Insect Respiratory System

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Introduction

All insects consume oxygen, so they are aerobic. The simple channel for respiration is named as tracheal system which is a complicated system carries any channels. Trachea carry oxygen from their environment and use the same metabolic reactions as other animals do like glycolysis, Kreb's cycle, electron transport chain to convert nutrients into ATP. At the last step of this process, oxygen atoms combine with hydrogen ions to produce water, releasing energy that is stored in the form of ATP. Insects inspire oxygen and exhale carbon dioxide, as a waste product of cellular respiration. Oxygen is transported to the cells directly through respiration, and not carried by blood as in vertebrates. Carbon dioxide diffuses 35 times faster than oxygen.

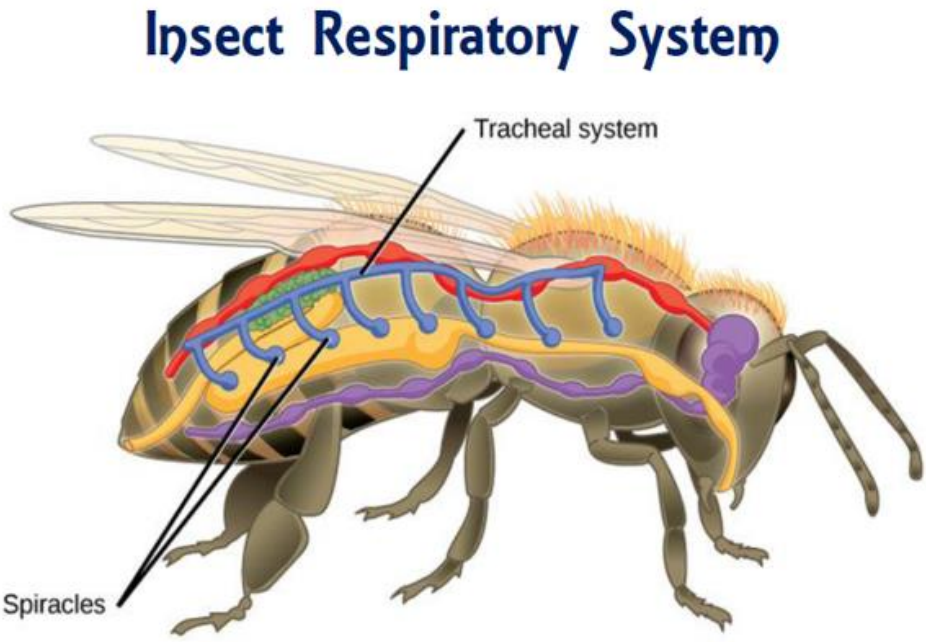

Fig 1. Insect respiratory system

Types of tracheal system

a) On the basis of connectives and commissure

1. **Simple type**: It is simple and opens through spiracles, but it does not connect one trachea to another. Example, springtails.

2. **Complex type**: It consists of dorsal, ventral, and lateral trachea connected with commissure and connectives. With this spiracles and air sacs are also present.

b) On the basis of spiracles

1. **Open tracheal system**: Spiracles present. Example, most insects.

2. **Closed tracheal system**: Spiracles absent and gaseous exchange takes place through integument. Example, *Chironomus* larva, mayfly nymph.

Respiratory organs

1. Spiracles

The sides of the thorax and abdomen consist of a row of small openings called spiracles. These allow the intake of oxygen from the air into the tracheal system **(FIG. 1)** The number and types of spiracles varies according to the species.

Types of spiracles

Simple spiracles: It is simply a hole with no provision of regulating the size of aperture. Example, Apterygote, Plecoptera.

Typical spiracles: This type of spiracle has a sclerotic plate called peritreme which surrounds the opening at atrial orifice. The atrial opening leads to the sac called atrium which further leads another opening. Tracheal orifice leads to trachea. It is found in most insects.

Biforous spiracles: Here two orifices are present primary and secondary. Primary orifice is functional only in moulting and secondary orifice is functional. Example, larva of certain Coleopterans.

