EEB 266

ANIMAL DIVERSITY: INVERTEBRATES

Laboratory Manual

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Goals and expectations

EEB266 Course Description

The diversity of invertebrates (e.g. sponges, jellyfish, flatworms, molluscs, segmented worms, round worms, arthropods, echinoderms and several smaller phyla) is explored, focusing on taxonomic characters that define each group, their placement in the evolutionary tree of life, as well as their ecological function, biological requirements, and geographic distributions. Major questions in the evolutionary relationships of animals are explored. Labs emphasize identification and recognition of major groups.

EEB266 Learning Outcomes

- Understand the diversity of invertebrate animals, their evolutionary relationships, and ways of life;
- Understand the relationships between animal phyla;
- By observing museum specimens, learn to make inferences about organisms and their ecology; and
- Formulate hypotheses about organisms and how they change over evolutionary time.

Labs

The questions herein provided for each phylum are meant to facilitate learning: it is possible that similar questions will appear in the lab quizzes.

The main goal of the labs is to apply the lecture content to real organisms by…

- Handling and observing museum specimens;
- Identifying specimens based on the anatomical features that define them;
- Familiarizing oneself with the vast diversity of animal life; and
- Practicing formulating hypotheses about organisms, their ecology, and their evolutionary relationships.

During labs, students are expected to actively engage with the lab materials, by…

- engaging in conversations with their peers, instructor, or TAs;
- thoroughly completing the activities contained within this manual; and
- carefully observing the available specimens beyond what is needed to complete lab manual activities.

Students are further expected to create a safe and welcoming learning environment for their peers by conducting themselves in a respectful, inclusive, and professional manner.

Finally, students are expected to abide by COVID-19 safety procedures, and asked to wear a mask during all lab sections.

How to use this manual

This manual contains questions and activities intended to guide students through the process of observing the specimens available in each lab, and relating those specimens to concepts learned in lectures.

For each phylum, students will be provided with lists of the major groups covered in class and charcteristics that define these groups. To the extent that it is possible given the available material, students are encouraged to **identify these characteristics in each specimen**, and **attempt to identify – as specifically as possible – the major group to which each specimen belongs**.

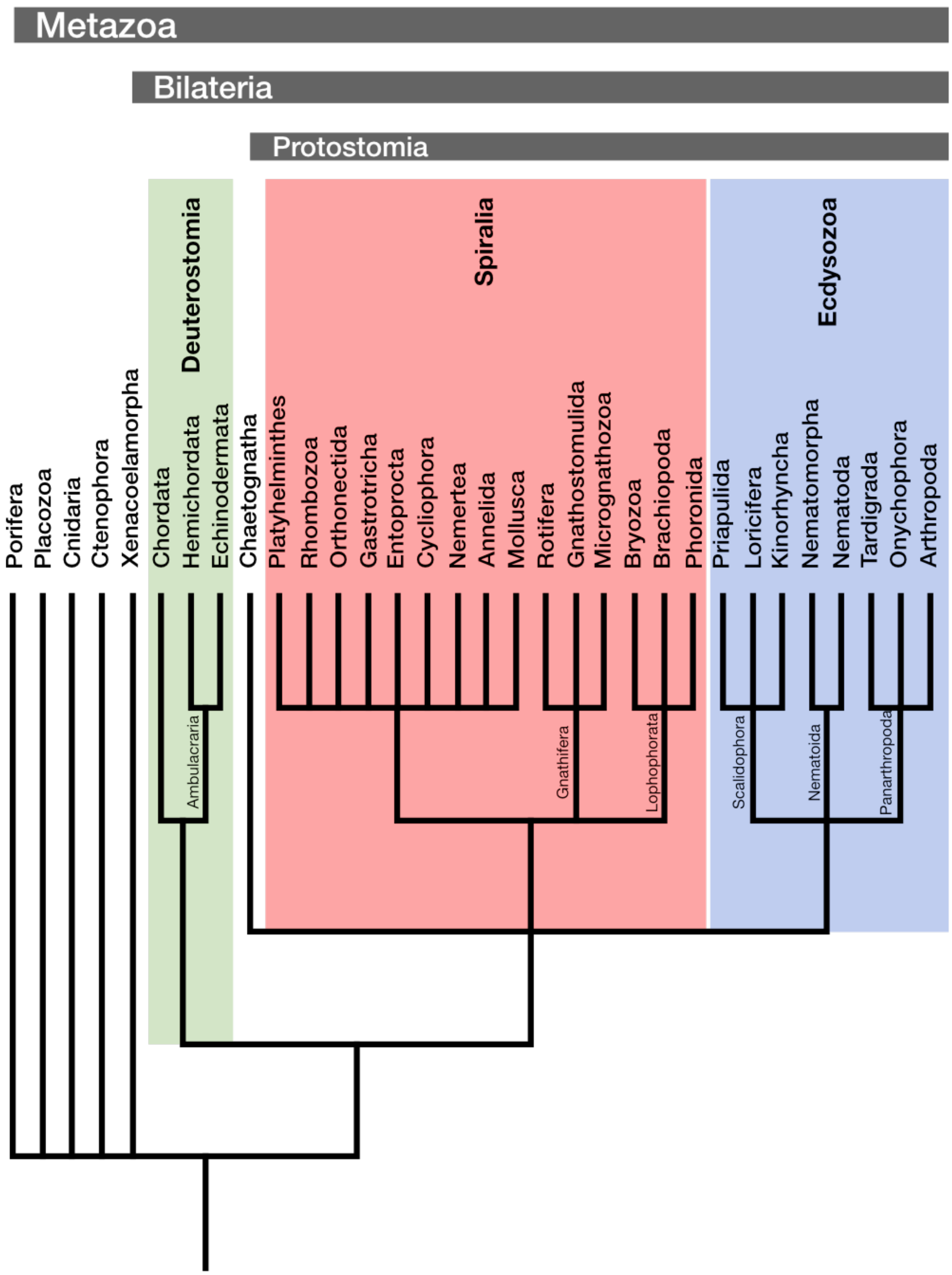


Figure 1. Phylogeny and higher classification of Metazoa. Adapted from *Invertebrates*, 3rd edition – Brusca *et al*., 2016

LAB 1

Porifera, Cnidaria, and Ctenophora

Phylum Porifera

Etymology	“pore-bearing” (Lat. *porus* + *ferre*)
Common name	sponges
No. Species	9,000
Habitat	benthic; mostly marine (some freshwater)
Reproduction	sexual & asexual

Sponges are sessile, suspension-feeding organisms that lack many of the features found in other animals, including true tissues, a gut, muscles, organs, and nerves. Their bodies are formed from two cell layers (**pinacoderm** and **choanoderm**) with **mesohyl** in between. The body is supported by a skeleton made from **collagenous proteins** (such as spongin) and/or **spicules**, which may either be calcareous (formed from calcium carbonate) or siliceous (formed from silicon dioxide). The four Poriferan classes are broadly distinguished by the presence, composition, and morphology of their **spicules**.

Major Groups

class Calcarea
class Demospongiae
class Hexactinellida
class Homoscleromorpha

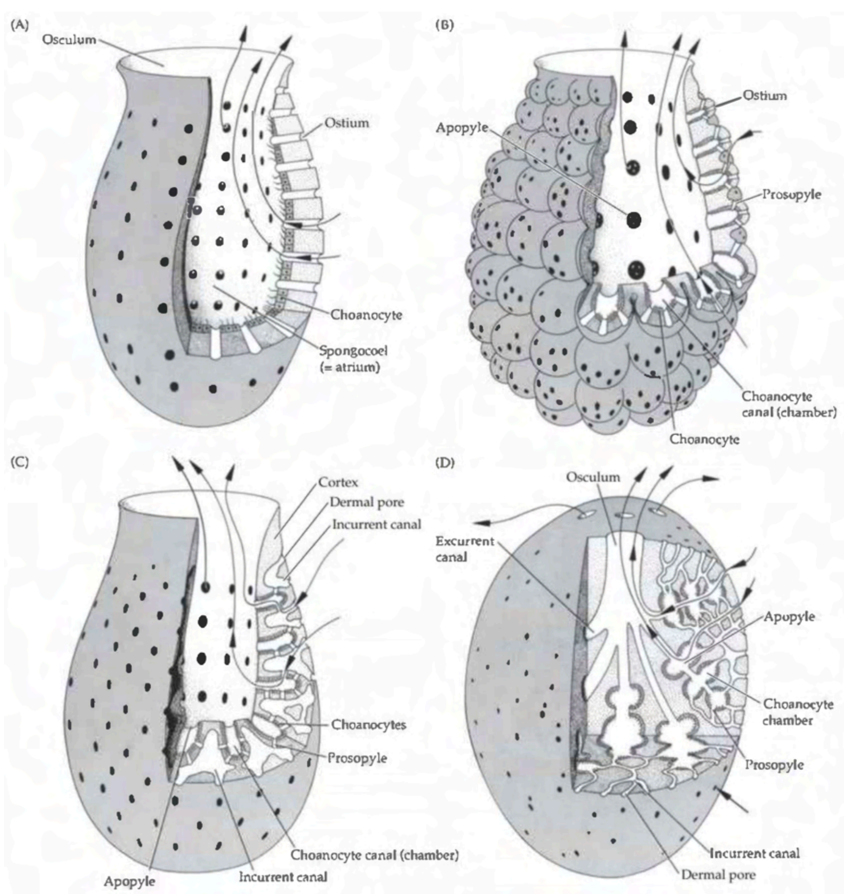


Figure 2. “Body complexity in sponges (arrows indicate flow of water). (A) The asconoid condition. (B) A simple syconoid condition. (C) A complex syconoid condition with ectosomal growth. (D) A leuconoid sondition. Asconoid and syconoid anatomies occur only in the class Calcarea.”

Figure from *Invertebrates*, 3rd ed. – Brusca *et al*., 2016

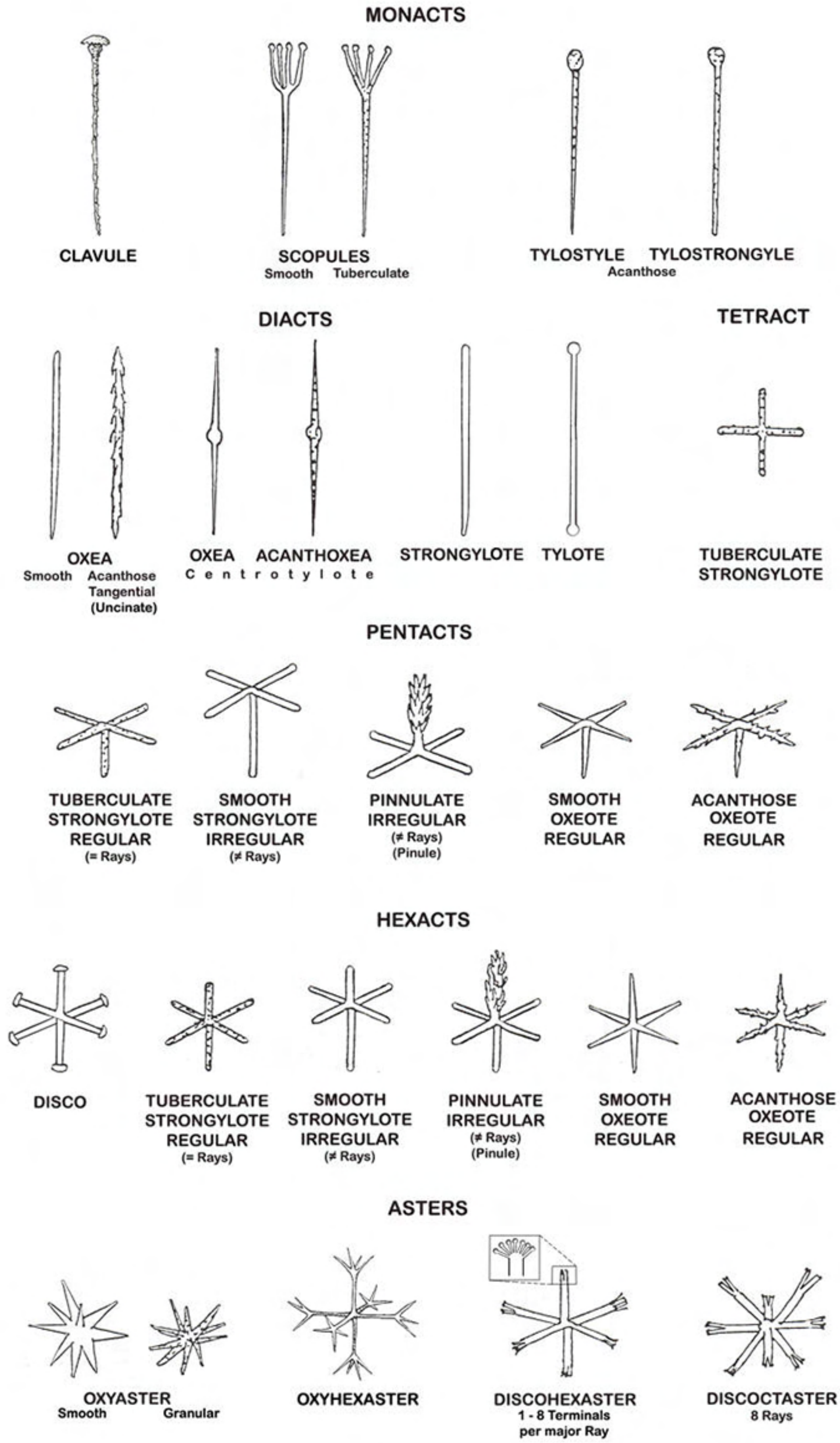


Figure 3. Examples of poriferan spicules. This list is not exhaustive, but may help to guide observations. Image from http://amirshahrokhi.christopherconnock.com.

Question 1 Generally, where are oscula placed on sponges? Why? Draw a diagram of the flow of water through a sponge. Include the pores where water enters and leaves, and the various cell layers of the animal.

Question 2 Examine the slides of *Euspongia*, and identify as many of the following features as you can: gemmules, spicules, choanocytes, amoebocytes, spongeocoel, pinacoderm, and choanoderm. Can you identify the general body plan?

Question 3 Examine the slides of *Spongilla*, and identify as many of the following features as you can: gemmules, spicules, choanocytes, amoebocytes, spongeocoel, pinacoderm, and choanoderm. Can you identify the general body plan?

Question 4 Examine the spicules of *Euspongia*, *Leucosolenia*, *Euplectella*, and *Spongilla*, and draw each. Are all spicules in each individual the same? Do the spicules of each species differ from one another? If so, how? What is the primary material that comprises the spicules in these and other demosponges?

Question 5 After examining representatives of the classes Demospongiae and Calcarea, can you identify any features that seem to differentiate these groups?

Question 6 Observe the specimens of the class Hexactinellida. What are some features that distinguish members of this group from other specimens in the lab? Consider the spicules, shape, size, etc.

Question 7 Draw or describe three specimens that preserve evidence of symbioses with other animals. What inferences can you make about these relationships (*e.g.* are they mutualistic, commensalist, parasitic, etc.)?

Notes

Phylum Cnidaria

Etymology	"nettle" (Greek: *knidē*)
Common name	*[various]*
No. Species	13,400
Habitat	marine (few freshwater); sessile or planktonic
Reproduction	sexual & asexual

Probably because cnidarians are so morphologically, developmentally, and ecologically diverse, there is no single common name for this phylum; however, Cnidaria contains several familiar groups, such as corals, anemones, and jellyfish. The name Cnidaria stems from their unique stinging structures, **cnidae**, which are housed in specialized cells called **cnidocytes**.

Cnidarians are **diploblastic** organisms: they possess a distinct endoderm and ectoderm with a jelly-like layer of **mesoglea** contained within. Most cnidarians exhibit one of two body plans: sessile – often colonial – **polyps**, or free-living **medusae.** Both of these forms are **radially symmetrical**, and many species have lifecycles which involve **alternation of sexual medusoid and asexual polypoid** generations, and unique larval forms called **planulae**.

Major Groups

- subphylum Medusozoa
  - class Scyphozoa
  - class Cubozoa
  - class Staurozoa
  - class Hydrozoa
    - order Siphonophora
- subphylum Anthozoa
  - subclass Hexacorallia
    - order Actinaria
    - order Scleractinia
  - subclass Octocorallia
- subphylum Myxozoa

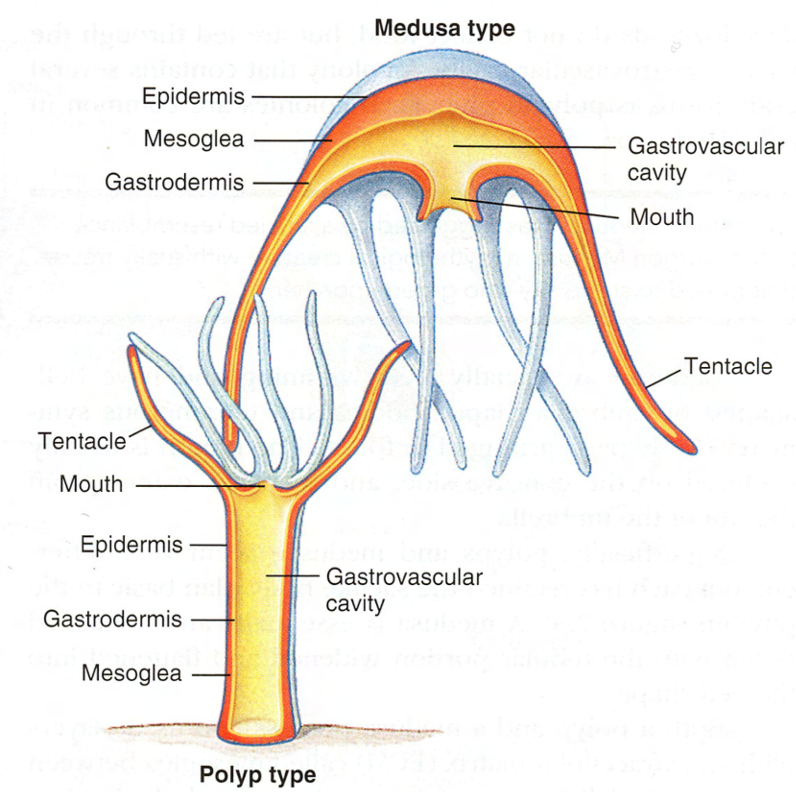


Figure 4. Comparison of the polypoid and medusoid cnidarian body plans. Image from Hickman et al., 2015. Animal Diversity.

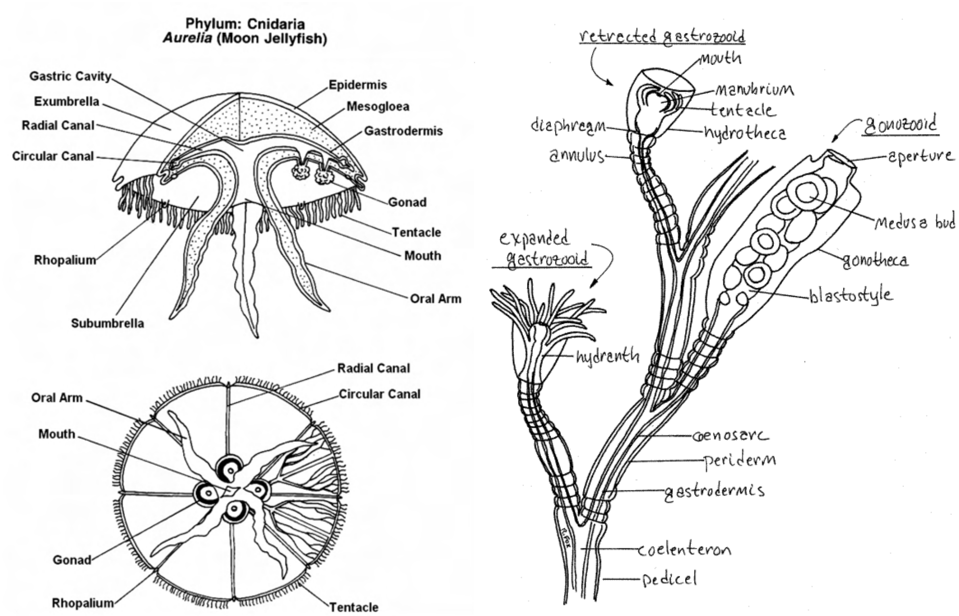


Figure 5. General body plan of the scyphozoan *Aurelia aurita* (left) and of the hydrozoan *Obelia* (right). Images from Tes Teach https://www.tes.com/lessons/mEimbaQLmxQDQA/jellyfish-intro

Question 8 Observe the lifecycle of the Moon Jelly, *Aurelia*. Using the specimens available, draw a diagram of the *Aurelia*'s lifecycle that shows how these specimens relate to one another. Wherever possible, indicate the location of the endoderm, ectoderm, and mesoglea. On the planula, indicate the blastopore; on the medusa, indicate the mesohyl/mesoglea.

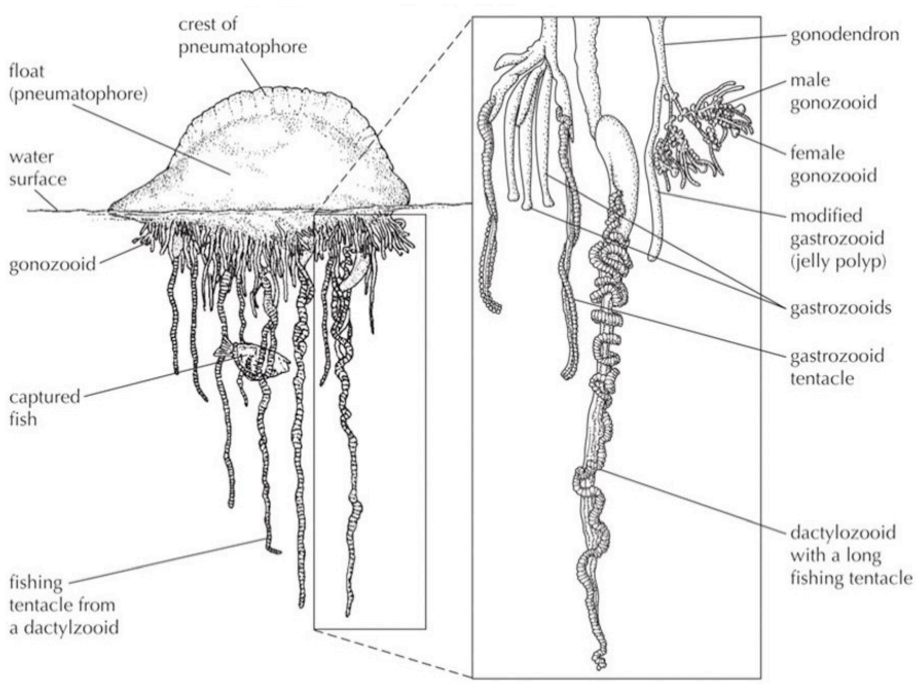


Figure 6. General body plan of *Physalia physalis.* Image from Wallace & Taylor, 1997.

