4 Excretory and Respiratory Systems; Cellular Respiration (Glycolysis and Kreb's Cycle)

B12CH4

Outcomes: To be able to:

- take appropriate steps to prevent damage to the excretory and respiratory organs,
- demonstrate comprehensive understanding of the excretory and respiratory systems in relation to substance abuse,
- realize that the energy released during gaseous exchange (respiration) is key to the survival of all living organisms.

Learning Objectives

At the end of this unit you will be able to:

- describe the excretory system and state the functions of all associated organs,
- list the tissues and organs involved in the mechanism of breathing,
- explain homeostasis in relation to the excretory system,
- explain the effects of substance abuse and STIs on the excretory and respiratory systems,
- state the characteristics of the types of respiration,
- distinguish between aerobic and anaerobic respiration,
- discuss cellular respiration citing the major stages sequentially noting the main events (Glycolysis, Krebs cycle and electron transport chain),
- discuss anaerobic respiration in the muscle and its importance in fermentation using yeast/fruits for (alcohol production),
- discuss the significance of phosphorylation in glycolysis,
- identify the final products of glycolysis,
- outline the fate of pyruvate after Glycolysis,

- distinguish oxidation and reduction with regards to oxygen, hydrogen and electrons,
- distinguish between decarboxylation reactions and dehydrogenation reactions,
- interpret the balanced chemical equation for respiration ($C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$)
- identify the three types of electron carriers located in the inner membrane of the mitochondria (flavoproteins, quinones and cytochromes).

4.1. EXCRETORY SYSTEM

Excretion is the removal of **metabolic waste products** from the body of living organisms. The common excretory product formed in the bodies of animals are: water, carbon (IV) oxide, mineral salts, bile pigments and nitrogenous waste products; such as urea, uric acid and ammonium compounds. The importance of excretion is to remove substance that could be toxic or poisonous from the body of living organisms. If waste substances are allowed to accumulate in the body, they could prevent the maintenance of constant internal environment and this could lead to death of the organism.

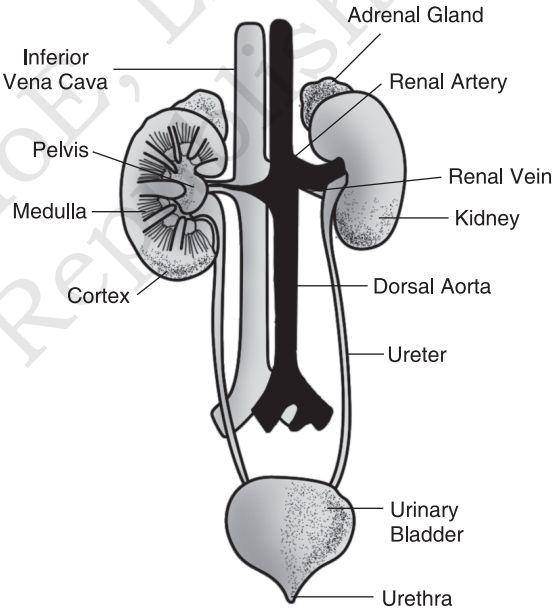


Fig. 4.1. Human urinary system

The human excretory system consists of a pair of kidneys, a urinary bladder, a urethra, skin, liver, lungs and large intestines.

4.1.1. Kidneys

Kidneys are reddish brown, bean shaped structures situated between the levels of last thoracic and third lumber vertebra close to the dorsal inner wall of the abdominal cavity. The last two pairs of ribs (floating ribs) protect the kidney. Each kidney has a notch called **hilum** on its inner side. Each kidney is covered by a layer of fibrous connective

tissue, the **renal capsule** which protects it from infection and injuries. Around the capsule, there is a layer of fat, the **adipose capsule**, and another outer fibrous membrane, the **renal fascia** help to protect the kidney. The fascia anchors it to the abdominal wall. Inner to the renal capsule there is an outer dark region, the **cortex**, and inner lighter region with a striated appearance, the **medulla**. The medulla is divided into a number of conical areas, the **medullary pyramids.** Each renal medullary pyramid terminates into a structure, the **renal papilla**. Between the medullary pyramids the substance of the cortex extends into the medulla and forms the **renal columns of Bertin**. The medullary pyramids are connected with minor calyces. The minor calyces lead into **major calyces**. A human kidney possesses two or three major calyces. The latter open into a funnel shaped structure, the **renal pelvis**, which in turn leads into the **ureter**. The functional units of the kidney called **nephrons** or **uriniferous tubules** are arranged in a radiating fashion with the renal pyramids. A kidney has about one million (ten lakhs) nephrons.

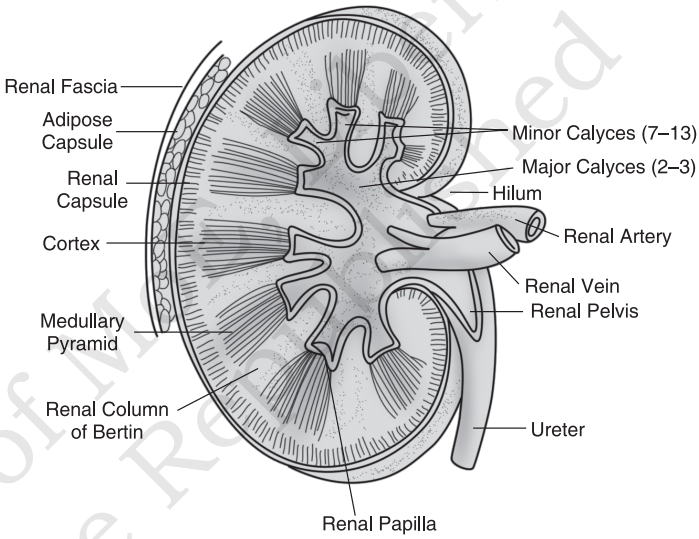


Fig. 4.2. L.S. human kidney (posterior view)

Function

The primary function of the kidneys is the elimination of excess water and wastes from the bloodstream by the production of the liquid waste known as urine.

4.1.2. Urinary Bladder

It is somewhat pear shaped muscular sac-like structure present in the pelvic cavity. It has a thick muscular distensible wall lined by **transitional epithelium** that allows its expansion. The muscles of the wall consist of three layers of smooth muscles—inner and outer layers of longitudinal fibres and a middle layer of circular fibres. The bladder muscle is called **detrusor muscle** (muscle having the action of expelling a substance). The bladder receives the ureters through the lower part of its back (dorsal) wall.

Internally, the urinary bladder has a triangular area, the **trigone**, between the three openings—two openings through which the ureters enter the bladder and one opening through which urethra leaves the bladder.

Function

The urinary bladder stores urine temporarily.

4.1.3. Urethra

It is a canal-like structure that starts from the lower part or neck of the urinary bladder and leads to the exterior. Its length differs in male and female. In female, it is short (about 4 cm in length).

Function

It carries only urine.

4.1.4. Skin

Certain substances are eliminated by the **sweat (sudoriferous) glands** and **sebaceous (oil) glands** present in the skin through their secretions.

The sweat or sudoriferous glands secrete an aqueous fluid called **sweat**. Sweat contains water (99.5%), some inorganic salts (chiefly NaCl) and traces of urea and lactic acid.

Function

Though the primary function of sweat is to facilitate a cooling effect on the body surface, it also helps in the removal of some of the wastes mentioned above.

4.1.5. Liver

Liver converts ammonia into urea, which is eliminated through kidneys. Liver cells also degrade the haemoglobin of wornout red blood corpuscles into bile pigments (**bilirubin** and **biliverdin**), and secrete cholesterol, degraded steroid hormones, vitamins and drugs.

Function

Liver secretes these substances in the bile. The bile carries these substances to the intestine and are passed out with faeces.

4.1.6. Lungs

Our lungs removes about 18 litres of CO_2 and about 400 ml of water per day. The loss of water through lungs is less in hot, humid weather as compared to cold dry weather.

4.1.7. Large Intestine

The epithelial cells of colon transfer certain inorganic ions such as calcium, magnesium and iron from the blood into the cavity of colon for removal with faeces.

4.1.8. Steps to Prevent Damage to the Excretory Organs

- Choose foods that are healthy for your kidney and your entire body: fresh fruits, fresh or frozen vegetables, whole grains, and low-fat or fat-free dairy products. Eat healthy meals, and cut back on salt and added sugars.
- Be active for 30 minutes or more on most days.
- If you are overweight or have obesity, work with your health care provider or dietitian to create a realistic weight-loss plan.
- Aim for 7 to 8 hours of sleep each night
- If you smoke or use other tobacco products, stop.
- Drinking too much alcohol can increase your blood pressure and add extra calories, which can lead to weight gain. If you drink alcohol extra, limit yourself to one drink per day if you are a woman and two drinks per day if you are a man.

Fig. 4.3. Healthy food

4.1.9. Effects of Substance Abuse and STIs on the Excretory System

Excretory Systems

Excretion refers to the process of the body eliminating toxins or waste products. The excretory system consists of numerous organs in the body that all contribute to the removal of waste products and toxins.

The majority of the metabolism of substances in the bloodstream occurs in the liver, but the majority of the elimination of waste products occurs through the kidneys (through urine). The function of kidney is to filter blood pumped throughout the body and to create urine.

Substance abuse may directly damage the kidneys or may indirectly damage them through some other process, such as increased body temperature or rhabdomyolysis (the breakdown of muscle tissue in the release of cells in the bloodstream).