Lid type: They are spiracles with external closing apparatus. The

opening and closing of aperture is controlled by outer lips of atrium.

Example, most insects.

Valvular type: They are the spiracles bearing internal closing apparatus called filter apparatus with bristles and a valve that regulate the aperture. Example, abdominal spiracles (FIG 2.) In flies, beetles and moths' spiracles are covered with sieve plate having large number of pores.

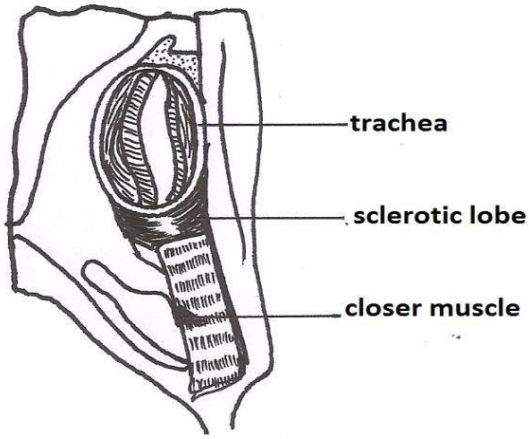

FIG 2. Outer and inner view of 2nd thoracic spiracle of grasshopper

Based on number of spiracles: The insects are also called polypneustic having many pairs of spiracles, oligopneustic having few and apneustic having nospiacles. In the case of polypneustic the insects may carry 10, 9 or 8 functional spiracles and named as holopneustic (in cocroaches), peripneustic (in some fly larva) and hemipneustic. Oligopneustic type consist of one mesothoracic and one abdominal spiracles functional while all rest are nonfunctional in amphineustic (second maggot stage of mosqutio), only last abdominal functional in metapneustic (first maggot stage of mosqutio) and only mesothoracic in propneustic type (in most of the dipteran larva).

The older orders Collembola, Protura and Chironomid larva consist of no spiracles **(FIG. 3)**

