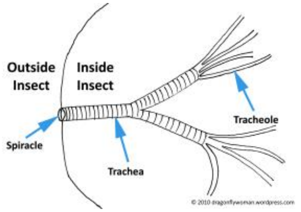
RESPIRATORY SYSTEM

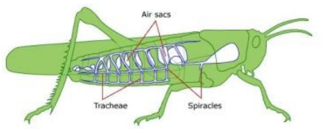
Zoo 514

Dr. Reem Alajmi

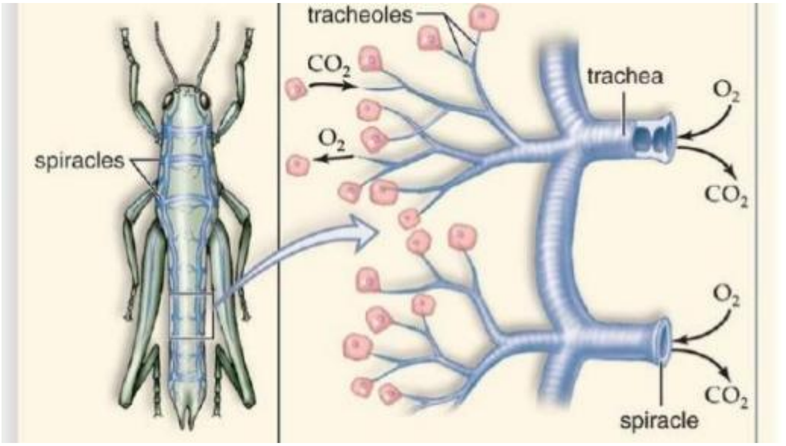
Structure of respiratory system

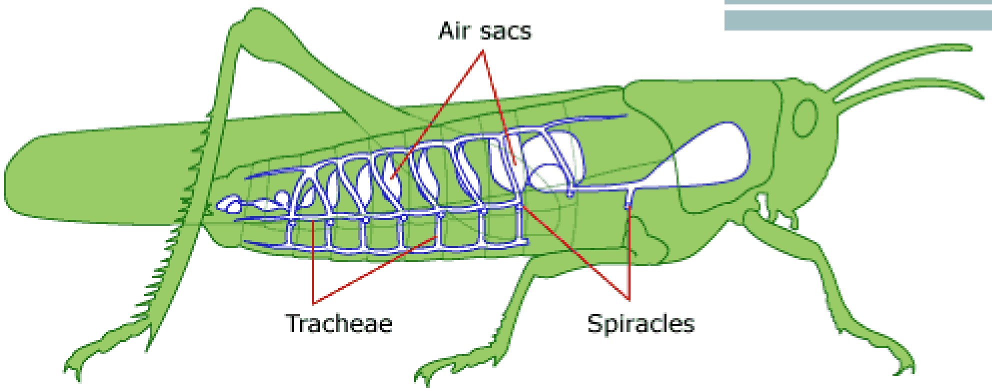


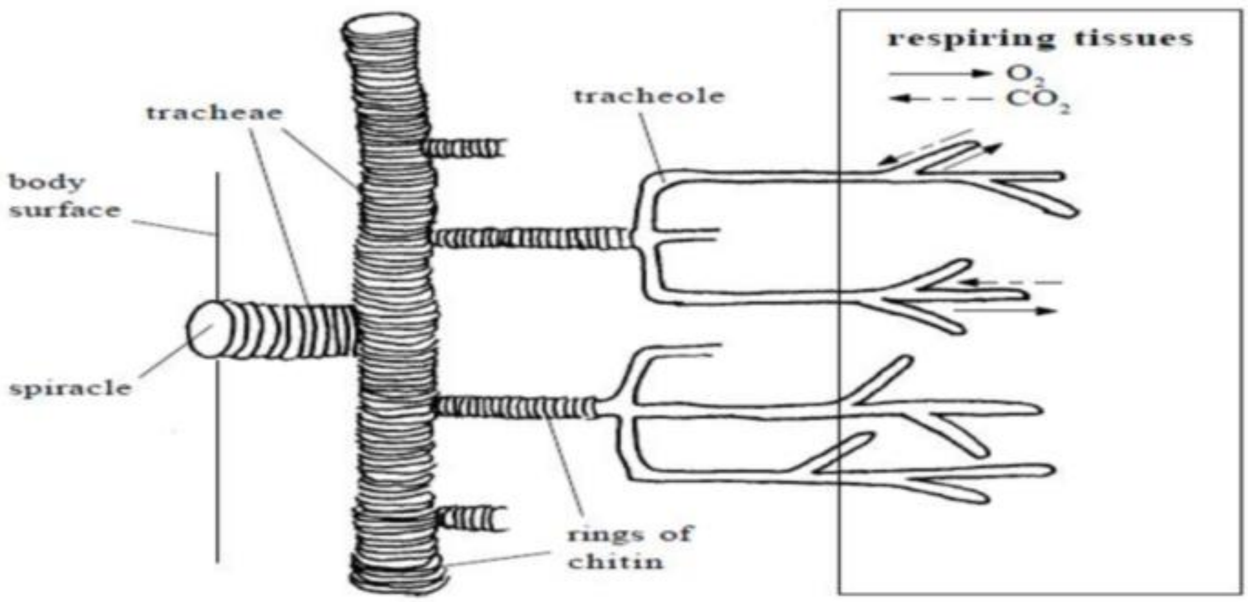
- Insect respiratory system refers to the open respiratory system composed of spiracles, tracheae and tracheoles (which extend to all parts of the body) that terrestrial arthropods have to transport metabolic gases through.
- In terrestrial insects and some aquatic species, the tracheae open to outside through segmental pores, the **spiracles**, which generally have some closing mechanism reducing water loss.
- The distribution of spiracles can vary greatly among the many orders of insects, but in general each segment of the body can have no more than one pair of spiracles.