Question 9 Locate the rhopalia on the *Aurelia* medusa and ephyra. What are these structures used for?

Question 10 Locate the specimens of *Obelia*. Identify the gastrozooid(s) and gonozooid(s). How do these zooids differ?

Question 11 Some of the cnidarians represented in the lab display polymorphism. What does polymorphism mean? Name at least two specimens in which this feature is present.

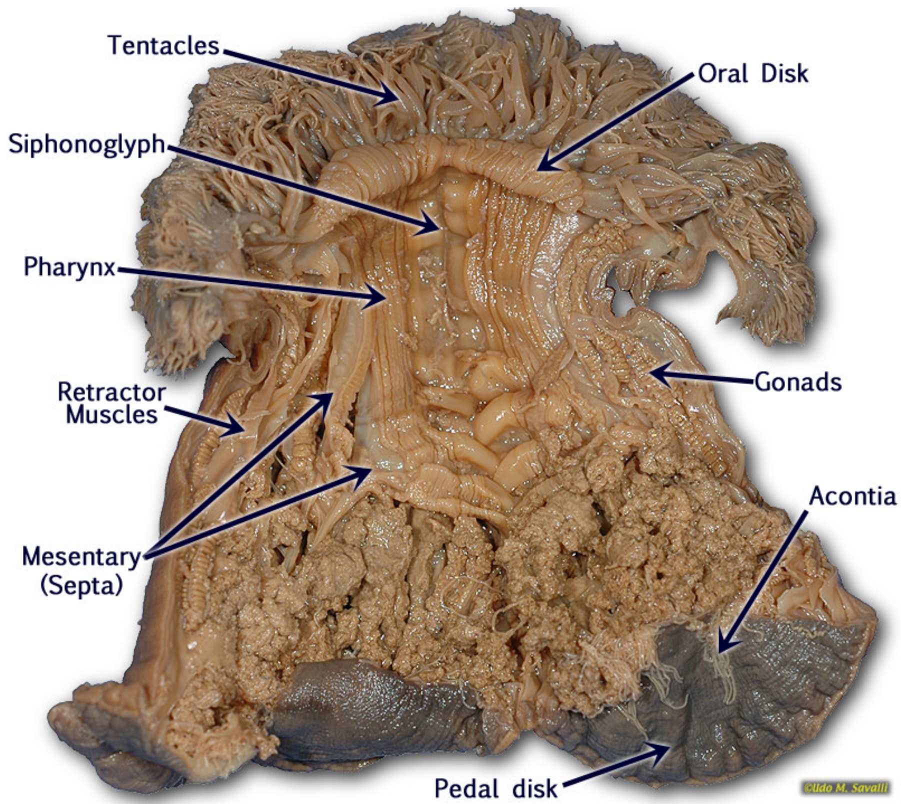


Figure 7. General body plan of *Metridium* and Image from Udo Savalli, Cornell University.

Question 12 Examine two different types of Octocorallia. What are they, and what are some similarities and differences between the two?

Question 13 Look under a stereomicroscope to find the polyps of one of the coral specimens? What do they look like? What are some differences between colonial and solitary polyps?

Notes

Phylum Ctenophora

Etymology	“comb-bearing” (Greek: *cten* + *phero*)
Common name	comb jellies
No. Species	100
Habitat	marine (mostly planktonic, some epibenthic)
Reproduction	sexual

The ctenophoran body plan is symmetrical on two axes in an arrangement known as **bi-radial symmetry**. Like members of the phylum Cnidaria, ctenophores are **diploblastic**, meaning that they possess true tissues. They also possess a **diffuse/decentralized nervous system**. However, unlike most other animals, they lack discrete circulatory and respiratory systems.

The common name for these animals comes from the eight rows of comb-like plates, called **ctenes**, which they use for locomotion. These animals also possess unique cells called **colloblasts**: sticky cells which are used to trap prey.

Major Groups

class Tentaculata

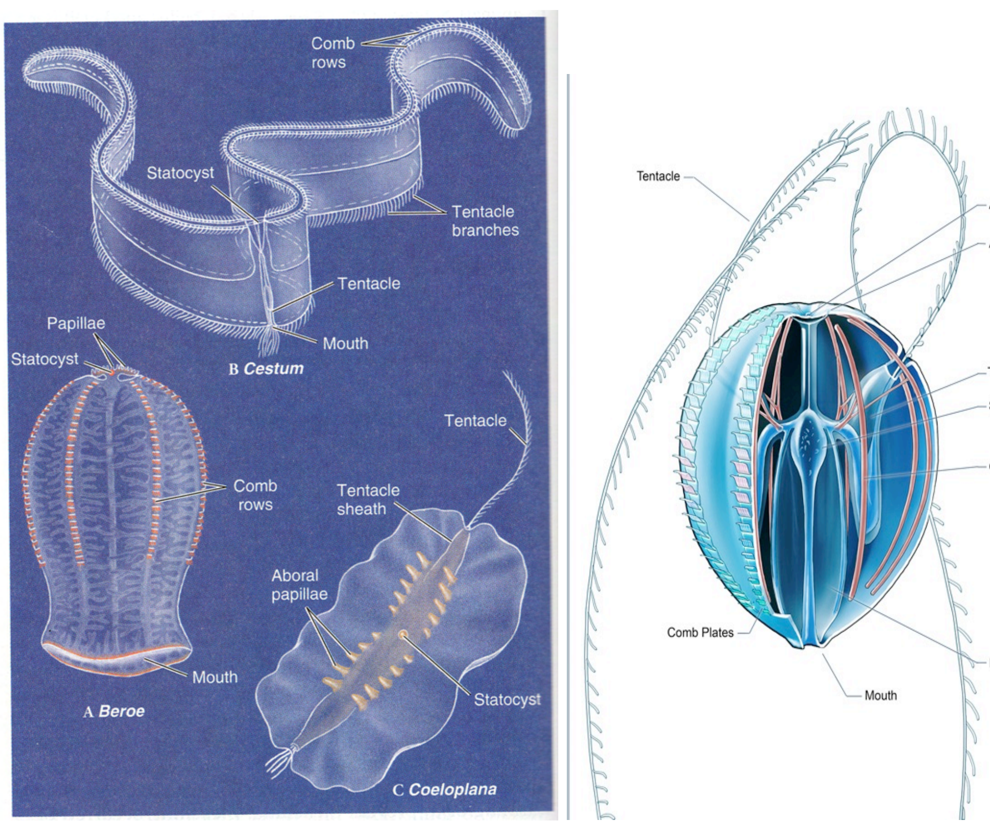


Figure 7. Bodyplans of various ctenophores (left) and general anatomy of *Pleurobrachia* (right). Images from Hickman et al., 2015 and Abiogenesis, abiogenisis.deviantart.com/art/Ctenophore-Anatomy-268989913

Question 14 Examine the specimens *Pleurobrachia*. Identify as many of the following features as possible: ctenes, comb rows, tentacles and tentacle sheaths, pharynx, mouth, statocyst, and gastrovascular canals.

Notes

LAB 2

Platyhelminthes

Phylum Platyhelminthes

Etymology	"flat worms" (Greek: *platy* + *helminth*)
Common name	flatworms
No. Species	26,500
Habitat	marine, terrestrial, freshwater, endoparasitic
Reproduction	sexual & asexual

The name Platyhelminthes stems from the dorsoventrally flattened bodies that characterize most members of the phylum. The Platyhelminthes are the first of the bilaterian phyla we will cover this semester. Like other members of the **Bilateria**, they are **triploblastic**, **bilaterally symmetrical**, and **cephalized**. Although their bodies are more complex than those of the animals we have seen so far, they lack certain body systems present in other bilaterians, such as dedicated structures for circulation and gas exchange, and a complete or through gut. They are also **acoelomate**, meaning that they lack a fluid-filled body cavity.

Most of flatworm diversity – in terms of species and body plans – is contained within the parasitic group Neodermata, which is divided into three groups: **Monogenia** (monogenian flukes), **Trematoda** (digenean and aspidogastrean flukes), and **Cestoda** (tapeworms). Because of the diversity of platyhelminth body plans, there is no definite synapomorphy that defines the phylum; however, it seems that **rhabdites** are the most likely candidate that has been identified to date.

Major Groups

Free-living flatworms ("Turbellaria") = paraphyletic
infraclass Neodermata
- cohort Monogenea
- cohort Trematoda
- cohort Cestoda

Figure 8. Platyhelminth diversity. From left to right, *Pseudobiceros* sp. (Florida Museum of Natural History); *Dugesia* (Edward Snow); *Fasciola hepatica* and *Taenia* sp. (Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.)

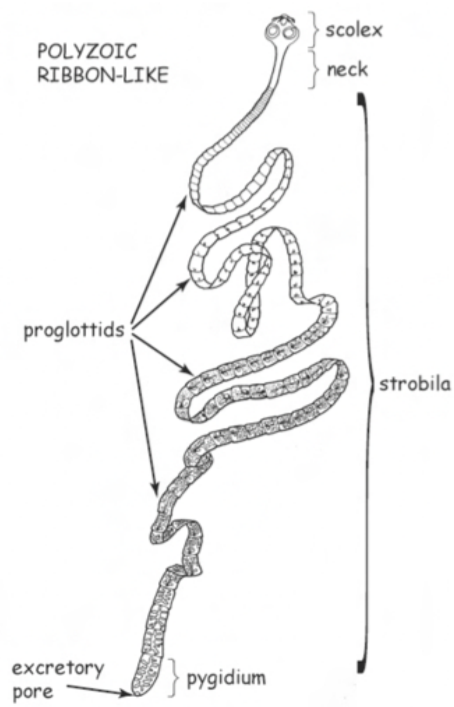


Figure 9. Cestoda, general body plan. Image from Janine Caira, UCONN

Question 1 Find the slides showing the scloleces of *Diphyllobothrium*, *Hymenolepsis*, *Echinococcus*, and *Taenia*. Draw each; label the rostellum, suckers, and bothria.

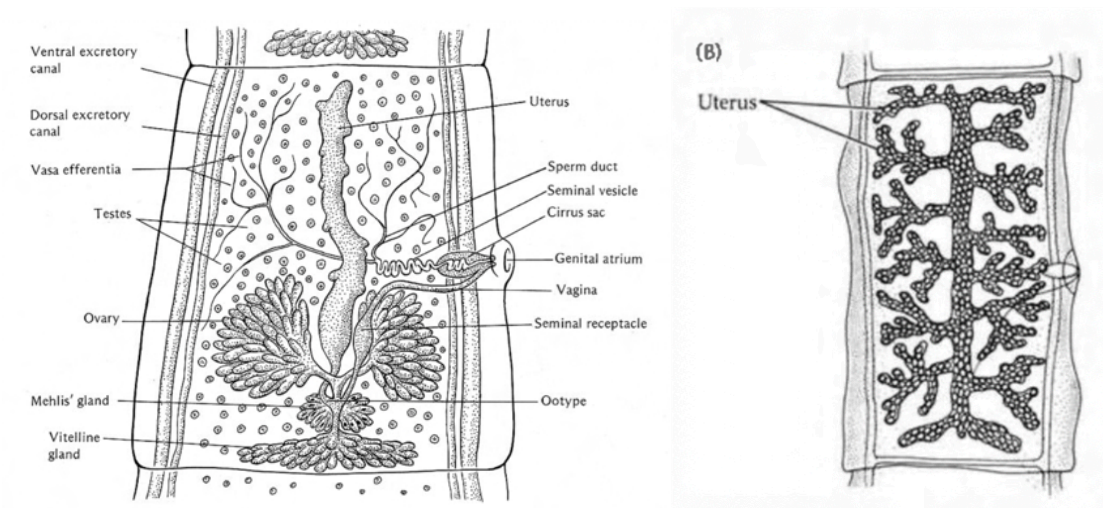


Figure 10. Tapeworm proglottids: mature (left) and gravid (right). Images from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 2 Examine the slide showing the cestode proglottid. Locate the following reproductive structures: ovary, vitelline gland, ootype, uterus, and testes. What is the function of the ovary, vitelline gland, ootype, ovary, seminal receptacle, and cirrus?

Question 3 Compare proglottids in different stages of maturity. What changes do you notice as the proglottids mature? Describe the process by which a proglottid develops, matures, and separates from the body.

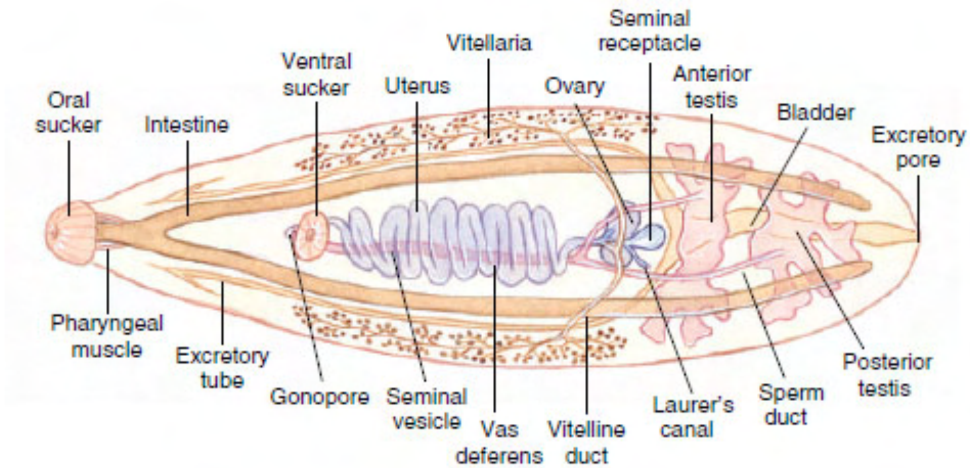


Figure 11. Trematoda, general body plan. Image from Miami University

Question 4 Compare the attachment structures of cestodes, trematodes, and monogeneans. What are the similarities and differences between them (*e.g.* in structure, size, shape, and location)?

Question 5 Examine the slides of *Haematolechus* (lung fluke) and *Clonorchis* (liver fluke). The bodies are almost entirely filled with gonads. Where are the testes, ovary, vitellaria (yolk glands) and uterus located?

Question 6 Using the slides provided, draw or describe the life cycle of *Fasciola hepatica*, the common liver fluke. Where does each life stage occur (*i.e.* definitive host, intermediate host, or external environment), and what is its role in the life cycle of the organism.

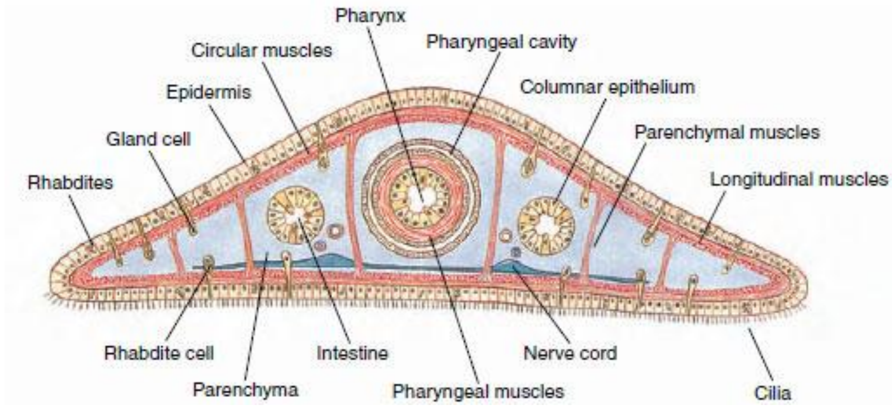


Figure 12. Cross section of a planarian. Image from Hickman *et al*., 2015

Question 7 Find the cross-section of *Dugesia*. Can you identify the pharynx, intestine muscles, nerve cord, epidermis (with cilia), and rhabdites?

Question 8 Observe the specimens of *Bdelloura* and *Leptoplana*. Find the pharynx and intestine. Which has a triclad (three-branched) gut, and which has a polyclad (multi-branched) gut? What kind of gut is present in the Planaria slides?

Question 9 What are the ear-like structures that are present in some of the free-living flatworms and what are they used for?

Notes

LAB 3

Nemertea & Annelida

In the following two labs, we will investigate the huge morphological diversity within Trochozoa: a group which includes the phyla Annelida, Nemertea, Mollusca, Brachiopoda, and Nemertea. This group is defined by a larval stage that possesses a prototroch – a ciliated ring that characterizes the trochophore larva. Beyond that, there are very few similarities between representatives of the five phyla.

Phylum Nemertea

Etymology	Greek, *Nēmertēs* (the name of a sea nymph) a.k.a. Rhynchocoela, "snout cavity" (Grk. *rhynchos* + *coel*)
Common name	ribbon worms
No. Species	1,300
Habitat	mainly marine (few terrestrial or freshwater)
Reproduction	sexual & asexual

Nemertea is the first phylum we will examine that is triploblastic, bilaterally symmetrical, and coelomate, with a complete digestive tract (through gut) and closed circulatory system. The group is defined by the possession of an eversible **proboscis** which is housed inside a **rhynchocoel**. This structure is primarily used to capture prey and manipulate prey: in some taxa the proboscis is armed with a nail-shaped **stylet**, which is used to introduce neurotoxins that subdue prey chemically as well as physically. The proboscis may extend from a dedicated pore (*i.e.* **rhynchodeum**) anterior to the mouth, or the mouth and proboscis pores may be combined.

Classes within Nemertea lack clear synapomorphies; however the two sub-classes within Neonemerta do have defining characteristics. Members of **Pilidiophora** exhibit a **pilidium** larval stage during development. Members of **Hoplonemertea** display unique proboscis characters, including stylets, and usually – but not always – have a single pore for both the mouth and proboscis.

Major Groups

class Paleonemertea
class Neonemertea
    subclass Pilidiophora
    subclass Hoplonemertea

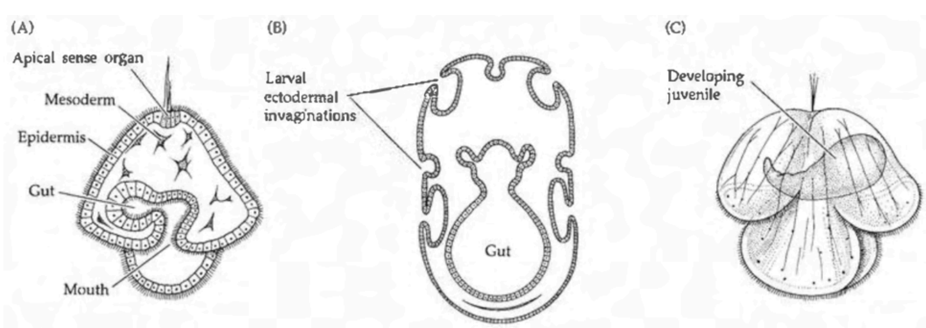


Figure 13. Development of a pilidium larva. (A) sagittal section. (B) transverse section during invagination of larval ectoderm to form adult skin. (C) late larva with juvenile formed within. Image from Brusca *et al.,* 2016 – *Invertebrates*, 3rd ed.

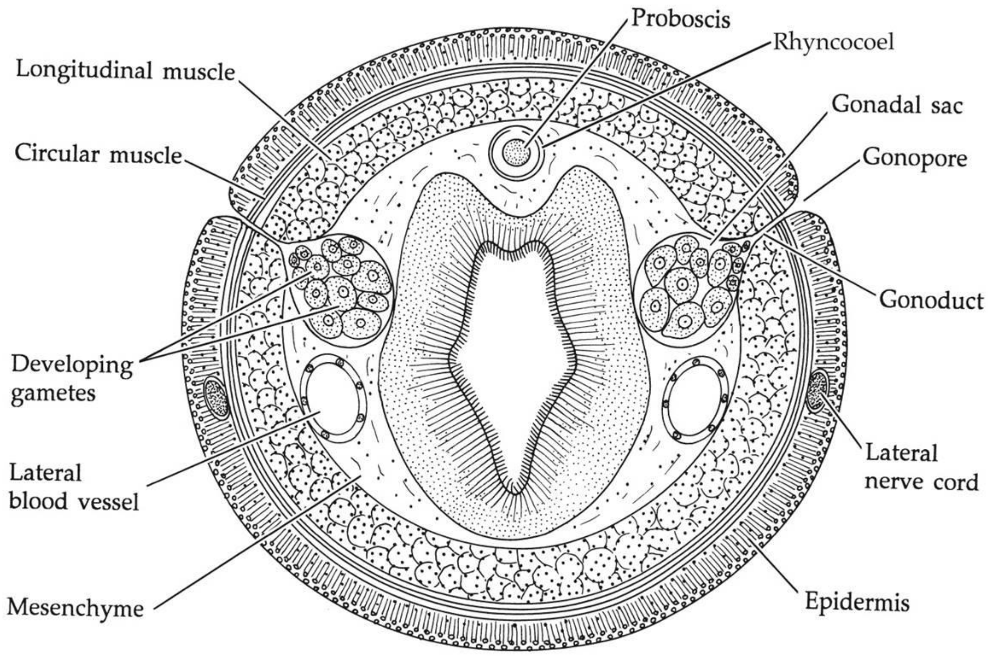


Figure 14. Nemertean proboscis in the (A) retracted and (B) extended state. Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 1 Find the slide showing the transverse section of a nemertean body. Identify as many of the following structures as you can: proboscis, rhynchocoel, nerve cords, blood vessels, intestine, circular muscles, longitudinal muscles, mesenchyme, epidermal cilia; gonads.

Question 2 Nemertea were originally thought to be acoelomate (like flatworms); however, we now this is not true. Describe the coelomic cavity/cavities of nemerteans. Can you see them in the slides?