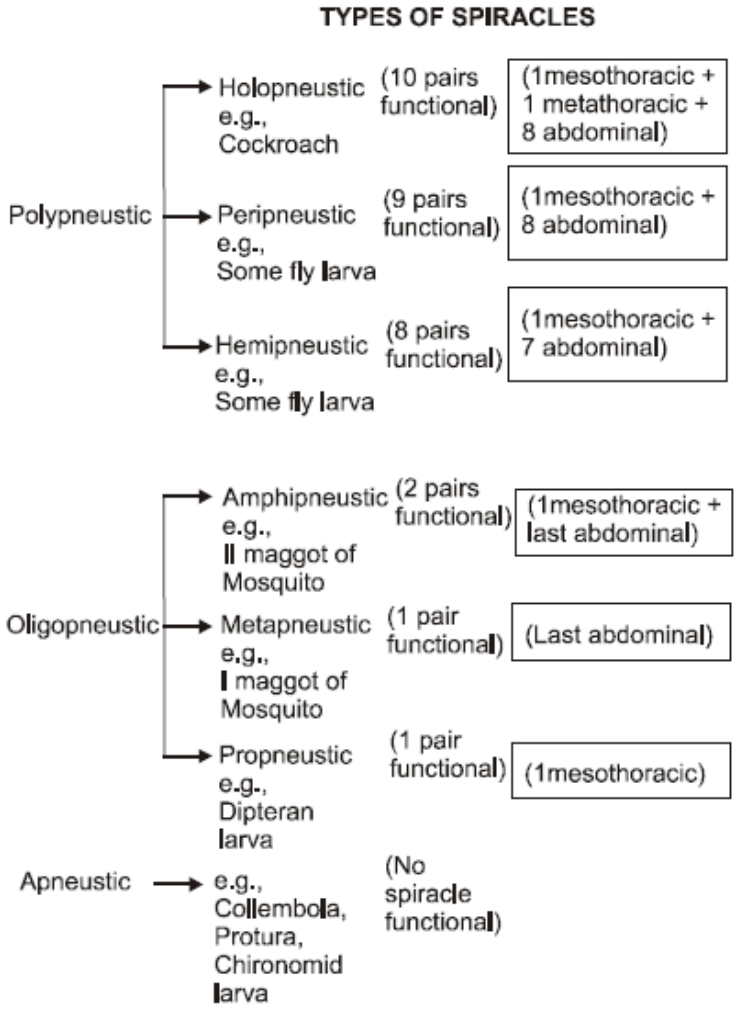

FIG 3. Types of insects based on number of spiracles functional

2. **Trachea**

The spiracles lead to the longitudinal tube called trachea lined with intima propria. Cuticulin layer of epicuticle covers entire integumental surface including trachea and tracheoles. The intima of of trachea sheds in each moult. Trachea develops from the invagination of ectoderm during embryonic development (FIG.4). Trachea is absent in Collembola, Protura and endoparasitic forms. The intima of the tracheal tube is folded, and forms spiral ridges called taenidia that protect the insect from

collapsing. Trachea is classified according to the place they are situated as dorsal, ventral, lateral, dorso-lateral, and ventral-lateral.

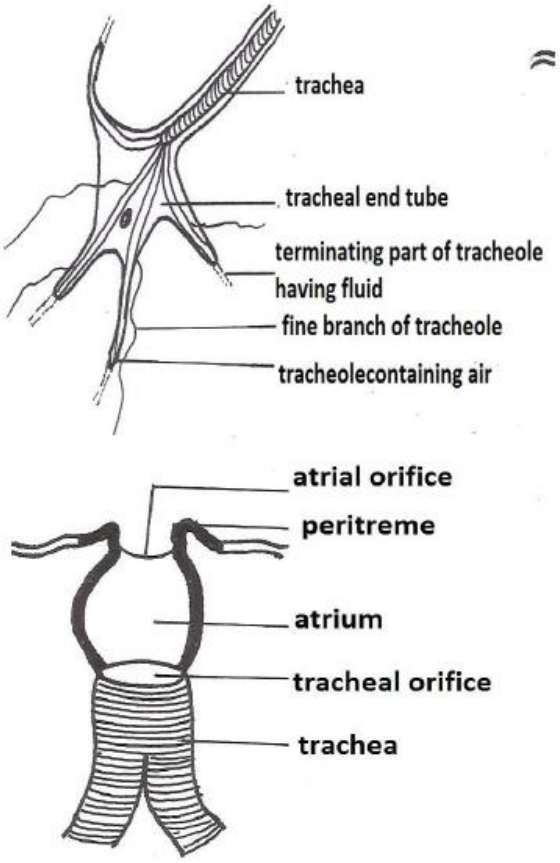

FIG 4. A) Trachea B) Spiracle

3. Tracheoles

The longitudinal tracheal trunk gives a complex, branching network of tracheal tubes that subdivide into smaller and smaller diameters and reaches every part of the body called tracheoles. Tracheoles are enclosed in a very thin layer of cytoplasm from the tracheal end cell (tracheoblast). It is 0.2μ- 1μ in diameter and is associated with the organs having more oxygen demand like flight muscles, ovaries, fat body, malphigian tubules, rectal papillae, and gut epithelium. Large tracheoles consist of cuticle and epidermis but in small tracheoles only epicuticle is present. In fifth instar of silkworm, 1.5 million tracholes are present **(FIG 5).**