- In insects the tracheal system, a series of gas-filled tubes derived from the integument, has evolved to cope with gas exchange.
- Terminally the tubes are much branched, forming **tracheoles** that provide an enormous surface area over which diffusion can occur.
- Tracheoles are so numerous that gaseous oxygen readily reaches most parts of the body, and, equally, carbon dioxide easily diffuses out of the tissues.
- Because they are in the gaseous state within the tracheal system, oxygen and carbon dioxide diffuse rapidly between the tissues and site of uptake or release. So because the system is gas-filled, much larger quantities of oxygen can reach the tissues in a given time.




Air sacs
Tracheae
Spiracles

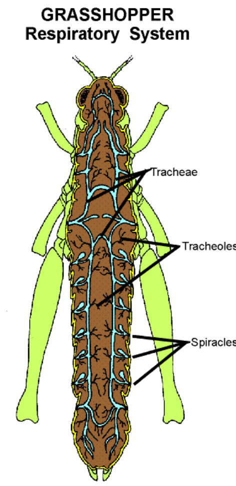

respiring tissues
O_2
CO_2
tracheole
tracheae
body surface
spiracle
rings of chitin

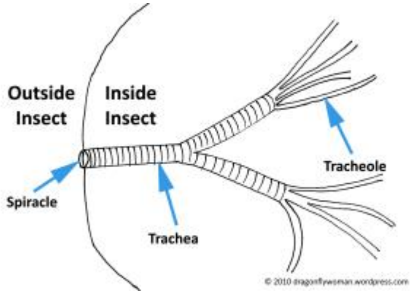
Organization and Structure of the Tracheal System

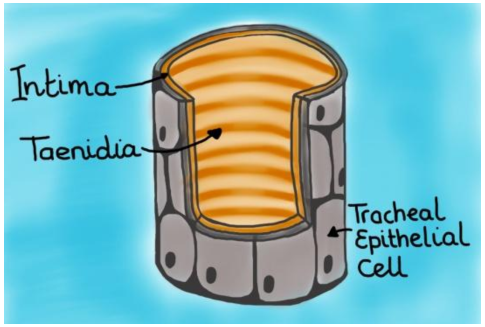
- A tracheal system is present in all insecta and in other hexapods with the exception of the Protura and many Collembola.
- In embryonic stage Up to 12 (3 thoracic and 9 abdominal) pairs of spiracles may be seen. this number is always reduced prior to hatching.
- The proportion of the body filled by the tracheal system varies widely, both among species and within the same individual throughout a stadium.

Trachea

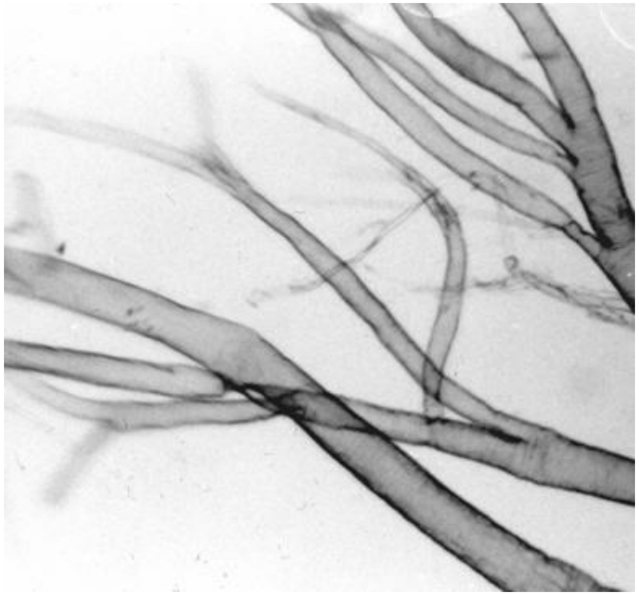
- ❖Generally, a pair of large-diameter, longitudinal tracheae (the lateral trunks) run along the length of an insect just internal to the spiracles.
- ❖Tracheae are formed by invaginations of the ectoderm and so are lined by a cuticular intima which is continuous with the rest of the cuticle.
- ❖Taenidia are distributed along the trachea to prevent collapse of the trachea if pressure within the tube is reduced.

