GASEOUS EXCHANGE

Gas exchange The uptake of molecular oxygen (O2) from the environment and the discharge of carbon dioxide (CO2) to the environment by cells.

Respiratory medium is the source of oxygen. These are majorly the atmospheric **air** for land animals and **water** for aquatic animals. Amount of oxygen in water varies (~ 1.03% in fresh water and 0.85% in sea water) but is always much less than in equal volume of air, being even lower in warmer, saltier, dirtier water than in cooler, fresh, cleaner water

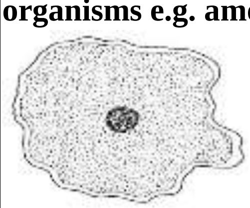
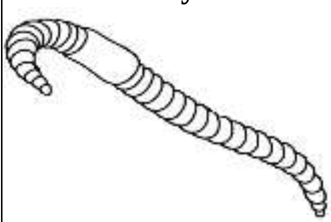
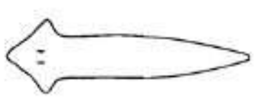
Specialized respiratory surfaces:

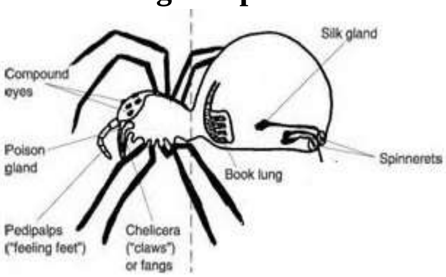
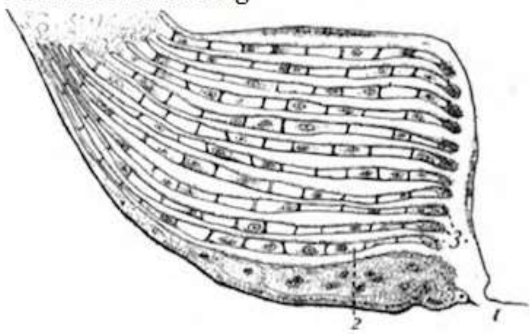
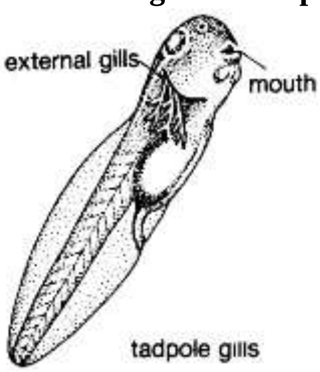
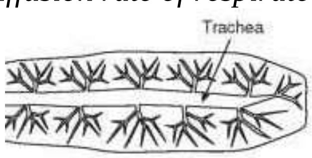
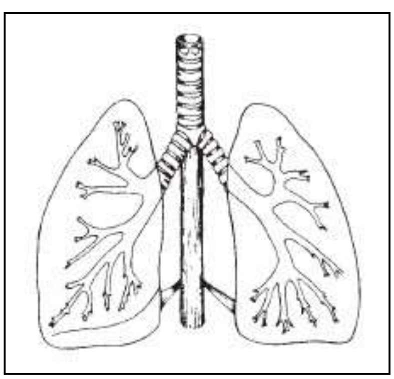
These are The boundary between the external environment and body interior. Gaseous exchange takes place across specialized surface in the body and the mechanism by which it occurs varies from one organism to another depending on the body size of an organism and where it leaves.

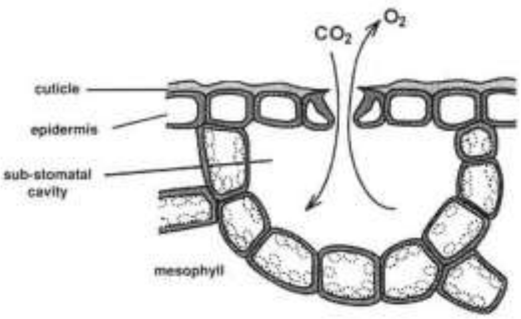
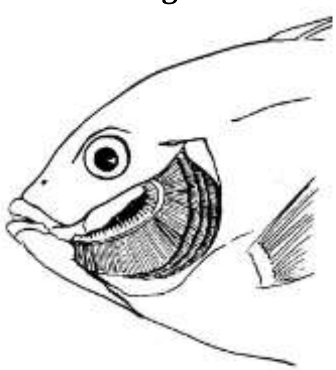
Small organisms have their gaseous exchange taking place across their body surfaces.

This is because they possess large surface area to volume ratio which enhance rapid diffusion of gases directly across their body surfaces.

On the other hand, large animals possess small surface area to volume ratio and their surfaces are not good for gaseous exchange e.g.

Gas exchange surfaces	Adaptation of gas exchange structures
1.Cell surface membrane in unicellular organisms e.g. amoeba 	• The cell surface membrane has a sufficiently large surface area to volume ratio enables efficient diffusion of gases. • Being aquatic, the cell membrane is always moist to dissolve respiratory gases to enable their diffusion. • The cell surface membrane is permeable to respiratory gases
2. Entire body surface e.g. skin of earthworms 	• Skin surface is moist to enable dissolving of respiratory gases for efficient diffusion. • Skin is thin to reduce the diffusion distance such that there is increased rate of diffusion of respiratory gases. • The epidermal tissue is highly vascular to deliver and carry respiratory gases such that a high concentration gradient for the gases is maintained
3.Across the surface of flattened body e.g. flatworms 	• The flatness increases the surface area to volume ratio to increase the rate of diffusion of respiratory gases.

4. Book-lungs in spiders  **Details of book-lung**  1, lung-slit 2, space filled with blood 3, leaves of the book-lung	The internal cavity increases the surface area for exchange of respiratory gases.
5. External gills in tad poles and lugworms  	There is increased surface area for diffusion of respiratory gases. **<u>Disadvantages of external gills</u>** **(i)** They offer great resistance because they are highly branched, since they are constantly moved in water to avoid oxygen depletion from the surrounding water, hence external gills are ineffective except in smaller animals. **(ii)** Easily get damaged since the thin epithelium required for gas exchange is thin and delicate.
6. Tracheoles in insects <u>Note</u>: *Size of insects is limited by the relatively slow diffusion rate of respiratory gases.*  	•Tracheae are kept open by circular bands of chitin to enable continual air movement to reach and leave tracheoles. •Tracheae highly branch to form tracheoles that reach every cell to ventilate respiring cells directly. •Tracheoles are moist to enable dissolution of respiratory gases for increasing their diffusion. •Tracheae are impermeable to gases to maintain a high diffusion gradient in the air that reaches the tracheoles.
7. Inner alveolar surface of lungs in mammals 	•Lungs have many saccular alveoli which provide a large surface area for gas exchange. •Diffusion of respiratory gases is made faster by the shortened distance due to **(1)** alveoli and capillary walls being only one cell thick **(2)** epithelial cells are flattened so are very thin **(3)** capillaries are pressed against alveoli. •The moistened alveolar surface enables dissolution of respiratory gases to increase the rate of diffusion. •Alveolar surface is internal to reduce water evaporation. •High concentration gradients of the gases, maintained by ventilation and flow of blood in the extensive capillary network. •Air is warmed as it passes through the nostrils, to increase diffusion rate.

8. Plasma membrane of cells in the leaf mesophyll and cortex of root and stem 	•When the stomata open, production and consumption of oxygen and carbon dioxide in the leaf is sufficient to maintain a concentration gradient steep enough to facilitate gas exchange with the atmosphere. •Large intercellular air filled spaces in the spongy mesophyll act as a reservoir for gaseous exchange. •The cortical air spaces of roots and stems are continuous up and down and also in a sideways direction, thus allowing gas transport throughout the stem and root tissues. •Root hairs lack a waxy cuticle and have moist surfaces to facilitate rapid diffusion of gases through the cell wall. •Mangrove species that grow in water logged soils with less air content develop breathing roots above the ground level to increase gas exchange. •Root hairs are numerous to increase the surface area for gas exchange. •In the stem, lenticels consist of loosely packed cells at the opening to enable diffusion of respiratory gases.
10. Internal gills in fish 	• Gill filaments have folds called ***secondary lamellae*** that increase the surface area for gas exchange. • The gill lamellae contain a network of capillaries for carrying away oxygen or bringing in Carbon dioxide for expulsion. • There is counter current flow i.e. water and blood in the gills flow in opposite directions to maintain a favorable concentration gradient for diffusion of respiratory gases. • Gill filaments are moist to enable dissolution of respiratory gases for efficient diffusion. • Gills filaments are ***thin-walled*** to provide a short distance for diffusion of respiratory gases. • Tips of adjacent gill filaments overlap = increases the resistance to the flow of water over gill surfaces and slows down the movement of water= more time for gaseous exchange to take place

CHARACTERISTICS OF A RESPIRATORY SURFACE

1.They have large surface area to enable diffusion of gases.

2.They are moist so as to dissolve gases and this enhances (improves) there diffusion normally gases diffuse faster in solution form.

3.The respiratory surfaces are permeable to allow gases to go through them.

4.They are thin so as to minimize the distance moved by gases during diffusion.

5.They are well ventilated i.e. they possess a dense network of capillaries so that oxygen and carbondioxide are carried to and from the surface to maintain the concentration gradient.

6.Being delicate, they are highly protected e.g. the gills in fish are protected by the operculum and lungs in man are protected by a rib cage.

7.Increase in the volume of the mouth

8.Pressure within the mouth decreases and water enters the mouth

9.The fish closes its mouth and floor of the water moves to the gills and O2 diffuses into blood while CO2 diffuses out of blood and water is raised covering a reduction in volume and increasing the pressures.

Role of Diffusion in Gaseous Exchange

Diffusion is the only process by which CO_2 and O_2 move across the gaseous exchange surfaces.
The factors that influence the rate of diffusion, surface area, concentration gradient, and diffusion distance, are described by Fick's Law:
"The rate of diffusion is proportional to the surface area across which diffusion occurs, and inversely proportional to the square of the distance through which molecules must move"
Animals have evolved to maximize the diffusion rate across respiratory membranes by **increasing the respiratory surface area, increasing the concentration gradient across the membrane, or decreasing the diffusion distance**

Fick's law shows that for a fast rate of diffusion you must have a large surface area, a small distance between the source and the destination, and maintain a high concentration gradient. All large organisms have developed systems that are well-adapted to achieving these goals, as this table shows. For comparison, a tennis court has an area of about 260 m² and a football pitch has an area of about 5000 m².

Gas exchange takes place at a respiratory surface - a boundary between the external environment and the interior of the body. For unicellular organisms the respiratory surface is simply the cell membrane, but for large multicellular organisms it is part of specialized organs like lungs, gills or leaves. This leads to confusing terminology, for while the word "respiration" in biology usually refers to cellular respiration (ATP generation in cells), from time to time (such as here) it can also refer to breathing, which is what non-biologists mean by it anyway.

Gases cross the respiratory surface by diffusion, so from Fick's law we can predict that respiratory surfaces must have:

i) a large surface area

ii) a thin permeable surface

iii) a moist exchange surface

Many also have: A mechanism to maximize the diffusion gradient by replenishing the source and/or sink.

1. **GAS EXCHANGE IN EARTHWORMS**

Earthworms exchange oxygen and carbon dioxide with water or air directly through their moist skin. Dissolved oxygen diffuses into tiny blood vessels under the skin surface, where it loosely combines with **haemoglobin** that moves it through bloodstream to tissues. Carbon dioxide released by tissues attaches to haemoglobin then detaches to diffuse out of the skin.

Adaptation of earthworms to use the skin for gas exchange.

(i) Earthworms have low metabolic rate, therefore require relatively low oxygen supply for aerobic respiration.

(ii) Moist surface with dense network of blood capillaries under the skin enable efficient gas exchange between air and blood.

(iii) Earthworm circulatory system contains haemoglobin in blood to increases the oxygen carrying capacity of blood.

(iv) Long, thin body provides large surface area compared to body size, efficient for gas exchange.

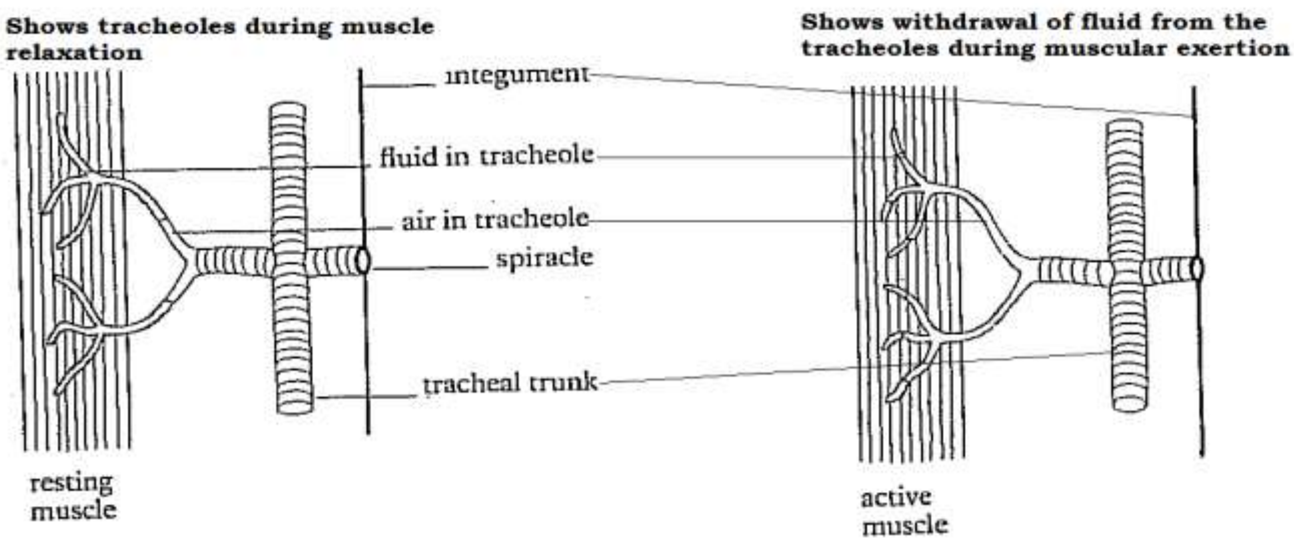
(v) Blood capillaries are very close to the skin surface to reduce the diffusion distance for gases.

