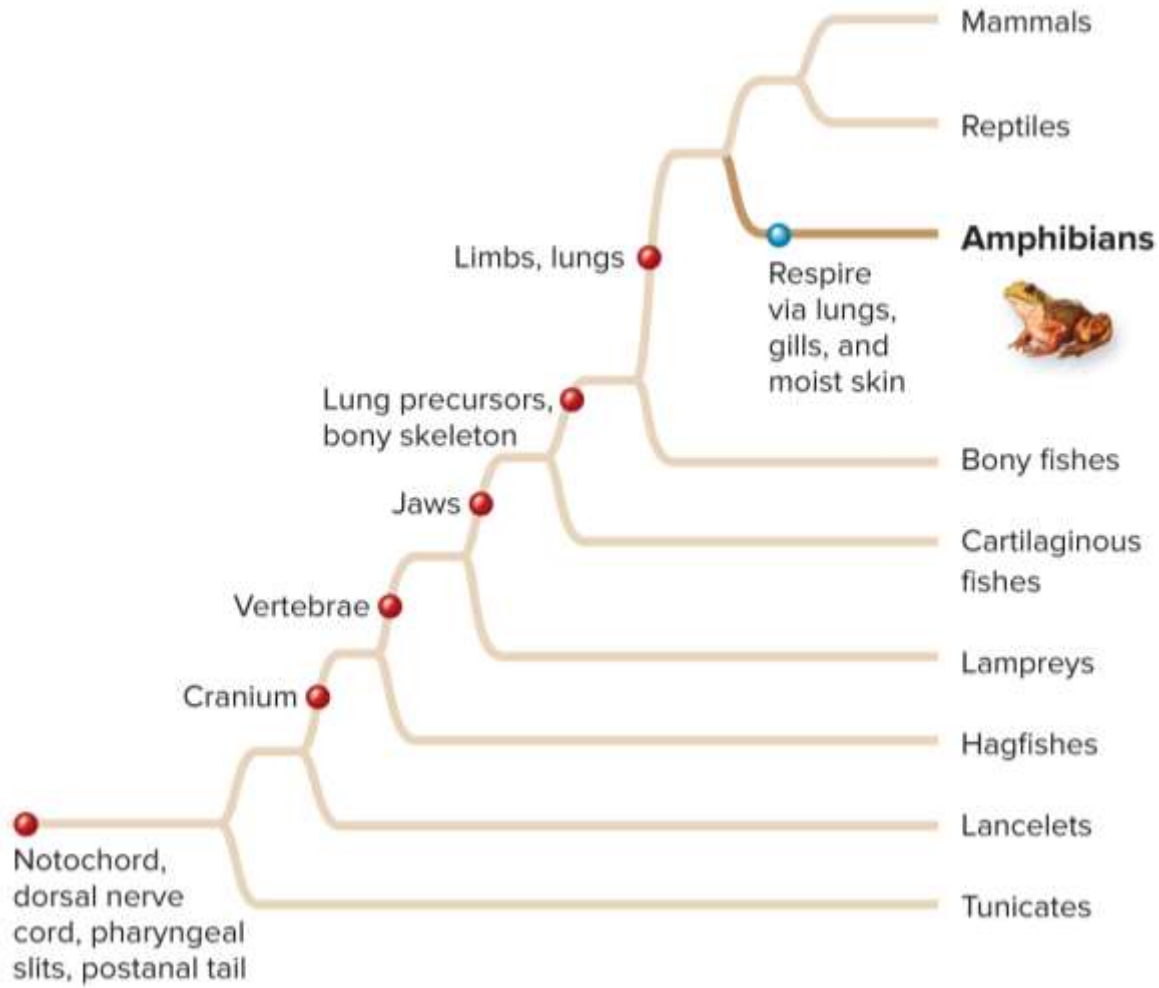


b. Early tetrapod

Amphibians were the first tetrapods

Lungs and limbs facilitated amphibians' move to land. Their eggs must remain moist, so amphibians retain a strong link to water.

(frog): ©Creatas/PunchStock RF; (caecilian): ©E.D. Brodie Jr.; (salamander): ©Suzanne L. Collins & Joseph T. Collins/Science Source



