

SQUID

Kingdom Animalia, Phylum Mollusca, Class Cephalopoda

External Anatomy

Head

large eyes

8 short arms and 2 longer, retractile tentacles all with suckerlike adhesive discs; surround mouth

Collar separates head and body

Body

protective muscular mantle

no external shell: flexible, stiffener or pen embedded in body wall
fins

muscular siphon controlled by retractor muscle

Locomotion

dorsoventrally, along tentacle axis

jet stream exiting from siphon provides main locomotor power

Internal Anatomy

Digestive System

mouth

buccal cavity

2 large, pincherlike jaws used to bite and incise organisms
tonguelike radula

salivary glands secrete enzymes for initial digestion

long tubular esophagus

muscular stomach has peristaltic activity to break down food

large liver and small pancreas located in front of and below stomach;
secretions from these two digestive glands enter stomach to assist in
chemical digestion of food

cecum extension of stomach where nutrients are absorbed into blood

tubular intestine through which undigested residues pass

anus discharges undigested residues to mantle cavity where it is washed
out through siphon

ink sac located above intestine; protective mechanism which secretes
black fluid which is released through siphon

Circulatory System

Closed Circulatory System

Systemic Heart

Ventricle pumps blood to front and back parts of body

Auricle receives oxygenated blood from Brachial Hearts

Two Brachial Hearts

Afferent Branchial Vessels direct blood within gills (ctenidium)
where gaseous exchange occurs

Efferent Branchial Vessels collect oxygenated blood and conduct
blood to auricle of systemic heart

Nervous System

Brain located between eyes

Reproductive System

gonads located in visceral mass

female: ovaries, oviduct; male: testes, vas deferens

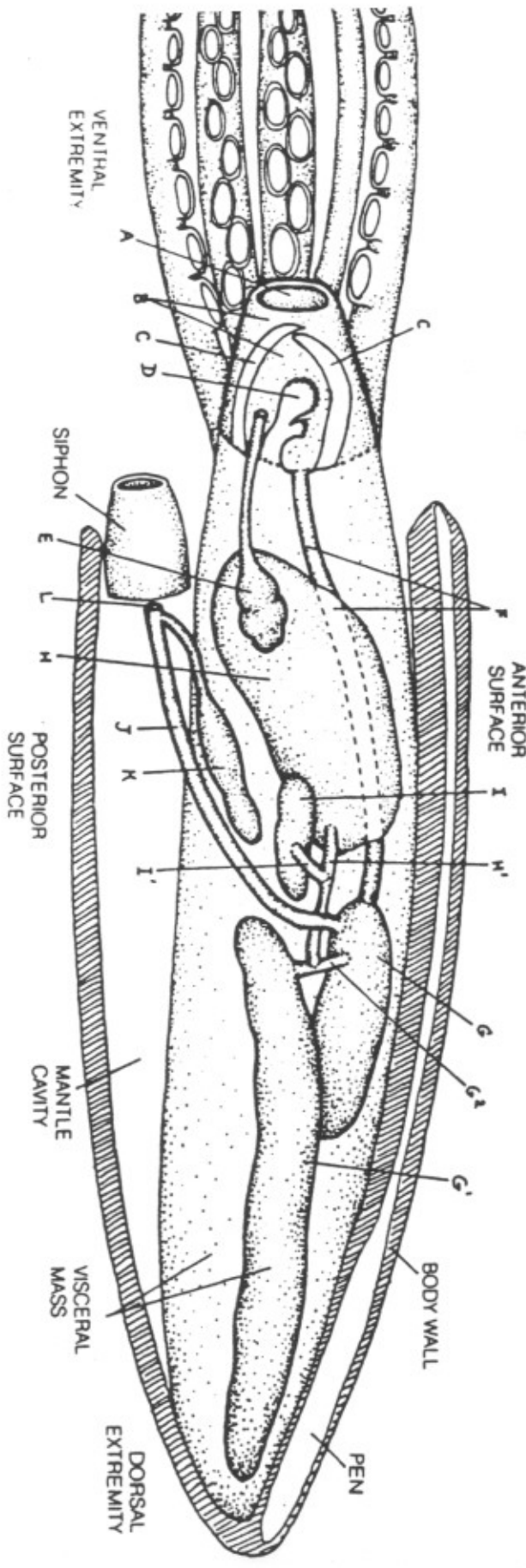
Excretory System

kidneys

REFER TO HANDOUTS AND TO BLUE BOOK PAGE 65 IN IDENTIFYING YOUR SPECIMEN

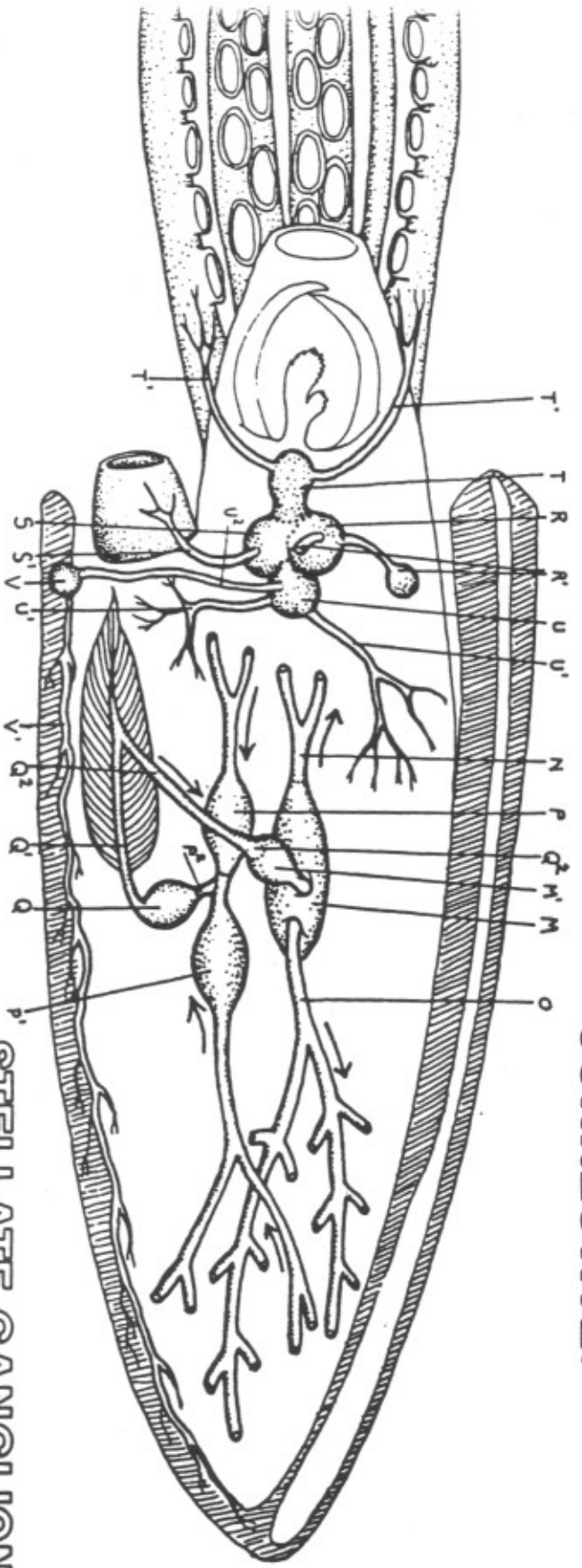
SQUID: II INTERNAL STRUCTURE.

- DIGESTIVE SYSTEM *
- MOUTH,
- BUCCAL CAVITY,
- JAW,
- RADULA,
- SALIVARY GLAND/DUCT_F
- ESOPHAGUS_F
- STOMACH,
- CECUM_G/DUCT_G,
- LIVER_H/DUCT_H,
- PANCREAS/DUCT_H,
- INTESTINE,
- INK SAC/DUCT_K
- ANUS_L



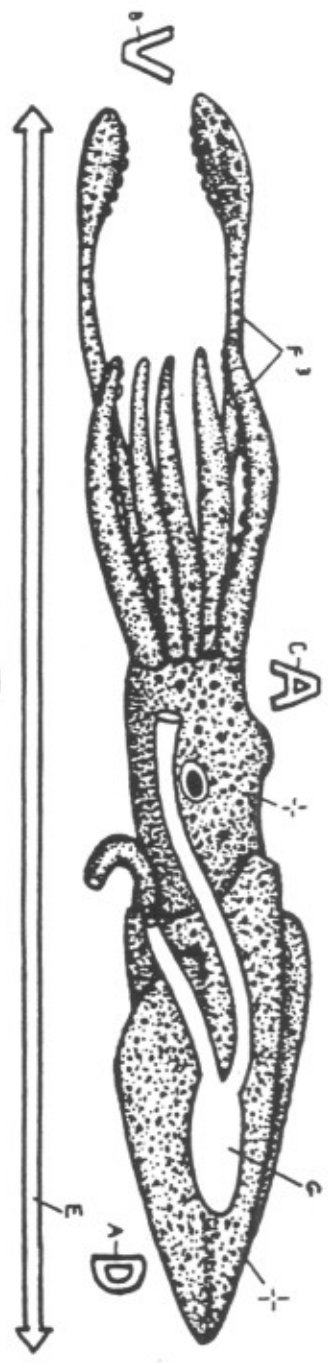
CIRCULATORY SYSTEM *
 VENTRICLE (SYS. HEART)^m
 VENTRAL AORTA/BRS.ⁿ
 DORSAL AORTA/BRS.^o
 VENT./DORS. VENA CAVA/TRIB.^{p, p'}
 LATERAL VENA CAVA^{p''}
 BRANCHIAL HEART.
 AFF. BRANCHIAL VESSEL.
 EFF. BRANCHIAL VESSEL.
 AURICLE (SYS. HEART)^{m'}

NERVOUS SYSTEM *
 BRAIN *
 CEREBRAL GANGLION^p
 OPTIC NERVE.^{p'}
 PEDAL GANGLION^{p''}
 N. TO SIPHON.^{p'''}
 BRACHIAL GANGLION^{p''''}
 N. TO TENTACLE.^{p'''''}
 VISCERAL GANGLION^{p''''''}
 N. TO VISCERA.^{p'''''''}
 CONNECTIVE.^{p''''''''}



STELLATE GANGLION^v
 N. TO MANTLE.^{v'}

ORIENTATION OF DIGESTIVE TRACT.



