General Characteristics of Arthropoda

Subject: Life Sciences

Lesson: General Characteristics of Arthropoda

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1.1 What are Arthropods?

Phylum Arthropoda is the largest phylum of all animal phyla. It represents a vast assemblage of segmented animals with unique features of chitinous exoskeleton and jointed appendages. It is the most successful group of animals with over a million described species, making up more than 80% of all described living animal species. These are the only invertebrates which can invade terrestrial, aquatic and aerial habitat as they are adapted to live on dry land or in water and some are even capable of flight. These can be found anywhere and everywhere where any signs of life exist, e.g. mountains, deserts, sea bottoms, lakes, sulphur springs, underground water, soil, petroleum pools, etc.

Arthropods are triploblastic, bilaterally symmetrical and true coelomates. They have evolved from polychaetes or have the same ancestor as that of polychaetes. Arthropods and annelids have many features in common, such as metameric segmentation, presence of appendages, ladder-like nervous system, spiral and determinate cleavage. The onychophoran, *Peripatus,* is believed to be the connecting link between these two phyla.

1.1.1 Outline Classification

Arthropods are basically divided into four subphyla: Trilobita, Chelicerata, Crustacea, Uniramia.

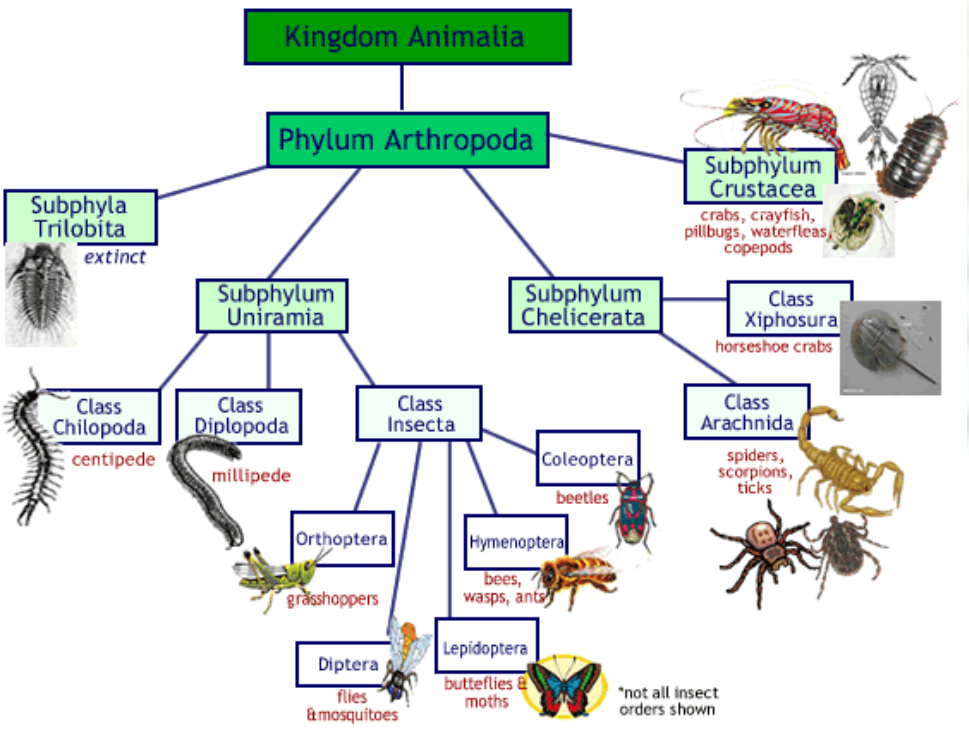


Fig. 1.1: Outline Classification of Arthropods

(Source: http://www.biologycorner.com/resources/arthropod_chart.gif)

1. **Trilobita** or **Trilobitomorpha**: This subphylum includes extinct, marine organisms whose body is divided into three longitudinal lobes by two furrows. Their body is many-segmented and each segment has a pair of biramous appendages. These are commonly called trilobite animals.

2. **Chelicerata**: Body of chelicerates is divided into two parts: prosoma and opisthosoma. Their appendages include one pair of biramous chelicerae bearing claws, a pair of pincer-like pedipalps and 4 pair of legs. The subphylum includes horse-shoe crabs, scorpions, spiders, etc.

3. **Crustacea**: Body of crustaceans is divided into two parts; cephalothorax and abdomen. Their appendages include biramous antennae, maxillae, mandibles and 3-5 pairs of walking legs. Examples of the subphylum crustacea are prawn, crabs, water fleas, barnacles, crayfish etc.

4. **Uniramia**: In Uniramia, body may not be distinctly divided or may be distinctly divided into three parts: head, thorax and abdomen. These animals have uniramous appendages; varied types of mouth parts and wings in certain cases. This subphylum contains insects, millipedes, centipedes.