Section 21.14

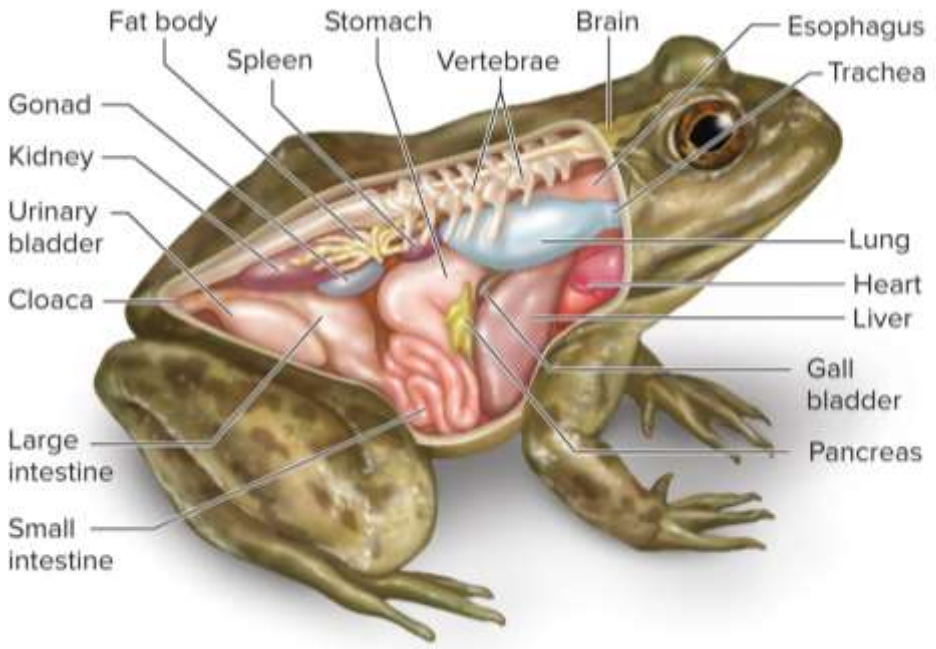
Figure 21.36

Amphibians are adapted to live on land and in water

Improved lungs coupled with porous skin used for breathing

Closed circulatory systems with a three-chambered heart

Denser, stronger skeletons



Section 21.14

Figure 21.37

Amphibians include three main lineages

Most amphibians are **frogs**: either smooth-skinned "true" frogs or warty-skinned toads.

Salamanders and newts resemble lizards.

Caecilians are amphibians that lack limbs and resemble giant earthworms.

Frog

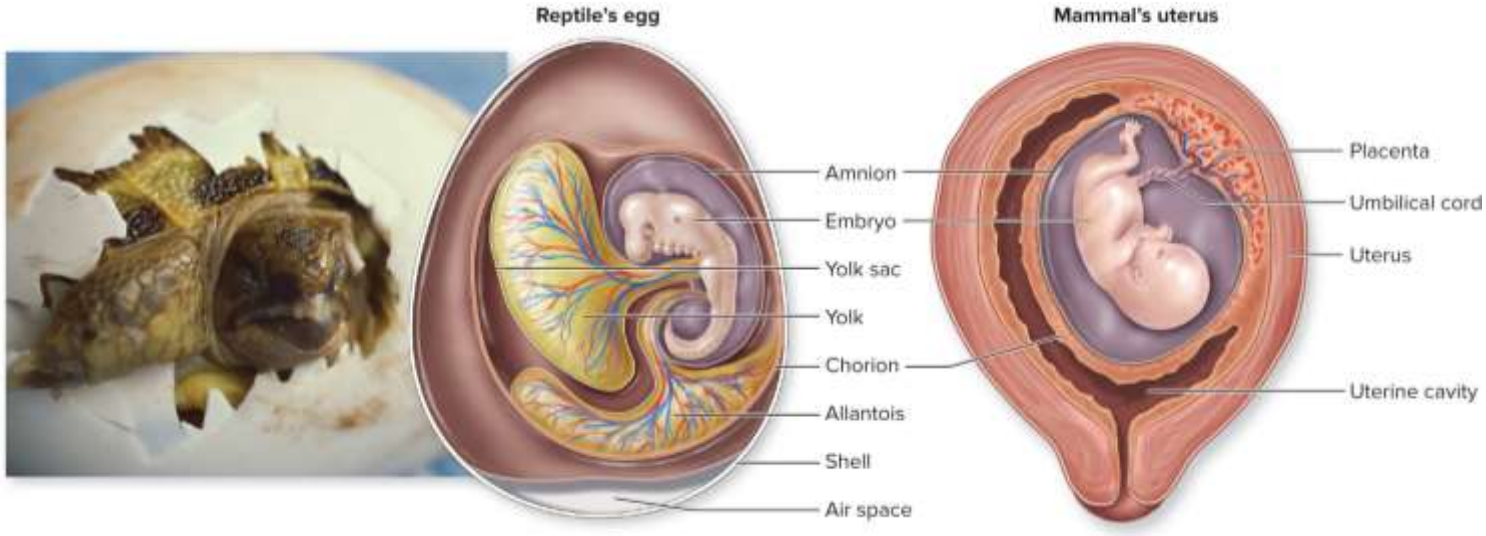
Caecilian

salamander

(frog): ©Creatas/PunchStock RF; (caecilian): ©E.D. Brodie Jr.;
(salamander): ©Suzanne L. Collins & Joseph T. Collins/Science Source

Amniotes include reptiles and mammals

An amniotic egg has a leathery or hard outer layer surrounding a yolk that nourishes the developing embryo. Similar structures surround a mammal's embryo.