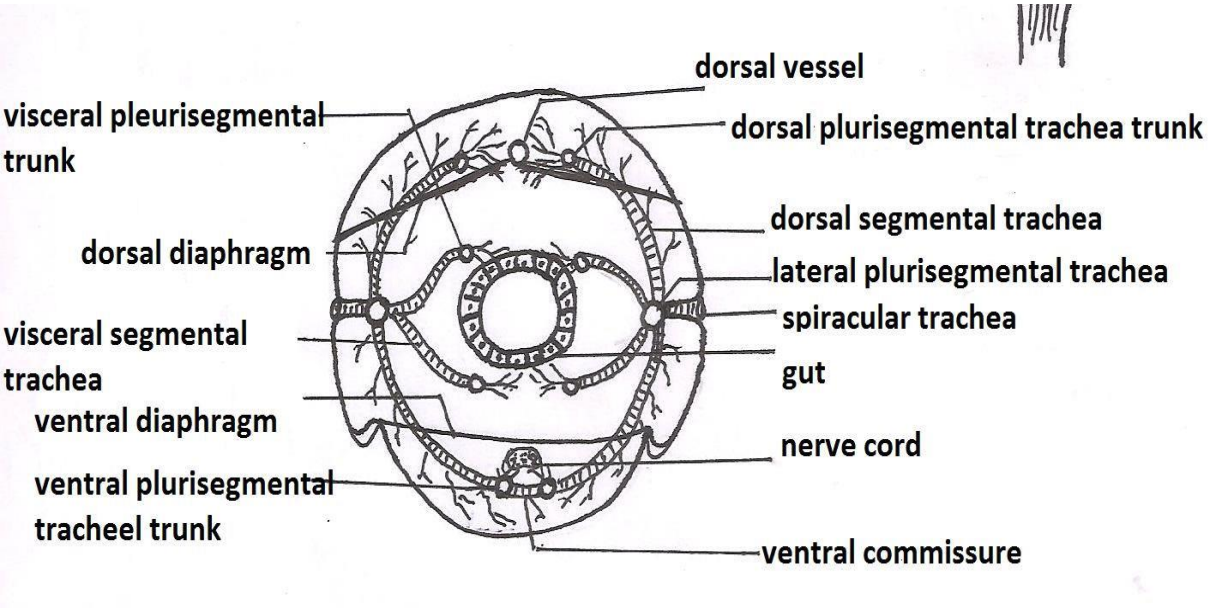

FIG 5 T.S. of generalized insect through abdomen showing main tracheal trunks.

Differences between trachea and tracheoles:

	Trachea	Tracheoles
1	These are large tubes running from spiracles	Fine tubes arising **distally** from trachea
2	Taenidia **present**	**Absent**
3	Intima layer is **shed** during moulting	Intima layer is **retained, unchanged** during moulting
4	Never become intracellular	Intracellular
5	The intima layer consist of protein – chitin matrix **with resilin**	Chitin – protein matrix present, **resilin absent**

4. Air sacs

In some areas, however, there are no taenidia, and the tube swell like a balloon

to form air sac capable of storing/reserve air. Air sacs are mostly the characteristic feature of flying insect as taenidia absent. It increases the volume of air which performs various functions prevent collapsing, heat conservation, forms tympanic cavity aid in hearing organ in *Cicada* moth. In terrestrial insects during high evaporative stress, air sacs conserve water by closing its spiracles. In aquatic insects stored air in sacs provide buoyancy in water. It also helps in moulting by air sacs enlargement that breaks old exoskeleton and expands a new one.

Mechanism of respiration

Gaseous exchange takes place between tissues and wall of tracheoles by the process of diffusion, active ventilation and passive ventilation. 1. Diffusion is based on tracheal length, its diameter and permeability. Oxygen in the tracheal tube first dissolves in the liquid of the tracheole and then diffuses into the cytoplasm of an adjacent cell. At the same time, carbon dioxide, produced as a waste product of cellular respiration, diffuses out of the cell and, eventually, out of the body through the tracheal system.

2. **Passive ventilation** facilitates respiration in larval stages and pupal ventilation occurs through suction. This uses high solubility of carbon dioxide in water and spiracular valve kept closed. When CO_2 is produced it is stored partly in haemolyph in the form of bicarbonates and partly in tracheal system.

3. **Active ventilation** occurs through alternatively decreasing and increasing the volume of tracheal system. This is due to the contraction of abdominal dorso-ventral muscles that increases the hemolymph pressure.