Interesting Fact
Diverse arthropods
The lightest insect weighs less than 25 micrograms, while the heaviest weighs over 70 grams. Some living crustaceans are much larger, for example the legs of the Japanese Spider Crab may span up to 4 meters (13 ft).
Source: Barnes, R.D. (1992) Invertebrate Zoology. Saunders College Publishing, USA

1.2 Chitinous Exoskeleton

The body of arthropods is covered by a thick **cuticle** which is made up of a horny substance called **chitin**. Cuticle forms a hard, rigid, non-flexible, non-cellular and thick exoskeleton formed of separate plates. It is further hardened by the biomineralization and sclerotization because of the deposition of the calcium salts. Presence of cuticle is a unique feature of all arthropods and is primarily responsible for the evolutionary success of the group.

1.2.1 Structure of the Cuticle

The cuticle of arthropods is composed of basically two layers; a thin, waxy outer epicuticle and a thick, inner procuticle.

a) **Epicuticle**: It is the outermost layer which is very thin and is secreted by the underlying epidermis. It is devoid of chitin; and made up of proteins and waxy lipids. It primarily helps to reduce water loss from the body.
b) **Procuticle**: The inner layer called procuticle is much thicker and can be further distinguished into an outer **exocuticle** and inner **endocuticle**. Both these layers are

made up of protein-chitin complex. However, the proteins of exocuticle are hardened and tanned by the presence of phenols.

The cuticle is further permeated by the pore canals through which the secretions from the underlying glands and cells reach to the outer surface.

Did you know?
Chitin
Chitin, a mucopolysaccharide, is a polymer of N-acetylglucosamine. It has high molecular weight and is found embedded in a proteinaceous matrix. It makes the cuticle of arthropods tough, rigid and resistant.
Source: Barnes, R.D. (1992). Invertebrate Zoology. Saunders College Publishing, USA

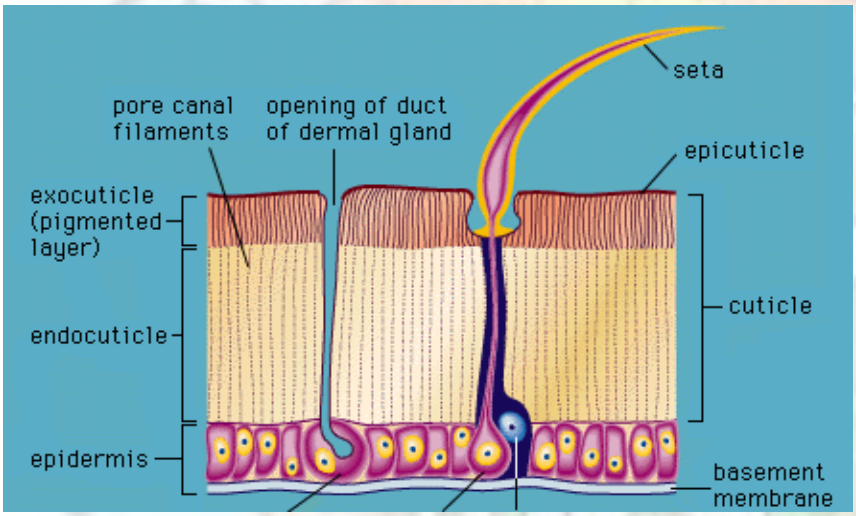


Fig. 1.2: Structure of the cuticle of arthropods
(Source: http://media-2.web.britannica.com/eb-media/99/5899-004-DBA32515.gif)

1.2.2 Advantages and Disadvantages of the Cuticle

The cuticle provides many benefits to the arthropods.

- It protects the organisms against mechanical stress and injuries.
- Being impervious to water it prevents desiccation and helps the arthropods survive in the adverse conditions.
- The innermost layer of cuticle, endocuticle, provides a surface for the attachment of the muscles.
- The organisms derive different colours because of the deposition of various pigments in the cuticle.
- The refraction of light by the outer cuticular layer results in the iridescence in a few organisms.