2.GASEOUS EXCHANGE IN INSECTS

Description of insect respiratory system

In grasshopper, the tracheal system consists of 10 pairs of spiracles, located laterally on the body surface. Of these, 2 pairs are thoracic and 8 pairs are abdominal. The spiracles are guarded by fine hairs to keep the foreign particles out and by valves that function to open or close the spiracles as required. The spiracles open into small spaces called the **atria** that continue as air tubes called the **tracheae**. The tracheae are fine tubes that have a wall of single layered epithelial cells. The cells secrete spiral cuticular thickenings called **taenidia** around the tube that gives support to the tubes. The tracheal tubes branch further into finer **tracheoles** that enter all the tissues and sometimes, even the cells of the insect. The ends of the tracheoles that are in the tissue are filled with fluid and lack the cuticular thickenings. The main tracheal tubes join together to form three main tracheal trunks- dorsal, ventral and lateral. At some places, the tracheae enlarge to form air sacs which are devoid of cuticle and serve to store air.

THE TRACHEAL SYSTEM



NOTE:

1. When water leaves body cells to fill the trachea, it reduces water's effective surface area when asleep or dormant hence reducing chances of evaporation because the spiracle valves will be closed.

2. In some insects like grasshopper, there is a one-way flow of air, which increases the efficiency of gas exchange as CO_2-enriched air can be expelled without mingling with the incoming flow of fresh air. Spiracle valves are opened and closed in a particular order which allows the insect to suck air into the tracheal system at one end of the body and to circulate the air through the system and pass it out at the other end of the body.

VENTILATION MECHANISMS IN INSECTS

a. Inspiration

During inspiration, Increased CO2 is detected by chemoreceptors, causing relaxation of the abdominal muscles, increased volume and lowering of pressure. The spiracle valves open and air rich in oxygen is drawn into the tracheal system.

Spiracles valves then close and oxygen is forced along the tracheal system into the fluid-filled tracheoles, which are in direct contact with the tissue fluid. Gaseous exchange occurs along concentration gradients of oxygen and carbon dioxide.

The abdomen of the insect will expand to allow air to enter the trocheal system when the spiracles are opened air diffuses along the tracheal and finally reaches the tracheoles which are thin walled and fluid filled. Inspired air contains much O2 which then dissolves in the fluid and diffuses out of the cells into the tracheoles.

b. Expiration

After exchange of gases in the tracheoles the abdomen contracts and this is due to the contraction of the abdominal muscles that cause the contraction of the insect body. This reduces the volume of the tracheoles system which forces air with much CO2 to move from the tracheoles into the trachea and finally out of the body through the spiracles.

Air is expelled out when muscles contract and flatten the insect body, decreasing the volume of the tracheal system.

During increased metabolic activity, the water potential of tissue lowers (hypertonic) due to accumulation of wastes like lactic acid, causing osmotic efflux of water from the tracheoles into tissues. Air fills the tracheoles and oxygen diffusion through tracheoles is faster.

In resting tissues, the water potential of tissue fluid increases (hypotonic), causing the fluid to fill the tracheoles.

Insects regulate the ventilation rates just like mammals do some insects have nerve centers in the thorax and abdominal ganglia which controls the rhythmical ventilation movement of the body.

In severe muscular activity e.g. during flight lactic acid may accumulate in tissues thus raising the salt drawn out of the tissue fluids. This results in water being air passages to facilitate diffusion of oxygen to tissues.

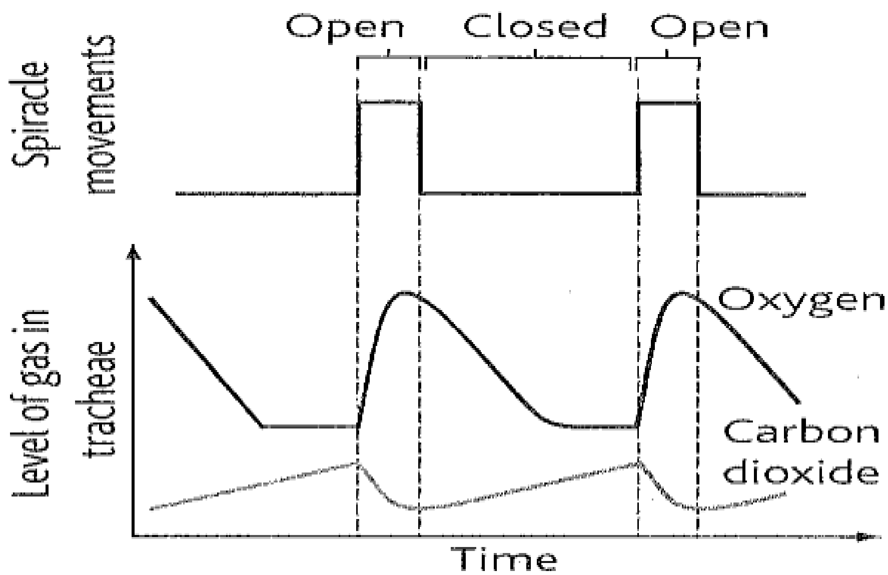
Therefore;

i. Insects have the most efficient method of supplying oxygen to body tissues.

ii. Insects have respiratory gases delivered directly to body cells and never carried in blood. Blood of insects lack haemoglobin and that’s why it appears colorless.

Question

The figure below shows results of an experiment to measure the levels of oxygen and carbon dioxide in the tracheal system of an insect over a period of time. During the experiment, the opening and closing of the insect’s spiracles was observed and recorded.



(a) Describe the pattern of level of gases in tracheae in relation to spiracle movements.

When spiracles are open the level of oxygen in the tracheae increases rapidly to a maximum; while the level of carbon dioxide decreases rapidly;

When spiracles close the level of oxygen immediately decreases rapidly; and thereafter remains constant; while the level of carbon dioxide increases gradually;

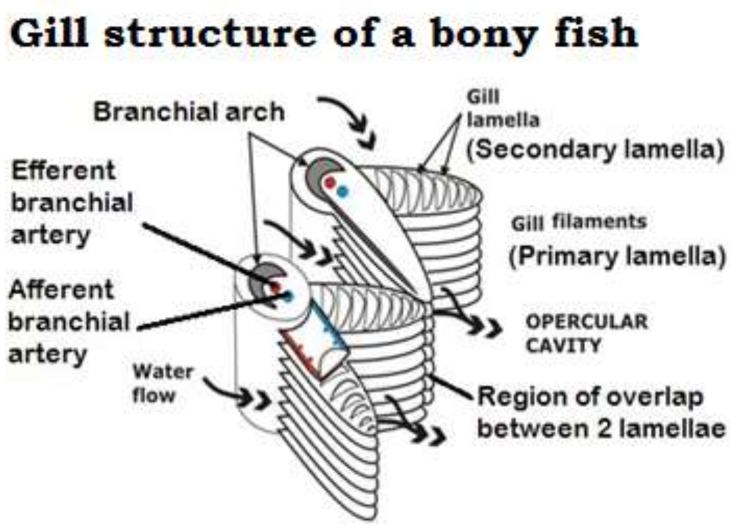
(b) Explain the pattern of level of gases in tracheae in relation to spiracle movements.
Opening of spiracles enables rapid entry of oxygen until the tracheae fill up. This is because of relaxation of abdominal muscles which increases abdominal volume while abdominal pressure decreases below atmospheric pressure.
When spiracles close oxygen rapidly diffuses along a concentration gradient into respiring cells until the gradient can no longer allow any more diffusion into cells hence oxygen level in the tracheae later remains constant.
Opening of spiracles enables rapid exit of carbon dioxide from tracheae along a concentration gradient.
When spiracles close carbon dioxide gradually diffuses along a concentration gradient from respiring cells into the closed tracheae.

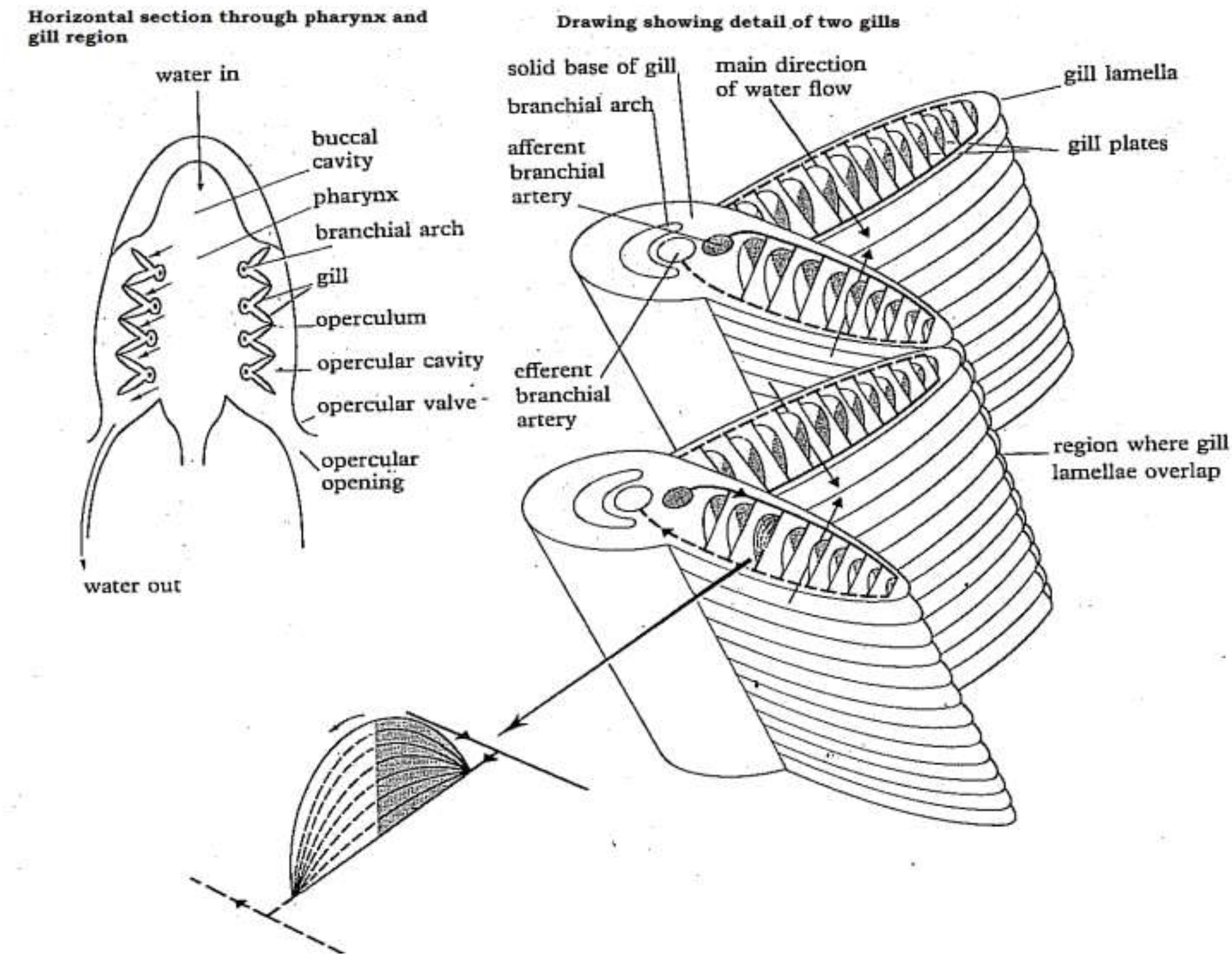
(c) (i) From the information provided by the graph, suggest what causes the spiracles to open
The increasing level of carbon dioxide

(c) (ii) What is the advantage of the observed spiracle movements to a terrestrial insect?
Observation: *Interval of spiracle opening is very short while interval of spiracle closure is relatively long.*
Advantage*: Longer spiracle closure period conserves water because water vapour does not diffuse out continually.*
(d) Fossil insects have been discovered that are larger than insects that occur on earth today. What does this suggest about the composition of the atmosphere at the time when these fossil insects lived?
The earlier atmosphere contained more oxygen than the present atmosphere.

