14

RESPIRATION AND ELIMINATION OF NITROGENOUS WASTES

Every living organism needs energy to perform various life activities, and the process of respiration fulfils this energy requirement. You have already learnt in the lesson on food and nutrition that animals take in high energy organic molecules in the form of food. During respiration, this food is broken down in the presence of oxygen and energy is released during respiration. Respiration also produces carbon dioxide, a toxic substance which is eliminated from the body. Thus, uptake of oxygen and removal of carbon dioxide is an essential requirement of all animals.

At the same time numerous other toxic wastes such as ammonia, and urea are also produced in the tissues during various cellular activities. Such toxic wastes need to be removed from the body. In this lesson you will learn about removal of nitrogenous wastes and maintenance of water and salt balance in the body.

OBJECTIVES

After completing this lesson you will be able to :

- *define respiration, breathing, inspiration, expiration and vital capacity;*
- *describe briefly the gaseous exchange in earthworm and cockroach;*
- *describe the parts of respiratory system in the human body and mention their functions;*
- *draw a labeled diagram of human respiratory system;*
- *differentiate between breathing and respiration; and inspiration and expiration;*
- *describe the mechanism of breathing and its regulation;*
- *describe the exchange of respiratory gases in the lungs and their transport to and from tissues;*

- *name some common ailments of respiratory system and suggest their prevention;*
- *define excretion and mention its importance;*
- *explain the terms such as ammonotelism, ureotelism and uricotelism;*
- *list the organs of excretion in cockroach;*
- *list the parts of human excretory system and mention their functions;*
- *explain ultrafiltration and describe how urine is formed in humans;*
- *draw the microscopic structure of the human kidney;*
- *list the normal and abnormal components of urine;*
- *explain the mechanism of osmoregulation and its regulation by ADH;*
- *explain the role renin-angiotensin system in regulating blood volume and blood pressure.*
- *explain the role of dialysis and kidney transplantation in case of kidney failure;*
- *explain the role of liver in excretion.*

14.1 RESPIRATION

Respiration is the stepwise oxidation of glucose (and other nutrients) which results in the release of energy that is stored in the cytosol in the form of ATP (adenosine triphosphate). Whenever energy is required by our body, ATP is broken down and large amount of energy is released.

Respiration is completed in following steps :

Step-1 Gaseous exchange

It involves exchange of gases between the cell and its surrounding medium. The cells obtain oxygen from the environment and return carbon dioxide and water vapour to it. In most higher animals this exchange of gases takes place in two phases :

(a) exchange of gases between the animal body and its external environment, also called **ventilation** or **breathing.**

(b) transport of gases O_2 and CO_2 between the respiratory surface and the cells.

Oxygen obtained from the atmosphere is used up in the second step i.e. during **cellular respiration**, which occurs inside the cell.

Step 2 Cellular Respiration

It is a complex and elaborate process which occurs in the cytoplasm and the mitochondria. It involves :

(i) the uptake of oxygen by tissues,

(ii) stepwise oxidation of glucose molecules and other nutrients, and

(iii) release of carbon dioxide and energy.

Thus ultimate goal of respiratory system is to provide oxygen to the tissues for oxidation of food and removal of carbon dioxide from them.

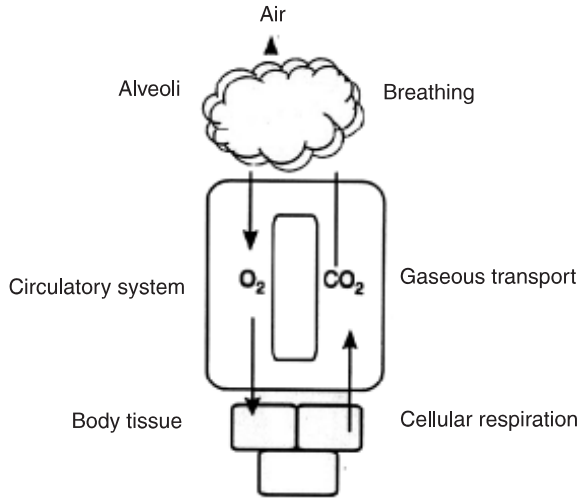


Fig. 14.1 General features of respiration

14.1.1. Respiratory Exchange in Different Animals

- All animals exchange gases with their surroundings by the mechanism of diffusion.
- A gas diffuses across a membrane from outside where its concentration (partial pressure) is higher than inside where its concentration is lower.
- Thus oxygen is taken up and carbon dioxide is released from the respiratory surface.
- For efficient gas exchange the respiratory surface should be large, moist, highly vascular, thin and easily permeable to oxygen and carbon dioxide.
- To fulfill this requirement complex respiratory systems have evolved in the animal world. You will study a few of them in this lesson.