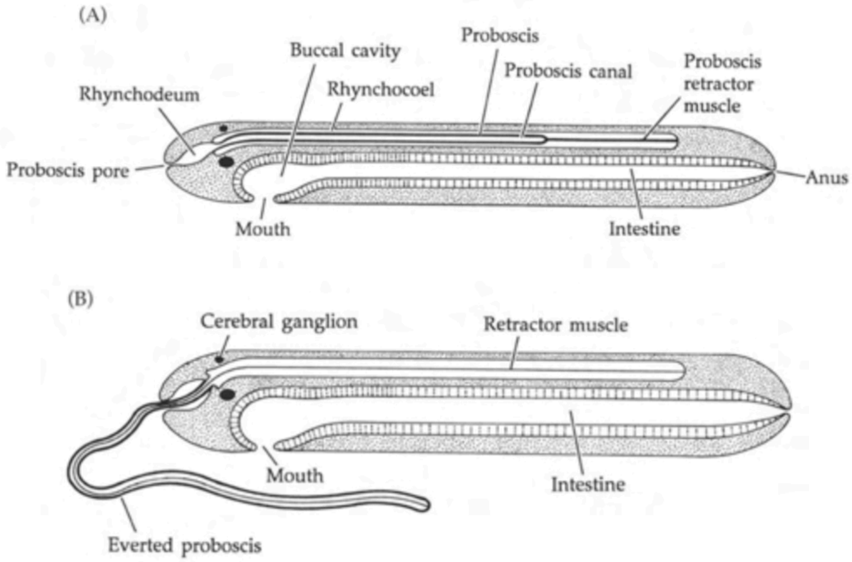


Figure 15. Nemertean proboscis in the (A) retracted and (B) extended state. Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 3 Examine the full-body nemertean specimens. Can you locate the rhynchodeum, mouth pore, and sense organs (*e.g.* eyes, cephalic slits)?

Question 4 Locate the slide showing the pilidium larva and draw it. Can you see the apical sense organ (it should appear as a small tuft of hairs)? Do you see an individual developing inside? If so, where is the embryo located?

Notes

Phylum Annelida

Etymology	Lat. *anellus*, “little ring”
Common name	segmented worms
No. Species	20,000
Habitat	marine, terrestrial, freshwater
Reproduction	sexual & asexual

The scientific and common names for this phylum come from the **metameric** organization of annelid bodies into **segments** which are **serial homologues** of one another. Segments are internally separated from one another by **septa**, though some structures continue through these boundaries, like the digestive tract, nerve cords, blood vessels, and longitudinal muscles. In addition to internal characters – such as nephridia, circular muscles and coelomic cavities – each segment has one pair of **parapodia**, which are split into two lobes: the notopodium (**dorsal**) and neuropodium (**ventral**). The notopodium and neuropodium each bear a cluster of **chaetae** (also called **setae**): stiff, chitinous bristles. Parapodia and chaetae may be specialized for a variety of functions, or may be altogether absent, depending on the group.

Before the advent of molecular phylogenetics, annelids were alternately divided according to two systems of classification, each reflecting the morphology and ecology of their members. The first system used the classes **Oligochaeta** (“few bristles”) and **Polychaeta** (“many bristles“), while the second used the classes **Errantia** and **Sedentaria** for more and less active species respectively. Today, we still use the names Errantia and Sedentaria, but with the understanding that they do not accurately reflect the biology of their members (some highly-mobile animals fall within Sedentaria, and some sessile ones fall within Errantia), and that some annelids (*e.g.* Chaetopteridae, Sipuncula, etc.) do not fall within either group.

Major Groups

clade Errantia
clade Sedenteria
clade Sipuncula
clade Amphinomidae
clade Chaetopteridae
clade Magelonidae
clade Oweniidae

Figure 16. Medicinal leech, *Hirudo verbana*.
Photo by Vincent Luk

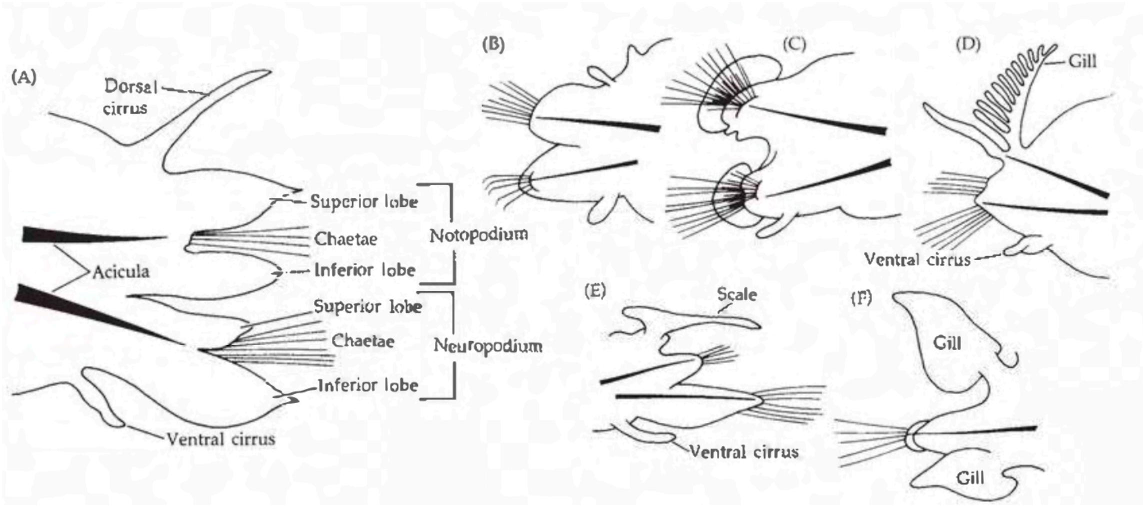


Figure 17. Annelid parapodia. (A) Stylized diagram of general parapodium anatomy; followed by examples of parapodia from several annelid taxa: (B) a glycerid with reduced lobes; (C) a nephtyid; (D) a eunicid with its modified notopodium; (E) a polynoid (scale worm) with the dorsal cirrus motified into a scale or elytron; (F) a phyllodocid with notopodia and neuropodia modified into gill blades. Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 5 What does serial homology mean? Describe at least five serially homologous features that can be found among the specimens displayed.

Question 6 Examine the slides showing the parapodia of a nereid worm (Phyllodocida). Locate the notopodium, neuropodium, dorsal and ventral cirri, and chaetae. Can you make any inferences about this animal's ecology based on the morphology of the parapodia?

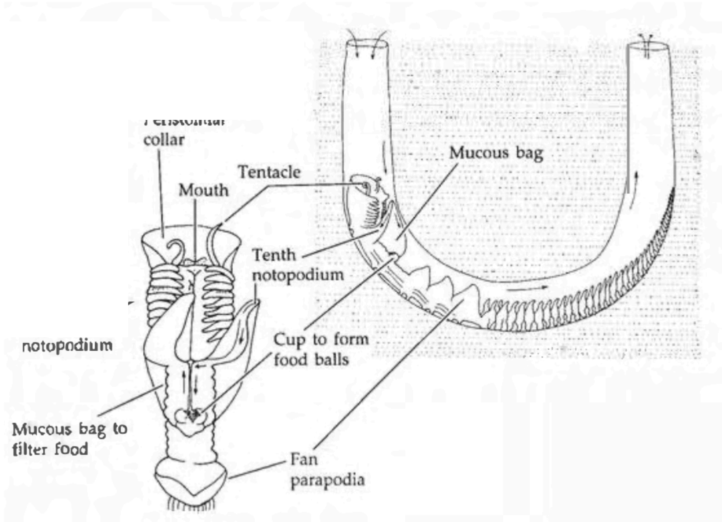


Figure 18. *Chaetopterus* sp. in its u-shaped burrow, with diagram showing details of the worm's anterior end (seen from the ventral view). Pumping of the fan parapodia generates water current (arrows) through the tube. Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 7 Find the specimens of Glyceridae (Phyllodocida). Judging by their morphology, how do you think these animals feed? Why?

Question 8 Although segmentation and chaetae are synapomorphies for the phylum, several taxa within Annelida have secondarily undergone losses or reductions of these features. Name at least three specimens in which this is the case, and describe those losses/reductions.

Question 9 Find the specimens of *Chaetopterus* (Chaetopteridae). How many separate body regions (*i.e.* groups of specimens specialized for a specific function) can you identify? What does each region do?

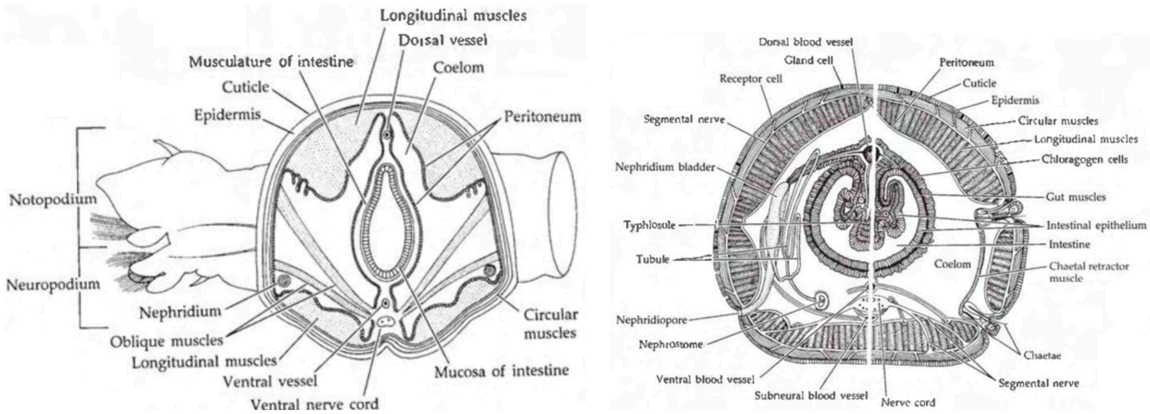


Figure 19. Cross sections of a nereid polychaete (Phyllodocida) and an earthworm (Clitellata). Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 10 Observe the specimen of *Sipunculus* (Sipuncula). Members of Sipuncula were once thought to represent their own phylum separate from Annelida. What are at least three ways in which they differ from other annelids?

Question 11 Which characters – if any – are common to the tube-dwelling annelids on display? What about taxa which are predators, parasites, or burrowers?

Question 12 Find the slides showing cross sections of an earthworm (Clitellata) and *Lumbrinereis* (Eunicida). Identify as many of the following structures as you can: circular muscles, longitudinal muscles, coelom, nephridia and nephridiopores, chaetae, blood vessels, nerve cords, intestine. What differences do you notice between the two specimens?

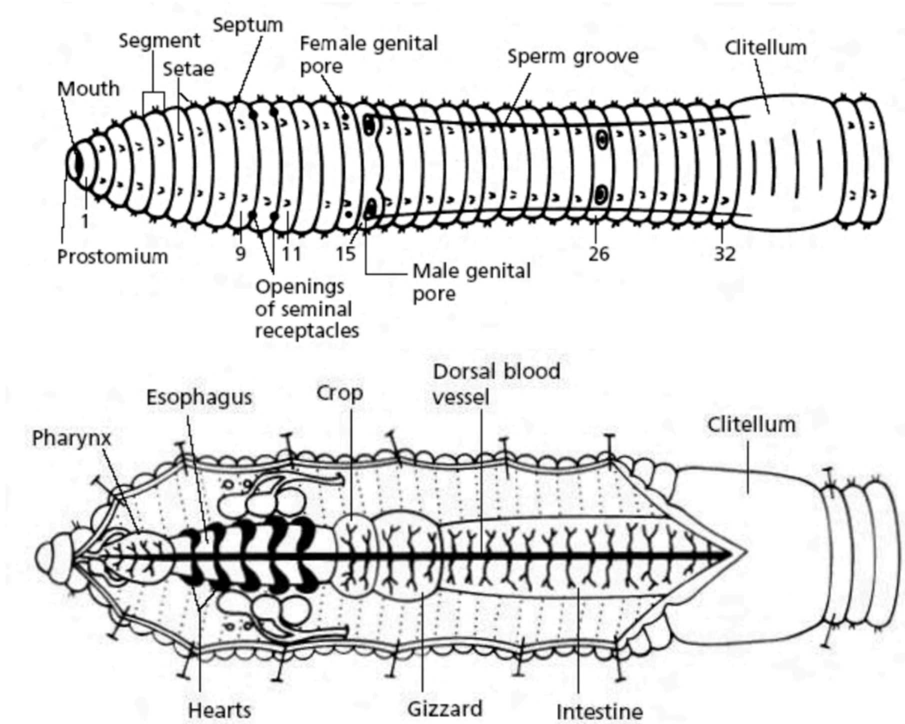


Figure 20. Earthworm external (top) and internal (bottom) anatomy, shown from the ventral side.

Question 13 Locate the earthworm specimen (*Lumbricus* sp.). Are these animals gonochoristic or hermaphroditic? Can you locate the gonopores?

Question 14 Together, oligochaetes (earthworms and their relatives) and Hirudinea (leeches and their relatives) comprise the class Clitellata, which is defined by the presence of a clitellum – a glandular region involved in secreting the cocoons into which eggs are laid. Can you locate this character in all representatives of these groups?

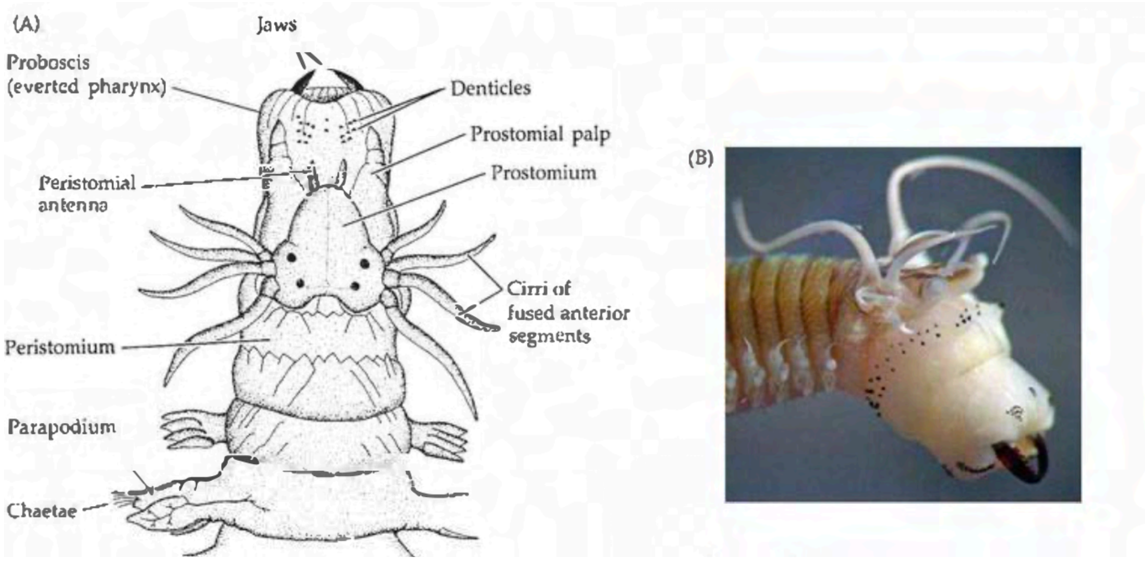


Figure 21. The eversible pharyngeal jaws of annelids.
(A) *Nereis* (Phyllodocida) with jaws everted. (B) *Perenereis* (Phyllodocida) with jaws everted.
Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 15 Look at the various specimens of leeches (Hirudinida) available in the lab. Some species are blood-feeders while others are predatory. Can you find any morphological characteristics that differentiate predatory from blood-feeding taxa?

Question 16 Compare the feeding structures of parasitic, deposit feeding, filter feeding, and predatory annelids. How do these structures reflect each taxon's diet?

Notes

LAB 4

Brachiopoda & Mollusca

Phylum Brachiopoda

Etymology	"arm feet" (Grk. *brachium* + *poda*)
Common name	lamp shells
No. Species	400
Habitat	marine
Reproduction	sexual

Brachiopoda is a member of the **Lophophorata**, along with two other phyla: Bryozoa and Phoronida. Lophophorata is defined by the presence of a **lophophore**: a ciliated, tentaculate feeding structure surrounding the mouth. Cilia on the lophophore create a current that directs water – and the food suspended therein – toward the mouth for ingestion. All members of the Lophophorata are **sessile**, **benthic**, **suspension-feeders**, and most of them secrete protective casings, such as tubes or skeletons.

Although there are only ~400 extant species of Brachiopoda, there are over 15,000 known fossil species, dating back at least as far as the Cambrian Period. In this phylum, the protective casing takes the form of two shells, or **valves**, on the dorsal and ventral sides of the body. These shells are secreted by the **mantle**, and articulate either via hinges (in the subphylum **Rhynchonelliformea**), or using the animal's musculature (in all other brachiopods). The **pedicle**, a stalk-like attachment structure, extends posteriorly from the ventral valve, and is generally buried in the substrate, leaving only the valves exposed. During feeding, the valves open, filling the mantle-cavity with water. The brachiopod lophophore takes the form of two tentacle-bearing arms that are alternately supported by hydrostatic pressure, or by a rigid structure called the **brachidium**. The lophophore extends into the mantle cavity, creating the current that allows the animal to feed, and passing food particles to the digestive system. Most of the viscera – including the better part of the digestive system – is separated from the mantle cavity by the anterior body wall.

Major Groups

subphylum Linguliformea (valves not hinged; pedicle present)
subphylum Craniiformea (valves not hinged; pedicle not present)
subphylum Rhynchonelliformea (valves with a hinge)

Figure 22. Extant Brachiopoda. LEFT: Brachiopod *in situ* with open valves showing spiraled lophophore. (image by Alexander Semyonov) RIGHT: *Terebratalia transversa* with valve removed to show lophophoral arms. (image by Alex Heyman on iNaturalist)

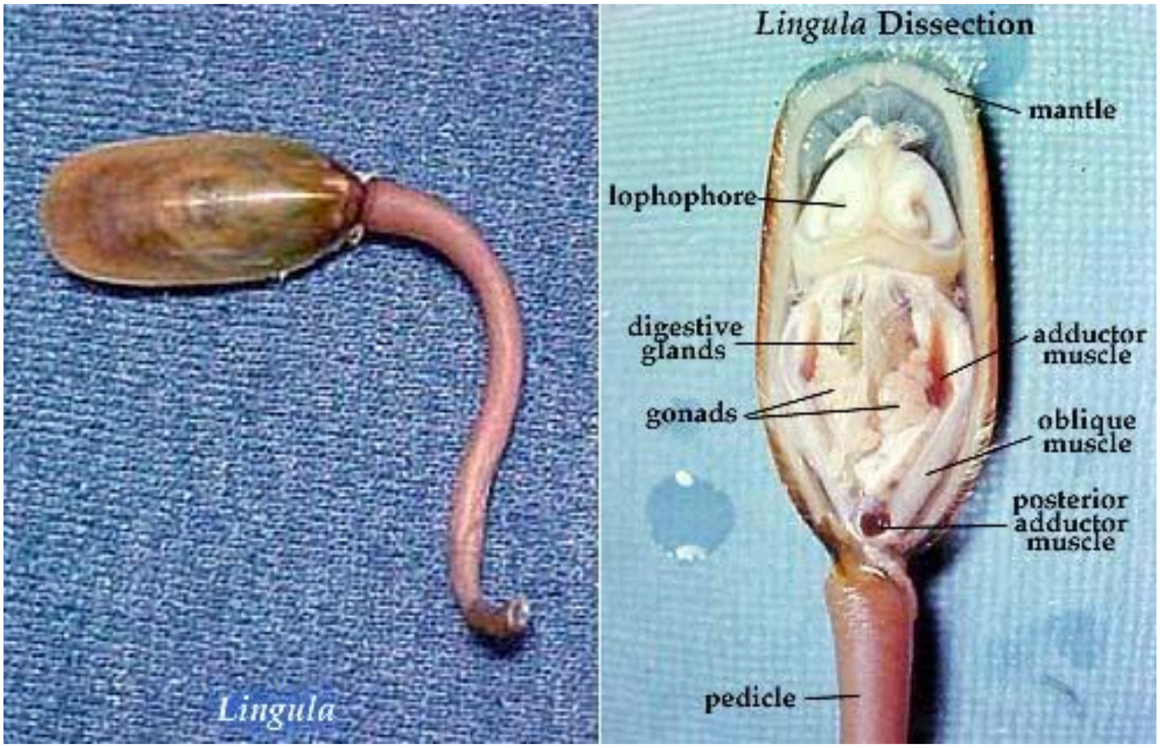


Figure 23. The brachiopod *Lingula*: (left) external morphology, and (right) internal morphology.

Question 1 How to the valves of *Lingula* articulate? Do the valves have a hinge, or do they only use musculature? What about *Terebratalia*?

Question 2 Examine the specimens of *Lingula* and *Terebratalia*: locate as many of the following features as you can: lophophore, mantle, pedicle, adductor muscles, gonads, mouth.