3. GASEOUS EXCHANE IN FISH
a) BONY FISH/TELEOST FISH

Bony fish have four pairs of bronchial arches supporting gill filaments. These filaments form a double vow arranged in a V-shape bearing gill plates at right angles to their surface. There are no bronchial valves and gill slits are covered by a body flat called the operculum. It offers protection and helps in ventilation.





Oxygenated blood leaves in the efferent brachial artery to join the dorsal aorta along which it passes to the rest of the body.

Bony fish gills demonstrate extremely well the counter current principals. The blood and water flow over the gill to remain in opposite direction. This allows a diffusion gradient to remain constant and to be maintained between the water across the gill. It ensures that blood which is already partly loaded with oxygen meets water which has very little oxygen removed from it.

Similarly, blood with very low oxygen circulation meets water which already had most of its oxygen removed. This mechanism allows bony fish to achieve 80% absorption of oxygen compared to 50% in the parallel flow system. The over lapping ends of the gill filaments also slow down the passage of water so that there is a greater time for diffusion to occur.

BONY FISH GILL STRUCTURE

- Has 4 gill arches in each Opercular cavity.
- Has 2 rows of gill filaments project from each gill arch.
- Each filament (primary lamella) is covered with
- rows of secondary lamellae perpendicular to *filament*
- Each gill arch contains an afferent & efferent *artery*. **Afferent blood vessels** carry deoxygenated blood

to the capillaries in the secondary lamellae. **Efferent blood vessels** carry oxygenated blood from the capillaries back to the gill arch.

- ➢ Has Secondary lamellae (**respiratory surface**) are semicircular, thin-walled and highly vascularized with capillaries
- ➢ Blood flow through capillaries in secondary lamellae is opposite the flow of water through the gills **(countercurrent flow)**.

VENTILATION MECHANISM IN BODY FISH

Alteration of the buccal pressure pump and an Opercular section pump allows water to be drawn over and between the gills more or less continuously.

Mechanism of ventilation in bony fish

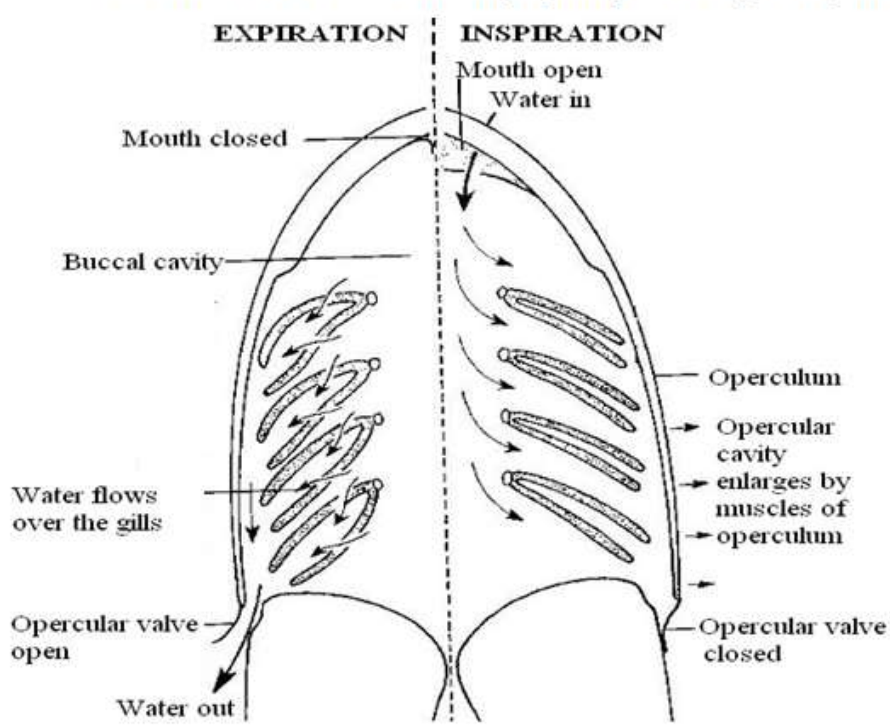
INHALATION

- ➢ Contraction of the mouth muscles lowers the floor of the mouth, increasing buccal cavity volume as pressure decreases.
- ➢ Water rushes to fill the buccal cavity, and at the same time, water's pressure outside presses against and closes opercular valves.
- ➢ Operculum muscles contract; causing operculum to bulge; and increase opercular volume but decreases opercular cavity pressure.
- ➢ Mouth contracts to decrease buccal cavity volume while increasing pressure, which forces/sucks water into opercular cavity which is at lower pressure;
- ➢ As water flows over gill filaments in opposite direction to flow of blood (countercurrent flow) O2 diffuses into blood capillaries to combine with haemoglobin while CO2 diffuse into the flowing water along concentration gradients.

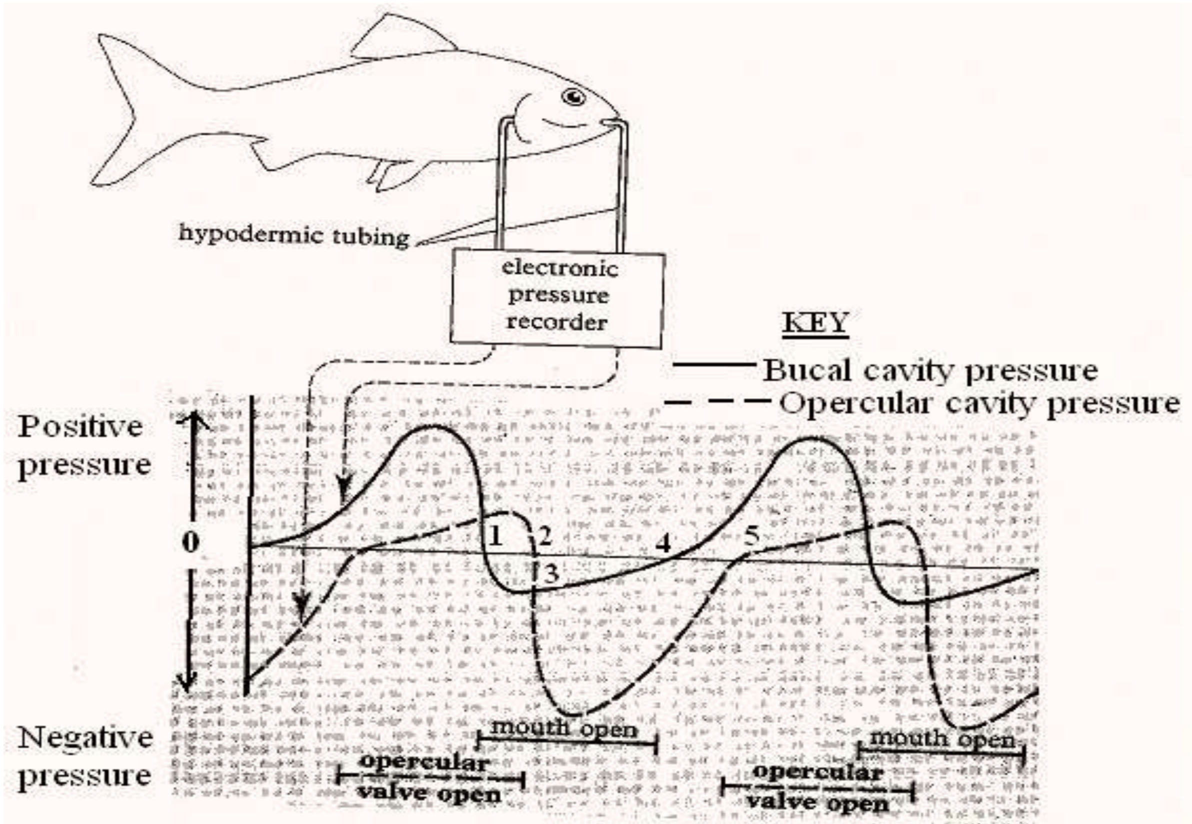
EXHALATION

- ➢ Mouth muscles are fully contracted with mouth valve tightly closed.
- ➢ Opercular muscles relax to decrease opercular cavity volume and increase pressure. • Pressured water in opercular cavity forces opercular valves to open as water exits.

Horizontal section through pharynx and gill region



PRESSURE CHANGES IN BUCCAL AND OPERCULAR CAVITIES IN BONY FISH VENTILATION



OBSERVATIONS AND EXPLANATIONS FROM THE GRAPH

At 1, the buccal cavity is expanding, the pressure reduces and falls below atmospheric pressure (acquires negative pressure); mouth valve opens and water enters from outside.

At 2, opercular cavity is expanding, pressure reduces below atmospheric pressure (acquires negative pressure); opercular valve closes.

At 3, buccal cavity begins to contract, volume gradually decreases as pressure gradually increases while expansion of opercular cavity increases the volume further as pressure decreases further to fall below buccal cavity pressure, resulting in water being sucked into opercular cavity from buccal cavity.

At 4, buccal cavity pressure increases above atmospheric pressure (acquires positive pressure); mouth valve closes and water flows along the pressure gradient from buccal cavity to opercular cavity.

At 5, opercular cavity is contracting to decrease the volume as pressure increases above atmospheric pressure (acquires positive pressure); opercular valve opens and water is expelled

NOTE:

(1) Water almost flows in one direction from the buccal cavity to the opercular cavity.

EVIDENCE: Throughout the ventilation cycle, except for one short period when the buccal cavity expands (see 1above), the pressure in the buccal cavity is higher than that in the opercular cavity forcing water to flow from the buccal cavity to the opercular cavity along the pressure gradient. Expansion of buccal cavity lowers the pressure below atmospheric pressure, causing the water to enter the buccal cavity but at the same time the opercular valves close to prevent entry of water.

(2) The buccal cavity acts as a force pump while the opercular cavity as a suction pump.

WORKED EXAMPLES

Qn. 1. (a) Explain why when fish are taken out of the water, they suffocate.

This is because **(1)** their gill lamellae collapse and there is not enough surface area for diffusion to take place **(2)** the gill lamellae surface dries and oxygen in air fails to dissolve and diffuse into blood.

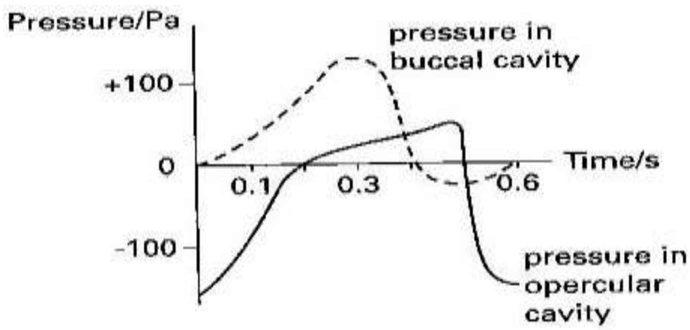
Note: There are actually some fish that can survive out of the water, such as the walking catfish because they have modified lamellae, allowing them to breathe air.

b) Under what circumstances do fish suffocate in the water?

(i) When the oxygen in the water is depleted by another biotic source such as bacteria/decomposers.

(ii) When oxygen greatly diffuses out of water due to increase in water's temperature.

Qn. 2. The graph below shows the changes in pressure in the buccal cavity and in the opercular cavity during a ventilation cycle.



(a) Calculate the rate of ventilation in cycles per minute

Since the duration of one cycle is 0.6 seconds, therefore ventilation rate

= 1.0 divided by 0.6 = 1.67 cycles per second.

(b) (i) With evidence from the graph, explain why water almost flows in one direction over the gills.

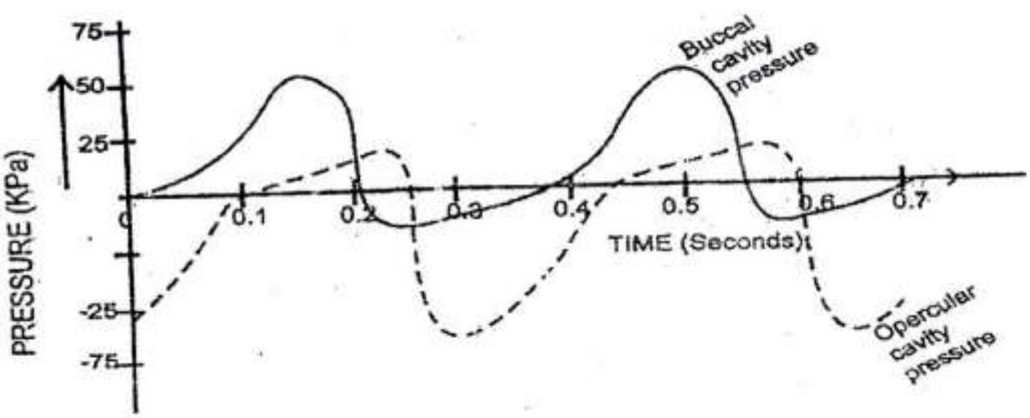
The pressure in the buccal cavity is higher than opercular cavity pressure in the first 0.4 seconds, therefore, water moves from buccal cavity over the gills to opercular cavity along the pressure gradient. After 0.3 seconds, the buccal cavity expands and lowers the pressure, causing the water to enter the mouth but at the same time the opercular valves close to prevent entry of water.

