# GASEOUS EXCHANGE IN MAMMALS (MAN)

❖ Gaseous exchange in man, like all other mammals occurs in lungs.

Lungs are a pair of delicate, compact and highly elastic organs located in the thoracic cavity. The thoracic cavity is outlined by the wall of the thorax and the diaphragm (separates thoracic cavity from abdominal cavity)

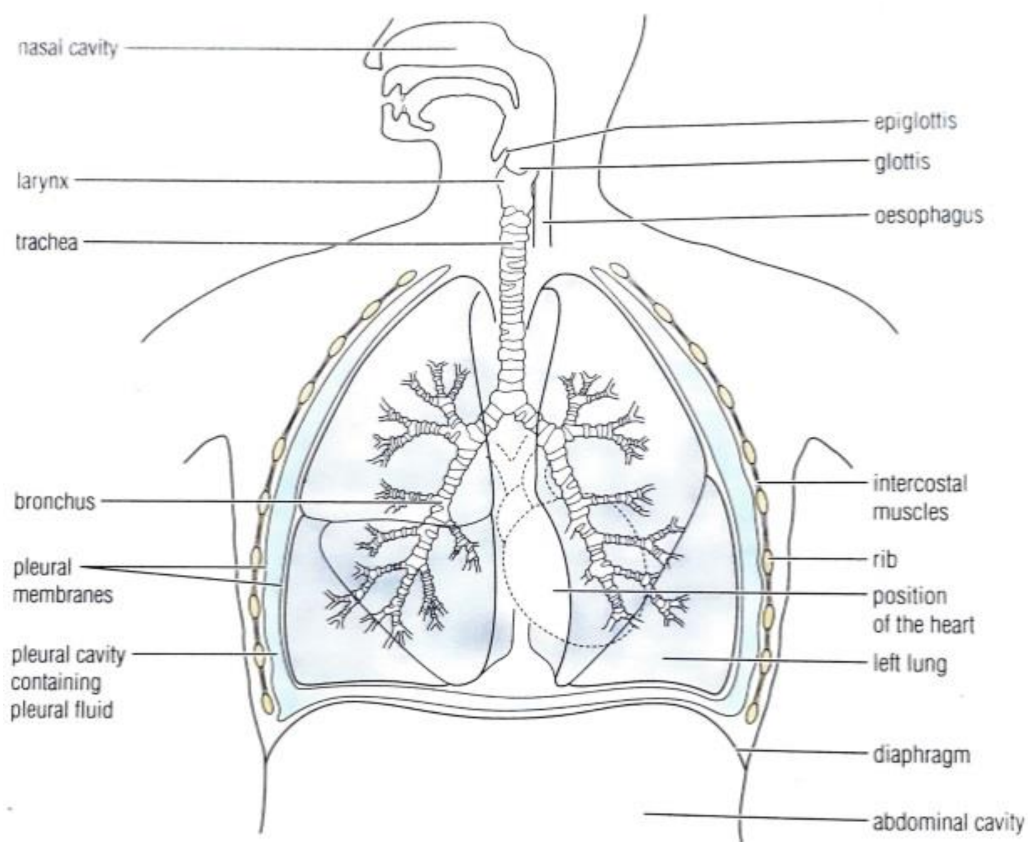
❖ Lungs are enclosed in a pair of pleural membranes between which is a pleural fluid for lubrication.

❖ Protecting the structures in the thorax is a rib cage which consists of twelve pairs of ribs. Each pair of ribs articulates with the thoracic vertebra. The first ten pairs of ribs are joined by cartilage to the sternum while the last two pairs of ribs articulate with the tenth pair.

❖ Between ribs are intercostal muscles whose contractions and relaxation move the rib cage.

❖ A system of tubes enables air flow from the atmosphere to lungs. In succession, the tubes consist of the trachea, bronchi and the bronchioles which channel air to the alveoli. The **alveoli** in the lungs are the **sites for gaseous exchange.**

**Structure of gaseous exchange system of man**



### *VENTILATION OF THE LUNGS*

- Air flow in and out of the lungs is a result of pressure changes. The pressure changes are due to changes in volume of the thorax. The volume of the thorax changes as a result of movements of the rib cage and the diaphragm.
- Air flow in a mammal is tidal i.e. air enters and leaves the lungs along the same route and as such lungs always contain residual air that cannot be expelled.