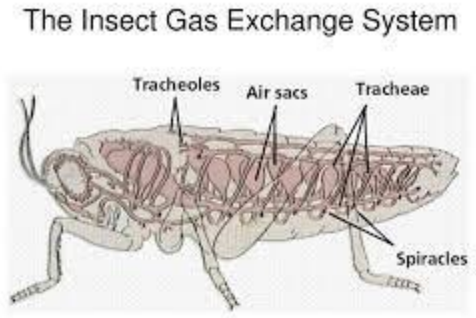






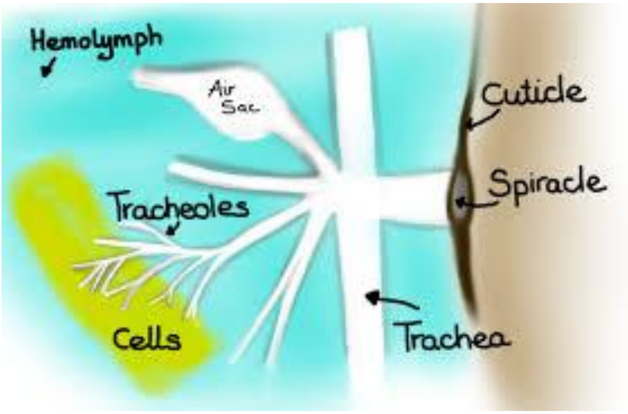
- In the wing tracheae of some insects, the taenidia are themselves twisted, giving some elasticity to the wall of the trachea.
- In places, tracheae are expanded to form thin walled airsacs in which taenidia are absent or poorly developed.
- These air sacs play a very important role in ventilation of the tracheal system as well as having other funchtions.

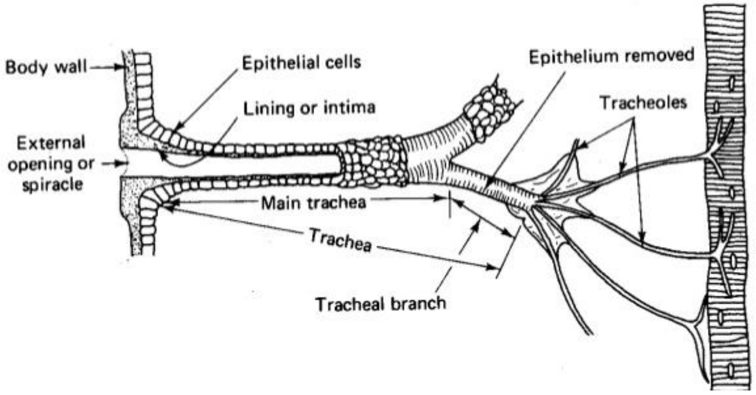




Tracheoles

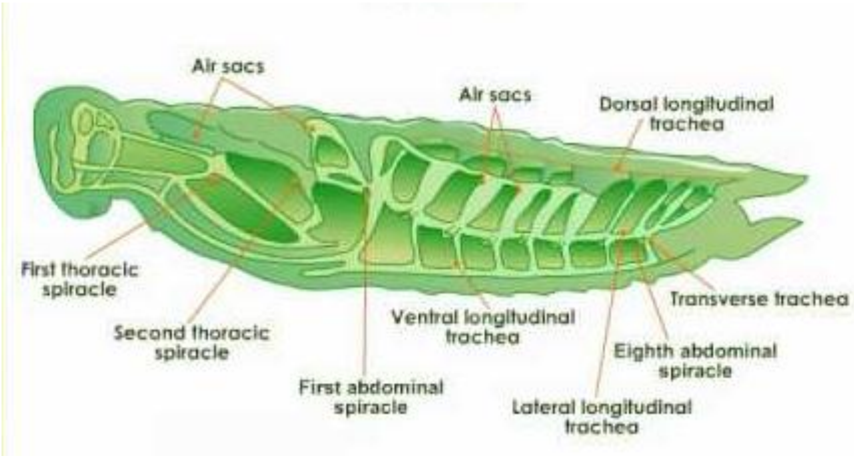
- Distally, the tracheae give rise to finer tubes, the tracheoles.
- Proximally they are about 1 micro m in diameter.
- They are formed in cells (often called tracheoblasts).
- Tracheoles are associated with the tissue.
- Each tracheolar branch ends blindly.

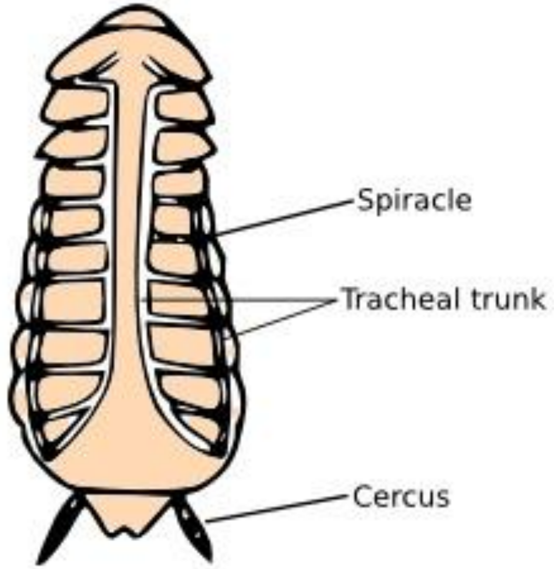


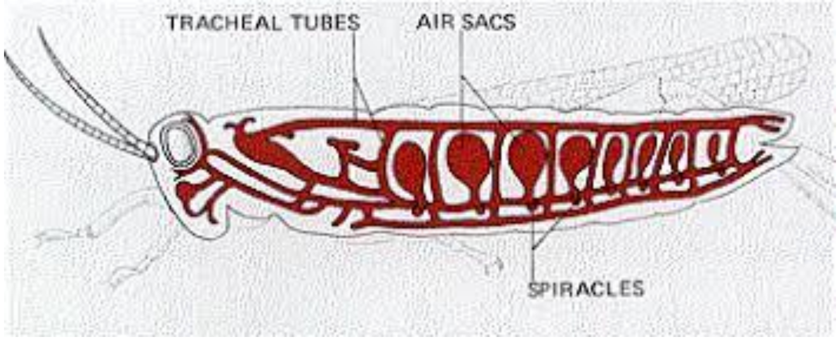


Distribution of tracheae within the insect

- In the majority of insects, the tracheae from neighboring spiracles join to form longitudinal trunks running the length of the body.
- There is a lateral trunk on either side of the body, and these are the largest tracheae and their branches supply the alimentary canal, gonads, legs and wings .
- Dorsal and ventral longitudinal trunks may also be present and their branches supply heart and dorsal muscles.





