Invertebrates اللافقاريات

Invertebrates (**animals without a backbone**) account for 95% of known animal species. Invertebrates inhabit nearly all environments on earth.

Table 1. Important Terms.

English	Arabic	English	Arabic
Amoebocyte	الخلايا الاميبية	Parasite	طفيلي
Antennae	قرون الاستشعار (الهوائيات)	Parthenogenesis	التكاثر العذري
Anterior	أمامي	Planaria	حيوان البلاناريا (حيوان ابتدائي)
Anthozoan	الزهريات (حيوانات تعود الى شعبة الاسعات)	Polyp	الشكل الانبوبي (القضيبي) (طور من اطوار الحيوانات اللاسعة)
Book lungs	رئات كتابية	Posterior	خلفي
Cephalization	التطور	Proglottid	قطعة جسمية للشريطيات
Chelicerates	ذوات الارجل المخلبية	Protozoa	الاوالي (حيوانات وحيدة الخلية)
Choanocyte	خلية قمعية (متواجدة في الاسفنجيات فقط)	Radula	عضو يشبه اللسان ومتواجد في الرخويات (النواعم)
Class Arachnida	صنف العنكبيات	Scolex	الروئيس (راس مصغر)
Class Insecta	صنف الحشرات	Scyphozoan	حيوانات تعود الى شعبة (اللاسعات)
Class Diplodia	صنف مزدوجة الارجل	Spongocoel	التجويف الاسفنجي
Class Chilopodia	صنف مخلبية الارجل	Tapeworm	الديدان الشريطية
Cnidarian	الحيوانات اللاسعة	Trematode	الديدان المثقبة (الثقبات)
Cnidocyte	الخلايا اللاسعة	Water vascular system	الجهاز الوعائي المائي
Complete gastrovascular Cavity	تجويف وعائي هضمي كامل		
Crustaceans	القشريات		
Cuticle	جليد (تصغير للجلد)		
Echinoderms	مشوكات الجلود		
Entomology	علم الحشرات		
Flatworm	ديدان مسطحة		
Ganglion (pl. Ganglia)	عقد عصبية		
Gastrovascular cavity	التجويف الوعائي الهضمي)		
Hydrozoan	الهدروانيات (حيوانات تعود الى شعبة الحيوانات اللاسعة)		
Invertebrates	الحيوانات اللافقرية (عديمة العمود الفقري)		
Malpighian tubules	انابيب مالبيجي		
Mandibles	الفكوك		
Medusa	الشكل المضلي (طور من اطوار الحيوانات اللاسعة)		
Metamorphosis	الاستحالة (التحول من طور الى طور)		
Molting	الانسلاخ		
Nematocyst	الكيس اللاسع		
Osculum (pl. oscula)	فويهة (تصغير للفوهة)		

The Course Description

The lectures will focus mainly on the biology (morphology and anatomy), taxonomy, ecology, and evolution of invertebrates. The animal phyla that contain the invertebrate animals will be described according to their position in the classification ladder starting with the primitive one (Subkingdom Protozoa) and finishing with the more advanced phylum (Phylum Echinodermata). The reason behind the success of the invertebrate animals in terms of species diversity and numbers of individuals will also be discussed. In addition, the medical and economic importance of the invertebrate animals will also be investigated.

The Course Objectives

After finishing this course, the student should be able to:

1. Identify the parts of a sponge and describe the function of the spongocoel, porocyte, epidermis, choanocyte, mesohyl, amoebocyte, osculum, and spicule.
2. List characteristics of the phylum Cnidaria that distinguish it from the other animal phyla.
3. Describe the two basic body plans in Cnidaria and their role in Cnidarian life cycles.
4. List the three classes of Cnidaria and distinguish among them based upon life cycle and morphological characteristics.
5. List characteristics of the phylum Ctenophora that distinguish it from the other animal phyla.
6. List characteristics that are shared by all bilaterally symmetrical animals.
7. List characteristics of the phylum Platyhelminthes that distinguish it from the other animal phyla.
8. Distinguish among the four classes of the Phylum Platyhelminthes and give examples of each.
9. Describe the generalized life cycle of a trematode and give an example of one fluke that infects humans.
10. Describe the anatomy and the general life cycle of a tapeworm.
11. List distinguishing characteristics of the members of Phylum Nemertea.
12. Describe unique features of rotifers that distinguish them from other pseudocoelomates.
13. List characteristics of the phylum Nematoda that distinguish it from other pseudocoelomates.
14. Give examples of both parasitic and free-living species of nematodes.
15. List characteristics that distinguish the Phylum Mollusca from the other animal phyla.
16. Distinguish among the following four Molluscan classes and give examples of each:
    a. Polyplacophora
    b. Gastropoda
    c. Bivalvia
    d. Cephalopoda
17. List characteristics that distinguish the Phylum Annelida from the other animal phyla.
18. Distinguish among the classes of annelids and give examples of each.
19. List characteristics of arthropods that distinguish them from the other animal phyla.
20. Describe advantages and disadvantages of an exoskeleton.
21. Distinguish between hemocoel and coelom.
22. Provide evidence for an evolutionary link between the Annelida and Arthropoda.

23. Explain what arthropod structure was a preadaptation for living on land.
24. Distinguish among the following arthropod classes and give an example of each:
    a. Arachnida
    b. Crustacea
    c. Diplopoda
    d. Chilopoda
    e. Insecta
25. Distinguish between incomplete metamorphosis and complete metamorphosis.
26. Define lophophore and list three lophophorate phyla.
27. List at least four characteristics shared by the deuterostome phyla that distinguish them from protostomes.
28. List characteristics of echinoderms that distinguish them from other animal phyla.
29. Describe the structures and function of a water vascular system.
30. Distinguish among the classes of echinoderms and give examples of each.

Introduction

The animals which are without backbones are called invertebrates. Invertebrates make up 95-99% of all species of animals on the earth. The invertebrate animals are classified into large groups called **Phyla**, on the basis of their patterns of symmetry and on the basis of their overall body plan. There are **9 particularly important invertebrate phyla** (and another 20 or so less important phyla). The major invertebrate groups are:

- Phylum Protozoa (amebae, trypanosomes, malaria)
- Phylum Parazoa (sponges)
- Phylum Cnidaria (Examples: sea anemones, corals, and jellyfish)
- Phylum Platyhelminthes (Flatworms such as Bilharzia worms and tapeworms)
- Phylum Nematoda (Examples Ascaris and pinworms)
- Phylum Annelida (Segmented worms such as leeches)
- Phylum Mollusca (Examples: clams, snails, and squids)
- Phylum Arthropoda (Examples: lobsters, beetles, crabs, and flies and scorpions)
- Phylum Echinodermata (Examples: sea urchins, sea cucumbers, and starfish)

Taxonomists have divided each Phylum into Classes, Classes into Orders, Orders into Families, and Families into Genera. Finally, animals are sorted into unique species, the individuals of which reproduce only with one another. **Every species is designated by a unique two-word Latin name, a genus and a species name.** It is important to note that the first word in the name begins with a capitalized letter, that the second word in the name is in small case, and that both the genus and species names are underlined. **[Why do we need a universal scientific names for animals?]**. **The answer is: we need universal, scientific names for each species because people in different parts of a country, and in different countries, use different, local names for the same species or similar names for different species.** This would result in incredible confusion if we could not keep our information on each species in the right category.

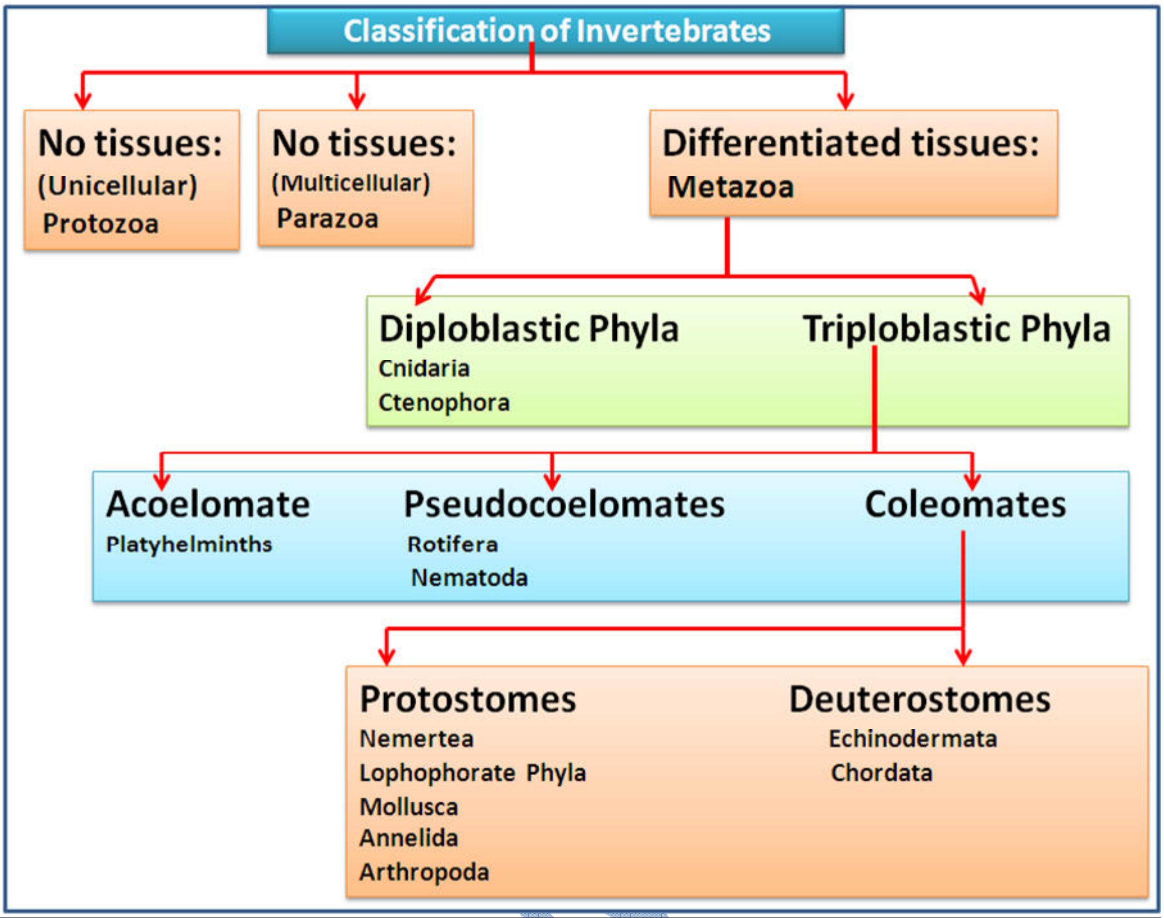


Figure 1. Classification of Invertebrates.

Course Outline

1. The Protozoa

A. Phylum Sarcomastigophora: this Phylum includes two Subphyla, Sarcodina (*Entamoeba*) and Mastigophora (*Giardia, Leishmania*, and *Trypanosoma*).
B. Phylum Ciliophora: This phylum includes only one genus, *Balantidium* which includes pathogenic parasites.
C. Phylum Microsporidia: Microsporidium.
D. Phylum Apicomplexa: *Plasmodium* (malaria) species

2. The Parazoa

A. Phylum Porifera: sponges are sessile with porous bodies and choanocytes.

3. The Radiata

A. Phylum Cnidaria: cnidarians have radial symmetry, a gastrovascular cavity, and cnidocytes
B. Phylum Ctenophora: comb jellies possess rows of ciliary plates and adhesive Colloblasts

4. The Acoelomates

A. Phylum Platyhelminthes: flatworms are dorso-ventrally flattened acoelomates.

5. The Pseudocoelomates
A. Phylum Rotifera: rotifers have jaws and a crown of cilia.
B. Phylum Nematoda: roundworms are unsegmented and cylindrical with tapered ends.

6. The Coelomates: Protostomes
A. Phylum Nemertea: The phylogenetic position of proboscis worms is uncertain.
B. The lophophorate phyla: bryozoans, phoronids, and brachiopods have ciliated tentacles around their mouths.
C. Phylum Mollusca: mollusks have a muscular foot, a visceral mass, and a mantle
D. Phylum Annelida: annelids are segmented worms.
E. Phylum Arthropoda: arthropods have regional segmentation, jointed appendages, and an exoskeleton.

7. The Coelomates: Deuterostomes
A. Phylum Echinodermata: Echinoderms have a water vascular system and secondary radial symmetry.
B. Phylum Chordata: the chordates include two invertebrate subphyla and all Vertebrates.

Table 2. Types of interactions between the host and the guest.

Interaction	Guest	Host
Commensalism	+ (Benefit)	- (no benefit)
Mutualism	+ (Benefit)	+ (Benefit)
Parasitism	+ (Benefit)	- (no benefit)
Competition	- (no benefit)	- (no benefit)

Protozoa:

Protozoa are unicellular (one-celled) animals found worldwide and live in most habitats. The Protozoa are considered to be a Subkingdom of the Kingdom Protista, although in the classical system they were placed in the Kingdom Animalia.

Although most species are free living, some protozoan parasites are pathogenic and cause a wide range of diseases such as malaria, leishmaniasis, bilharziasis and many more. Protozoan diseases range from very mild to life-threatening. Individuals with a good immune system (immunecompetent) are able to control but not eliminate a parasitic infection and become carriers and form an important source of infection for others (Reservoir hosts). In contrast, many protozoan infections that are asymptomatic or mild in apparently healthy individuals can be life-threatening in immunocompromised patients, particularly patients with acquired immune deficiency syndrome (AIDS).

The protozoa have very diverse lifecycles with multiple morphological stages (mainly two), depending on species. Most protozoa have a **cyst** stage, which is dormant and highly resistant to environmental conditions. In the pathogenic species, these cysts are often the infective stages, usually acquired by fecal-oral contamination. The **trophozoite** stage is the active, reproductive, and feeding stage. The trophozoite is the stage that typically causes disease by pathogenic protozoa.

Protozoa have been separated into four main groups based on the structures used to generate movement. We are going to look at all four groups individually, highlighting the key points and providing examples of important species within the group.

Group 1: Flagellates

The first group is the **Mastigophora**, also known as the **Flagellates** because they move by waving long, whip-like flagella. The protozoal flagellum is structurally different than the bacterial flagellum. Also, the protozoal flagellum waves while the bacterial flagellum spins.

There are several important disease-causing flagellates. *Trypanosoma brucei* causes African sleeping sickness, a disease that kills an estimated 65,000 people in Africa every year. The lifecycle of Trypanosomes is interesting because it uses two hosts. The disease manifests in humans but must be transmitted through the bite of an infected tsetse fly.

Giardia is a common pathogenic flagellate that causes diarrhea and is known informally as Beaver Fever. Another common protozoa is *Trichomonas*, a sexually transmitted flagellate that can cause urogenital symptoms in infected women.

Group 2: Amoebas

The **Sarcodina** group are commonly known as the **Amoebas**. This is a huge group with members found in nearly every environment imaginable. These amoebas are characterized by having a trophozoite stage that is naked, meaning the cell has no structural components on its membrane that maintain a shape. What results is an amorphous blob that moves by pseudopod projections.

The cell extends forward a portion of its cell membrane, called a pseudopod, as it slowly withdraws the cell membrane on the opposite end. The result is slow movement in one direction by simply pushing forward and pulling up the rear. These are classic microbes examined in intro bio classes to demonstrate an interesting mode of motility.

There are many genera of Amoebas that live symbiotically with animals, typically in the oral cavity or gastrointestinal tract. Very few cause disease, but one species in particular, *Entamoeba histolytica*, can be quite deadly. The disease is acquired by drinking water contaminated with Entamoeba cysts, usually present in areas with poor sanitation. Entamoeba can cause amoebic dysentery characterized by painful ulcers in the large intestine and diarrhea. Every year about 100,000 people die worldwide from *Entamoeba histolytica*.