©Creatas/PunchStock RF

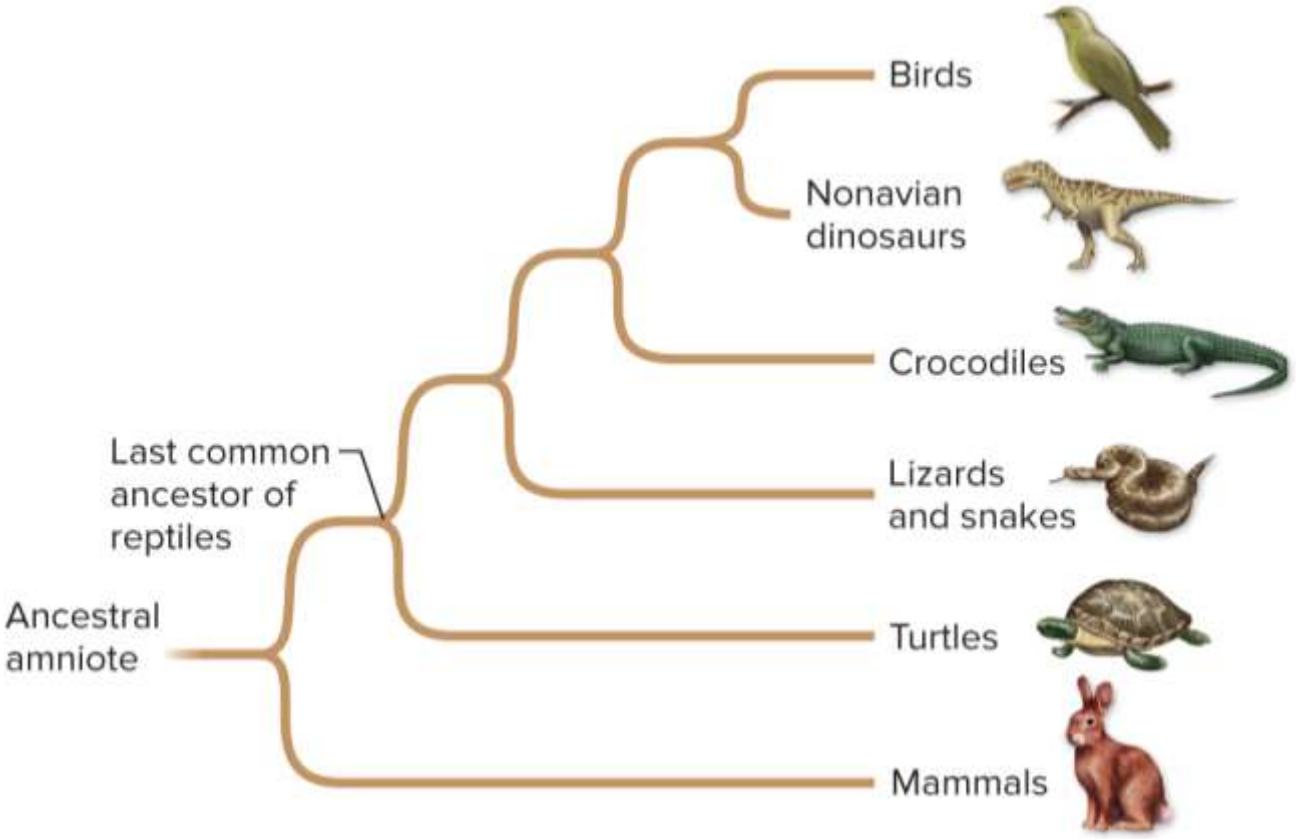
Section 21.15

Figure 21.29

The amniotic egg broke the tie to water

The amnion allows **reptiles** and **mammals** to breed in dry habitats.

Birds are considered a clade of reptiles, although they used to be thought of as a separate group.