Numerous drugs of abuse can affect the function of the kidneys.

Alcohol

Chronic heavy use of alcohol can lead to direct damage to the kidneys. It can significantly change the structure and function of the kidneys.

Alcohol also affects the liver and how the liver and kidneys work together. Damage to the liver can affect kidney functioning. Even moderate to mild alcohol consumption will affect any existing condition of the liver, which will indirectly result in kidney damage.

Chronic heavy alcohol consumption can also:

- Lead to kidney swelling, which can impair renal functioning.
- Alter the cells in the kidneys, leading to impaired functioning.
- Produce electrolyte disturbances, which can disrupt the function of the kidneys.
- Change the acidity levels of the fluids in the system, which can result in alcoholic ketoacidosis, a condition that is characterized by a significantly dangerous high blood acidity level, and produce alkalosis or low acidity in the fluids.
- Due to fluid accumulation in the system, kidneys do not function properly.

Chronic heavy consumption of alcohol can result in liver disease. Such as cirrhosis of the liver which causes enlarged kidneys. Individuals with liver damage as a result of cirrhosis of the liver are also at a higher risk for acute kidney failure.

Cocaine

Cocaine is a central nervous system stimulant. It can lead to a condition known as rhabdomyolysis where muscle tissue breaks down and enters the bloodstream. This condition can lead to kidney failure.

Cocaine can also lead to renal infarctions (dead tissue on the kidneys). Its excess use is also associated with cardiovascular issues, such as

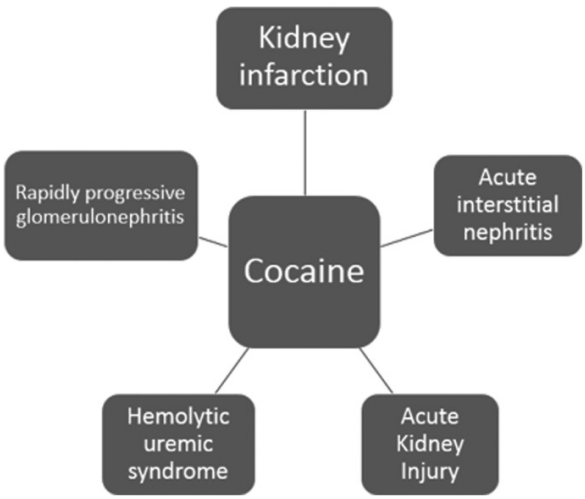


Fig. 4.4. Cocaine: kidney failure

atherosclerosis in the walls of the renal arteries (the buildup of plaque) which can also lead to kidney damage, disruptions in kidney functioning.

Opiates

Opiate drugs consist of numerous pain-relieving (analgesic) prescription drugs and several drugs that are illicit, such as heroin. The drugs can be taken orally, ground up and mixed with liquid and injected, and even snorted.

- Opiate abusers who inject drugs are at a high risk to share needles and may contract HIV-associated nephropathy, which is a kidney disease that often affects individuals who are intravenous drug users and have HIV.
- Intravenous drug users (e.g., heroin users) are more likely to contract fungal and bacterial infections, which can result in acute kidney inflammation.
- Intravenous drug users have an increased risk of buildup of protein in organs and tissues associated with chronic infections and inflammation (secondary amyloidosis). This can progress to kidney failure.

Ecstasy

Ecstasy (MDMA) is a synthetic drug that is classified as a dissociative hallucinogenic drug. It produces hallucinations and feelings of leaving one's body or being out of touch with reality. The drug has numerous side effects that can lead to issues with renal functioning, including its ability to increase body temperature (produce hyperthermia), which can lead to dehydration. This can result in rhabdomyolysis and acute renal failure.

The drug can also cause hypertension, and lead to acute renal failure or damage to the kidneys.

STIs Affects Excretory Systems

The adolescent population is particularly vulnerable to STDs. Those that cause significant kidney disease are of viral origin.

Causes of acute renal failure are frequently reversible and should be treated aggressively. These include HUS, vaso-motor or ischemic acute tubular necrosis, and drug toxicities. The spectrum of chronic kidney disease associated with VVD is broad and may include systemic manifestations of vasculitis.

4.1.10. The process of Excretion In a Nephron

The process of excretion may be divided into three stages—filtration, selective reabsorption and tubular secretion.

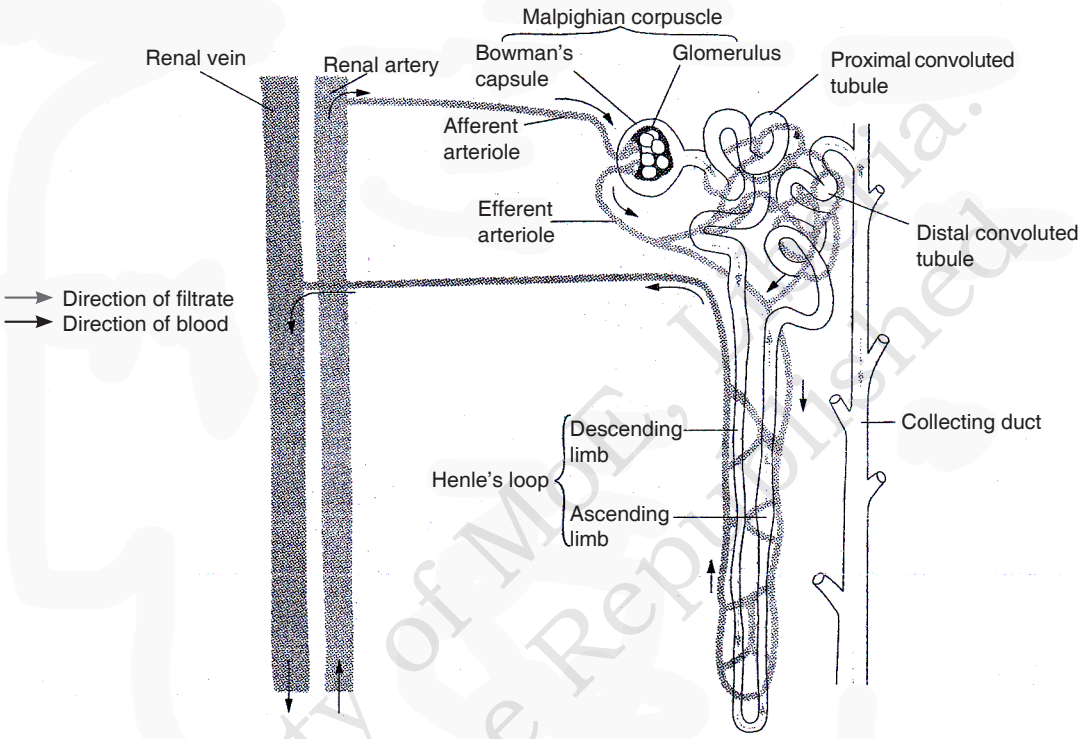


Fig. 4.5. Process of excretion

Filtration: Filtration of blood occurs under high pressure in the nephrons of the kidney. Blood enters the glomerulus through the afferent arteriole (with a wider lumen) and leaves through the efferent arteriole (with a narrow lumen). Therefore, blood passes through the glomerulus under pressure. This results in filtration of blood. Water and small molecules are forced out of the walls of the capillaries of the glomerulus and Bowman's capsule and enter the tubule of the nephron. Large molecules remain in the blood of the glomerulus. The filtrate contains water, glucose, salts, urea, vitamins, etc. It is called the glomerular filtrate.

Selective reabsorption: Some molecules of the glomerular filtrate are selectively reabsorbed into the blood. The glomerular filtrate flows through the proximal convoluted tubule, the U-shaped Henle's loop and the distal convoluted tubule. It contains many useful substances such as glucose, amino acids and salts. These are reabsorbed by a process,

which requires energy. Without reabsorption, these nutrients could have been lost with the urine. The filtrate now contains urea, some salts and water. Reabsorption of solutes into the blood increases the water concentration of the filtrate.

Then water is reabsorbed into the blood by the process of osmosis, and the osmotic balance is restored. The amount of water reabsorbed depends on the amount of excess water in the body and that of the dissolved waste to be excreted. This reabsorption of water from the filtrate to maintain the water balance of the body fluid is known as osmoregulation. In this way the kidneys serve as water-conserving organs. After reabsorption from 180 L of filtrate in the kidney, only 1–2 L of urine is produced.

Tubular secretion: Some introgenous waste products like creatinin and some other substances like potassium ions are removed from the blood by the distal convoluted tubule, and are then added to the urine. This is called tubular secretion.

Control of Excretion

The urine that is formed continually collects in the urinary bladder. As the bladder expands, its pressure creates an urge to pass urine through the urethra. As the bladder is muscular, the urge to urinate is under voluntary nervous control.