14.1.2 Gas exchange through the general body surface in earthworm – cutaneous respiration

- Earthworm has no respiratory organs. The entire skin on the body of earthworm functions as the respiratory surface.
- The skin of earthworm is thin, moist and has a rich supply of blood capillaries. Thus, it is very suitable for respiration.
- The body surface is covered with a moist film consisting of secretions of mucous glands, coelomic fluids and excretory wastes.
- The capillaries on the skin take up O_2 dissolved in the water (in the moisture) on the surface of skin and release CO_2 into the atmosphere.
- Earthworms have a closed circulatory system which means that blood flows within blood vessels. The respiratory pigment haemoglobin remains dissolved in blood plasma and not in any cell. In human beings and other vertebrates, Haemoglobin is inside RBC
- There is regular rhythmic contraction of blood vessels which helps in the circulation of blood and hence in the transport of dissolved gases in the body.

Even frogs show cutaneous respiration (respiration through skin) across their moist skin, particularly during hibernation when they become inactive during the winter to avoid cold. However, frogs are mainly lung breathing animals.

14.1.3 Tracheal System in Cockroach

You must have noticed that the insects keep expanding and contracting their abdomen. This is to allow gaseous exchange.

- Like majority of insects, cockroach respires by means of internal tubes called **tracheae**.
- These tubes branch out extensively inside the body and carry air directly to the tissues from the atmosphere.
- In cockroach, respiration does not involve blood as shown in the flow chart given below and therefore it is very fast and very efficient. Tracheae open up to the exterior by paired slit like apertures called **spiracles**. Spiracles are found on the sides in the thorax and abdomen.
- The fine branches of tracheal trunks called **tracheoles** finally penetrate the cells of the body and allow diffusion of respiratory gases directly into and from the cells.
- The ends of the tracheoles are thin and filled with fluid in which respiratory gases dissolve. The inflow and outflow of air is affected by alternate contraction and expansion of the abdomen.

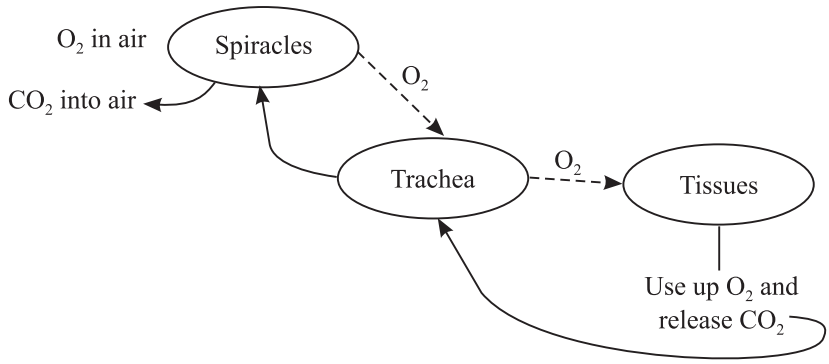


Fig. 14.2 Tracheal system in a cockroach

14.1.4 Respiratory system in humans (pulmonary respiration)

- Humans have a well developed respiratory system suitable for meeting the higher requirement of oxygen in their bodies.
- The respiratory system consists of nostrils, nasal cavity, pharynx, larynx, trachea, and bronchi.
- The two bronchi branch extensively into bronchioles, terminal bronchioles and ultimately end in the air sacs called alveoli. The bronchioles, their branches and air sacs are enclosed in a double membrane called pleural membrane to form the lungs. The lungs are the main respiratory organs.