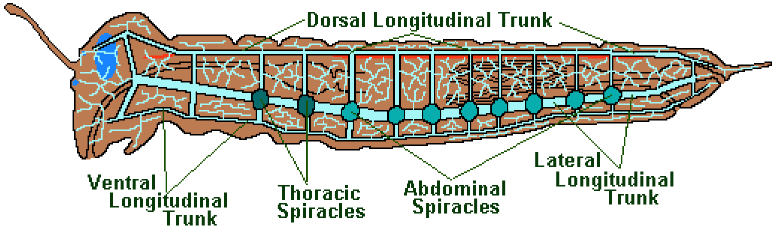


- The longitudinal tracheae are connected to those of the other side of the body by transverse commissars.
- The arrangement of tracheae are the same in each body segment.
- This basic arrangement is modified, however, in the head where there are no spiracles.
- The head is supplied with air form spiracle 1 (often on the prothorax).
- In the flying insects, air supply in the thorax are isolated from the rest of the body to cover the large demand of air for wing muscles.
- To some extent, the distribution of tracheae and tracheoles reflect the demands for oxygen by different tissues.

- High number of tracheoles are present in areas of high metabolic activity (flight muscle, nervous system chemical synthetic activity as in pheromone glands).
- The tracheal system varies with the state of development and becomes more complex at each molt. This may changes in the functional spiracles as well as in tracheation.

Spiracles

- They are the external openings of the tracheal system.
- They are lateral in position, and never than more one pair of spiracles on a segment, usually on the pleuron.
- Each spiracle is contained in a small, distinct sclerite, the peritreme.



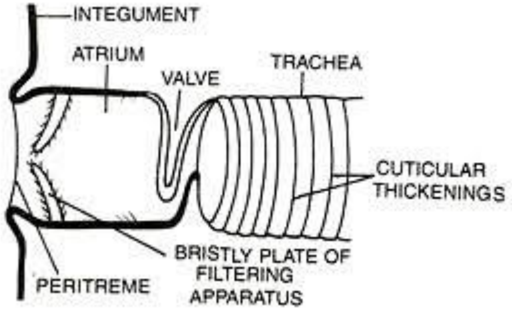


Fig. 7A.32. A spiracle with atrium, valve and a part of trachea.

Number and distribution of spiracles

- The largest number of spiracles found in insects is ten pairs, two thoracic and eight abdominal.
- In numerous insects, the first spiracle is on the prothorax, but is mesothorcic in origin.
- Spiracles never present on head.
- The respiratory system can be classified on the basis of the number and distribution of the functional spiracles as the followings:

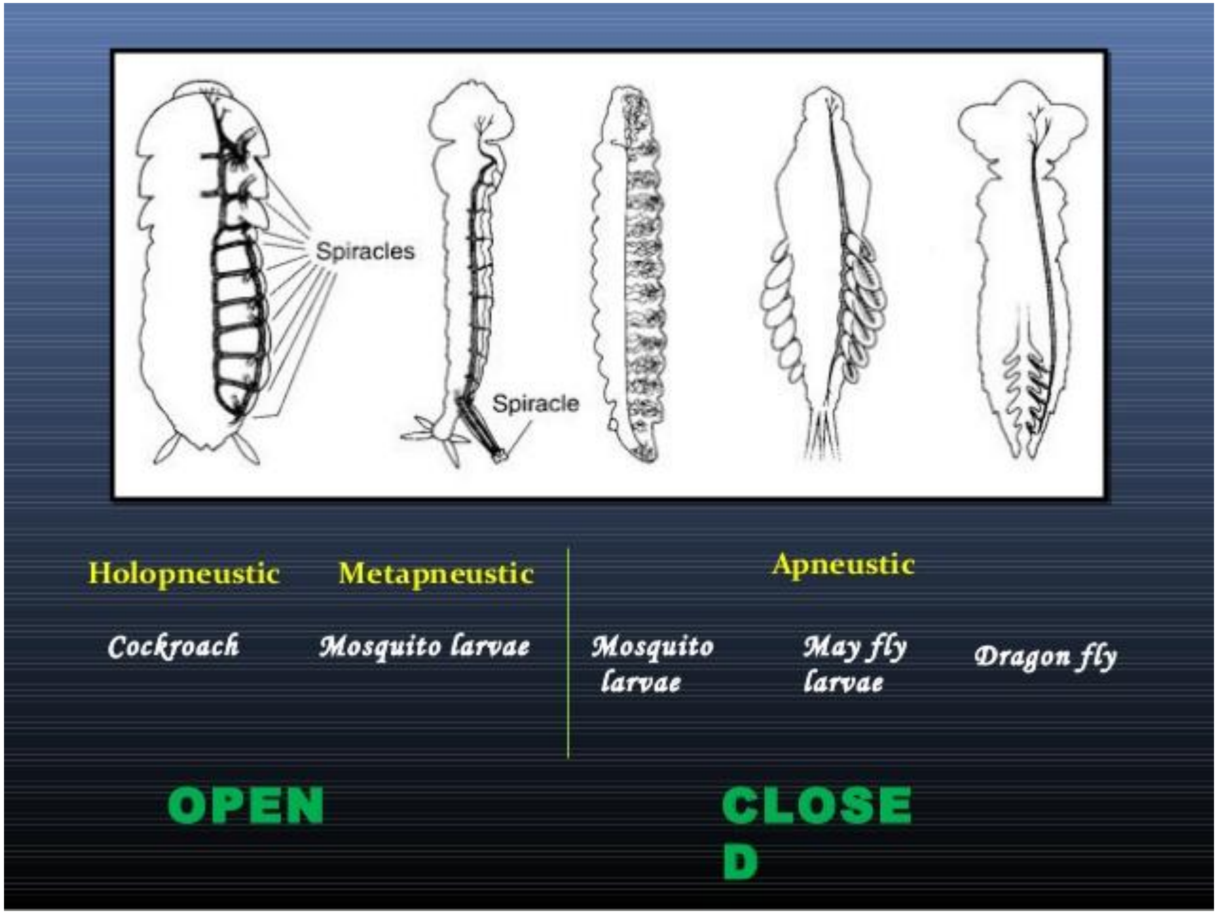
1- Polypneustic: at least 8 functional spiracles on each side