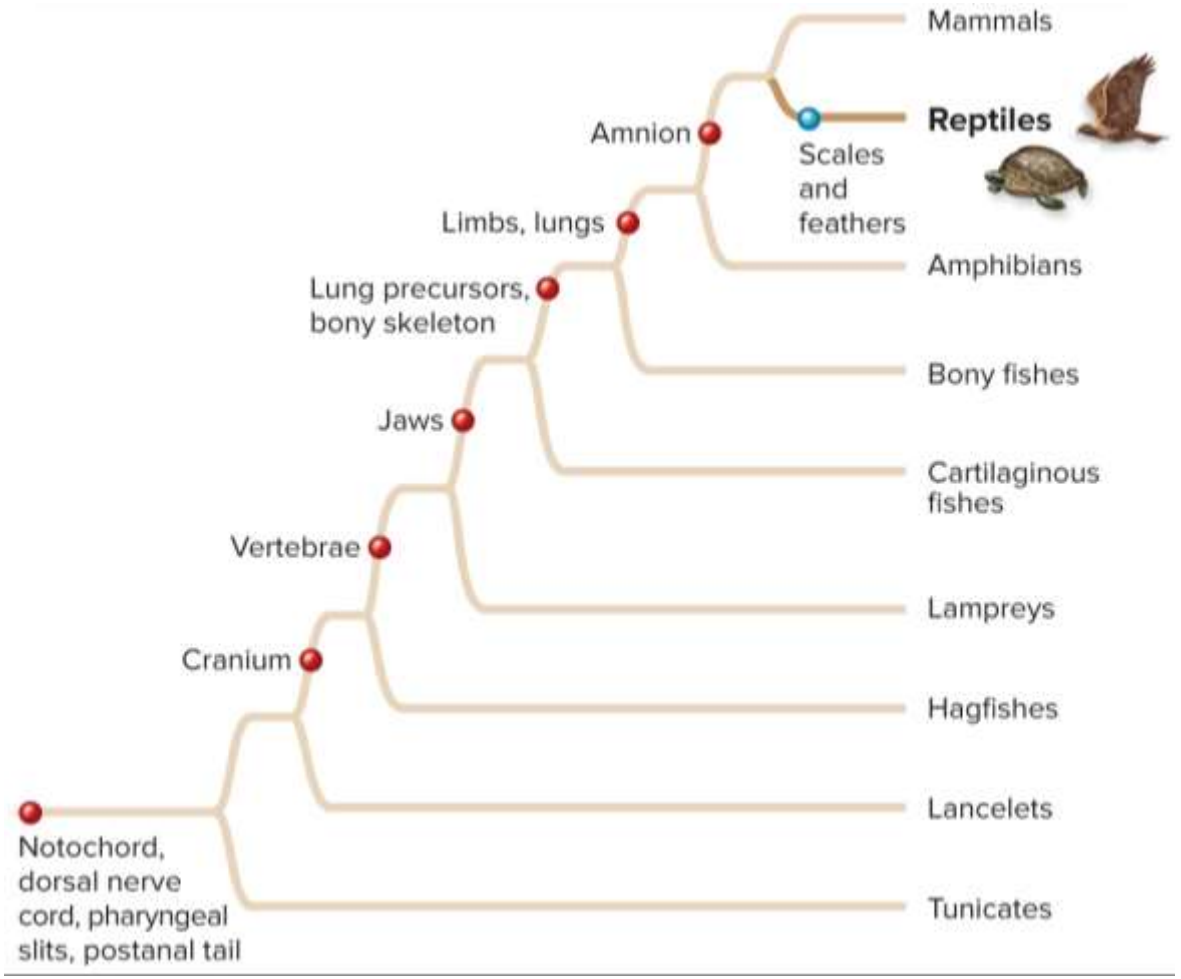
Section 21.15

Figure 21.38

Reptiles were the first vertebrates to thrive on land

Reptiles evolved about 310 MYA. Many reptiles that once dominated the planet are now extinct.

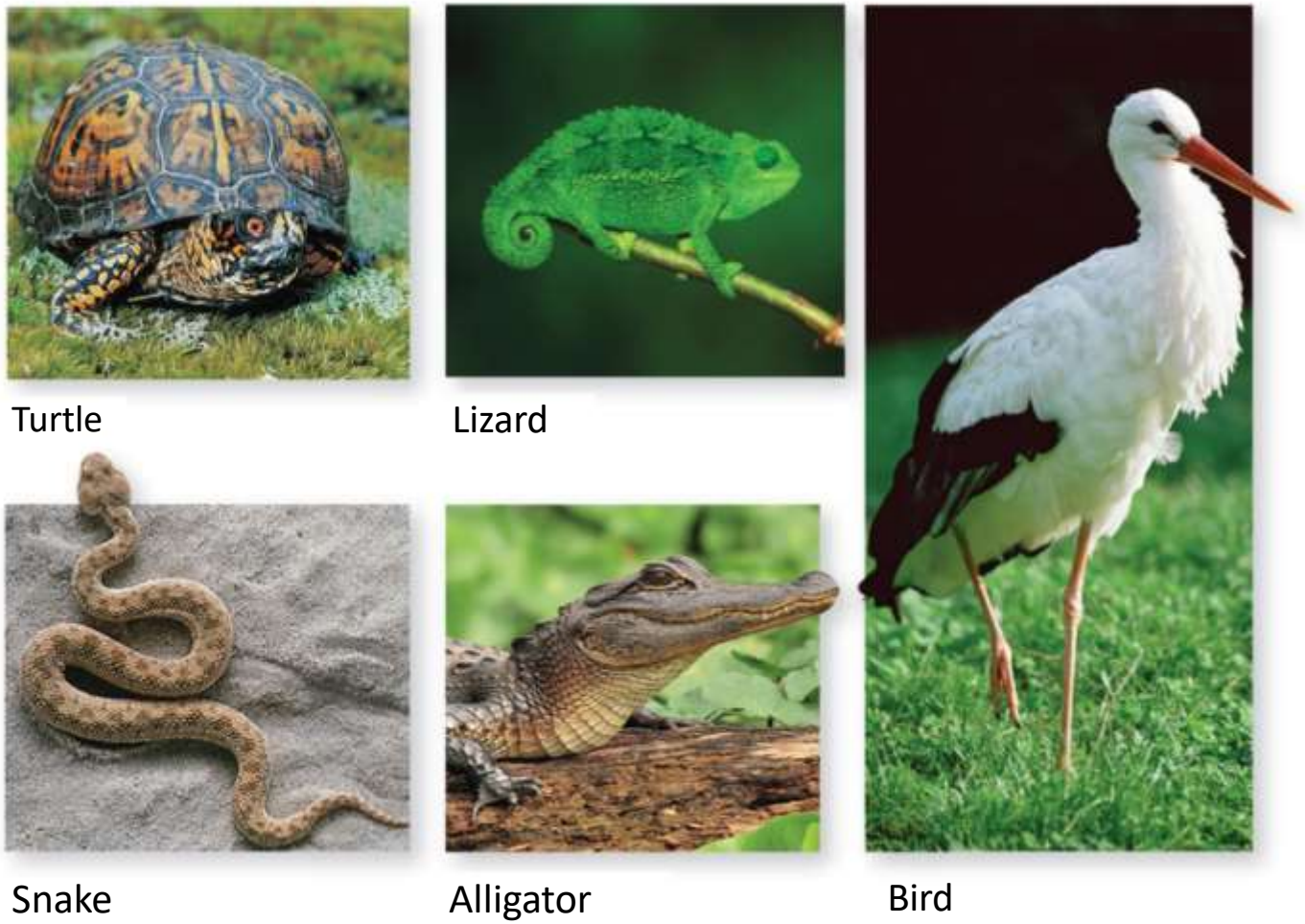
Reptiles are adapted to retain water inside their bodies, and reproduce outside of it.