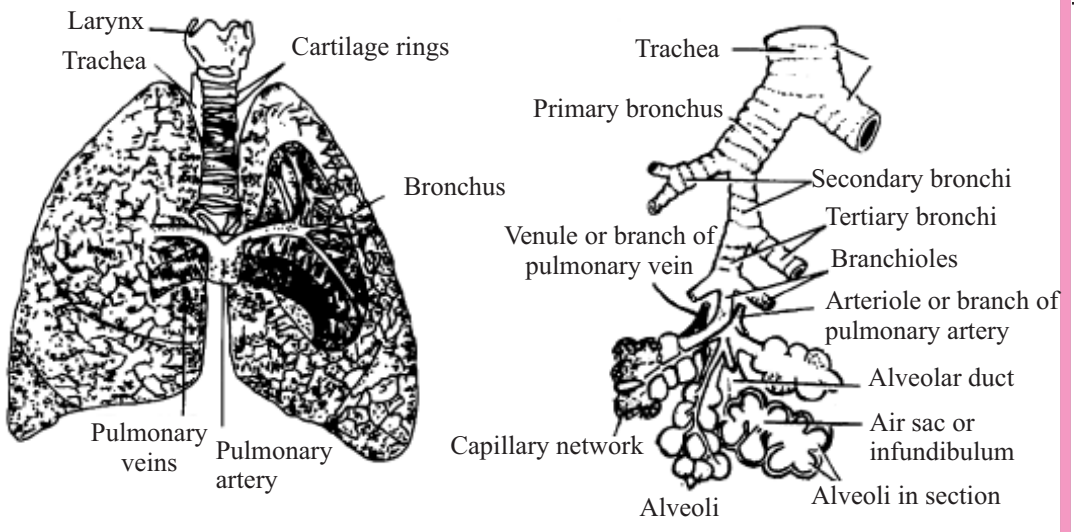
- Air passes through nostrils into bronchi, to bronchioles and into air sacs which are thin walled sacs with a single layer of cells and heavily covered with blood capillaries. O_2 from alveoli passes into capillaries and CO_2 from other capillaries diffuses into alveoli for being removed. Alveoli are the organs where the actual gaseous exchange occurs.
- The double layer pleural membrane covers the lungs for its protection. It contains pleural fluid, which makes the movement of the lungs easy.
- Each lung consists of a tree like system of branched bronchial tubes.
- The finest of them terminate into millions of tiny sac like structures called alveoli.
- Alveolar membrane is very thin, moist and richly supplied with blood capillaries.
- The walls of both the capillaries and alveoli consist of a single layer of flattened epithelial cells.

Refer to the following table 14.1 to get an idea of the structure and functions of different parts of the human respiratory system.

Table 14.1 Respiratory organs of human body

Organ	Structure	Function
Nostril Nasal Cavity	Opening of Nose Covered with mucous membrane and cilia	Filtration of unwanted particles. Traps dust, bacteria; warms and moistens the air in the pharynx.
Pharynx (Throat)	Muscular Tube	The common passage for both respiratory gases and food moving into digestive passage, separated by epiglottis Epiglottis is a flap like structure that closes the tracheal opening (opening of the wind pipe) called glottis when food is swallowed.
Larynx /Voice Box)	A small cartilaginous organ with vocal cords : lined by ciliated epithelium	Connects pharynx to the trachea; helps in sound production.
Trachea (Wind pipe)	Supported by C-shaped cartilaginous rings to prevent it from collapsing. Trachea divides into two bronchi and enters the two lungs	Passage for air upto bronchi.
Bronchus (Plural : Bronchi)	Elastic, ciliated and covered with mucous epithelium	Enters the lungs and divides to form secondary bronchi, tertiary bronchioles and ultimately terminal bronchioles. Together they form the bronchial tree.

Bronchioles	Small terminal branches of bronchus leading to alveoli	Convey air into alveoli.
Alveoli (Air sacs)	Supplied with blood capillaries, thin moist	Exchange of Gases.



(a) (b)

Fig. 14.3 (a) Human lungs (b) branching of bronchi upto terminal alveoli

Table 14.2 : Differences between breathing and respiration

Breathing	Respiration
1. Physical process	1. Bio-chemical process involving enzymes
2. Takes place only in reptiles, birds and mammals	2. Occurs in all organisms
3. It is a rhythmic process	3. It is a continuous process
4. It is an extracellular process	4. It is an intracellular process
5. It involves gaseous exchange between the animal and its external environment	5. It involves enzymatic breakdown of glucose in the presence or absence of Oxygen to release energy

INTEXT QUESTIONS 14.1

1. Define respiration

   .....

2. Name the two gases that are exchanged during respiration.

   .....

Notes

3. What is cutaneous respiration? Name one animal that undertakes cutaneous respiration.

   .....

4. What is the colour of the blood of the earthworm? Name the pigment responsible for the colour.

   .....

5. How is oxygen transported to the cells in the cockroach?

   .....