On the basis of light and electron microscopic morphology, the protozoa are currently classified into six phyla. Most species causing human disease are members of the phyla Sacromastigophora and Apicomplexa.

Life Cycle Stages

The stages of parasitic protozoa that actively feed and multiply are frequently called trophozoites; in some protozoa, other terms are used for these stages. Cysts are stages with a protective membrane or thickened wall. Protozoan cysts that must survive outside the host usually have more resistant walls than cysts that form in tissues.

Reproduction

Binary fission, the most common form of reproduction, is asexual; multiple asexual division occurs in some forms. Both sexual and asexual reproductions occur in the Apicomplexa and Ciliophora.

Nutrition

All parasitic protozoa require preformed organic substances—that is, nutrition is holozoic as in higher animals.

Pylum Ciliophora

Ciliophora is phylum in the Subkingdom Protista consisting of the ciliates (complex freshwater or saltwater protozoans) which swim by the coordinated beating of their cilia (short, hair-like structures that cover the cell surface). Like other protozoans, ciliates are unicellular heterotrophs. Some feed on bacteria and other particles as well as algae by means of cilia-created currents; many are carnivorous. Ciliates contain a variety of organelles plus two kinds of nuclei (large one which is called macronucleus and small one which is called micronucleus). Although the ciliates typically reproduce asexually, they also exchange genetic information with other ciliate cells by the process of conjugation (sexual process). There are approximately 8,000 species of ciliates.

Example: Paramecium

As other protozoans, Paramecium is composed of a single cell that does everything necessary for life (Figure 1). Paramecium moves back and forth in the water by beating hairy projections called cilia. In contrast to other single-celled organisms such as bacteria, paramecia and other protozoans have organelles (such as nuclei, food vacuoles, contractile vacuoles and others) inside them, which make them eukaryotic.

Paramecium lives in aquatic environments, usually in still, warm water. The species *Paramecium bursaria* forms symbiotic relationships with green algae. The algae live in its cytoplasm. Algal photosynthesis provides a food source for Paramecium. Some species form relationships with bacteria.

Paramecium feed on microorganisms like bacteria, algae, and yeasts. *Paramecium* capture their prey through phagocytosis. The paramecium uses its cilia to sweep the food along with some water into the mouth after it falls into the oral groove. The food goes through the mouth into the gullet and when there is enough food in it breaks away and forms a food vacuole. As it moves along, enzymes from the cytoplasm enter the vacuole and digest it. The digested food then goes into the cytoplasm and the vacuole gets smaller and smaller. When the vacuole reaches the anal pore the remaining undigested waste is removed.

Paramecium are capable of both sexual and asexual reproduction. Asexual reproduction is the most common, and this is accomplished by the organism dividing transversely. The macronucleus elongates and splits. Under ideal conditions, Paramecium can reproduce asexually two or three times a day. Normally, Paramecium only reproduce sexually under stressful conditions where one individual exchanges genetic information with other individual by the process of conjugation (sexual process). *Paramecium* belongs to the Family Paramecidae**.**

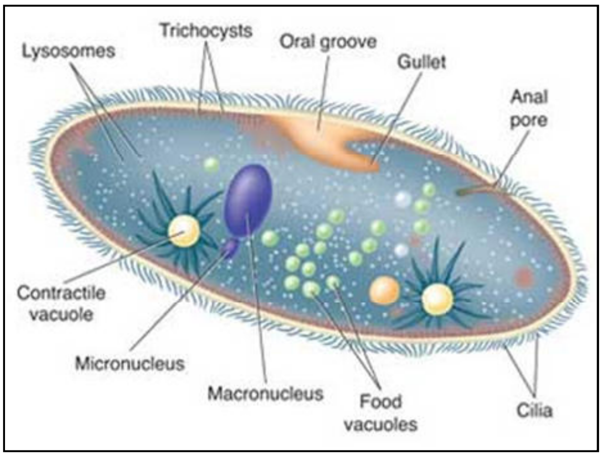


Figure 1. Paramecium.

Phylum Apicomplexa (Sporozoa)

The ***Apicomplexa*** (also called Apicomplexia) is a large phylum of parasitic protozoans. Most of them possess a unique form of organelle that comprises a type of plastid called an apicoplast, and an apical complex structure and from this structure the name of the phylum derived. The organelle is an adaptation that the *apicomplexan* applies in penetration of a host cell.

The apicomplexans are composed almost entirely of parasitic (meaning no free-living) species. Previously, the apicomplexans were part of a group called sporozoa and this name is still sometimes used. There have been some suggestions to revert back to the name sporozoa.

Electron microscopy revealed unique ultrastructural features among the various sporozoa which were subsequently used to redefine the groups. A defining characteristic of the apicomplexa is a group of organelles found at one end--called the apical end--of the organism. This 'apical complex' includes secretory organelles known as micronemes and rhoptries, polar rings composed of microtubules, and in some species a conoid which lies within the polar rings. The apical organelles play a role in interaction of the parasite with the host cell and the subsequent invasion of the host cell. Motile forms of apicomplexa crawl along the substratum in a non-ameboid fashion known as gliding motility. Many apicomplexan species have flagellated gametes.

The apicomplexans have complex life cycles that are characterized by three distinct processes: sporogony, merogony and gametogony (Figure 2). Although most apicomplexans exhibit this overall general life cycle, the details can vary between species. Furthermore, the terminologies used to describe these various life cycle stages vary between the species. The life cycle consists of both asexually reproducing forms and sexual stages.

Sporogony occurs immediately after a sexual phase and consists of an asexual reproduction that culminates in the production of sporozoites. Sporozoites are an invasive form that will invade cells and develop into forms that undergo another asexual replication known as merogony. In contrast to sporogony, in which there is generally only one round of replication, quite often there are multiple rounds of merogony. After many rounds of merogony and for unkown reasons, the merozoites develop into gametes through a process generally called gametogony, gamogony or gametogenesis. As in other types of sexual reproduction, the gametes fuse to form a zygote which will undergo sporogony.

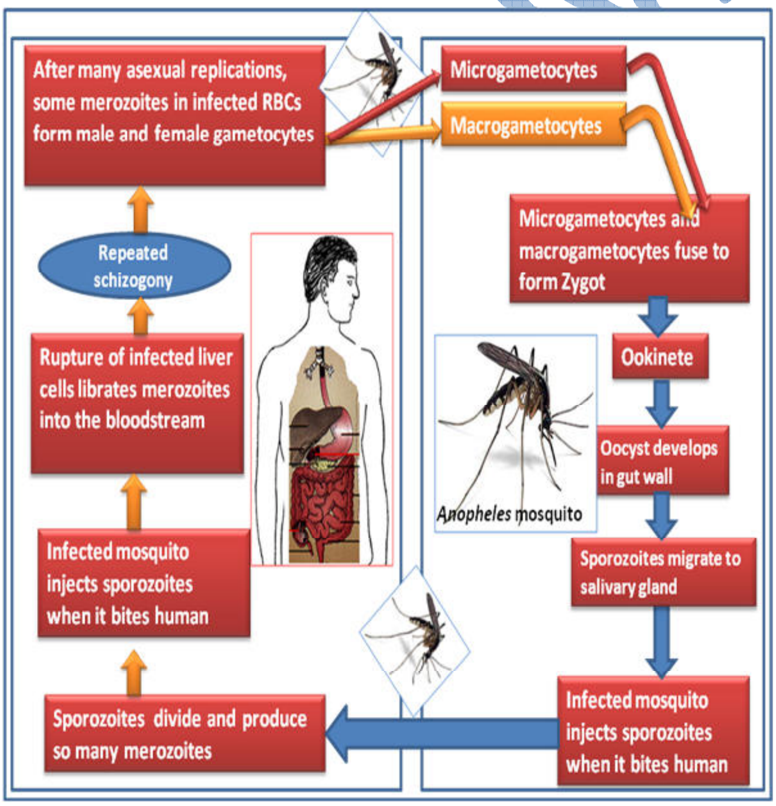


Figure 2. General life cycle of malarial parasites.

Parazoa: The Phylum Porifera (Sponges)

The Phylum Porifera includes the sponges. It is important to mention that some scientists still question whether sponges are real animals and if so, are they really individuals or colonies of individuals? Although sponges are composed of a loose collection of cells, they actually lack the true tissue-level organization that is characteristic of eumetazoans. Given that they appear to be a mass of relatively unspecialized cells, one might wonder if sponges are actually individuals or colonies of individuals. **There is evidence that supports both choices.**

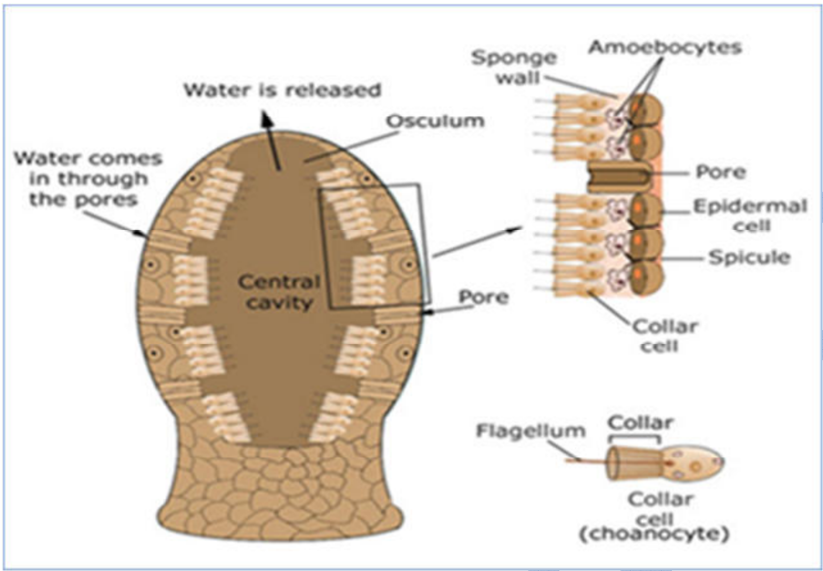


Figure ٣A. Sponge structure.

Sponges have an epidermis composed of tightly packed cells, underneath which lies a gelatinous matrix and a few specialized cell types that surround a central cavity called the **spongocoel**. The spongocoel is connected to the outside through an opening called the **osculum**. The spongocoel is lined with **choanocytes**, which are cells that have a central flagellum and a sticky collar that surrounds the flagellum. Water is drawn into the spongocoel through the osculum, and food particles in the water may pass the sponge's choanocytes. The flagellum of a choanocyte pulls in food particles, which get stuck in the sticky mucus of the collar and are picked up by **amoebocytes**. Amoebocytes are mobile and can transport nutrients throughout the body of the sponge.

Life cycle of sponges (Figure 3B)

A sponge has an embryonic form similar to a blastula because it is hollow. One-half of this embryonic form is flagellated, hence the embryo is free-swimming. This hollow, half-flagellated ball will eventually settle and stuck to a substrate. The flagellated half will invert, and the point where it inverts will become the **osculum**. The space created during inversion will become the **spongocoel**. It is important to mention that the **adult sponge is sessile, whereas the embryonic form is motile**.

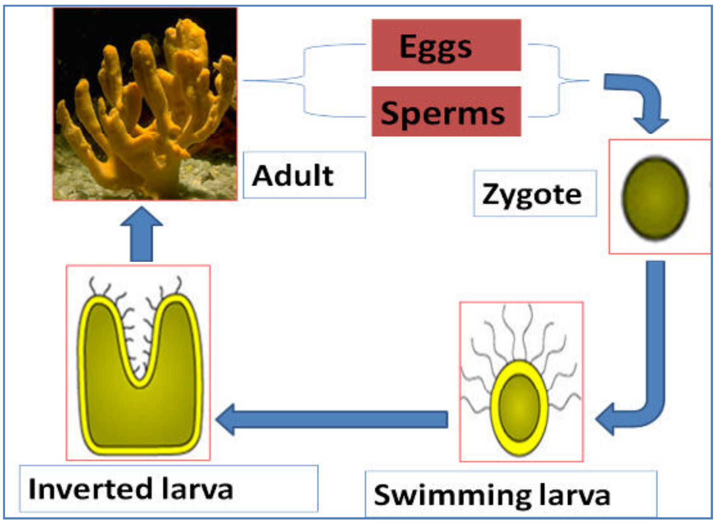


Figure 3B. Life cycle of the sponges (Zygot – free-swimming larva- inverted larva- Sessile sponge).

Summary

The animals within the Phylum Porifera can be considered individuals and colonies because they have features of both. In fact, there are some biologists who argue that they really are not animals; however, they do have animal characteristics (**<u>they are multicellular, motile, heterotrophic</u>**), which is why they are placed in the Kingdom Animalia.

Radiata: The Phylum Cnidaria (Pron: Nee-daria)

The radiata include organisms that have a radial morphology. The radiata include two Phyla; Cnidaria and Ctenophora. Examples of **cnidarians** include jellyfish, corals, hydra, and sea anemones. Some cnidarians are bioluminescent (radiate light), and some can sting. In addition, they all obtain and digest nutrients in an organized cellular manner which means that they have true tissues and hence they are placed in the Eumetazoa. Moreover, cnidarians have an unsophisticated <u>gastrovascular cavity.</u>

The cnidaria have two general body plans and these are: the **polyp** and the **medusa (see Figure 4, left panel)**. **<u>The polyp form is sessile, attached to a substrate while the medusa form is motile</u>**. It is important to mention that the mouth and anus are actually a single structure.

It is important to mention that the radiata have only two embryonic tissue layers (diploblastic), ectoderm and endoderm. They lack mesoderm (the tissue that gives rise to structures like muscles in triploblastic organisms). Consequently, they lack the level of sophisticated movement seen in triploblastic organisms.

Cnidarians also have **cnidocytes** (specialized cells that function in defence and the capture of prey); cnidocytes contain organelles called **cnidae**, which are able to evert. Cnidae that sting are called **nematocysts**. These nematocysts (see Figure 4, right panel) can immobilize fish for capture, and they can also be used for defence.

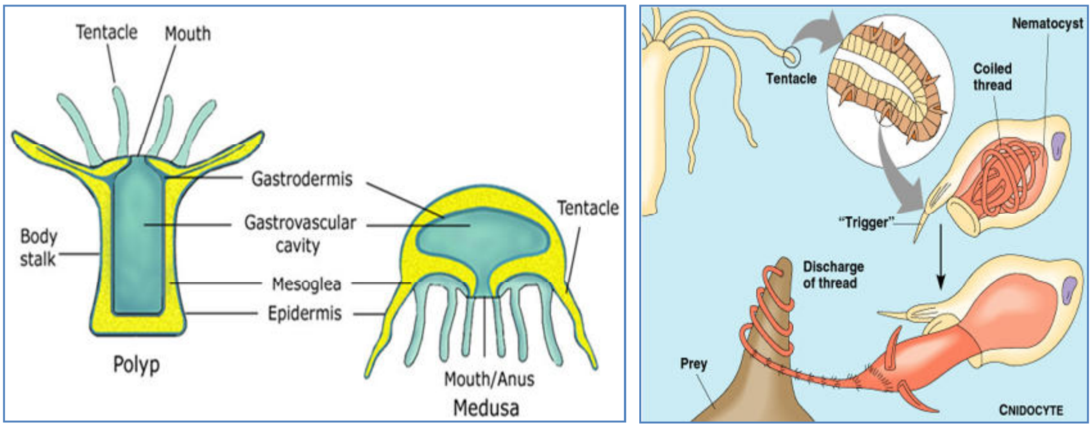


Figure 4. Body forms (left panel) and nematocytes (right panel) in Cnidaria.

Cnidarian Classes

There are three classes in the Phylum Cnidaria.

1. **Class Hydrozoa** which includes hydras and Obelia. Most **hydrozoans** exist in the polyp and medusa forms. For example, *Obelia* exists as an asexually reproducing polyp that alternates with a sexually reproducing medusa form.

2. **Class Scyphozoa** includes the jellyfish. **Scyphozoans** exist predominantly in the medusa form.