(ii) How does the fish increase buccal cavity pressure?

The mouth closes, the floor of buccal cavity is raised and the buccal cavity pressure increases.

SECTION A QUESTION (40 MARKS)

The figure below shows the pressure changes in the buccal and opercular cavities of a teleost fish obtained by using hypodermic tubing connected to a pressure recorder. Negative pressure indicates expansion while positive pressures mean contraction of the cavities.



The table below summarizes the features of gills in three species of teleost fish A, B and C.

Fish Species	Thickness of lamellae / µm	Distance between lamellae /µm	Distance between blood and surrounding water / µm
A	35	75	6
B	15	40	3
C	5	20	1

Describe the pressure changes in the buccal cavity for the first 0.5 seconds. *(10 marks)*
Compare the pressure changes in the buccal cavity and opercular cavity in the first 0.4 seconds. *(06 marks)*
(i) Explain the observed changes in the buccal cavity and opercular cavity from 0.2 seconds to 0.6 seconds. *(06 marks)*
(ii) What is the physiological significance of the differences between the pressure in the buccal and opercular cavities? *(02 marks)*
(i) Comment on the relationship of the thickness of the lamellae and distance between blood and surrounding water. *(02 marks)*
(ii) Explain the significance of the features of the gills in the table in gas exchange. *(04 marks)*
State other structure features of the teleost fish which are important in breathing and gas exchange. *(06 marks)* Blood in the lamellae of the teleost fish flows in opposite direction to that of water. Comment on the efficiency of this mechanism in gas exchange. *(04 marks)*

(a) Comparison of pressure changes in buccal cavity and opercular cavity for the first 0.4 seconds (8 marks) ***Similarities (4 mks)*** *Both*;

- Increase from 0 second to 0.15 second and from 0.3 second to 0.4 second;
- Have positive pressure from 0.1 second to 0.2 second;
- Have negative pressure from 0.25 second to 0.4 second;
- Are equivalent at 0.2 second and 0.25 second;

Differences (don't put in table)– 4 MARKS

From 0 second to 0.1 second, opercular cavity pressure is negative **while** buccal cavity pressure is positive;
From 0 second to 0.1 second, opercular cavity pressure increases rapidly **while** buccal cavity pressure increases slowly;
From 0.1 second to 0.15 second, opercular cavity pressure increases slowly **while** buccal cavity pressure increases rapidly;
From 0.15 second to 0.2 second, opercular cavity pressure increases **while** buccal cavity pressure decreases;
From 0.25 second to 0.3 second, opercular cavity pressure decreases **while** buccal cavity pressure increases;
The maximum buccal cavity positive pressure is **higher** than the maximum opercular cavity positive pressure;
The minimum buccal cavity negative pressure is **lower** than the minimum opercular cavity negative pressure;

(b) Account for the observed changes in pressure in the buccal and opercular cavities from 0.2 seconds to 0.6 seconds (14 marks)

From 0.1 second to 0.25 second, opercular valves are open while mouth valve is closed;
From 0.1 second to 0.15 second, the buccal cavity expands, the pressure decreases below atmospheric pressure (acquires negative pressure)**;** mouth valve opens and water enters from outside.
From 0.25 second to 0.4 second mouth valve is open while opercular valves close; opercular cavity expands, pressure reduces below atmospheric pressure (acquires negative pressure); Pressure in opercular cavity decreases below that of buccal cavity which has begun to contract, resulting in water being sucked into opercular cavity from buccal cavity;
At 0.4 second, floor of buccal cavity is elevated to reduce buccal cavity volume as buccal cavity pressure rises above atmospheric pressure (acquires positive pressure); mouth valve closes and water is forced from buccal cavity to opercular cavity;
At 0.45 second, opercular cavity contracts to reduce opercular volume and increase opercular pressure above atmospheric pressure (acquires positive pressure)**;** opercular valve opens and water is expelled via operculum

(c) Physiological significance of the differences in pressure between opercular and buccal cavity pressure (6 marks)

The pressure in the buccal cavity is higher than that in the opercular cavity forces water to flow in one direction from the buccal cavity to the opercular cavity along the pressure gradient.

Expansion of opercular cavity lowers the pressure below that of buccal cavity, causing the water to flow over gills in the opercular cavity but at the same time the opercular valves close to prevent entry of water. The buccal cavity acts as a force pump while the opercular cavity as a suction pump.

(d) How lamellae thickness relates to fish's activities (7 marks)

Fish A is the **most sluggish/slow;** because has the thickest lamellae; which increases the diffusion distance for oxygen from blood capillaries into lamellae; reducing the rate of **aerobic respiration**; ATP energy is released **slowly** for muscle contraction;

Fish C is the **most active;** because has the **thinnest lamellae**; which offer **very short** diffusion distance for oxygen from blood capillaries into lamellae; enabling **very fast** rate of **aerobic respiration**; ATP energy is released fast for muscle contraction;

Fish B is **moderately fast;** because has **relatively thin lamellae**; which offer **moderately short diffusion** distance for oxygen from blood capillaries into lamellae; enabling moderately fast rate of **aerobic respiration**; ATP energy is moderately fast released for muscle contraction;

(e) Blood in the lamellae flows in opposite direction to that of water. Comment on the efficiency of this mechanism in gaseous exchange (5 marks)

(1) Enables blood of the gill lamellae to extract maximum oxygen from the water (80-90%) for the entire period the water flows across the gill filaments. Although dissolved oxygen levels in water drop as the water flows across the gill lamellae, the blood has lower levels; therefore a sustained diffusion gradient is maintained throughout.

Because, the gradient is always such that the water has more available oxygen than the blood, and oxygen diffusion continues to take place after the blood has acquired more than 50% of the water's oxygen content.

(2) Under conditions permitting adequate oxygen uptake, the counter-current fish uses low energy in respiration

b) GASEOUS EXCHANGE IN CARTILAGINOUS FISH

Examples of cartilaginous fish are sharks, rays and dog fish

They live in sea water and have no body operculum covering their gills and there skeleton is made up of cartilage.

VENTILATION MECHANISM IN CARTILAGINOUS FISH

Inspiration;

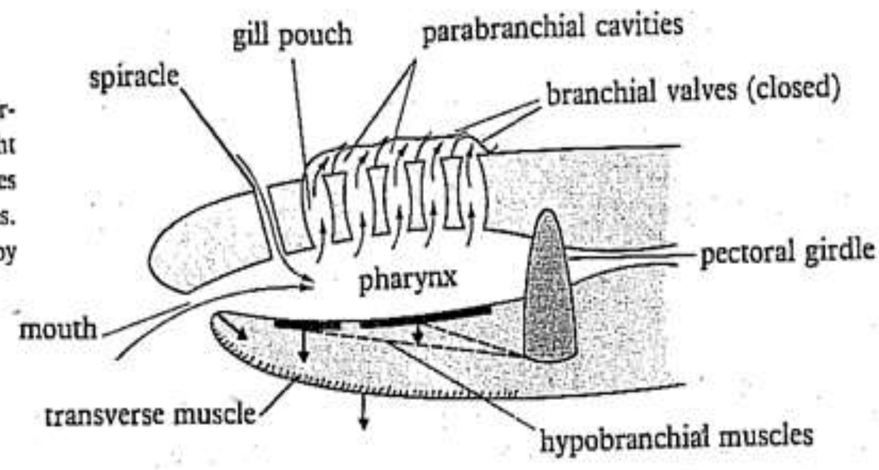
During this process, water is taken into the body through the mouth by;

Hyptobranchial muscles contracting causing the floor of the buccal cavity to be lowered.

The volume of the pharynx increases.

The pressure inside the pharynx and buccal cavity is lowered and this cause the opening of the bronchial valves and water will be the taken in. Water taken in blows around the gills and gaseous.

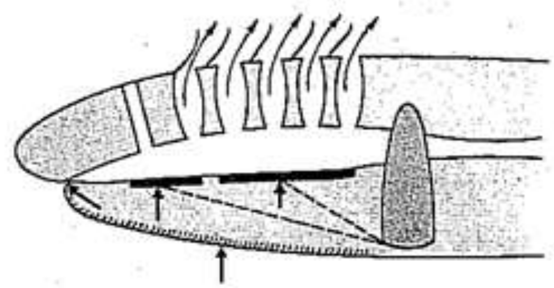
Water drawn into pharynx, by lowering floor of mouth cavity and pharynx, brought about by contraction of hypobranchial muscles accompanied by relaxation of transverse muscles. Then water drawn into parabranchial cavities by outward movement of branchial valves.



Expiration

When the buccal cavity is full of water, the mouth and the spiracles (nostrils) are closed and the floor of the buccal cavity and pharynx are raised. This raises pressure inside the pharynx which forces water to flow over the gill lamellae and later out of the body through the gill slits.

Water expelled from gill pouches by raising floor of mouth cavity and pharynx, brought about by relaxation of hypobranchial muscles and contraction of transverse muscles. In these schematic side views the gill pouches are shown in section at the top of the head though in reality they lie on either side. Water flow shown by fine arrows, movements of mouth and pharynx by thick arrows.



GASEOUS EXCHANGE IN GILLS OF CARTILAGINOUS FISH

After water has been taken through the mouth. It flows to the gills. Water flows parallel to the flow in the efferent bronchial vessels i.e. water and blood flow side by side in the same direction and at the same speed. This is termed as parallel flow. There are five pairs of gills which lie either sides of the pharynx; the gills on each side are arranged in a row of five gills slits which open from the pharynx to the extort at right angles.

Each gill is composed of a cartilaginous wall called the bronchial arch which supports a series of sheet-like-structures called lamellae. Each lamella has vertical foils called gill plates which increase the surface area further. The free end of each gill is a septum which is elongated forming a bronchial valve which is useful during the ventilation activity.

MECHANISM OF GAS EXCHANGE AND WATER FLOW OVER THE GILLS

When water passes over the gill lamellae and gill plates diffusion of gases takes place between water and blood capillaries of the gills.

Deoxygenated blood enters the gill capillaries through Afferent branchial vessels while oxygenated blood flows through the efferent branchial vessels.

In Bony fish gaseous exchange is efficient due to counter current flow of water and blood in the capillaries.ie. the flow of water and blood is in opposite direction.

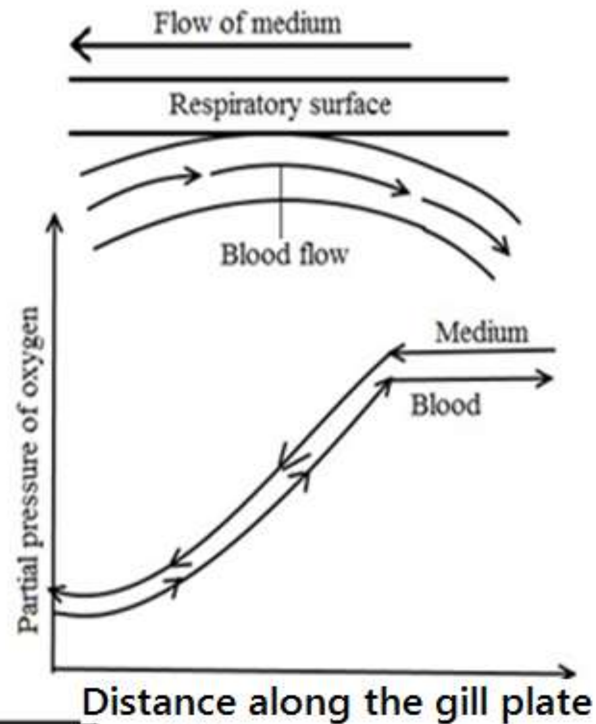
a) Countercurrent flow

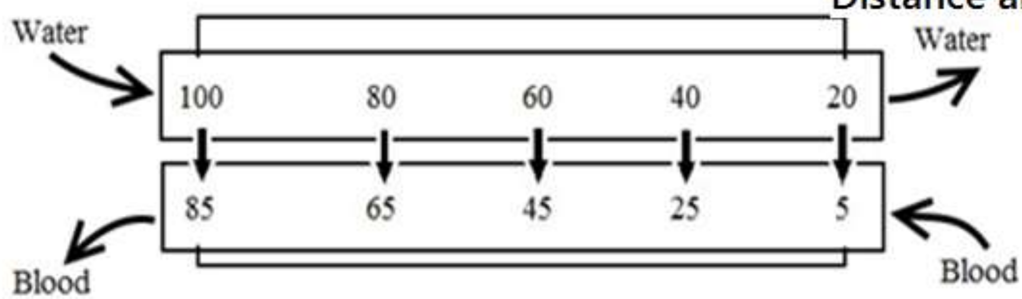
- Water flows across the gill lamellae in an opposite direction to the blood flow, enabling much of the oxygen (80-90%) from the water diffusing into the blood.
- Although dissolved oxygen levels in water drop as the water flows across the gill lamellae, the blood has lower levels; therefore a sustained diffusion gradient is maintained throughout.
- Countercurrent flow maintains high O_2 gradient between water and blood, such that O_2 diffusion into blood occurs even after blood acquires more than 50% of the water's O_2 content.

Advantages of counter flow

(1) Enables blood of the gill lamellae to extract maximum oxygen from the water for the entire period the water flows across the gill filaments.