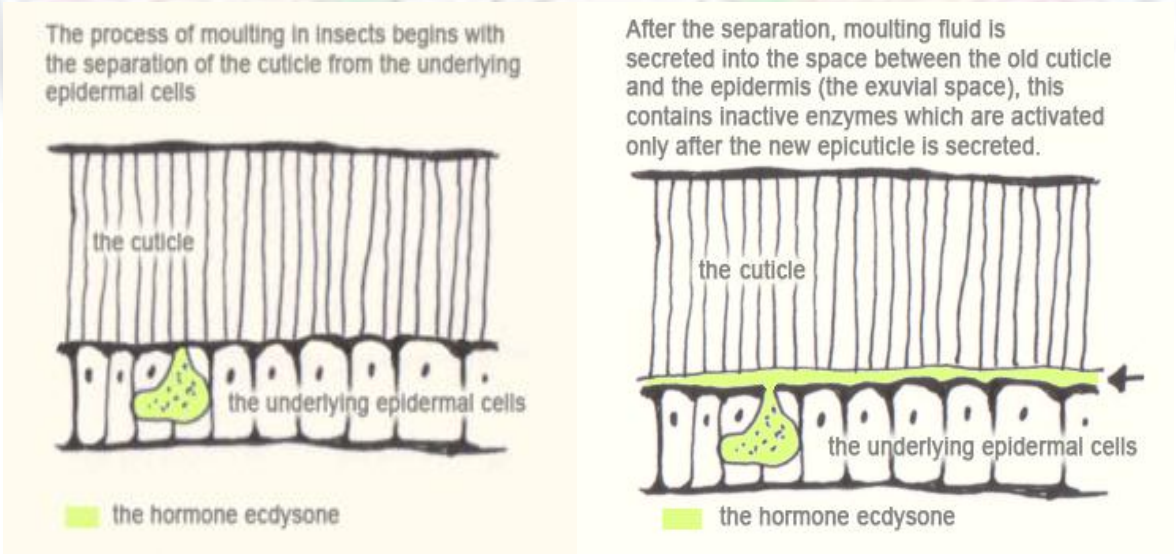
Besides above advantages, the non-flexible nature of cuticle poses primarily two problems for the arthropods:

- Restricted growth of the organism, which is overcome by shedding their cuticle through a specialized process of **moulting**.
- Limited movement in the organisms which is assisted by a thin, flexible membrane, called **arthrodial membrane,** present between the cuticular plates.

1.2.3 Moulting of the Cuticle

Arthropods shed their cuticle periodically to overcome the problem of growth. The periodic shedding of old cuticle and formation of a new cuticle is called **moulting** or **ecdysis**. This phenomenon, which is under the hormonal control, takes place through a series of steps which are as follows.

- The cuticle separates from the epidermal layer (hypodermis) and the **moulting fluid** is secreted in the space created by separation under the influence of a hormone called **ecdysone**. The fluid contains chitinase and protease enzymes which digest the endocuticle completely.
- Hypodermis secretes a new cuticle, called **procuticle**, beneath the remaining old cuticle.
- The animal absorbs water or air and swells as a result of which it puts a pressure on the old exoskeleton which splits longitudinally and the animal pulls out of it.
- The newly emerged animal grows gradually and the cuticle stretches resulting in the growth of animal.
- The newly formed cuticle gets hardened by tanning of the protein.



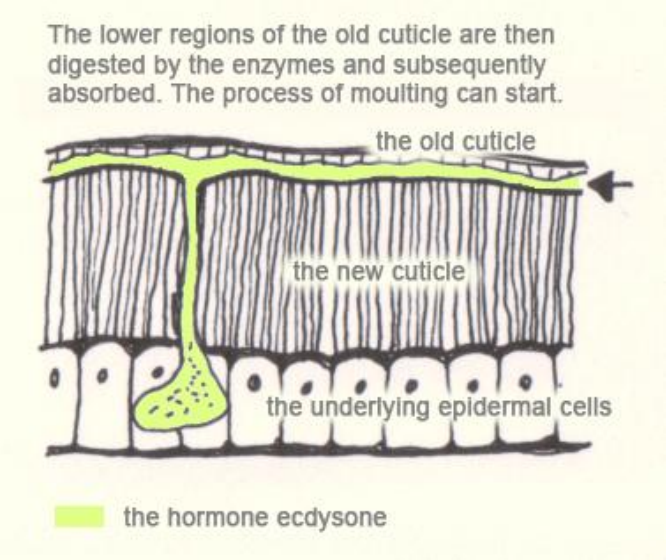


Fig. 1.3: Process of moulting in insects

(Source: http://tmp.kiwix.org:4201/A/Ecdysis.html)

Fig. 1.4: Series of pictures depicting moulting in crab

(Source: http://bioweb.uwlax.edu/bio203/s2009/luchterh_wesl/molting.jpg)

Do you know?
Moulting: Necessary but dangerous
Moulting, a necessary phenomenon in arthropods for growth may be responsible for 80 to 90% of all arthropod deaths. This is because of the fact that arthropods are in danger of being trapped in the old cuticle and of being attacked by predators as are they nearly immobilized until the new cuticle has hardened.
Source: Barnes, R.D. (1992) Invertebrate Zoology. Saunders College Publishing, USA

1.3 Jointed Appendages

The most characteristic feature of Phylum Arthropoda, from which they have derived their name, is the presence of jointed appendages. These appendages include not only the organs of locomotion – limbs; but also other appendages, such as antennae, gills, genitalia etc. are jointed in structure. Out of these three pairs of locomotory appendages are attached to the ventral surface of the body through a soft arthrodial membrane.