3. **Class Anthozoa** includes sea anemones, corals, and sea fans. **Anthozoans** exist only in the polyp form.

Members of all of the cnidarian classes can respond to external stimuli and can use stinging nematocysts for prey capture and defence.

Figure 5 shows the life cycle of *Obelia* and as you can see the medusa form is that which produces gametes. Once fertilization occurs, the animal undergoes development and a free-swimming planular larva results. The planula settles and develops into a sessile polyp that can develop asexually by budding. Mature polyps can differentiate into both feeding polyps (specialized for feeding) and reproductive polyps (specialized for reproduction). The reproductive polyp produces a medusa and the cycle continues.

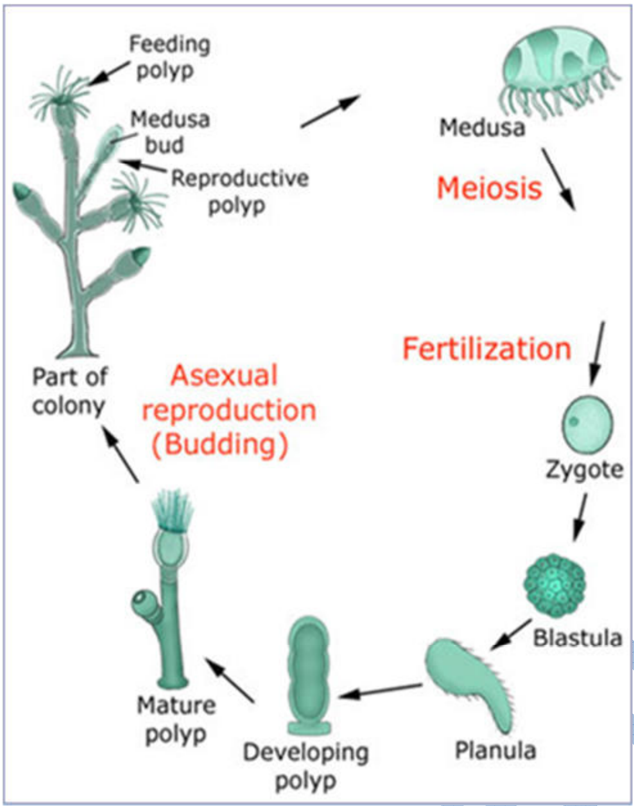


Figure 5. the life cycle of Obelia.

Summary

Phylum Cnidaria includes simple animals, such as the common jellyfishes. These animals do have true tissues; however, they possess only two embryonic tissues (diploblastic). The major body forms observed in this phylum are the polyp and the medusa. In many cnidarians, these forms alternate during the life cycle, **but in Class Hydrozoa the polyp is prominent, whereas in Class Scyphozoa the medusa is prominent**. Members of Class Anthozoa do not have a medusa stage (this class includes the coral reef-building animals).

Class	Polyp	Medusa
Hydrozoa	+	+
Scyphozoa	-	+
Anthozoa	+	-

Radiata: The Phylum Ctenophora (Teen-o-fora)

Phylum Ctenophora (comb-bearers): comb jellies possess rows of ciliary plates and adhesive colloblasts.

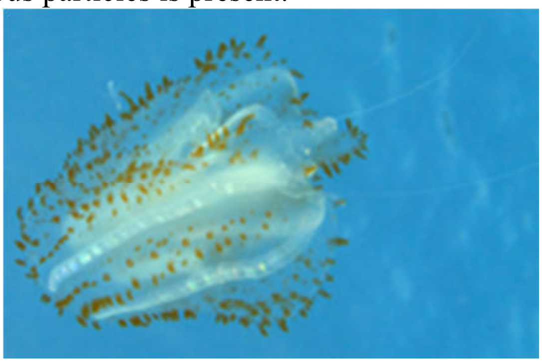
The phylum Ctenophora (comb-bearing animals) is a small phylum containing about 100 species of generally small and delicate animals known as Comb Jellies. Many species are quite and many are also almost transparent, a few species can be very beautiful as they have the ability to produce green and blue coloured light.

Characteristics of Ctenophora:-

1. Radially or biradial symmetrical.

2. Body is multicellular, few tissues, some organs and organelles.

3. Body contains an internal cavity and a mouth and anal pores.
4. Body surface has eight rows of comb-like paddles.
5. Comb paddles have thousands of cilia used for swimming.
6. Reproduction mostly sexual as hermaphrodites, occasionally asexual.
7. Nerves extending from the sensory organ to the combs of cilia coordinate movement.
8. Has a distinct larval stage which is planktonic.
9. Live in marine environments.
10. All are carnivorous.
11. A resemblance to the medusa of Cnidarians in that the body of most is spherical or ovoid; a few are elongate and ribbon-like.
12. Transparent body, 1 - 10 cm in diameter (spherical/ovoid forms) or up to 1 m long (ribbon-like forms) (see Figure 6)
13. One pair of long retractable tentacles that function in capturing food; these tentacles have adhesive structures called *colloblasts*.
14. A sensory organ containing calcareous particles is present.



Flgure 6. *Leucothea pulchra*

Bilateria

This group of animals have true tissues and bilateral symmetry, the bilateria (have a single plane of symmetry). Beside this single plane of symmetry is the development of advanced sensory material in the **anterior** (front) part of the body. Although the eyes of **planaria** lack the resolution of human eyes, they do detect light. They are connected to a primitive brain (simple brains that contain a low number of neurons are sometimes referred to as **ganglia**). This trend toward a concentration of sensory and nervous material is termed **cephalization**. It is important to mention that the bilateria are triploblastic, possessing a third embryonic tissue layer (mesoderm).

Bilateria include three main groups; acoelomates, pseudocoelomates, and coelomates.

1. Acoleomates: The Phylum Platyhelminthes (Flatworms)

The acoelomate animals do not have a fluid-filled internal body cavity, but instead, have a relatively solid body mass. The Phylum Platyhelminthes is divided into four classes.

1. Class Turbellaria: Members of this class include carnivorous **flatworms** (e.g., planarians). Cephalization occurs in the form of eyespots and paired ganglia, as well as an actual nervous system. These features are characteristic of the level of complexity observed in the bilateria. This class consists predominantly of free-living (nonparasitic) representatives.

2. Class Monogenea: Members of this class are all parasitic. Six suckers are used to suck digested material from their hosts.
3. Class Trematoda: Members of this class are also parasitic. Some **trematodes** exhibit very complex life cycles. Examples include the various species of blood flukes in the family *Schistosoma*, and the liver flukes.
4. Class Cestoda: Members of this class are also parasitic, and include the **tapeworms**. Tapeworms consist of a **scolex** (head), which has hooks for attaching to their host and suckers for extracting food. The majority of their body is actually a series of **proglottids (body segments)**, which basically are repeating units packed with sexual organs.

Phylum Platyhelminthes: flatworms are dorsoventrally flattened acoelomates.

1. The members of the phylum Platyhelminthes differ from the phylum Cnidaria in that they:
   - Exhibit bilateral symmetry with moderate cephalisation.
   - Are triploblastic (develop from three-layered embryos: ectoderm, endoderm and mesoderm).
   - Possess several distinct organs, organ systems, and true muscles.

1. Although more advanced than cnidarians, two things point to the early evolution of platyhelminths in bilateria history.
   - A gastrovascular cavity is present.
   - They have an acoelomate body plan.

1. Class Turbellaria

1. Mostly free-living, marine species; a few species are found in freshwater and moist terrestrial habitats).
2. Planarians are familiar and common freshwater forms.
3. Carnivorous, they feed on small animals.
4. Lack specialized organs for gas exchange or circulation.
5. Gas exchange is by diffusion (flattened body form places all cells close to water).

6. Fine branching gastrovascular cavity distributes food throughout the animal.
7. Flame cell excretory apparatus present which functions primarily to maintain osmotic balance of the animal.
8. Nitrogenous waste (ammonia) diffuses directly from cells to the water.
9. Move by using cilia on the ventral dermis to glide along a film of mucus. Muscular contractions produce undulations which allow some to swim.
10. On the head are a pair of eyespots which detect light and a pair of lateral auricles that are olfactory sensors.
11. Possess a rudimentary brain which is capable of simple learning.
12. Reproduce either asexually or sexually. □Asexually by regeneration: mid-body constriction separates the parent into two halves, each of which regenerates the missing portion. □Sexually by cross-fertilization of these hermaphroditic forms.

2. Classes Monogenea and Trematoda

- All members of these two classes are parasitic.
- Flukes are members of the class Trematoda.
- Suckers are usually present for attaching to host internal organs.
- Primary organ system is the reproductive system; a majority are hermaphroditic.
- Life cycles include alternations of sexual and asexual stages with asexual development taking place in an intermediate host. □□Larvae produced by asexual development infect the final hosts where maturation and sexual reproduction occurs.
- *Schistosoma* spp. (blood flukes) infect 200 million people worldwide.
- Members of the class Monogenea are mostly external parasites of fish.
- Structures with large and small hooks are used for attaching to the host.
- All are hermaphroditic and reproduce sexually.

3. Class Cestoda (ses-toda)

- Adult tapeworms parasitize the digestive system of vertebrates.
- Possess a scolex (head) which may be armed with suckers and/or hooks that help maintain position by attaching to the intestinal lining.
- Posterior to the scolex is a long ribbon of units called proglottids.
- A proglottid is filled with reproductive organs.
- No digestive system is present.
- The life cycle of a tapeworm includes an intermediate host.
- Mature proglottids filled with eggs are released from the posterior end of the worm and pass from the body with the feces.
- Eggs are eaten by an intermediate host and a larva develops, usually in muscle tissue.
- The final host becomes infected when it eats an intermediate host containing larvae.
- Humans can become infected with some species of tapeworms by eating undercooked beef or pork containing larvae.

Platyhelminthes and Diseases

The life cycle of *Schistosoma mansoni*, from the phylum Platyhelminthes, is complicated. The image below shows a copulating pair of male and female *Schistosoma* (blood flukes). Sexual reproduction occurs inside a vertebrate host (e.g. a human).

Fertilized eggs are eliminated in the feces of the final host. The larvae (miracidium) that emerge parasitize a second host, a snail.

The larval stages reproduce asexually within the snails until the emergence of the cercariae which in turn infect the suitable vertebrate host, including humans.

People who suffer from schistosomiasis exhibit various symptoms, including a distended abdomen. Other symptoms include pain and extreme diarrhea.

People that work in, or around, freshwater contaminated with human feces are at risk for harboring *Schistosoma* and contracting schistosomiasis.

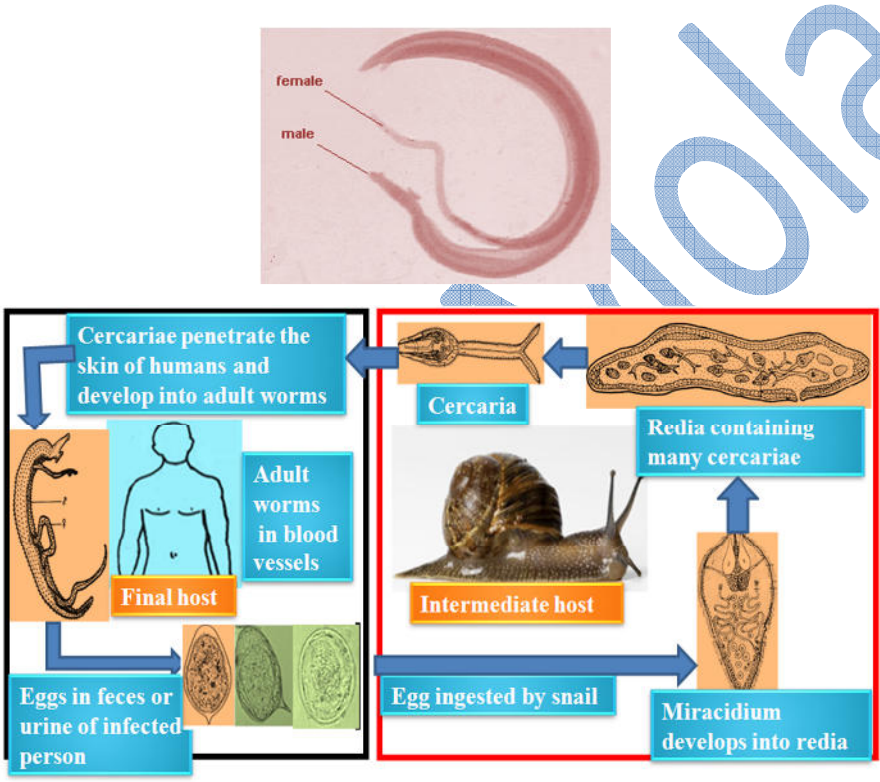


Figure 7. Male and female schistosomes (top panel) and life cycle of schistosome parasites (lower panel).

<u>**Summary**</u>

Bilaterally symmetrical animals not only have a single plane of symmetry, their sensory and cephalic areas are usually displaced toward the anterior part of the animal.

The Phylum Platyhelminthes is composed of animals that are commonly called flatworms. These animals are triploblastic and show an organ level of complexity.

Although many members of this phylum are free-living, some are parasitic and cause major health problems in some parts of the world.

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2. The Pseudocoelomates

This group includes two phyla:

A. Phylum Rotifera: rotifers have jaws and a crown of cilia

- They are small, mainly freshwater organisms, although some are marine and others are found in damp soil.
- Size ranges from 0.05-2.0 mm
- Pseudocoelomate with the pseudocoelomic fluid serving as a hydrostatic skeleton and as a medium which transports nutrients and wastes when the body moves
- *Complete digestive system* is present.
- Rotifer refers to the crown of cilia that draws a vortex of water into the mouth.
- Posterior to the mouth, a jaw-like organ grinds the microscopic food organisms suspended in the water.
- Reproduction in rotifers may be by *parthenogenesis* or sexual.
- Some species consist only of females with new females developing by parthenogenesis from unfertilized eggs.
- Other species produce two types of eggs, one that develops into females, the other into degenerate males.
- Males produce sperm that fertilize eggs which develop into resistant zygotes that survive desiccation.
- When conditions improve, the zygotes break dormancy and develop into a new female generation that reproduces by parthenogenesis until unfavorable conditions return.
- Rotifers have no regeneration or repair abilities.
- Rotifers contain a certain and consistent number of cells as adults. The zygotes undergo a specific number of divisions and the adult contains a fixed number of cells.

B. Phylum Nematoda: roundworms are unsegmented and cylindrical with tapered ends.

- There are about 90,000 species of roundworms, ranging in size from less than 1.0 mm to more than 1 m.
- Bodies are cylindrical with tapered ends.
- Found in fresh water, marine, moist soil, tissues of plants, and tissues and body fluids of animals.
- A complete digestive tract is present and nutrients are transported through the body in the pseudocoelomic fluid.
- A tough, transparent cuticle forms the outer body covering.
- Longitudinal muscles are present and used for whip-like movements.
- Sexes are separated (Dioecious) and females are larger than males.
- Sexual reproduction only, with internal fertilization.

- Female may produce 100,000 or more resistant eggs per day.
- Free-living forms are important in decomposition and nutrient cycling.
- Plant parasitic forms are important agricultural pests.
- Animal parasitic forms can be hazardous to health (*Trichinella spiralis* in humans via undercooked infected pork).
- One species, *Caenorhabitis elegans*, is cultured extensively and is a model species for the study of development.

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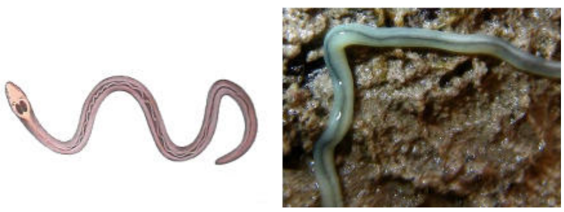
3. The Coelomates: Protostomes

The protostome lineage of coelomate animals gave rise to many phyla. In many, the coelom functions as a hydrostatic skeleton (e.g., molluscs, annelids).