(2) Under conditions permitting adequate oxygen uptake, the counter-current fish expends less energy in respiration compared to parallel flow.





The counter flow system ensures maximum gaseous exchange takes place. As blood flows through the gills, it meets water with a higher oxygen concentration as it extracts oxygen from it.by diffusion. The same steep diffusion gradient is maintained throughout the respiratory surface.

Counter flow is also observed in;

1.Exchange of materials in the loop of Henle (countercurrent multiplier flow).

2.Exchange of materials in the placenta.

3.Heat exchange between limb blood vessels of endotherms in cold region eg Arctic regions. (countercurrent heat exchange)

b**) Parallel flow/Concurrent flow**.

In cartilaginous fish like sharks, rays, skate, dog fish and others; the system is parallel flow. i.e. blood in the capillaries flow in the same direction with water.

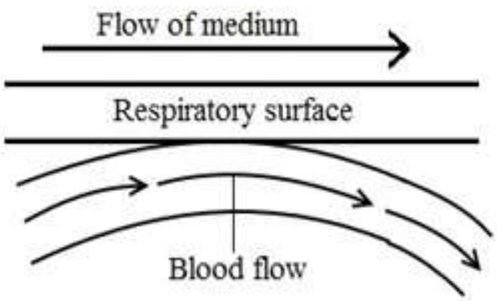
The rate of diffusion of gases is always higher at the beginning due to the fact that;

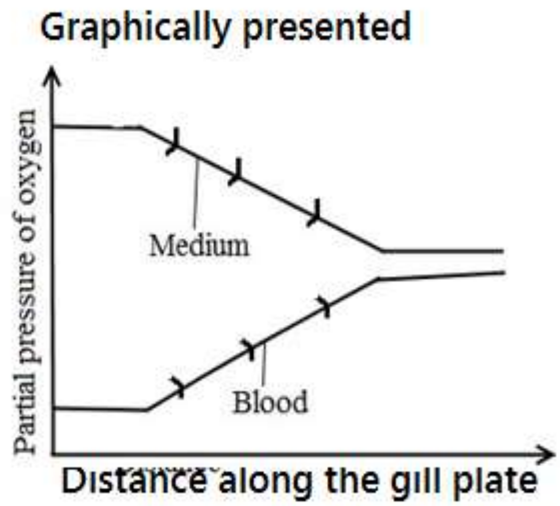
The concentration gradient between the respiratory surface and respiratory medium is very steep. As blood moves out of the gills, it will reach an equilibrium with water in percentage of oxygen concentration. However, blood will leave the gills at a point below its maximum saturation with oxygen.

There the parallel flow system in not efficient in exchange of gases. Organisms that have parallel flow system are generally less active compared to the ones with counter flow system.

The system can be improved by; Increasing the speed of blood flow which maximize oxygen uptake. By;

- ➢ The fish swimming fast in slow moving water or slow in fast flowing water.
- ➢ The fish swimming against the direction of water flow.

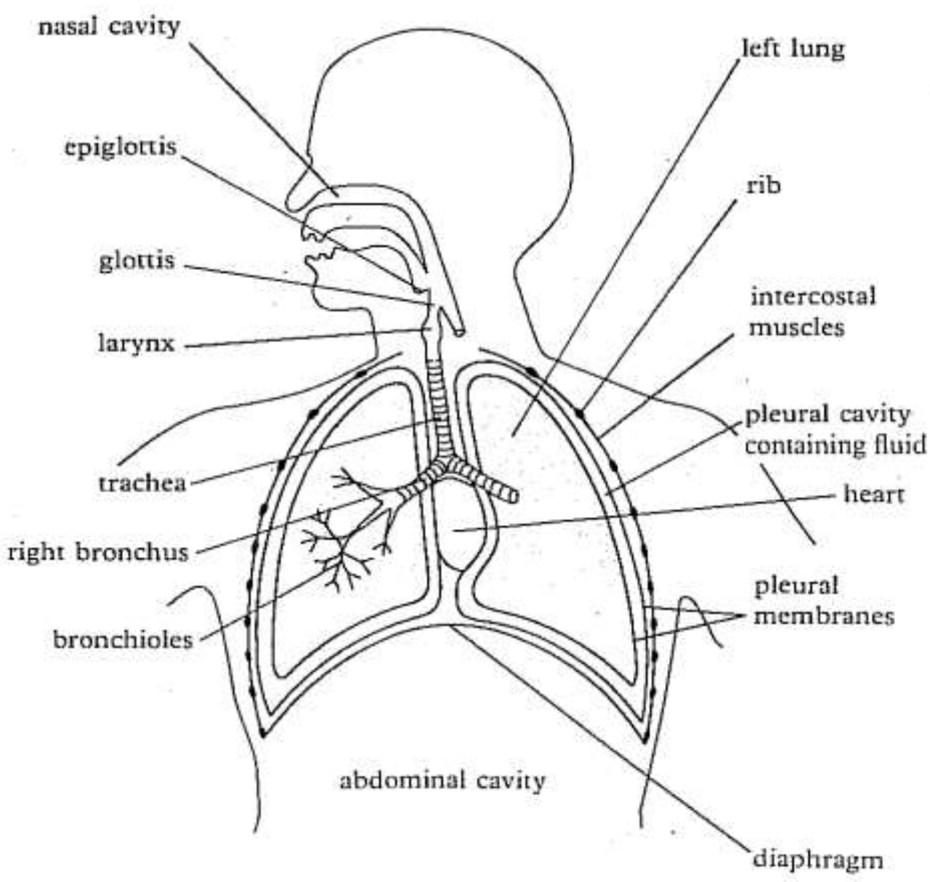




4.GAS EXCHANGE IN MAMMALS

Mammals is the lungs as respiratory organ. The respiratory system in mammals including man is located into the thoracic region. It consists of two lungs, bronchi, bronchioles and alveoli.

Respiratory tract and associated structures



Tubes in and from the lungs to outside;

1.TRACHEA

This is a tube running from the pharynx to the lungs and carries air from the pharynx to the lungs. The trachea is made up of a C-shaped cartilage linked wall to prevent it from being blocked or collapsing, every time the neck is bent during leaving movement. The wall of the trachea is also lined with cilia and mucus. The mucus traps the germs and dust while the cilia remove them from the trachea back to the pharynx by beating rhythmically.

2.BRONCHUS

The trachea divides into two to give rise to two bronchi each leading into respective lung. The bronchi also have C-shaped ring of cartilage to keep them permanently open without being blocked. The bronchis divide again to form mass of very fine branches of tubes called bronchiole.

3. BRONCHIOLES

These terminate into numerous branches of tubes called alveolar ducts which are also further sub-divide into smaller tubes known as atria. Atria contain many bubbles like sacs called air sacs which are also referred to as alveoli. An alveolus is the major structure where gaseous exchange occurs.

LUNGS

They;

(1) are spongy and elastic - are capable of expanding and contracting

(2) consist of air sacs and the alveoli

(3) have blood vessels that are the branches of the pulmonary artery and veins

(4) each is enclosed by two membranes called the outer and the inner pleural membrane. The membranes enclose a space called the **pleural cavity** that contains a **fluid that lubricates** free lung movement**.**

Alveolar ducts and alveolar sacs: lack cartilage, are non-ciliated and lack goblet cells. There is connective tissue with elastic and collagen fibres

Alveoli: lack cartilage, are non-ciliated and lack goblet cells. Epithelium is **squamous** (thin flattened cells) with **liquid surfactant** on **inner surface** and blood capillaries on **outer surface.**

LUNG SURFACTANT

Lung surfactant is a detergent-like substance formed by type II alveolar cells, which adsorbs to the air-water interface of alveoli with the hydrophilic head groups in the water and the hydrophobic tails facing towards the air.

FUNCTIONS OF LUNG SURFACTANT

(1) It greatly reduces alveolar surface tension, increasing compliance allowing the lung to inflate much more easily, thereby reducing the effort needed to breath in air.

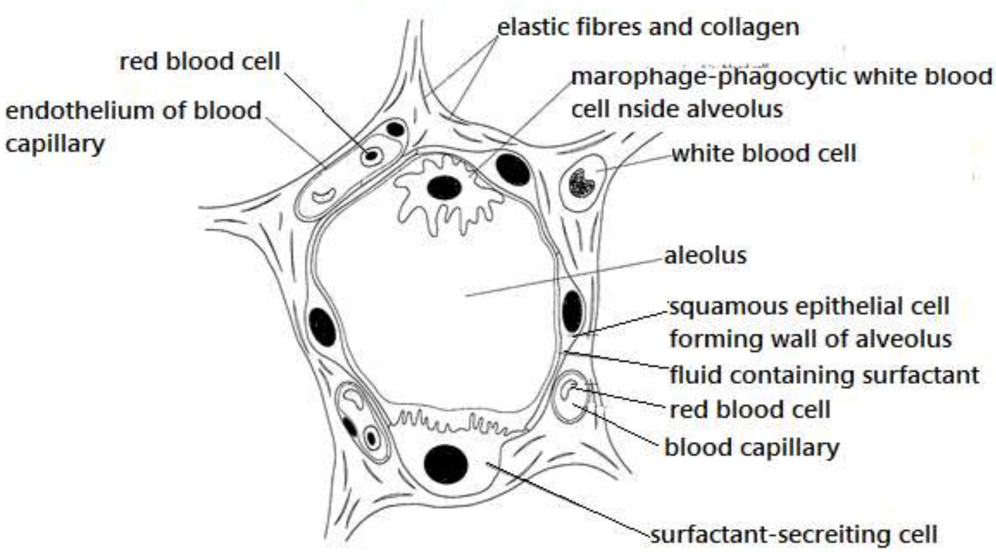
NB: Compliance is the ability of lungs and thorax to expand.

(2) It speeds up the diffusion of oxygen and carbon dioxide between the air and the liquid lining the alveoli.

(3) It kills bacteria that reach the alveoli

(4) It lowers pressure when the radius is small, and therefore stabilizes the alveoli to prevent collapse.

Cross-section through an alveolus showing structures between the alveoli



MECHANISM OF VENTILATION IN MAN

Breathing refers to the muscular movement of some body parts that result in air containing oxygen entering the body and elimination of waste gases from the body.

Breathing takes place into two phases namely

- Inspiration (inhalation)
- Expiration / exhalation

INSPIRATION:

Inhalation is an **active** process brought about by several muscles. ***The inspiratory muscles*** (major muscles which cause active increase in lung volume) include: **(1)** Diaphragm **(2)** external intercostals

•The external intercostal muscles contract while the inner intercostal relax at the same time causing the rib cage to move upwards and outwards.

•Diaphragm muscles contract and flatten / move downwards.

•These movements increase the volume of the thoracic cavity; and lung volume.

•Alveolar lung pressure decreases below atmospheric pressure causing air to rush into lungs through the nostrils, into nasal passages, pharynx, larynx, trachea, main bronchi, bronchioles, alveolar ducts, and into alveoli.

•Air dissolves in the moisture lining the alveolar epithelium, oxygen then diffuses into blood capillaries while carbon dioxide diffuses from blood capillaries into alveolar air along the concentration gradients.

EXPIRATION:

Exhalation in mammals is mainly **passive**, although some muscles are involved. ***The expiratory muscles*** (major muscles which cause active decrease in lung volume) include: **(1)** Abdominal rectus **(2)** internal intercostals

•Internal intercostal muscles contract while external intercostals muscles relax causing the rib cage to move downwards and inwards.

•Diaphragm muscles relax to move upwards / assume its dome shape.

•The volume of thoracic cavity and lungs decreases; causing increased lung pressure above atmospheric pressure.

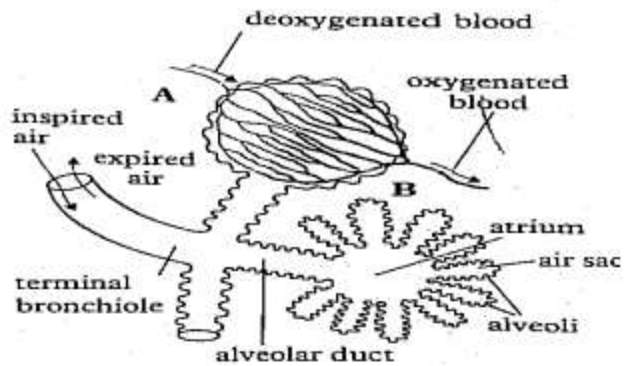
Carbon dioxide-**rich air** but with **low oxygen** is then forced out of the lungs

Gaseous exchange across the alveolus:

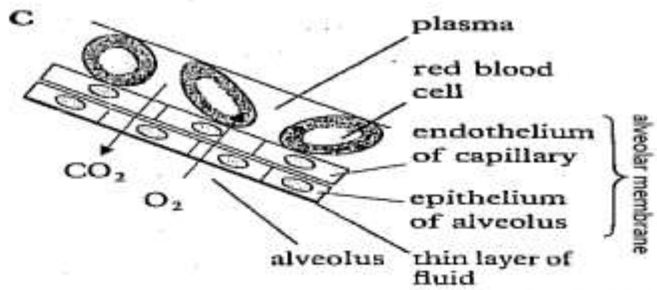
This occurs across the alveoli which are made up of the squamous epithelium and some elastic collagen fibres. The alveoli are surrounded by numerous blood capillaries which are extremely narrow. Blood flows through this capillary slowly, allowing more time for diffusion to occur and increasing the surface area of the red blood cells attached in the endothelium of the capillaries.