Based on the basic structure, arthropods may have two kinds of appendages in their body:

a) **Uniramous appendages**: These appendages have a single series of segments which are attached end to end. All appendages of insects, myriapods; and some appendages of arachnids and crustaceans are uniramous in structure.

b) **Biramous appendages**: The appendages which branch into two and each branch is made up of a series of attached segments are called biramous type. Most of the appendages in crustaceans are biramous.

The appendages are variously modified depending on their functions and location in the body. For example, the appendages of aquatic forms are paddle-like while the terrestrial forms have long and slender appendages.

1.4 Metameric Segmentation

The arthropods are metamerically segmented organisms. Metamerism is quite evident in the embryonic stages but during the course of evolution, segments have been lost, fused or differentiated into other kinds of segments. As a result, the segmentation varies in different groups of arthropods.

- The body of crustaceans is divided into **cephalothorax** (formed by fusion of head and thorax), and **abdomen**. Both regions are further divided into a number of segments.
- The chelicerates are formed of a short, unsegmented cephalothorax called **prosoma** and the segmented abdomen, called **opisthosoma**.
- The body of insects is divided into a **head** comprising of 6 fused segments, a 3-segmented **thorax** and an **abdomen** containing 7-11 segments.

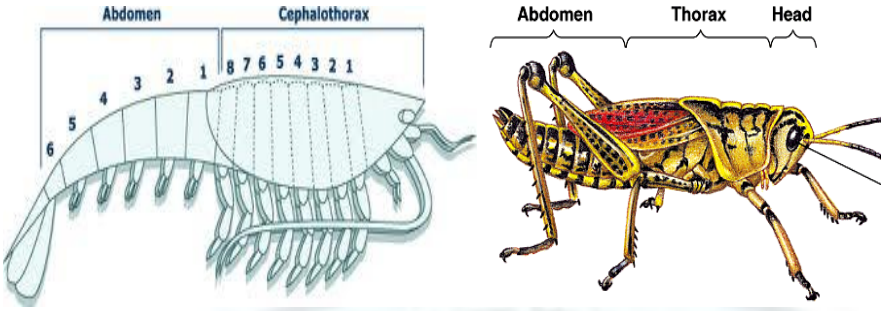


Fig. 1.5: Pattern of segmentation in (a) A crustacean and (b) an insect

Source: (a) http://evolution.berkeley.edu/evolibrary/images/arth_xsection.gif

(b) http://www.bio.miami.edu/dana/pix/insectanatomy.gif

1.5 Coelom

All organisms belonging to the Phylum Arthropoda possess a very thick exoskeleton and thus they do not need compartmentalized perivisceral coelom for turgidity and locomotion. As a result, their coleom is reduced to a tiny cavity around the reproductive and excretory organs in the form of **gonocoel** and **nephrocoel**.

Instead, the dominant body cavity in arthropods is a **haemocoel**, which is merely a sinus of spaces in the tissues. It is filled with straw-coloured fluid or blood called haemolymph which bathes the organs directly.

1.6 Open Circulatory System

All arthropods have open type of circulatory system. It consists of a tubular heart, few arteries or an aorta and blood which mostly flow in sinuses. The capillaries and veins are completely absent.

1.6.1 Heart

The heart is a tubular, long, contractile muscular tube enclosed in a **pericardial sinus** which is filled with blood. Structurally heart is made of one or more chambers and each chamber is perforated by a pair of minute and lateral openings called **ostia**. The ostia enable the blood to flow unidirectionally into the heart from the pericardial sinus. The muscular walls of the heart pump the blood to the arteries or **aorta** through which blood enters the haemocoel where it bathes the tissues directly. Thereafter, the blood returns to the pericardial sinus and enters the heart repeating the cycle again.

1.6.2 Blood

The blood of the arthropods is called **haemolymph**, as it flows in open sinuses and functions as both blood and lymph. It is a straw-coloured fluid which lacks any respiratory pigment and does not have any role in respiration. In certain arthropods, it may have copper-based haemocyanin (in crustaceans) or iron-based haemoglobin pigment (a few insects). Whatever is the kind of pigment, it is dissolved in the blood plasma. Certain cells

are suspended in the blood plasma which are called haemocytes. These cells are responsible for a variety of functions.

1.6.3 Functions of the blood

The blood of arthropods serves various functions which are as follows.