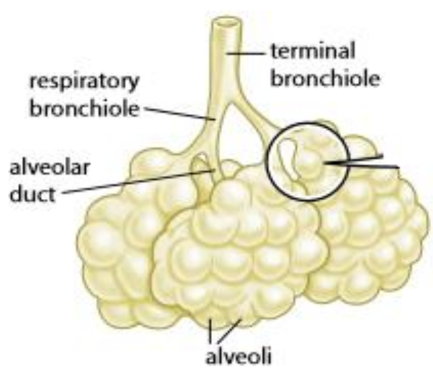
#### *Inhalation*

- **Contraction** of the **external intercostal muscles** with **internal intercostal muscles relaxed** together with the **contraction of the diaphragm** result into <u>increased volume</u> in the thorax and a <u>reduction in pressure below atmospheric pressure</u>
- Air flows in through the nostrils (and mouth) passing through the glottis, larynx and into the trachea.
- The trachea is kept open and prevented from collapsing even when air pressure in the thorax is low due to presence of horizontally placed C shaped cartilages along the whole length of trachea wall.
- Air from trachea moves into the bronchi, bronchioles and into the alveoli.

#### *Exhalation*

- Internal intercostal muscles contract, the external intercostal muscles and diaphragm muscles relax, diaphragm regains its dome shape.
- Volume in the thorax reduces and the pressure increases above atmospheric pressure.
- This forces air out of the lungs through bronchioles, bronchi, trachea, larynx, glottis and out through the nostrils.

The bulk of lungs consists of millions of microscopic air sacs or alveoli in grape like clusters with a combined surface area of about $100m^2$. The alveoli are the actual sites of gaseous exchange in mammals.



**Structure of the alveoli**

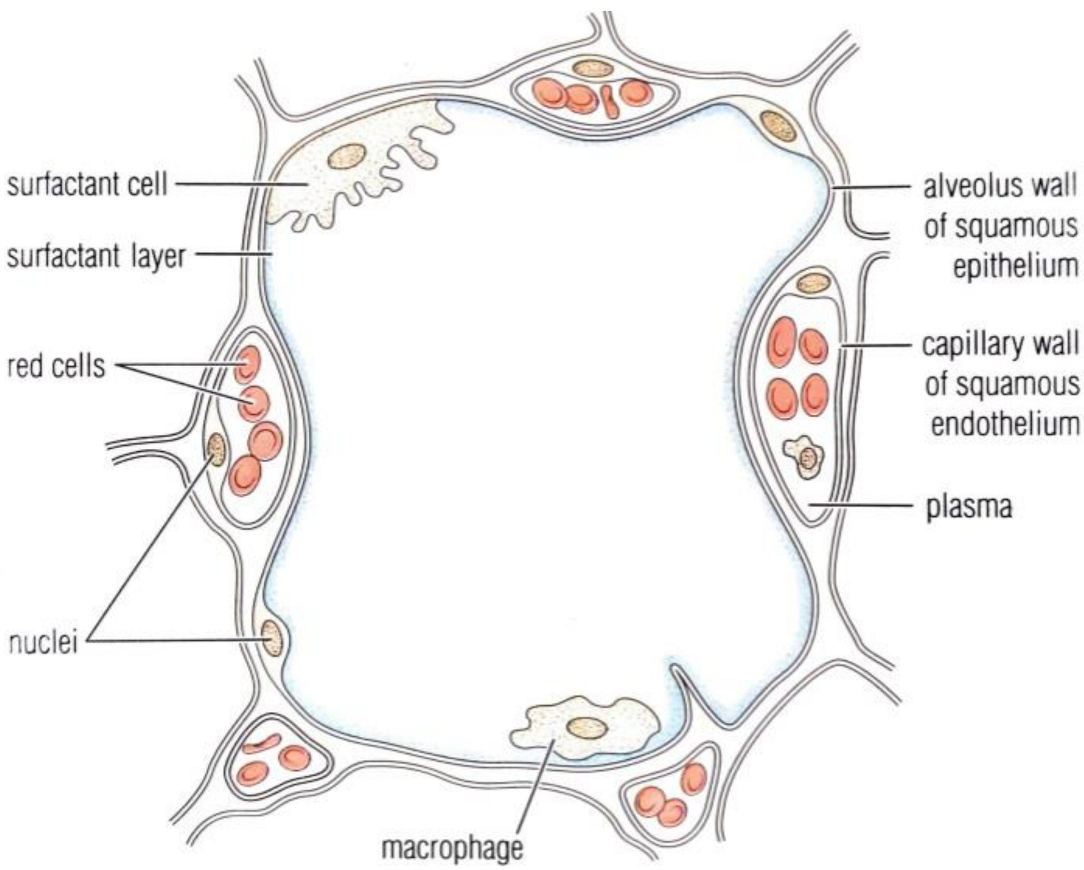
- An alveolus is a minute sac like structure with a narrow diameter consisting of some collagen fibres to make them tough and resist tear when stretched and elastic fibres to ease stretching when filled with air and to easily spring back during exhalation.