This facilitates the diffusion of oxygen into the red blood cells. The oxygen is inspired air diffuses across the alveolar epithelium and the endothelium of the capillaries and finally into the red blood cells.

Inside the red blood cells, the oxygen combines with the respiratory pigment called haemoglobin to form oxy-haemoglobin. Normally, the carbon dioxide diffuses from the alveolus through the alveolar epithelium then leave the lungs in expired air.



The bronchioles in the mammalian lung terminate as cavities across whose much folded and highly vascularized walls gas exchange takes place (**A**). The principal site of gas exchange are the numerous alveoli shown in **B**.



The alveoli are separated from the bloodstream by a very thin alveolar membrane consisting of only two layers of pavement epithelial cells shown schematically in **C**. The alveolar epithelium is covered with a very thin layer of fluid in which the oxygen dissolves before it diffuses through the cells. If this fluid had a normal surface tension it would pull the alveolar walls inwards, making it difficult to expand the lungs and possibly causing the alveoli to collapse. However, the fluid contains a 'surfactant', a detergent-like lipoprotein which reduces the surface tension and prevents this happening.

TERMS DESCRIBING LUNG VOLUMES AND LUNG CAPACITIES

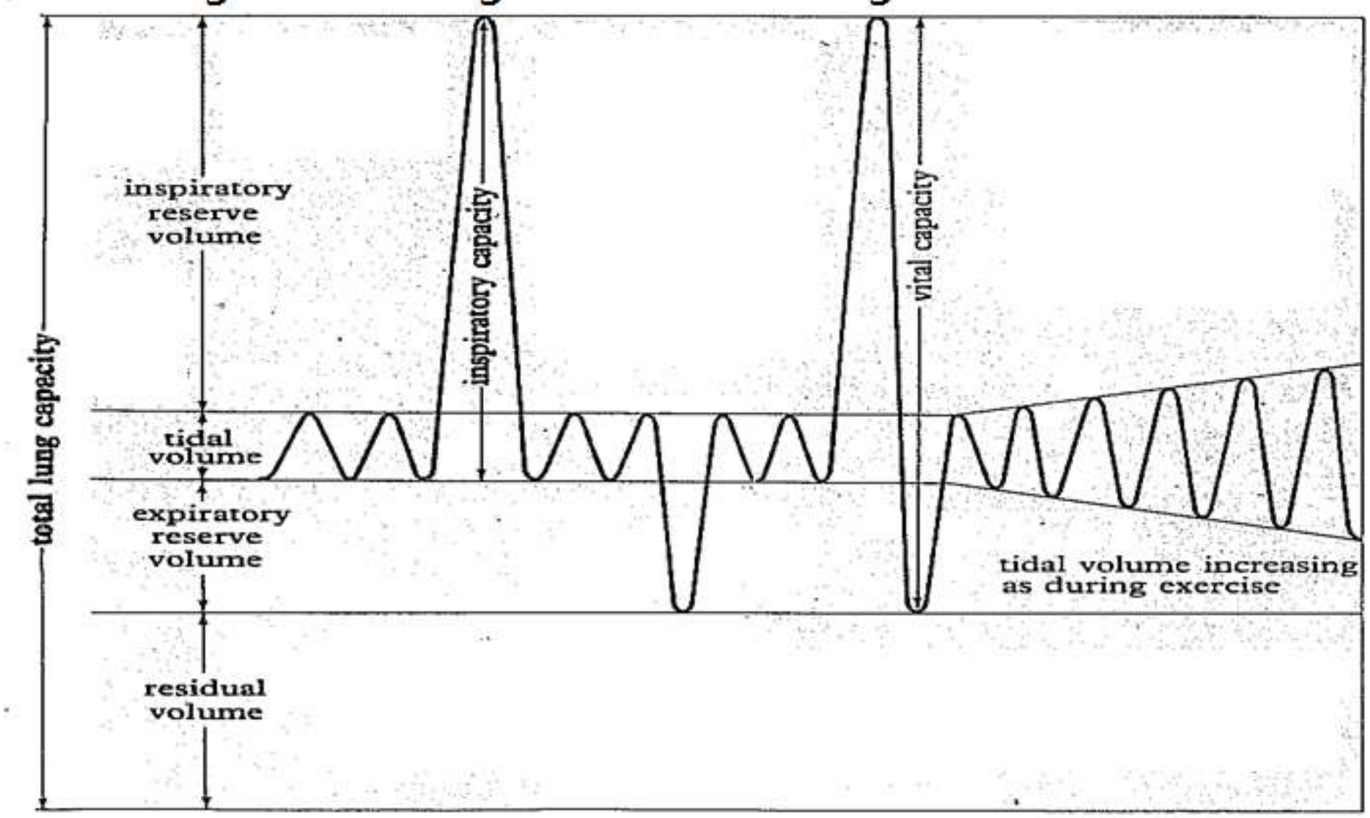
1.Total lung capacity; The volume of air contained in the lung at the end of maximal inspiration. The total volume of the lung.
2.Vital capacity; The amount of air that can be forced out of the lungs after a maximal inspiration.
3.Tidal volume; Volume of air normally breathed in when the body is at rest.
4.Residual volume; The amount of air left in the lungs after a maximal exhalation can't be expired
Expiratory reserve volume; The amount of additional air that can be pushed out after the end expiratory level of normal breathing.
5.Inspiratory capacity ; The maximal volume that can be inspired following a normal expiration.
6.Alveolar dead space The volume of inspired air that is not used for gas exchange as a result of reaching alveoli with no blood supply
7.Anatomical dead space; Space within the airways that does not permit gas exchange with blood.

VENTILATION RATE

Ventilation (Breathing rate): The number of breaths taken in one minute. This is normally 12 – 20 breaths in a healthy adult.
Pulmonary ventilation(PV) is expressed as dm3min-1
Pulmonary ventilation (dm3 min-1) = tidal volume (dm3) x ventilation rate (min-1)
also
Ventilation rate/breathing rate = total volume x number of breath per minute
The ventilation changes with the prevailing circumstances e.g. during muscular exercise. Both the frequency and depths of p breathe increases and these results into high-ventilation rate.
The maximum amount of air taken into the lungs after a deep breath is called the inspiratory reserve volume and thus volume is about 3L of air which is over and above the tidal volume.
Extra amount of air expelled out of the lungs of the end of normal expiration is called the expiratory reserve volume.
The total amount of air that can be expired after a maximum inspiration i.e.
(inspiratory reserve volume + tidal volume + expiratory reserve volume.
The vital capacity varies from one person to another and it normally ranges from 45ltrs but in a fit athlete, it may be more than that.
There is a certain amount of air which remains in the lungs even after maximum expiration. This volume of air is called the residual volume and it's approximately 1.5ltrs.

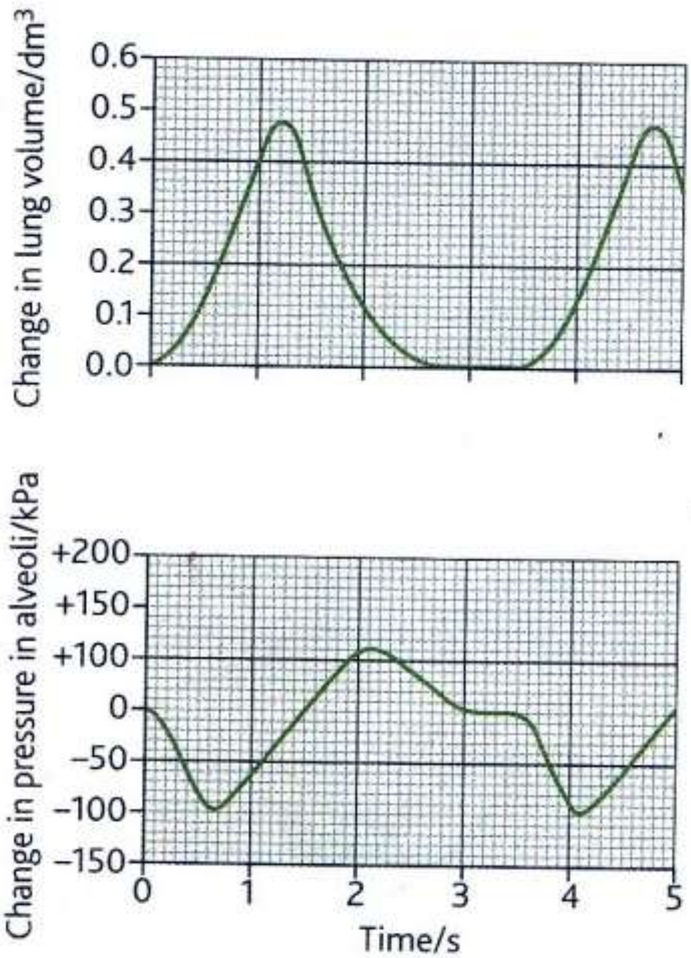
Although gaseous exchange takes place across the alveoli, it doesn't occur in other parts of the respiratory system such as the trachea, bronchi and bronchioles. Such areas or spaces are referred to as dead spaces.

Diagram showing the different lung volumes in man



Exam Question

Graphs below show volume and pressure changes that occur in the lungs of a person during breathing while at rest.



(a) From the graphs:

(i) Determine the tidal volume of this person **From the graph of change in lung volume, the highest volume of air taken in peaks at 0.48dm^3 Therefore, tidal volume of the person was 0.48dm^3** (ii) Work out the rate of breathing per minute. **The duration of one breath is the interval of time between two successive corresponding peaks on the volume graph = 4.7 seconds – 1.2 seconds**

= 3.5 seconds

The number of breaths in a minute (60 seconds) is therefore <u>60 seconds</u>

3.5 seconds

= 17.14 breaths per minute

(b) If the volume of air in the lungs when this person inhaled was 3000cm^3, work out the volume of air in the lungs after the person had exhaled?

3000cm^3 = 3.0dm^3

From the graph, exhaled volume

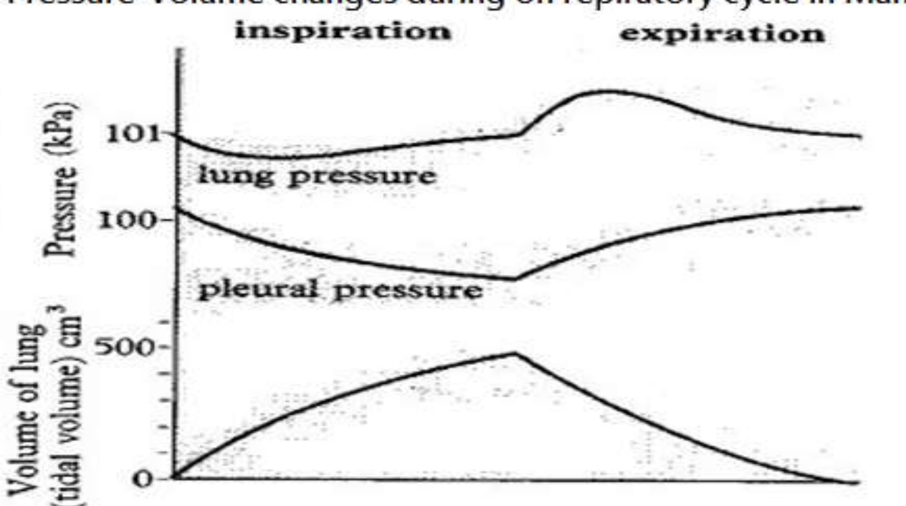
= **0.48dm^3 less than the maximum inhaled volume.**

The exhaled volume is therefore

3.0 - 0.48 = 2.52dm^3 (OR 2520cm^2)

(c) Explain how muscles create the change of pressure in the alveoli over the period 0 to 0.5 seconds **Diaphragm muscles contract to flatten it; external intercostal muscles contract to move the rib cage upwards and outwards; thoracic cavity volume increases while alveolar pressure decreases below atmospheric pressure.**