- Blood helps to distribute food and collect waste from different parts of the body.
- It stores food in their cells for future needs.
- As blood flows in open sinuses it helps in egg hatching, moulting and expansion of wings by exerting pressure on the cuticle.
- The haemocytes phagocytose harmful microbes, parasites, etc. and protect the body.
- Certain haemocytes help in wound healing because of their clotting properties.

More to know…
Haemoglobin in insects
Certain insects such as *Chironomous* larvae, *Gastrophilus* beetle and bugs like *Anisops, Buenoa* have haemoglobin in their blood.
Source: Klaus Urich (1990), Comparative Animal Biochemistry. Gustav Fischer Verlag, Stuttgart, New York

1.7 Respiratory Organs

Arthropods have a wide variety of respiratory organs. These include gills, book lungs, tracheae, and even integument in some cases.

1.7.1 Book-gills

The crustaceans are the aquatic forms and have gills as the organs of gaseous exchange. The gills are composed of rhomboidal gill-plates which look like the leaves of a book. Thus, these gills are termed as **book-gills**. The diffusion of gases occurs between the blood flowing through the gill plates and the surrounding water. These are typically associated with the appendages and depending on their position and attachment, these are of three types:

a) **Podobranchs**: attached to the coxa of appendages (basal part through which appendages are attached to the body)

b) **Arthrobranchs**: attached to the arthrodial membrane which joins an appendage with the body or

c) **Pleurobranchs**: attached to the lateral wall of the segment bearing the limb.

1.7.2 Book-lungs

Chelicerates, being terrestrial forms possess **book-lungs**. They occur in pairs and are located on the ventral side of the abdomen. Like book-gills, these are also composed of leaf-like lamellae. Air circulates in the interlamellar spaces and the exchange of gases takes place between the blood circulating in the lamellae and this air.

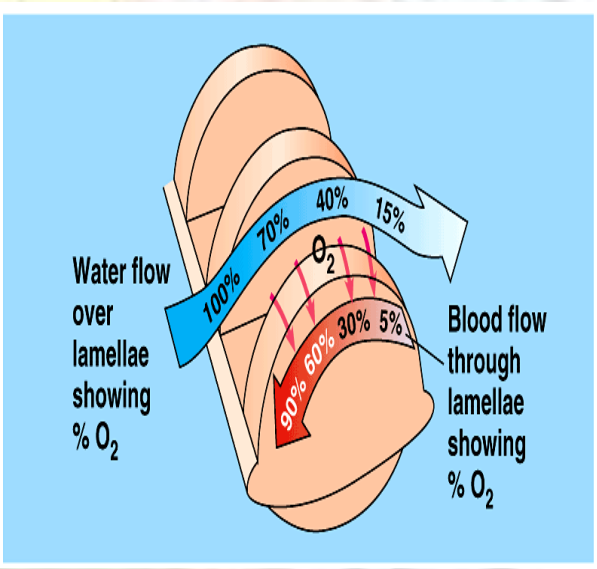
1.7.3 Tracheal System

Tracheal system is the characteristic feature of insects. It is made of a network of branching tubes which are filled with the air. These open to the outside by small openings, **spiracles**, present on the lateral side of the body. The gaseous exchange occurs partly by diffusion and partly by ventilation. The abdominal movements help in the entry of air into tracheae which is circulated throughout the body by tracheal system. Finally, oxygen diffuses into the tissues in exchange with carbon dioxide.