A. Phylum Nemertea (ribbon or proboscis worms): the phylogenetic position of these worms is uncertain.

- There are about 900 species; most are marine with a few in fresh water and damp soil.
- The phylum Nemertea contains the proboscis worms (see Figure below)
- Sizes range from 1 mm to more than 30 m.
- Some active swimmers, others burrow in sand.
- Possess a long, retractable hollow tube (proboscis) which is used to probe the environment, capture prey, and as defense against predators.
- Excretory, sensory, and nervous systems are similar to planarians.
- Structurally acoelomate, like flatworms.
- There are some important differences between the Nemertea and Platyhelminthes: Nemertea possess a closed circulatory system, which consists of vessels through which blood flows. Some species have red blood cells containing a form of hemoglobin which transports oxygen. No heart is present, but body muscle contractions move the blood through vessels.
- Nemertea possess a complete digestive system with a mouth and an anus.
- Although the body is structurally acoelomate, the fluid-filled proboscis sac is considered a true coelom by some researchers.
- A simple blood vascular system and a complete digestive system are characteristics shared with more advanced phyla.



B. The lophophorate phyla: bryozoans, phoronids, and brachiopods have lopophores (lophophore is a fan of ciliated tentacles around the mouth).

The lophophorate animals contain three phyla: Phoronida, Bryozoa and Brachiopoda.

- These three phyla are grouped together due to presence of a lophophore.
- *Lophophore* = Horseshoe-shaped or circular fold of the body wall bearing ciliated tentacles that surround the mouth at the anterior end of the animal and used for feeding and may play role in respiration.
- Cilia direct water toward the mouth between the tentacles which trap food particles for these suspension-feeders.
- The presence of a lophophore in all three groups suggests a relationship among these phyla.
- The three phyla also possess a U-shaped digestive tract (the anus lies outside of the tentacles) and have no distinct head—both adaptations for a sessile existence.
- Lophophorates are difficult to assign as protostomes or deuterostomes.
- Their embryonic development more closely resembles deuterostomes; however, in the Phoronida, the blastopore develops into the adult mouth.
- Molecular systematics places the lophophorate phyla closer to the protostomes than the deuterostomes.

1. Phylum Bryozoa (moss animals):

- This phylum contains the moss animals. There are about 5000 species which are mostly marine and are widespread.
- Bryozoans are small, colonial forms.
- In most, the colony is enclosed within a hard exoskeleton and the lophophores are extended through pores when feeding.

2. Phylum Phoronida (phoronoid worms):

- This phylum contains about 15 species of tube-dwelling marine worms.
- Length from 1 mm to 50 cm
- Phoronids live buried in sand in chitinous tubes with the lophophore extended from the tube when feeding.

3. Phylum Brachiopoda (lamp shells):

- The phylum Brachiopoda contains the lamp shells. There are approximately 330 extant species, all marine.
- The body of a brachiopod is enclosed by dorsal and ventral shell halves.
- Attach to the substratum by a stalk
- Open the shell slightly to allow water to flow through the lophophore

<u>**Economic Importance**</u>

1. Fossil bryozoa used extensively by petroleum companies as indicator fossils to find oil deposits.
2. Over 17 antitumor chemicals have been extracted from various species.
3. Since they grow on hard surfaces sometimes cause fouling of ship hulls and pilings.



C. Phylum Mollusca: mollusks have a muscular foot, visceral mass, and a mantle.

- There are more than 50,000 species of snails, slugs, oysters, clams, octopuses, and squids.
- Mollusks are mainly marine, though some inhabit fresh water and many snails and slugs are terrestrial.
- Mollusks are soft-bodied, but most are protected by a hard calcium carbonate shell.
- Squids and octopuses have reduced, internalized shells or no shell.
- The molluscan body consists of three primary parts: muscular *foot* for locomotion, a *visceral mass* containing most of the internal organs, and a *mantle,* which is a heavy fold of tissue that surrounds the visceral mass and secretes the shell.
- A *radula* is present in many and functions as a rasping tongue to scrap food from surfaces.
- Some species are monoecious while most are dioecious.
- Gonads are located in the visceral mass.
- Some zoologists believe the mollusks evolved from annelid-like ancestors (although true segmentation is absent in mollusca) because the life cycle of many molluscs includes a ciliated larva, called a *trochophore*, which also is characteristic of annelids, while others believe that mollusks arose earlier in the protostome lineage before segmentation evolved.

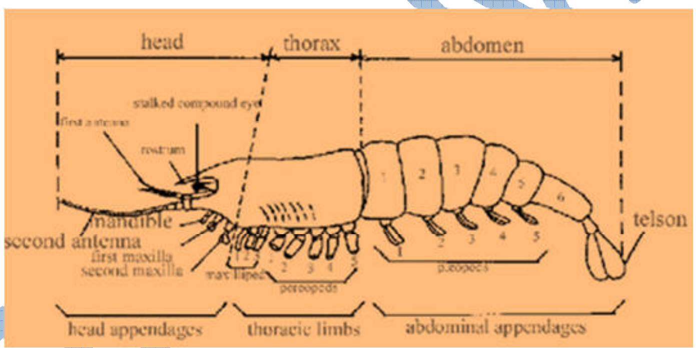
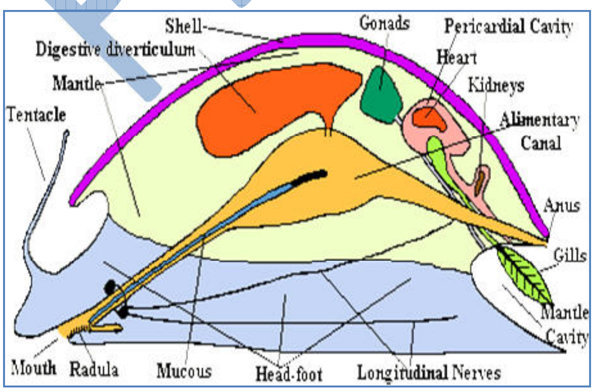


Figure. A generalised diagram of a crustacean, showing the basic body plan.



1. Class Polyplacophora (poly-pla-kof'o-ra)

- The class Polyplacophora contains the marine species known as chitons.
- They have an oval shape with the shell divided into eight dorsal plates.
- Cling to rocks using the foot as a suction cup to grip the rock. This muscular foot also allows it to creep slowly over the rock surface.
- A radula is used to cut and ingest ("graze") algae.

2. Class Gastropoda (gas-trop' o-da)

- The class Gastropoda contains the snails and slugs.
- Largest molluscan class with more than 40,000 species
- Mostly marine, but many species are freshwater or terrestrial
- *Torsion* during embryonic development is a distinctive characteristic:
- Body protected by a shell (absent in slugs and nudibranchs) which may be conical or flattened.
- Many species have distinct heads with eyes at the tips of tentacles.
- Movement results from a rippling motion along the elongated foot.
- Most gastropods are herbivorous, using the radula to graze on plant material; several groups are predatory and possess modified radulae.
- Most aquatic gastropods exchange gases via gills; terrestrial forms have lost the gills and utilize a vascularized lining of the mantle cavity for gas exchange.

3. Class Bivalvia (bi-val'vi-a)

- The class Bivalvia contains the clams, oysters, mussels and scallops.
- The shell halves are hinged at the mid-dorsal line and are drawn together by two adductor muscles to protect the animal.
- The mantle cavity (between shells) contains gills which function in gas exchange and feeding.
- Most are suspension-feeders and they trap small food particles in the mucus coating of the gills and then use cilia to move the particles to the mouth.
- Water enters the mantle cavity through an incurrent siphon, passes over the gills, and then exits through an excurrent siphon.
- No radula or distinct head is present.
- Bivalves lead sedentary lives. They use the foot as an anchor in sand or mud. Sessile mussels secrete threads that anchor them to rocks or other hard surfaces.
- Scallops can propel themselves along the sea floor by flapping their shells.

4. Class Cephalopoda (sef'a-lop'o-da)

- This class contains the squids and octopuses.
- Cephalopods are carnivores

- Use beak-like jaws to crush prey
- The mouth is at the center of several long tentacles
- A mantle covers the visceral mass, but the shell is either reduced and internal (squids) or totally absent (octopuses).
- Squids swim backwards in open water by drawing water into the mantle cavity, and then firing a jet stream of water through the excurrent siphon which points anteriorly.
- Directional changes can be made by pointing the siphon in different directions.
- Most squid are less than 75 cm long but the giant squid may reach 17 m and weigh 2 tons.
- Octopuses usually don't swim in open water, but move along the sea floor in search of food.
- Cephalopods are the only mollusks with a *closed circulatory system* in which the blood is always contained in vessels.
- Cephalopods have well developed nervous systems with complex brains capable of learning. They also have well developed sense organs.
- The cephalopod ancestors were probably shelled, carnivorous forms - the *ammonites*.
- These cephalopods were the dominant invertebrate predators in the oceans until they became extinct at the end of the Cretaceous.

Phylum Mollusca
Classification

Class Polyplacophora (pol'y-pla-kof' o-ra).
Chitons. Elongated, dorsally flattened body with reduced head; bilaterally symmetrical; radula present; shell of eight dorsal plates; foot broad and flat; gills multiple, along sides of body between foot and mantle edge; sexes usually separate. Examples: Mopalia, Katharina

Class Scaphopoda (ska-fop'o-da) .
Body enclosed in a one piece, tubular shell open at both ends; conical foot; mouth with radula and tentacles; head absent; mantle for respiration; sexes separate. Example: Dentalium

Class Gastropoda (gas-trop' o-da). Snails, slugs, conchs, whelks, and others.
Body asymmetrical, usually in a coiled shell (shell uncoiled or absent in some); head well developed, with radula; foot large and flat; one or two gills or with mantle modified into secondary gills or lung; dioecious or monoecious.

Examples: Norrisia, Haliotis, Helix, Aplysia

Class Bivalvia (bi-val'vi-a) .
Body enclosed in a two-lobed mantle; shell of two lateral valves of variable size and form, with dorsal hinge; cephalization much reduced; no radula; foot usually wedge-shaped; gills platelike; sexes usually separate. Examples: Mytilus, Venus, Tagelus, Teredo

Class Cephalopoda (sef'a-lop'o-da).
Squids and octopuses. Shell often reduced or absent; head well developed with eyes and radula; foot modified into arms or tentacles; siphon present; sexes separate. Examples: Loligo, Octopus, Sepia

Class Caudofoveata (kaw' do-fo-ve-at' a) (L. cauda, tail, + fovea, small pit). Wormlike; shell, head, and excretory organs absent; radula usually present; mantle with chitinous cuticle and calcareous scales; oral pedal shield near anterior mouth; mantle cavity at posterior end with pair of gills; sexes separate; formerly united with solenogasters in class Aplacophora.
Examples: Chaetoderma, Limifossor

Class Solenogastres (so-len' o-gas'trez).
Solenogasters. Wormlike; shell, head, and excretory organs absent; radula usually absent; rudimentary mantle usually covered with scales or spicules; mantle cavity posterior, without true gills but sometimes with secondary respiratory structures; foot represented by long, narrow, ventral pedal groove; hermaphroditic.
Example: Neomenia

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D. Phylum Annelida: annelids are segmented worms
The presence of a true coelom and segmentation are two important evolutionary advances present in the annelids. There are more than 15,000 species of annelids.

The most important characteristic features are:

- The coelom serves as a hydrostatic skeleton, permits development of complex organ systems, protects internal structures, and permits the internal organs to function separately from the body wall muscles.
- Segmentation also provided for the specialization of different body regions.
- They have segmented bodies and range in size from less than 1 mm to 3 m.
- There are marine, freshwater, and terrestrial (in damp soil) annelids.

- Annelids have a coelom partitioned by septa. The digestive tract, longitudinal blood vessels, and nerve cords penetrate the septa and extend the length of the animal.
- The complete digestive system is divided into several parts, each specialized for a specific function in digestion: pharynx esophagus crop gizzard intestine
- Annelids have a closed circulatory system. Hemoglobin is present in blood cells. Dorsal and ventral longitudinal vessels are connected by segmental pairs of vessels. Five pairs of hearts circle the esophagus. Numerous tiny vessels in the skin permit gas exchange is across the body surface.
- An excretory system of paired *metanephridia* is found in each segment; each metanephridium has a nephrostome (which removes wastes from the coelomic fluid and blood) and exits the body through an exterior pore.
- The annelid nervous system is composed of a pair of cerebral ganglia lying above and anterior to the pharynx. A nerve ring around the pharynx connects these ganglia to a subpharyngeal ganglion, from which a pair of fused nerve cords run posteriorly. Along the ventral nerve cords are fused segmental ganglia.
- Annelids are hermaphroditic but cross-fertilize during sexual reproduction. Two earthworms exchange sperm and store it temporarily. A special organ, the clitellum, secretes a mucous cocoon which slides along the worm, picking up its eggs and then the stored sperm. The cocoon slips off the worm into the soil and protects the embryos while they develop. Asexual reproduction occurs in some species by fragmentation followed by regeneration.
- Movement involves coordinating longitudinal and circular muscles in each segment with the fluid-filled coelom functioning as a hydrostatic skeleton. Circular muscle contraction makes each segment thinner and longer; longitudinal muscle contraction makes the segment shorter and thicker. Waves of alternating contractions pass down the body.
- Most aquatic annelids are bottom-dwellers that burrow, although some swim in pursuit of food.

1. Class Oligochaeta

- This class contains earthworms and a variety of aquatic species.
- Earthworms ingest soil, extract nutrients in the digestive system and deposit undigested material (mixed with mucus from the digestive tract) as casts through the anus.
- Important to farmers as they till the soil and castings improve soil texture.
- Darwin estimated that one acre of British farmland had about 50,000 earthworms that produced 18 tons of castings per year.

2. Class Polychaeta

- This class contains mostly marine species.
- A few drift and swim in the plankton, some crawl along the sea floor, and many live in tubes they construct by mixing sand and shell bits with mucus.
- Tube-dwellers include the fanworms that feed by trapping suspended food particles in their feathery filters which are extended from the tubes.
- Each segment has a pair of parapodia which are highly vascularized paddle-like structures that function in gas exchange and locomotion.
- Traction for locomotion is proved by several chitinous setae present on each parapodium.

3. Class Hirudinea

- This class contains the leeches.
- A majority of species are freshwater but some are terrestrial in moist vegetation.
- Many are carnivorous and feed on small invertebrates, while some attach temporarily to animals to feed on blood.
- Size ranges from 1 – 30 cm in length.
- Some blood-feeding forms have a pair of blade-like jaws that slit the host's skin while others secrete enzymes that digest a hole in the skin.
- An anesthetic is secreted by the leech to prevent detection of the incision by the host.
- Leeches also secrete hirudin which prevents blood coagulation during feeding.
- Leeches may ingest up to ten times their weight in blood at a single meal and may not feed again for several months.
- Leeches are currently used to treat bruised tissues and for stimulating circulation of blood to fingers and toes reattached after being severed in accidents.

E. Phylum Arthropoda: arthropods have regional segmentation, jointed appendages, and exoskeletons

- This phylum is the largest phylum of animals with approximately one million described species.
- Arthropods are the most successful phylum based on species diversity, distribution, and numbers of individuals.

1. General characteristics of arthropods

- The success and great diversity of arthropods is related to their segmentation, jointed appendages, and hard exoskeleton.
- The segmentation in this group is much more advanced than that found in annelids.
- In the arthropods, different segments of the body and their associated appendages have become specialized to perform specialized functions.
- Jointed appendages are modified for walking, feeding, sensory reception, copulation and defense.
- The arthropod body is completely covered by the *cuticle*, an *exoskeleton* (external skeleton) constructed of layers of protein and chitin.
- The cuticle is thin and flexible in some locations (joints) and thick and hard in others.
- The exoskeleton provides protection and points of attachment for muscles that move the appendages.
- The exoskeleton is also relatively impermeable to water.
- The old exoskeleton must be shed for an arthropod to grow (molting) and a new one secreted.