EXTERNAL STRUCTURE

HEAD_H

EYES_E

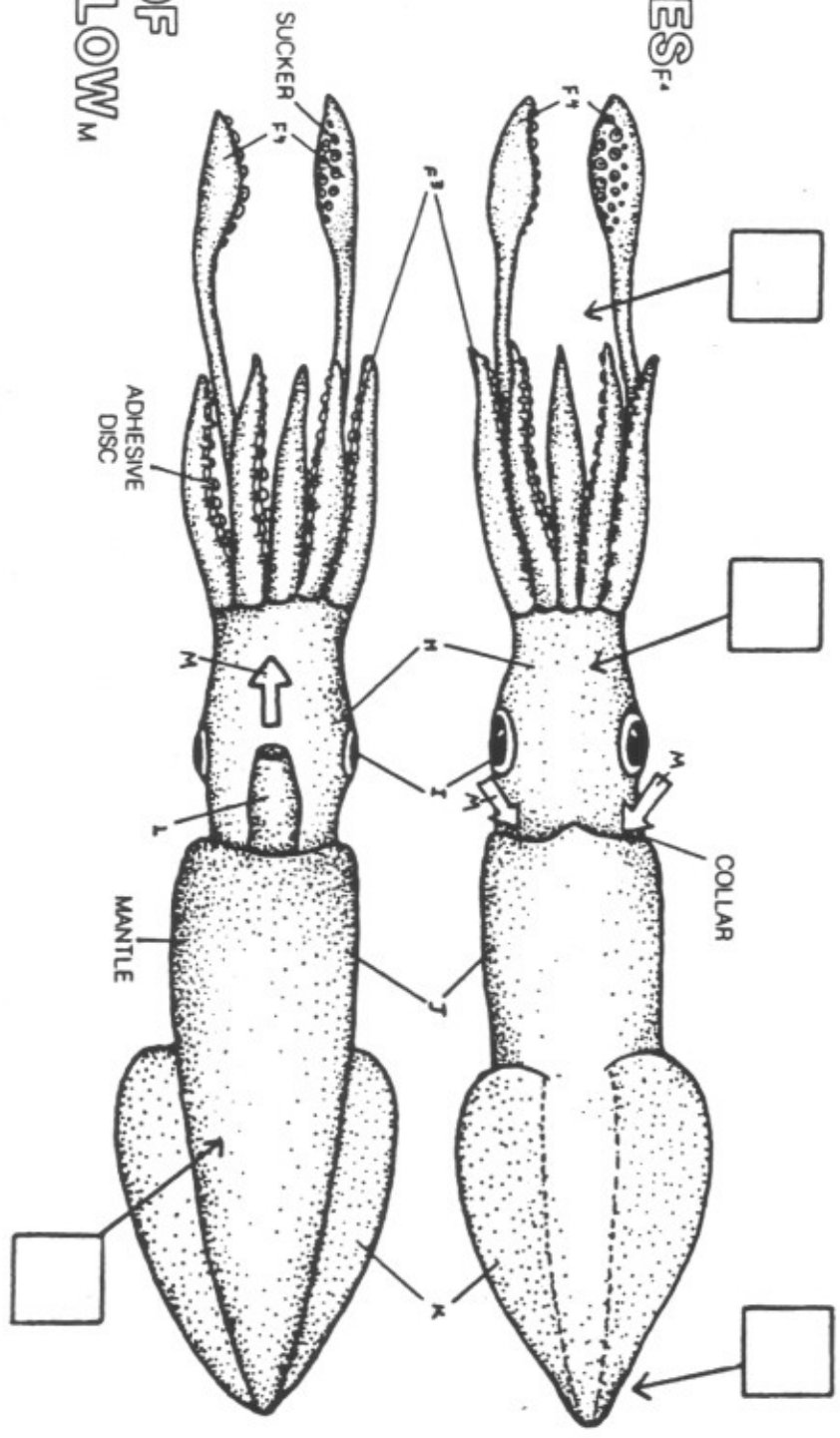
ARMS_{F-1}

TENTACLES_{F-2}

BODY_J

FIN_K

SIPHON_L



PATTERN OF WATER FLOW_M

E. CLASS CEPHALOPODA (SQUIDS AND OCTOPUSES)

The cephalopods are considered the most advanced and highly developed class of mollusks (Fig. 35-5D). In contrast to other mollusks, the cephalopods are active, free-swimming animals.

All cephalopods are marine organisms that are characterized by the modification of a foot to form tentacles and a head with prominent, highly developed eyes. The eye is remarkably similar to the vertebrate eye in that it has an eyelid, iris, pupil, lens, cornea, and retina. In some species the shell is external, and in others it is internal. Some species reach sizes of several meters in length. The giant squid of the North Atlantic ocean is the largest living invertebrate.

Examine a squid. What morphological characteristics can you see on this organism that are adaptations to a predatory existence?

Because the squid relies on its ability to swim rapidly for protection, it has no need of a cumbersome external shell. Consequently, the shell is a vestigial structure, consisting of a horny plate buried in the visceral mass. Interestingly, the shell, called a **cuttlebone**, is sold in pet stores as a source of calcium for pet birds. It is attached to a bird's cage to be used by the bird to "sharpen" its beak.

Nautilus is the only extant cephalopod that has a well-developed shell (Fig. 35-5D). Its flat, coiled shell consists of many chambers separated by transverse septa. The animal occupies only the outermost

chamber. By secreting air into its inner chambers, the *Nautilus* is able to float.

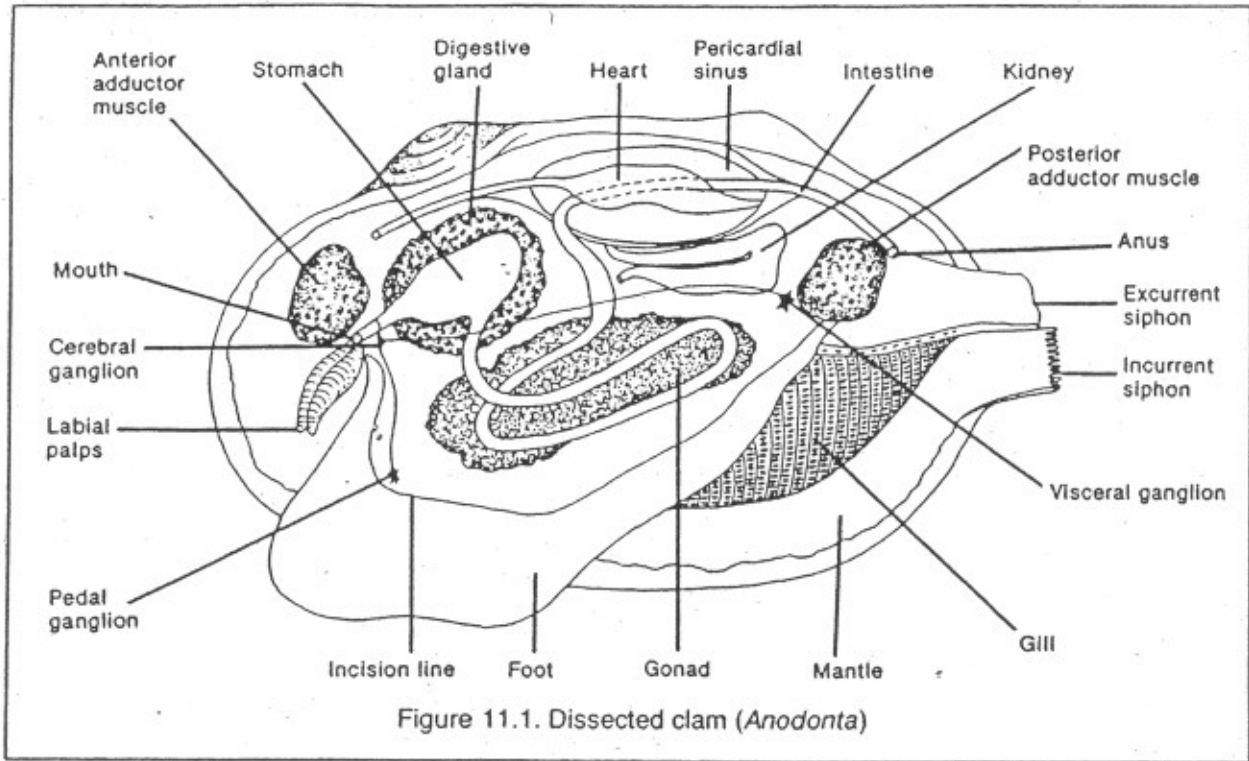
In the cuttlefish (*Sepia*), the shell is greatly reduced, to become an internal stiffening support (cuttlebone) overgrown by the mantle.

Examine an octopus. How are the squid and octopus similar?

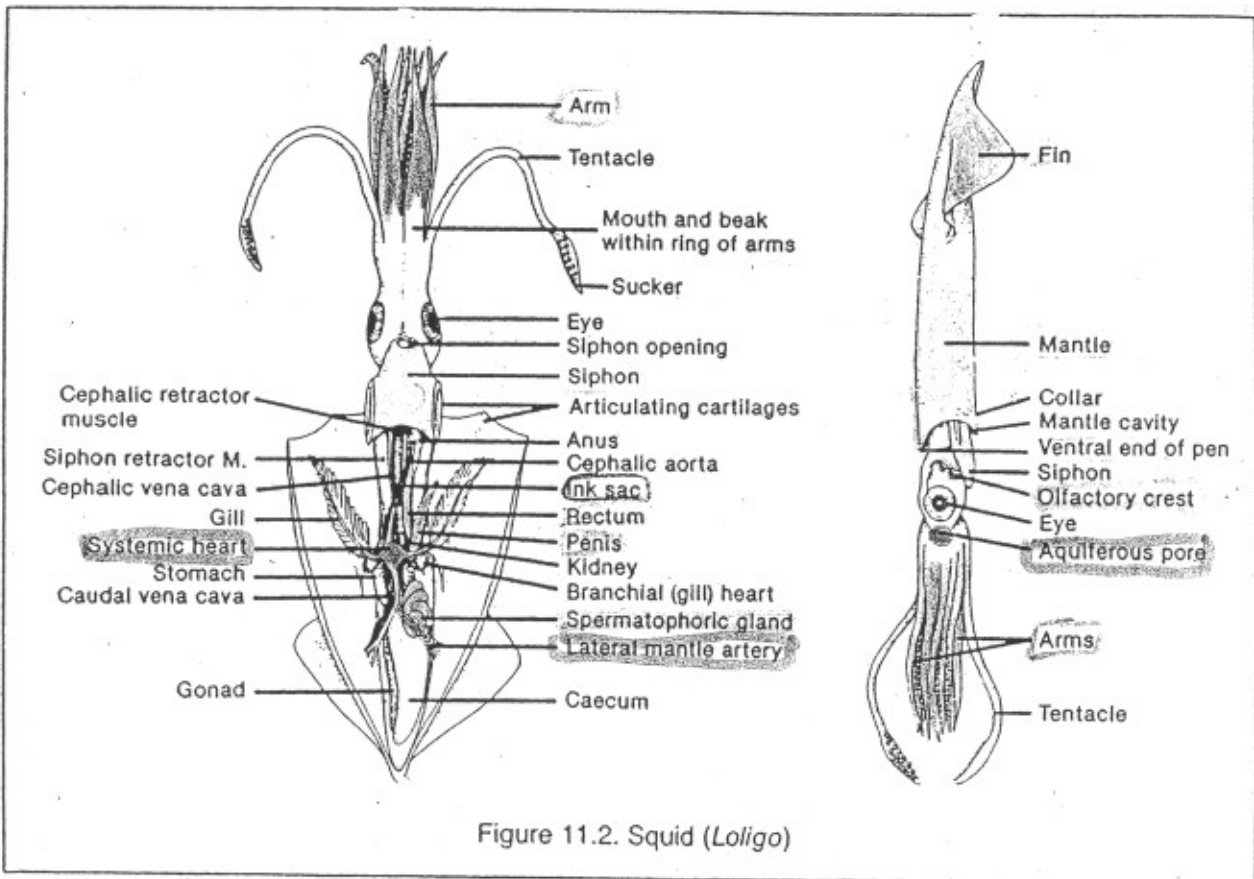
How are they different?