4.1.11. Process of Urination

The act of expulsion of urine from the urinary bladder is called **micturition** or **urination**. The urine formed by the nephrons is ultimately carried to the urinary bladder, where it is stored till a voluntary signal is given by the central nervous system (CNS). As the bladder wall is stretched by gradual filling of the bladder, the stretch receptors in the wall of the bladder generate nerve impulses that are carried by sensory neurons to the CNS (brain and spinal cord), producing the sensation of fullness (around 500 ml). The CNS passes on motor messages to initiate

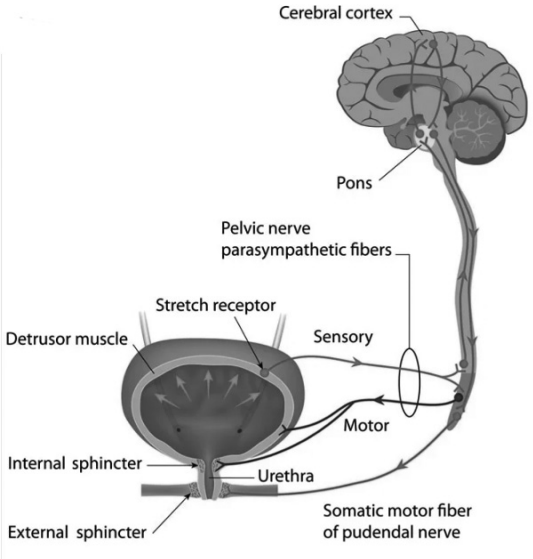


Fig. 4.6. The process of urination

the contraction of smooth muscles of the bladder and simultaneous relaxation of the urethral sphincter causing the release of urine. The neural mechanism starting from sensory stretch receptors of the distended bladder to CNS and back to urinary bladder for its emptying is called **micturition reflex**.

Voluntary micturition is achieved through contraction of abdominal muscles with increases pressure over the urinary bladder and activate sensory stretch receptors to initiate the reflex.

Urine

Urine is a transparent, pale yellowish fluid which is slightly acidic (pH 6.0). The colour of urine is due to a pigment, **urochrome** derived from the breakdown of haemoglobin from the worn out RBCs.

ACTIVITY 1

Draw and label the longitudinal section of human kidney.

|| Do it Yourself ||

1. The _____ _____ stores urine temporarily.
2. The act of expulsion of urine from the urinary bladder is called _____ .
3. _____ converts ammonia into urea.
4. A kidney has about one million _____ .
5. Filtration blood occurs under high pressure in the nephrons of the _____ .

INFOBOX

The human bladder can stretch to hold about 400 ml of urine.

4.2. HUMAN RESPIRATORY SYSTEM

The human respiratory system consists of lungs, pharynx, larynx, alveoli, bronchi and bronchioles.

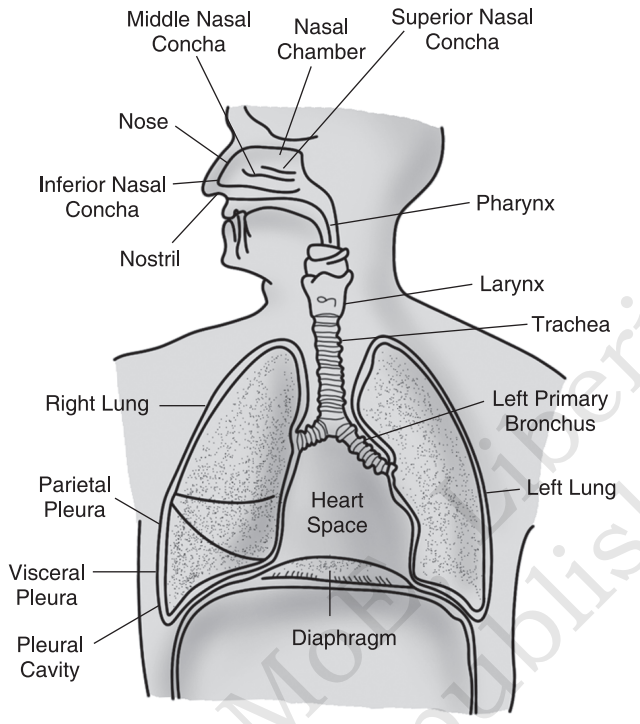


Fig. 4.7. Human Respiratory System

4.2.1. Lungs

A pair of lungs lie in the thoracic or pleural cavity, one on either side of the heart. The thoracic cavity is anatomically an airtight chamber which is enclosed behind by the thoracic vertebrae, laterally by the ribs and in front the sternum. The thoracic cavity is closed below by the diaphragm.

Each lung is enclosed in two membranes called the **pleurae**. The outer membrane, called parietal pleura remains attached to the wall of thoracic cavity. The inner membrane, known as **visceral pleura**, which closely invests the lungs. A very narrow space exists between the two pleurae. It is called **pleural cavity** that contains a **plural fluid** secreted by the pleurae. The pleural fluid lubricates the pleurae so that they may slide over each other without friction during breathing.

The space between pleural sacs of the two sides has a gap called **mediastinum**. It contains heart, trachea, oesophagus, thoracic duct of lymphatic system, etc.

Lungs and the Air Passage Ways

- Breathing starts when we inhale air into nose or mouth. It travels

down the back of throat and into windpipe, which is divided into air passages called bronchial tubes.

- As the bronchial tubes pass through lungs, they divide into smaller air passages called bronchioles. The bronchioles end in tiny balloon-like air sacs called alveoli. Our body has about 600 million alveoli.
- The alveoli are surrounded by a mesh of tiny blood vessels called capillaries. Here, oxygen from inhaled air passes into our blood.
- After absorbing oxygen, blood goes to heart. Heart then pumps it through body to the cells of tissues and organs.
- As the cells use the oxygen, they make carbon dioxide that goes into blood. Blood then carries the carbon dioxide back to lungs, where it's removed from body when we exhale.

4.2.2. Pharynx

It is a short, vertical tube behind the buccal cavity. It consists of **nasopharynx**, **oropharynx** and **laryngopharynx**. The pharynx provides passage for both food and air.

4.2.3. Larynx (= voice box)

The larynx is the upper part of the trachea. It is a short, tubular chamber supported by a cartilaginous framework. It opens into the laryngopharynx by a slitlike aperture, the **glottis**. The latter always remains open except during swallowing. The glottis bears a leaflike cartilaginous flap, the **epiglottis**, at its anterior margin. The epiglottis projects into the pharynx opposite to uvula. During swallowing, the larynx moves upward to meet the epiglottis. This closes the glottis to check the entry of food into it. Besides forming a part of the respiratory tract, it also serves as the voice box.

4.2.4. Alveoli

Alveoli are tiny air sacs present in the lungs which appears as a bunch of grapes. These are also known as pulmonary alveoli.

The pulmonary alveolus is a sac roughly 0.2 to 0.5 mm in diameter. These alveoli are located at the ends of air passageways in the lungs. In the average adult lung, there is an average of 480 million alveoli.

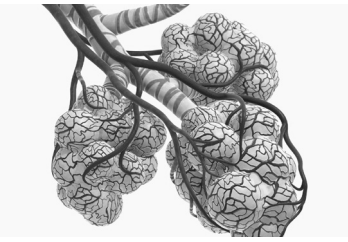


Fig. 4.8. Alveoli

Alveoli are the endpoint of the respiratory system which starts when we inhale air into the mouth or nose. The oxygen-rich air travels down the trachea and then into one of the two lungs via the right or left bronchus. Carbon dioxide molecules, a by-product of cellular respiration, are diffused back into alveolus where they are expelled out of the body through the nose or mouth. During inhalation, alveoli expand as the negative pressure in the chest is created by the contraction of the diaphragm. During exhalation, the alveoli recoil (spring back) as the diaphragm relaxes.

4.2.5. Bronchi

Bronchi are the large tubes that connect to your trachea (windpipe) and direct the air you breathe to your right and left lungs. The left bronchus carries air to your left lung. The right bronchus carries air to your right lung.

As you breathe and your lungs expand, your bronchi distribute the air within your lung.

Your bronchi carry air to and from your lungs. The bronchi also help moisturize the air you breathe and screen out foreign particles.

4.2.6. Bronchioles

The bronchioles are part of the lower respiratory system. As they branch off from the bronchi, they become smaller and smaller, traversing the interior of each lung before ending at clusters of alveoli. There are three types of bronchioles. These are:

- Lobular bronchioles
- Respiratory bronchioles
- Terminal bronchioles

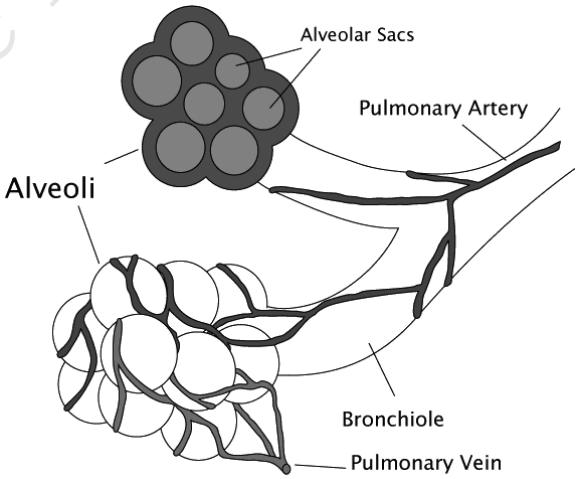


Fig. 4.9. Bronchioles

The function of the bronchioles is to deliver air to a diffuse network of around 300 million alveoli in the lungs. As you inhale, oxygenated air is pulled into the bronchioles. Carbon dioxide collected by the alveoli is then expelled from the lungs as you exhale.

4.2.7. Homeostasis

Homeostasis is the maintenance of a constant internal environment. The cells in the body of multicellular organisms are able to carry out their metabolic functions perfectly. They can, however, do this only when the conditions in their external environmental are kept constant. A change in the external conditions of the cells can greatly affect the proper functioning of the cells. The maintenance of the constancy of this internal environment constitutes **homeostasis**. It involves the maintenance of constant (or changes kept within very narrow limits) temperature, pH, concentration of bood glucose, carbon (IV) oxide, Oxygen and many other factors.