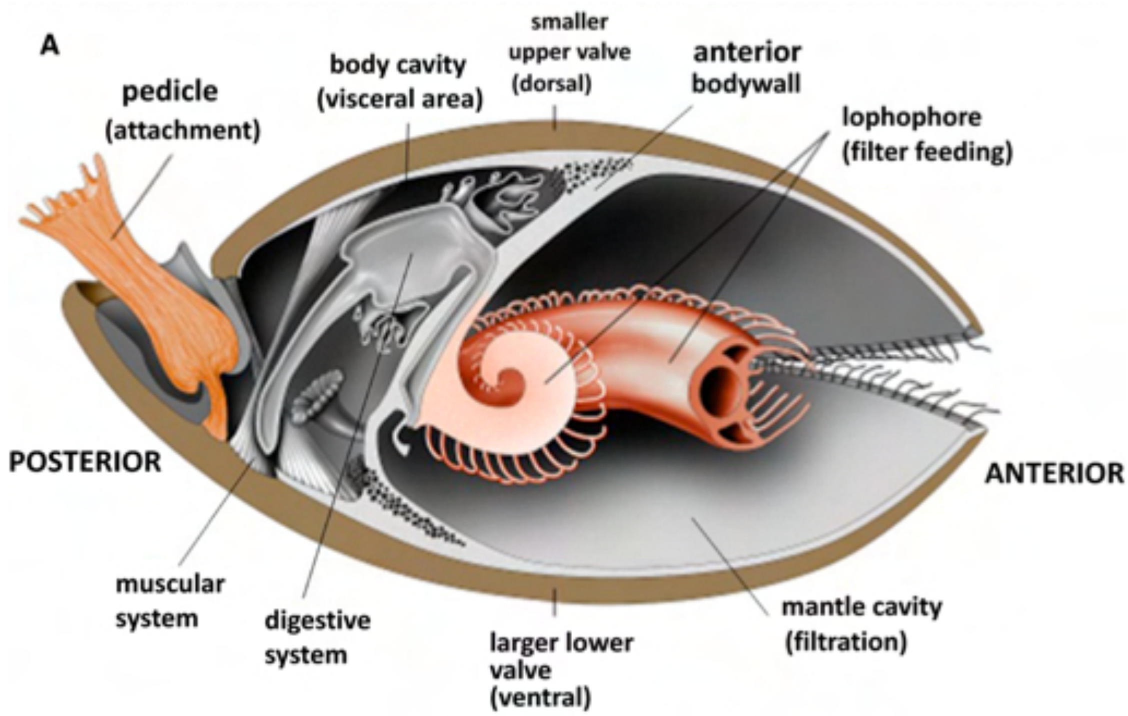


Figure 24. Cross section of a brachiopod showing internal anatomy. Image from Harper *et al*., 2017 – *Palaeontology*

Question 3 Brachiopods share many similarities with bivalve molluscs. So much so, in fact, that competition with bivalves following the End-Permian Mass Extinction is likely to be one of the reasons why brachiopods is far less diverse today than in the fossil record. Examine the specimens of Brachiopoda and Bivalvia, and contrast the morphology of their shells, their mechanism of feeding (and the structures involved), and their method of attachment to the substrate.

Notes

Phylum Mollusca

Etymology	"the soft ones" (Grk. *malákia*, "softness")
Common name	*[various]*
No. Species	80,000
Habitat	marine, freshwater, terrestrial
Reproduction	sexual

Mollusca is the second largest animal phylum, and the diversity of species is appropriately paralleled by a diverse assemblage of forms. Although these animals exhibit a variety of body plans, they are always organized into three regions: the **head**, **visceral mass**, and **foot**. The visceral mass houses the internal organs, and is covered by the **mantle**: a sheet-like organ that forms the dorsal body wall and secretes the shell when one is present. The space between the mantle and the body – the **mantle cavity** – is open to the external environment, and typically houses the **ctenidia** (gills) in addition to serving as the space where gametes and waste exit the animal (via the gonopores, anus, and nephridiopores respectively). Opposite the mantle is the foot, a muscular organ used for locomotion.

Molluscs feed using a **radula**: a toothed, tongue-like strap used for rasping or tearing foodstuffs, which is supported by the muscular **odontophore**. Like other members of the Trochozoa, mollusc development features a **trochophore larva**. Bivalves and gastropods have an additional unique larval stage, the free-swimming **veliger**, which may alternatively take the form of a parasitic **glochidium** in some freshwater bivalves.

Major Groups

class Aplacophora (spicule worms)
class Monoplacophora
class Polyplacophora (chitons)
class Scaphopoda (tusk shells)
class Gastropoda (snails, slugs, limpets)
class Cephalopoda (squids, octopuses, cuttlefish, nautiluses)
class Bivalvia (oysters, clams, scallops, mussels, etc.)

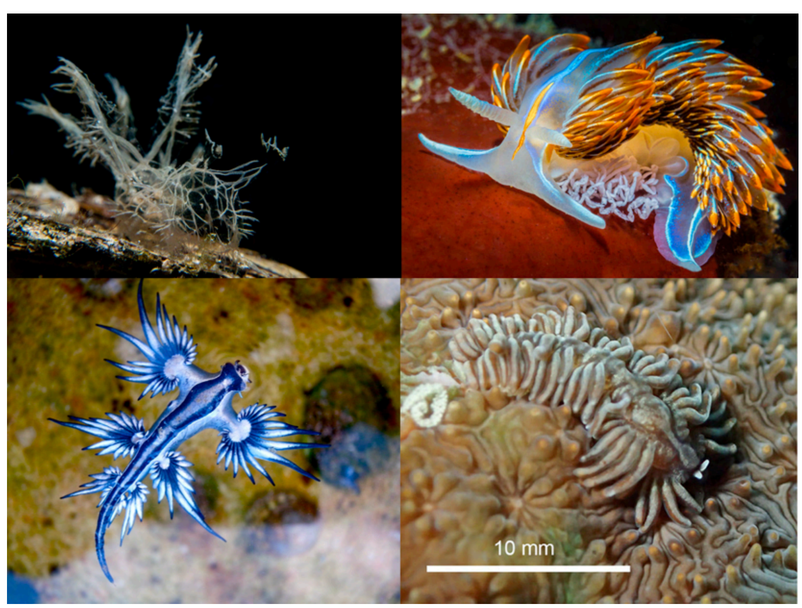


Figure 25. Sea slug diversity: (top left) ghost nudibranch, *Melibe* sp. by "nofundiving"; (top right) *Phestilla viei* from Mehrotra et al., 2020 – Marine Biodiversity; (bottom left) *Glaucus atlanticus* by Sylke Rohrlach; (bottom right) *Flabellina triophina* – Jett Britnell

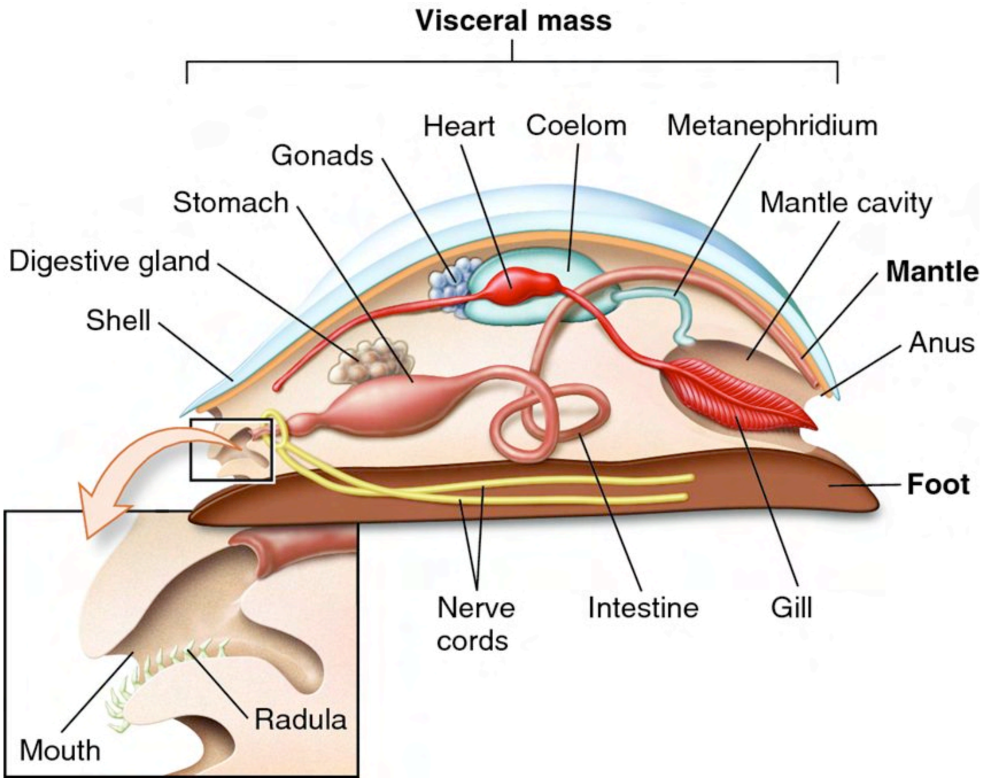


Figure 26. Generalized anatomy of a mollusc (shown in cross section)

Question 4 Examine the limpet and chiton specimens; locate the mouth and anus in each. Why does the position of the anus differ between these two taxa?

Question 5 Find the abalone specimen. These animals move relatively slowly, grazing on microorganisms that cover the substrate. Like some other taxa, including members of Lophophorata, this lifestyle can result in problems with fouling. How do you think abalones have solved this problem, and what evidence did you use to reach this conclusion?

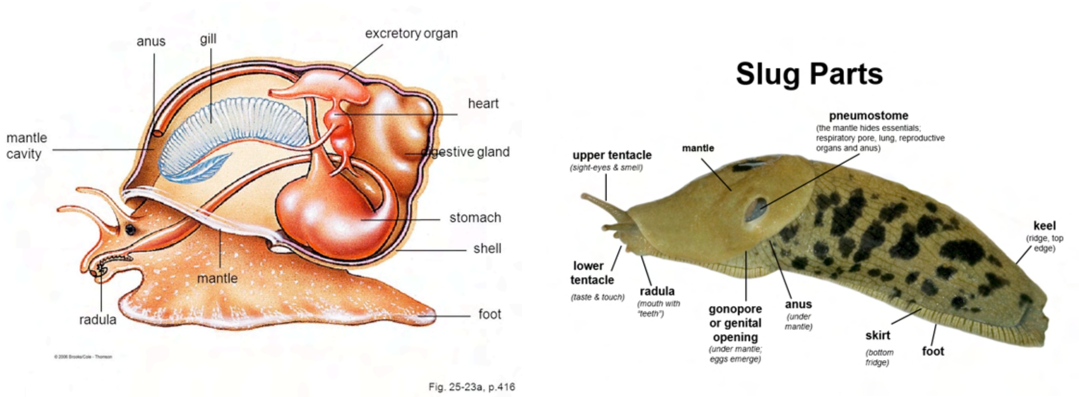


Figure 27. Generalized anatomy of gastropod taxa: (left) a snail shown in cross section; (right) a terrestrial slug – image from Jeffrey C. Miller & Amy. J. Dreves, Oregon State University

Question 6 Locate the mantle cavity in as many gastropods as you can. Which structures are typically found in the mantle cavity? Where is this cavity located on taxa which have lost their shells (*e.g.* terrestrial slugs)?

Question 7 Examine the specimen of *Aplysia* (Gastropoda). Can you find a shell?

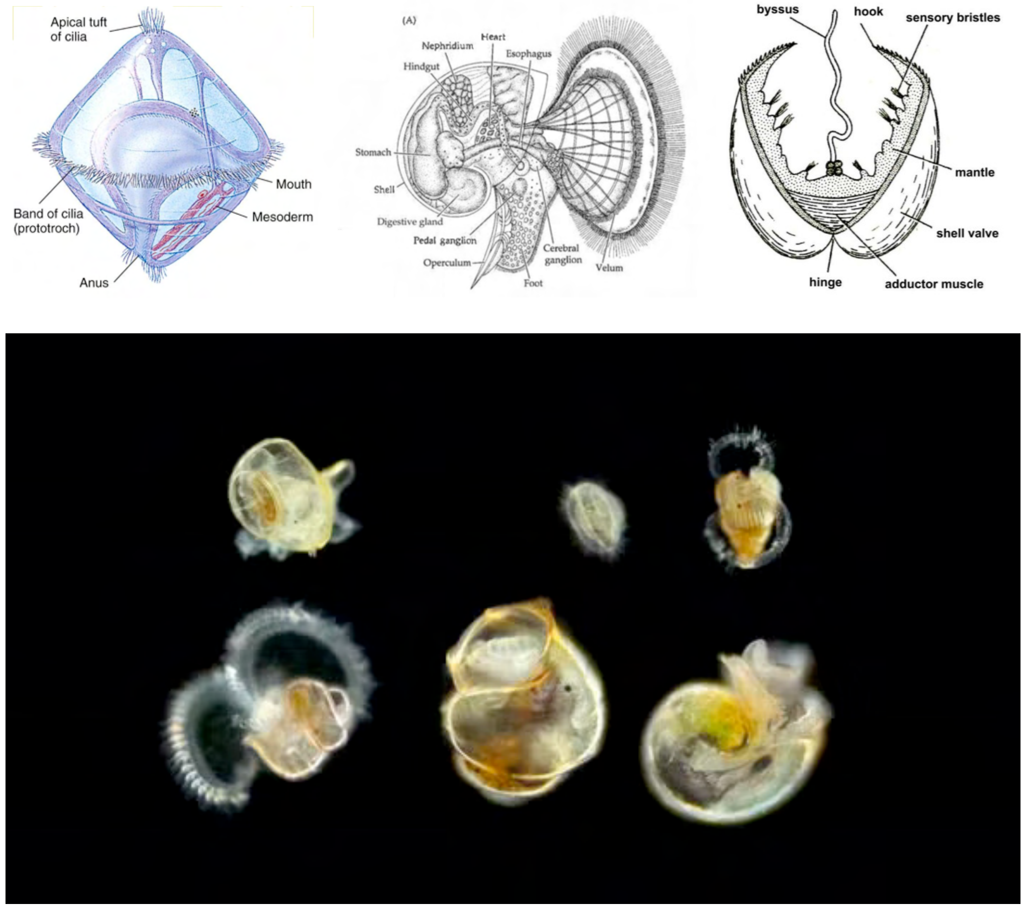


Figure 28. Top (left to right): generalized mollusc trochophore; gastropod veliger, side view (image from Brusca *et al*., 2016); glochidium larva (image from Invertebrate by Kotpal). Bottom: various mollusc veligers

Question 8 Observe the slides of the trochophore, veliger, and glochidium larvae. What role does each type of larva play in an animal's life cycle? How does their morphology reflect this?

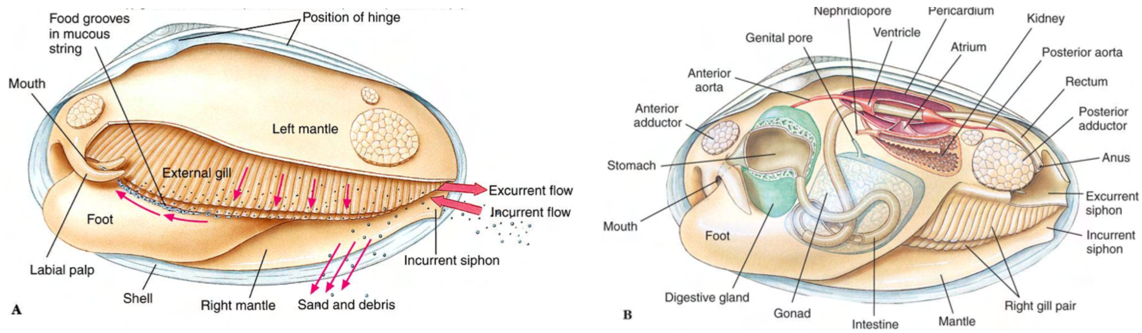


Figure 29. Bivalvia anatomy: (left) mantle cavity, showing structures involved in filter feeding; (right) internal anatomy

Question 9 Examine the various bivalve specimens. How does filter feeding work in these organisms? Can you locate the ctenidia, foot, siphons, mantle, visceral mass, and labial palps in any of the taxa?

Question 10 Locate the scaphopod specimen. What are three ways in which these animals differ from most gastropods? How are Scaphopoda situated in the sediment? Describe the flow of water through their shell.

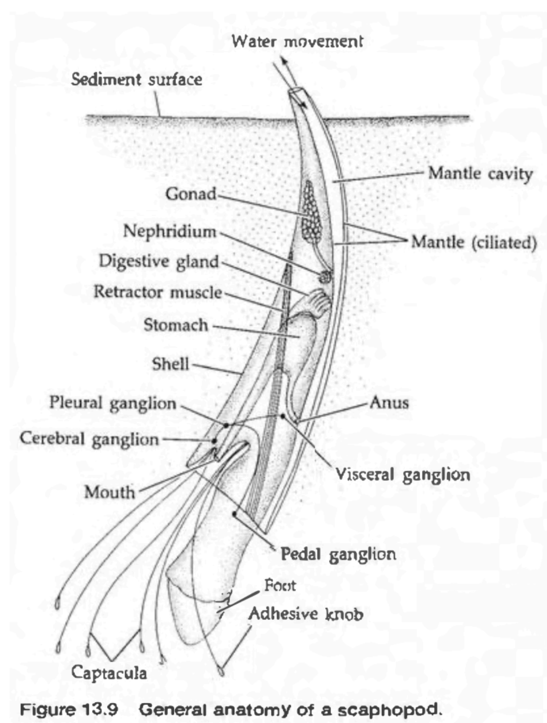


Figure 30. Diagram showing general anatomy of Scaphopoda. Image from Brusca *et al*., 2016 – *Invertebrates,* 3rd ed.

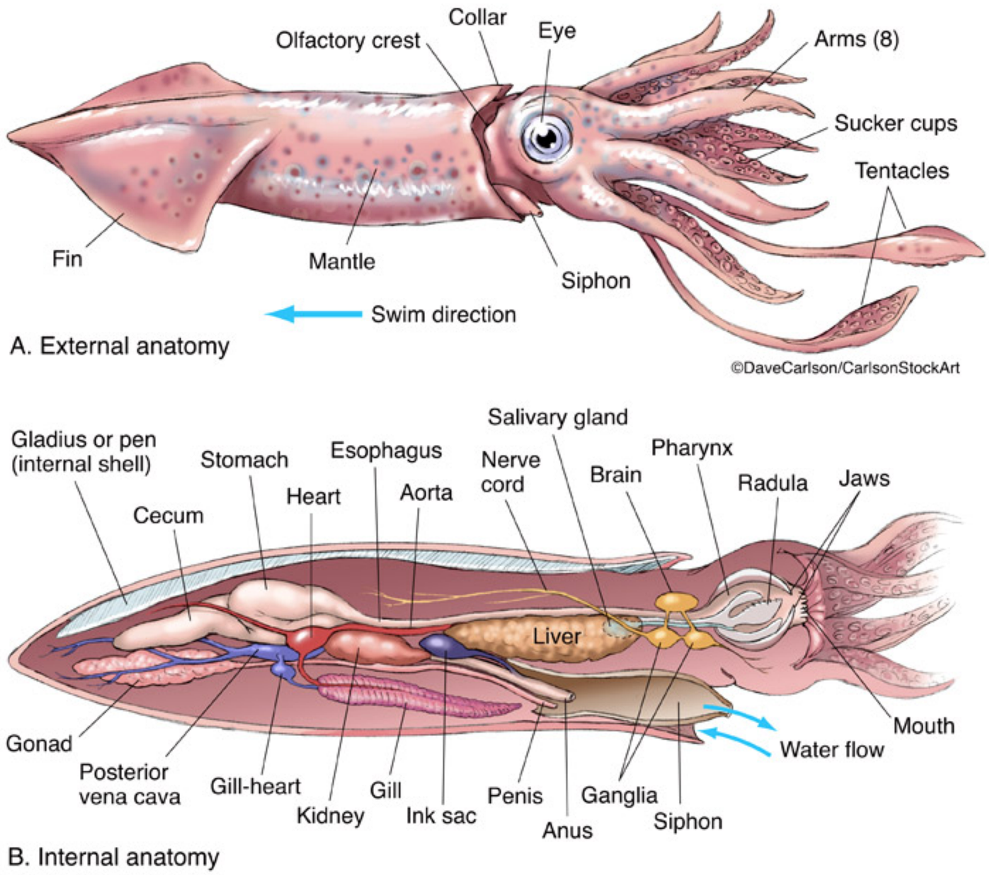


Figure 31. Anatomy of a squid (Cephalopoda), image by Dave Carlson.

Question 11 How does the feeding apparatus of cephalopods differ from that of other molluscs? Why might this be the case?

Question 12 Look at the various cephalopod. How are the anteroposterior and dorsoventral axes oriented when the animal is in motion? How does this differ from the other molluscs on display?

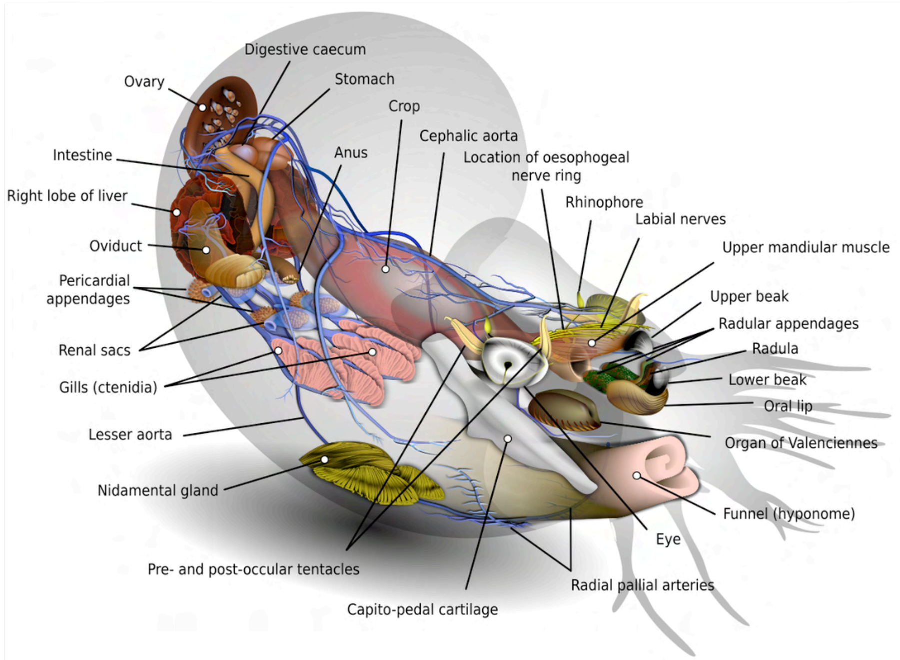


Figure 32. Anatomy of a nautilus (Cephalopoda).

Question 13 Examine the dissected squid specimens, and locate as many of the following structures as possible: mantle, funnel, buccal mass (with beak and radula), brain, gonads, pen (shell), esophagus, stomach, intestine, heart, ctenidia (gills), ink sac

Question 14 Observe the *Nautilus* specimens. How does its overall morphology differ from that of other cephalopods? What role does the shell play in locomotion, and how does it work?

Question 15 Look at all the specimens that have shells. List at least four functions different functions that these shells have.

Question 16 Name at least four different taxa that have lost, reduced, or internalized their shells. How do you think these animals may have compensated for the loss of this protective structure?