Autoventilation may occur in orders Odonata, Orthoptera, Hemiptera, Isoptera, Lepidoptera and Hymenoptera.

Respiration in endoparasitic forms

Mostly endoparasitic insects fulfill their requirement through cutaneous espiration. In larva of *Blastothrix* (FIG 4.8, A), (Order Hymenoptera) attaches remains of egg posteriorly and maintains contact with atmosphere. In larva of *Thrixion* (FIG 4.8, B). order Diptera forms respiratory funnel formed by ingrowth of host integument. In first instar larva of endoparsitic Hymenoptera and Diptera tracheal system is filled with liquid. In *Cotesia* larva hindgut has an everted structure called caudal vesicle.

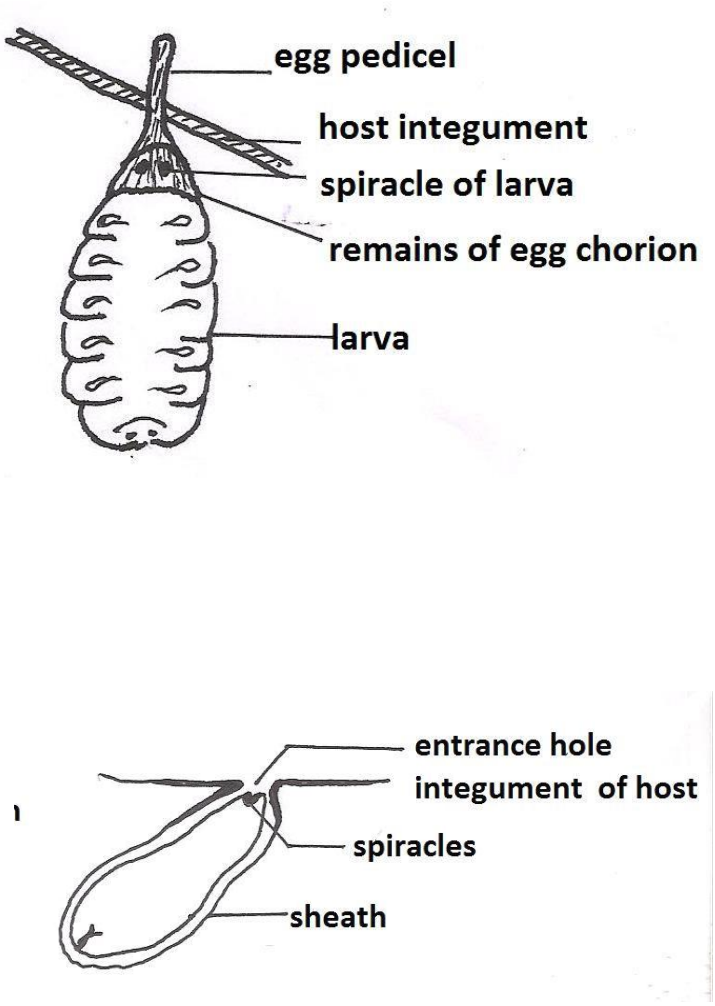

FIG 6. A) larva of Blastothrix (Hymenoptera) B) larva of Thrixion (Diptera)

Adaptations in aquatic insects and immature stages

Aquatic insects also respire through intake of oxygen, but air has to be stored in air sacs so that they can breathe under water. The insects having open tracheal system come to the water surface to store air in tracheal system often at regular intervals. The insects with closed tracheal system the air may be directly taken by body wall. They are equipped with a variety of adaptations as follows:

1. **Tracheal gills**: They are the outgrowth of body wall of hindgut, example, Mayflies and Damselflies larva. The outgrowth may be of caudal region called caudal lamella in Zygoptera, lateral abdominal gills in Ephemeroptera, Plecoptera, Coleoptera and rectal gills in Anisoptera.

2. **Hydrofuge hairs:** In some aquatic insects spiracles are surrounded by water repellent hairs on the base lies special oil secreting cells, dipteran larvae, *Notonecta*

3. **Cuticular Respiration:** Many aquatic species can exchange gases through thin and permeable integument, black fly pupa.