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3 layers of shell
Organic matter
CaCO₃



Kingdom Animalia: Phylum Echinodermata

Members of the phylum Echinodermata (Greek *echinos*, hedgehog; *derma*, skin) are exclusively marine, bottom-dwelling animals commonly known as starfish, sea urchins, sand dollars, sea cucumbers, and sea lilies. The phylum is so named because of the presence of spiny plates (**calcareous ossicles**), which form a dermal skeleton. Most echinoderms are radially symmetrical (though the larva is bilaterally symmetrical), and they have true coeloms arising as outpocketings from embryonic mesoderm of the gut. It is on the basis of this last characteristic, and because the bipinnaria larva more closely resembles the chordate larva, that the echinoderms are thought to be closely related to the chordates.

The most distinctive feature of the echinoderms is their unique system of coelomic canals and surface appendages that make up the water vascular system. Although a circulatory system is present, it is greatly reduced. Thus, the coelomic fluid acts as the principal medium for the transport of food and respiratory gases. Because echinoderms have no excretory organs, they have little capacity for ionic exchange. Explain how this has kept echinoderms from invading fresh water habitats.

The phylum includes many classes of extinct echinoderms but only the following five include living species:

- Class Stelleroidea** (Asteroidea) (starfish and sea stars): Have a star-shaped body, with 5–25 arms, that is covered by a flexible, spiny skeleton.
- Class Crinoidea** (feather stars and sea lilies): Have a flowerlike body with many slender, branched arms.
- Class Ophiuroidea** (brittle stars): Have a body with a central disc and five distinct slender, jointed arms.
- Class Echinoidea** (sea urchins and sand dollars): Have a cylindrical or discshaped body in a shell of fused plates that bear movable spines.
- Class Holothuroidea** (sea cucumbers): Have a soft, wormlike body with no arms or spines.

A. CLASS STELLEROIDEA (ASTEROIDEA) (STARFISH OR SEA STAR)

The simplest and perhaps the most familiar of all echinoderms is the starfish. The common starfish

Asterias, found along the Atlantic coast of North America, is a typical example. Starfish crawl on the shallow bottom or in tide pools among the rocks and sand of the seashore and coral reefs. They have been serious predators of oysters. At one time, oyster fishermen caught starfish, cut them up, and threw them back into the ocean. Then it was discovered that each piece could regenerate and grow into another starfish. Today, "sea mops" made of cloth are dragged over the oyster beds to entrap the starfish. They are then exposed to the sun to dry.

1. External Anatomy

Examine a preserved specimen and note that the body is composed of a central disc from which radi-

ate five **arms** or rays (Fig. 38-1A). Some of your specimens may have fewer arms, but this is usually because they have broken off in handling. Some starfish have more than five arms; rare specimens with as many as 25 have been found. The ventral or oral surface of each arm contains grooves extending outward from the centrally located mouth. The **aboral**, or dorsal, surface is spiny. The spines are extensions of small **calcareous plates (ossicles)** that lie buried beneath the surface. These plates form the **endoskeleton**. Surrounding each spine are numerous minute pincerlike **pedicellariae** and tiny **skin gills**, which function in respiration (Fig. 38-1B). Each **pedicellaria** has two jaws, moved by muscles, that open and shut when touched. They keep the body surface clean of debris and may also help to capture food.

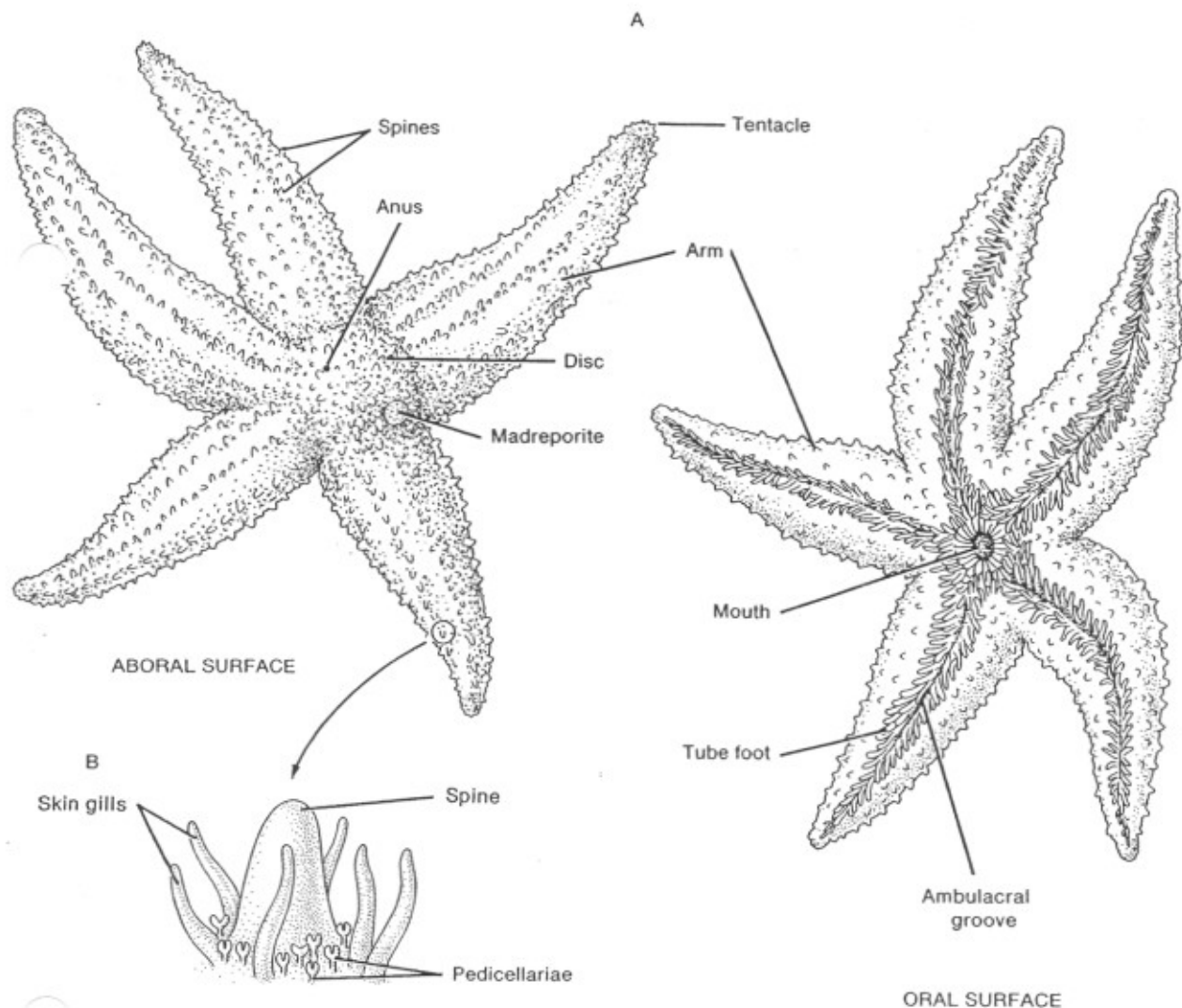


FIGURE 38-1

Asterias: (A) external features of the aboral and oral surfaces and (B) spines, pedicellariae, and skin gills.

The groove in the oral surface of each arm is called the **ambulacral groove**. Along the sides of the groove are a series of flexible **spines** that lie across the groove and protect rows of small, fingerlike **tube feet**, which are organs of locomotion. If you separate the tube feet, you may be able to see a thick, white **radial nerve cord** that runs down the center of each arm. At the tip of each arm are small, light-sensitive **eye spots**. These light-sensitive tips are thrust upward during locomotion.

2. Internal Anatomy

Cut off one-half inch from the tip of one of the arms, and then make longitudinal cuts on both sides of this arm to the central disc. Carefully remove the aboral surface to expose the internal organs (Fig. 38-2A). Note that most of the coelom in the arm is taken up by two highly branched digestive glands, the **hepatic caecae**. Examine the glands with a hand lens or dissecting microscope and note the numerous lobes that secrete digestive enzymes. The ducts of the hepatic caecae join at the base of the arm to form the **pyloric duct**, which enters the centrally located, sac-like **stomach**. The ventral **mouth** and a short **esophagus** lead directly into the stomach, which consists of a multilobed lower **cardiac stomach** and an upper **pyloric stomach**. The food is partly digested in the cardiac stomach and passed into the pyloric stomach in which digestion is completed. The pyloric region then empties into the anus located in the center of the aboral disc. Two small **rectal caecae**, usually found near the anus, function as temporary storage areas for waste products.

Cut the pyloric duct where it enters the stomach and remove the hepatic caecae to expose the glands. If the starfish was caught during the breeding season, the arms will be filled with the **gonads** (reproductive organs). At other times the gonads are very small.

The male and female gonads look alike. To determine the sex of the starfish, the contents of the gonads must be examined microscopically. To do this, remove a small piece of the reproductive organ and mince it in a drop of water on a slide. Add a coverslip and examine under the low and the high power of the microscope. The testes of the male have flagellated sperm. The ovaries of the female produce spherical eggs that are considerably larger than the sperm. Eggs and sperm are discharged into the water through openings called **gonopores** on the oral surface of each arm. Fertilization takes place in the water. The fertilized eggs develop into bilaterally symmetrical, ciliated larvae. A similar larval stage is

formed during the development of the hemichordates. This larva may pass through several distinct stages before it develops into an adult. The similarity between the larval stage of Echinodermata and Hemichordata (primitive chordates), as well as similarities in their early development, suggest that both groups arose from a common ancestor at some remote time.

The **water vascular system**, which is unique to the echinoderms, consists of a series of interconnected canals and appendages associated with the body wall (Fig. 38-2B). This system is well developed in the Stelleroidea and functions as a mechanism of locomotion. To study the anatomy of this system, carefully remove, from one arm, the reproductive organs and digestive system, including the stomach and anus.

The internal canals of the water vascular system are connected to the outside through a button-shaped **madreporite** located on the aboral (dorsal) surface. This sievelike structure opens into the **stone canal**, which descends to the oral side of the animal. The stone canal is so named because of **calcareous deposits in its walls**. On the oral side, the stone canal joins the circular **ring canal**. The inner sides of the ring canal give rise to several pair of pouches called **Tiedemann bodies**, which are believed to produce amoeboid cells that circulate in the system. From the ring canal, a long **radial canal** extends into each arm. **Lateral canals** arise from both sides of each radial canal along its entire length. Each lateral canal contains a valve and terminates in a bulb, called an **ampulla**, and a **tube foot**. Typically, the tip of the tube foot is flattened, forming a sucker.