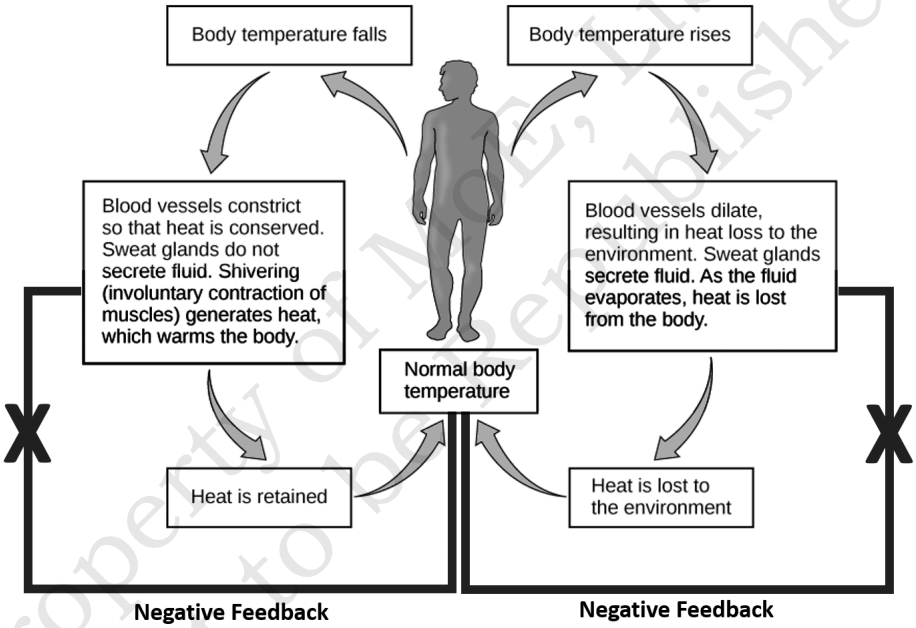


Fig. 4.10. Homeostasis

The Role of the Lungs in Homeostasis: The lungs regulate the concentration of carbon (IV) oxide in the body. High concentrations of carbon (IV) oxide in the blood are detected by the chemoreceptors in the wall of the aortic arch.

Through the stimulation of the hypothalamus, the breathing rate or the rate of expiration increases. The lungs remove (excess) carbon (IV) oxide from the body during expiration.

Low concentrations of carbon (IV) oxide in the blood do not stimulate the chemoreceptors in the aortic arch. The rate of expiration therefore remains normal.

The Role of the Skin in Homeostasis: Thermoreceptors in the brain detect low or high temperature in the body. **When the body temperature is high, superficial blood capillaries dilate**, or **vasodilation takes place**, to allow heat loss by convection and radiation. **Erector muscles relax**, hairs lie flat and heat is lost by radiation and convection through the skin. **Sweating increases** to effect heat loss through evaporation of sweat.

When the body temperature is low, superficial blood capillaries constrict, or vasoconstriction takes place, thereby conserving heat by preventing heat loss by radiation and convection. **Erector muscles contract**, hairs are raised to stand on end. This traps air around the skin to prevent heat loss by radiation and convection. Spontaneous contraction of muscles, called **shivering** occurs. This generates heat which raises the body temperature.

The Role of the Kidneys in Homeostasis: The kidneys regulate the water and salt balance in the body. Antidiuretic hormone, ADH, increases the permeability of the walls of the collecting duct. This results in the production of more concentrated or hypertonic urine. In the absence of ADH, the permeability of the walls of the collecting duct decreases. Dilute or more hypotonic urine is, therefore, produced.

4.2.8. Effects of Substance Abuse and SITs on the Respiratory Systems

Smoking

Smoking Tobacco and the People who continue to smoke tobacco products lose elasticity in the walls of the system, and many of the small structures within the system rupture or become thickened. Toxic chemicals in cigarettes lead to an increase in the risk of getting certain respiratory conditions and the risk of developing numerous forms of cancer by changing the cellular structure of the tissue.

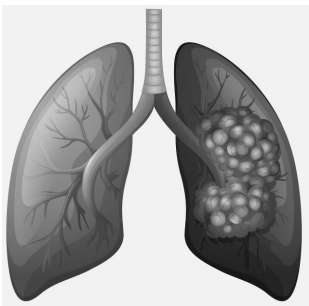


Fig. 4.11. Lung cancer

Opioid Drugs

Opioids are central nervous system depressant drugs that reduce the activity of the neurons in the brain and spinal cord. This central nervous system depressant action also affects the functioning of the respiratory system by slowing down a person's breathing rate.

In most cases, opioid drugs are taken in pill form, ground up and snorted, or mixed with liquid and injected. Nonetheless, due to their significant ability to suppress breathing, chronic use of these drugs can lead to respiratory issues.

- Decreased functioning of the immune system, which can lead to susceptibility for numerous infections and diseases, including pneumonia and other diseases.
- Worsening existing respiratory issues, such as emphysema, bronchitis, and asthma.
- A significant increase in the risk to develop pulmonary edema, fluid buildup in the lungs, which can be fatal if left unchecked and can also facilitate the development of other respiratory problems.

Alcohol

Chronic use of alcohol is associated with an increased risk for numerous diseases and health conditions. Alcohol is also a central nervous system depressant and reduces the breathing rate of people who use it.

Cocaine Use

Cocaine is a controlled substance that is typically snorted or smoked. This type of use can result in numerous respiratory issues.

Cocaine is a very harmful central nervous system stimulant that increases the firing rates of the neurons in the brain and spinal cord. Its use results in a constriction of the veins, arteries, and capillaries in the vascular system, and it can lead to hardening of the cellular walls in organs like the lungs and death of cells in the respiratory system.

Smoking cocaine can lead to:

- Pulmonary edema, swelling of the lungs, and even hemorrhages (ruptures of the veins or arteries) in the lungs.
- Ruptures of the air sacs in the lungs (pulmonary barotrauma).
- Increased probability to develop asthma, bronchitis, or emphysema, or exacerbation of these conditions.

STIs Affects Respiratory Systems

STI consequences may lead to reproductive disorders, infant infections, liver failure, cancer, and nervous system disease.

Chlamydia trachomatis may be an important cause of lower respiratory tract infection (LRTI) in infants born to mothers amongst whom there is a high prevalence of sexually transmitted disease.

4.2.9. Steps to Prevent Damage to the Respiratory Organs

Steps to prevent damage to the Respiratory organs:

- Stop smoking, and avoid secondhand smoke or environmental irritants.
- Eat foods rich in antioxidants.
- Get vaccinations like the flu vaccine and the pneumonia vaccine.
- Exercise more frequently, which can help your lungs function properly.
- Improve indoor air quality.

4.2.10. Mechanism of Breathing

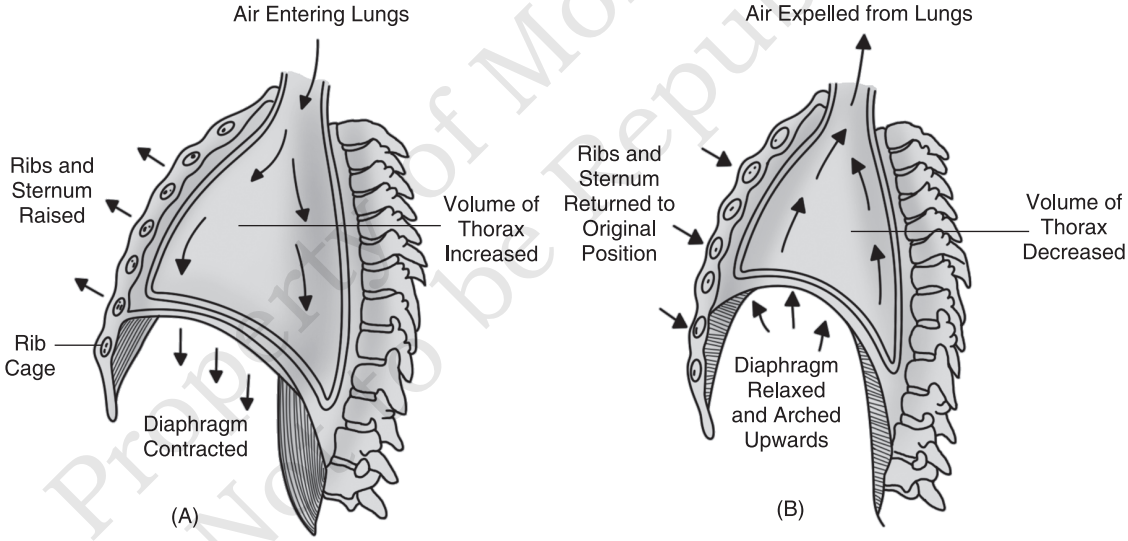


Fig. 4.12. Movement of ribs and diaphragm during inspiration and expiration

Breathing as mentioned earlier consists of two processes—breathing in, inspiration or inhalation and breathing out, expiration or exhalation.

During **breathing in**, the external intercostal muscles contract while the internal intercostal muscles relax. This causes the ribs and sternum to move **upwards and outwards**, which **increases the volume of the thoracic or pleural cavity** laterally. The diaphragm muscles also contract simultaneously, which **flattens** the dome-shaped diaphragm,

increasing the volume of the thoracic cavity or pleural cavity ventrally. The increased volume of the thoracic cavity **decreases the pressure on the lungs**. The relatively high atmospheric air pressure causes air to move passively into the lungs through the nostrils.