4. **Spiracular gills:** They are the outgrowth of body wall near spiracles, pupa of *Psephenoides gahani* (Coleoptera) and pupa of certain Diptera.

5. **Plastrons:** These are special hydrophobic hairs which are bending on tip and thickened at base so as to create air space next to the body. Air is trapped within a plastron when insect comes regularly to exchange gases. Examples, *Elmis* (Coleoptera) and *Aphelocherirus* (Hemiptera).

6. **Biological Gills:** These are organs which can allow dissolved oxygen from the water to pass into an organism's body by the process of diffusion. In insects gills are usually outgrowths of the tracheal system. They are covered by a thin layer of cuticle that is permeable to both oxygen and carbon dioxide. Example, *Dytiscus, Notonecta*.

7. **Breathing Tubes/ siphons**: Many aquatic insects living under water and come to surface to get air from hollow breathing tubes, in mosquito larvae, the siphon tube is an extension of the posterior spiracles in abdomen. The opening of the tube is

surrounded by a waterproof layer of hairs. When the insect goes down in water the hairs comes close to each other and closes the opening.

8. **Air Bubbles:** Some aquatic insects carry a bubble of air with them whenever they dive beneath the water surface, such as in diving beetles. This bubble may be held under the elytra, specialized hairs or around one or more spiracles. An air bubble provides insect with a short-term supply of oxygen.

9. **Integument/ cuticular respiration:**

Many aquatic insects have comparatively thin integument for the diffusion of gases oxygen and carbon dioxide. These are present in insects living in cold and fast moving streams where there is enough dissolved oxygen. Sometimes integument acts as respiratory organ, example, *Chironomus* larva.