- Arthropods show extensive cephalization with many sensory structures clustered at the anterior end. Well-developed sense organs including eyes, olfactory receptors, and tactile receptors are present.
- An *open circulatory system* containing hemolymph is present. Hemolymph leaves the heart through short arteries and passes into the sinuses (open spaces) which surround the tissues and organs. The hemolymph reenters the heart through pores equipped with valves. The blood sinuses comprise the hemocoel. Although the hemocoel is the main body cavity, it is not part of the coelom.
- The true coelom is reduced in adult arthropods.
- Gas exchange structures are varied and include: Feathery gills in aquatic species, tracheal systems in insects, and book lungs in other terrestrial forms (e.g., spiders)

2. Arthropod phylogeny and classification

- Arthropods are segmented protostomes which probably evolved from annelids or a segmented protostome common ancestor.
- Early arthropods may have resembled onychophorans which have unjointed appendages. However, many fossils of jointed-legged animals resembling segmented worms support the evolutionary link between the Annelida and Arthropoda. Such comparisons also indicate that annelids and arthropods are *not* closely related.
- Parapodia may have been forerunners of appendages.
- Some systematists suggest that comparisons of ribosomal RNA indicate that onychophorans are arthropods and not transitional forms.
- This evidence presents an alternative hypothesis that segmentation evolved independently in annelids and arthropods. Thus, the most recent common ancestor of these two phyla would have been an unsegmented protostome.
- Although the origin of arthropods is unclear, most zoologists agree that four main evolutionary lines can be identified in the arthropods. Their divergence is represented by the subgroups: Trilobites (all extinct), Chelicerates, Uniramians, and Crustaceans.

3. Trilobites

- Early arthropods, called trilobites, were very numerous, but became extinct approximately 250 million years ago.
- Trilobites had extensive segmentation, but little appendage specialization.
- As evolution continued, the segments tended to fuse and appendages became specialized for a variety of functions.

4. Spiders and other chelicerates

- Other early arthropods included chelicerates, such as the *eurypterids* (sea scorpions) which were predaceous and up to 3 m in length.
- The chelicerate body is divided into an anterior cephalothorax and a posterior abdomen.
- Their appendages were more specialized than those of trilobites, with the most anterior ones being either pincers or fangs.
- Chelicerates are named for their feeding appendages, the *chelicerae*.
- Only four marine species remain; one is the horseshoe crab.
- The bulk of the modern chelicerates are found on land in class Arachnida.
- Includes terrestrial spiders, scorpions, ticks, and mites.

- Arachnids possess a cephalothorax with six pairs of appendages: chelicerae, pedipalps (used in sensing and feeding), and four pairs of walking legs.
- In spiders,

  -Fang-like chelicerae, equipped with poison glands, are used to attack prey.

  -Chelicerae and pedipalps masticate the prey while digestive juices are added to the tissues. This softens the food and the spider sucks up the liquid.

  -Gas exchange is by book lungs (stacked plates in an internal chamber), whose structure provides an extensive surface area for exchange.

  -**Spiders weave silken webs to capture prey**.

  -The proteinaceous silk is produced as a liquid by abdominal glands and spun into fibers by spinnerets. The fibers harden on contact with air.

  -Web production is apparently an inherited complex behavior.

  -Silk fibers are also used for escape, egg covers, and wrapped around food presented to females during courtship.

5. Millipedes and centipedes

The class Diplopoda includes the millipedes.

- Wormlike with a large number of walking legs (two pairs per segment)
- Eat decaying leaves and other plant matter
- Probably among the earliest land animals

The class **Chilopoda** includes the centipedes.

- They are carnivorous.
- One pair of antennae and three pairs of appendages modified as mouthparts (including mandibles) are located on the head.
- Each trunk segment has one pair of walking legs.
- Poison claws on the most anterior trunk segment are used to paralyze prey and for defense.

6. Insects [*Entomology*: The study of insects]

- The class Insecta has greater species diversity than all other forms of life combined.
- There are about 26 orders of insects.
- They inhabit terrestrial and freshwater environments, but only a few marine forms exist.
- The oldest insect fossils are from the Devonian period (about 400 million years ago), and an increase in insect diversity can be attributed to:
- The evolution of flight during the Carboniferous and Permian
- The evolution of specialized mouth parts for feeding on gymnosperms and other Carboniferous plants. The fossil record holds examples of a diverse array of specialized mouth parts. A second major radiation of insects, which occurred during the Cretaceous period, was once thought to have paralleled radiation of flowering plants.
- Current research indicates the major diversification of insects preceded angiosperm radiation during the Cretaceous period (65 million years ago). If this is true, insect diversity played a major role in angiosperm radiation, the reverse of the original hypothesis.

- Flight is the key to the success of insects, enabling them to escape predators, find food and mates, and disperse more easily than nonflying forms.
- One or two pairs of wings emerge from the dorsal side of the thorax in most Species.
- Wings are extensions of the cuticle and not modified appendages.
- Wings may have first evolved to help absorb heat, then developed further for flight.
- Other views suggest wings may have initially served for gliding, as gills in aquatic forms, or even as structures for swimming.
- Dragonflies were among the first to fly and have two coordinated pairs of wings. Modifications are found in groups which evolved later.
- Bees and wasps hook their wings together (act as one pair).
- Butterflies have overlapping anterior and posterior wings.
- Beetles have anterior wings modified to cover and protect the posterior (flying) wings.
- Insects have complete digestive system with specialized regions, open circulatory system with hemolymph, and excretory organs are the *Malpighian tubules,* which are outpocketings of the gut
- Gas exchange is by a tracheal system, which opens to the outside via spiracles that can open or close to regulate air and limit water loss
- Nervous system is composed of a pair of ventral nerve cords (with several segmental ganglia) which meet in the head where the anterior ganglia are fused into a dorsal brain close to the sense organs. Insects show complex behavior which is apparently inherited (e.g., social behavior of bees and ants).
- Many insects undergo metamorphosis during their development.
- *Incomplete metamorphosis* = A type of development during which young resemble adults but are smaller and have different body proportions
- For example, in grasshoppers a series of molts occur with each stage looking more like an adult until full size is reached.
- *Complete metamorphosis* = A type of development characterized by larval stages (e.g., maggot, grub, caterpillar) which are very different in appearance from adults.
- Larva eats and grows before becoming adults.
- Adults find mates and reproduce with the females laying eggs on the appropriate food source for the larval stages.
- Insects are dioecious and usually reproduce sexually with internal fertilization.
  - -In most, sperm are deposited directly into the female's vagina during copulation. Some males produce spermatophores which are picked up by the female.
  - -Inside the female, sperm are stored in the spermatheca.
  - -Most insects produce eggs although some flies are viviparous.
  - -Many insects mate only once in a lifetime with stored sperm capable of fertilizing many batches of eggs.
- Insects impact terrestrial organisms in a number of ways by:
  - -Competing for food
  - -Serving as disease vectors
  - -Pollinating many crops and orchards

7. Crustaceans

There are more than 40,000 species of crustaceans in marine and fresh waters.
The crustaceans have extensive specialization of their appendages.

• Two pairs of antennae, three or more pairs of mouthparts including mandibles, walking legs on the thorax, appendages are present on the abdomen.

• Lost appendages can be regenerated.

Characteristics of their physiology:

• An open circulatory system is present with hemolymph.

• Nitrogenous wastes are excreted by diffusion across thin areas of the cuticle.

• Most are dioecious and some males (e.g., lobsters) have a specialized pair of appendages to transfer sperm to the female's reproductive pore during copulation.

• Most aquatic crustaceans have at least one swimming larval stage.

• The decapods are relatively large crustaceans that have a carapace (calcium carbonate hardened exoskeleton over the cephalothorax).

Examples:

1. Freshwater crayfish
2. Marine lobsters, crabs and shrimp
3. Tropical land crabs

• The isopods are mostly small marine crustaceans but include terrestrial sow bugs and pill bugs.

• Terrestrial forms live in moist soil and damp areas.

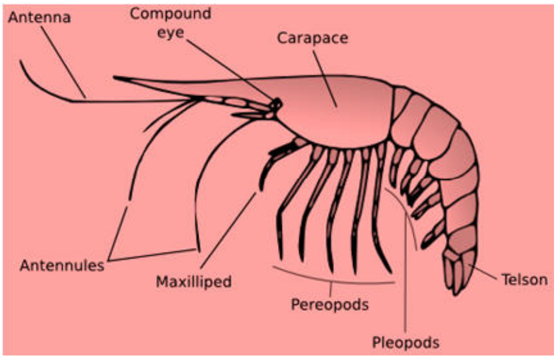
• Copepods are numerous small marine and freshwater planktonic crustaceans.

• The larvae of larger crustaceans may also be planktonic.

The most common body plan is a **tripartite** arrangement, consisting of a **head, thorax,** and **abdomen**. Unlike the insects, where the head and thorax are separated by a flexible joint, in the Crustacea they are almost always rigidly fused together. Sometimes the head and thorax are covered by a carapace, producing a single functional unit known as a **cephalothorax**. Some species have a prominent anterior projection from this cephalothorax called the **rostrum**.

The Crustacea are characterized by these features:

- Body composed of a 5-segmented head and a more or less distinct thorax and abdomen.
- Abdomen composed of 6 segments.
- Cephalic shield or carapace usually present.
- Appendages are multiarticulate and biramous (or secondarily uniramous in the case of limbs).
- Mandibles are multiarticulate limbs that function as basic jaws.
- Gas exchange is typically by aqueous diffusion across gill surface.
- Simple ocelli and compound eyes present in most taxa at some point during their life cycle.
- Compound eyes commonly raised on stalks.
- Produce a nauplius larva.



Basic anatomy of a decapod crustacean. In some groups such as brachyurans, the pleon is folded beneath the carapace.

7. The Coelomates: Deuterostomes

The deuterostomes, while a very diverse group, share characteristics which indicate their association: radial cleavage, enterocoelous coelom formation, and the blastopore forms the anus.

Phylum Echinodermata

Members of Phylum Echnodermata are exclusively marine. The name derived from the Greek word for "spiny skin". **The most striking characteristic of this phylum is their radial symmetry (the body can usually be divided into five parts arranged around a central axis,** but its larva is divided into two equal parts**), many having five or multiples of five arms.** The Phylum contains about 7,000 known species found usually on the sea floor in every marine habitat and they have calcareous exoskeletons. Although these animals have separate sexual organs, no copulation takes place. **The gonads discharge their gametes to outside and fertilization takes place in the sea water**.

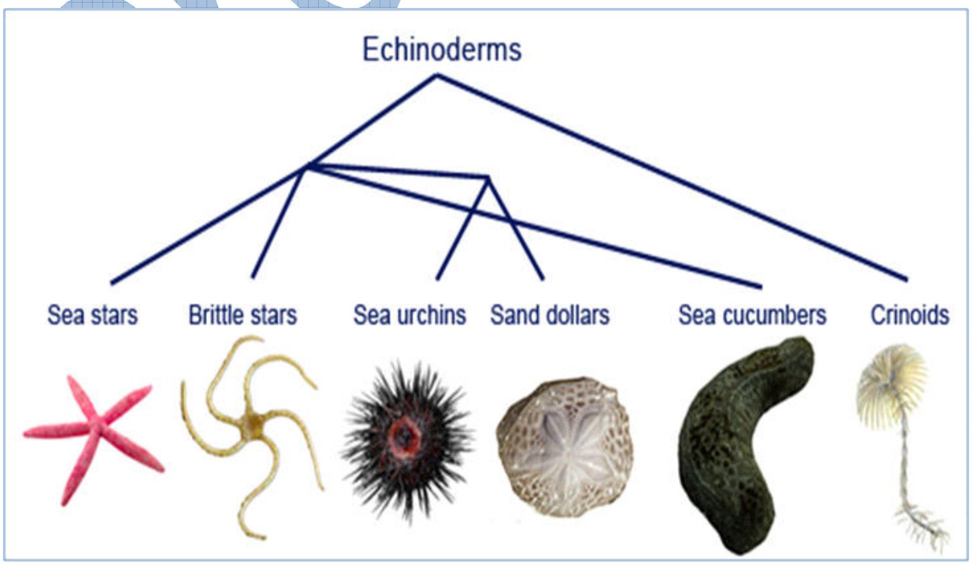


Figure. Tube feet

The Phylum Echinodermata includes more than 6000 marine species such as Sea Stars, Brittle Stars, Serpent Stars, Basket Stars, Sand Dollars, Sea Biscuits, Sea Urchins, Sea Lilies, Sea Cucumbers, and Sea Apples.

The various Echinoderms share many features such as the symmetry where they all have a round or nearly round body with body parts radiating from its center in an orderly fashion and this is called radial symmetry.

Ehinoderms also share a unique body system called the water-vascular system, which no other group of animals possess. This is a complex system of muscles, canals, pouches, bladders, tubes, and suckers that allow Echinoderms to move around and to eat. It is not easy to see it, but if you have a close look at any Sea Star, you will see that they have many suction cup-tipped "tube feet" that emerge from the grooves on their undersides. Through coordinated movement of these tube feet, the Sea Star can move quickly and also grab hold the prey for feeding. Similarly, other Echinoderms use their tube-feet, or similar extensions of the water-vascular system to capture planktonic foods, or to burrow through substrates.

Although it is not a unique character, all Echinoderms share the ability to regenerate damaged or lost body parts within a few weeks. Moreover, all Echinoderms have a skeleton of some sort which is composed of mineral calcite and is covered by an epidermis (outer skin).

Although the different species show so many similarities, still many differences can be recognised and accordingly this Phylum has been divided into five classes.

1. Class Asteroidea (as'ter-oy'de-a)

   This class contains all of the true Sea Stars which are easily recognized as having a relatively thick body that spreads out into arms. All of them are also mobile, and almost all of them have 5 arms, although, some Asteroids may have as many as 40 arms.

   They move about by using the tube feet on the undersides of their arms, but they don't really use the arms themselves for crawling as they cannot bend the arms (stay straight out) even when they are moving.

   Like other echinoderms, the asteroids can find food by chemical detection. They "smell" things nearby, and can even find prey that is buried well below the surface. Some are active predators that will attack and eat clams, snails, sponges, corals, anemones, and just about anything else they can get a hold on with their tube feet.

2. Class Ophiuroidea

This class contains all of the Brittle and Serpent Stars which are incorrectly thought to be just skinny Sea Stars. The beautiful and unusual basket stars are also Ophiuroids, and all together these three make up the largest group of all the Echinoderms. Although they may superficially look like Sea Stars, there are actually a few fundamental differences between the Ophiuroids and the Asteroids (which is why they are different classes, of course). **To start with, Ophiuroids have long thin arms that are clearly distinct from the body, or disc, which is typically rather small and somewhat flat compared to that of an Asteroid.**

The Brittle Stars and Serpent Stars are also restricted to having only 5 arms which are used for locomotion. **In addition, unlike the Asteroids the Ophiuroids don't use their tube feet for locomotion, but can crawl around using the arms themselves.** This gives them considerably more speed than Asteroids.


Figure. Brittle Star (left) and Serpent Star (right).

Basket Stars on the other hand, have exceptionally long, thin arms which are branched, branched again, and again, and form an efficient net to capture food. Sometimes the arms are tightly rolled up, but when preys come they are expanded to cover bigger area.

Fig. Basket Star is beautiful ophiuroid with unique branching arms.

3. **Class Crinoidea** (cry-noy'de-a)

1. Much like the Asteroids and the Ophiuroids, most Crinoids are free-living animals that have a central body with numerous arms radiating from it. Crinoids however, have far more arms and these arms are exceptionally thin and are covered with tiny branches. **Their plume-like arms have also led to another common name "Feather Star."** This shape gives the impression that they are some sort of large sea-dwelling flowers, and earns them the common name "Sea Lily".

Figure. Crinoids have unique arms designed for filter feeding.