Section 21.15

Figure 21.40

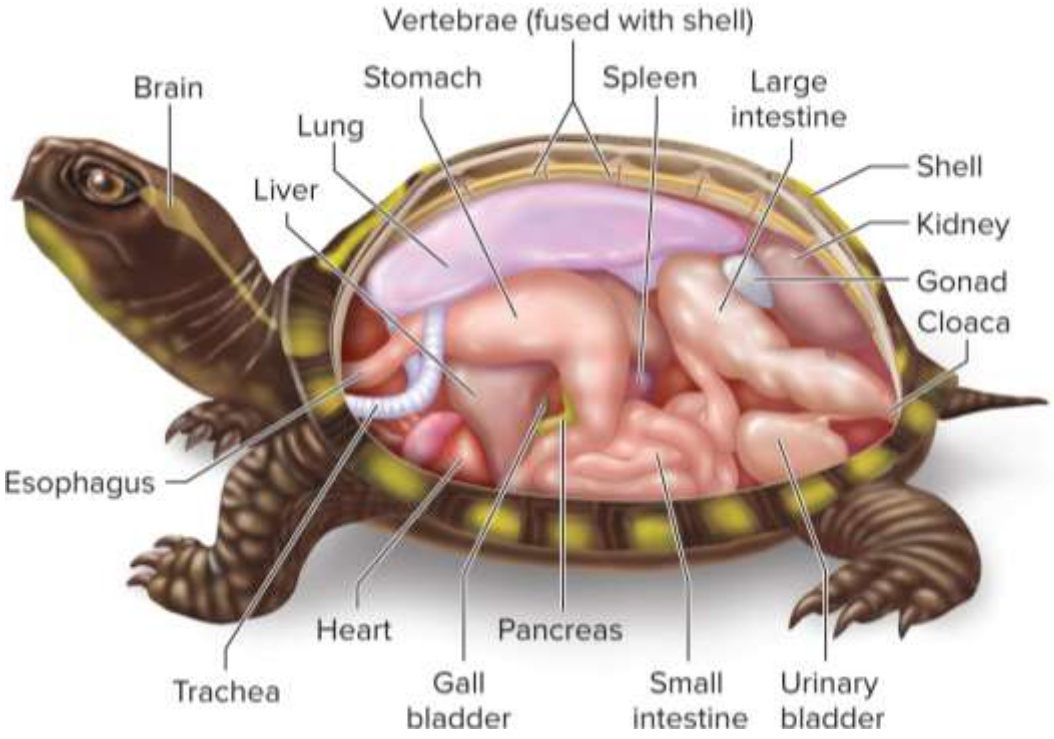
There are five main groups of reptiles



(turtle): ©Ed Reschke/Peter Arnold/Getty Images; (lizard): ©Creatas/PunchStock RF;
(snake): ©Dorling Kindersley/Getty Iamges; (alligator): ©LaDora Sims//Flickr/Getty Images RF; (bird): ©Image Source RF

Turtles and tortoises have a tough shell

Turtles are aquatic whereas tortoises live on land. Their shells are fused with the vertebrae, making it an integral component of the skeleton.