Notes

LAB 5

Rotifera, Nematoida & Scalidophora

Phylum Rotifera (Gnathifera)

Etymology	"wheel-bearing" (Lat. *rota* + *fera*)
Common name	wheel animals & spiny-headed worms (Acanthocephala)
No. Species	3,200
Habitat	marine, freshwater, semiterrestrial, parasitic
Reproduction	sexual, asexual

Rotifera is one of three phyla that makes up the clade **Gnathifera**. Like other members of this group, they have a complex pharyngeal jaw apparatus. The unique pharyngeal structure in rotifers – called the **mastax** – is comprised of **trophi** (jaws). Many species also possess a **corona**: a ciliated circumoral organ used to facilitate feeding, typically by generating current to draw food particles toward the mouth. The wheel-like appearance of this organ gives the phylum its common name.

Free-living rotifers (class Monogononta and subclass Bdelloidea) are small: generally under 1mm in length. Their bodies are comprised of a head (which includes the corona), trunk, and foot (used for temporary or permanent attachment to the substrate). They display a range of ecologies and feeding modes: they may be marine, freshwater, or semiterrestrial (inhabiting damp areas, such as mosses, on land); solitary or colonial; motile or sessile; and predatory or suspension feeding. Many species alternate between sexual (**mictic**) and asexual (**amictic**) reproductive modes on a seasonal basis.

Members of the subclass **Acanthocephala** differ dramatically from other members of the Rotifera. They are macroscopic – with some species exceeding 60 cm in length – and all are endoparasitic. Most of their body systems are highly reduced (*e.g.* nervous system) or entirely absent (*e.g.* digestive and circulatory systems). Like many other parasites, their bodies are largely dominated by reproductive organs. They can be readily identified by the large, hooked, retractable **proboscis**, which is used to anchor the worms into their host's intestinal walls, and which gives the subclass its name.

Major Groups

class Monogononta
class Hemirotatoria
- subclass Bdelloidea
- subclass Acanthocephala

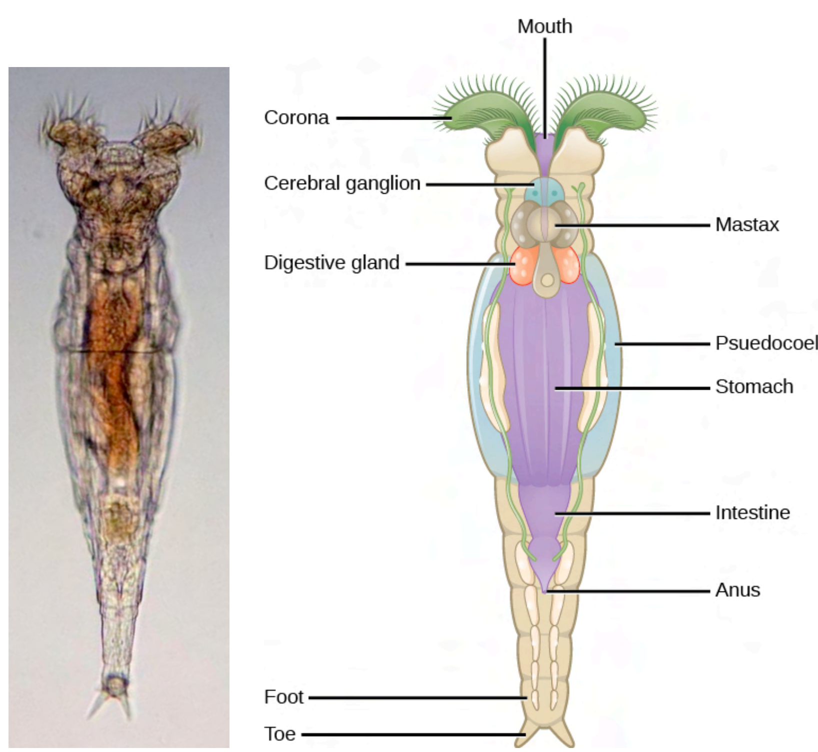


Figure 33. Photo (left) and schematic (right) of a free-living rotifer. Photo by polaroidia (cloudynights.com)

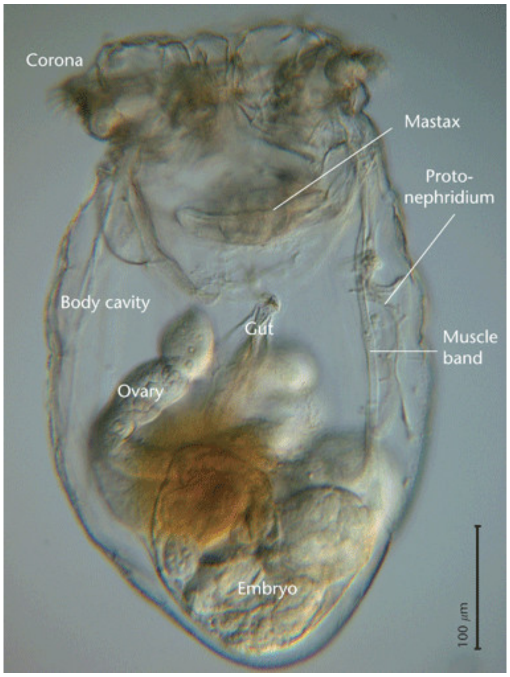


Figure 34. Live specimen of *Asplachna* sp. Image from Wallace and Smith, 2013 – *Encyclopedia of Life Sciences*

Question 1 Find the slides of the free-living rotifer *Asplachna* sp. Locate the corona, mastax, and any other internal structures you can find. Which body region commonly found in other free-living rotifers is missing from this taxon? What might that indicate about its ecology?

Question 2 Can you find eggs inside any of the *Asplachna* sp. and *Rotaria citrina* specimens? What are the two types of eggs free-living rotifers produce? What is the difference between these two egg types and when might each be produced?

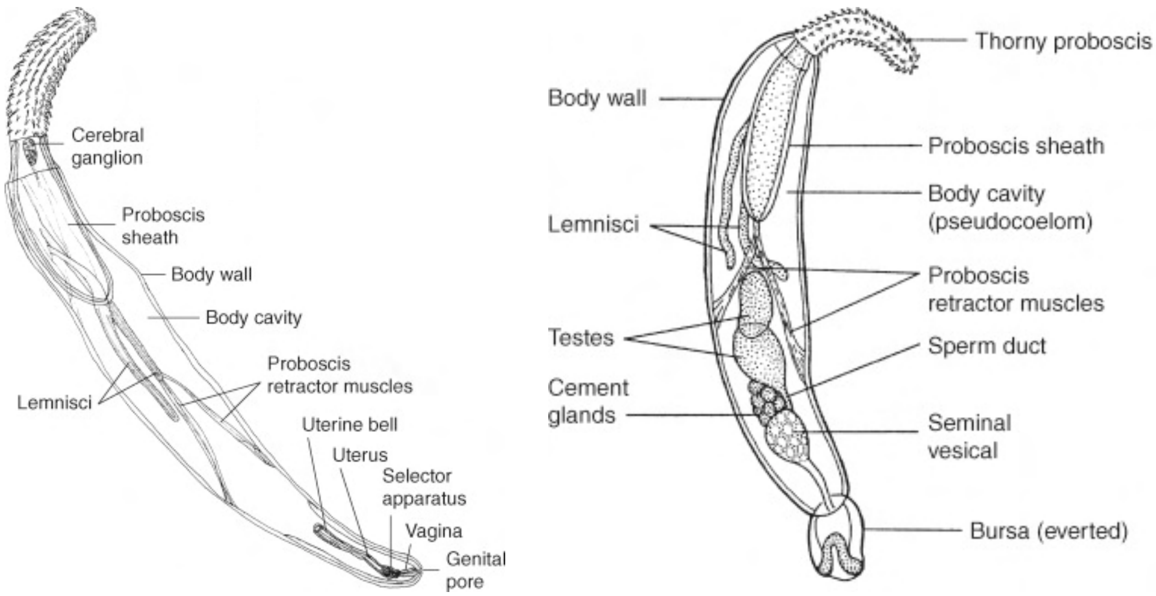


Figure 35. Female (left) and male (right) Acanthocephala (*Leptorhynchoides thecatus*). Illustrations by L. Meszoly.

Question 3 Locate the specimen showing Acanthocephala *in situ* within a host. What structure do these animals use to attach to their hosts? Draw or describe it.

Question 4 Examine the slides and models of Acanthocephala. Describe at least three ways in which they differ from free-living members of the same phylum.

Notes

Phylum Nematoda (Nematoida)

Etymology	"thread resembling" (Grk. *nema* + *-odes*)
Common name	roundworms, threadworms
No. Species	25,000
Habitat	marine, freshwater, terrestrial, parasitic
Reproduction	sexual

Nematodes are likely the most abundant animals on Earth. With 25,000 species currently described, Nematoda is the fourth largest animal phylum (after Arthropoda, Mollusca, and Platyhelminthes), but the undescribed diversity within this group is undoubtedly staggering – some have estimated that the true number of species may be as much as 1 million.

Together with Nematomorpha, Nematoda comprises the clade **Nematoida**. One of the most notable features of these animals is their thick, multi-layered cuticle, which helps their bodies keep their shape and exist in some harsh environments. Because of this, their **pseudocoelomate** bodies are characteristically round in cross section. Nematoda possess **renette cells**: unique excretory structures which connect directly to a ventral excretory pore located part way along the length of the body. Nematodes possess **epidermal cords**: areas of thickened epidermis that project inside of the body. These cords house the nerve cords (dorsal and ventral), and the excretory canals (lateral). Nematoda exhibit two unique sensory structures: **amphids**, located anteriorly, and **phasmids**, located posteriorly. The mouths of nematodes are surrounded by lips, which often bear sensory papillae. The lips may be modified with projections of the cuticle to facilitate different feeding modes, including deposit feeding, scavenging, predation, and parasitism of plants and animals.

Major Groups

class Chromadorea (amphids pore-like or slit-like; may be elaborated into coils/spirals)
class Enoplea (amphids pocket-like)

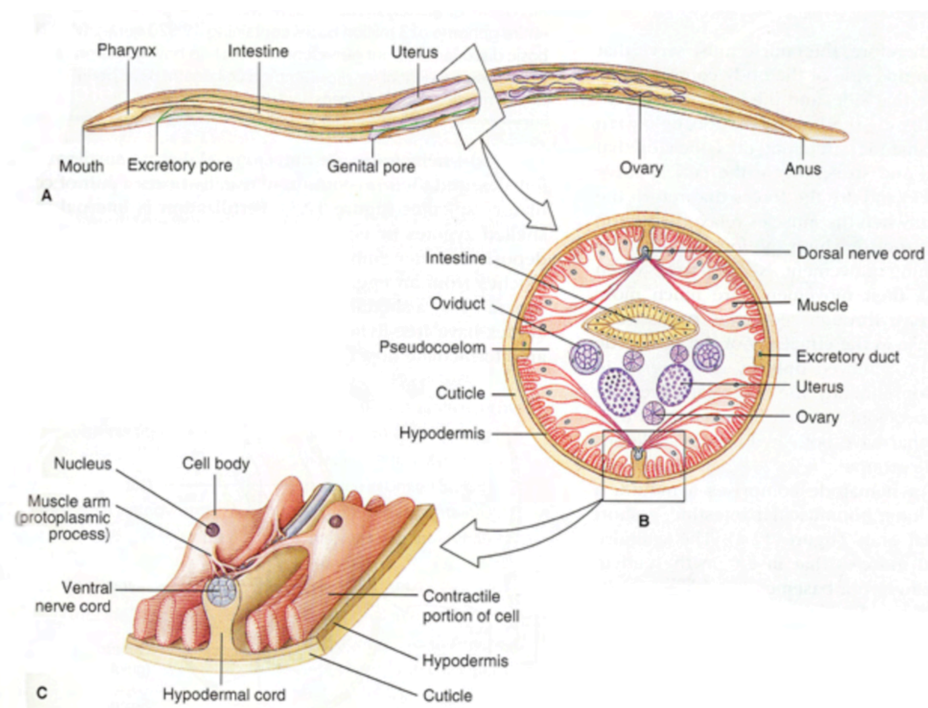


Figure 36. Nematoda anatomy represented by a female specimen of *Ascaris* sp. (A) Full body, showing digestive and reproductive systems. (B) Cross section through the body. (C) Detail of the body wall showing epidermal cord, cuticle, and musculature. Image from Hickman *et al*., 2015 – *Animal Diversity*

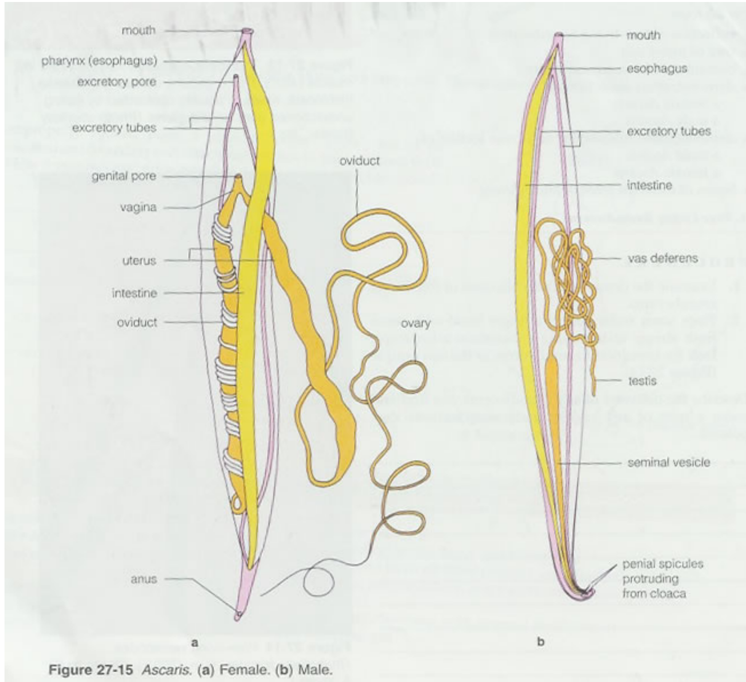


Figure 37. Female (left) and male (right) specimens of *Ascaris suum*. Illustrations by L. Meszoly.

Question 5 Observe the full-body specimens of *Ascaris suum*. What are the long masses inside the body?

Question 6 Find the slide showing the hookworm *Ancylostoma* sp. Are you looking at a male or female? How can you tell? Describe the differences between male and female nematodes in terms of reproductive structures and overall morphology.

Question 7 As you examine the specimens, try to locate the amphids and phasmids. Where are these structures located, what are they used for, and on which specimens are they visible?

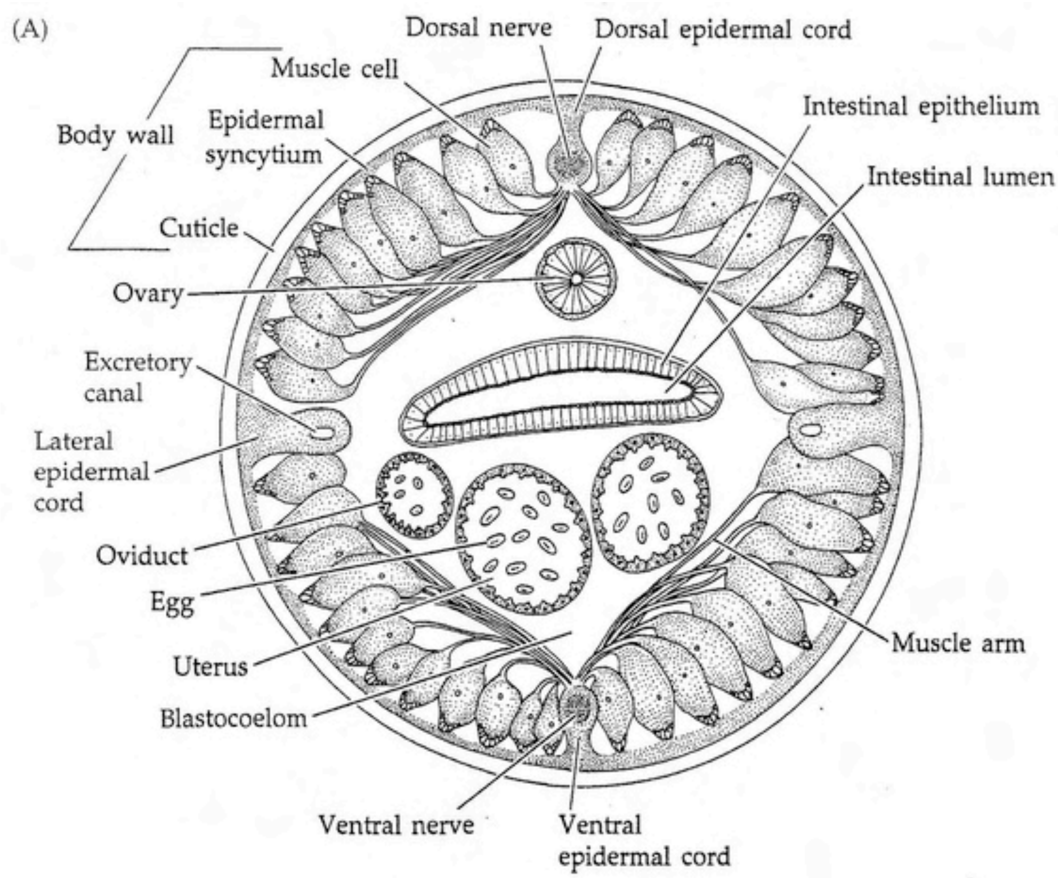


Figure 38. Cross section of a nematode. Image from Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 8 Look at the slides showing a cross section of the nematode body. Identify as many of the following structures as you can: cuticle, epidermal cords, intestine reproductive organs, longitudinal muscles.

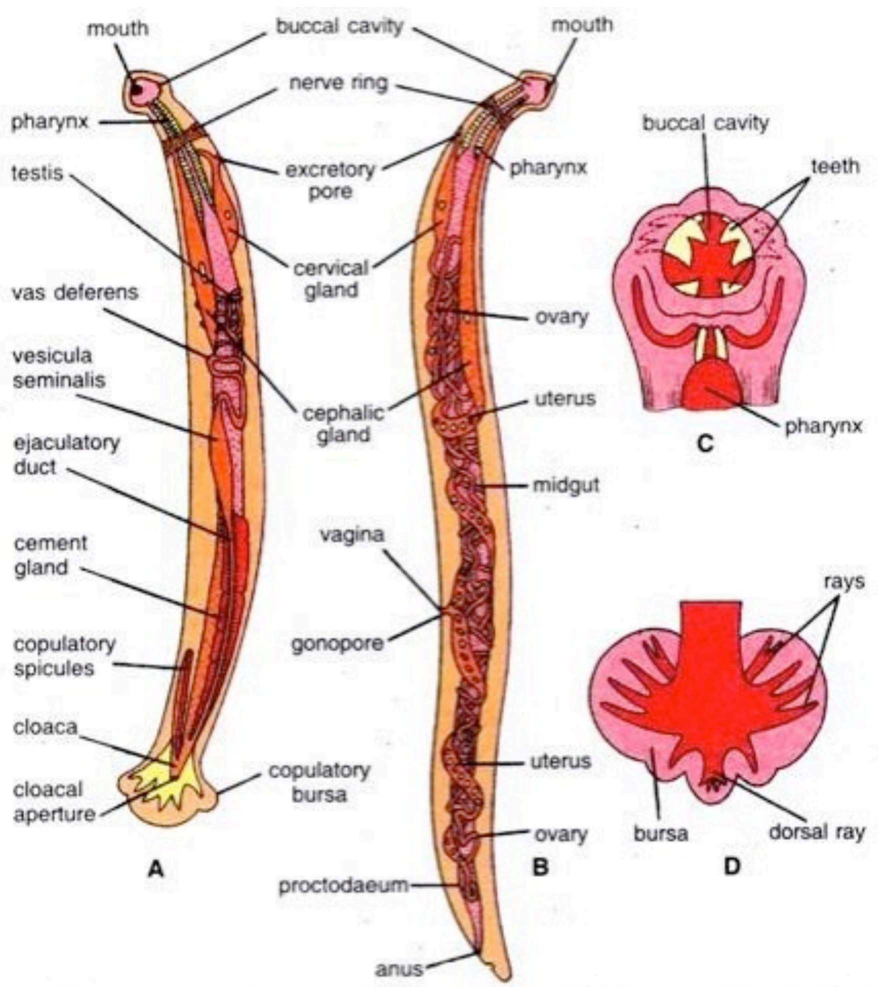


Figure 39. Schematic of the hookworm *Ancylostoma duodenale* (A) adult male, (B) adult female, (C) anterior body region, and (D) male posterior body region. Image from Biology Discussions.

Question 9 Using the available slides of the hookworm *Necator* sp., draw a diagram showing the pharynx, nerve ring, excretory system, intestine, and anus. Include any other structures you observe.

Notes

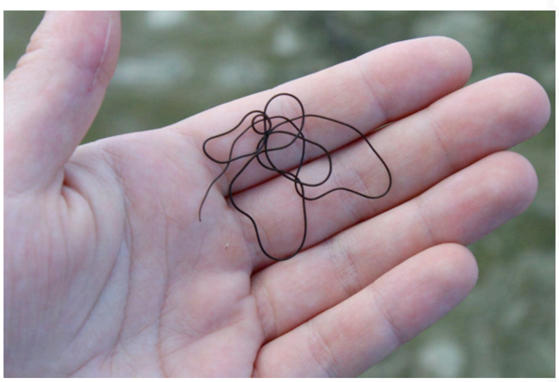
Phylum Nematomorpha (Nematoida)

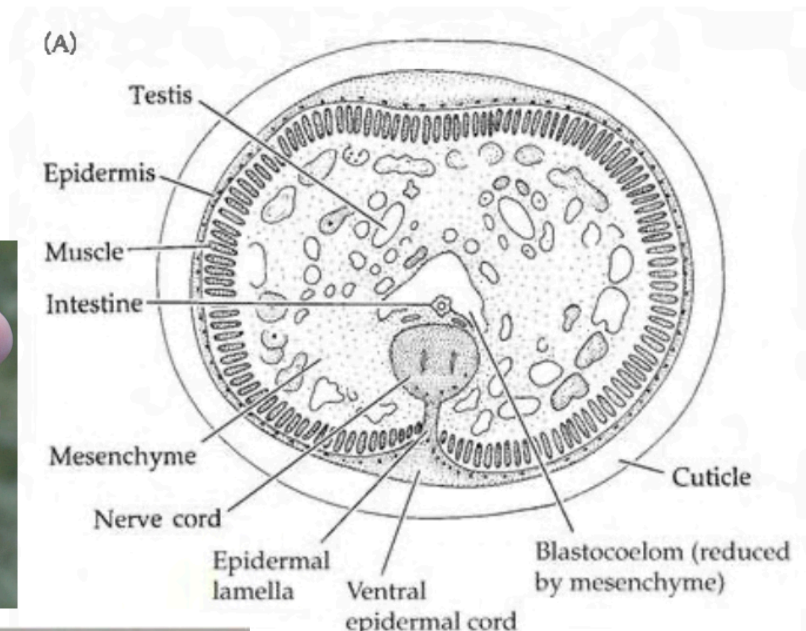
Etymology	"thread shaped" (Grk. *nema* + *morph*)
Common name	horsehair worms
No. Species	360
Habitat	most freshwater (few marine), larvae parasitic
Reproduction	sexual

Nematomorpha is the second of two phyla that make up the clade **Nematoida**. They share many similarities with nematodes: they have a **thick cuticle**, **epidermal cords** (areas of thickened epidermis projecting into the body), and **no circular muscles**. Unlike Nematoda, nematomorphans have a true larval stage that differs from the adult, and the adult digestive system is either highly reduced or entirely absent. Most commonly, they are **acoelomate**. The larvae are endoparasitic, typically relying on a **paratenic host** host (an aquatic arthropod) which will then be eaten by the **primary host** (usually a terrestrial insect). Once the larvae have matured, they emerge from the hosts as adults, whose only function is to mate.