The entire water vascular system is filled with a fluid that is similar to sea water except that it contains some protein, a high potassium-ion content, and amoeboid cells. This system functions as a hydraulic system during locomotion. When the ampulla contracts, the valve in the lateral canal closes and water is forced into the foot, which then elongates. When the foot contacts the surface on which the animal is moving, the center of the terminal sucker is withdrawn. This produces a vacuum, thereby causing the foot to adhere to the surface. A thick secretion produced at the tip of the foot also aids adhesion.

After adhesion of the foot, longitudinal contractile fibers of the foot contract, shortening the foot and forcing fluid back into the ampulla. Thus, during locomotion, each foot performs a sort of stepping motion. The foot elongates, swings forward, adheres, contracts, and moves backward. The net result of many feet "walking" is that the animal moves forward.

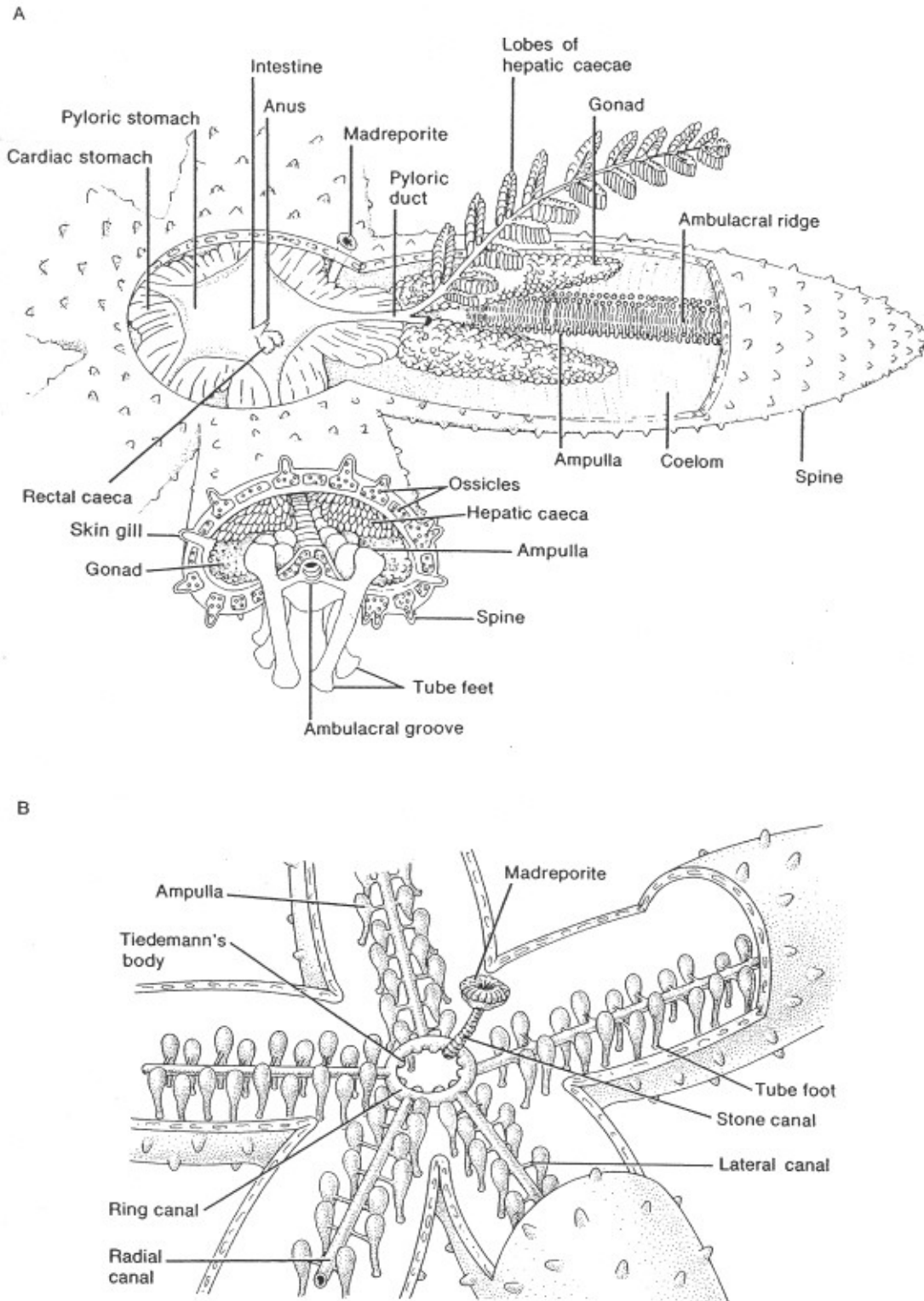


FIGURE 38-2
Starfish: (A) internal organs of the starfish and (B) the water vascular system.

B. CLASS CRINOIDEA (FEATHER STARS AND SEA LILIES)

Examine preserved or plastic-mounted specimens of feather stars and sea lilies, the oldest and most primitive of the extant echinoderms. The habitat of these flowerlike animals ranges from just below the tide-line to depths of more than 3600 m. The body of a feather star (*Antedon*) consists of a small cup-shaped calyx of calcareous plates, to which are attached five

flexible arms that bear many slender lateral pinnules, arranged like barbs on a feather, thus giving the animal its common name (Fig. 38-3A).

The sea lily (*Metacrinus*) has a long, jointed stalk that attaches to the sea bottom by rootlike outgrowths called cirri (Fig. 38-3B). Both mouth and anus are on the oral surface of the calyx. In the crinoids, the oral surface is oriented upward, which is different from all other modern echinoderms. Each arm has an ambulacral groove that is lined with cilia and contains tentaclelike tube feet.

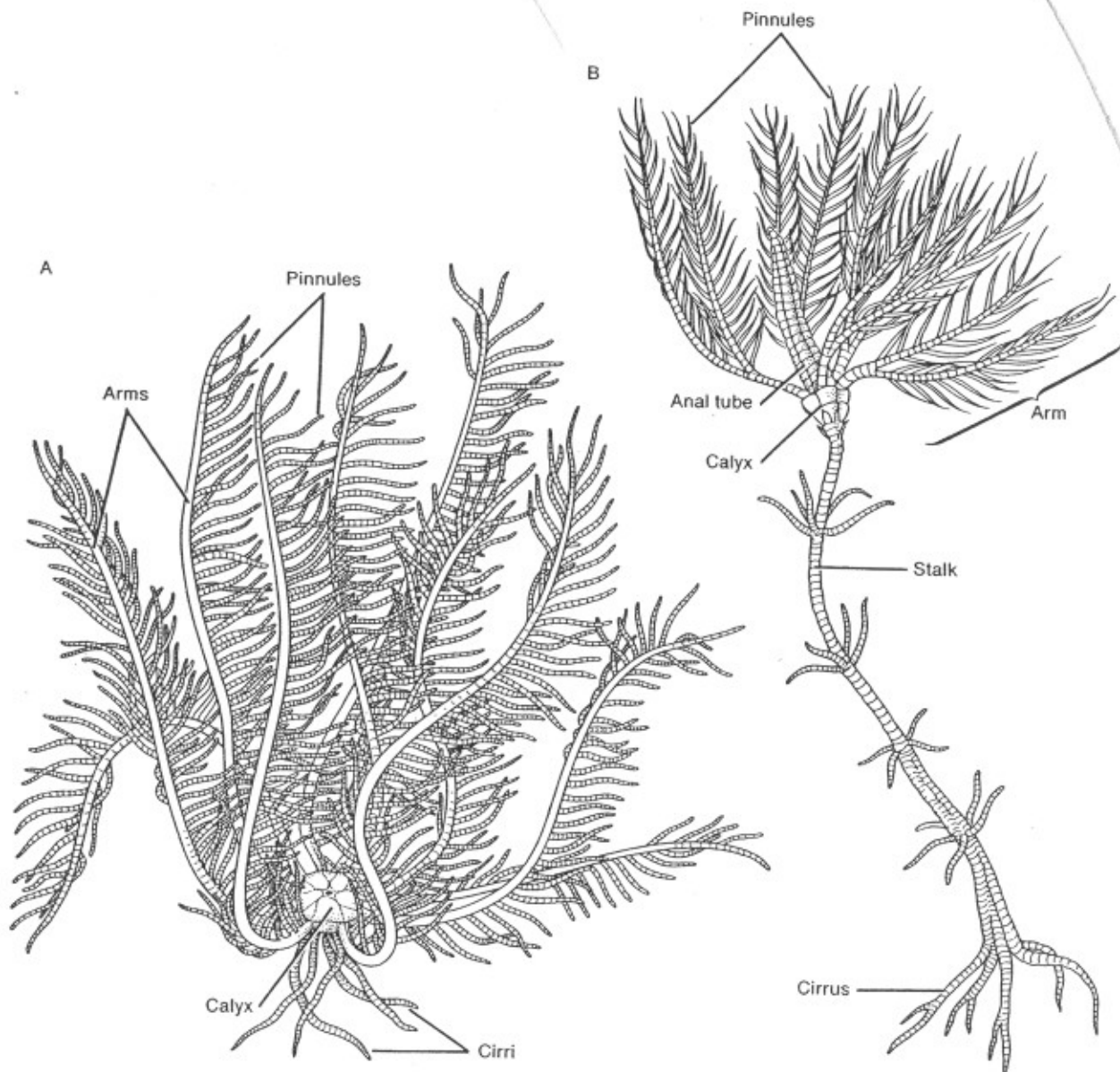


FIGURE 38-3 Crinoidea: (A) feather star (*Antedon*) and (B) sea lily (*Metacrinus*).

C. CLASS OPHIUROIDEA (BRITTLE STARS)

Examine preserved or plastic-mounted specimens of brittle stars. These echinoderms have five arms like the sea stars, but the arms are longer, more slender, and more flexible (Fig. 38-4). The skeleton consists of an outer, superficial endoskeleton and a deeper, internal, articulated series of vertebral ossicles. This arrangement permits the solidly armored arm to move quite freely, which enables this animal to crawl rapidly or swim. The arms, which break easily, are quickly regenerated.

D. CLASS ECHINOIDEA (SEA URCHINS AND SAND DOLLARS)

Members of this class have globose, oval, or disc-shaped bodies that lack free arms or rays but are covered with slender movable spines and tube feet.