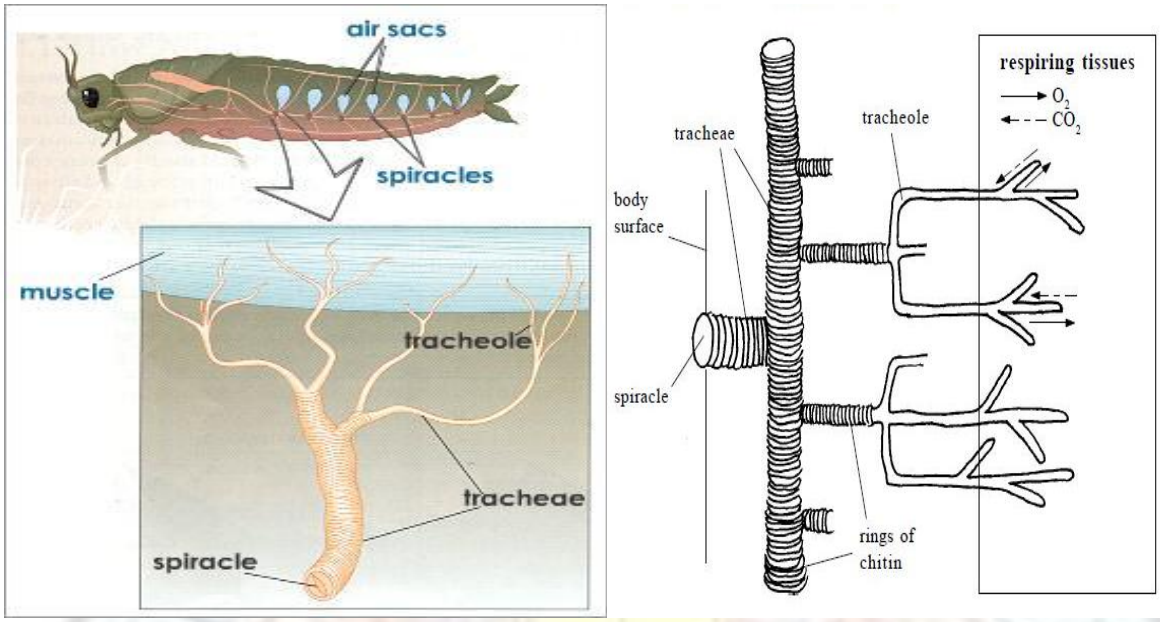
1.7.4 Integumentary Respiration

A few insects have soft skin and live in moist surroundings. They lack any respiratory structures and respire by the process of diffusion through body surface.

(a)



(b)



(c) (d)

Fig. 1.6: (a) Book-gills of horshoe carb, (b) Mechanism of respiration in crab, (c) Tracheal system in insects, (d) Mechanism of tracheal respiration

(Source:
(a) http://horseshoe-crabs.com/wp-content/uploads/2009/05/horseshoe-crab-book-gills.jpg,
(b) http://faculty.uca.edu/johnc/CountercurrentExch.gif,
(c) http://image.wistatutor.com/content/respiration/tracheal-system-in-insects.jpeg,
(d) http://3.bp.blogspot.com/_hhUdKwzDmA4/TIPHcZJAMyI/AAAAAAAAArg/KxrwHwlJeRs/s1600/Tracheal+system.jpg)

1.8 Digestive Tract

The digestive system or gut of arthropods is basically divided into three parts; **foregut**, **midgut** and **hindgut**. The foregut and hindgut are derived from ectoderm and are lined with chitin, whereas midgut is derived from endoderm and lacks chitinous lining.

- The foregut is chiefly concerned with the ingestion, trituration, and storage of food. Its parts are variously modified for these functions depending upon the diet and mode of feeding.

- The midgut is the site of enzyme production, digestion of food and absorption of the digested food material. The surface area of midgut is generally increased by the presence of villi-like structures and digestive glands. In insects, it is lined with a thin **peritrophic membrane** which protects it from the abrasions due to hard components of food.

- The hind gut is mainly responsible for the absorption of water and the formation of faeces.

1.9 Excretory Organs

Like respiratory organs, different arthropods possess different organs of excretion. These are as follows:

1.9.1 Green glands

The crustaceans possess green glands as their excretory organs which are also called **antennary or maxillary glands** depending on whether they are located in antenna or maxilla (leaf-like mouth parts). They absorb nitrogenous waste products from the blood and throw out of the body mainly in the form of ammonia, along with small amounts of urea and uric acid. These glands also play an important role in osmoregulation by throwing out extra water and maintaining ionic balance of the body.

1.9.2 Coxal glands

Coxal glands are characteristic of chelicerates. They are so named because they open onto the posterior of the coxae (basal part) of appendages. These are present in pairs and never more than four pairs. They absorb waste from the blood and throw out of the body in the form of guanine, urea and uric acid.

1.9.3 Malpighian Tubules

Insects and a few arachnids have malpighian tubules as the chief excretory organs. These are yellow-coloured, thin, convoluted tubules which arise from the gut and are suspended in the haemolymph. The tubules absorb the nitrogenous excreta present in the haemolymph in the form of uric acid and urates. Along with the excreta, other substances such as amino acids, extra water and dissolved salts are also absorbed from the haemolymph. Some of the useful substances are returned to the haemolymph, while the excreta are discharged into the hindgut, which is voided through the faeces.

1.9.4 Secondary Organs

The arthropods have certain other organs also which carry out excretion as a secondary function. These are as follows

- Cuticle of arthropods throws excess salt and other unwanted materials during ecdysis.
- Fat bodies store uric acid and act as the organs of storage excretion.
- Cephalic glands of certain insects also help in excretion.
- Male cockroaches possess uricose glands which store uric acid and discharge over spermatophore.