- Alveoli walls consist of squamous epithelium which is extremely thin to reduce diffusion distance.

- Alveoli walls secrete a surfactant which reduces the surface tension of the fluid that coats their surface. This prevents alveoli from collapsing especially when pressure in the thorax is low.

- Alveoli are surrounded by network of blood capillaries delivering blood from the pulmonary artery. Alveoli are ultimately drained by the pulmonary vein.

***Illustration of Structure of the alveoli***




<u>*Process of gaseous exchange in the alveoli*</u>

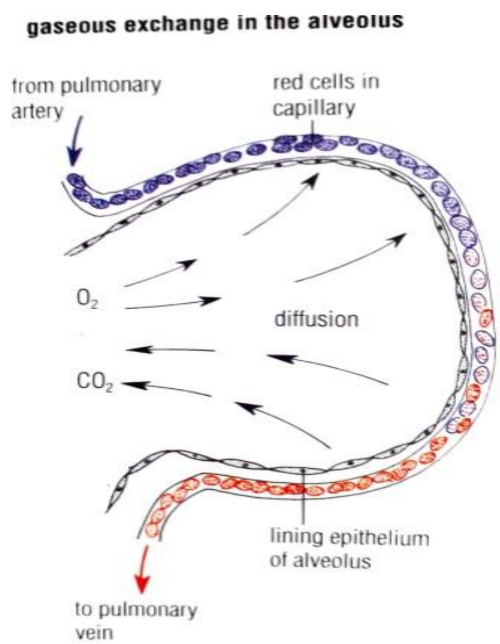
- ✓ Oxygen from inspired air dissolves in the fluid on the surface of alveoli epithelium.

- ✓ Dissolved oxygen diffuses across the epithelial cells of alveoli and capillary endothelial cells into the blood plasma.

- ✓ In the plasma, oxygen diffuses into erythrocytes and combines with haemoglobin to form oxyhaemoglobin.

- ✓ Carbon dioxide from the red blood cells and plasma diffuse into the alveoli.
- ✓ Blood capillaries are narrow, only just wide enough for red blood cells to squeeze through, exposing a large surface of the cells for oxygen to diffuse into. Blood passes through these capillaries at a slow rate. This allows adequate time for oxygen to diffuse and combine with haemoglobin and for carbon dioxide to diffuse out of blood.

**Illustration**






The table below shows percentage composition of inspired, alveolar and expired air

| *AIR* | INSPIRED AIR | ALVEOLAR AIR | EXPIRED AIR |
|---|---|---|---|
| *OXYGEN* | 20.95 | 13.80 | 16.40 |
| *CARBON DIOXIDE* | 0.04 | 5.50 | 4.00 |
| *NITROGEN* | 79.01 | 80.70 | 79.60 |

**NB:** Though present, composition of water vapour is not included because it keeps varying in inspired air depending on humidity.