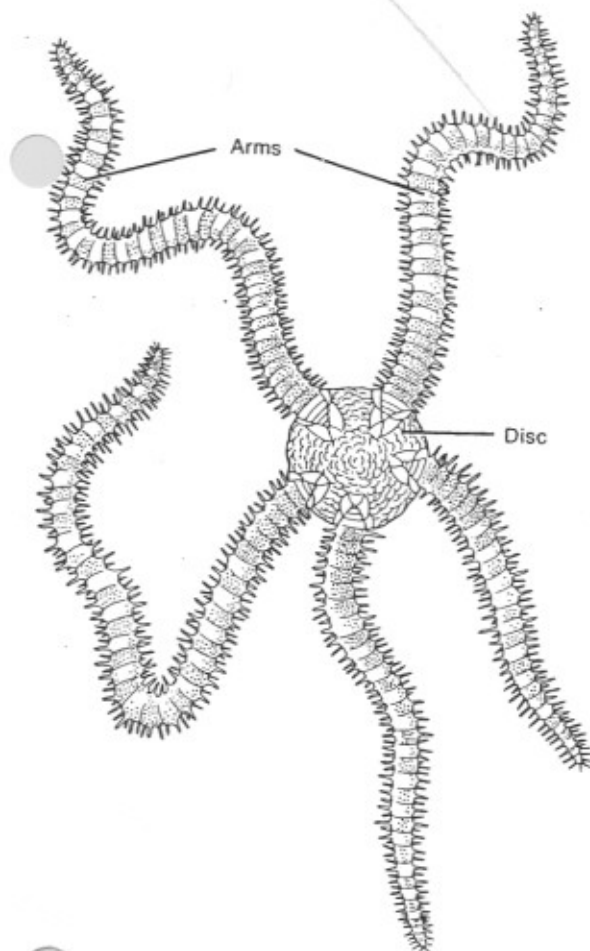


FIGURE 38-4
Brittle star.

1. Sea Urchin

Examine a preserved specimen of the sea urchin *Arbacia* or *Strongylocentrotus*. Study the surface of this animal and observe the sharp, movable spines that are anchored to the solid shell, or test (Fig. 38-5A). On the shell are the rounded tubercles to which the spines are attached. Among the spines are pedicellariae on long, flexible stalks. Some echinoids have several kinds of pedicellariae; a few bear poison-producing glands. Locate the long, slender tube feet and note that they are restricted to regions of the shell known as the ambulacra.

Hold the sea urchin so that the oral side faces you (Fig. 38-5B). In the center of the oral surface is the mouth, which contains a highly developed scraping apparatus called Aristotle's lantern. This apparatus is made up of five plates, or "teeth," each looking like a barbed arrowhead with its point directed toward the mouth. The lantern can be projected and retracted through the mouth by special muscles. Sea urchins, most of which are grazers, scrape the substrate over which they move by opening and closing the lantern plates. They thereby obtain a diverse diet of plant and animal material.

2. Sand Dollar

Examine the concave aboral surface of the sand dollar *Echinarachnius* (Fig. 38-6). Observe the arrangement of the ambulacra on the surfaces. In the center of the aboral surface, you will find the madreporite, at the periphery of which are five genital pores (gonopores). Turn your specimen over and locate the mouth in the center of the disc and the anus at the edge.

E. CLASS HOLOTHUROIDEA (SEA CUCUMBERS)

Examine preserved specimens of the sea cucumber *Cucumaria* or *Thyone* (Fig. 38-7). Note that the body surface has no spines. The endoskeleton is reduced to microscopic spicules, thus giving the body wall a tough, leathery texture. The mouth is located at the center of a conspicuous crown of tentacles that are modified tube feet. In *Cucumaria*, you also observe lengthwise zones of tube feet that are tactile and respiratory in function. In *Thyone*, the tube feet are distributed over the whole body.

The body wall of the sea cucumber is composed of a cuticle over a nonciliated epidermis, a dermis, a layer of circular muscles, and five double bands of longitudinal muscles. The action of these muscles enables the sea cucumber to extend or contract its body and to move by wormlike movements.

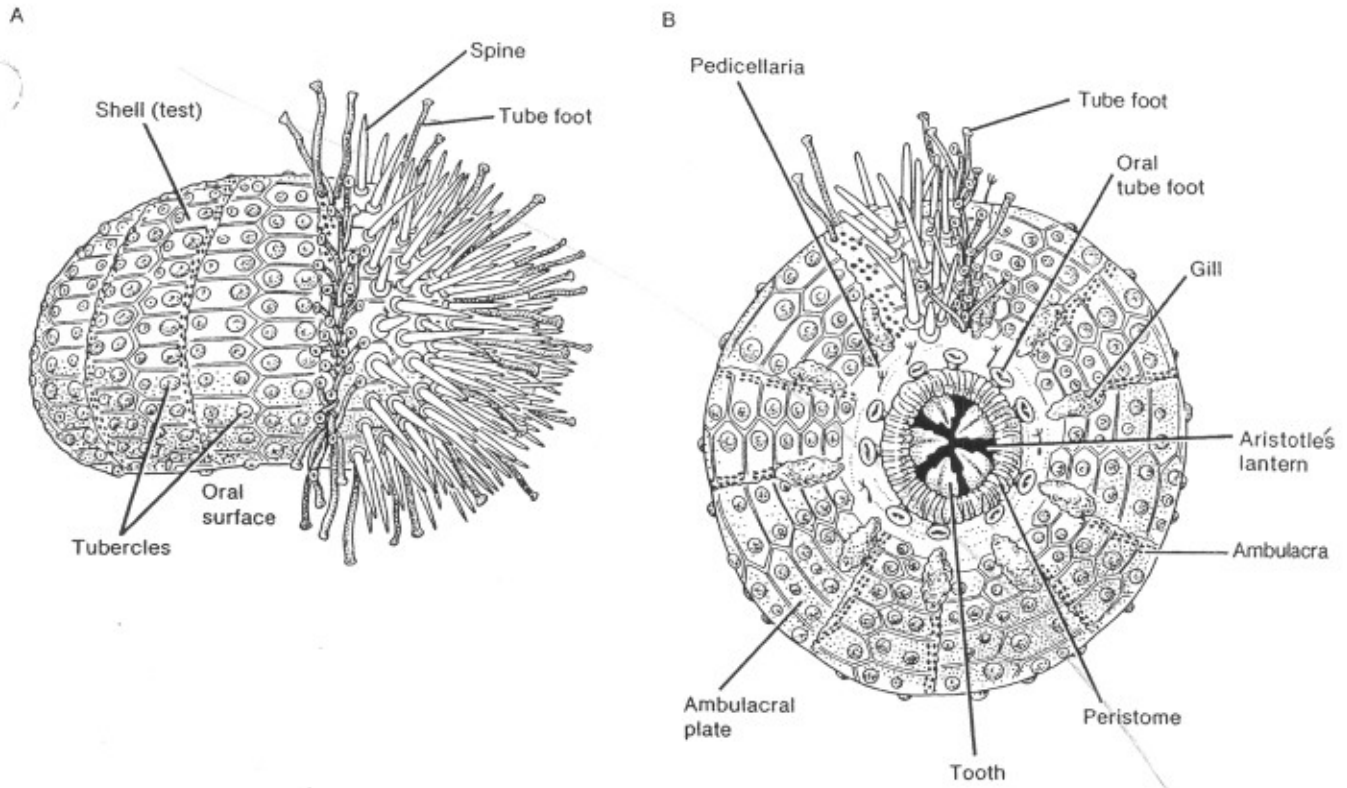


FIGURE 38-5
 Sea urchin: (A) lateral view and (B) oral surface. Spines and tube feet have been removed from the left side to show structure of the test.

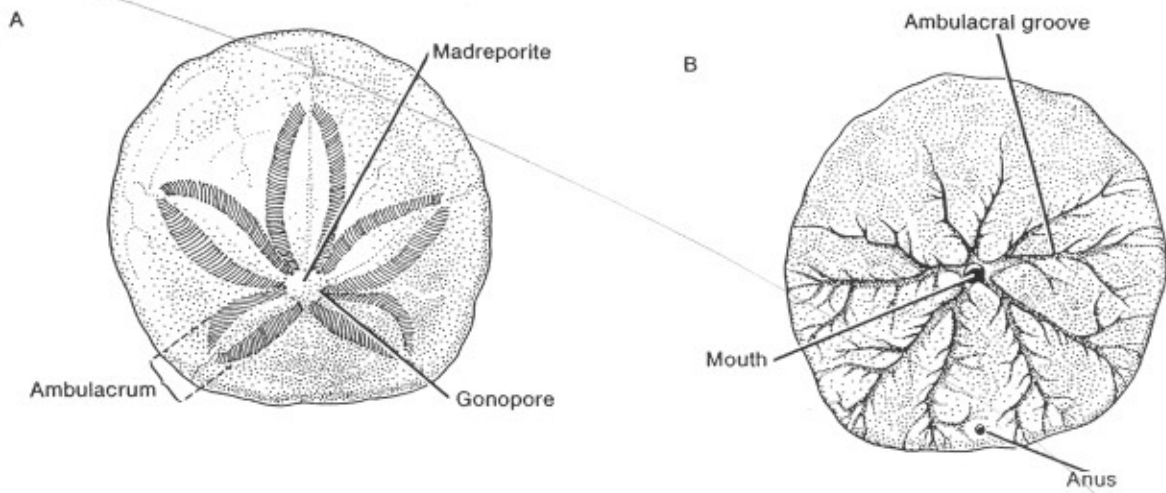


FIGURE 38-6
Echinarachnius (sand dollar): (A) aboral and (B) oral surfaces.