During **breathing out**, the system goes into **reverse** or **recoil**. The external intercostal muscles relax while the internal intercostal muscles contract, causing the ribs and sternum to move **downwards and inwards**. This **decreases volume of the thoracic** or **pleural cavity** laterally. At the same time, the diaphragm muscles relax, causing the diaphragm to **regain its dome shape**. This **decreases the volume of the thoracic** or **pleural cavity** ventrally. The decrease in volume of the thoracic or pleural cavity **increases pressure on the lungs**. The increased pressure, forces air out of the lungs through the nostrils, into the atmosphere.

4.2.11. Functions of Tissues and Organs in External and Internal Respiration

The exchange of gases (*i.e.*, O_2 and CO_2) between lung alveoli and pulmonary capillaries is called **external respiration**. The wall of alveoli is very thin and has rich network of blood capillaries. Thus, the alveolar wall is like a sheet of flowing blood, and is called **respiratory membrane**.

It is made up of three major layers (i) the thin squamous epithelium of alveoli, (ii) the endothelium of alveolar capillaries and (iii) the basement substance in between them. However, its total thickness is much less than a millimetre. The respiratory membrane has a limit of gaseous exchange between alveoli and pulmonary blood. It is called **diffusing capacity**. The diffusing capacity is defined as 'the volume of gas, that diffuses through the membrane per minute for a pressure difference of 1 mm Hg'. It is further dependent on the solubility of the diffusing gases. As the solubility of CO_2 is 20–25 times higher than that of O_2, the amount of CO_2 that can diffuse through the diffusion membrane per unit difference in partial pressure is much higher compared to that of O_2.

The partial pressure of oxygen (PO_2) in the alveoli is higher (104 mm Hg) than that in the deoxygenated blood in the capillaries of the pulmonary arteries (95 mm Hg). As the gases diffuse from a higher to a lower concentration, the movement of oxygen is from the alveoli to the blood. The reverse is the case in relation to carbon dioxide.

The partial pressure of carbon dioxide (PCO_2) is higher in deoxygenated blood (45 mm Hg) than in alveoli (40 mm Hg). Therefore, carbon dioxide passes from the blood to the alveoli.

Gaseous Exchange in Tissues. The exchange of gases (*i.e.*, O_2 and CO_2) between tissue blood capillaries and tissue cells is called **internal respiration**. The partial pressure of oxygen in the oxygenated blood is higher (95 mm Hg) than that of the tissue cells (40 mm Hg) and the partial pressure of carbon dioxide in the oxygenated blood is lesser (40 mm Hg) than that of the tissue cells (45 mm Hg). Therefore, oxygen diffuses from the capillary blood to the tissue cells through tissue fluid and carbon dioxide diffuses from the tissue cells of the capillary blood through tissue fluid.

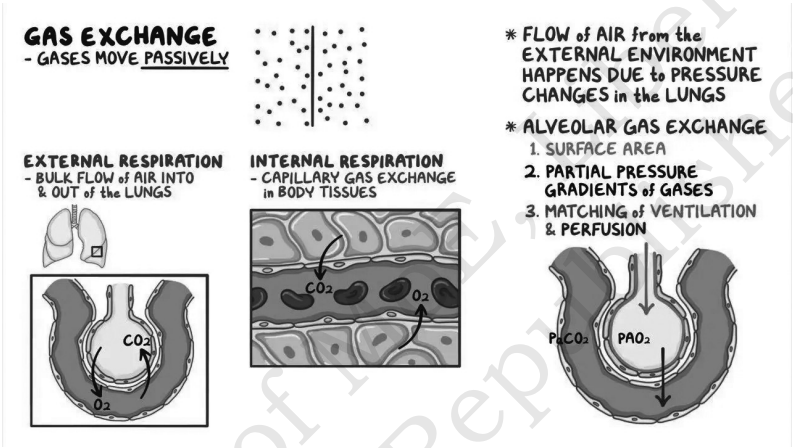


Fig. 4.13. Gas exchange in tissues

4.2.12. Inspiration and Expiration

Inspiration

It is a process by which fresh air enters the lungs. Inspiration occurs when the pressure within the lungs (intra-pulmonary pressure) is less than the atmospheric pressure, *i.e.*, there is a negative pressure in the lungs with respect to atmospheric pressure. The diaphragm and a specialised set of muscles **external intercostal muscles** between the ribs, help in generation of such gradients. Inspiration is initiated by the contraction of diaphragm which increases the volume of thoracic cavity in the anterioposterior axis. The contraction of external intercostal muscles lifts up the ribs and the sternum causes an increase in the volume of the thoracic chamber in the dorsoventral axis. The overall increase in the thoracic volume causes a similar increase in pulmonary volume. An increase in pulmonary volume decreases the intrapulmonary pressure to less than the atmospheric pressure which forces the air from the outside to move into the lungs.

The sequence of air flow during inspiration is:

External nares → Nasal chambers → Internal nares → Pharynx → Glottis → Larynx → Trachea → Bronchi → Bronchioles → Alveolar ducts → Alveoli.

Expiration

It is a process by which the foul air (carbon dioxide) is expelled out from the lungs. Normal expiration is a **passive process**. Relaxation of the diaphragm and contraction of the internal intercostal muscles returns the diaphragm and sternum to their normal positions. It reduces the thoracic volume and thereby the pulmonary volume. This leads to an increase in intrapulmonary pressure to slightly above the atmospheric pressure causing the expulsion of air from the lungs. The foul air follows the following route:

Alveoli → Alveolar ducts → Bronchioles → Bronchi → Trachea → Larynx → Glottis → Pharynx → Internal nares → Nasal chambers → External nares → Atmosphere.

Activity 2

To demonstrate the mechanism of breathing:

Materials Required: Transparent plastic bottle, Y-shaped glass or plastic tube, 2 balloons, plasticine, rubber sheet, rubber band.

Method:

- Take a wide transparent plastic bottle (a soft drink plastic bottle will do) and get someone to cut off its bottom.
- Make a hole through the bottle's cap.
- Fix and tie two deflated balloons at the two forked ends of a y-shaped glass or plastic tube.
- Introduce the tube fitted with the two deflated balloons from cut end of the bottle and pass the tube through the hole in the cap. Use plasticine to seal the cap and make it airtight.
- A thin rubber sheet is tied around the open base of the bottle using a large rubber band. Your apparatus is ready.
- In this apparatus, the space inside the bottle represents the chest cavity, the balloons represent the lungs, where as the rubber sheet represents the diaphragm.

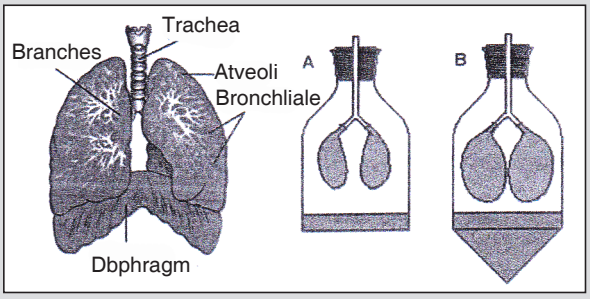


Fig. 4.14. (a) and (b) the action of diaphragm in breathing bottle-balloon experiment

Observation: (i) When you pull the rubber sheet downwards, the space inside the bottle increases lowering the air pressure inside the bottle. The air from outside rushes in through y-shaped tube into balloons, due to which the balloons get inflated (i.e. their size increases). This how you inhale air during breathing.

(ii) When you push the Rubber sheet up, the space inside the bottle decreases. This pushes out the air inside the balloons through the tube, due to which, the balloons get deflated (their size decreases). This is how you exhale air during breathing.

Conclusion: The action of rubber sheet in this activity shows, how we inhale and exhale air during breathing with the help of the downward and upward movement of the diaphragm in our body. When the diaphragm moves downward during inhaling, the lungs are filled with air. But when the diaphragm moves upward during exhaling, then the air is forced to go out of the lungs.

|| Do it Yourself ||

1. This provides passage for both food and air.
(a) Pharynx (b) Larynx
(c) Alveoli (d) Bronchi

2. During this process, the foul air (CO_2) is expelled out from the lungs.
(a) Expiration (b) Inspiration
(c) Warming (d) None of these

3. This is also known as voice box.
(a) Pharynx (b) Larynx
(c) Alveoli (d) Bronchi

4. During this process fresh air enters into the lungs.
   (a) Expiration (b) Inspiration
   (c) Warming (d) All of the above
5. This organ regulate the concentration of carbon (IV) oxide in the body
   (a) Kidney (b) Liver
   (c) Lungs (d) Alveoli

INFOBOX

Smoking tobacco in form of cigarette, beedi or cigar damages our lungs gradually and causes ill health. Smoking also causes lung cancer.

4.2.13. Vigourous Exercise Exemplifying Breathing

Even when you are resting, your muscles use up a certain amount of oxygen and glucose. This is because some of your muscle fibres are constantly contracting to keep you in position against the pull of gravity. Muscles are also involved in your life processes such as breathing and circulation of the blood. But when you begin to do heavy exercise, your muscles start contracting harder and faster. As a result they need more glucose and oxygen to supply their energy needs. During exercise the muscles also produce increased amounts of carbon dioxide, which needs to be removed for them to keep working effectively.