Percentage composition of water vapour in expired air is normally higher than that of inspired air because aerobic respiration yields water which is expelled as vapour.

EXPLANATIONS TO OBSERVATIONS IN THE TABLE ABOVE

| OBSERVATION | EXPLANATION |
|---|---|
| 1. Inspired air contains higher oxygen percentage than expired air | Inspired air from atmosphere contains more oxygen from plants released during photosynthesis. Once in blood, oxygen is transported away and diffuses into tissues |
| 2. Exhaled air contains higher percentage of carbon dioxide than inspired air | Carbon dioxide from tissue respiration diffuses into blood, from blood, diffuses into alveolar air and expelled in expired air |

| | |
|---|---|
| 3. Percentage of nitrogen is higher in expired air than inspired air | Nitrogen not used in cell respiration. Increase in expired air is due to reduction in percentage of oxygen in expired air |
| 4. Percentage of Oxygen in alveolar air is intermediate of inspired and expired air | Oxygen diffuses across epithelium into blood in capillaries. fresh air with high oxygen mixes with air that remains in the alveoli, thus reducing percentage of oxygen |
| 5. Percentage of carbon dioxide highest in alveolar air | Lowest percentage of oxygen in alveolar air as it diffuses into blood capillaries as more carbon dioxide diffuses from blood into alveoli air |



**Control of breathing**

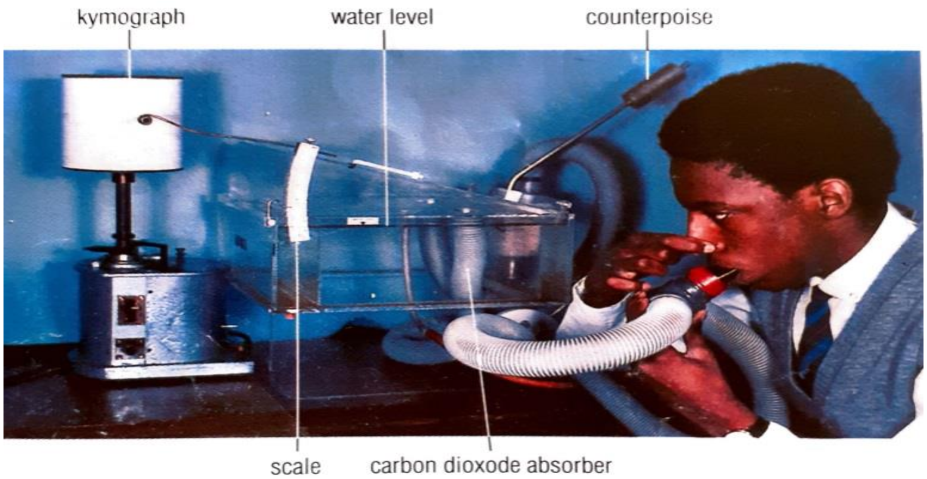
- Breathing movements occur by intrinsic rhythm of contractions and relaxations and is controlled automatically by the respiratory centre in medulla oblongata, found in the hind brain. The respiratory centre consists of the inspiratory centre in the ventral portion, the rest being the expiratory centre.
- Chemoreceptors in the medulla, carotid and aortic bodies are sensitive to carbon dioxide concentration and to a lesser extent low oxygen concentrations.
- When the carbon dioxide concentration in blood increases, it is detected by receptors in the respiratory centre in the medulla, carotid bodies and aortic bodies resulting into generation of impulses.
- Impulses are sent to the inspiratory centre via a branch of the vagus nerve (afferent nerve).
- Impulses from the inspiratory centre are sent via the **phrenic** and **thoracic nerve** to the **diaphragm** and **external intercostal muscles respectively**. This results into increased rate of contraction and faster and deeper inspiration.
- As the lungs expand, their stretch receptors are stimulated and impulses are sent via the vagus nerve to the respiratory centre in the medulla. This automatically results into switching off of the inspiratory centre such that expiration occurs.
- The expiratory centre in turn becomes inactive such that inspiration can start again.
- Responses of the intercostal muscles and diaphragm can also be consciously overridden by impulses from the higher centres of the brain; this occurs during singing and talking.