Section 21.15

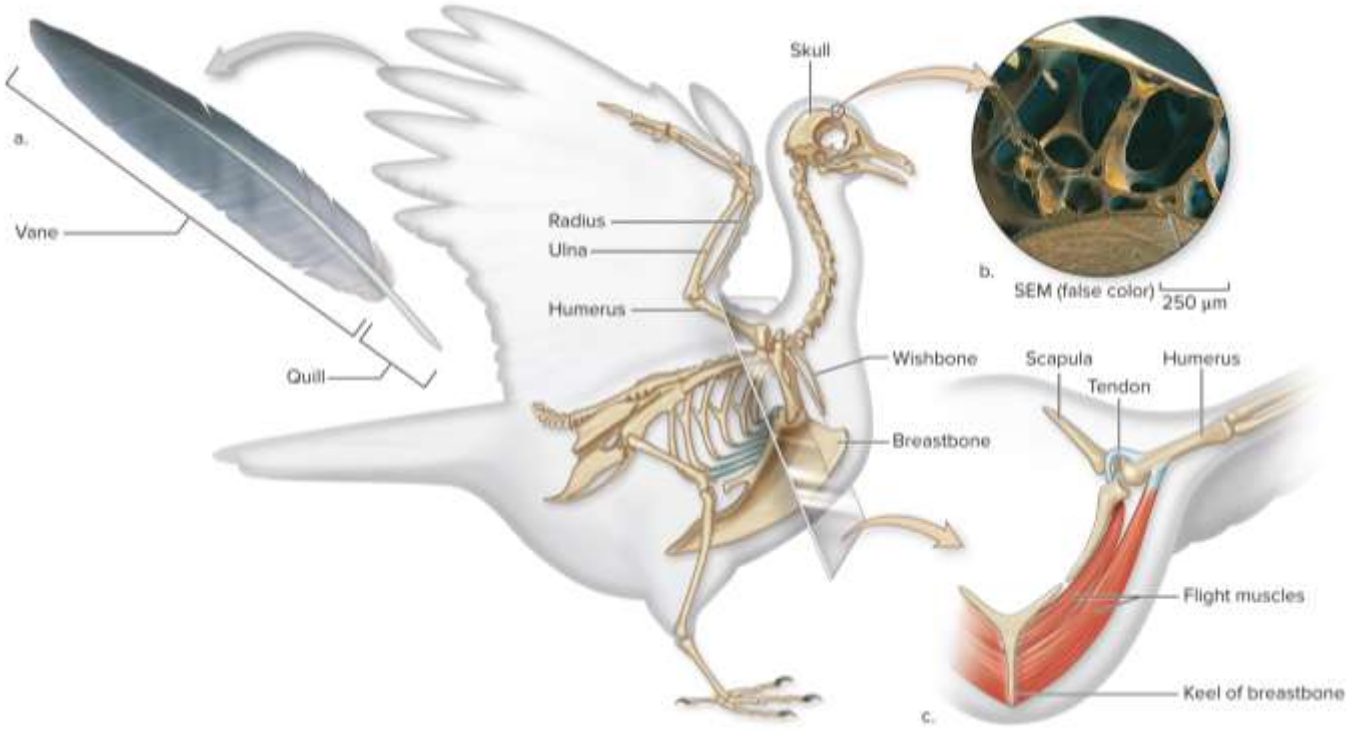
Figure 21.39

Birds are warm, feathered reptiles adapted to flight

Feathers provide lift

Hollow bones keep the body lightweight

Specialized flight muscles attach to the breastbone



(b): ©Meckes/Ottawa/Science Source

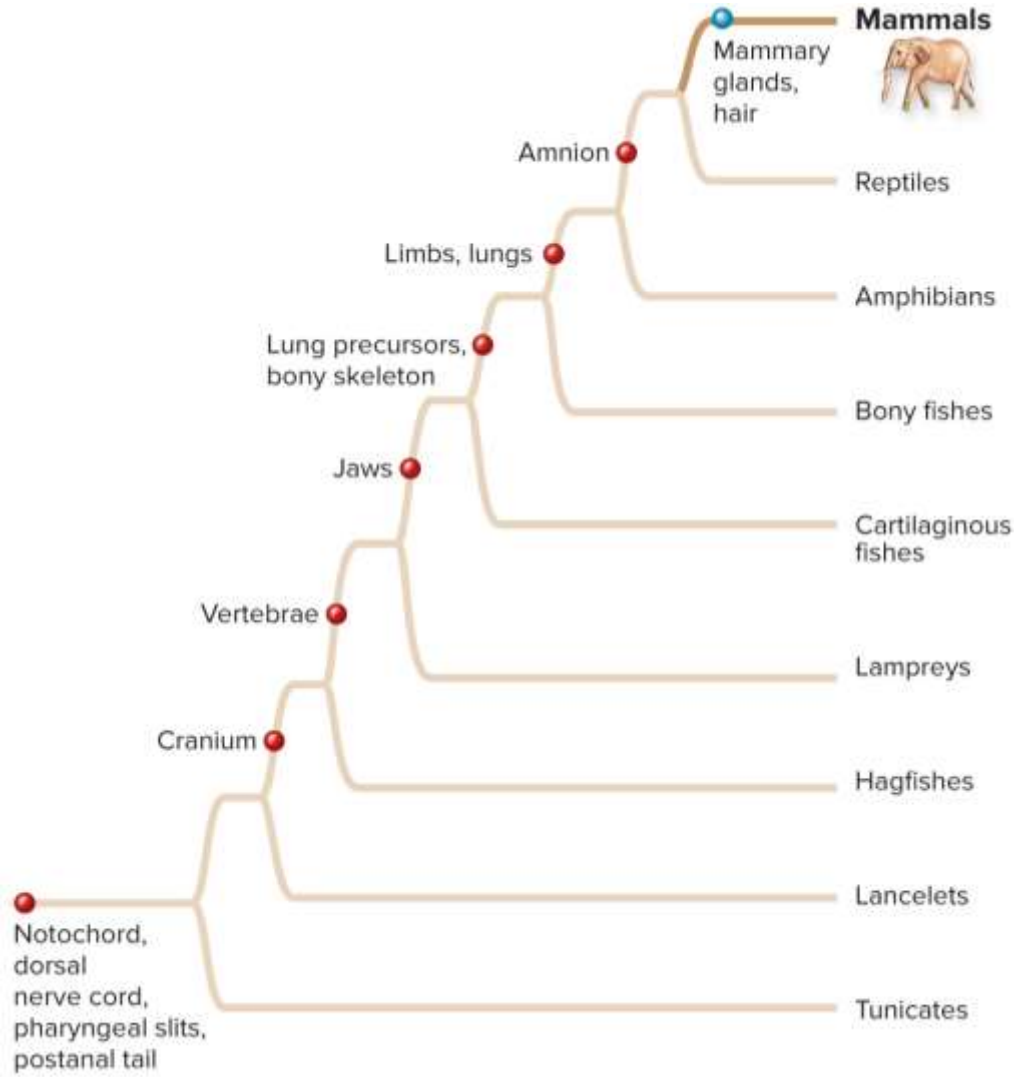
Section 21.15

Figure 21.41

Mammals are warm, furry milk-drinkers

Mammals evolved about 200 MYA.

They are amniotes with hair and milk-secreting mammary glands.



Section 21.16

Figure 21.42

Monotremes are mammals that lay eggs

These animals have distinctive anatomy that is similar to reptiles – the digestive, urinary, and reproductive tracts share a single opening to the outside of the body.