6. Name the group of animals in which blood is not involved in gaseous exchange.

   .....

7. How does trachea communicate with the exterior in cockroach?

   .....

8. Trace the path of air from the nostrils to the lungs in the human body.

   .....

9. Name the part of the respiratory system where air is filtered, moistened and warmed in humans

   .....

10. What is the function of the epiglottis in humans?

   .....

14.2 MECHANISM OF PULMONARY RESPIRATION

The main purpose of respiratory system is to provide oxygen to the tissues and to remove carbon dioxide from them. This entire process is achieved through the following steps:

(i) Breathing or pulmonary ventilation leading to exchange of oxygen and carbon dioxide between the atmospheric air and the lungs.

(ii) Exchange of gases at the alveolar surface.

(iii) Transport and exchange of gases in the tissues.

(iv) Cellular respiration.

14.2.1 Breathing or pulmonary ventilation

It is a mechanical process of taking in atmospheric air into the lungs and giving out carbon dioxide. Breathing is an involuntary process but under special conditions it can become voluntary also. It consists of two steps during which lungs are contracted and expanded alternately.

1. Inspiration or taking air in, and
2. Expiration or forcing air out (refer to Fig. 14.4).

1. Inspiration (The intake of air) : A muscular dome shaped diaphragm is present at the base of the lungs. On contraction it becomes flattened and lowered. The lower surface of lungs is pulled downwards and the volume of lungs increases.

External intercostal muscles present between the ribs contract, the rib cage moves outwards and upwards. These contractions together increase the volume of the chest cavity, lower the air pressure within the lungs and the atmospheric air rushes in filling the lungs with fresh air. Thus, inspiration is an active phase of breathing.

2. **Expiration (releasing air) :** This step involves the relaxation of external intercostal muscles and contraction of internal intercostal muscles. As a result the rib cage lowers and moves inwards. The diaphragm also relaxes and rises again into its original dome shaped condition. The abdominal organs press up against the diaphragm. This change decreases the volume of the chest cavity, thus, increasing the air pressure within the lungs and the air, which is laden with CO_2 and is forced out.

Forced breathing. It is possible that during forced breathing both inspiration and expiration are active processes because some more intercostal muscles and the abdominal muscles are brought into action for deeper breathing movements

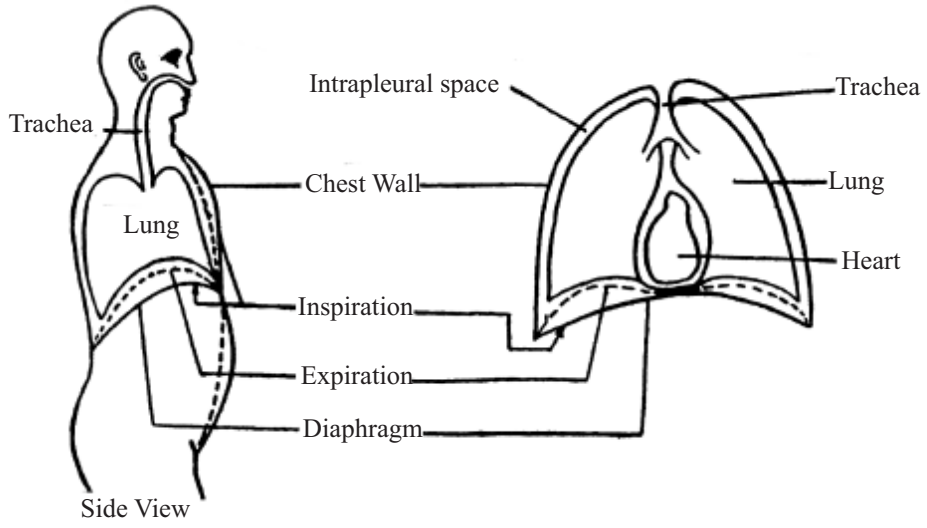


Fig. 14.4 Breathing movements

14.2.2 Exchange of gases at the alveolar surface

- Blood is the medium for the transport of oxygen from the lungs to the different tissues and carbon dioxide from tissues to the lungs.
- The deoxygenated blood is brought to the lungs by pulmonary artery which divides into fine capillaries that surround alveoli.
- Both alveoli and capillaries are made up of thin walled single layer of epithelial cells and therefore allow gaseous exchange easily.
- There is more oxygen in alveolar air and more carbon dioxide in the capillaries. Due to the pressure difference of oxygen and carbon dioxide between the alveoli and blood capillaries, the oxygen diffuses from alveolar air into the blood

capillaries. At the same time carbon dioxide diffuses from blood capillaries into the alveolar air.