**NOTE:** The control of breathing through monitoring carbon dioxide concentration is a homeostatic control mechanism involving negative feedback in which the level of carbon dioxide in blood triggers corrective mechanism

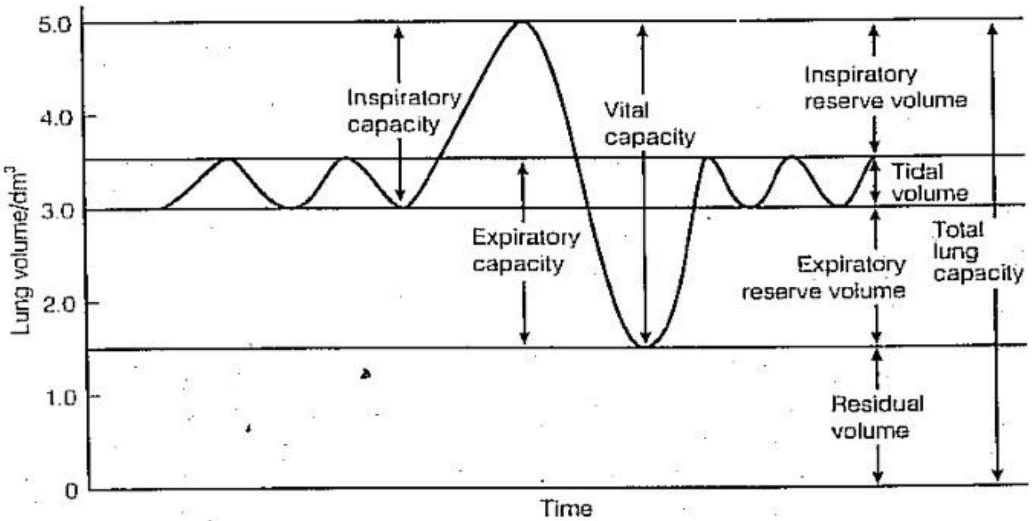
**Lung capacities;** this refers to the volume changes that occur in the lungs during ventilation.

- Lungs in adults have a total volume of about 5dm$^3$, however the air that is moved in and out of the lungs varies depending on the state of the body.
- Measurement of respiratory activity can be done using a spirometer which is attached to a kymograph to record all movements and in effect compare the different lung volumes

ILLUSTRATION of spirometer attached to kymograph **(NOT TO BE DRAWN)**




On the kymograph, the following is recorded, showing the different volumes recorded.




<u>**TERMS TO DESCRIBE LUNG VOLUMES AND CAPACITIES**</u>

- ***Tidal volume (TV)***; volume of air breathed in and out during normal rhythmical breathing. **TV** is normally about 10% of total lung capacity.
- ***Residual volume (RV)***; volume of air that remains in the lungs after maximum exhalation.
- ***Inspiratory reserve volume*** **(IRV)**; volume of air above tidal volume that can be breathed in during force inspiration (3dm$^3$)
- ***Expiratory reserve volume*** **(ERV)**; volume of air that can be breathed out after normal expiration (1.5dm$^3$)

- ***Vital capacity* (VC)**; this is the maximum volume of air that can be exhaled after a full inhalation.

$$VC=TV+IRV+ERV$$

- ***Inspiratory capacity* (IC)**; maximum amount of air that can be inspired.

$$IC = TV + IRV$$

- ***TOTAL LUNG CAPACITY* (TLC)**; volume of air contained in the lungs after maximal inspiration **or** maximum amount of air that can fill the lungs.

  Total lung capacity can also be described as the total volume of the lungs. It is about $5dm^3$ for an adult

$$TLC = TV + IRV + ERV + RV$$

$$TLC = IC + ERV + RV$$

$$TLC = VC + RV$$

- ***Dead space air***; this is air that is found in the air passages of the trachea, bronchi that is not exchanged.