Monotremes

Platypus

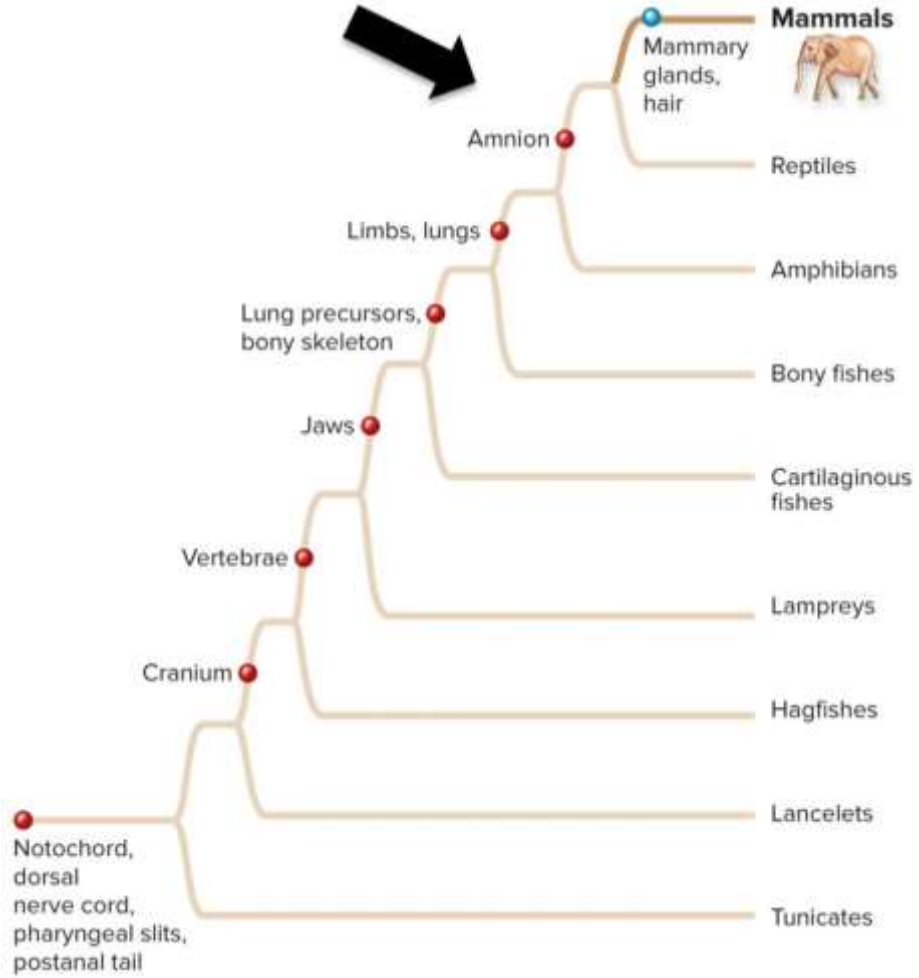
Echidna

(platypus): ©JohnCarnemolla/Getty Images RF; (echidna): ©Paul Hobson/Nature Picture Library;

Mammals and reptiles share a common ancestor

Unique mammal traits arose after mammals and reptiles diverged.

- Mammary glands
- Hair
- Three middle ear bones
- Four types of teeth
- Four chambered hearts
- Muscular diaphragm for breathing
- Large brains



Section 21.16

Figure 21.42

Marsupials are mammals that bear live young

Babies are very tiny at birth and spend additional time developing in a marsupium (pocket).

Marsupials

Kangaroo

Opossum

(kangaroo): ©Anan Kaewkhammul/123RF; (opossum): ©Frank Lukasseck/Photoghrapher's Choice/Getty Images

Eutherians are mammals that bear live young

Babies develop inside a uterus before birth. The placenta connects the maternal and fetal circulatory systems, nourishes, and removes waste from the developing offspring.

Placental mammals

Human Dolphin Bat

(human): ©JGI/Blend Images LLC RF; (dolphin): ©imageBROKER/Alamy RF; (bat): ©Grzegorz Gust/Alamy RF

Key vertebrate adaptations allowed rapid expansion and diversification

Key Vertebrate Adaptations

Adaptation		Adaptive significance	Animals with adaptation
Vertebrae		Expand range of motion	Lampreys, fishes, amphibians, reptiles, mammals
Jaws		Increase feeding versatility	Fishes, amphibians, reptiles, mammals
Lungs		Enable animal to breathe air	Bony fishes (a few species), amphibians, reptiles, mammals
Limbs		Allow for locomotion on land	Amphibians, reptiles, mammals
Amnion		Enables reproduction away from water	Reptiles, mammals

Figure 21.48

Summary of chordate diversity

Mammals
- ~5800 species
- Hair/fur and mammary glands
- Amnion surrounds developing embryo
- Monotremes, marsupials, placentals

Birds
- ~10,000 species
- Feathers and hollow bones
- Amniotic eggs

Nonavian reptiles
- ~8000 species
- Dry, scaly skin; amniotic eggs
- Turtles, lizards, snakes,
- tuataras, crocodilians

Amphibians
- ~6000 species
- Scale-less tetrapods
- Can live on land but reproduce in water
- Frogs, salamanders, caecilians

Fishes
- ~30,000 species
- Scale-covered bodies with gills and fins
- Cartilaginous fishes (sharks and rays) and bony fishes

Lampreys
- 38 species
- Fishlike bodies; jawless
- Consume invertebrates or parasitize fish

Hagfishes
- ~70 species
- Fishlike bodies; jawless
- Marine carnivores
- "Slime hags"

Tunicates and lancelets
- ~3000 species (tunicates)
- ~30 species (lancelets)
- Invertebrate filter feeders
- Sea squirts and amphioxus

Figure 21.47

Clicker question #5

Which feature characterizes tetrapods but not other vertebrates?