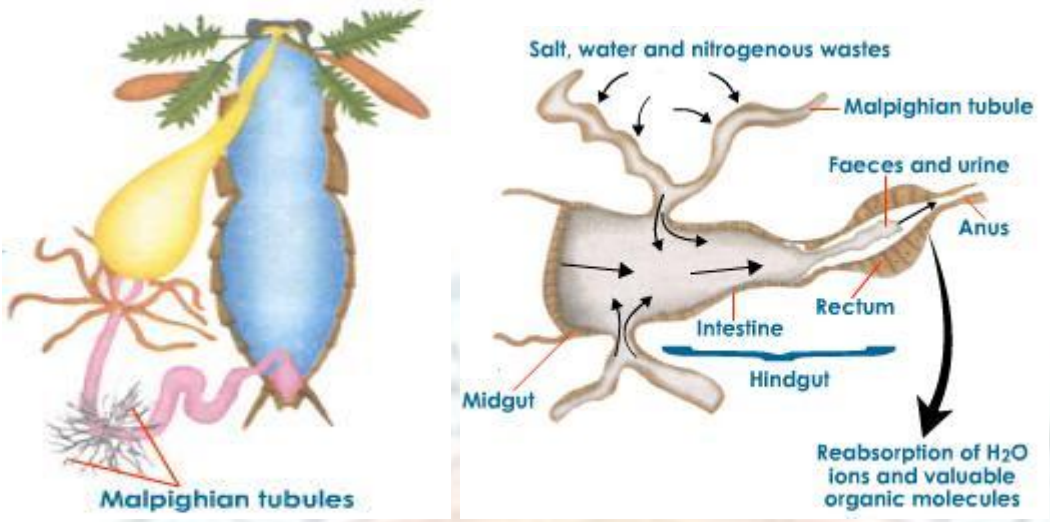


Fig. 1.7: Malpighian tubules and their function in cockroach

(Source: http://image.wistatutor.com/content/excretion/cockroach-malpighian-tubules.jpeg, http://image.wistatutor.com/content/feed/tvcs/malpighian-tubules-excretion-process5B15D_0.jpg)

1.10 Ladder-like Nervous System

All arthropods have a double ventral nerve cord running through their bodies. In each segment the nerve cord bears a bilobed ganglion from which sensory and motor nerves arise and run to other parts of the segment. The pairs of ganglia in each segment are connected by a bundle of nerves called **commissures**. This gives arthropod nervous systems a characteristic "ladder-like" appearance.

The brain consists of the two or three fused ganglia and directs the movement of the body. In insects other head ganglia fuse to form a pair of suboesophageal ganglia, under and behind the oesophagus. The brain is connected to suboesophageal ganglia by a pair of circumoesophageal connectives.

1.11 Compound Eyes

Many arthropods, such as insects and most of the crustaceans possess compound eyes, so called because they are made up of a large number of visual units called **ommatidia**. Each ommatidium is an independent sensor, with its own light-sensitive cells and often rods and cones. Thus, each unit is capable of forming independent image resulting in small pieces of image put together like a mosaic. Thus, it is called **mosaic vision**.

Though the images formed by the compound eyes are not very clear but these can detect even the slightest movement of the object because of the shift in the corresponding stimulated ommatidium. Another advantage is the wide visual field because of the greatly convex corneal surface. This results in **peripheral vision** covering an arc of 180° or more.

In different light conditions, the compound eye form different kinds of image.

a) In bright light, the compound eye forms **apposition image**. This consists of fragmented images formed by widely separated ommatidia which are fitted together in a single image. The image is incomplete and discontinuous. All diurnal arthropods form apposition image, e.g. butterflies, bees, prawns.

b) In weak/dim light, the overlapping images are formed which thus forms a continuous image. This kind of image is termed as **superposition image.** Though comntinuous, it is neither sharp nor well focused. The eyes of nocturnal arthropods such as moths or those which live in poor-lighted habitats form superposition image.

More to know…
Colour Vision in Arthropods
Certain arthropods are able to discriminate certain colours. Few examples are: • Hermit crab can distinguish between snails which are painted yellow, blue or have shades of grey. • Shrimps adapt themselves to yellow, orange, or red backgrounds but not grey. • Mosquitoes are attracted to black colour while aphids to yellow. • Cockroaches have receptors for ultraviolet and green wavelengths. This property is being used to trap the organisms.
Source: Barnes, R.D. (1992) Invertebrate Zoology. Saunders College Publishing, USA

In addition, some arthropods, such as arachnids and insects also possess simple eyes or **ocelli**. These are visual receptors found on the anterior dorsal surface of the head and are generally three in number. The photoreceptor cells on each ocellus are organized like those of the single ommatidium. These can detect changes in light intensity and may be very sensitive to low intensities. They function in orientation and enhance the reception of stimuli by other sensory structures.