Major Groups

order Nectonematoidea (marine)
order Gordioidea (freshwater)





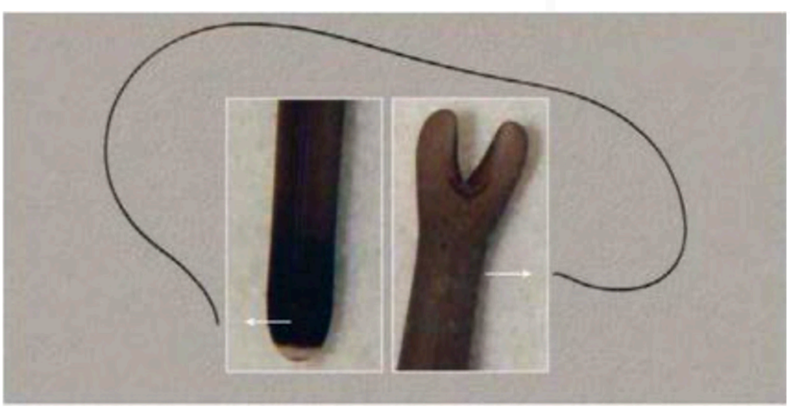


Figure 40. Top left: adult Gordioidea sp. (image: LoMack on NatureLynx). Top right: cross section of an adult nematomorphan. Bottom: anterior (left) and posterior (right) ends of an adult male nematomorphan. (images: Brusca *et al*., 2016 – *Invertebrates*, 3rd ed.

Question 10 Examine the specimens of *Gordius* sp. Idenify the anterior and posterior ends. How do you know which is which?

Question 11 Draw or describe the general lifecycle of Nematomorpha. What phylum do their hosts typically belong to?

Question 12 Which major body systems are missing from adult nematomorphans?

Notes

Phylum Kinorhyncha (Scalidophora)

Etymology	“moveable snout” (Grk. *kineo* + *rhynchos*)
Common name	mud dragons
No. Species	200
Habitat	marine (infaunal)
Reproduction	sexual

Kinorhyncha is not a speciose phylum, yet its members can be found in marine sediments around the world, from intertidal to deep sea habitats. Along with Annelida and Panarthropoda, Kinorhyncha is one of only three truly **segmented** animal clades. Their bodies are comprised of three regions: the **head**, a short **neck** region, and a segmented **trunk**. The head is composed of a retractable mouth cone tipped with **oral styles**, and an **introvert** surrounded by appendages called **spinoscalids**. The neck is made up of plates, called **placids**, which operate as a closing apparatus when the head is inverted. The trunk is divided into **eleven segments**, the most posterior of which contains the anus, and generally bears two long spines. Kinorhynchs move through the mud by extending their heads, anchoring the anterior spines in the substrate, and pulling the rest of their body along after them.

Major Groups

class Cyclorhagida (neck with 14-16 placids)
class Allomalorhagida (neck with 9 or fewer placids)

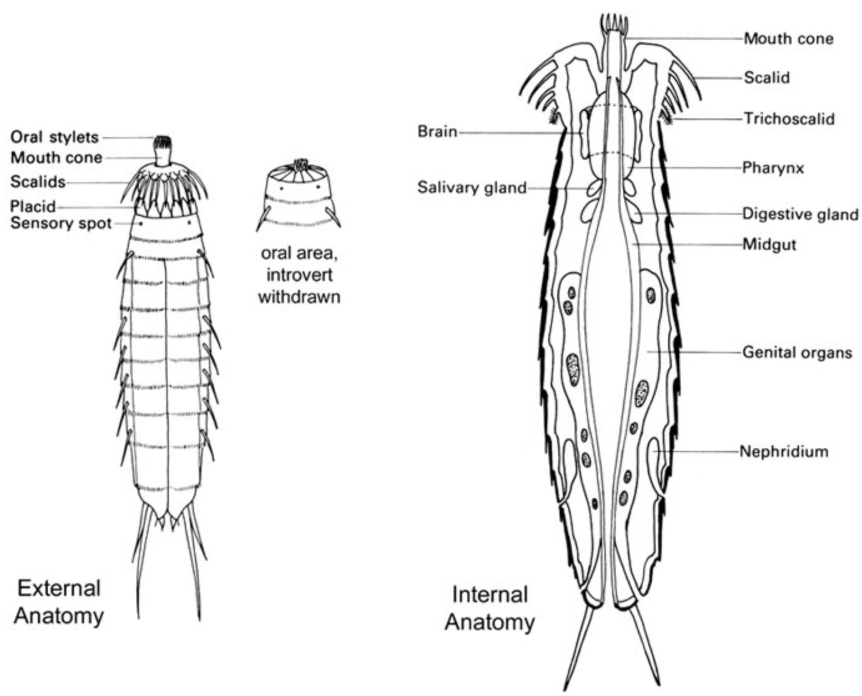


Figure 41. General Kinorhyncha bodyplan. Image: NC State University.

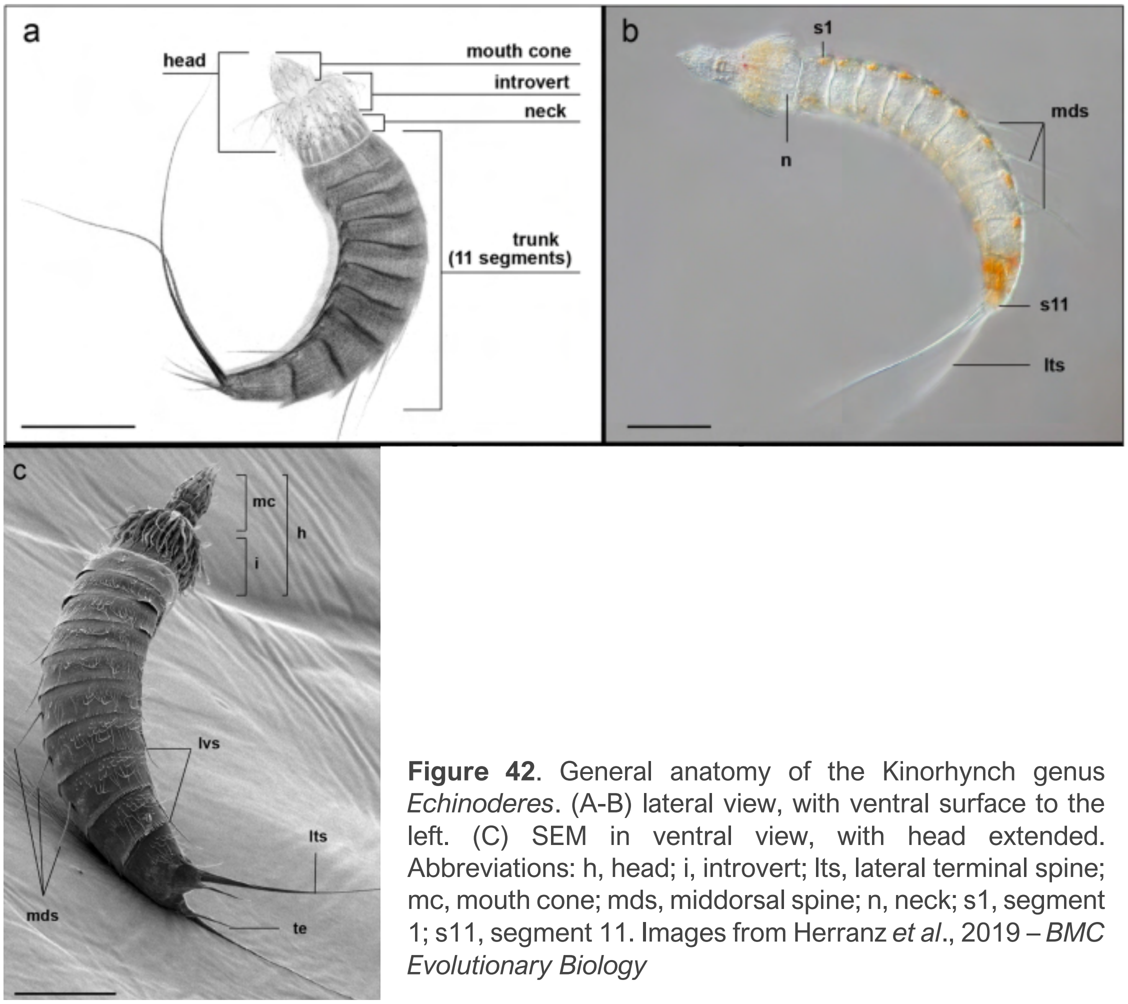


Figure 42. General anatomy of the Kinorhynch genus *Echinoderes*. (A-B) lateral view, with ventral surface to the left. (C) SEM in ventral view, with head extended. Abbreviations: h, head; i, introvert; lts, lateral terminal spine; mc, mouth cone; mds, middorsal spine; n, neck; s1, segment 1; s11, segment 11. Images from Herranz *et al*., 2019 – *BMC Evolutionary Biology*

Question 13 How many segments comprise the trunk of this specimen? Do all kinorhynchs have the same number of segments?

Question 14 Describe how kinorhynchs move through their environment. Why might their bodies be covered in spines that face posteriorly?

Question 15 Do kinorhynchs possess specialized nervous, circulatory, excretory, and respiratory structures?

Question 16 Draw the kinorhynch specimen; label as many body features as you can identify.

Notes

Phylum Priapulida (Scalidophora)

Etymology	from Priapos, Greek god of reproduction
Common name	penis worms
No. Species	20
Habitat	marine (infaunal)
Reproduction	sexual

Priapulida are active, infaunal, predatory organisms: larger species produce burrows or tubes, while smaller taxa live interstitially among the sediment. Although there are very few extant species, priapulids are conspicuous members of the fossil record, dating back to the Cambrian period, where they may have been one of the major predatory groups.

Their bodies are composed of an anterior, retractable **introvert** followed by a **trunk**, and may also include a **caudal appendage**, which likely aids in gas exchange. Their mouths are surrounded by **scalids** (homologous with the spinoscalids of Kinorhyncha), which are used in sensation and locomotion. During feeding, a portion of the pharynx is everted to grasp the prey. The introvert then retracts, dragging the prey down into the digestive system.

Major Groups

(Classes and orders are not recognized within extant Priapulida.)

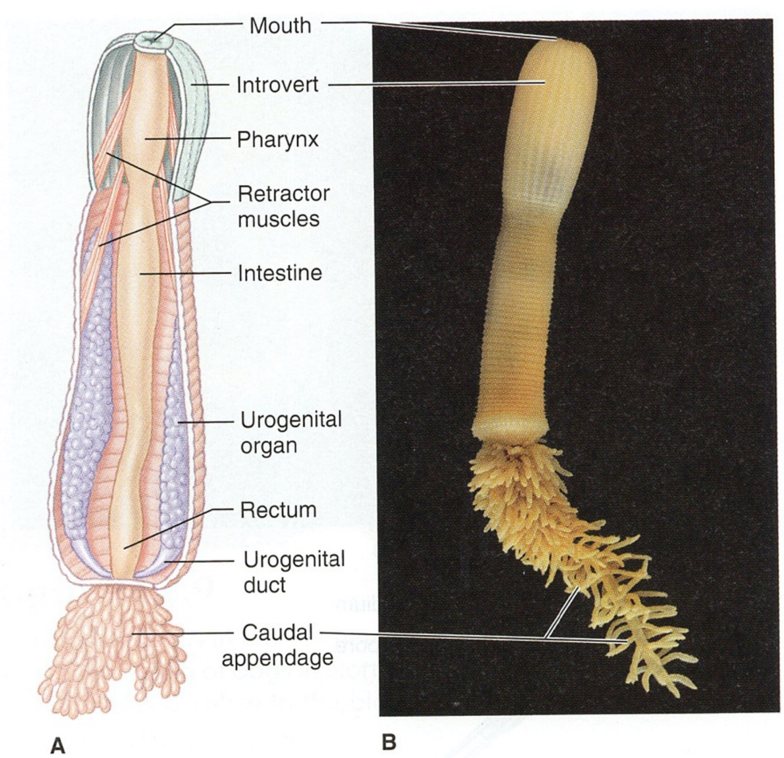


Figure 43. General Priapulida bodyplan. (A) schematic and (B) living specimen of *Priapulus caudatus*. Images from Hickman *et al*., 2015 – *Animal Diversity*

Question 17 Observe the single specimen of *Priapulus*. Identfy as many body features as you can, including the tree body regions (introvert, trunk, and caudal appendage) and scalids. Is the trunk annulated? Are there any additional spines/tubercles outside of the introvert?

Notes

LAB 6

Panarthropoda

Phylum Tardigrada

Etymology	"slow stepping" (Lat. *tardus* + *gradus*)
Common name	water bears
No. Species	1,200
Habitat	marine, freshwater, semiterrestrial
Reproduction	sexual

Like all members of the clade Panarthropoda, tardigrades are **triploblastic**, **bilaterally-symmetrical**, **coelomate**, and **segmented**. Tardigrades are small creatures with **four pairs of non-jointed, telescoping legs**, all of which are tipped with **claws**. Unlike the arthropods, their cuticle is thin and uncalcified, and they have no blood vessels or gas exchange structures. Instead of nephridia, osmoregulation is likely carried out by **malphigian tubules**, which are similar to – but probably not homologous with – those of arthropods.

Although some species are fully aquatic in marine and freshwater environments, most tardigrades are **semiterrestrial** – inhabiting films of water on mosses, lichens, liverworts, soil, or forest litter. To endure the stochastic nature of these habitats, tardigrades are capable of **anabiosis** (a state of dormancy in which metabolic activity is greatly reduced) or **cryptobiosis** (an extreme form of anabiosis in which all external signs of metabolic activity are absent). In this state, they can survive toxins, extreme temperatures, anoxic environments, the vacuum of space, radiation, and – of course – desiccation.

Major Groups

class Heterotardigrada
class Mesotardigrada
class Eutardigrada

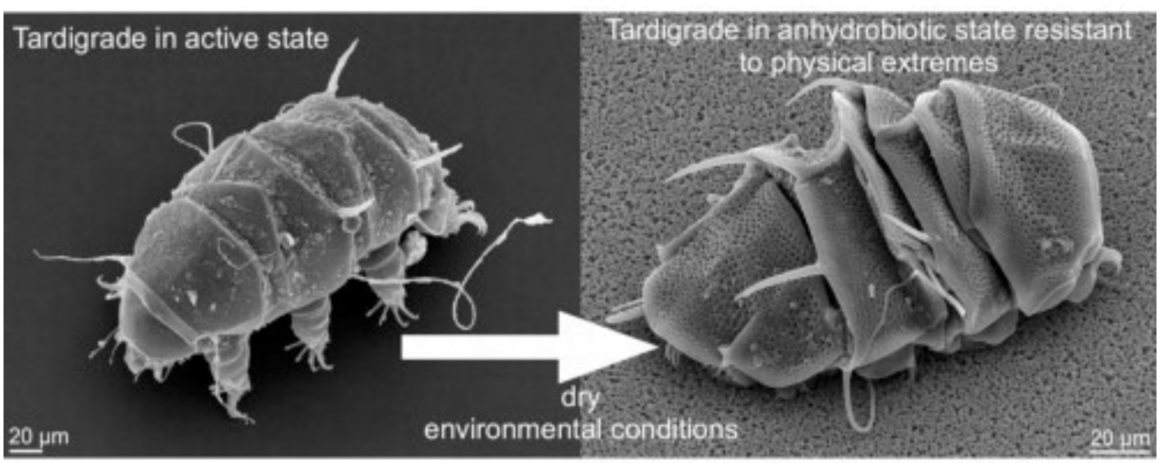


Figure 44. The tardigrade Echiniscus granulatus in its active (left) and anhydrobiotic (right) states. From Wełnicz *et al*., 2011. *Journal of Insect Physiology*

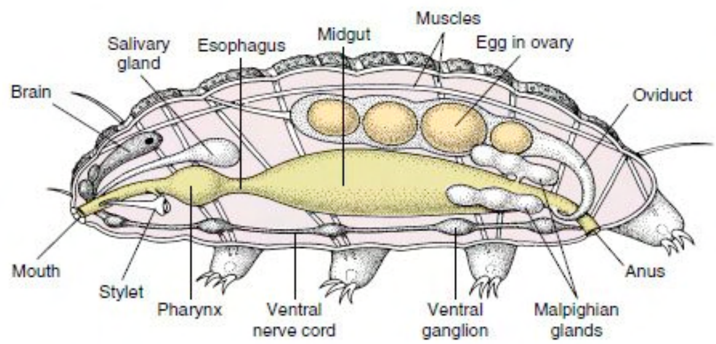


Figure 45. Left: anterior region of a tardigrade showing the oral stylets (used to puncture animal or plant cells to access the fluids within) and muscular pharynx. Right: generalized tardigrade body plan.

Question 1 Observe the moss specimens through a dissecting microscope. Can you find any tardigrades? If so, can you see any of their internal structures (*e.g.*, gut, reproductive system, gametes, feeding apparatus, etc.)?

Question 2 Do you see any other organisms in the moss? Are any of them members of other panarthropod taxa? Identify as many animals as you can, and list them here.

Notes

Phylum Onychophora

Etymology	"talon bearer" (Grk. *onycho* + *phora*)
Common name	velvet worms
No. Species	200
Habitat	terrestrial
Reproduction	sexual

Onychophora is the only entirely terrestrial phylum. Like tardigrades, their **chitinous cuticle** is thin and uncalcified; its rugose texture and distinctive sheen give these animals their common name: the velvet worms. They are easily recognized by their caterpillar-like, **unjointed legs** which are tipped with **claws**. Most phylogenetic analyses recover Onychophora as the sister group to Arthropoda, and it is thought that their **jaws** are homologous with some arthropod head appendages. To facilitate respiration, velvet worms have a system of **tracheae and spiracles** which resembles that of insects and some other arthropods, but which almost certainly arose convergently.

Their permeable integument means that onychophorans must stay moist at all times to avoid desiccation: fittingly, their distribution is limited to tropical and moist temperate areas; they are nocturnal, and often burrow to avoid dry conditions. Perhaps their most charismatic feature are their **oral papillae**, through which they shoot an **adhesive slime** to immobilize prey.

Major Groups

class Peripatidae
class Peripatopsidae

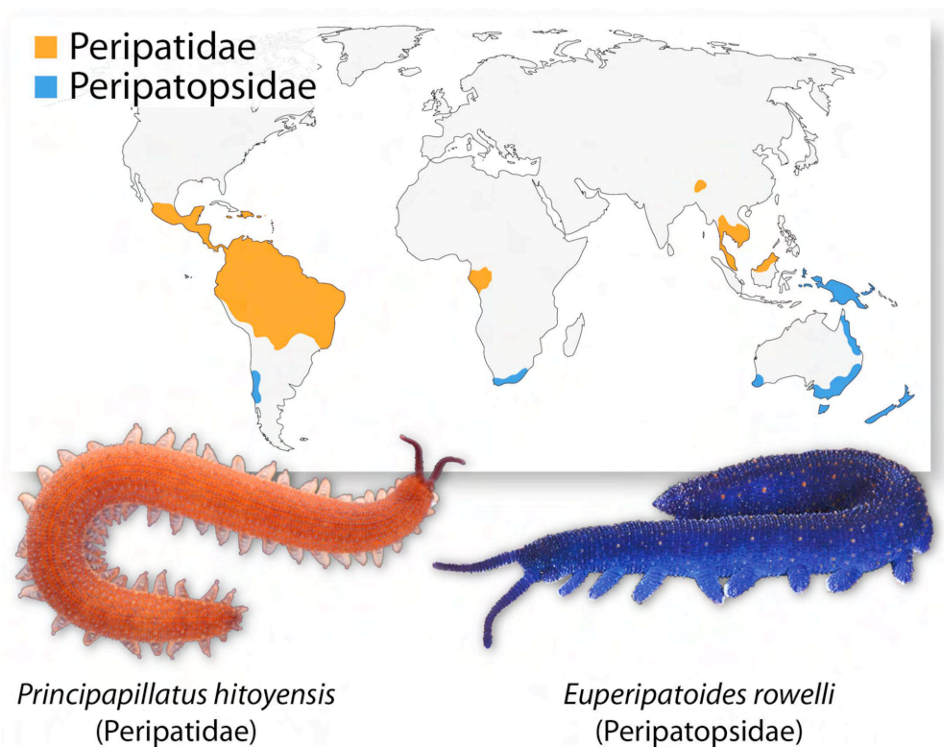


Figure 46. The distribution of extant onychophoran taxa, with representative species of each family. Figure by Sandra Treffkorn: https://thenode.biologists.com/a-day-in-the-life-of-an-onychophoran-lab/lablife/

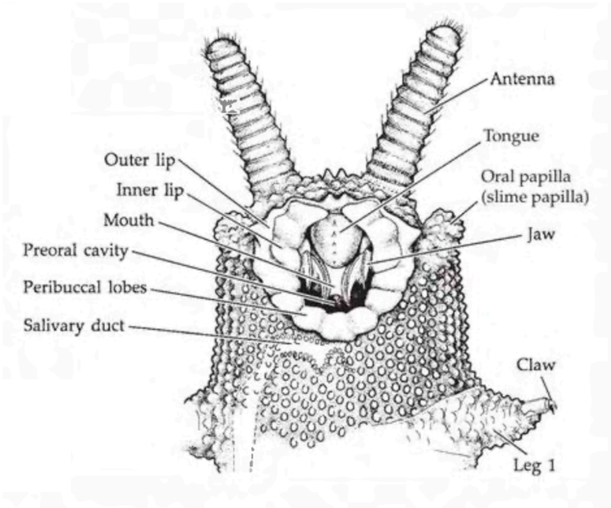


Figure 47. Left: ventral view of the anterior region of an onychophoran showing antennae, mouthparts, and first pair of legs. Image: Brusca *et al*., 2016. *Invertebrates.* Right: a slime-slingin' action shot from Baer *et al*., 2018. *Biomacromolecules*.