A. amnion
B. skull and backbone
C. limbs
D. bilateral symmetry
E. tail

Clicker question #5, solution

Which feature characterizes tetrapods but not other vertebrates?

C. limbs

21.11 to 21.16 Mastering concepts

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Describe the adaptations that mark the transition from fishes to amphibians, reptiles, and mammals.

Investigating life:
Sponges fill holes in animal evolution

All the animal phyla appear in the fossil record during a 25-million year interval in the Cambrian period (543–490 MYA).

This trilobite fossil shows evidence of a complex body plan.

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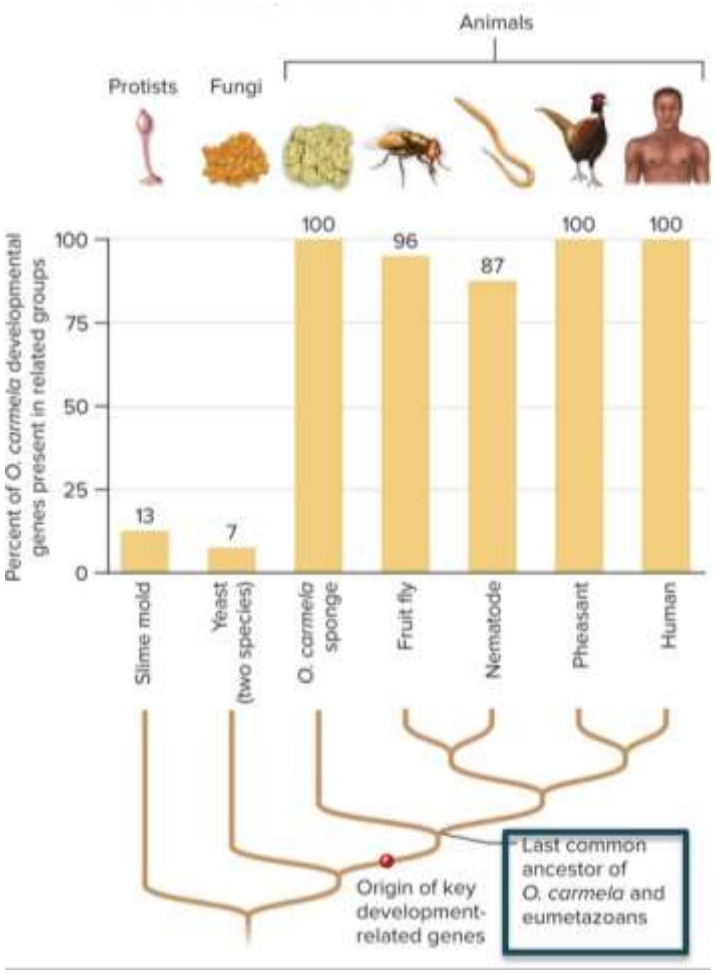
Investigating life:
Who has genes for complex bodies?

Scientists tested a hypothesis that critical developmental genes for complex bodies were already present in animals, before the Cambrian explosion.



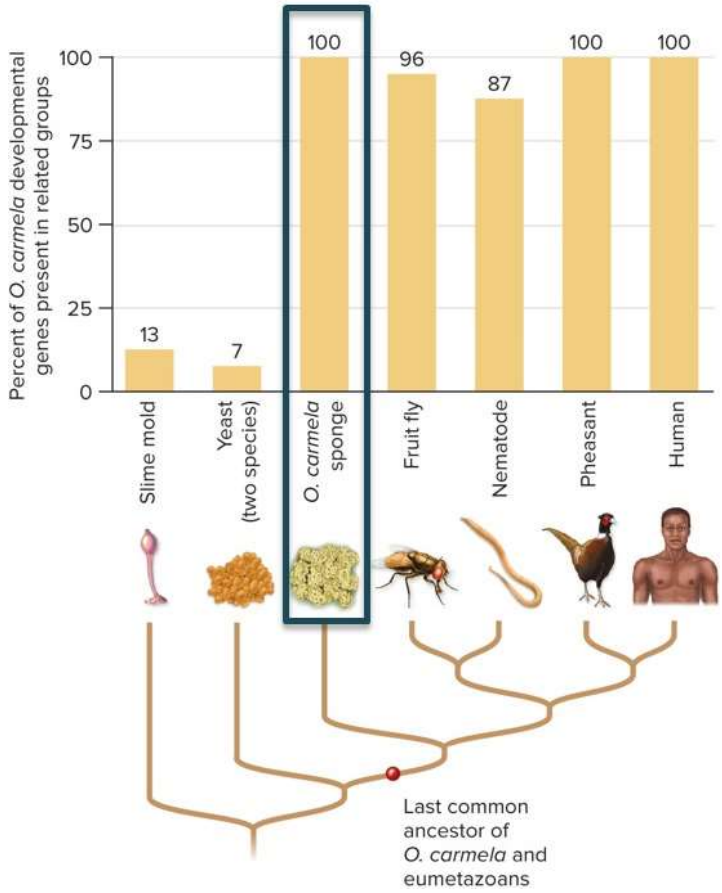
Section 21.17

Figure 21.44

Investigating life:

Sponges have genes for a complex body

By testing animals for 68 different genes, the researchers found support for their hypothesis. A group of sponges contains all major types of developmental genes present in eumetazoans.



Section 21.17

Figure 21.44

Investigating life:
The genes preceded the fossils

The appearance of new animal groups in the Cambrian “explosion” may represent the most visible, but not the initial, step in animal evolution.

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