- Oxygenated blood is taken from the lungs to the heart by pulmonary vein.

Volumes exchanged

Following table 14.3 shows the air volumes exchanged during breathing in a normal adult human being.

Table 14.3 : Air volume exchanged during breathing

Tidal volume (TV)	Volume of air inhaled and exhaled without any noticeable effort (normal breathing).	500mL
Vital capacity (VC)	Volume of air that can be maximally breathed out after a maximum inspiration (VC = IRV+TV+ERV).	3400-4800mL
Inspiratory reserve volume (IRV)	Volume of air that can be taken in by forced inspiration over and above the normal inspiration.	2000-3000 mL
Expiratory reserve volume (ERV)	Volume of air that can be expelled by forced expiration over and above the normal expiration.	1000 mL
Residual volume (RV)	Volume of air that cannot be forced out even on forced expiration. This is the air that remains in the lungs and in the air passage.	1000-1500mL
Total lung capacity	Sum of all lung volumes (maximum air that remains in the lungs after a maximum inhalation).	5500-6000mL

Vital capacity may be highly reduced in smokers and people suffering from tuberculosis. Athletes and singers on the other hand have higher vital capacity.

14.2.3 Transport of oxygen by blood from lungs to tissues

Efficient transport of oxygen is by a complex blood protein called haemoglobin. This iron rich protein is packed in Red Blood Corpuscles (R.B.Cs) giving blood a red colour. About 97 percent of the total oxygen is transported from lungs to the tissues in combination with haemoglobin. Only 3% of oxygen is transported in dissolved form by plasma. Oxygenation of blood takes place in lungs. Four molecules of oxygen form a reversible bond with haemoglobin forming the compound oxyhaemoglobin.

$$\underset{\text{(Haemoglobin)}}{Hb} + 4O_2 \underset{\text{Active Tissue}}{\overset{\text{Lung alveoli}}{\rightleftharpoons}} \underset{\text{(Oxyhaemoglobin)}}{Hb(4O_2)}$$

When the oxygenated blood reaches the tissue surface there is high concentration of CO_2 in the tissues, oxygen having been used up and low concentration of O_2. As a result the bonds holding oxygen and haemoglobin in Hb ($4O_2$) becomes unstable and blood releases oxygen and takes up CO_2.

14.2.4 Transport of carbon dioxide (from tissues to lungs)

Blood transports carbon dioxide with comparative ease because of its high solubility. Active tissues constantly produce CO_2. This CO_2 is transported to the lungs in three ways:

(i) CO_2 is physically dissolved in blood plasma (only 5-7% of the total CO_2 is transported).

(ii) CO_2 directly combines with haemoglobin of RBCs to form carbaminohaemoglobin (about 21-23% only).

(iii) As bicarbonate it is dissolved in plasma but produced in RBCs catalysed by the enzyme carbonic anhydrase and then diffuses into plasma (largest fraction of CO_2, about 75% to 80%) to be transported in this manner.

$$CO_2 + H_2O \underset{\text{Carbonic anhydrase}}{\overset{\text{Enzyme}}{\rightleftharpoons}} \underset{\text{(Carbonic acid)}}{H_2CO_3}$$

$$\underset{\text{Carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{(Bicarbonate ion)}}{HCO_3^- + H^+}$$

Bicarbonate is extremely soluble and dissolves in blood plasma. It again passes into RBC and breaks into CO_2 and H_2O in the alveoli. Inside the lungs the CO_2 is transported to lungs from tissues in the three ways mentioned above and is released into the alveolar air and finally breathed out (Fig. 14.5).