Question 3 Examine the full-body specimens of *Peripatus* sp. and the resin-mounted specimen of *Peripatoides* sp. How many legs does each specimen have? How many body segments?

Question 4 Draw a diagram of a generalized onychophoran and label the following structures: antennae, eyes, mouth (with jaws), legs, oral papillae ("slime cannons"), claws, and anus.

Notes

Phylum Arthropoda

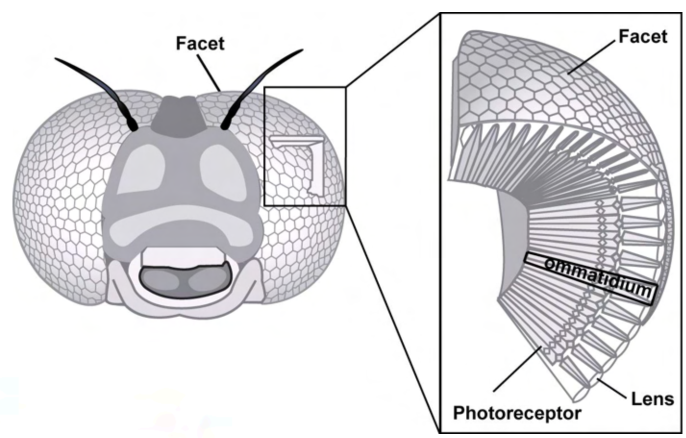
Etymology	“jointed foot” (Grk. *arthron* + *pous*)
Common name	*[common names vary by group]*
No. Species	1,126,000
Habitat	terrestrial, marine, freshwater, endoparasitic, etc.
Reproduction	sexual, asexual

Arthropods are by far the most diverse phylum on the planet. At present, there are well over one million described species, but it is thought that the actual number of arthropod species may be over 100 million. Arthropods are segmented, and each body segment bears one pair of jointed appendages. The body is – at minimum – divided into **head** and **trunk** regions, but most taxa are further regionalized via **tagmosis**: the combination of segments into functional units called **tagmata**. They typically have one pair of **compound eyes** composed of units called **ommatidia**, each with its own lens, photoreceptive cells, and optic nerve. Their cuticle is hardened into a well-developed, chitinous **exoskeleton**, which protects these animals from biotic and abiotic threats, including predation and desiccation. In spite of its many advantages, the exoskeleton is inflexible, meaning that arthropods must rely on **ecdysis** (molting) to grow.

Arthropoda is divided into five “subphyla”: **Trilobita**, **Myriapoda**, **Chelicerata**, **Crustacea**, and **Hexapoda**; however, Hexapoda nests within Crustacea rendering it paraphyletic. Hexapods and Crustacea together are known as **Pancrustacea**.

Major Groups

subphylum Trilobita (extinct)
subphylum Crustacea (crabs, shrimps, isopods, etc.)
subphylum Myriapoda (centipedes, millipedes)
subphylum Chelicerata (arachnids, horseshoe crabs); paraphyletic: includes Hexapoda
subphylum Hexapoda (insects, etc.)



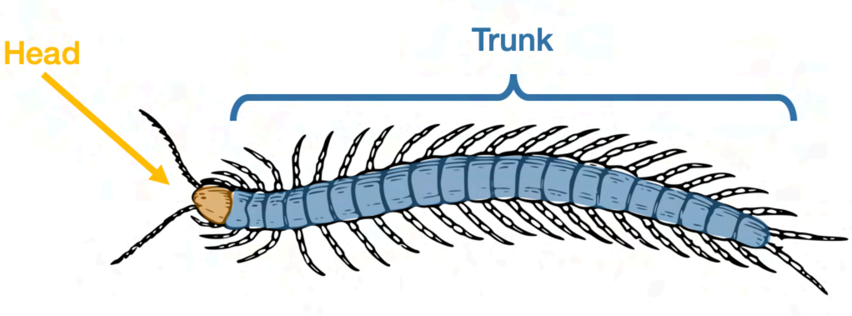


Figure 48. Common features of arthropods. Top: compound eyes (image from CURVed Artificial Compound Eyes, EPFL.ch). Bottom: generalized arthropod body regions.

Question 5 What are the main morphological features that define arthropods? Sketch any specimen from this lab and label those features.

Question 6 Identify three different specimens that are parasitic. What are some common features they share? How do they differ?

Question 7 As you look at the arthropod specimens in the lab, look for examples of mimicry and crypsis. Name those specimens, and identify what you think they may be mimicking.

Subphylum Chelicerata

The chelicerate body plan consists of two tagmata: the **prosoma** (cephalothorax) and **opisthoma** (abdomen). The prosoma bears the **chelicerae**, **pedipalps**, and four pairs of walking legs; whereas appendages on the opisthoma are typically either reduced or absent. Unlike other arthropods, chelicerates have neither antennae nor mandibles. They have a variety of **gas exchange structures**, including book gills, book lungs, and tracheae/spiracles.

Major Groups

class Pycnogonida (sea spiders)
class Euchelicerata
    subclass Merostomata (horseshoe crabs)
    subclass Arachnida (spiders, scorpions, ticks, mites, etc.)

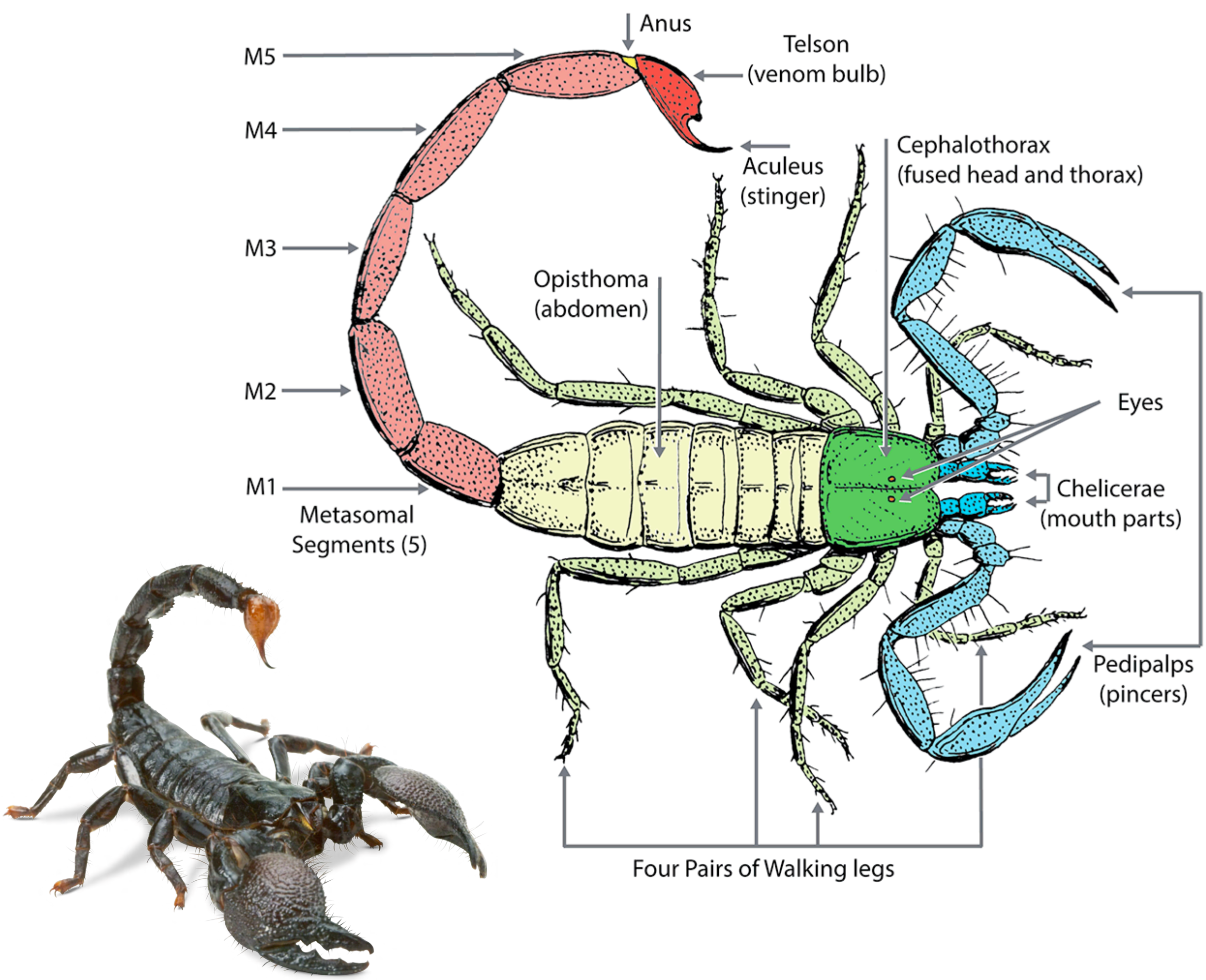


Figure 49. Diagram of a scorpion demonstrating the general features of a chelicerate body plan. Illustration by Pearson Scott Foresman & Ask a Biologist, Arizona State University

Question 8 Examine the specimens of the horseshoe crab, *Limulus* sp. How does the morphology of the book gills facilitate respiration? Can you see any features that identify these structures as modified legs?

Question 9 Compare the spider specimens, including the orbweaver (order: Araneida), cellar spider (*Pholcus* sp.) and tarantula (family: Theraphosidae). Do any of the pedipalps show obvious modifications for mating? Can you identify the opening of the book lungs?

Question 10 Draw a diagram of a generalized spider, and label the following structures: chelicerae, eyes, prosoma, opisthoma, pedipalps, legs, and spinnerets.

Question 11 Observe the specimens of Pseudoscorpiones, Scorpiones, Uropygii and Amblypygii. What are the main distinguishing features of each group?

Question 12 Find the specimens of Opiliones (harvesters/daddy long legs), such as *Phalangium* sp. What are the differences between these and true spiders?

Subphylum Myriapoda (Mandibulata)

The bodies of myriapods are divided into two tagmata: the **head** and the **trunk**. Each of their trunk segments bears one pair of multi-jointed, uniramous legs. The trunk segments of millipedes (class Diplopoda) are fused by pairs into **diplosegments**; therefore, each apparent segment has two pairs of legs. From anterior to posterior, their heads possess the following appendages: antennae, mandibles, first and second maxillae (each usually with palps). The second maxillae may be fused into a single flap-like labium, or they may be absent. Centipedes additionally have a pair of maxillipeds anterior to the other mouthparts, which are modified as fangs to deliver venom. While they have eyes, they are not compound as in other arthropods.

Major Groups

class Chilopoda (centipedes)
class Diplopoda (millipedes)
class Pauropoda
class Symphyla

Figure 50. Myriapod diversity. Top left: a scolopendrid centipede (Chilopoda). Top right: a juliform millipede (Diplopoda). Bottom left: family Eurypauropodidae (Pauropoda). Bottom right: unidentified Symphyla. Image from Animalparty, WikiMedia Commons

Question 13 What are some major differences between myriapods and other arthropod taxa? Examine the eyes; the mouthparts; the number, location, and morphology of the appendages; and the overall body plan, for example.

Question 14 What key differences can you observe between Chilopoda (centipedes) and Diplopoda (millipedes)?

Subphylum Crustacea (Mandibulata, Pancrustacea)

Crustaceans – excluding the hexapods – comprise over 70,000 species. They can be recognized by their **two pairs of antennae**, exoskeleton that is usually hardened with calcium salts, **biramous appendages**, and the unique **Nauplius larva**, which is unsegmented, planktonic, and bears a single eye, a shield, two pairs of antennae, and at least one other pair of appendages, which is homologous to the adult mandibles. In lecture, we talked about six classes, but the phylogeny and classification of Crustacea are still being revised.

Major Groups

class Remipedia
class Thecostraca
class Cephalocarida
class Branchiopoda (*e.g. Daphnia*, sea monkeys, fairy shrimp)
class Maxillopoda (copepods, barnacles, etc.)
class Malacostraca (shrimps, crabs, lobsters, krill, etc.)

Question 15 Observe the decapod specimens, and identify at least three major morphological differences between the three main “groups”: lobsters, crabs, and shrimps.

Question 16 Malacostracans display a variety of claw morphologies. Describe three unusual claw morphologies, and speculate about their potential ecological significance.

Subphylum Hexapoda (Mandibulata, Pancrustacea)

Hexapoda is, by far, the most diverse group of arthropods. Their bodies are divided into three regions – the **head**, **thorax**, and **abdomen** – with the head bearing the following appendages: **compound eyes**, **ocelli**, uniramous **antennae**, a clypeolabrum, and three sets of jaws (**mandibles**, **maxillae**, and **labium**). Their legs are **uniramous**, and only present on the three thoracic segments. Wings, when present, are located on the second and third thoracic segments.

Major Groups

Entognatha (Collembola, Protura, Diplura)
class Insecta
    subclass Pterygota (winged insects)
        infraclass Neoptera (wing-folding insects)
            superorder Holometabola (insects with complete metamorphosis)

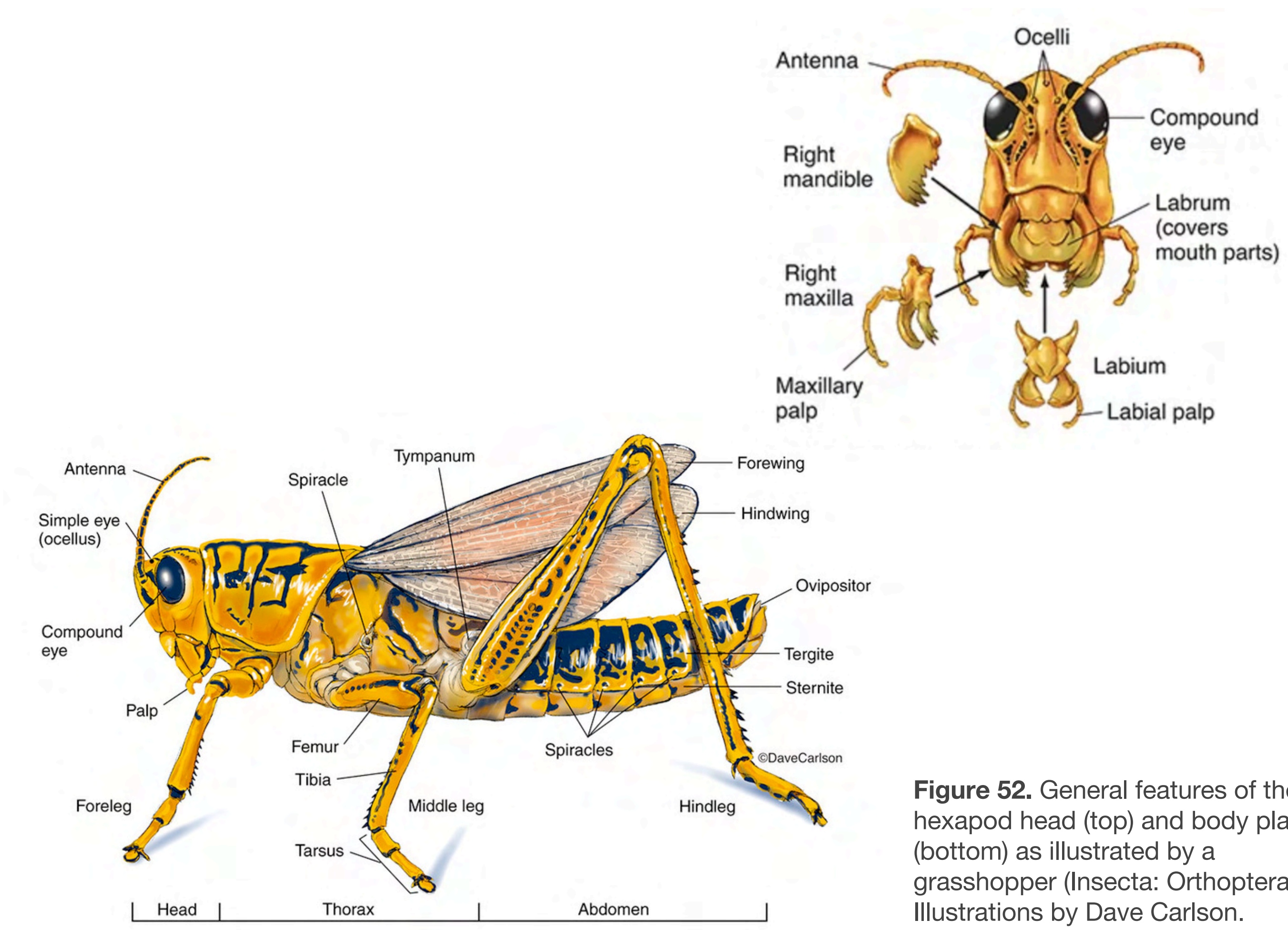


Figure 52. General features of the hexapod head (top) and body plan (bottom) as illustrated by a grasshopper (Insecta: Orthoptera). Illustrations by Dave Carlson.

Question 17 Sketch three Coleoptera (beetles) with features that you think might be used in sexual selection. Describe how you think these sturcures would be used.

Question 18 Coleoptera alone comprise over ¼ of all animal species. Looking at the specimens in the lab suggest two features beetles possess that might contribute to this enormous biological success.

Question 19 Draw two different Diptera (flies) that have significantly different morphologies (*e.g.* size, mouthparts, ornamentation, colouration, etc.). Speculate about what niches each might occupy.

Question 20 Contrast the feeding structures of Lepidoptera (moths, butterflies) with those of a member of Coleoptera (beetles) or Hymenoptera (ants, bees, wasps). Based on the morphology of these structures, what do you think each might feed on?

Question 21 What distinct form of social organisation have ants – and some other hymenopterans – developed? What might be the advantages of this social structure? Can you think of any disadvantages?

Question 22 Blood-feeding lice in the order Psocodea may have chewing mouthparts (such as *Pthirus* spp.), whereas others (such as those in the family Anoplura) may have sucking mouthparts. How would you determine whether these mouthparts were plesiomorphic or derived? What evidence would you need to support your hypothesis?

Question 23 Examine the microscope slides of the fleas *Xenospylla* sp. and *Ceratophylus* sp. Why do you think their spines are pointed posteriorly?

Notes

LAB 7

Ambulacraria

Phylum Echinodermata

Etymology	"spiny skin" (Grk. *echinos* + *derma*)
Common name	*[common names vary by group]*
No. Species	7,300
Habitat	marine
Reproduction	sexual, asexual

Echinodermata and Hemichordata together comprise the clade **Ambulacraria**, which is within the broader group **Deuterostomia**. Like other deuterostomes, echinoderms are **triploblastic**, **coelomate**, and have a **complete gut** (though sometimes the anus is absent) but other similarities are harder to recognize.

Three major synapomorphies make echinoderms easy to identify: pentaradial symmetry, the stereom, and the water vascular system. Whereas their larvae are bilaterally symmetrical, adult echinoderms exhibit **pentaradial symmetry**, wherein there are five axes of symmetry radiating out around a single point. Unlike most other invertebrates, they also possess an endoskeleton – called a **stereom** – which is make of calcium carbonate ($CaCO_3$) and composed of individual units called **ossicles**. Ossicles can be arranged in a variety of ways: they might be loosely associated and embedded in the skin (as in Holothuroidea, the sea cucumbers) or fused into a single, large unit (as in Echinoidea, the sea urchins).

Echinoderms rely on the **water vascular system** for a number of functions, including movement, regulation of the hydrostatic skeleton, respiration, and internal transportation of gasses and nutrients. The system has four main components: the **madereporite** (the point through which water enters the system); **ring canal** (the ring-shaped "central hub"); **ambulacra** or **radial canals** which extend throughout the body; and **tube feet** (hydrostatically operated appendages which perform various functions, such as locomotion, transportation of food to the mouth, and interaction with the environment).

Major Groups

class Crinoidea (sea lilies, feather stars)
class Asteroidea (sea stars)
class Echinoidea (sea urchins)
class Ophiuroidea (brittle stars)
class Holothuroidea (sea cucumbers)

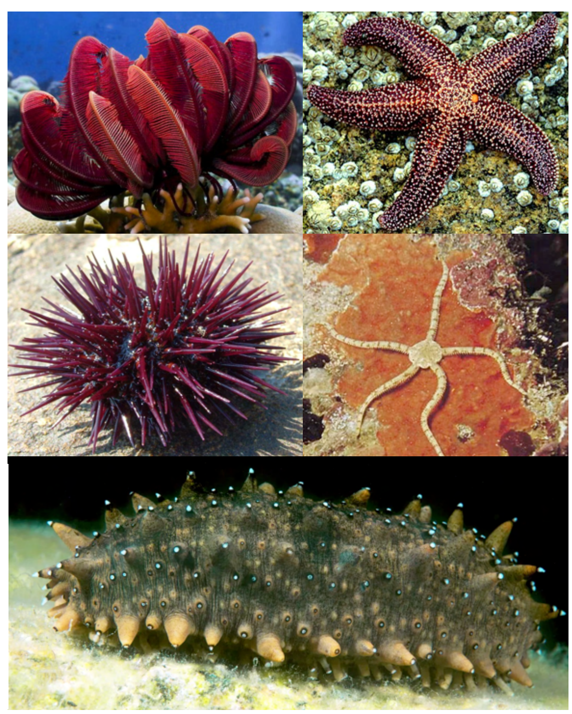


Figure 53. General echinoderm diversity: Crinoidea (top left), Asteroidea (top right), Echinoidea (middle left), Ophiuroidea (middle right), and Holothuroidea (bottom).