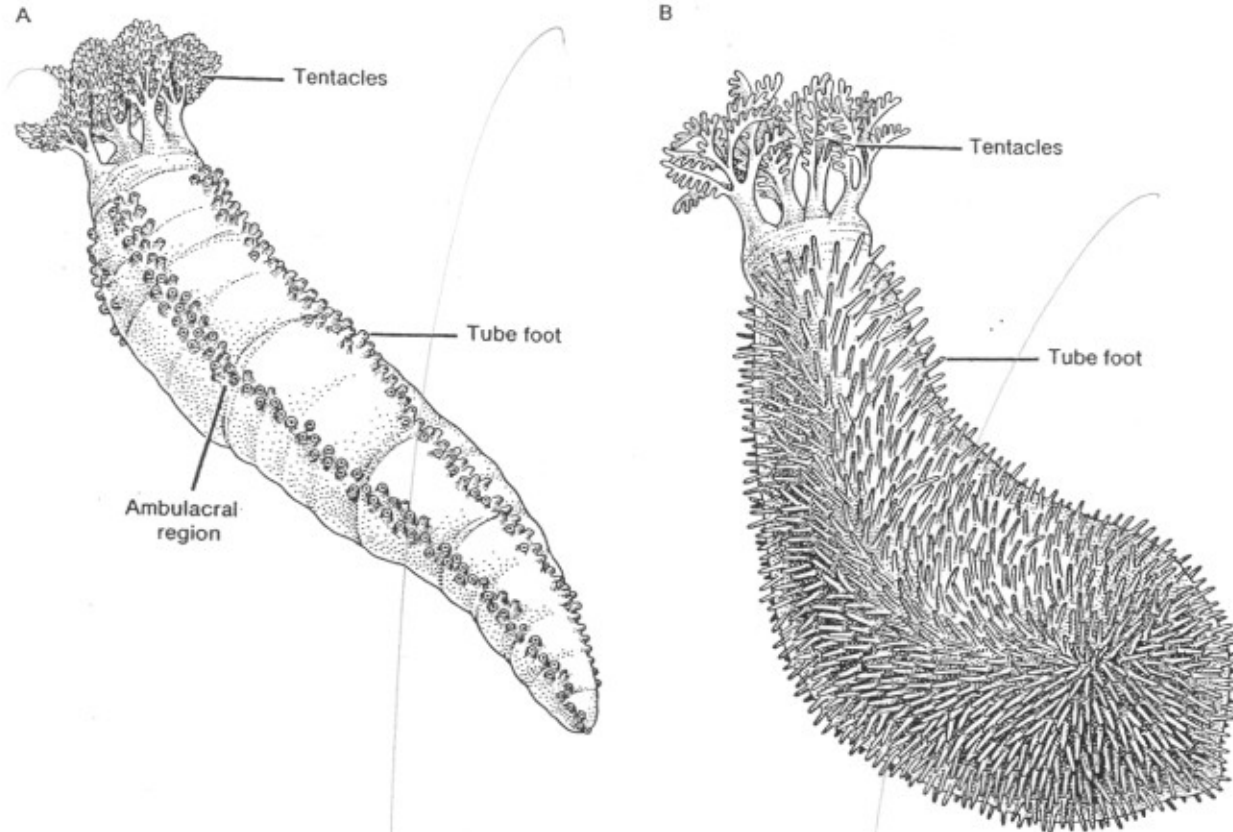


FIGURE 38-7
Sea cucumbers: (A) *Cucumaria* and (B) *Thyone*.

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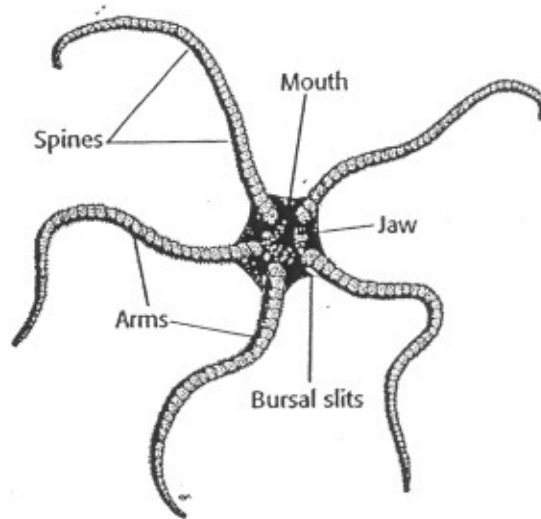
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functions as a type
of circulatory system because it provides
nutrients

Water-Vascular System. To dissect the water-vascular system you must remove the entire stomach from the central disc. Remove the digestive glands and gonads from one arm. You have already identified the madreporite on the aboral surface of the animal; therefore, using the drawing in Figure 11-2, find the stone canal, ring canal, radial canals, lateral canals, ampullae, and tube feet. Locomotion in sea stars is rather complicated. The muscles that control lateral movement of the rays are important, but of primary importance is the functioning and coordination of the numerous tube feet. The tube feet are connected to ampullae and filled with sea water. When the small valve in the connecting canal is closed, contraction of the muscles in an individual ampulla forces water into the tube foot. The tube foot elongates lengthwise. Postural muscles in the tube foot alternately contract and relax. Contraction of one set of muscles results in the movement of the tube foot. Finally, contraction of retractor muscles in the tube foot shortens the tube foot and forces the water back into the ampulla. The coordination of the hundreds of tube feet is accomplished by the nerve ring and radial nerves without any cephalization!

Obtain a prepared slide of a cross-section of an arm of a sea star. Identify all of the structures in Figure 11-2. Be able to identify the epidermis, dermis, ossicle (with spine), skin gill, pedicellaria, digestive gland, gonad, ampulla, tube foot, ambulacral groove, radial nerve, lateral canal, and coelomic cavity. How is the water vascular system similar or different from the hydrostatic skeleton of *Hydra*?

When you have finished the exercises in this section, fill in the sections of the Review Charts in Appendix E that correspond to this phylum.

**FIGURE 11-3.**

Example of the class Ophiuroidea—a brittle star

4 Internal Anatomy

The ophiuroids are unique in two other ways: (1) the digestive tract is saclike with neither intestine nor anus and (2) gas exchange takes place by means of small saclike invaginations into the central disc. The openings of the sacs are small slits located at the margins of the arms around the mouth.

CLASS HOLOTHUROIDEA (Sea Cucumbers)

5 External Anatomy

These animals come by their name honestly. They are moderately sized, cucumber-shaped echinoderms (Fig. 11-4A). The body of the holothuroids is soft compared to other members of this phylum. The soft, leatherlike texture is due to the fact that the endoskeleton of the holothuroids is greatly reduced. The calcified skeletal ossicles in this group are microscopic in size. The outer skin of these animals lacks spines, pedicellariae, and skin gills. Tube feet may be present, but restricted in their distribution. Some tube feet become highly modified into tentacles around the mouth. The holothuroid tentacles are thus part of the water-vascular system. The madreporite does not open into the environment, but rather opens into the coelom.

CLASS OPHIUROIDEA (Brittle Stars)

3 External Anatomy

These animals consist of a small central flattened disc with very slender and long arms (Fig. 11-3). These beautiful animals do not move by means of the water vascular system, but rather by pushing themselves with their long arms. When the ophiuroids move, the central disc is held above the ground. The arms act as oars and row against the substrate. This tends to move the animal in a jerky motion. Compared to the sea star or the sea urchin, these animals can move very quickly.

some gastropod shells appear old and weathered, while others look polished. These "polished" shells are covered by the mantle in life and not exposed to the elements. When the animal dies, the shell washes up on shore and appears shiny and new.



LIVING SPECIMENS

Movement. Slugs and many snails are active herbivores, searching their environments for suitable material to ingest. Observe a living specimen of *Viviparus* or *Campeloma* as it browses on algae-covered glass. Chitons and gastropods move by peristaltic action of the foot, somewhat similar to the crawling motion of flatworms. The waves can be seen by allowing a living animal to attach to the side of an aquarium and viewing the animal from the behind the glass. Note how the expanded part of the foot remains in contact with the glass by means of mucus secreted by the pedal glands, and how the contracted region advances forward.

Locomotor activity in gastropods is not always restricted to the sole of the foot. The role of the columellar muscle in retracting the animal into its shell is one example; this muscle serves other functions as well, and is particularly important in the righting reaction. Place a living snail specimen on its back and note the righting response. By contraction of the circular portions of the columellar muscle, the sole is pushed outward, and when it attaches to the substrate, the sharp contraction of the longitudinal muscles turns the animal upright.

Behavior. The sensory organs of gastropods are fairly well-developed in comparison with other molluscs. They do not reach the complexity shown by the cephalopods but far outdo the chitons and bivalves. Chemoreception, photoreception, and geotaxis are some fundamental sensory functions of gastropods which influence their behavior. Torsion results in bringing the chemoreceptor of the mantle cavity, the osphradium, to a forward position. This supplements the other sensory organs associated with the head, such as eyes and tentacles. Examine specimens of *Stramonita* (*Thais*) and identify the osphradium, eyes, and tentacles. Chemoreception is easily demonstrated by offering some oyster juice to live *Stramonita* (*Thais*); note their accelerated crawling behavior.

Photoreception is an important adaptive ability of many gastropod species. *Physa*, *Campeloma*, *Viviparus*, and *Stramonita* (*Thais*), among others, use light as a cue, directing themselves with reference to the light beam as if it were a compass. The eyes are normally borne on stalks, and contain a spherical lens. A double corneal layer covers the lens. Only light falling on the eye between 35 and 130 degrees of the body reaches the retina, so that orientation angles outside these limits cannot be used. You can determine whether the

animals orient toward light or dark by placing some specimens in a container that is immersed half in darkness and half in light. Allow the animals to crawl in diffuse subdued light, and then brightly illuminate them with a horizontally directed beam. Geotaxis (orientation in response to gravitational forces) is controlled by statocysts which are usually located in the foot. Allow a snail to crawl along on a glass plate and note the change in its direction of movement as one edge of the plate is lifted, for example, the edge in front of the snail.

CLASS CEPHALOPODA: NAUTILUS AND LOLIGO

From a structural and behavioral standpoint, the cephalopods have reached the pinnacle of molluscan evolution. Their sensory structures are extremely well designed and include an eye which rivals the vertebrate eye in complexity. Their behavior can be very complicated, including integumentary color changes and the expulsion of "ink" to confuse predators. Their circulatory system is closed, an advancement over the open, largely unvesselized systems of other molluscs. They are a strictly marine group that includes the octopods, squid, cuttlefish, and the nautili. Cephalopods are active, highly motile swimmers that generally move head-backwards by means of water-propulsion. Water is pumped into and out of the mantle cavity by the contraction of strong muscles, forcing the water to be expelled through a tube-like siphon. Squid are among the fastest invertebrates, swimming at speeds of 43 km/hr. The giant squid, *Architeuthis*, is the world's largest invertebrate reaching a length of 18–20 meters. *Architeuthis* is occasionally preyed upon by sperm whales and their epic battles are sometimes evidenced by sucker scars, left by the squid tentacles, on the whales. Some of these scars are so large that the squid that delivered them are calculated to be up to 25–30 meters long; however, no specimens quite this large have ever been captured.

Cephalopods are carnivorous animals, efficiently pursuing fishes and crustaceans. Prey is captured by agile tentacles, which bear suckers, and are modifications of the foot. The number of tentacles differs within the Cephalopoda, ranging from the decapods (squid and cuttlefish, with 2 tentacles and 8 arms) to the octopods (which lack the tentacles and have 8 arms), to finally the nautili which may bear up to 90 arms. Indeed, the cephalopod foot is by far the most highly adaptive feature of all mollusc locomotory devices. As the name of the group implies, the foot is modified into a head-like analogue which bears arms, eyes, nerve ganglia, a piercing chitinous beak, and toxic poison glands which help immobilize the prey. The shell is usually reduced (an internal proteinaceous rod in squid) or absent (octopods). Many ancient cephalopods, such as

the ammonites, were common marine animals with a thick outer shell. Today, only the *Nautilus* retains an external shell (Figure 3.11).