- Holopneustic: 10 spiracles: 1 mesothoracic, 1 metathoracic, 8 abdominal (e.g: dragonflies grasshoppers, cockroaches, fleas).
- Peripneustic: 9 spiracles: 1 mesothoracic, 8 abdominal (e.g. caterpillars and many endopterygote larvae).
- Hemipneustic: 8 spiracles: 1 mesothoracic, 7 abdominal.

2- Oligopneustic: 1 or 2 functional spiracles on each side.

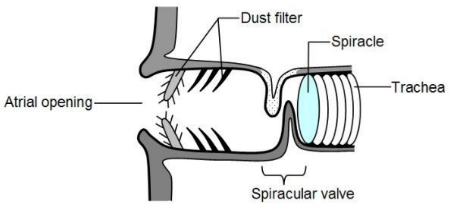
- Amphipneustic: 2 spiracles: 1 mesothoracic, 1 posterior abdominal (e.g. larval Diptera)
- Propneustic: 1 spiracle: 1 mesothoracic (e.g. mosquitoes pupae).
- Metapneustic: 1 spiracle: 1 posterior abdominal (e.g Mosquito and some aquatic beetle larvae)

3- A pneustic: no functional spiracles (e.g. many aquatic larvae).


Spiracles
Spiracle
Holopneustic
Metapneustic
Apneustic
Cockroach
Mosquito larvae
Mosquito larvae
May fly larvae
Dragon fly
OPEN
CLOSE
D

Structure of spiracle

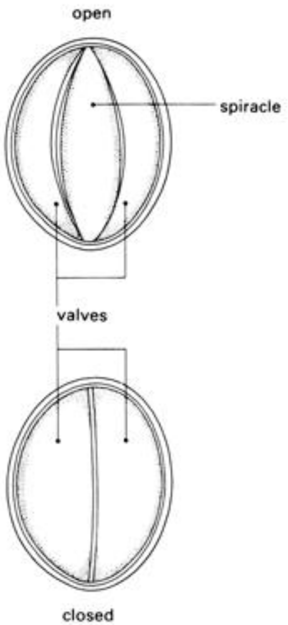
- The visible opening to outside leads into a cavity, the atrium, from which the tracheae arise.
- The opening and the atrium is known as spiracle.
- The wall of the atrium are lined with hairs which filter out dust.



A spiracle equipped with valve, atrium and dust filter

- In some Diptera, Coleoptera and Lepidoptera the spiracles are covered by a sieve plate with large numbers of pores (prevention of dust or from entry of water in aquatic insects).

- Terrestrial insects have spiracles with closing mechanism which control water loss.
- This closing mechanism may consist of one or two movable valves in the spiracular opening or it may be internal, closing the atrium from the trachea by means of a constriction with the help of muscle.
- Opening is produced by the elasticity of the cuticle associated with the spiracle or a second muscle.
- The motor neurons to the spiracle muscle in each segment arise in the ganglion of the same segment or that immediately in front.

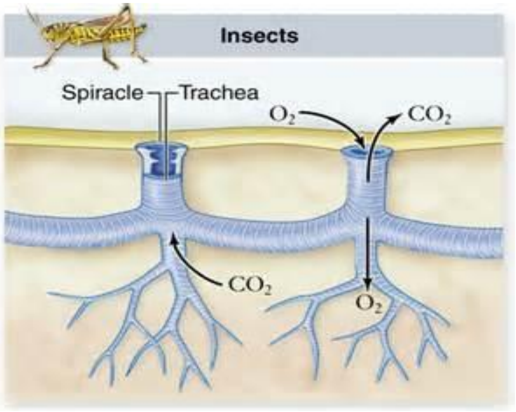


RESPIRATION IN TERRESTRIAL INSECTS

- Diffusion alone can account for the gaseous requirements of the tissues of most Insects at rest, but in larger insects or during activity demands on oxygen are greater.
- To meet these demands the insect pumps air in and out of the tracheal system by expanding and collapsing air-sacs, which are enlarged parts of the tracheae whose volume can be changed by movements of the body .
- These movements are controlled by endogenous rhythms in the central nervous system.