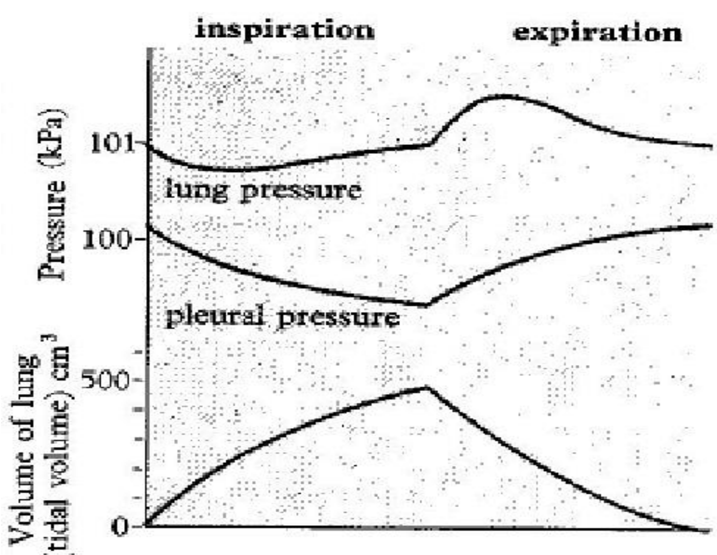


## VENTILATION RATE/ BREATHING RATE

- This refers to the number of breaths per minute. The breathing rate in a healthy adult is about 15 breaths per minute at rest
- Pulmonary ventilation; this describes the amount of air that is exchanged during breathing per minute and is expressed in $dm^3min^{-1}$

*Pulmonary ventilation* ($dm^3min^{-1}$) = *tidal volume* ($dm^3$) × *ventilation rate* ($min^{-1}$)

*The graph below shows the pressure and volume changes that occur during a single breathing cycle in man.*




**WORK OUT**

a) *Describe the relationship between;*
   (i) *Lung pressure and pleural pressure*
   (ii) *Lung pressure and lung volume.*

b) *Explain the relationship between;*
   (i) *Lung pressure and pleural pressure*
   (ii) *Lung pressure and lung volume.*

**Factors affecting rate of breathing in mammals**

- Carbon dioxide concentration in blood; higher $CO_2$ concentration results into increased rate of breathing than when $CO_2$ concentration is low in blood
- Oxygen concentration in blood; lower rate of breathing during high oxygen concentration, lower rate of breathing during high oxygen concentration in blood.
- pH of blood; rate of breathing higher when pH of blood is low than when pH is higher
- Temperature; increased sensitivity of chemoreceptors to pH
- Level of activity; rate of breathing increases when individual is engaged in activity to deliver required oxygen for aerobic respiration. At rest, rate of breathing is lower
- Age; rate of breathing higher in infants and lower in adults.
- Gender; generally higher rate of breathing in males than females
- Anxiety; results into increased rate of breathing.
- Smoking habit;
- Size; breathing rate higher in smaller animals than larger animals.
- Medicines



***EFFECT OF ALTITUDE ON VENTILATION***

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 to 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 above sea level and when the rate of ascent exceeds 1,000 feet (300 meters) per day.

***Symptoms:*** Fatigue, Headache, Dizziness, Insomnia (sleeplessness), Nausea, Decreased appetite, swelling of extremities like legs.

Effects of changes in altitude can be avoided by **acclimatization; (refer to work on transport in animals)**

**Quick work out;**

*Define acclimatization.*

*How is acclimatization different from adaptation?*

Adjustments to minimize altitude sickness

(i) Increased number of red blood cells

(ii) Increased haemoglobin content

(iii) Increased ventilation rate

(iv) Increased cardiac out put

(v) Increased cardiac frequency.

*ADAPTATIONS OF DIVING ANIMALS TO LOW OXYGEN ENVIRONMENTS*

(i) Increased 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 in muscles

(iv) Slower heart beat to conserve use of oxygen

(v) Reduction or shutting down blood supply to organs and tissues tolerant to oxygen deficiency e.g. digestive system, muscles with more blood channeled to brain, spinal cord, adrenal glands, eyes and placenta (when pregnant).