SHELLS AND PRESERVED SPECIMENS

Nautilus

A primitive cephalopod representative, *Nautilus* is a remnant of a once successful group of shelled marine cephalopods that were common during the dinosaur age. Today, the nautili are restricted to the tropical Pacific, where they spend most of their time on the ocean floor searching for prey. In comparison to other cephalopods, nautili are slow swimmers, a trade-off for a thick, protective, somewhat cumbersome shell. The shell of *Nautilus* is multichambered and the organism occupies only the outermost chamber. As the *Nautilus* grows it secretes a new shell chamber and seals off the old chamber, leaving only a small opening in the center of the partition. A long tube of tissue, the siphuncle,

passes through this opening and those of the previous chambers, providing chemical and metabolic communication with the inner chambers. The siphuncle absorbs fluid from the empty chambers which subsequently fills with gas, a by-product of respiration. The animal regulates the amount of gasses in these internal chambers to increase or decrease buoyancy, and hence regulate its placement in the water column. Nautili are not found below depths of 600 meters because the water pressure at that depth is so great (over 40 times that of atmospheric pressure) that it superceeds their ability to equalize internal pressures and their shells collapse. Examine the thick calcified shell of *Nautilus* and note the distinctive color pattern. If available, observe a sectioned shell and look for the inner chambers, which are larger near the aperture. Observe the passageway in the chamber partitions that house the siphuncle.

Loligo

Squid are extremely common marine animals, often swimming near the surface in large schools. They are found in both the Pacific and Atlantic coastal waters and some species inhabit the ocean depths. Squid are

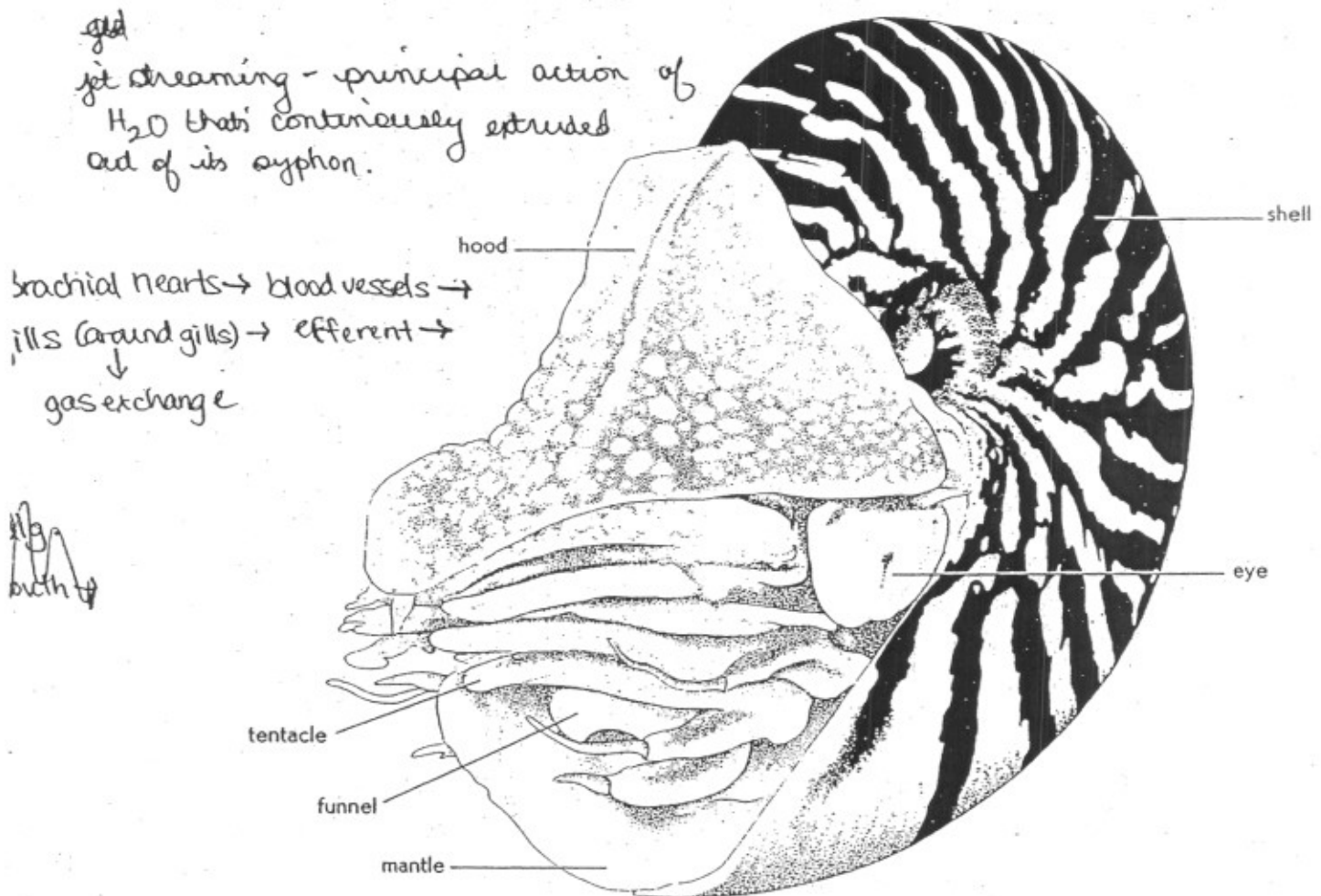


FIGURE 3.11 External anatomy of *Nautilus*, a shelled cephalopod.

favorite food items of many fish and sharks, and are an important food source in many Asian cultures. To facilitate swimming, squid are streamlined with a tapered leading end, the apex. The orientation of the squid is quite unusual because the animal is extended dorsoventrally. Despite resembling an anterior end, the head and tentacles represent the ventral surface. The leading dorsal surface is pointed to reduce water resistance when swimming and opposes the head and tentacles. The funnel or siphon is found along the posterior, while the opposite side represents the anterior.

External anatomy and dissection. Examine a preserved specimen of the squid, *Loligo* (Figure 3.12). Note that there is no external shell and that the major part of the body is enclosed by the muscular, fleshy mantle. Note

the pattern of chromatophores, or pigment spots, on the surface of the mantle. Squid have the ability to camouflage the mantle by manipulating the surface pigmentation. Observe the head-foot region, and note the eight arms are completely lined with suckers. Two of the appendages are longer than the arms. These tentacles only bear suckers at the expanded distal tips and can be extended and retracted by internal muscle control. Place the animal so that the apex is farthest from you and the arms closest. Turn the animal so that the siphon (the tubular projection between the opening of the mantle and the head-foot region) is facing you. The eyes are on the left and right sides of the body, and the head has moved to a position that is dorsal to the foot.

Squid are active predators, and the walls of the mantle cavity play an important locomotory function.

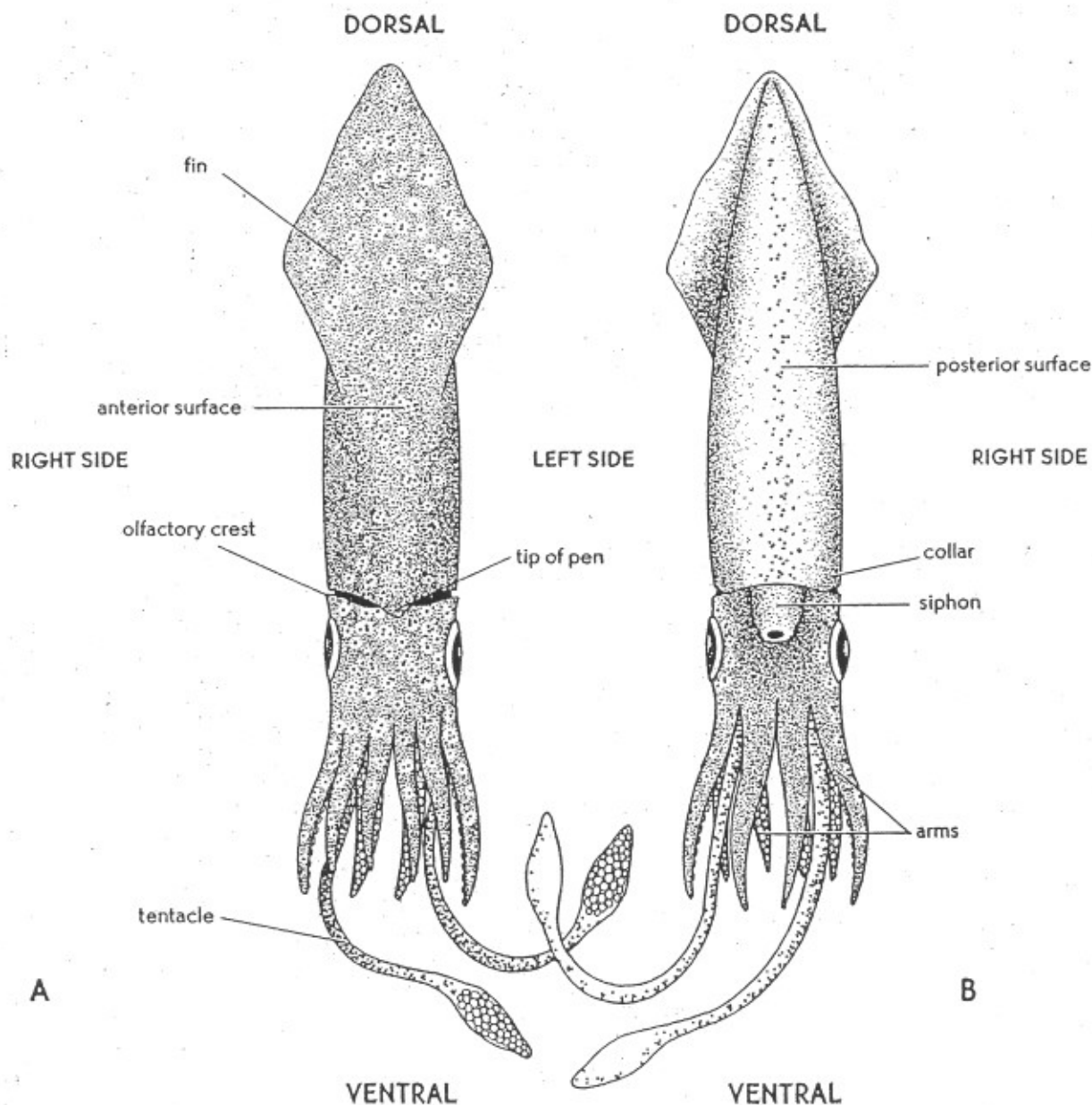


FIGURE 3.12 External anatomy of *Loligo*, the commercial squid. A) anterior view; B) posterior view.

Highly muscularized, the mantle controls movement of water within the cavity. With the ventral side of the squid facing you, observe the construction of the mantle collar and its relationship to the siphon. In life, the mantle cavity expands by muscular action, allowing water to enter. The collar then locks tightly against the head, utilizing a system of ridges and grooves in the mantle. Once the mantle collar is locked in place, the siphon is the only exit pathway from the mantle cavity. The siphon is well equipped with muscles, and can be pointed for making directed jet-propulsive movements.