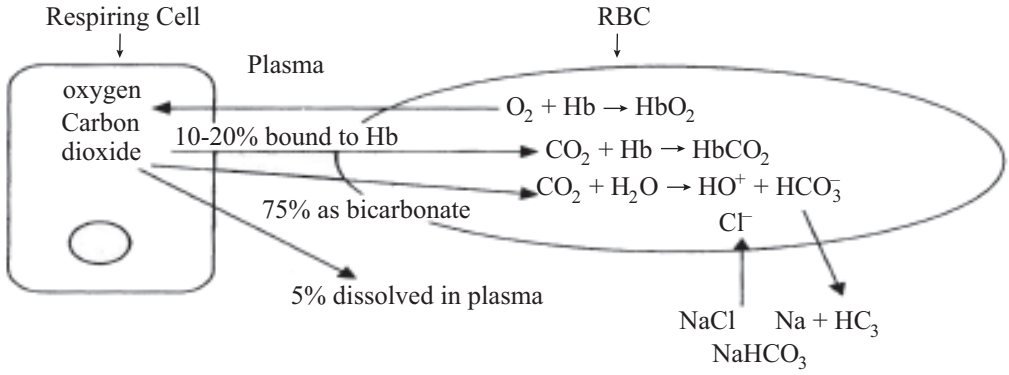


Fig. 14.5 Transport of carbon dioxide in the blood.

14.2.5 Regulation of respiration

Count the number of times you breathe during normal resting condition and when climbing up the stairs. How is the change in the breathing rate brought about? You will now study about regulation of respiration.

The regulation of respiration is under nervous control. There are three groups of neurons called respiratory centres present in the medulla oblongata and pons the brain. These are:

(a) **Dorsal respiratory group** – generates basic respiratory rhythm. It stimulates the external intercostal muscles, the diaphragm contracts and inspiration occurs. When the stimulation ceases, these muscles relax and expiration takes place.

(b) **Ventral respiratory group** sends signals under enhanced respiratory needs. It controls both inspiration and expiration.

(c) **Pneumotaxis center** in the pons controls switch off point of inspiration and thereby smoothens the transition between inspiration and expiration.

Increase in blood carbon dioxide and hydrogen ions increase the rate of respiration.

> If we try to hold our breath, we are not able to hold it for long time. This is because the respiratory centres of the medulla automatically reinstate breathing when the concentration of CO_2 in blood reaches a critical level.

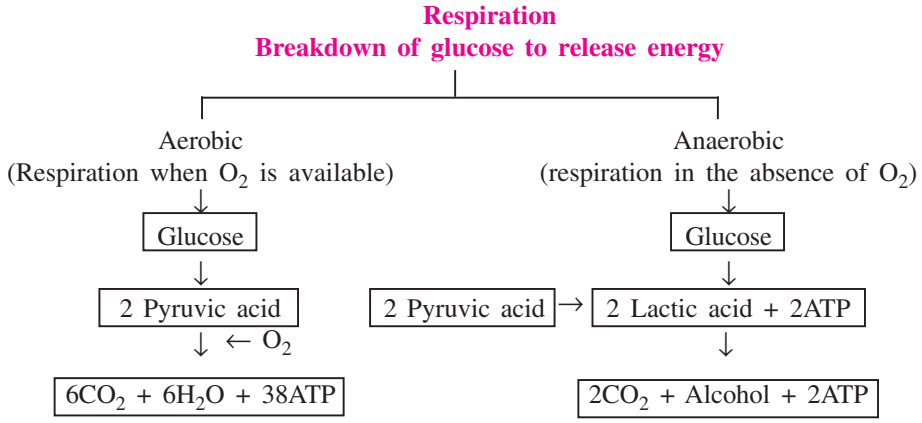
14.2.6 Cellular respiration

Oxygen taken in the blood is utilised in all the living cells during cellular respiration. It is a complex process that is completed in the mitochondria. During cellular respiration, glucose is oxidized to release energy. Energy released is stored in ATP (Adenosine Triphosphate) molecules and is readily available for cell use. The process can be summed up as follows:

$$C_6H_{12}O_6 + 6CO_2 \xrightarrow[\text{Cell Respiration}]{\text{Mitochondria}} 6CO_2 + H_2O + ATP \text{ (e}$$

Respiration that takes place in the presence of O_2 is called **aerobic respiration**. It is more efficient as 38 molecules of ATP are released on the oxidation of one glucose molecule.

Absence of oxygen for sometime may lead to **anaerobic respiration**. It is inefficient as only 2 molecules of ATP are produced from one glucose molecule (Refer lesson 12 for details).