So during exercise, when muscular activity increases, your breathing rate increases and you breathe more deeply.

The energy released during gaseous exchange (respiration) is key to the survival of all living organisms

As we know all organisms are made of small microscopic units called **cells**. A cell is the smallest structural and functional unit of an organism. Each cell of an organism performs certain functions such as nutrition, transport, excretion and reproduction. To perform these functions, the cell needs energy. Even when we are eating, sleeping or reading we require energy. The food has stored energy, which is released during respiration. Therefore, all living organisms respire to get energy from food. During breathing, we breathe in air contains oxygen. We breathe out air which is rich in carbon dioxide. The air we breathe in is transported to all parts of the body and ultimately to each cell. In the cells, oxygen in the air helps in the breakdown of food. The process of breakdown of food in the cell with the release of energy.

In the cell, the food (glucose) is broken down into carbon dioxide and water using oxygen. Break down of food releases energy. Our muscle cells can also respire anaerobically, but only for a short time, when there is a temporary deficiency of oxygen. During heavy exercise, fast running, cycling, walking for many hours or heavy weight lifting, the demand for energy is high. But the supply of oxygen to produce the energy is limited. Then anaerobic respiration takes places in the muscle cells to fulfil the demand of energy:

4.2.14. Cellular Respiration

Cellular or tissues respiration, also known as **internal respiration**, is the oxidation or breakdown of digested or absorbed food to release energy, which is needed for life activities by all living organisms. It consists of two types: **aerobic respiration** and **anaerobic respiration**.

I. Aerobic Respiration

In aerobic respiration, organic food is completely oxidised with the help of oxygen (as terminal oxidant) into carbon dioxide and water. Aerobic respiration, occurs in mitochondria. 686 kcal or 2870 kJ of energy per molecules of glucose is liberated during aerobic respiration. The earlier estimate was 673 kcal.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzymes}} 6CO_2 + 6H_2O + \text{Energy (686 kcal/2870 kJ)}$$

II. Anaerobic Respiration

In anaerobic respiration, organic food is oxidised incompletely without oxygen being used as oxidant. Anaerobic respiration occurs in the cytoplasm and releases a small amount of energy. The common products of anaerobic respiration are carbon dioxide and ethyl alcohol or lactic acid. During anaerobic respiration, water is not produced.

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2CO_2 + \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + \text{Energy (59 kcal/247 kJ)}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} \underset{\text{Lactic acid}}{2C_3H_6O_3} + 36 \text{ kcal/150 kJ)}$$

Anaerobic respiration, is the only mean of respiration in some microorganisms (*e.g.*, yeast and some bacteria) and parasitic worms. In microorganisms, the term **fermentation** is often used in place of anaerobic respiration.

4.2.15. Differences between Anaerobic and Aerobic Respiration

Table 3.1. Difference between Anaerobic and Aerobic Respiration

Anaerobic Respiration		Aerobic Respiration	
1.	It does not utilize molecular oxygen.	1.	It uses molecular oxygen.
2.	It may or may not release carbon dioxide.	2.	It always releases carbon dioxide.
3.	It provides less energy.	3.	It provides much more energy.
4.	It occurs in cytoplasm.	4.	It completes both in cytoplasm (glycolysis) and in the mitochondria (Krebs cycle and electron transport chain).
5.	It occurs in anaerobic bacteria, yeasts, muscles and parasitic worms like *Ascaris*, *Taenia*, *Fasciola*, etc.	5.	It occurs in most of plants and animals.

4.2.16. Characteristics of Anaerobic and Aerobic Respiration

Characteristics of Anaerobic respiration

- The anaerobic respiration is, that this respiration does not need any oxygen content to continue this process.
- The anaerobic respiration is this respiration significantly happens in mitochondria.
- The outcome of this type of anaerobic respiration is alcohol and some energy.

Characteristics of aerobic respiration

- The aerobic respiration is this respiration needs oxygen content to move this process.
- The aerobic respiration is this respiration majorly occurs in the cytoplasm and as well as mitochondria.
- The outcome of this type of aerobic respiration is carbon dioxide and water.

4.2.17. Major Stages in Cellular Respiration

Cellular respiration can be divided into four main sequential stages: glycolysis, the link reaction, the Krebs cycle (also referred to as the citric acid cycle), and electron transport chain.

A. Glycolysis

Glycolysis is common to both aerobic and anaerobic modes of respiration and is therefore called **common pathway**. Glycolysis is the first stage in the breakdown of glucose and is common to all organisms. It occurs in the cytosol and results in the breakdown of glucose or similar hexose sugar into two molecules of a three carbon compound—pyruvic acid, releasing some energy (as ATP) and reducing power (as $NADH_2$). The steps of glycolysis are described below:

1. **Phosphorylation**

   Glucose phosphorylated to glucose-6-phosphate by ATP in the presence of enzyme *hexokinase* and Mg^{2+}.

2. **Isomerisation**

   Glucose-6-phosphate is changed into its isomer, fructose-6-phosphate with the help of enzyme *phosphohexose isomerase* (= *phos-phoglucoisomerase*).

3. **Phosphorylation**

   Fructose-6-phosphate is phosphorylated by ATP to form fructose 1, 6-diphos-phate in presence of enzyme *phospho-fructokinase* and Mg^{2+}.

   Phosphorylation of glucose to fructose 1, 6-diphosphate activates the sugar and prevents it from getting out of the cell.

4. **Splitting**

   Fructose 1, 6-diphosphate is then broken down into two molecules of triose phosphate (3 carbon sugars), *viz*. glyceraldehyde-3 phosphate (PGAL) and dihydroxyacetone phosphate (Di-HAP). The reaction is catalysed by enzyme *aldolase*. Dihydroxy acetone phosphate is further converted into glyceraldehyde 3 phosphate with the help of *enzyme phosphotriose isomerase*.

5. **Dehydrogenation and Phosphorylation**

   Each glyceraldehyde 3-phosphate molecule loses hydrogen to NAD^+ to form NADH + H^+ and accept inorganic phosphate from phosphoric acid (H_3PO_4) to form 1, 3-diphosphoglycerate in the presence of enzyme *triose-phosphate dehydrogenase*.

6. Dephosphorylation (ATP Formation)

One of the two phosphates of 1, 3-diphosphoglycerate is linked by high energy bond. In the presence of enzyme *phosphoglycerate kinase*, 1, 3-diphosphoglycerate is converted to 3-phosphoglycerate. One molecule of ATP is phosphorylated to ATP in the reaction. Formation of ATP directly from metabolites is known as **substrate level phosphorylation**.

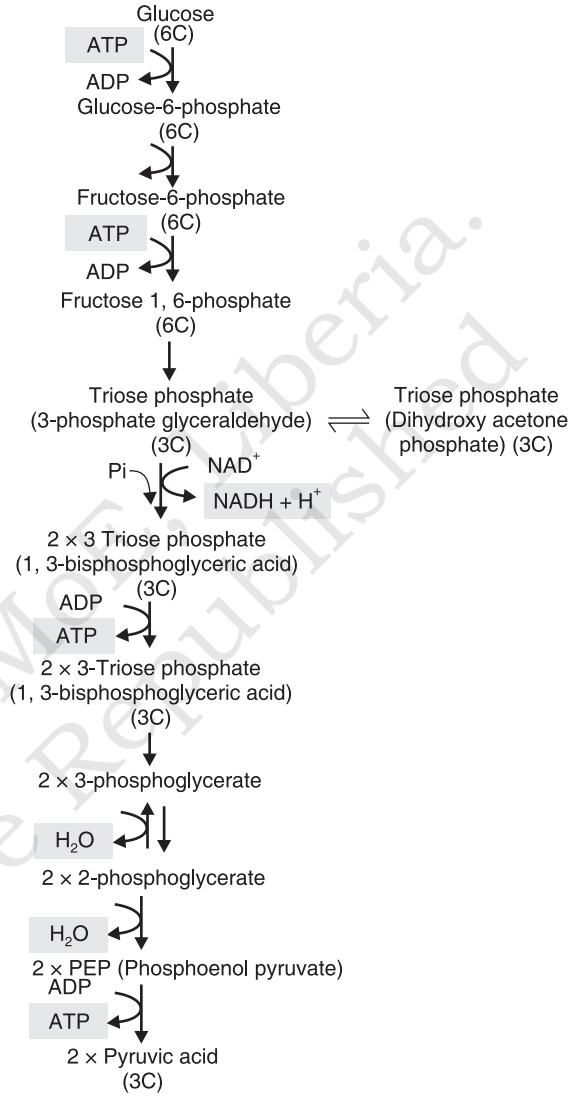


Fig. 4.15. Schematic representation of glycolysis

7. Isomerisation

3-phosphoglycerate is changed to its isomer 2-phosphoglycerate by the enzyme *phosphoglyceromutase*.

8. Dehydration

2-phosphoglycerate loses a molecule of water in the presence of enzyme *enolase* and Mg^{2+}, and changes into phosphoenol pyruvate.

9. Dephosphorylation (ATP Formation)

High energy phosphate group of phosphoenol pyruvate is transferred to a molecule of ADP with the help of the enzyme *pyruvate kinase* in the presence of Mg^{2+} and K^{+}. This produces pyruvate and a molecule of ATP by **substrate level phosphorylation**.