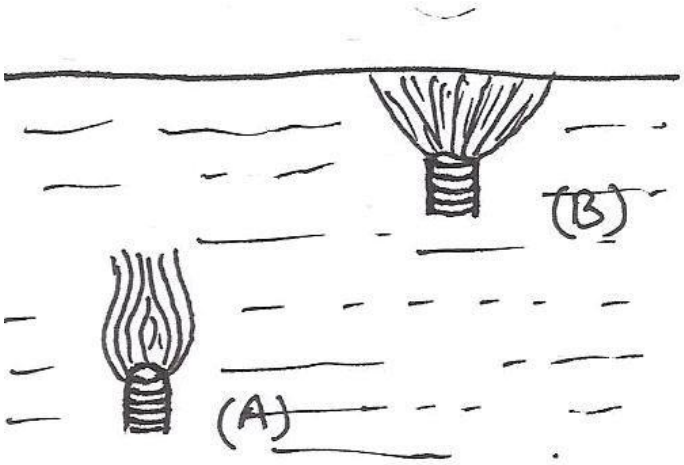

FIG 7. A) Hydrofuge hair around spiracle in submerged stage B) on water surface

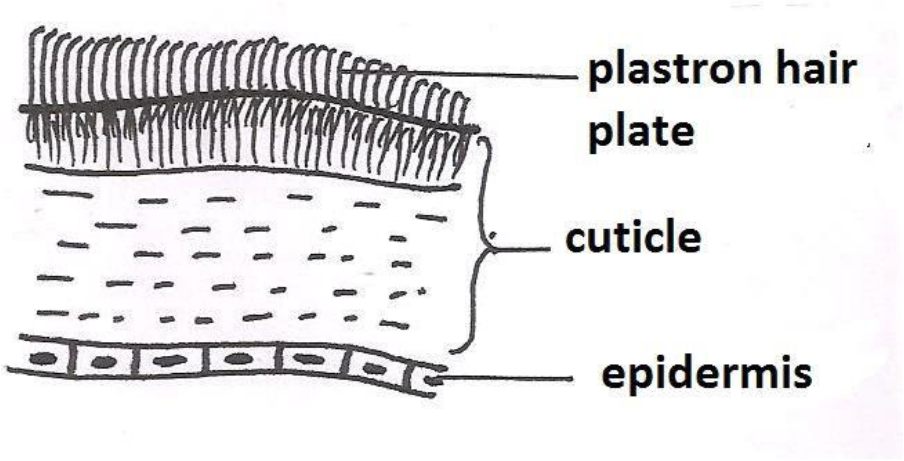

FIG 8. Diagram showing plastron hair for respiration

Respiratory pigments in insects

Respiratory pigments are the molecules that can carry oxygen and other gases present in blood. Crustaceans and arachnids contains haemocyanin respiratory pigment.Most insects does not have these pigments but Chironomus larva (midges/ commonly known as bloodworms), backswimmers, horse bot fly (*Gasterophilus*) are red in color due to haemoglobin in plasma. Kat haemoglobin in *Rhodnius*, carotene, flavin, xanthophil in herbivore insects and protapin in aphids are present in plasma. Riboflavin, flurocyanine, insectoverdin are found in locust.

Summary

Respiratory system is meant for gaseous exchange and oxygen is more readily diffuses than carbon dioxide. This exchange is possible through tracheal system in insects which is a system developed from invagination of the integument. Two diaphragm divides whole thoraco-abdominal cavity into three compartments pericardial, perivisceral and perineural cavities. Insect respiration is specialized system without lungs by a complicated system of internal tubes and sacs through which gases either diffuse in and out of the body. Oxygen is directly transported to the tissues that need oxygen and eliminate carbon dioxide via their cells as RBC are

not present in the haemolyph. Air is taken in through spiracles, situated laterally in the pleural wall, usually a pair on the anterior margin of the meso and meta thorax, and pairs on each of the eight or less abdominal segments. Numbers of spiracles vary from 1 to 10 pairs on which basis the insect is said to be olopneustic, oligopneustic, apneustic. The oxygen passes from the tracheae to the tracheoles and lastly to the end cell. The major tracheae are thickened spirally by taenidia that prevent it from collapsing and often swell into air sacs. Spiracles are closed and opened by means of valves and are of different types. The closures of spiracles are essential from losing moisture from the body. There are some aquatic insects have a closed tracheal system, for example, in Odonata, Tricoptera, Ephemeroptera, hich have tracheal gills for respiration and having no functional spiracles. The racheal system may be open or close and number of spiracles may vary from pecies to species. Aquatic and endoparasitic insects have modification to adapt their environment.

Respiratory system of insects

1. In most insect species, the trachea is the primary organ responsible for respiratory function.
2. Spiracles are exterior openings found on insects.
3. The air enters the body through these spiracles and travels to the trachea, which is part of the internal respiratory system.
4. The muscularity around the spiracle's entrance is such that it only opens and closes when necessary to avoid moisture loss.
5. The muscle must relax to open the spiracle's aperture.
6. Although muscle movement is governed by the central nervous system, it can also occur because of a response to external stimuli at times.
7. The trachea is a complex network of tubules capable of maintaining pressure throughout the body.

8. Tracheal tubes are split into smaller tubes that connect to every area of the body.
9. A unique cell known as a tracheole may be found at the end of each branch of the trachea.
10. The tracheole serves as a surface for the exchange of gases between the environment and the body's cells.

Glossary

- **Alary muscles:** Muscles which are attached laterally to the walls of each heart chamber to keep them in position.
- **Apneustic:** No functional spiracle.
- **Haemocoel:** These are the open body cavities with blood/ haemolyph.
- **Oligopneustic:** Having one or two functional spiracles.
- **Pericardial sinus:** It is the cavity surrounding heart.
- **Perineural sinus:** It is the cavity around nervous system.
- **Perivisceral sinus:** It is the cavity surrounding alimentary canal.
- **Polypneustic:** Having three or more functional spiracles.
- **Spiracles:** Small openings on the sides of thorax and abdomen.
- **Respiratory pigments:** They are the molecules that can carry oxygen and other gases present in blood.