4. **Class Echinoidea (eki'i-noy'de-a)**

Unlike the Asteroids, the Ophiuroids, and the Crinoids, Echinoids have no arms. These are better known as the Sea Urchins, Sea Biscuits, and Sand Dollars, and while they still have five-fold radial symmetry, tube feet, and a calcite skeleton made of solidly fused plates.

Echinoids can be loosely split into two groups: **the urchins, which are covered with relatively long spines and live on the surface of the seafloor or substrate, and Sand Dollars and Sea Biscuits which don't have long spines and live under the surface of the seafloor.** Instead of long spines, Sand Dollars and the Sea Biscuits are covered with numerous tiny moving structures. These, with the help of short tube feet, help them to burrow through soft sediments where they feed on buried organic material.

Figure. Sea Urchin.

5. Class Holothuroidea (hol' o-thu-roy' de-a)

Holothuroids are commonly known as Sea Cucumbers. Again, unlike the Stars and Lilies these have no arms. Instead, they have a number of highly-branched fleshy tentacles that can be extended from their oral end. They crawl on their sides, too. Whereas Sea Stars and such have a "top side" and a "bottom side" where the mouth is found, Holothuroids have their anus at one end and mouth at the other.

Despite their elongate shape, Holothuroids do have five-fold symmetry.

The Holothuroids can also be placed into two basic groups. There are those that get their food from the sediment and those that filter feed from the water column.

Figure. Sea Apple.

Digestive System

Echinoderms have a simple digestive system with a mouth, stomach, intestine and anus. In many, the mouth is on the underside and the anus on the top surface of the animal. **Sea stars can push their stomachs outside of their body and insert it into its prey allowing them to digest the food externally.** This ability allows sea stars to hunt prey that are much larger than its mouth would otherwise allow.

Nervous System and Senses

Echinoderms do not have brains; they have nerves running from the mouth into each arm or along the body. They have tiny eyespots at the end of each arm which only detect light or dark. Some of their tube feet are also sensitive to chemicals and this allows them to find the source of smells, such as food.

Circulatory System

Echinoderms have a network of fluid-filled canals that function in gas exchange, feeding and in movement. The network contains a central ring and areas which contain the tube feet which stretch along the body or arms. They do not have a true heart and the blood often lacks any respiratory pigment (pike haemoglobin).

Respiratory System

Echinoderms have a poorly developed respiratory system. They use simple gills and their tube feet to take in oxygen and pass out carbon dioxide

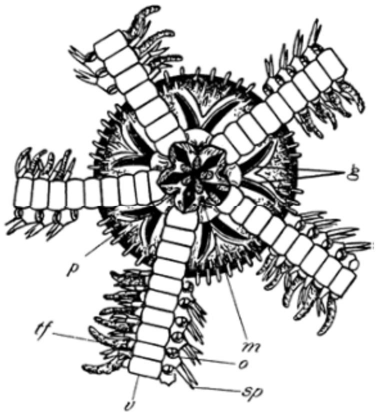
Reproductive System

Echinoderms are either male or female and become sexually mature after about two to three years. Most release their eggs and sperm into the water where they are fertilized. A female can release one hundred million eggs at once. Larvae develop which eventually settle on the sea floor in their adult form.

If an arm breaks off some echinoderms, a new arm or even a new echinoderm can regrow. Some sea stars and brittle stars have the ability to reproduce asexually by dividing in two halves while they are small juveniles.

Excretory System

Echinoderms have a simple excretory system with no kidneys and use diffusion to rid their bodies of nitrogenous waste which is mainly ammonia gas.



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Echinoderms are deuterostomes, thus sharing with Hemichordata and Chordata several embryological features that set them apart from the rest of the animal kingdom:

- anus developing from or near the blastopore
- mouth developing from a structure that is not the blastopore
- enterocoelous coelom
- radial and regulative cleavage
- mesoderm derived from enterocoelous pouches

Thus, all three phyla (Echinodermata, Hemichordata and Chordata) are presumably derived from a common ancestor.

B. Phylum Chordata: The chordates include two invertebrate subphyla and all vertebrates.

The phylum to which we belong consists of two subphyla of invertebrate animals plus the hagfishes and vertebrates.

The Chordata diverged from a common deuterostome ancestor with echinoderms at least 500 million years ago.

• The two phyla are grouped together due to similarities in early embryonic development.

• This phylum contains three subphyla: Urochordata, Cephalochordata, and Vertebrata.

LECTURE NOTES

I. The Parazoa

Phylum Porifera: sponges are sessile with porous bodies and choanocytes

1. The sponges are the only members of the subkingdom Parazoa due to their unique development and simple anatomy.
2. Sponges are so sedentary that they were mistaken for plants by the early Greeks.
3. The body of a simple sponge resembles a sac perforated with holes. after which the phylum is named
4. Approximately 9000 species, mostly marine with only about 100 in fresh water
5. Unlike eumetazoa, sponges lack true tissues and organs, and contain only two layers of loosely associated unspecialized cells
6. No nerves or muscles, but individual cells detect and react to environmental changes
7. Size ranges from 1 cm to 2 m
8. All are suspension-feeders (= filter-feeders)
9. Possibly evolved from colonial choanoflagellates

10. **Parts of the sponge include** (see Figure 3):
    - *Spongocoel* = Central cavity of sponge
    - *Osculum* = Larger excurrent opening of the spongocoel
    - *Epidermis* = Single layer of flattened cells which forms outer surface of the Sponge
    - *Porocyte* = Cells which form pores; possess a hollow channel through the center which extends from the outer surface (incurrent pore) to spongocoel.
    - *Choanocyte* = Collar cell, majority of cells which line the spongocoel; possess a flagellum which is ringed by a collar of fingerlike projections. Flagellar movement moves water and food particles which are trapped on the collar and later phagocytized.
    - *Mesohyl* = The gelatinous layer located between the two layers of the sponge body wall (epidermis and choanocytes)
    - *Amoebocyte* = Wandering, pseudopod bearing cells in the mesohyl; function in food uptake from choanocytes, food digestion, nutrient distribution to other cells, formation of skeletal fibers, gamete formation.
    - *Spicule* = Sharp, calcium carbonate or silica structures in the mesohyl which form the skeletal fibers of many sponges
    - *Spongin* = Flexible, proteinaceous skeletal fibers in the mesohyl of some sponges
11. Most sponges are hermaphrodites, but usually cross-fertilize.
    - Eggs and sperm form in the mesohyl from differentiated amoebocytes or choanocytes.
    - Eggs remain in the mesohyl.
    - Sperm are released into excurrent flow of the spongocoel and are then drawn in with incurrent flow of another sponge.

• Sperm penetrate into mesohyl and fertilize the eggs.
• The zygote develops into a flagellated larva which is released into the spongocoel and escapes with the excurrent water through the osculum.
• Surviving larvae settle on the substratum and develop. In most cases the larva turns inside-out during metamorphosis, moving the flagellated cells to the inside.

12. Sponges possess extensive regeneration abilities for repair and asexual reproduction.

II. The Radiata

This group is composed of phylum Cnidaria and phylum Ctenophora

A. Phylum Cnidaria: Cnidarians have radial symmetry, a gastrovascular cavity, and cnidocytes.

1. There are more than 10,000 species in the phylum Cnidaria, most of which are marine. The phylum contains hydras, jellyfish, sea anemones and coral animals. Some characteristics of cnidarians include:
    • Radial symmetry
    • Diploblastic
    • Simple, sac-like body
    • *Gastrovascular cavity,* a central digestive cavity with only one Opening (functions as mouth and anus).

2. There are two possible cnidarian body plans: sessile polyp and motile, floating medusa (see Figure 4). Some species of cnidarians exist only as polyps, some only as medusae, and others are dimorphic (both polyp and medusa stages in their life cycles).

Polyp = Cylindrical form which adheres to the substratum by the aboral end of the body stalk and extends tentacles around the oral end to contact prey.
Medusa = Flattened, oral opening down, bell-shaped form; moves freely in water by passive drifting and weak bell contractions; tentacles dangle from the oral surface which points downward.

3. Cnidarians are carnivorous.
    • Tentacles around the mouth/anus capture prey animals and push them through the mouth/anus into the gastrovascular cavity.
    • Digestion begins in the gastrovascular cavity with the undigested remains being expelled through the mouth/anus.
    • Tentacles are armed with stinging cells, called cnidocytes—after which the Cnidaria are named. *Cnidocytes* are specialized cells of cnidarian epidermis that contain eversible capsule-like organelles, or *cnidae*, used in defense and capture of prey (see Figure 5).

4. Nematocysts are stinging capsules.
5. The simplest forms of muscles and nerves occur in the phylum Cnidaria. Epidermal and gastrodermal cells have bundles of microfilaments arranged into contractile fibers.

6. The gastrovascular cavity, when filled with water, acts as a hydrostatic skeleton against which the contractile fibers can work to change the animal's shape.
7. A simple nerve net coordinates movement; no brain is present. The nerve net is associated with simple sensory receptors radially distributed on the body. This permits stimuli to be detected and responded to from all directions.
8. There are three major classes of cnidarians (see Table 1):

1. Class Hydrozoa

- Most hydrozoans alternate polyp and medusa forms in the life cycle although the polyp is the dominant stage. Some are colonial (e.g., *Obelia*, Figure 6), while others are solitary (e.g., *Hydra*). ***Hydra* is unique in that only the polyp stage is present.**
- They usually reproduce asexually by budding; however, in unfavourable conditions they reproduce sexually. In this case a resistant zygote is formed and remains dormant until environmental conditions improve.

2. Class Scyphozoa

- The planktonic medusa (jellyfish) is the most prominent stage of the life cycle.
- Coastal species usually pass through a small polyp stage during the life cycle.
- Open ocean species have eliminated the polyp entirely.

3. Class Anthozoa

- This class contains sea anemones and coral animals.
- They only occur as polyps. Coral animals may be solitary or colonial and secrete external skeletons of calcium carbonate.
- Each polyp generation builds on the skeletal remains of earlier generations. In this way, coral reefs are formed.
- Coral is the rock-like external skeletons.

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Glossary

Camouflage: To hide something by making it look like its surroundings.

Carnivore: Any animal or plant that feeds on animals.

Ecdysis: The periodic shedding of the cuticle or outer skin in insects and other invertebrates/arthropods.[All invertebrates in order to grow larger must shed their skin, a process known as ecdysis.].

Ectotherm: Any animal that relies on external heat sources to maintain body temperature.

Exoskeleton: The external protective structure or cuticle of arthropods.

Herbivore: Any animal that feeds on plant matter.

Hermaphrodite: Possessing both male and female reproductive organs.

Invertebrate: Any animal lacking a backbone.

Parthenogenic: The ability to produce a fertile egg without being fertilized.

 

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Chapter 33 - Invertebrates

- Invertebrates—animals without a backbone—account for 95% of known animal species and all but one of the roughly 35 animal phyla that have been described.
- More than a million extant species of animals are known, and at least as many more will probably be identified by future biologists.
- Invertebrates inhabit nearly all environments on Earth, from the scalding water of deep-sea hydrothermal vents to the rocky, frozen ground of Antarctica.

Concept 33.1 Sponges are sessile and have a porous body and choanocytes

- Sponges (phylum Porifera) are so sedentary that they were mistaken for plants by the early Greeks.
- Living in freshwater and marine environments, sponges are suspension feeders.
- The body of a simple sponge resembles a sac perforated with holes.
  - Water is drawn through the pores into a central cavity, the spongocoel, and flows out through a larger opening, the osculum.
  - More complex sponges have folded body walls, and many contain branched water canals and several oscula.
- Sponges range in height from about a few mm to 2 m and most are marine.
  - About 100 species live in fresh water.
- **Unlike eumetazoa, sponges lack true issues, groups of similar cells that form a functional unit.**
- The germ layers of sponges are loose federations of cells, which are not really tissues because the cells are relatively unspecialized.
  - The sponge body does contain different cell types.
- Sponges collect food particles from water passing through food-trapping equipment.
  - Flagellated choanocytes, or collar cells, lining the spongocoel (internal water chambers) create a flow of water through the sponge with their flagella and trap food with their collars.
  - Based on both molecular evidence and the morphology of their choanocytes, sponges evolved from a colonial choanoflagellate ancestor.
- The body of a sponge consists of two cell layers separated by a gelatinous region, the mesohyl.
- Wandering though the mesohyl are amoebocytes.

- They take up food from water and from choanocytes, digest it, and carry nutrients to other cells.
- They also secrete tough skeletal fibers within the mesohyl.
  - In some groups of sponges, these fibers are sharp spicules of calcium carbonate or silica.
  - Other sponges produce more flexible fibers from a collagen protein called spongin. We use these pliant, honeycombed skeletons as bath sponges.

- Most sponges are sequential hermaphrodites, with each individual producing both sperm and eggs in sequence.
  - Gametes arise from choanocytes or amoebocytes.
  - The eggs are retained, but sperm are carried out the osculum by the water current. Sperm are drawn into other individuals and fertilize eggs in the mesohyl.
  - The zygotes develop into flagellated, swimming larvae that disperse from the parent. When a larva finds a suitable substratum, it develops into a sessile adult.
- Sponges produce a variety of antibiotics and other defensive compounds.

Cnidarians have radial symmetry, a gastrovascular cavity, and cnidocytes

- All animals except protozoans and sponges belong to the Eumetazoa, the animals with true tissues.
  - The cnidarians (hydras, jellies, sea anemones, and coral animals) have a relatively simple body construction. Most of which are marine.
  - They exhibit a relatively simple, diploblastic body plan that arose 570 million years ago.
  - The basic cnidarian body plan is a sac with a central digestive compartment, the gastrovascular cavity. A single opening to this cavity functions as both mouth and anus.
- This basic body plan has two variations: the sessile polyp and the floating medusa.
- The cylindrical polyps, such as hydras and sea anemones, adhere to the substratum by the aboral end and extend their tentacles, waiting for prey.
- Medusas (also called jellies) are flattened, mouth-down versions of polyps that move by drifting passively and by contracting their bell-shaped bodies.
  - The tentacles of a jelly dangle from the oral surface.
  - Some cnidarians exist only as polyps. Others exist only as medusas. Some pass sequentially through both a medusa stage and a polyp stage in their life cycle.
- Cnidarians are carnivores that use tentacles arranged in a ring around the mouth to capture prey and push the food into the gastrovascular chamber for digestion.
  - Batteries of cnidocytes on the tentacles defend the animal or capture prey.
    - Organelles called cnidae evert a thread that can inject poison into the prey, or stick to or entangle the target.
  - Cnidae called nematocysts are stinging capsules.
- Muscles and nerves exist in their simplest forms in cnidarians.

- Cells of the epidermis and gastrodermis have bundles of microfilaments arranged into contractile fibers.
  - True muscle tissue appears first in triploblastic animals.
  - When the animal closes its mouth, the gastrovascular cavity acts as a hydrostatic skeleton against which the contractile cells can work.
- Movements are controlled by a noncentralized nerve net associated with simple sensory receptors that are distributed radially around the body.
- The phylum Cnidaria is divided into four major classes: Hydrozoa, Scyphozoa, Cubozoa, and Anthozoa.
- The four cnidarian classes show variations on the same body theme of polyp and medusa.
- Most hydrozoans alternate polyp and medusa forms, as in the life cycle of Obelia.
  - The polyp stage, often a colony of interconnected polyps, is more conspicuous than the medusa.
- Hydras, among the few freshwater cnidarians, are unusual members of the class Hydrozoa in that they exist only in the polyp form.
  - When environmental conditions are favorable, a hydra reproduces asexually by budding, the formation of outgrowths that pinch off from the parent to live independently.
  - When environmental conditions deteriorate, hydras form resistant zygotes that remain dormant until conditions improve.
- The medusa generally prevails in the life cycle of class Scyphozoa.
  - The medusae of most species live among the plankton as jellies.
- Most coastal scyphozoans go through small polyp stages during their life cycle.
  - Jellies that live in the open ocean generally lack the sessile polyp.
- Cubozoans have a box-shaped medusa stage.
  - They can be distinguished from scyphozoans in other significant ways, such as having complex eyes in the fringe of the medusae.
- Cubozoans, which generally live in tropical oceans, are often equipped with highly toxic cnidocytes.
- Sea anemones and corals belong to the **Class Anthozoa**.
  - They occur only as polyps.
  - Coral animals live as solitary or colonial forms and secrete a hard external skeleton of calcium carbonate.
  - Each polyp generation builds on the skeletal remains of earlier generations to form skeletons that we call coral.
- Coral reefs provide habitat for a great diversity of invertebrates and fishes.
  - Coral reefs in many parts of the world are destroyed by human activity.
  - Pollution, overfishing, and global warming are contributing to their demise.