(vi) Higher proportion of red blood cells per $mm^3$ of blood.

(vii) Swimming with little muscular effort by gliding upward or downward by changing their buoyancy. This results into conservation of oxygen.

(viii) Carrying out anaerobic respiration to provide energy during prolonged periods of a dive when oxygen is depleted in muscles.

**Adjustments that occur in anticipation of and during an exercise**

- ✓ In anticipation of a race or exercise, impulses from the cerebral cortex stimulate increased heart beat such that cardiac frequency and cardiac output increase.
- ✓ There is general constriction of arterioles except for those serving vital organs. This ensures that blood at high pressure is diverted to active muscles
- ✓ There is an increase in ventilation rate
- ✓ Before and during the early stages of an exercise, the sympathetic nervous system is stimulated, adrenaline is released from the adrenal medulla into the blood stream
- ✓ During the exercise, metabolic rate increases, progressively, the number of ATP molecules available reduces.
- ✓ Reduction in number of ATP molecules relative to ADP molecules activates enzymes such that more glucose molecules are broken down and more ATP molecules are synthesized.

- ✓ Increased metabolic rate during exercise results into increased carbon dioxide buildup in muscle tissues, pH of blood lowers.
- ✓ This is detected by chemoreceptors in carotid and aortic bodies such that impulses are sent to the inspiratory centre resulting into increased ventilation rate
- ✓ Increased carbon dioxide levels in blood causes local dilation of surrounding arterioles such that more blood with oxygen is delivered to active muscle tissue
- ✓ Temperature in muscles increases such that more blood delivered as sensitivity to carbon dioxide levels in blood is increased
- ✓ Rapid movement of limbs stimulates stretch receptors in muscles and tendons. Impulses are sent to the respiratory centre in the medulla resulting in an increase in ventilation rate.
- ✓ Despite increased ventilation, the high metabolism in muscles is such that less oxygen than required is delivered. Muscles start to respire anaerobically such that more ATP molecules are synthesized.
- ✓ Anaerobic respiration results into accumulation of lactic acid
- ✓ Increased lactic acid concentration stimulates dilation of arterioles so that more oxygen can be delivered to tissues.
- ✓ Oxygen debt builds up and accounts for the increased ventilation rate after the exercise to deliver more oxygen to metabolize lactic acid in the liver during the Krebs cycle.



***Sample application questions***

- *State effects of inhaling little oxygen; **hypoxia** to an individual*

- ➢ Reduction in metabolism
- ➢ Increased anaerobic respiration leading to accumulation of lactic acid in tissues
- ➢ Misjudgment of situations
- ➢ Special senses like vision are impaired
- ➢ Unconsciousness
- ➢ paralysis
- ➢ Brain cells die and regions of brain become impaired
- ➢ Death

**Breathing pure oxygen at pressure higher than atmospheric**

Atmospheric oxygen is only 21% of air. Breathing in 100% oxygen at low pressure may not be a hazard, however, breathing in pure oxygen at pressure higher than atmospheric (hyperoxia) is dangerous as it causes **oxygen poisoning.**

This results from highly reactive oxygen particles which damage the epithelium of alveoli, hindering efficient gaseous exchange

***Describe the effects of breathing in pure oxygen at pressure higher than atmospheric pressure.***

- Increased metabolism in tissues to keep pace with oxygen uptake
- Further oxygen uptake inhibits enzymes in the Krebs cycle, thus interfering with cell respiration
- Damage to epithelium of alveoli
- Increased fluid in lungs
- Muscular twitching occurs. This is the initial sign of oxygen poisoning
- Nausea, dizziness
- impaired hearing
- impaired vision
- breathing difficulties
- Confusion
- Lack of body coordination
- Convulsions
- Death



## Diseases of the respiratory system

a) **Pulmonary tuberculosis (TB)**

This is an infectious disease that can affect any part of the body although usually manifests in the lungs as the first site of infection.
TB is caused by a rod shaped bacteria; *Mycobacterium tuberculosis.*

Symptoms

- Persistent cough
- Loss of appetite
- Weight loss
- tiredness

Tuberculosis can be treated.

b) **Pulmonary fibrosis**

This arises when scars form on epithelium of the lungs causing them to become irreversibly thickened. This reduces efficiency of gaseous exchange since diffusion distance is increased. This thickening also reduces volume of air that lungs can contain for exchange.