14.3 Common respiratory disorders and their prevention

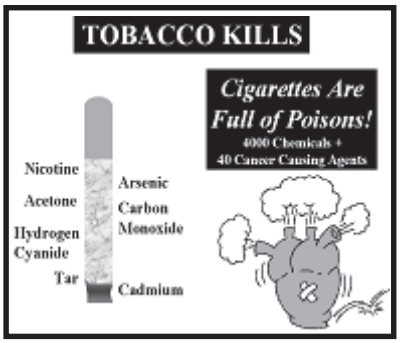
Disease	Cause	Symptoms	Prevention
Bronchial asthma	It is an allergic disease caused due to certain foreign substance in the air.	Causes difficulty in breathing and coughing because excess mucous secretion may narrow down (clog) the bronchioles.	Avoiding exposure to the foreign substance is the best preventive measure.
Bronchitis	Inflammation of bronchi caused by infection. It can also be caused by smoking and by exposure to air pollution.	Regular coughing with greenish blue sputum	Avoiding exposure to smoke and dust prevents bronchitis.
Pneumonia	Acute inflammation caused by diplococcus infection in the alveoli of the lung.	It causes fever, pain and severe cough. Most of the air space is occupied by fluid and dead W.B.C.	Avoid crowded places where infection is prevalent.
Tuberculosis	It is a bacterial infection that spreads through droplets of infected persons	It can affect many other organs but pulmonary T.B. is most common. Weight loss and cough are common symptoms. It is accompanied by low fever. In extreme cases blood may come out while coughing.	BCG vaccine can prevent T.B. Well – ventilated dwellings and protein rich diet is also essential for T.B. patients.
Occupational lung hazards	Caused due to exposure to harmful substance like silica, asbestos, dust etc. present in the environment where a person works.	It is expressed after exposure of 10-15 years or more. It causes fibrosis of the lungs.	Such diseases can be prevented by minimizing the exposure to such substances by using protective masks and clothing. Regular health check – up is necessary.

The suffix 'itis' means inflammation of an organ. Bronchitis, pharyngitis or tonsillitis affects different respiratory tissues. Can you tell the specific organ affected?

Some Basic Facts

Why is cigarette smoking harmful?

Cigarette smoking is harmful because it leads to:



- diminished or extinguished sense of smell and taste
- smoker's cough
- gastric ulcers
- chronic bronchitis
- increase in heart rate and blood pressure
- premature and more abundant face wrinkles
- heart disease
- stroke
- cancer of the mouth, larynx, pharynx, oesophagus, lungs, pancreas, cervix, uterus, and bladder

14.2.7 Emphysema

Emphysema is a respiratory disorder caused by excessive cigarette smoking and chronic bronchitis. Either the bronchioles or the alveolar sacs get distended abnormally in Emphysema resulting in loss of elasticity of these parts. Gradually due to continuous distention, lung increases in size and air remains in lungs even after expiration.

Emphysema can be prevented by giving up smoking before damage is done to alveoli. Cure is difficult as elasticity is lost irreversibly.

INTEXT QUESTIONS 14.2

1. What is breathing?

   .....

2. What is the position of the diaphragm at the time of expiration?

   .....

3. What is the capacity of tidal volume?

   .....

4. What is the maximum number of oxygen molecules with which haemoglobin can combine?

   .....

5. Name the blood vessel that takes oxygenated blood from the lungs to the heart.

   .....

6. What are the three forms in which carbon dioxide is transported by the blood?

   .....

7. Name the vaccine used for prevention of TB.

   .....

8. What is an occupational hazard.

   .....

9. What is the difference between bronchitis and asthma?

   .....

10. The alveoli of a heavy smoker were damaged, their surface area was reduced and elasticity was lost. What is the technical term for this condition.

   .....

14.3 EXCRETION

All animals possess some mechanism of getting rid of the waste substances produced in their body during metabolic activities. These waste substances include CO_2, water, urea, uric acid and ammonia. Such substances can be harmful if retained in the body.

Besides metabolic wastes, excess salt (eg. NaCl taken in food), H_2O and even excess of some vitamins needs to be eliminated. Certain medicines (antibiotics) too are removed from the blood in the urine. **Removal of all harmful, unwanted products (specially nitrogenous wastes) from the body is called excretion**. Excretory system is primarily associated with removal of nitrogenous wastes.

Urea is the main nitrogenous waste in our body. It is formed by the breakdown of surplus amino acids and nucleic acids in the liver. Blood transports urea to the kidneys for filtration and removal in the form of urine.

14.3.1 Modes of removal of nitrogenous wastes

Depending upon the nitrogenous wastes excreted, animals can be classified as **ammonotelic, ureotelic** and **uricotelic**. Table 14.4 gives categories of animals on the basis of nitrogenous waste produced.