Pressure-Volume changes during on repiratory cycle in Man

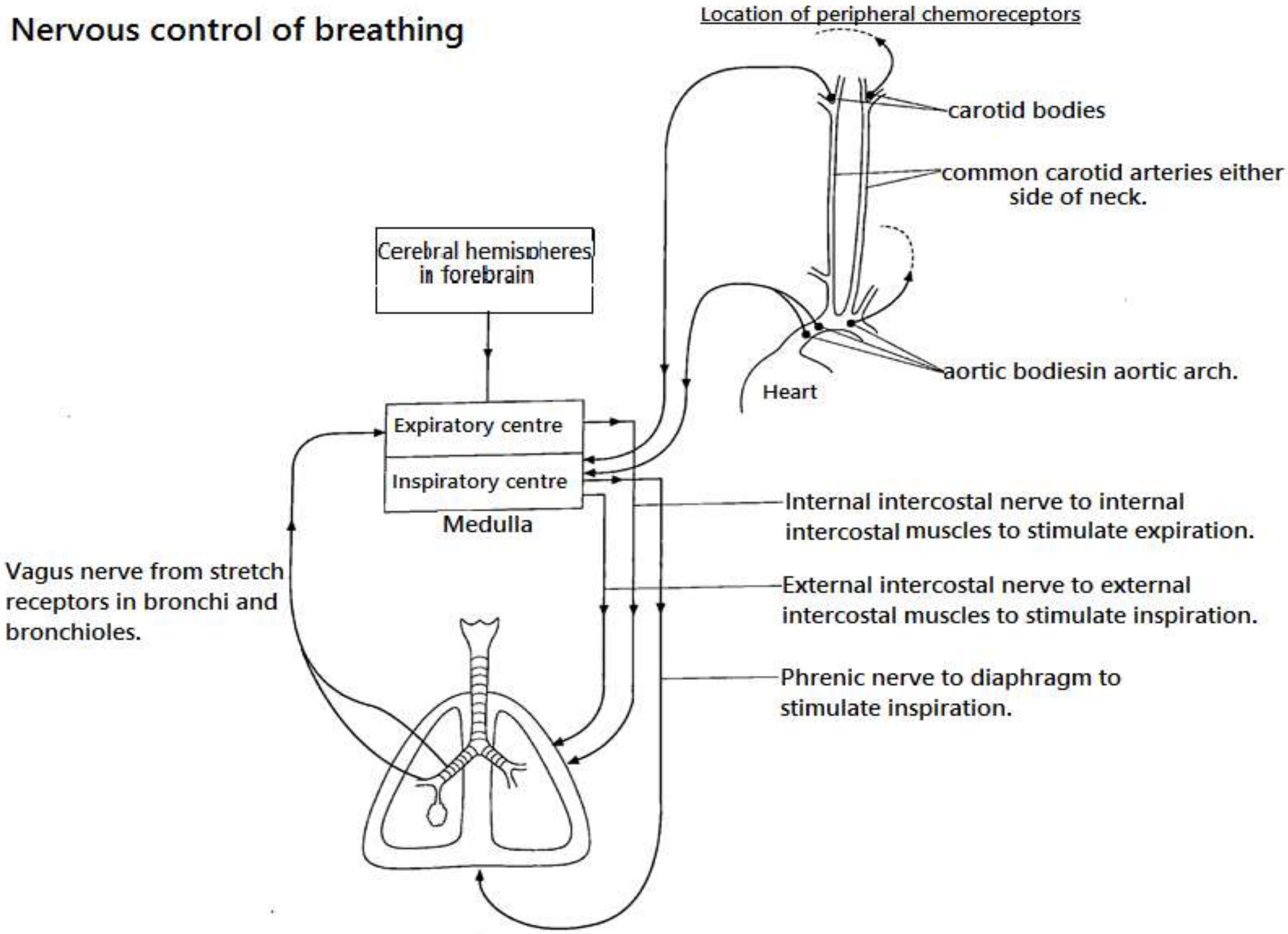


CONTROL OF VENTILATION IN MAN

Question: Describe the mechanism of gas exchange in man

Nervous Control on the rate of Breathing/Ventilation in man

Control of the breathing rate is clearly an involuntary process and like many involuntary processes (such as heart rate, coughing and sneezing) it is controlled by a region of the brain called the **medulla**. The region of the medulla that controls breathing is called the **respiratory center**. It receives inputs from various receptors around the body and sends output through two nerves to the muscles around the lungs.



The respiratory centre depends on information relayed via chemoreceptors that pick up changes in:

i) Carbon dioxide concentration – levels in the blood go up when the rate of respiration increases and more carbon dioxide is produced as a waste product.

ii) Oxygen concentration – levels in the blood go down as it is used in respiration to produce extra ATP as an energy source for exercise.

The chemoreceptors are stimulated by a rise in carbon dioxide levels and a fall in pH and oxygen in the blood. The respiratory centre received the information as a nerve impulse from the chemoreceptors and uses this to regulate breathing.

Summary

1. Respiring tissues release CO_2 from aerobic respiration which is transported to lungs in three different ways:

a. As dissolved CO_2 in plasma.
b. As carbamino compound bound to haemoglobin in RBCs; -As bicarbonate ions HCO_3^- and H^+ from Red Blood Cells.

$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$

2. HCO_3^- ions in pulmonary capillaries react with hydrogen ions (H^+) to form carbonic acid (H_2CO_3);
3. Carbonic acid dissociates into water (H_2O) and carbon dioxide gas (CO_2); which diffuse into alveoli;
4. Increased H^+ (acidity) stimulates central chemoreceptors in the medulla oblongata while Increased blood CO_2 stimulates peripheral chemoreceptors in carotid and aortic bodies to send impulses via glossopharyngeal nerve and vagus nerve respectively to the inspiratory centre in medulla oblongata;
5. Inspiratory centre sends impulses via phrenic nerve to the diaphragm and intercostal nerves to the intercostal muscles;
6. Diaphragm and external intercostal muscles contract to increase thoracic volume while thoracic pressure decreases below atmospheric pressure;
7. Air rushes to inflate lungs and stimulate stretch receptors in lung walls, which send impulses via the vagus nerve to expiratory centre in medulla oblongata;
8. Inspiratory centre is inhibited / switched off, causing relaxation of external intercostal muscles and diaphragm;
9. Thoracic volume decreases while thoracic pressure increases above atmospheric pressure, forcing lungs to deflate and expel air rich in carbon dioxide;

How the respiratory centre control ventilation

Muscles that cause breathing need nerve impulses from the brain for each breath. The respiratory centre transmits regular nerve impulses to the diaphragm and intercostal muscles to cause inhalation. Stretch receptors in the alveoli and bronchioles detect inhalation and send inhibitory signals to the respiratory centre to cause exhalation. This negative feedback system in continuous and prevents damage to the lungs.

One difference between ventilation and heartbeat is that ventilation is also under voluntary control from the cortex, the voluntary part of the brain. This allows holding of breath or blow out air, but it can be overruled by the autonomic system in the event of danger. For example, if breath is held for a long time, the carbon dioxide concentration in the blood increases so much that the respiratory centre forces you to gasp and take a breath. Pearl divers hyperventilate before diving to lower the carbon dioxide concentration in their blood, so that it takes longer to build up.

During sleep there is so little cellular respiration taking place that it is possible to stop breathing for a while, but the respiratory centre starts it up again as the carbon dioxide concentration increases (blood pH lowers). It is possible that one cause of deaths may be an underdeveloped respiratory centre in young babies, which allows breathing to slow down or stop for too long.

EFFECT OF OXYGEN VARIATION

Breathing air with low Oxygen	**Breathing air with excess Oxygen (Hyperoxia)**
Under conditions of low oxygen levels, e.g. at higher altitude, the partial pressure of oxygen in arterial blood drops significantly from about 100 mm Hg to about 60 mm Hg. Chemoreceptors in carotid and aortic bodies are stimulated to send impulses to the inhalation centre of the medulla, causing increased breathing rate. As more air is drawn into the alveoli, oxygen diffuses into alveolar capillaries until breathing returns to normal.	It is dangerous to breath air with pure O2 because blood's ability to carry it away oxygen is exceeded, causing binding of free O2 to surface proteins of lungs, interfering with the operation of the central nervous system and also attacking the retina; all of which can be toxic / poisonous. Prolonged exposure to above-normal oxygen partial pressures, or shorter exposures to very high partial pressures, can cause: (i) Oxidative damage to cell membranes, (ii) Collapse of the alveoli in the lungs, (iii) Retinal detachment, and seizures.

The medulla oblongata has a group of cells that control the ventilation rate and blood flow. These groups of cells form centers i.e. the medulla has a centres that help in the control of carbon dioxide in the body.
These centres are;

1.Respiratory centre.

2.Caudal vascular centres.

•An increase in carbon dioxide partial pressure stimulates the sensory cells within the aortic and carotid bodies to send impulses through the afferent nerves to the respiratory centres

•They respond by sending impulses to the breathing apparatus (lungs) so as to increase the rate and depth of breathing. It results in more carbon dioxide in blood to be removed the rough breathing out hence raising the blood PH.

•An increase in carbon dioxide level stimulates the carotid body to generate impulses which are carried by the afferent nerves to the cordial vascular centre of the medulla.

•The cardiac vascular centre to the arteries causing them to constrict. This results in increased blood pressure and therefore increased cardiac output.

•An increase in blood pressure results in rapid transport of carbon dioxide to the lungs. Accumulation of carbon dioxide in muscles and other organs has a direct effect of causing arterioles to dialled increasing blood flow to these body parts this process is termed as vasodilatation.

The carotid sinus which is an enlarged portion of the internal carotid artery plays an important role in controlling of blood pressure. It has stretch as a result of increased blood pressure in arteries.

Once stimulated, they transmit impulses through the afferent nerves to the cardiovascular centres. Once impulses react, it generates impulses which decrease the cardiac output and cause dilation of the blood vessels. This helps in lowering pressure.

However, respiratory and cardio vascular centres of the medulla oblongata can be influenced by impulses generate from the celeberum i.e. higher centres of the brain e.g. we can all speed up or slow down our rate of breathing consciously because the higher centres of the brain exerts either.

REGULATION OF CARBON DIOXIDE IN THE BODY

•The human body requires a certain amount of oxygen for normal function depending on the level of activities.

•The body is subjected to if the amount of oxygen in blood is low. Its means the amount of carbon dioxide in high and a deficiency of oxygen in the body is termed as hypoxia.

•In man hypoxia results into impureness of the brain and other special senses particularly vision. This results in sudden unconsciousness and paralysis due to damage of nerve cells followed by death.

•In case of excess oxygen breathed at pressures more than atmospheric pressures e.g. when diving tissues metabolism very rapidly to keep up with pace of oxygen supply. As oxygen accumulates in the body it inhibits certain enzymes controlling the Kerb cycle hence interfering with cellular expiration. This is normally followed by dizziness, nausea, impaired hearing and vision, breathing difficulties, confusion, convulsions, death.

•Increase in carbon dioxide in the body may be due to anaerobic respiration, since carbon dioxide is acidic in body. It lowers the PH and these interfere with the Krebs cycle. An increase or decrease in carbon dioxide levels is detected by chemical receptors which are found either in the aorta, carotid arterioles and medulla oblongata.

•Chemo receptors found in the walls of the aorta close to the heart are called the aortic body and those found between the internal and external carotid arteries and its side of the neck are called the carotid bodies.

•Chemo receptors found in the medulla are very sensitive to changes in the level of carbon dioxide and changes in blood pH.

EFFECT OF ALTITUDE ON BREATHING

At high altitudes (e.g. mountains), there is low atmospheric pressure and therefore a low partial pressure of oxygen while at lower altitudes (e.g. deep sea), atmospheric pressure is high.

Rapid ascent of high heights causes mountain sickness while diving into deeper water causes difficulties in breathing.

Altitude Sickness (Mountain Sickness): An illness that develops when the rate of ascent into higher altitudes outpaces the body's ability to adjust to low partial pressure of oxygen.

Altitude sickness generally develops at elevations higher than 8,000 feet (about 2,400 meters) above sea level and when the rate of ascent exceeds 1,000 feet (300 meters) per day.

Symptoms: Fatigue, Headache, Dizziness, Insomnia (sleeplessness), Shortness of breath during exertion, Nausea, decreased appetite, Swelling of extremities, Social withdrawal.

Effects of changes in altitude can be avoided by **acclimatization**; Which is a period / time during which the body physiologically and physically adjusts to changes in partial pressure of oxygen.

1. At a higher altitude there is a lower partial pressure of oxygen than sea level this causes increase in the amount of carbon dioxide in the body increasing the rate of breathing.
2.However, organisms that do live permanently at higher altitudes have increased number of red blood cells to increase on the carbon dioxide carrying.
3.The organs also have a higher ventilation rate and cardiac output compared to animals at the sea level.
4.Certain animals e.g. those that live in water like the seals, a whale, can survive in a long period of oxygen desperation.
5.During this state, there is a sudden decrease in the cardiac output, a condition known as **brandy cardiac.**

Adjustments to minimize altitude sickness

(i) Increased number of red blood cells

(ii) Increased haemoglobin content

(iii) Increased ventilation rate

(iv) Increased cardiac frequency

ADAPTATIONS OF DIVING ANIMALS

(i) Oxygen carriage by having greater blood volume e.g. man's blood is about 7% of body weight while in diving marine mammals it is about 15% of the body weight.

(ii) Enlarge blood vessels to work as reservoirs of oxygenated blood.

(iii) High concentration of myoglobin

(iv) Slower heart beat to conserve use of oxygen

(v) Reduction of blood supply to organs and tissues tolerant to oxygen deficiency e.g. digestive system, muscles, etc (vi) Compression of air spaces to reduce unnecessary body bends e.g. lungs, middle ear, etc.

(vii) Higher proportion of red blood cells

(viii) Respiratory centers do not function automatically to cause breathing at a certain concentration of CO_2

EXPLAIN THE FOLLOWING OBSERVATIONS

1. A person who is born and lives at sea level will develop a slightly smaller lung capacity than a person who spends their life at a high altitude.

This is because the partial pressure of oxygen is lower at higher altitude which, as a result means that oxygen less readily diffuses into the bloodstream. In response to higher altitude, the body's diffusing capacity increases in order to process more air.