Gaseous exchange

- **Oxygen** passes through the tracheal system to the tissues and ultimately must reach the mitochondria in order to play a part in oxidative processes.
- **Carbon dioxide** follows the reverse path.



Diffusion

- The rate of diffusion of a gas depends on a number of factors.

1- It is inversely proportional to the square root of the molecular weight of the gas, so that in air :oxygen, with a molecular weight of 32 , diffuses 1-2 times faster than carbon dioxide , molecular weight 44 .

2- The differences in concentration of the gas at the two ends of the system and in the absence of a difference in concentration there is no net movement of gas.

3- Finally the permeability of the substrate, in **air** or the **tissues** , through which the gas is diffusing affects **the rate of diffusion**.

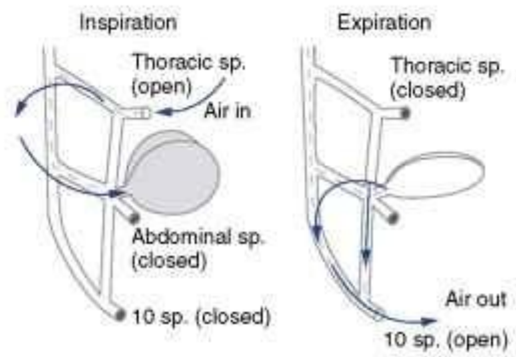
- The inward diffusion of oxygen from the partial pressure within the tracheoles being lower than in the outside air and this will arise from the passage of oxygen into the tissues when it is utilized.
- Hence a system capable of bringing an adequate supply of oxygen to the tissues will also suffice to take the carbon dioxide away.
- Carbon dioxide is more soluble and despite its higher molecular weight, it travels more quickly than oxygen through tissue. And it has a higher concentration in tissue than oxygen.
- Thus some carbon dioxide , instead of passing directly into the tracheal system, might diffuse outwards through the tissues and enter the tracheae near the spiracles or pass out directly through the integument.

- The exchange of gases between the tracheal system and the tissues is partly limited by the walls of the tracheae and tracheoles.
- The whole system may be permeable , with no marked difference between tracheoles and tracheae, but since the tracheoles are more closely associated with the tissues they will, in general , be more important than the tracheae in transfer of oxygen to the tissues .
- The rate of exchange of gases also varies with the surface area through which they are diffusing.

Ventilation

- In large, active insects diffusion alone does not bring sufficient oxygen to the tissues to meet their requirements and it is supplemented by changes in the volume of the tracheal system.
- Ventilation of the tracheal system involves the convective movements of gases.
- These movements are produced primarily by changes in the volume of the tracheal system.
- Most tracheae are circular in cross-section and resist any change in form, but some, such as the longitudinal trunks of *Dytiscus* (Coleoptera) larvae, are oval in cross-section and are subject to collapse.
- The collapse of a trachea forces air out of the tracheal system while its subsequent expansion sucks air in again.

- But changes in shape of the trachea only produce small volume changes.
- Much larger changes, and hence better gaseous exchange, are produced by the alternating collapse and expansion of air-sacs.
- Compression of the system , causing expiration , results indirectly as a result of heamolymph pressure.
- This is achieved in two ways: by reduction in the body volume, usually of the abdomen, and by displacement of hemolymph from different parts of the body while the total body volume remains constant.
- Expansion of the air-sacs and inspiration result from the reduction of pressure due to the muscular or elastic expansion of the abdomen or the movement of hemolymph to another part of the body.



- Changes in abdominal volume may be produced in various ways.
- In Heteroptera and Coleoptera the tergum moves up and down.
- In Odonata, Orthoptera, Hymenoptera and Diptera both tergum and sternum move and this movement may be associated with telescoping movements of the abdominal segments.

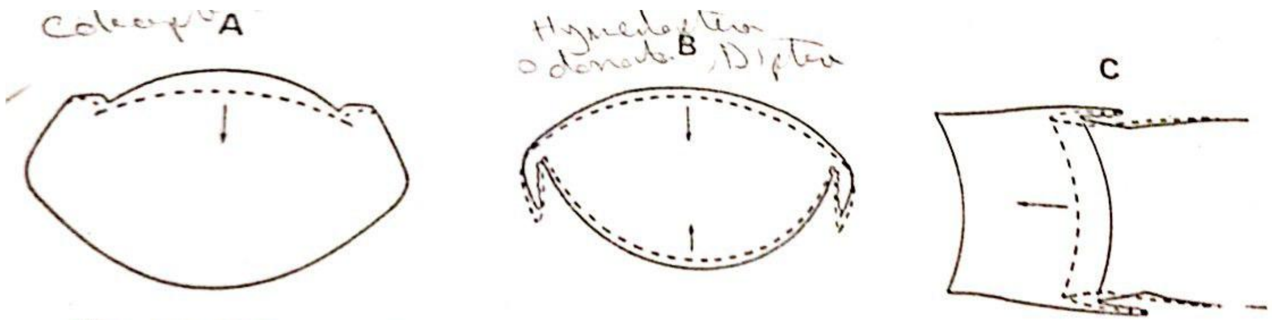
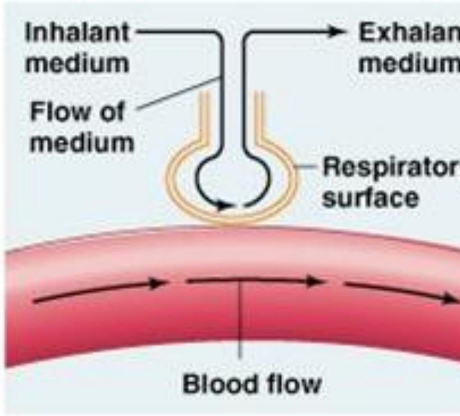