Most animals have bilateral symmetry

- The vast majority of animal species belong to the clade Bilateria, which consists of animals with bilateral symmetry and triploblastic development.
- Most bilaterians are also coelomates.

Phylum Platyhelminthes: Flatworms are acoelomates with gastrovascular cavities.

- Flatworms live in marine, freshwater, and damp terrestrial habitats. They also include many parasitic species, such as the flukes and tapeworms.
- Flatworms have thin bodies, ranging in size from nearly microscopic to tapeworms more than 20 m long.
- Flatworms and other bilaterians are triploblastic, with a middle embryonic tissue layer, a mesoderm, which contributes to more complex organs and organ systems and to true muscle tissue.
- While flatworms are structurally more complex than cnidarians, they are simpler than other bilaterians.
  - Like cnidarians, flatworms have a gastrovascular cavity with only one opening (**and tapeworms lack a digestive system entirely and absorb nutrients across their body surface**). Unlike other bilaterians, flatworms lack a coelom.
- The flat shape of a flatworm places all cells close to the surrounding water, enabling gas exchange and the elimination of nitrogenous wastes (ammonia) by diffusion across the body surface.
- Flatworms have no specialized organs for gas exchange and circulation, and their relatively simple excretory apparatus functions mainly to maintain osmotic balance.
- Flatworms are divided into four classes: Turbellaria, Monogenia, Trematoda, and Cestoidea.
- Turbellarians are nearly all free-living (nonparasitic) and most are marine.
  - Planarians are carnivores or scavengers in unpolluted ponds and streams. Planarians move using cilia on the ventral epidermis. Some turbellarians use muscles for undulatory swimming.
- A planarian has a head with a pair of eyespots to detect light, and lateral flaps that function mainly for smell.
- The planarian nervous system is more complex and centralized than the nerve net of cnidarians.
- Planarians reproduce asexually through regeneration. They can also reproduce sexually.
- The monogeneans (class Monogenea) and the trematodes (class Trematoda) live as parasites in or on other animals.
    - Many have suckers for attachment to their host.
    - A tough covering protects the parasites.
    - Reproductive organs nearly fill the interior of these worms.
  - Trematodes parasitize a wide range of hosts, and most species have complex life cycles with alternation of sexual and asexual stages.
    - Many require an intermediate host in which the larvae develop before infecting the final hosts (usually a vertebrate) where the adult worm lives.
    - The blood fluke Schistosoma infects 200 million people, leading to body pains and dysentery.
    - The intermediate host for Schistosoma is a snail.

- Living within different hosts puts demands on trematodes that free-living animals do not face.
    - A blood fluke must evade the immune systems of two very different hosts.
    - By mimicking their host's surface proteins, blood flukes create a partial immunological camouflage.
    - They also release molecules that manipulate the host's immune system.
    - These defenses are so effective that individual flukes can survive in a human host for more than 40 years.
  - Most monogeneans are external parasites of fishes.
  - Their life cycles are simple, with a ciliated, free-living larva that starts an infection on a host.
  - While traditionally aligned with trematodes, some structural and chemical evidence suggests that they are more closely related to tapeworms.
- Tapeworms (class Cestoidea) are also parasitic.
  - The adults live mostly in vertebrates, including humans.
- Suckers and hooks on the head, or scolex, anchor the worm in the digestive tract of the host.
  - Tapeworms lack a gastrovascular cavity and absorb food particles from their hosts.
- A long series of proglottids, sacs of sex organs, lie posterior to the scolex.
  - Mature proglottids, loaded with thousands of eggs, are released from the posterior end of the tapeworm and leave with the host's feces.
  - In one type of cycle, tapeworm eggs in contaminated food or water are ingested by intermediary hosts, such as pigs or cattle.
  - The eggs develop into larvae that encyst in the muscles of their host.
  - Humans acquire the larvae by eating undercooked meat contaminated with cysts.
  - The larvae develop into mature adults within the human.

Phylum Rotifera: Rotifers are pseudocoelomates with jaws, crowns of cilia, and complete digestive tracts.

- Rotifers are tiny animals (5 µm to 2 mm), most of which live in freshwater.
  - Some live in the sea or in damp soil.
- Rotifers are smaller than many protists but are truly multicellular, with specialized organ systems.
- Rotifers have an alimentary canal, a digestive tract with a separate mouth and anus.
- Internal organs lie in the pseudocoelom, a body cavity that is not completely lined with mesoderm.
  - The fluid in the pseudocoelom serves as a hydrostatic skeleton.
  - Through the movements of nutrients and wastes dissolved in the coelomic fluid, the pseudocoelom also functions as a circulatory system.
- The word rotifer, "wheel-bearer," refers to the crown of cilia that draws a vortex of water into the mouth.
  - Food particles drawn in by the cilia are captured by the jaws (trophi) in the pharynx and ground up.

- Some rotifers exist only as females that produce more females from unfertilized eggs, a type of parthenogenesis.
- Other species produce two types of eggs that develop by parthenogenesis.
  - One type forms females, and the other forms degenerate males that survive just long enough to fertilize eggs.
  - The zygote forms a resistant stage that can withstand environmental extremes until conditions improve.
  - The zygote then begins a new female generation that reproduces by parthenogenesis until conditions become unfavorable again.
- It is puzzling that so many rotifers survive without males.
  - The vast majority of animals and plants reproduce sexually at least some of the time, and sexual reproduction has certain advantages over asexual reproduction.
  - For example, species that reproduce asexually tend to accumulate harmful mutations in their genomes faster than sexually reproducing species.
  - As a result, asexual species experience higher rates of extinction and lower rates of speciation.
- A class of asexual rotifers called Bdelloidea consists of 360 species that all reproduce by parthenogenesis without males.
  - Thirty-five-million-year-old bdelloid rotifers have been found preserved in amber.
  - The morphology of these fossils resembles the female form.
  - DNA comparisons of bdelloids with their closest sexually reproducing rotifer relatives suggest that bdelloids have been asexual for far more than 35 million years.
- Bdelloid rotifers raise interesting questions about the evolution of sex.

The lophophorate phyla: ectoprocts, phoronids, and brachiopods are coelomates with ciliated tentacles around their mouths.

- Bilaterians in three phyla—Ectoprocta, Phoronida, and Brachiopoda—are traditionally called lophophorate animals because they all have a lophophore.
  - The lophophore is a horseshoe-shaped or circular fold of the body wall bearing ciliated tentacles that surround and draw water toward the mouth.
  - The tentacles trap suspended food particles.
- In addition to the lophophore, these three phyla share a U-shaped digestive tract and the absence of a head.
  - These may be adaptations to a sessile existence.
- In contrast to flatworms, which lack a body cavity, and rotifers, which have a pseudocoelom, lophophorates have true coeloms completely lined with mesoderm.
- Ectoprocts are colonial animals that superficially resemble plants.
  - In most species, the colony is encased in a hard exoskeleton.
  - The lophophores extend through pores in the exoskeleton.
- Most ectoprocts are marine, where they are widespread and numerous sessile animals, with several species that can be important reef builders.
  - Ectoprocts also live in lakes and rivers.

- Phoronids are tube-dwelling marine worms ranging from 1 mm to 50 cm in length.
  - Some live buried in the sand within chitinous tubes.
  - They extend the lophophore from the tube when feeding and pull it back in when threatened.
- Brachiopods, or lampshells, superficially resemble clams and other bivalve molluscs.
  - However, the two halves of the brachiopod are dorsal and ventral to the animal, rather than lateral as in clams.
- All brachiopods are marine.
  - Most live attached to the substratum by a stalk, opening their shell slightly to allow water to flow over the lophophore.
- The living brachiopods are remnants of a richer past.
  - Thirty thousand species of brachiopod fossils have been described from the Paleozoic and Mesozoic eras.

Phylum Nemertea: Proboscis worms are named for their prey-capturing apparatus.

- The members of the Phylum Nemertea, proboscis worms or ribbon worms, have bodies much like those of flatworms.
  - However, they have a small fluid-filled sac that may be a reduced version of a true coelom.
  - The sac and fluid hydraulics operate an extensible proboscis, which the worm uses to capture prey.
- Nemerteans range in length from less than 1 mm to several meters.
- Nearly all nemerteans are marine, but a few species inhabit fresh water or damp soil.
  - Some are active swimmers, and others burrow into the sand.
- Nemerteans and flatworms have similar excretory, sensory, and nervous systems.
- However, nemerteans have an alimentary canal and a closed circulatory system in which the blood is contained in vessels.
  - Nemerteans have no heart, and the blood is propelled by muscles squeezing the vessels.

Molluscs have a muscular foot, a visceral mass, and a mantle

- The phylum Mollusca includes many diverse forms, including snails and slugs, oysters and clams, and octopuses and squids.
- Most molluscs are marine, though some inhabit fresh water, and some snails and slugs live on land.
- Molluscs are soft-bodied animals, but most are protected by a hard shell of calcium carbonate.
  - Slugs, squids, and octopuses have reduced or lost their shells completely during their evolution.

- Despite their apparent differences, all molluscs have a similar body plan with a muscular foot (typically for locomotion), a visceral mass with most of the internal organs, and a mantle.
  - The mantle, which secretes the shell, drapes over the visceral mass and creates a water-filled chamber, the mantle cavity, with gills, anus, and excretory pores.
  - Many molluscs feed by using a straplike rasping organ, a radula, to scrape up food.
- Most molluscs have separate sexes, with gonads located in the visceral mass.
  - However, many snails are hermaphrodites.
- The life cycle of many marine molluscs includes a ciliated larva, the trochophore.
  - This larva is also found in marine annelids (segmented worms) and some other lophotrochozoans.
- The basic molluscan body plan has evolved in various ways in the eight classes of the phylum.
  - The four most prominent are the Polyplacophora (chitons), Gastropoda (snails and slugs), Bivalvia (clams, oysters, and other bivalves), and Cephalopoda (squids, octopuses, cuttlefish, and chambered nautiluses).
- Chitons are marine animals with oval shapes and shells divided into eight dorsal plates.
  - The chiton body is unsegmented.
- Chitons use their muscular foot to grip the rocky substrate tightly and to creep slowly over the rock surface.
- Chitons are grazers that use their radulas to scrape and ingest algae.
- Almost three-quarters of all living species of molluscs are gastropods.
  - Most gastropods are marine, but there are also many freshwater species.
  - Garden snails and slugs have adapted to land.
- During embryonic development, gastropods undergo torsion in which the visceral mass is rotated up to 180 degrees, so the anus and mantle cavity are above the head in adults.
  - After torsion, some of the organs that were bilateral are reduced or lost on one side of the body.
- Most gastropods are protected by single, spiral shells into which the animals can retreat if threatened.
  - Torsion and formation of the coiled shell are independent developmental processes.
- While gastropod shells are typically conical, those of abalones and limpets are somewhat flattened.
- Many gastropods have distinct heads with eyes at the tips of tentacles.
- They move by a rippling motion of their foot or by means of cilia.
- Most gastropods use their radula to graze on algae or plant material.
- Some species are predators.
  - In these species, the radula is modified to bore holes in the shells of other organisms or to tear apart tough animal tissues.

- In the tropical marine cone snails, teeth on the radula form separate poison darts, which penetrate and stun their prey, including fishes.
- In place of the gills found in most aquatic gastropods, the lining of the mantle cavity of terrestrial snails functions as a lung.
- The class Bivalvia includes clams, oysters, mussels, and scallops.
- Bivalves have shells divided into two halves.
  - The two parts are hinged at the mid-dorsal line, and powerful adductor muscles close the shell tightly to protect the animal.
- Bivalves have no distinct head, and the radula has been lost.
  - Some bivalves have eyes and sensory tentacles along the outer edge of the mantle.
- The mantle cavity of a bivalve contains gills that are used for feeding and gas exchange.
- Most bivalves are suspension feeders, trapping fine particles in mucus that coats the gills.
  - Cilia convey the particles to the mouth.
  - Water flows into the mantle cavity via the incurrent siphon, passes over the gills, and exits via the excurrent siphon.
- Most bivalves live rather sedentary lives, a characteristic suited to suspension feeding.
  - Sessile mussels secrete strong threads that tether them to rocks, docks, boats, and the shells of other animals.
  - Clams can pull themselves into the sand or mud, using the muscular foot as an anchor.
  - Scallops can swim in short bursts to avoid predators by flapping their shells and jetting water out their mantle cavity.
- Cephalopods are active predators that use rapid movements to dart toward their prey, which they capture with several long tentacles.
  - Squids and octopuses use beak-like jaws to bite their prey and then inject poison to immobilize the victim.
- A mantle covers the visceral mass, but the shell is reduced and internal in squids, missing in many octopuses, and exists externally only in chambered nautiluses.
- Fast movements by a squid occur when it contracts its mantle cavity and fires a stream of water through the excurrent siphon.
  - By pointing the siphon in different directions, the squid can rapidly move in different directions.
- The foot of a cephalopod has been modified into the muscular siphon and parts of the tentacles and head.
- Cephalopods are the only molluscs with a closed circulatory system.
  - They also have well-developed sense organs and a complex brain.
- The ancestors of octopuses and squid were probably shelled molluscs that took up a predatory lifestyle.
- Shelled cephalopods called ammonites were the dominant invertebrate predators of the seas for hundreds of millions of years until their disappearance in the mass extinctions at the end of the Cretaceous period.

- Most squid are less than 75 cm long.
  - In 2003, a squid with a mantle 2.5 meters long was captured near Antarctica.
    - The specimen was possibly a juvenile, only half the size of an adult.
    - Large squid are thought to feed on large fish in the deep ocean, where sperm whales are their only natural predators.

Annelids are segmented worms

- All annelids ("little rings") have segmented bodies.
- They range in length from less than 1 mm to 3 m for the giant Australian earthworm.
- Annelids live in the sea, most freshwater habitats, and damp soil.
- The phylum Annelida is divided into three classes: Oligochaeta (earthworms), Polychaeta (polychaetes), and Hirudinea (leeches).
- Oligochaetes are named for their relatively sparse chaetae, or bristles made of chitin.
- This class of segmented worms includes the earthworms and a variety of aquatic species.
- Earthworms eat their way through soil, extracting nutrients as the soil passes through the alimentary canal.
  - Undigested material is egested as castings.
  - Earthworms till the soil, enriching it with their castings.
- Earthworms are cross-fertilizing hermaphrodites.
  - Two earthworms exchange sperm and then separate.
  - The received sperm are stored while a special organ, the clitellum, secretes a mucous cocoon.
  - As the cocoon slides along the body, it picks up eggs and stored sperm and slides off the body into the soil.
- Some earthworms can also reproduce asexually by fragmentation followed by regeneration.
- Each segment of a polychaete ("many setae") has a pair of paddlelike or ridgelike parapodia ("almost feet") that function in locomotion.
  - Each parapodium has several chitinous setae.
  - In many polychaetes, the rich blood vessels in the parapodia function as gills.
- Most polychaetes are marine.
  - Many crawl on or burrow in the seafloor, while a few drift and swim in the plankton.
  - Some live in tubes that the worms make by mixing mucus with sand and broken shells. Others construct tubes from their own secretions.
- The majority of leeches inhabit fresh water, but land leeches move through moist vegetation.
- Leeches range in size from about 1 to 30 cm.
- Many leeches feed on other invertebrates, but some blood-sucking parasites feed by attaching temporarily to other animals, including humans.