Net Product of Glycolysis. In glycolysis, two molecules of ATP are consumed during double phosphorylation of glucose to form fructose 1, 6-diphosphate. In return four molecules of ATP are produced by substrate level phosphorylation (conversion of 1, 3-diphosphoglycerate to 3-phosphoglycerate and phosphoenol pyruvate to pyruvate) and two molecules of $NADH_2$ are formed at the time of oxidation of glyceraldehyde 3-phosphate to 1, 3-diphosphoglycerate. The whole process may be expressed as under:

$$\text{Glucose} + 2NAD^+ + 2ADP + 2H_3PO_4 \longrightarrow 2\text{Pyruvate} + 2NADH + 2H^+ + 2ATP.$$

Two molecules of NADH + H^+ on oxidation produce 6 molecules of ATP. Therefore, a net gain of 8ATP molecules occurs during glycolysis.

Pyruvate and its Fate

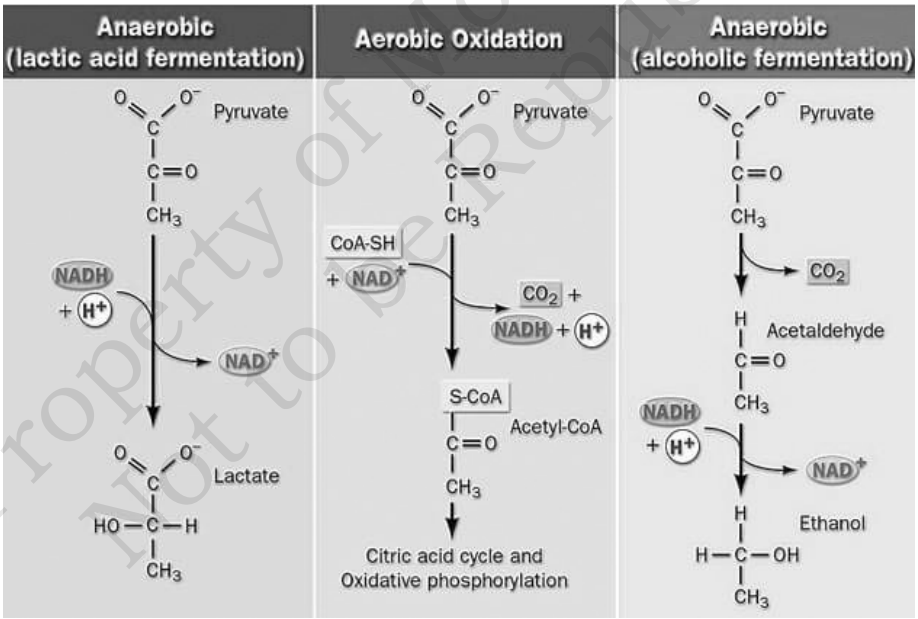


Fig. 4.16. Three fates of pyruvate produced by glycolysis

Pyruvate can enter in lactic acid fermentation and alcoholic fermentation in anaerobic condition, in aerobic condition pyruvate loss hydrogen and carbon dioxide and convert into acetyl CoA and enter into the TCA cycle, and also enter into the biosynthetic pathway. In the case of low glucose levels, pyruvate enters into gluconeogenesis.

B. Link Reaction

The link reaction refers to the stage of respiration that "links" glycolysis to the Krebs (citric acid) cycle. In this stage, the products of glycolysis are converted into the reactants of the Krebs cycle. The final product of glycolysis is a pyruvate molecule. The pyruvate molecule is transported from the cytoplasm, the site of glycolysis, to the mitochondria for the rest of the cellular respiration processes. After the pyruvate is transported into the mitochondria, it is now ready to undergo a series of changes in the link reaction to be ready to enter the Krebs cycle. A simple outline of the link reaction is given.

In the link reaction, the 3-carbon compound pyruvate (or pyruvic acid) is converted into the 2-carbon compound acetyl coenzyme A. In a series of steps, the pyruvate molecule undergoes the following changes:

1. Pyruvate loses a carbon atom to become a 2-carbon compound.
2. This carbon atom is released in the form of carbon dioxide.
3. The 2-carbon compound is oxidized, and it transfers electrons to NAD.
4. The coenzyme NAD becomes reduced NAD (NADH) as it gains a hydrogen and two electrons.
5. Coenzyme A combines with the 2-carbon compound to form acetyl coenzyme A.

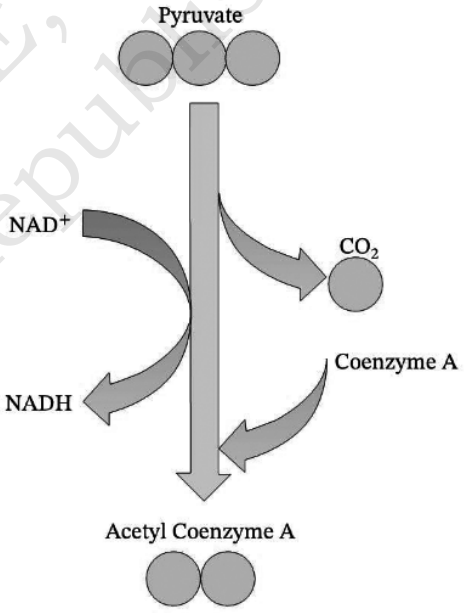


Fig. 4.17. An illustration of link reaction

C. Kreb's Cycle or TCA Cycle

The cycle is also named as **Citric acid cycle or Tricarboxylic acid cycle (TCA)** after the initial product. Krebs cycle is stepwise oxidative and cyclic degradation of acetyl CoA derived from pyruvate. Krebs cycle occurs in mitochondrial matrix and serves as a common oxidative pathway for carbohydrates, fats and proteins.

The actual citric acid cycle or Krebs cycle begins when acetyl CoA enters into a reaction to form citric acid. It explains how pyruvate is

broken down to CO_2 and water. It also highlighted the concept of cycles in metabolism.

The various steps of Krebs cycle are as follows:

1. **Dehydrogenation.** Isocitrate is dehydrogenated to oxalosuccinate in the presence of enzyme *isocitrate dehydrogenase* and Mn^{2+}. A pair of hydrogen atoms is released which is accepted by NAD^+ to form NADH + H^+.

$$\text{Isocitrate} + NAD^+ \xrightarrow[Mn^{2+}]{\text{Isocitrate Dehydrogenase}} \text{Oxalosuccinate} + NADH + H^+$$

2. **Decarboxylation.** Oxalosuccinate is decarboxylated to form a 5-carbon α-ketoglutarate in the presence of enzyme *decarboxylase*, one molecule of carbon dioxide is released in the reaction.

$$\text{Oxalosuccinate} \xrightarrow{\textit{Decarboxylase}} \alpha\text{-ketoglutarate} + CO_2$$

3. **Dehydrogenation and decarboxylation.** α-ketoglutarate is both dehydrogenated (with the help of NAD^+) and decarboxylated by an enzyme complex α-*ketoglutarate dehydrogenase*. The enzyme complex contains TPP and lipoic acid. The product combines with CoA to form a 4-carbon succinyl CoA.

$$\alpha\text{-ketoglutarate} + CoA + NAD^+ \xrightarrow[TPP,\ Lipoic\ acid,\ Mg^{2+}]{\alpha\textit{-ketoglutarate Dehydrogenase}} \text{Succinyl CoA} + NADH + H^+ + CO_2$$

4. **Formation of GTP/ATP.** Succinyl CoA splits into succinate and CoA in the presence of enzyme succinyl thiokinase. The reaction releases sufficient energy to form GTP (in animals) and ATP (in plants).

$$\text{Succinyl CoA} + GDP/GTP + H_3PO_4 \xrightarrow{\textit{Succinylthiokinase}} \text{Succinate} + CoA + GTP/ATP$$

5. **Dehydrogenation.** Succinate undergoes dehydrogenation to form 4-carbon fumarate with the help of enzyme *succinate dehydrogenase* and liberates a pair of hydrogen atom. The latter pass to FAD (Flavin adenine dinucleotide) to form $FADH_2$.

$$\text{Succinate} + \text{FAD} \xrightleftharpoons{\textit{Succinate dehydrogenase}} \text{Fumarate} + \text{FADH}_2$$

6. **Hydration.** Fumarate is changed into 4-carbon malate with the addition of water in the presence of enzyme *fumarase*.

$$\text{Fumarate} + \text{H}_2\text{O} \xrightleftharpoons{\textit{Fumarase}} \text{Malate}$$

7. **Dehydrogenation.** Malate is dehydro-genated in the presence of enzyme malate *dehydro-genase* to produce 4-carbon oxaloacetate. Hydrogen is accepted by $NAD^+/NADP^+$.

$$\text{Malate} + NAD^+/NADP^+ \xrightleftharpoons{\textit{Malate dehydrogense}} \text{oxaloacetate} + NADH/NADPH + H^+$$

Oxaloacetate picks up another molecule of activated acetate to repeat the cycle.