Symptoms

- Shortness of breath (when exercising)
- Chronic dry cough
- Chest pain
- Body weakness
- fatigue

c) **Asthma**

This is a localised allergic reaction to allergens such as pollen, dust and animal fur which causes release of histamine in the lining of bronchi and bronchioles that leads to inflammation.

Secretion of histamine may also cause;

- Cells of epithelium lining to secrete larger quantities of mucus than normal
- Fluid to enter air ways from capillaries
- Constriction of muscles around bronchioles, which narrows the airways.

Generally, there is increased resistance to air flow, making ventilation of lungs difficult

<u>Symptoms</u>

- Difficulty in breathing
- Wheezing sound when breathing
- Tight feeling in the chest
- Chest pain
- cough

d) **Emphysema**

This is when the elastic tissue in lungs has become permanently stretched and the lungs are no longer able to force out all the air from alveoli. The alveoli surface area reduces and they sometimes burst resulting into little or no exchange of gases.

<u>Symptoms</u>

- Shortness of breath
- Chronic cough
- Bluish skin coloration

e) **Lung cancer**

<u>RISK FACTORS FOR LUNG DISEASE</u>

(factors that increase likelihood of lung disease)

- Smoking; tars from tobacco may induce epithelial cells to become cancerous or increase secretion of mucus and inflammation leading to lung disease.
- Air pollution; some pollutants like sulphur dioxide, tars may increase likelihood of lung disease
- Genetic make-up; some people are more likely to get lung disease than others
- Infections; other chest problems and infections can increase likelihood of lung disease.
- Occupation; people working in areas with chemicals gases and dust can easily inhale them and increase risk of lung disease

**Trial questions**

1. a)Explain the following:
   (i) Breathing in pure oxygen at higher pressures than atmospheric is dangerous. (04 marks)
   (ii) Breathing in air rich in carbon dioxide is dangerous. (03 marks)

   b) Outline three adaptations of animals that live in environments of low oxygen tension. (03 marks)

2. The volume and surface area of four animals A, B, C and D are shown in the following table

| ANIMALS | VOLUME $cm^3$ | Surface area $cm^2$ |
|---|---|---|
| A | 1 | 6 |
| B | 8 | 24 |
| C | 64 | 96 |
| D | 64 | 28 |

**Which one of the organisms would most need a specialised respiratory system?**

3. Figure (a) illustrates two different mechanisms of gaseous exchange in fish **A** and **B**.

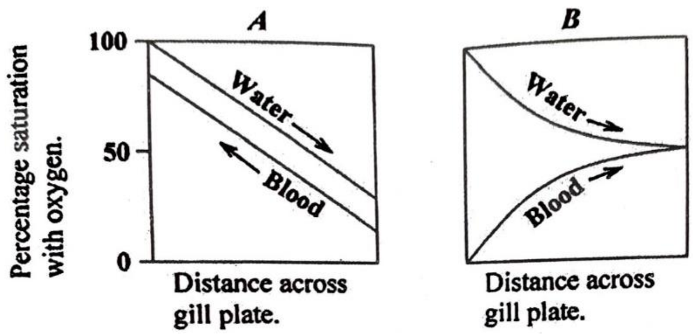



**Fig. (a)**

(i) State **two** differences between the two systems in terms of oxygen concentration. (02 marks)

(ii) Explain the physiological advantage of fish **A** over fish **B** (02 marks)

(iii) Suggest **two** ways of improving efficiency of the mechanism in fish **B** (02 marks)

(iv) Describe how a gill is structurally adapted as a respiratory surface. (04 marks)

END