- Some parasitic species use blade-like jaws to slit the host's skin, while others secrete enzymes that digest a hole through the skin.
- The host is usually unaware of the attack because the leech secretes an anesthetic.
- The leech also secretes hirudin, an anticoagulant, into the wound, allowing the leech to suck as much blood as it can hold.

- Until the 20th century, leeches were frequently used by physicians for bloodletting.
    - Leeches are still used to drain blood that accumulates in tissues following injury or surgery.
    - Researchers are also investigating the potential use of hirudin to dissolve unwanted blood clots from surgery or heart disease.
    - A recombinant form of hirudin has been developed and is in clinical trials.

Nematodes are nonsegmented pseudocoelomates covered by a tough cuticle

- Roundworms are found in most aquatic habitats, wet soil, moist tissues of plants, and the body fluids and tissues of animals.
- They range in size from less than 1 mm to more than a meter.
- The bodies of roundworms are covered with a tough exoskeleton, the cuticle.
    - As the worm grows, it periodically sheds its old cuticle and secretes a new one.
- They have an alimentary tract and use the fluid in their pseudocoelom to transport nutrients since they lack a circulatory system.
- Nematodes usually reproduce sexually.
    - The sexes are separate in most species, and fertilization is internal.
    - Females may lay 100,000 or more fertilized eggs per day.
- Abundant, free-living nematodes live in moist soil and in decomposing organic matter on the bottom of lakes and oceans.
    - There are 25,000 described species, and perhaps ten times that number actually exist.
    - They play a major role in decomposition and nutrient recycling.
        - **The soil nematode, Caenorhabditis elegans, has become a model organism in developmental biology.**
- The nematodes include many species that are important agricultural pests that attack plant roots.
- Other species parasitize animals.
    - More than 50 nematode species, including various pinworms and hookworms, parasitize humans.
    - *Trichinella spiralis* causes trichinosis when the nematode worms encyst in a variety of human organs, including skeletal muscle.
    - They are acquired by eating undercooked meat that has juvenile worms encysted in the muscle tissue.
- Parasitic nematodes are able to hijack some of the cellular functions of their hosts.

- Plant-parasitic nematodes produce molecules that induce the development of root cells that provide nutrients to the parasites.

Arthropods are segmented coelomates that have an exoskeleton and jointed appendages

- Nearly a million arthropod species have been described. Two out of every three known species are arthropods. They live in nearly all habitats in the biosphere.
- On the criteria of species diversity, distribution, and numbers, arthropods must be regarded as the most successful animal phylum.
- The diversity and success of arthropods are largely due to three features: body segmentation, a hard exoskeleton, and jointed appendages.
- Groups of segments and their appendages have become specialized for a variety of functions, permitting efficient division of labour among regions.
  - The body of an arthropod is completely covered by the cuticle, an exoskeleton constructed from layers of protein and chitin. It is thick and inflexible in some regions, such as crab claws, and thin and flexible in others, such as joints.
- The exoskeleton of arthropods is strong and relatively impermeable to water.
  - In order to grow, an arthropod must molt its old exoskeleton and secrete a larger one, a process called ecdysis that leaves the animal temporarily vulnerable to predators and other dangers.
- The exoskeleton's relative impermeability to water helped prevent desiccation and provided support on land.
  - Arthropods have well-developed sense organs, including eyes for vision, olfactory receptors for smell, and antennae for touch and smell. Most sense organs are located at the anterior end of the animal, which shows extensive cephalization.
- Arthropods have an open circulatory system in which hemolymph fluid is propelled by a heart through short arteries into sinuses (the hemocoel) surrounding tissues and organs.
- Arthropods have evolved a variety of specialized organs for gas exchange.
  - Most aquatic species have gills with thin, feathery extensions that have an extensive surface area in contact with water.
  - Terrestrial arthropods generally have internal surfaces specialized for gas exchange.
- Molecular systematics is suggesting new hypotheses about arthropod relationships.
  - Evidence shows that arthropods diverged early in their history into four main evolutionary lineages: cheliceriformes (sea spiders, horseshoe crabs, scorpions, ticks, spiders), myriapods (centipedes and millipedes), hexapods (insects and their wingless, six-legged relatives), and crustaceans (crabs, lobsters, shrimps, barnacles, and many others).
- Cheliceriformes are named for their clawlike feeding appendages, chelicerae, which serve as pincers or fangs.
  - Cheliceriformes have an anterior cephalothorax and a posterior abdomen.
  - They lack sensory antennae, and most have simple eyes (eyes with a single lens).

- The earliest cheliceriformes were eurypterids, or water scorpions, marine and freshwater predators that grew up to 3 m long.
- Modern marine cheliceriformes include the sea spiders (pycnogonids) and the horseshoe crabs.

- The majority of living cheliceriformes are arachnids, a group that includes scorpions, spiders, ticks, and mites.
- Nearly all ticks are blood-sucking parasites on the body surfaces of reptiles or mammals.
  - Parasitic mites live on or in a wide variety of vertebrates, invertebrates, and plants.
- The arachnid cephalothorax has six pairs of appendages.
  - There are four pairs of walking legs.
  - A pair of pedipalps function in sensing or feeding.
  - The chelicerae usually function in feeding.
- Spiders inject poison from glands on the chelicerae to immobilize their prey and while chewing their prey, spill digestive juices into the tissues and suck up the liquid meal.
- In most spiders, gas exchange is carried out by book lungs.
  - These are stacked plates contained in an internal chamber.
  - The plates present an extensive surface area, enhancing exchange of gases between the hemolymph and air.
- A unique adaptation of many spiders is the ability to catch flying insects in webs of silk.
  - The silk protein is produced as a liquid by abdominal glands and spun by spinnerets into fibers that solidify.
  - Web designs are characteristic of each species.
  - Silk fibers have other functions as egg covers, drop lines for a rapid escape, and “gift wrapping” for nuptial gifts.
- Millipedes and centipedes belong to the subphylum Myriapoda, the myriapods.
  - All living myriapods are terrestrial.
  - Millipedes (class Diplopoda) have two pairs of walking legs on each of their many trunk segments, formed by two fused segments.
  - They eat decaying leaves and plant matter.
  - They may have been among the earliest land animals.
- Centipedes (class Chilopoda) are terrestrial carnivores.
  - The head has a pair of antennae and three pairs of appendages modified as mouth parts, including the jawlike mandibles.
  - Each segment in the trunk region has one pair of walking legs.
  - Centipedes have poison claws on the anteriormost trunk segment that paralyze prey and aid in defense.
- Insects and their relatives (subphylum Hexapoda) are more species-rich than all other forms of life combined.
- They live in almost every terrestrial habitat and in fresh water, and flying insects fill the air.

  - They are rare, but not absent, from the sea, where crustaceans dominate.
- The oldest insect fossils date back to the Devonian period, about 416 million years ago.
  - When insect flight evolved in the Carboniferous and Permian periods, it sparked an explosion in insect varieties.
  - Diversification of mouthparts for feeding on gymnosperms and other Carboniferous plants also contributed to the adaptive radiation of insects.
  - In one widely held hypothesis, the radiation of flowering plants triggered the greatest diversification of insects in the Cretaceous and early Tertiary periods.
    - However, new research suggests that insects diversified first and, as pollinators and herbivores, may have caused the angiosperm radiation.
- Flight is one key to the great success of insects.
  - Flying animals can escape many predators, find food and mates, and disperse to new habitats faster than organisms that must crawl on the ground.
- Many insects have one or two pairs of wings that emerge from the dorsal side of the thorax.
  - Wings are extensions of the cuticle and are not true appendages.
- Several hypotheses have been proposed for the evolution of wings.
  - In one hypothesis, wings first evolved as extensions of the cuticle that helped the insect absorb heat and were later modified for flight.
  - A second hypothesis argues that wings allowed animals to glide from vegetation to the ground.
  - Alternatively, wings may have served as gills in aquatic insects.
  - Still another hypothesis proposes that insect wings functioned for swimming before they functioned for flight.
- Insect wings are also very diverse.
  - Dragonflies, among the first insects to fly, have two similar pairs of wings.
  - The wings of bees and wasps are hooked together and move as a single pair.
  - Butterfly wings operate similarly because the anterior wings overlap the posterior wings.
  - In beetles, the posterior wings function in flight, while the anterior wings act as covers that protect the flight wings when the beetle is on the ground or burrowing.
- The internal anatomy of an insect includes several complex organ systems.
  - In the complete digestive system, there are regionally specialized organs with discrete functions.
  - Metabolic wastes are removed from the hemolymph by Malpighian tubules, outpockets of the digestive tract.
  - Respiration is accomplished by a branched, chitin-lined tracheal system that carries O_2 from the spiracles directly to the cells.
- The insect nervous system consists of a pair of ventral nerve cords with several segmental ganglia.
  - The two cords meet in the head, where the ganglia from several anterior segments are fused into a cerebral ganglion (brain).

    - This structure is close to the antennae, eyes, and other sense organs concentrated on the head.
- Metamorphosis is central to insect development.
    - In incomplete metamorphosis (seen in grasshoppers and some other orders), the young resemble adults but are smaller and have different body proportions.
        - Through a series of molts, the young look more and more like adults until they reach full size.
    - In complete metamorphosis, larval stages specialized for eating and growing change morphology completely during the pupal stage and emerge as adults.
- Reproduction in insects is usually sexual, with separate male and female individuals.
    - Coloration, sound, or odor bring together opposite sexes at the appropriate time.
    - In most species, sperm cells are deposited directly into the female's vagina at the time of copulation.
        - In a few species, females pick up a sperm packet deposited by a male.
    - The females store sperm in the spermatheca, in some cases holding enough sperm from a single mating to last a lifetime.
    - After mating, females lay their eggs on a food source appropriate for the next generation.
- Insects affect the lives of all other terrestrial organisms.
    - Insects are important natural and agricultural pollinators.
    - On the other hand, insects are carriers for many diseases, including malaria and African sleeping sickness.
    - Insects compete with humans for food, consuming crops intended to feed and clothe human populations.
        - Billions of dollars each year are spent by farmers on pesticides to minimize losses to insects.
        - In parts of Africa, insects claim about 75% of the crops.
- While arachnids and insects thrive on land, most crustaceans remain in marine and freshwater environments.
- Crustaceans typically have biramous (branched) appendages that are extensively specialized.
    - Lobsters and crayfish have 19 pairs of appendages, adapted to a variety of tasks.
    - In addition to two pairs of antennae, crustaceans have three or more pairs of mouthparts, including hard mandibles.
    - Walking legs are present on the thorax and other appendages for swimming or reproduction are found on the abdomen.
    - Crustaceans can regenerate lost appendages during molting.
- Small crustaceans exchange gases across thin areas of the cuticle, but larger species have gills.
- The circulatory system is open, with a heart pumping hemolymph into short arteries and then into sinuses that bathe the organs.
- Nitrogenous wastes are excreted by diffusion through thin areas of the cuticle, but glands regulate the salt balance of the hemolymph.

- Most crustaceans have separate sexes. In lobsters and crayfish, males use a specialized pair of appendages to transfer sperm to the female's reproductive pore.
- The isopods, with about 10,000 species, are one of the largest groups of crustaceans. Most are small marine species, and some are abundant at the bottom of deep oceans. Isopods also include the land-dwelling pill bugs, or wood lice, that live underneath moist logs and leaves.

- Decapods, including lobsters, crayfish, crabs, and shrimp, are among the largest crustaceans.
  - The exoskeleton over the cephalothorax forms a shield called the carapace.
  - While most decapods are marine, crayfish live in fresh water and some tropical crabs are terrestrial as adults.
- Many small crustaceans are important members of marine and freshwater plankton communities.
  - Planktonic crustaceans include many species of copepods, which are among the most numerous of all animals.
  - Krill are shrimplike planktonic organisms that reach about 3 cm long.
  - A major food source for whales and other ocean predators, they are now harvested extensively by humans for food and agricultural fertilizer.
- Barnacles are primarily sessile crustaceans with parts of their cuticle hardened by calcium carbonate.
  - They anchor themselves to rocks, boat hulls, and pilings and strain food from the water by extending their appendages.

Echinoderms and chordates are deuterostomes

- At first glance, sea stars and other echinoderms would seem to have little in common with the phylum Chordata, which includes the vertebrates.
- However, these animals share the deuterostome characteristics of radial cleavage, type of development of the coelom, and formation of the anus from the blastopore.
- Molecular systematics suggest that the Deuterostomia as a group of bilaterian animals.

Phylum Echinodermata: Echinoderms have a water vascular system and radial symmetry.

- Sea stars and most other echinoderms are sessile or slow-moving marine animals.
- A thin skin covers an endoskeleton of hard calcareous plates.
  - Most echinoderms are prickly from skeletal bumps and spines that have various functions.
- Unique to echinoderms is the water vascular system, a network of hydraulic canals branching into extensions called tube feet.
  - These function in locomotion, feeding, and gas exchange.
- Sexual reproduction in echinoderms usually involves the release of gametes by separate males and females into the seawater.

- The internal and external parts of the animal radiate from the center.
    - However, the radial anatomy of adult echinoderms is a secondary adaptation, as echinoderm larvae have bilateral symmetry.
    - The symmetry of adult echinoderms is not perfectly radial.
- Living echinoderms are divided into six classes: Asteroidea (sea stars), Ophiuroidea (brittle stars), Echinoidea (sea urchins and sand dollars), Crinoidea (sea lilies and feather stars), Holothuroidea (sea cucumbers), and Concentricycloidea (sea daisies).
- Sea stars have multiple arms radiating from a central disk.
    - The undersides of the arms have rows of tube feet.
    - Each can act like a suction disk that is controlled by hydraulic and muscular action.
- Sea stars use the tube feet to grasp the substrate, to creep slowly over the surface, or to capture prey.
    - When feeding on closed bivalves, the sea star grasps the bivalve tightly and averts its stomach through its mouth and into the narrow opening between the shells of the bivalve.
    - Enzymes from the sea star's digestive organs then begin to digest the soft body of the bivalve inside its own shell.
- Sea stars and some other echinoderms can regenerate lost arms and, in a few cases, even regrow an entire body from a single arm.
- Brittle stars have a distinct central disk and long, flexible arms.
    - Their tube feet lack suckers.
    - They move by a serpentine lashing of their arms.
    - Some species are suspension feeders, and others are scavengers or predators.
- Sea urchins and sand dollars have no arms, but they do have five rows of tube feet that are used for locomotion.
    - Sea urchins can also move by pivoting their long spines.
    - The mouth of an urchin is ringed by complex jawlike structures adapted for eating seaweed and other foods.
    - Sea urchins are spherical, while sand dollars are flattened and disk-shaped.
- Sea lilies are attached to the substratum by stalks, and feather stars crawl using their long, flexible arms.
    - Both use their arms for suspension feeding.
    - The arms circle the mouth, which is directed upward, away from the substrate.
    - Crinoids are an ancient class with very conservative evolution.
    - Fossilized sea lilies from 500 million years ago could pass for modern members of the class.
- Sea cucumbers do not look much like other echinoderms.
    - They lack spines, the endoskeleton is much reduced, and the oral-aboral axis is elongated.
- However, they do have five rows of tube feet, like other echinoderms, and other shared features.

- Some tube feet around the mouth function as feeding tentacles for suspension feeding or deposit feeding

- Sea daisies were discovered in 1986, and only two species are known.
    - Their armless bodies are disk-shaped with five-fold symmetry.
    - They are less than a centimeter in diameter.
    - Some taxonomists consider sea daisies to be highly derived sea stars.

Phylum Chordata: The chordates include two invertebrate subphyla and all vertebrates.

- The phylum to which we belong consists of two subphyla of invertebrate animals plus the hagfishes and vertebrates.
- Both groups of deuterostomes, the echinoderms and chordates, have existed as distinct phyla for at least half a billion years.

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