Fig. 352 Diagrammatic representations of types of abdominal ventilatory movements. Dashed lines indicate the contracted positions, arrows the directions of movement. (A) and (B) in transverse section, (C) in longitudinal section (from Snodgrass, 1935)

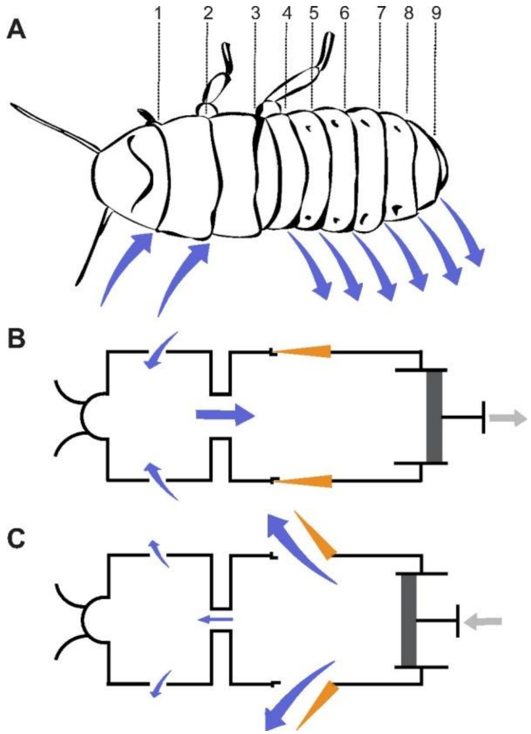
- In Lepidoptera the movement is complex and involves movements of the pleural regions as well as terga and sterna.
- Ventilation in large insects, such as **locusts**, is continuous, although there may be periods of a minute more without ventilation.
- After periods of activity abdominal ventilation is supplemented by other types of ventilation
- In **Schistocerca** these involve protraction of the head the prothorax, neck ventilation, and movement of the prothorax on the mesothorax, prothoracic ventilation
- In adult insects in which hemolymph circulation primarily involves shunting hemolymph back and forth between thorax and abdomen without any marked change in body volume, these movements also produce changes in tracheal volume.



Tidal flow

- Alternate movements of compression and expansion pump air out from and in to the tracheal system through the spiracles.
- Air may flow in and out of each of the spiracles and such a movement of air is called a tidal flow.
- In many insects, however opening and closing of certain spiracles is synchronized with the ventilator pumping movements of the abdomen, so that air is sucked in through some spiracles and pumped out through others and a directed flow of air is produced.
- This is a more efficient form of ventilation than tidal flow since the ‘dead’ air, trapped in the inner parts of the system by tidal movements, is removed.
- In most insects the flow of air is from front to back and in Schistocerca spiracle movements are always coupled with ventilatory movements.
- In many insects, however , the two activities may become uncoupled so that they are not always synchronized and the coupling may even be modified so as to produce a reversal of the airstream.

- In Schistocerca spiracles 1, 2 and 4 are open during inspiration , and then they close and spiracle 10 opens for expiration.
- When the insect is more active expiration takes place through spiracles 5 to 10, the spiracles for inspiration open immediately after the expiratory spiracles have closed and remain open for about 20 % of the cycle while air is drawn in.
- Then they closed and for a short time all the spiracles are closed.
- The abdomen starts to contract while the spiracles are still closed , so that air in the tracheae is under pressure , this is known as the compression phase, Then the expiratory spiracles open and air is forced out.
- The expiratory spiracles are only open for some 5-10 % of the cycle.
- During activity the frequency of ventilation and spiracular movements is increased. The times for which the spiracles open remain the same, but the period of closure is reduced and the compression phase eliminated.



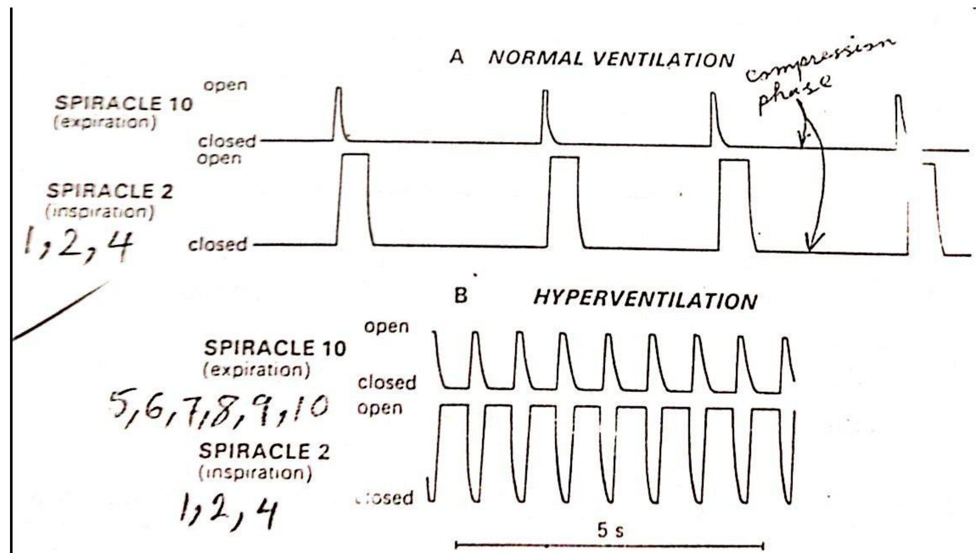


Fig. 353 Diagram illustrating the activity of the spiracles of *Schistocerca* in ventilatior
A. Normal ventilation. B. Hyperventilation (after Millar, 1960b)