Internal anatomy. Open the mantle cavity by making an incision which runs the entire length of the posterior surface from siphon to apex. Keep your scalpel close to the body wall so as not to destroy any internal organs. Turn the mantle edges laterally and insert some heavy dissection pins at frequent intervals. After preservation, the mantle may be quite rubbery and resistant to pinning, be patient! Note that the tip of the siphon has a valve which regulates the outflow of water from the mantle cavity (Figures 3.13 and 3.14). The inner side of the mantle has cartilaginous ridges which keep the inhalant currents separate from the exhalant. There are two ctenidia (gills) which are placed so that the

inhalant streams immediately pass over each, then converge and exit as a single exhalant stream. If the circulatory system is injected with latex (red and/or blue) study the relationship of the gills to the blood vessels and the hearts. Squid have three hearts, two round **branchial hearts** just dorsal to each gill and a triangular **systemic heart** located between the branchial hearts. A system of vessels and sinuses include the conspicuous anterior and posterior **venae cavae** and the **lateral mantle arteries** and veins. The blood flows from the systemic heart to the body via the aorta. Blood from the body pools in the venae cavae, passes to the ctenidia via the branchial hearts, and then returns to the systemic heart.

Reproductive system. Squid are sexually dimorphic, with individual males and females (Figure 3.13). Females have one or two short oviducts lying next to the rectum. Two large, conspicuous **nidamental glands** secrete albumin, yolk, and protective membranes around the eggs. The **ovary** lies anterior to the cecum in the apex. Males possess a well-developed **testis** which lies posterior to the cecum and produces sperm that passes through a **seminal vesicle** to a coiled **spermatophoric gland**. Here the sperm are enclosed in a spermatophore

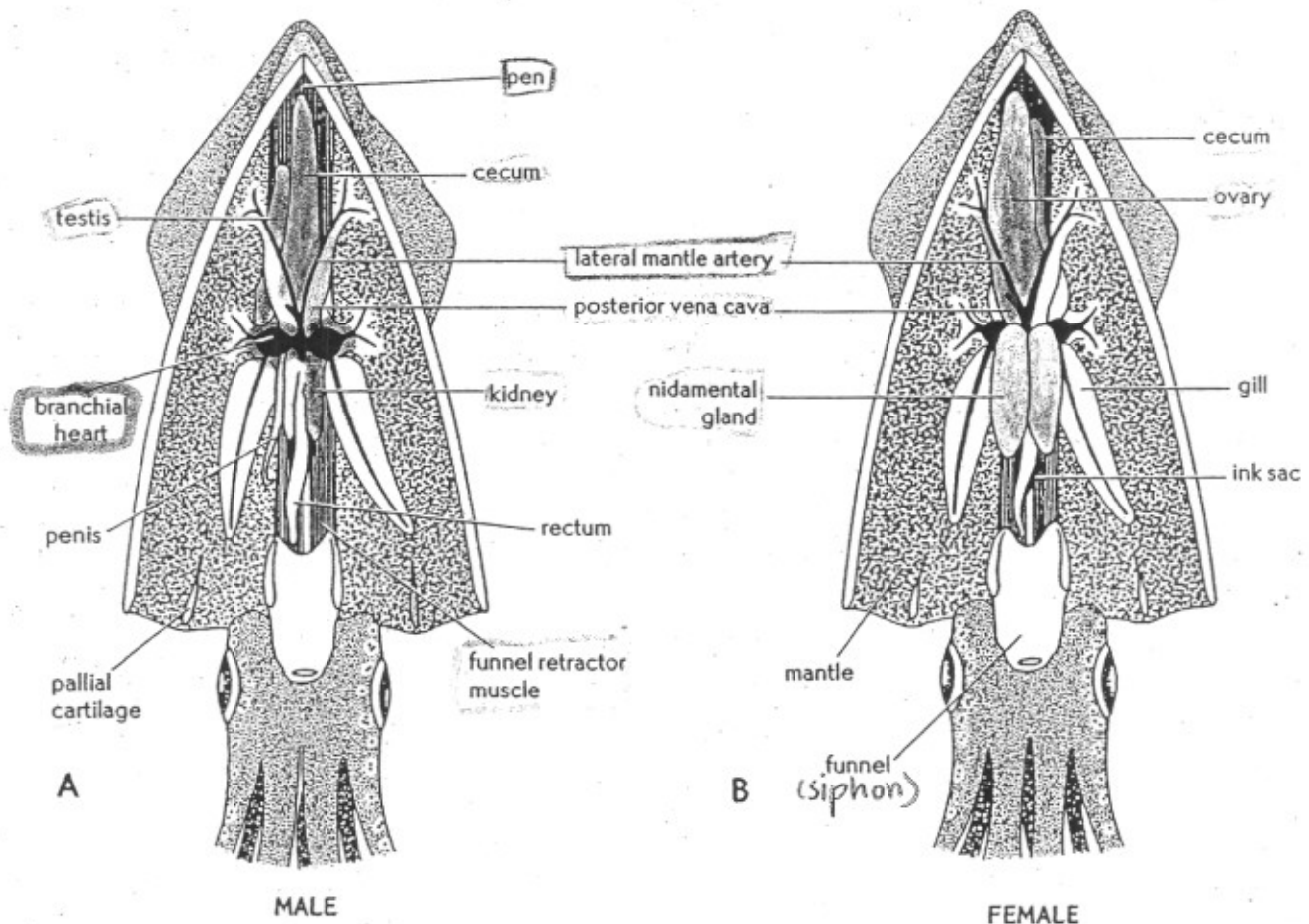


FIGURE 3.13 Dissection of *Loligo*, posterior view, showing the arrangement of major reproductive organs. A) male; B) female.

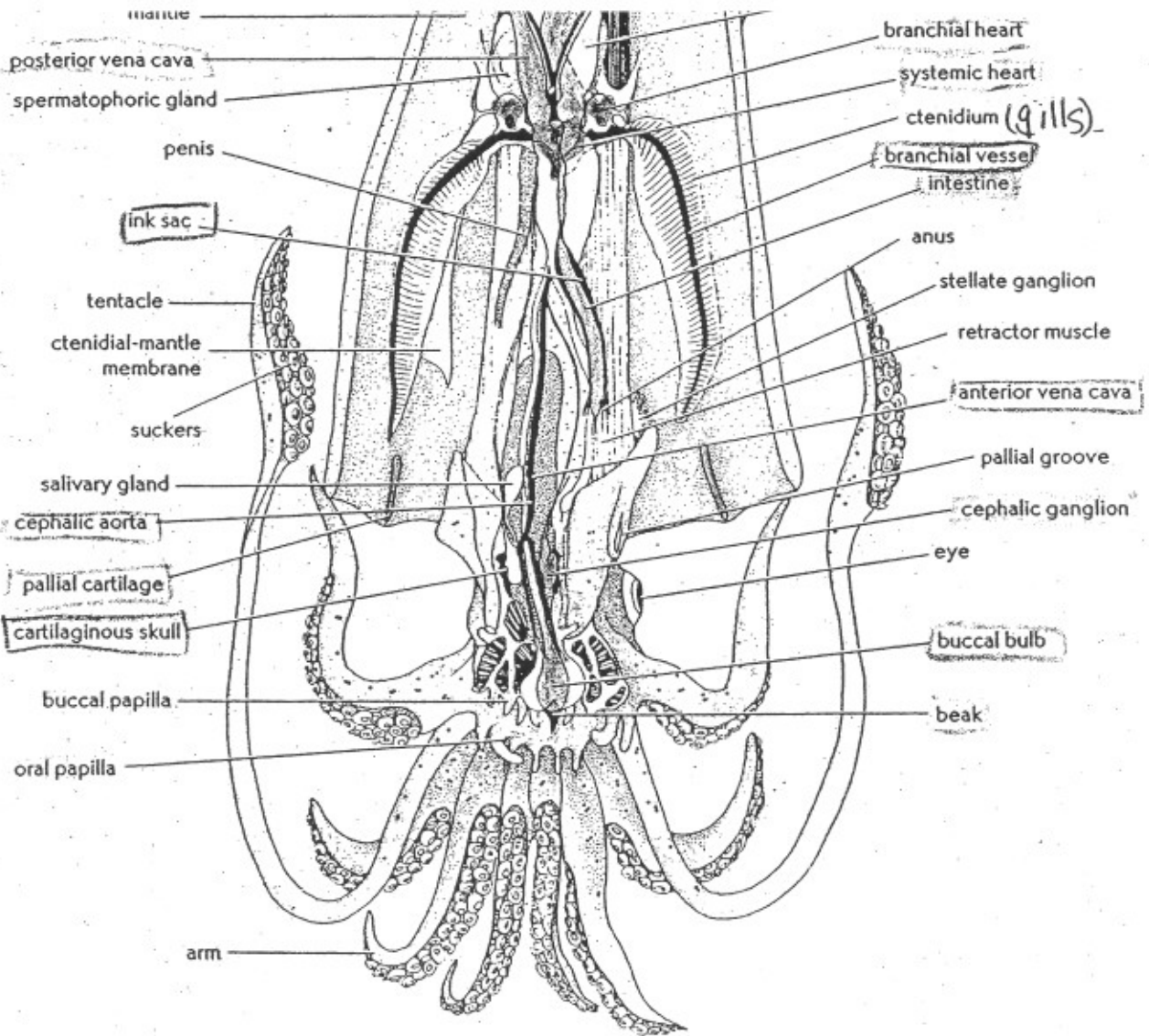


FIGURE 3.14 Dissection of *Loligo*, male specimen in posterior view, showing major internal features.

where they wait until copulation. An elongate penis, lateral to the intestine, carries the spermatophores to the anterior region near the funnel. In squid, the penis is not a copulatory organ.

Squid show a complex mating ritual where they encircle one another while waving their arms and tentacles and displaying color changes. During copulation, they line up head-to-head, intertwine their arms and one of the male's arms, the **hectocotylus**, reaches through his funnel, picks up spermatophores and inserts them into the female's mantle cavity, where fertilization occurs.

Digestive system. The **mouth** is ventral and surrounded by the tentacles and arms. The prey is held firmly in place by these prehensile arms and suckers, and food is brought toward the mouth. Remove the siphon, and by a superficial median incision, cut into the head, separating the eyes, and exposing the round **buccal mass** (Figure 3.14). This is a muscular organ which possesses two horny, raptor-like beaks, used for ripping and shredding the prey. Pry open the beak and observe the

internal radula and the odontophore. Run your finger along the radula and feel the serrations. Place the radula under a dissecting microscope and compare with the scanning electron micrograph in Figure 3.2.

Posterior to the buccal mass are a pair of **salivary glands** which pour their toxic secretions into the buccal cavity as the prey passes into the mouth. These may be indistinct and hard to identify. Pull out the buccal mass and identify the thin-walled **esophagus**. The esophagus is surrounded by the liver and runs to the muscular **stomach**. The stomach emerges to form the gelatinous **cecum**, which is harbored in the apex. The **intestine** runs toward the head from the stomach and terminates in the **rectum**. The anus opens near the internal opening of the siphon, so that waste products are immediately expelled. A diverticulum extends from the intestine; this is the infamous **ink sac** that produces a murky secretion, clouding the water when expelled in an effort to deter predation. The ink is a conglomerate of pigment, which not only visually obscures the view of a predator, but may desensitize a predator's chemoreceptors.]