Class Crinoidea

The crinoids are sister to the rest of Echinodermata. The main body of a crinoid is called a **calyx** or **cup**. The mouth and anus both face upward into the water column, and the oral surface is ringed by arms. They are suspension feeders: food is captured from the water column and transported to the mouth by the tube feet that cover the **pinnules** (branches) of their arms. Unlike other echinoderms, they have **no madreporite**: instead, the water vascular system is filled with coelomic fluid. There are two main morphotypes: the **sea lilies**, which have a **stalk** extending from the aboral surface of the calyx, and the **feather stars**, which have no stalk. Those that move do so by swimming with their arms.

Figure 54. Diagrams and photos representing the two morphotypes of Crinoidea: (left) sea lilies, and (right) feather stars. Diagrams from Brusca *et al*., 2016. Photos by David Liddell and aquaristmatt on iNaturalist

Question 1 Observe the mounted crinoid specimen. Is this a sea lily or a feather star? Draw it and label the following features: feeding arms, pinnules, calyx, holdfast/cirri and stalk (if present).

Question 2 Crinoids are anatomically very different from the other classes within Echinodermata. List three morphological difference between crinoids and other echinoderms.

Class Asteroidea

Asteroidea (sea stars) are probably the most familiar group of echinoderms, and their pentaradial symmetry is readily apparent. Their general body plan consists of five **arms** or **rays** (which are tipped with eyespots, or **ocelli**) radiating out from a **central disc**, with the ambulacra, stomach, and gonads extending into the rays. The mouth faces downward (toward the substrate) and the mouth and madreporite are aboral, facing upward into the water column. Like echinoids, their skin is covered in small pincer-like structures called **pedicellariae**, which probably serve to keep the animal free of algae and other microorganisms. Sea stars are often voracious predators – especially in intertidal areas – that feed by everting their stomachs. They walk along the substrate using their tube feet.

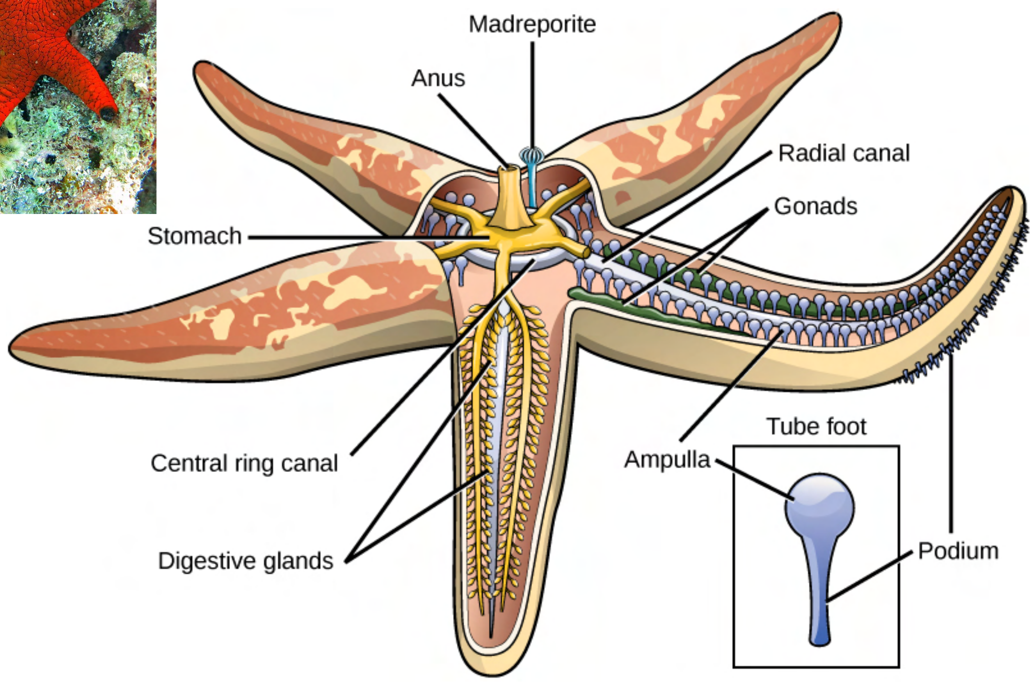


Figure 55. General asteroid body plan. Photo by Frédéric Ducarme on WikiMedia Commons.

Question 3 Observe the wet and dry Asteroidea specimens. Locate the madreporite on as many specimens as you can. Are there any specimens in which pentaradial symmetry appears to be modified/reduced/absent?

Question 4 Observe the wet and dry Asteroidea specimens. Be sure to look at both the oral and aboral surfaces. Draw a generalized sea star and label the following features: arms, mouth, madreporite, ocelli, and tube feet.

Question 5 Today in lab, we will be doing a group dissection of a sea star. Use your notes from the dissection and the microscope slides of a sea star arm cross section to draw the internal anatomy of a sea star, labelling the following features: madreporite, stone canal, central ring of the water vascular system, amulacra/radial canals, stomach, gonads, tube feet, and ampullae. Indicate how water flows through the water vascular system.

Class Ophiuroidea

The ophiuroids (brittle stars) are visually similar to the asteroids: both typically have five **rays** radiating out around a **central disc**, and both have oral surfaces that are oriented downward, toward the substrate. Unlike the sea stars, however, brittle stars have no anus (waste is ejected through the mouth), and their stomach and gonads are restricted to the central disc. Their **madreporite** is located next to the mouth, near the modified ossicles that form their circumoral **jaws**. They are typically scavengers, but may also be predatory, deposit feeding, or scavenging (or a combination of those). In any case, food is transferred to their mouths by the **tube feet** along their arms; this process may be aided by spines or scales that are often present. They crawling across the substrate using their arms to pull themselves along.

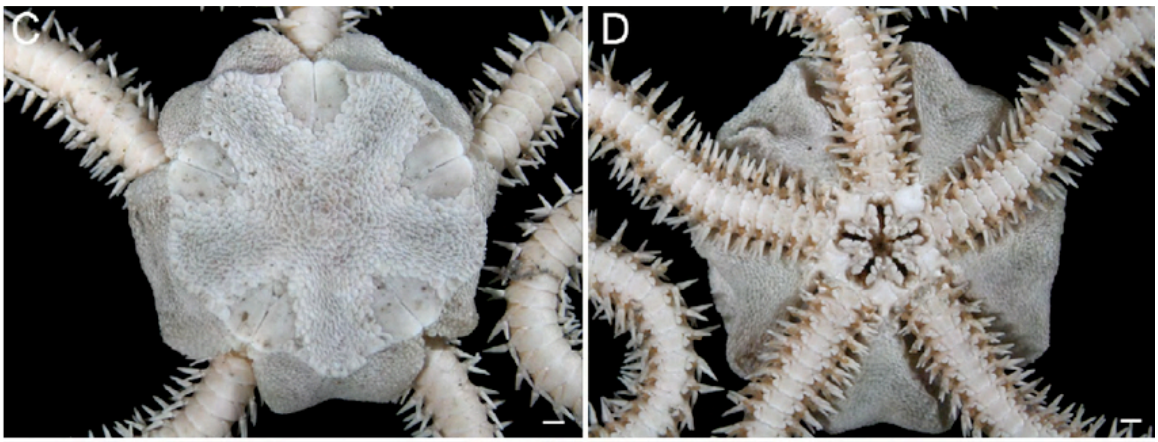


Figure 56. Aboral (left) and oral (right) surfaces of a brittle star. Note the mouth and jaws visible in the aboral view. Images from Alitto *et al*., 2016.

Question 6 One popular hypothesis of echinoderm relationships posits that Ophiuroidea and Asteroidea are sister to one another (forming the clade Asterozoa). What similarities have you observed between the two classes? And what differences? Name at least 4 of each.

Question 7 Observe the specimen of *Ophiuro* sp. and the dry brittle star specimens under a dissecting scope (make sure to examine both the oral and aboral surfaces). Can you find the madreporite in any of the specimens? Draw an ophiuroid and label the following features: arms, central disc, jaws, and mouth.

Question 8 Examine the basket stars. These animals have many more than 5 arms. Do you see any evidence that they are still pentaradially symmetrical?

Class Holothuroidea

Holothuroids, the sea cucumbers, are externally very distinct from other members of Echinodermata. Their bodies are elongate, with a clear **anteroposterior axis**. Their **madreporite** is internal, as are most of the signs of their pentaradial symmetry; their endoskeletons are not obvious, with **ossicles** loosely associated and embedded in their skin; and their mouths are surrounded by **buccal tentacles**, which they use to feed. Internally, sea cucumbers have some unique anatomical structures, including the **respiratory trees** (tubules extending from the anus that facilitate gas exchange) and the associated **cuverian tubules** (sticky strands which can be everted for defense). Although some species are pelagic, most craw along the sea floor using their tube feet, or undulations of their bodies.

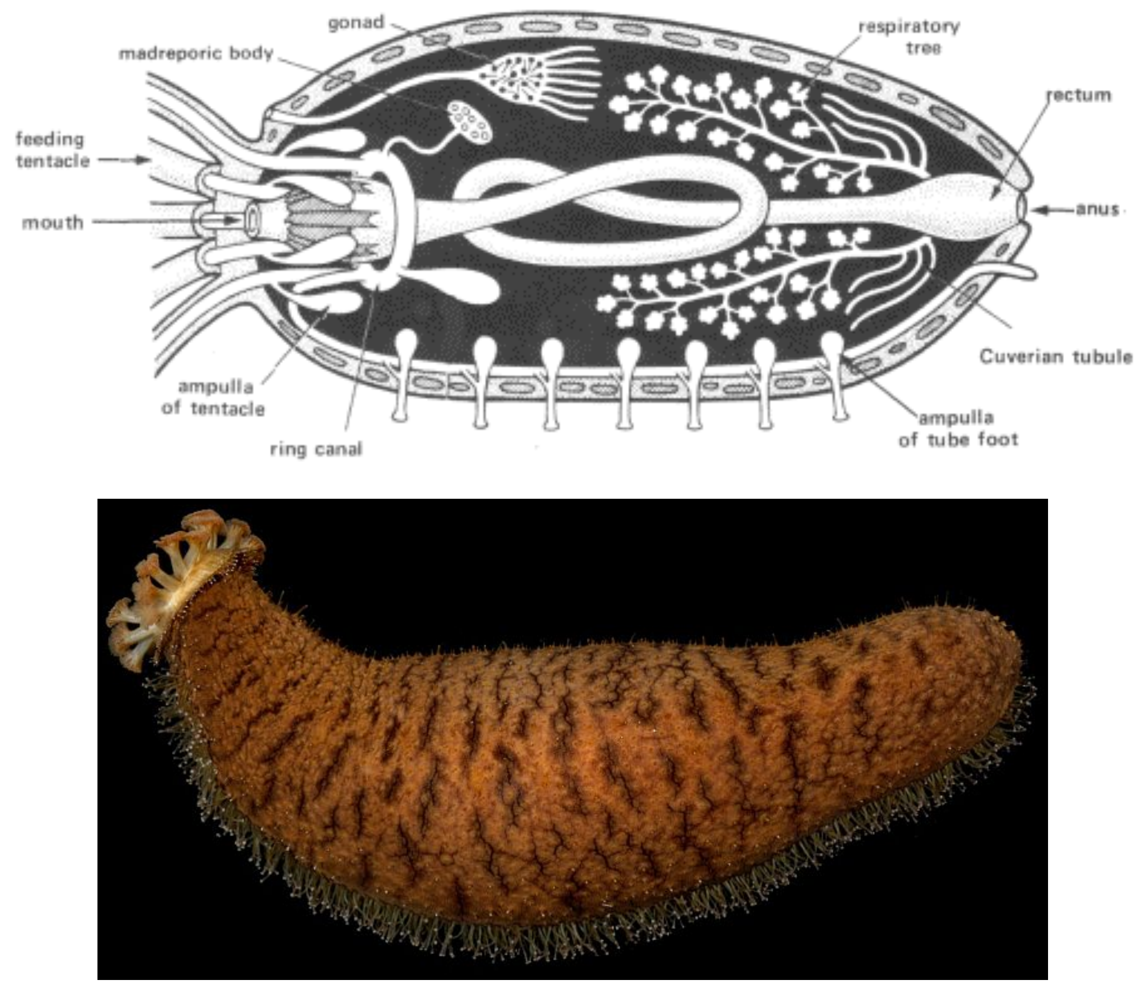


Figure 57. Internal (top) and external (bottom) anatomy of Holothuroidea (with buccal tentacles facing left). Image by François Michonneau, WikiMedia Commons.

Question 9 Observe the wet, whole body specimens of the sea cucumber *Cucumaria* sp. Draw a holothuroid, and label the following structures: buccal tentacles, mouth, anus, and tube feet. Are the tube feet similar in size all over the body, or are they more prominent in some areas?

Question 10 Today, we will be doing a group dissection of *Cucumaria* sp. Use your notes from the dissection to draw the internal anatomy of a sea cucumber and label the following structures: pharynx, intestine, respiratory tree, gonads, and longitudinal muscle bands.

Class Echinoidea

Echinoids, or sea urchins, prominently display the radial aspect of echinoderm symmetry. Their ossicles are fused into a single unit, called a **test**, which is covered in elaborate, articulated **spines** used for defense. (This body plan is modified in some common groups, however, such as the sand dollars and heart urchins, which have reduced spines and are generally less rounded.) Like the asteroids, the **oral surface** of Echinoidea is oriented downwards, while the anus and **madreporite** are **aboral**, along with the **gonopores**. Their skin is also covered in **pedicellariae**. The echinoid feeding apparatus is called **Aristotle's lantern**: it is a complex, five-part, muscular structure bearing powerful jaws. Most sea urchins use these jaws for scavenging or herbivory (most famously, they feed on the holdfasts of giant kelp and other aquatic algae). Echinoids walk along the substrate using their spines and tube feet.

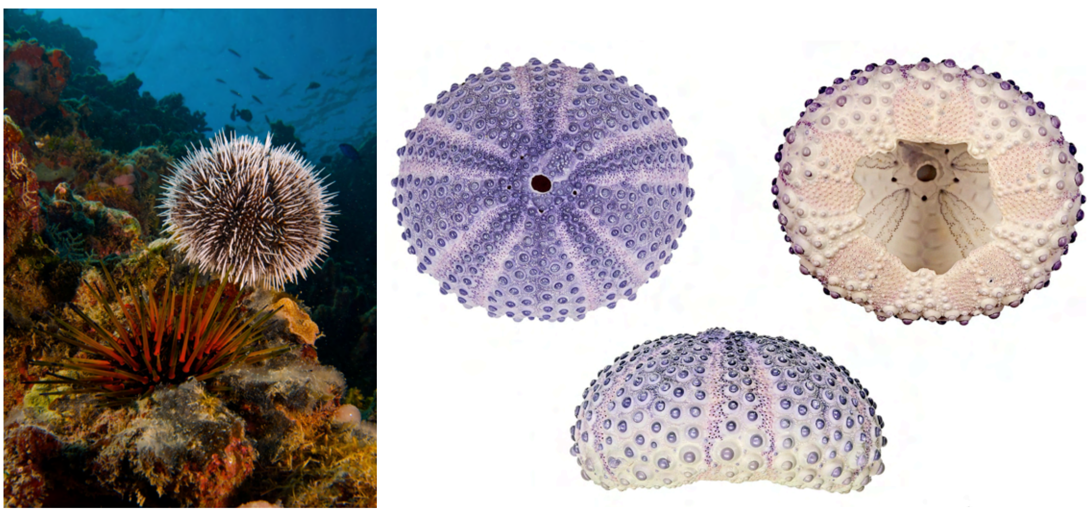


Figure 58. Left: two urchin species, *Tripneustes ventricosus* (West Indian Sea Egg; top) and *Echinometra viridis* (Reef Urchin; bottom) – Nick Hobgood. Right: test of the shingle urchin, *Colobocentrotus atratus* – Didier Descouens. Images from WikiMedia Commons.

Question 11 Compare the tests of the sea urchins, heart urchins, and sand dollars, howd o they differ? Are all pentaradially symmetrical?

Question 12 Observe wet, whole body specimens of the sea urchin *Strongylocentrotus* sp. and the dry urchin tests. Draw an echinoid and label the following structures: ambulacra, tube feet, madreporite, spines, mouth, anus, gonopores, and Aristotle's lantern.

Question 13 Now that you have observed and drawn representatives of the five echinoderm classes, compare the position of their tube feet. What does the location of the tube feet tell you about the lifestyle of each class?

Phylum Hemichordata

Etymology	“half chordate” (Grk. *hemi-* + *chorde*)
Common name	*[common names vary by group]*
No. Species	135
Habitat	marine
Reproduction	sexual, asexual

Hemichordata is the other phylum that makes up the clade **Ambulacraria**, which is within the broader group **Deuterostomia**. Like other deuterostomes, hemichordates are **triploblastic**, **coelomate**, **bilaterally symmetrical**, and have a **complete gut**. The main synapomorphy that defines this group is the **heart-kidney-stomochord complex**, which consists of three parts: the stomochord (a vacuolated support structure once thought to be homologous with the vertebrate notochord); the heart sinus, which pumps blood throughout the body; and the **glomerulus**, a kidney-like organ responsible for filtering blood.

Hemichordates have a tri-partite body plan, in which the body is divided into three regions: the **prosome**, **mesosome** (or **collar**), and the **metasome** (or **trunk**). The trunk houses most of the organs, and bears **paired, lateral gill slits** which connect the pharynx to the external environment for filter feeding. The phylum consists of two classes, which are morphologically and ecologically distinct. **Enteropneusta**, the acorn worms, are relatively large, **vermiform**, **solitary**, **deposit**-**feeding** animals that crawl along/burrow into the benthos using their ciliated epidermis. Their prosome is called a **proboscis**, and is supported by a collagenous proboscis skeleton. **Pterobranchia**, by contrast are **small**, **sessile**, **colonial** animals that live in collagenous **tubes**. Their prosome is modified into a **cephalic shield**, and their mesosome bears two, **tentaculate feeding arms** which facilitate suspension feeding. They have a **u-shaped gut**, and their trunk terminates in a **stolon**, which facilitates attachment to other zooids in the colony.

Major Groups

class Enteropneusta (acorn worms)
class Pterobranchia

Figure 59. Members of the classes Enteropneusta (left) and Pterobranchia (right).

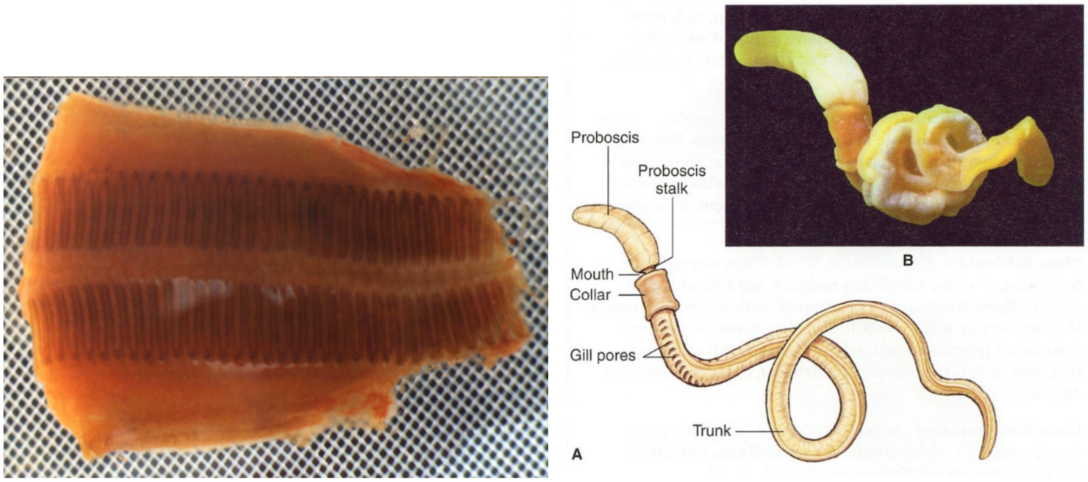


Figure 60. Left: internal view of the pharynx of the enteropneust *Saccoglossus pusillus*. Photo by Karma Nanglu. Right: External anatomy of *Saccoglossus kovalevskii* (A) and a photograph of the live animal (B). Images from Hickman *et al*., 2015.

Question 14 Inside the enteropneust pharynx, we cal see gill bars (see figure above). Do these structures remind you of any other anatomical features in different groups of animals? (Hint: we may not have covered them in this course.) Why might this be an informative morphological/evolutionary feature?

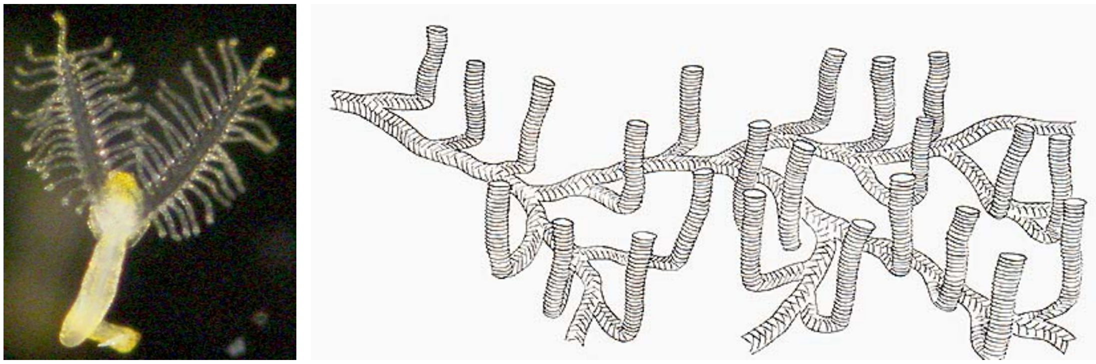


Figure 61. Left: a single zooid of the pterobranch species *Rhabdopleura compacta*. Note the paired feeding arms. Right: a colony of rhabdopleurid tubes.

Question 15 Observe the specimens of the enteropneust *Balanoglossus* sp. Considering the significant morphological disparity between extant, adult enteropneusts, pterobranchs, and echinoderms, what other evidence could be used to determine that they are closely related? (Hint: examine some of the microscope slides for ideas.)

Notes