1.12 Reprooduction and Development

All arthropods are dioecious, except a few such as barnacles which are hermaphrodites. Most arthropods undergo sexual reproduction, though some insects and crustaceans can reproduce by parthenogenesis. Fertilization is always internal in case of terrestrial forms as unprotected sperm and ova can not survive long in these environments. However, the aquatic forms may have external fertilization.

The sperm transfer from the male to the female may be direct, but it is more often indirect. Some crustaceans and spiders use modified appendages to transfer the sperm to the female. On the other hand, many male terrestrial arthropods produce sperms in a case called spermatophores which is deposited in the body of females. The fertilized eggs hatch into immature arthropods which have diverse forms. Maximum diversity in immature forms can be seen in insects and their development is called **metamorphic development**. The eggs of insects hatch as apparently miniature adults, called nymphs or naiads. Many insects hatch as grubs or caterpillars, which metamorphose into adult forms by entering an inactive pupal phase. Crustaceans commonly hatch as tiny nauplius larvae that have only three segments and 3 pairs of appendages. Since the larva and adult forms differ greatly in the way they live and what they eat, metamorphosis enables organisms to reduce competition for resources that otherwise would occur between the immature and adult forms. Parental care is well marked off in arthropods.

Fig. 1.8: Above left: caterpillar, Above right: Nymphs, below: Nauplius larva

(Source: www.insectpod.com, www.photographyontherun.com, http://www.globalwarmingart.com/wiki/Wikipedia:Nauplius_%28larva%29)

General Characteristics of Arthropoda

Summary

- Phylum Arthropoda is the largest phylum of all animal phyla with over a million described species.
- Arthropods can be divided into four subphyla; Trilobitomorpha, Crustacea, Chelicerata and Uniramia.
- The body of arthropods is covered by a thick cuticle which is made up of a horny substance called chitin.
- The cuticle of arthropods is composed of a thin, waxy outer epicuticle and a thick, inner procuticle, further composed of exocuticle and endocuticle.
- The cuticular plates are joined by an arthrodial membrane to permit movement.
- The arthropods shed their cuticle periodically to overcome the problem of restricted growth.
- The most characteristic feature of arthropods is the presence of jointed appendages, which may be uniramous or biramous.
- These are metamerically segmented animals with varied segmentation in adults.
- The circulatory system is open type with blood also called haemolymph flowing in sinuses.
- Arthropods have a wide variety of respiratory organs, which include book-gills in crustaceans, book lungs in chelicerates, tracheae in insects, and even integument in some cases.
- The digestive tract of arthropods is basically composed of three parts; foregut, midgut and hindgut.
- The different organs of excretion present in arthropods are green glands, coxal glands, malpighian tubules, cuticle, etc.
- They have ladder-like nervous system like that of annelids.
- The compound eye forms a mosaic vision, made of fragmented or overlapped images, while ocelli can detect changes in low intensity of light.
- Most of the arthropods are dioecious with internal fertilization and exhibit larval stages during development.

Exercises

1.1 Give an outline classification of the Phylum Arthropoda.

1.2 Explain the structure of cuticle of arthropods. Add a note on its advantages and disadvantages.

1.3 How do arthropods overcome the problem of restricted growth caused by hard exoskeleton?

1.4 Differentiate between the uniramous and biramous appendages.

1.5 Write a brief note on the different kinds of respiratory organs present in arthropods.

1.6 What are the various organs of excretion in arthropods? Describe.

1.7 Why is the nervous system of arthropods called ladder-like?

1.8 What is a compound eye? Explain the two kinds of images formed by compound eye in arthropods.

1.9 Why is the blood of arthropods called haemolymph? Write its functions.

1.10 Distinguish between book-gills and book-lungs.

Glossary

Apposition Image: Discontinuous image formed in pieces during bright light.

Arthrodial membrane: A thin, flexible membrane present between the cuticular plates to facilitate movement.

Book-gills: Respiratory organs of crustaceans comprising of lamellae arranged like the leaves of a book.

Chitin: A horny mucopolysaccharide that forms the thick cuticle of the arthropods.

Haemocoel: Body cavity filled with the blood.

Haemolymph: Blood that flows in open sinuses and act as both blood and lymph.

Metamorphic Development: Development of an egg to adult through a series of larval stages.

Mosaic image: Independent image comprising of small pieces put together like a mosaic.

Moulting: Shedding of old cuticle and secretion of new cuticle, also called ecdysis.

Moulting fluid: The fluid, containing proteases and chitinases, secreted by hypodermis to digest the old cuticle during moulting.

Ommatidium: A single visual unit of a compound eye capable of forming an independent image.

Peripheral Vision: Image formed with wide visual field.

Superposition Image: Overlapped and continuous image formed during dim light.

Tracheae: Air tubes of insects that help in exchange of gases in insects.

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