Ventilation in flight

- Massive increase of oxygen occur during flight.
- So insects require a greatly increased airflow thought the tracheae to the flight muscles.
- During flight of Schistocerca, abdominal ventilation increase, but still insufficient.
- However, the distortion of the thorax, and in particular the raising and lowering of the nota sclerites, produces large volume changes in the extra-muscular air sacs of the pterothoracic tracheal system.
- This pterothoracic ventilation produce adequate supply of airflow for flight muscles.
- Also spiracles opening pattern differ according to the demand of the insect to airflow.

Discontinuous gas exchange

- Although ventilation is often continuous, there may be extended periods during which all the spiracles are closed.
- In this case, gas movement occur in discrete bursts when spiracles open; relatively little gas exchange occurs while they are closed.
- This phenomenon is known as discontinuous gas exchange.
- It is common in adult when they are inactive and their metabolic rate is low. Also the pupae of many insects exhibit this type of gas exchange.
- During the closed phase carbon dioxide produced are dissolved in the hemolymph. When spiracles open, oxygen rushes into the system and carbon dioxide and water vapor diffuse out.

- Between periods of complete closure and complete opening, some insects exhibit a period in which the spiracles repeatedly open slightly and close again, a movement is known as **futtering**.

- During this period, oxygen enters the system, but relatively little carbon dioxide escape out.

RESPIRATION IN AQUATIC AND ENDOPARASITIC INSECTS

- Aquatic insects obtain oxygen directly from the air or from air dissolved in the water. The former necessitates some semi-permanent connection with the surface or frequent visits to the surface, but the frequency of surfacing may be reduced by increasing the size of the air with they submerge.
- Insects which obtain air from the water nearly always retain the tracheal system so that the oxygen comes out of solution into the gaseous phase.
- This is important because the rate of diffusion in the gas phase is very mush greater than in solution in the haemolymph.

Aquatic insects obtaining oxygen from the air

- Most aquatic forms obtaining air from above the water surface must make periodic visits to the surface, but a few have semi-permanent connections with the air such as:
- Siphon
- Thrusting their spiracles into the aerenchyma of aquatic plants.

Gas exchange via air bubbles

- Some insects, such as mosquito larvae, can remain submerged only as long as the supply of oxygen in the tracheae lasts
- Others have extra-tracheal air store, carrying a bubble of air down into the water when they dive.
- The position of the store is characteristics for each species.
- Also these air store gives the insect buoyancy.

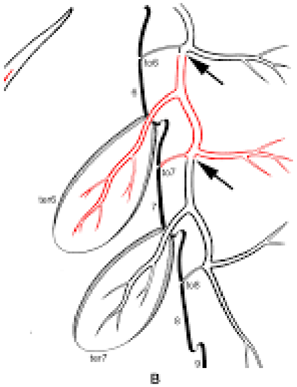
Insects obtain oxygen from water

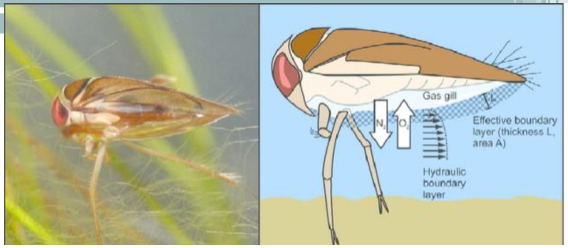
1-Diffusion

- Some aquatic insects inward diffusion of oxygen from the water takes place through the cuticle .
- Insects that obtain oxygen from water do have a tracheal system although the spiracles are non-functional, this is called a closed tracheal system.

2- Tracheal gills

- These are a network of tracheoles covered by a very thin cuticle known as tracheal gills.
- often are leaf-like extension of the body.
- Their number and position depend on species.





3- Plastron respiration

- Some insects have specialized structures holding a permanent thin film of air on the outside of the body.
- This film of gas is known as plastron.
- Tracheae open into it so that oxygen can pass directly to the tissues.
- The volume of the plastron is constant and usually small as it does not provide a store of air, but acts solely as a gill.
- The constant volume is maintained by a various hydrofuge devices spaced very close together so that water does not penetrate between them except under considerable pressure.
- An example of hydrofuge device is very close hair pile in which the hairs resist wetting because of their hydrofuge properties and their orientation.

Gas exchange in Endoparasitic insects

- Endoparasitic insects obtain their oxygen directly from the air outside the host or by diffusion through the cuticle from the surrounding host tissues.
- Most larval forms depend on diffusion through cuticle to obtain oxygen, while adults may penetrate host body and contact with the outside to obtain oxygen though their posterior spiracles.