GASEOUS EXCHANGE IN PLANTS

In plants, different structures (roots, stems, leaves, flowers, fruits) care for their own gas exchange needs; therefore, the medium of gas exchange varies depending on environmental location of each plant part.

Plants respire all the time, but photosynthesis only occurs when there is light. This means that **the net gas exchange** from a leaf depends on the light intensity.

$$C_6H_{12}O_6 + 6O2 \rightarrow 6CO_2 + 6H_2O \text{ (aerobic respiration)}$$

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \text{ (photosynthesis)}$$

NET GAS EXCHANGE IN PLANTS

The net (overall) effect depends on the time of day and the light intensity.

In darkness no photosynthesis occurs, hence in the absence of photosynthesis there is **a net release of carbon dioxide and a net uptake of oxygen**.

In bright light during the day, the rate of photosynthesis is much higher than the rate of respiration hence there is a **net release of oxygen and a net uptake of carbon dioxide**

In Dim light during **early morning** and **evening**, photosynthesis greatly decreases hence the release of oxygen also decreases while respiration occurs normally hence the release of carbon dioxide increases causing c**ompensation point.**

What is compensation point? The light intensity at which the photosynthetic intake of carbon dioxide is equal to the respiratory output of carbon dioxide.

WHY MOST PLANTS LACK SPECIALIZED ORGANS FOR GAS EXCHANGE

(i) Each plant part takes care of its own gas exchange needs without dependence on a liquid transport system.

(ii) Roots, stems, and leaves respire at rates much slower than occurs in animals. Only during photosynthesis are large volumes of gases exchanged, and each leaf is well adapted to take care of its own needs.

(iii) The diffusion distance for gases is very short, even in a large plant because each living cell in the plant is located close to the surface. In stems, middle placed cells are dead while the only living cells are organized in thin layers just beneath the bark.

(iv) The loose packing of parenchyma cells in leaves, stems, and roots provides an interconnecting system of air spaces which exposes one surface of most of the living cells in a plant to air.

(v) Both the cell walls and plasma membranes are permeable to oxygen and carbon dioxide, enabling diffusion of the gases across. Carbon dioxide diffusion may be aided by **aquaporin** channels inserted in the plasma membrane.

WHY MOST ANIMALS HAVE SPECIALIZED RESPIRATORY SYSTEMS

(i) Animal bodies are large with a small surface area to volume ratio, which limits the efficiency of diffusion alone in supplying oxygen and exit of carbon dioxide.

(ii) Outermost integuments of most parts on animal bodies are impermeable to respiratory gases.

(iii) Animal bodies are active therefore depend on fast metabolic rates to supply metabolites, which necessitates fast mechanisms for supplying oxygen and disposal of carbon dioxide.

(iv) Animal tissues are thickened layers of cells, for which diffusion alone would be ineffective.

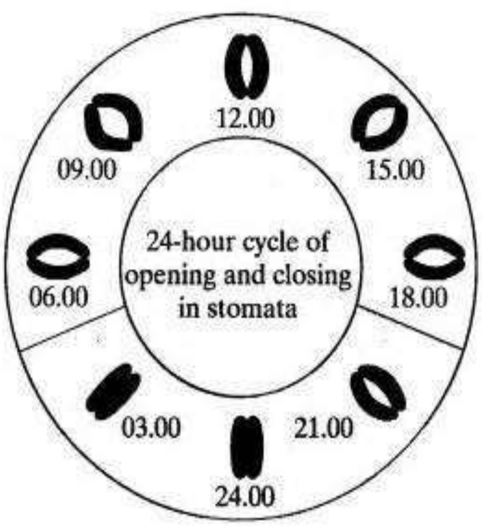
HOW AIR ENTERS THE PLANT BODY

Structure	**Explanatory notes**
Lenticels	Pores in woody plants that form between the atmosphere and the cambium layer of stems and trunks.
Stomata	Typically found in epidermis of leaves, but can occur on herbaceous stems. Stomata open and close by guard cells, regulated by CO_2 and moisture.

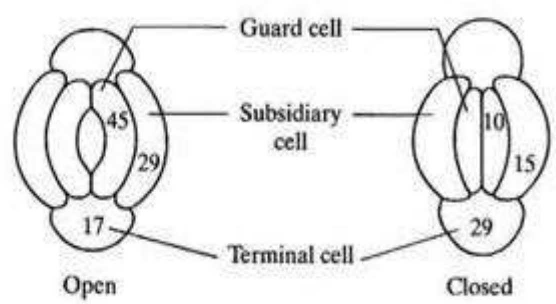
GAS EXCHANGE IN LEAVES

The exchange of oxygen and carbon dioxide in the leaf occurs through **stomata** (singular = stoma).

STOMATAL CYCLE

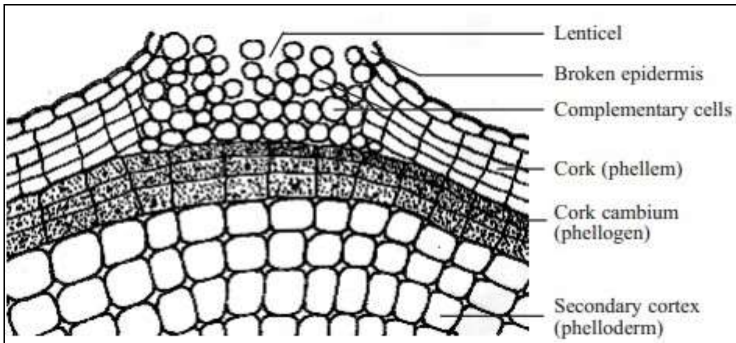


Stomatal aperture remains tightly closed from midnight to 3am, after which there is slight opening by 6am. Stomatal aperture then gradually opens up until becoming maximally wide at 9am, narrow by 12 noon, widely open by 3pm, and then progressively decreases through 6pm, 9pm until becoming tightly closed by midnight.



NOTE:
The numbers represent solute concentration in cells.

GASEOUS EXCHANGE IN PLANT ROOTS AND STEMS



ROLE OF OXYGEN IN PLANTS

(i) Facilitates aerobic respiration to release ATP for active transport (ii) Decreases toxicity of reduced compounds (e.g. sulfides).
(iii) Supports nitrification and methane oxidation. (iv) Precipitates metals in soil

The medium of gas exchange for roots and stems of land plants is air.

For mature roots, dissolved oxygen from soil air diffuses through the loosely attached dead cork cells where there are non-suberized pores called **lenticels**. On reaching inner tissues, O_2 diffuses across the permeable cell walls and plasma membranes of living cells into the protoplasm while CO_2 diffuses from cells into intercellular spaces, then through lenticels into soil air.

For mature stems, atmospheric oxygen diffuses through lenticels to dissolve in the moisture of intercellular spaces of inner tissues, then diffuses across the permeable cell walls and cell membranes of living cells into the protoplasm while carbon dioxide diffuses from cells into intercellular spaces to atmosphere.

EXPERIMENTS ON GAS EXCHANGE EXPERIMENT

Five small discs cut from spinach leaves were floated on a small volume of buffered hydrogen carbonate solution in a flask attached to a respirometer. The discs were first exposed to bright light, then to dim light and finally left in the dark. Oxygen release was recorded as positive values and oxygen uptake as negative values as given in the table.

Light intensity	Time interval in minutes	Oxygen uptake or release in mm^3
Bright light	0 – 3 3 – 6 6 – 9 9 – 12	+57 +64 +58 +60
Dim light	12 – 15 15 – 18	+16 +3
Dark	18 – 21 21 – 24 24 – 27 27 – 30	-16 -12 -15 -14

(a) Present the data in a suitable graphical form

(b) (i) Calculate the mean rate of oxygen release in bright light

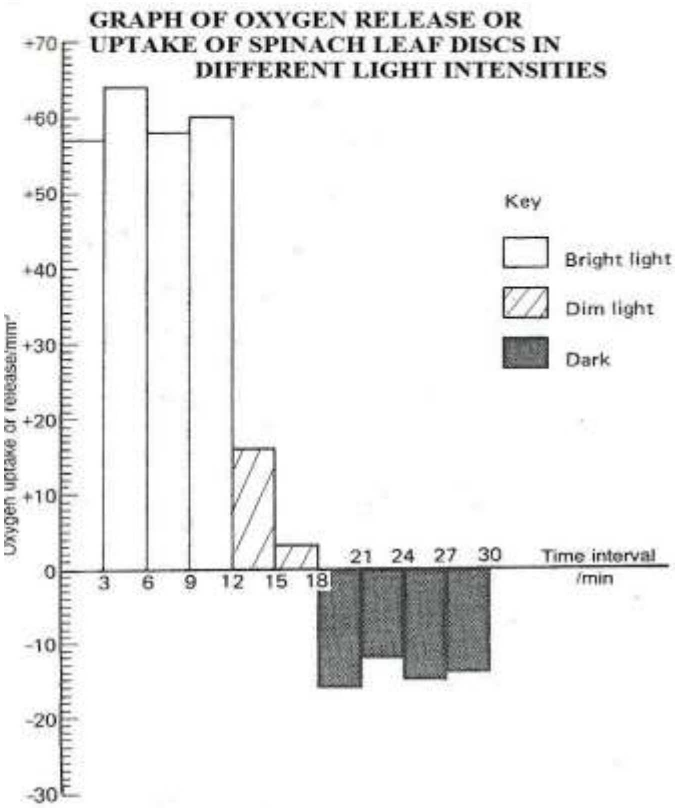
(ii) Explain the significance of the results obtained from this experiment.

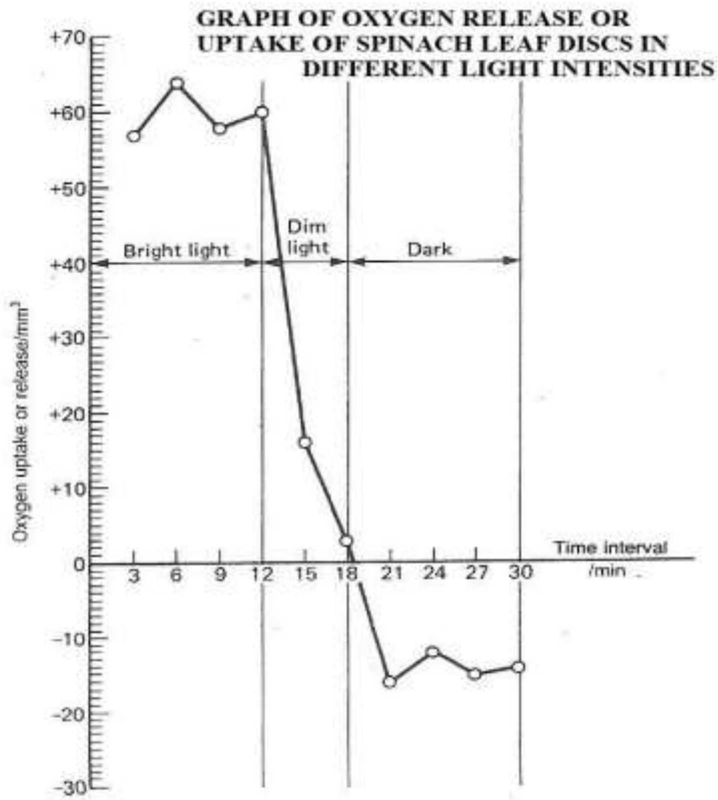
(c) Explain the use of the following in the experiment above: (i) Five small leaf discs, not one. (ii) Hydrogen carbonate solution (iii) Buffered hydrogen carbonate

Malavy H.

SUGGESTED ANSWERS

(a)





(b) (i) Total oxygen released = 57 + 64 + 58 + 60 = 239 mm^3

Total period of oxygen release = 12 minutes

Rate = $\frac{239}{12}$ = 19.9 mm^{3}min^{-1} **OR** 19.9 mm^3/min **OR** 19.9 mm^3 per minute

(ii)

Observations / Description	**Explanation**
In bright light, rate of oxygen release is rapid and relatively constant.	Oxygen release is a measure of photosynthesis. In bright light photosynthesis is rapid hence releasing oxygen rapidly. The constancy in oxygen release is because some factor other than light intensity is limiting photosynthesis (e.g. carbon dioxide concentration), hence additional light has no further effect.
In darkness, rate of oxygen uptake is slow and relatively constant.	Oxygen uptake is a measure of respiration. In darkness, photosynthesis is inhibited while respiration occurs. The slow uptake of oxygen is because plant leaves respire slowly since energy demands are low. The constancy in oxygen uptake is because of factors limiting respiration.

In dim light, rate of oxygen release decreases rapidly.	In dim light intensity limits photosynthesis and therefore reduction in light intensity produces a great decrease in the rate of photosynthesis. At about 18.5 minutes represents **compensation point** which represents the light intensity at which the oxygen the oxygen released in photosynthesis is exactly counterbalanced by that taken up in respiration**.**

(c)

(i)

-To minimise errors in the experiment which may be caused by deficiencies in one leaf disc.

-Oxygen released would be very low to be detected.

(ii) To increase on / provide carbon dioxide to the photosynthesizing leaf discs.

(iii) To maintain PH so as to avoid inhibiting the activity of photosynthetic and respiratory enzymes.

END