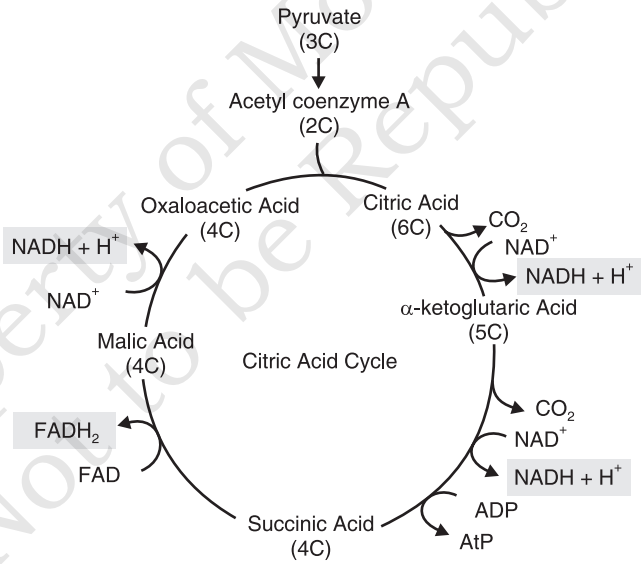


Fig. 4.18. The Citric acid cycle

D. Electron Transport Chain

As the Krebs cycle spins round and round, it generates high-energy electrons that are passed on to NADH and $FADH_2$. These carriers then pass on the electrons to the *electron transport chain*. The electron transport chain uses the high-energy electrons from the Krebs cycle to convert ADP to ATP.

1. High-energy electrons from NADH and $FADH_2$ are passed into and along the electron transport chain. In eukaryotes, the chain is composed of a series of *carrier proteins* that are located in the inner membrane of the mitochondria. In prokaryotes, the same chain is found in the cell membrane. High-energy electrons pass on to carrier proteins to the next and at the end of the chain is an *enzyme* that combines electrons from the chain with *hydrogen ions* and *oxygen* to form water (H_2O). Oxygen serves as the final acceptor of the electron transport chain, Oxygen is important in order to get rid of low-energy electrons and hydrogen ions, which are the wastes of cell respiration.
2. During electron transport, H^+ ions build up in the intermembrane space making it positively charged. The other side of the membrane is now negatively charged.
3. The inner membranes of the mitochondria contain protein spheres called *ATP synthases*. As ATP synthases rotate, the enzyme grabs a low energy ADP and attaches a *phosphate* forming ATP. Each pair of high-energy electrons that moves down the electron transport chain provides enough energy to convert 3 ADP into 3 ATP molecules.

E. Oxidative Phosphorylation

Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated by oxidation of reduced coenzymes ($NADH_2$, $FADH_2$) produced during respiration. The enzyme required for their synthesis is called *ATP synthetase*. It is present in F_1 or head piece of F_0–F_1 or elementary particle. The particles are located in the inner mitochondrial membrane. The enzyme *ATP synthetase* becomes active in ATP formation only when there is proton gradient, having higher concentration of protons on the F_0 side (outer side) as compared to F_1 side (inner side).

Because of the higher proton concentration outside the inner membrane, protons return to the matrix down the proton gradient. Just as a flow of water from a higher to a lower level can be utilised to turn a water wheel or a hydroelectric turbine, the energy released by the flow of protons down the gradient is utilised in synthesising ATP. The enzyme *ATP synthetase* synthesises ATP from ADP and inorganic phosphate using the energy from the proton gradient.

Transport of two electrons from NADH + H^+ by the electron transport chain simultaneously transfers three pairs of protons to the outer compartment. One high energy ATP bond is produced per pair of protons returning to the matrix through the inner membrane particles. Therefore, oxidation of one molecule of $NADH_2$ produces 3 ATP molecules, while that of $FADH_2$ forms only 2 ATP molecules, as the latter donates its electron further down the chain.

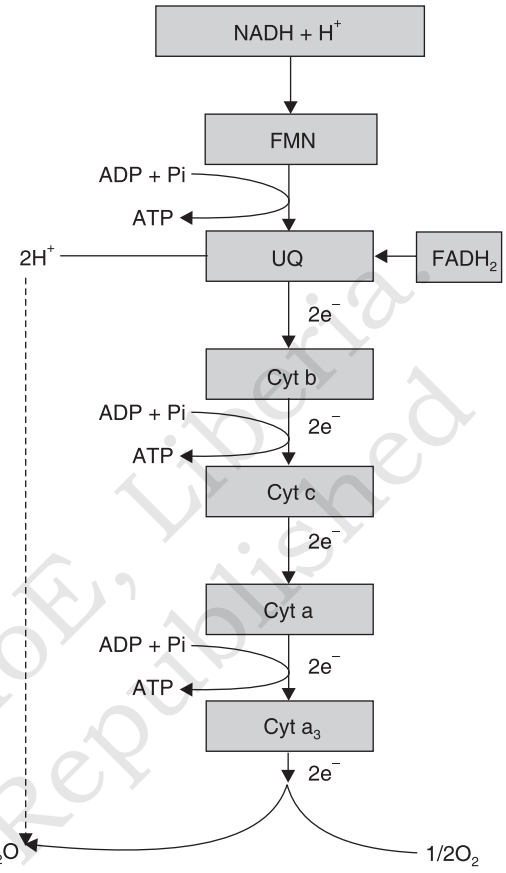


Fig. 4.19. A simplified system of terminal oxidation and oxidative phosphorylation

4.2.18. Coenzymes and Respiration

Coenzyme A

- A coenzyme is a molecule that **helps an enzyme carry out its function** but is **not used in the reaction itself.**
- Coenzyme A consists of a nucleoside (ribose and adenine) and a vitamin.
- In the link reaction, CoA binds to the remainder of the pyruvate molecule (acetyl group 2C) to form acetyl CoA.
- It then **supplies the acetyl group to the Krebs cycle** where it is used to continue aerobic respiration.
- This is the stage that brings part of the carbohydrate (or lipid/ amino acid) into the further stages of respiration and **links** the initial stage of respiration in the cytoplasm to the later stages in the mitochondria.

NAD & FAD

- **Coenzymes** NAD and FAD play a critical role in aerobic respiration as hydrogen carriers.
- When hydrogen atoms become available at different points during respiration NAD and FAD accept these hydrogen atoms
  - o A hydrogen atom consists of a hydrogen ion and an electron
- When the coenzymes gain a hydrogen they are '**reduced**'
- They **transfer the hydrogen atoms** (**hydrogen ions** and **electrons**) from the different stages of respiration to the **electron transport chain** on the inner mitochondrial membrane, the site where hydrogens are removed from the coenzymes
- When the hydrogen atoms are removed the coenzymes are '**oxidised**'
- Hydrogen ions and electrons are important in the electron transport chain at the end of respiration as they play a role in the **synthesis of ATP**
  - **Electrons** from reduced NAD (NADH) and reduced FAD ($FADH_2$) are given to the electron transport chain
  - **Hydrogen ions** from reduced NAD (NADH) and reduced FAD ($FADH_2$) are released when the electrons are lost
  - The electron transport chain drives the movement of these hydrogen ions (protons) across the inner mitochondrial membrane into the intermembrane space, creating a proton gradient (there are more hydrogen ions in the intermembrane space)
  - Movement of hydrogen ions down the proton gradient, back into the mitochondrial matrix, gives the energy required for ATP synthesis

$$NAD + 2H \underset{\text{OXIDATION}}{\overset{\text{REDUCTION}}{\rightleftharpoons}} NADH + H^+$$

$$FAD + 2H \underset{\text{OXIDATION}}{\overset{\text{REDUCTION}}{\rightleftharpoons}} FADH_2$$

The reduction and oxidation of NAD and FAD

4.2.19. Nicotinamide Adnine Dinucleotide (NAD) and Dehydrogenase

Anzymes

NAD (Nicotinamide adenine dinucleotide) is a coenzyme found in all cells. It is an electron carrier used to temporarily store energy during cellular respiration. This is found in two forms in cells. NAD is an oxidizing agent–it electrons from other molecules and becomes reduced. This reaction forms NADH, which can then be used as a reducing agent to donate electrons. These electron transfer reactions are the main function of NAD.

Dehydrogenase is an oxidoreductase enzyme, which takes part in redox reactions. They transfer two hydrogens from organic compounds to the electron carriers such as NAD+ and thereby oxidise the organic compounds. E.g. glyceraldehyde-3-phosphate dehydrogenase, pyruvate dehydrogenase, succinate dehydrogenase, isocitrate dehydrogenase and α-ketoglutarate dehydrogenase, etc.

4.2.20. Alcoholic Fermentation

It occurs in fungi (*e.g.*, *Rhizopus*, yeast) and bacteria. Yeast can respire both aerobically and anaerobically. Anaerobic respiration occurs in sugary solution causing fermentation. If the fungus is not in contact with atmosphere, pyruvate first undergoes decaboxylation (removal of carboxyl group in the form of carbon dioxide) with the help of enzyme pyruvate *decarboxylase*, *transacetylase*, Mg^{2+} and TPP (thiamine pyrophosphate). This produces acetaldehyde and carbon dioxide from pyruvic acid.

$$\text{Pyruvate} \xrightarrow[Mg^{2+},\ TPP]{\textit{Pyruvate decarboxylase}} \text{Actaldehyde} + CO_2$$

Acetaldehyde then accepts hydrogen from $NADH_2$ and is reduced to ethyl alcohol (ethanol) producing oxidised NAD^+. The process is catalysed by the enzyme *alcohol dehydrogenase*.

$$\text{Acetaldehyde} + NADH + H^+ \xrightarrow{\textit{Alcohol dehydrogenase}} \text{Alcohol} + NAD^+$$

Accumulation of ethanol by fermentation in a culture of yeast may stop further multiplication and lead to the death of cells. In the presence of oxygen, however, yeast can respire aerobically.

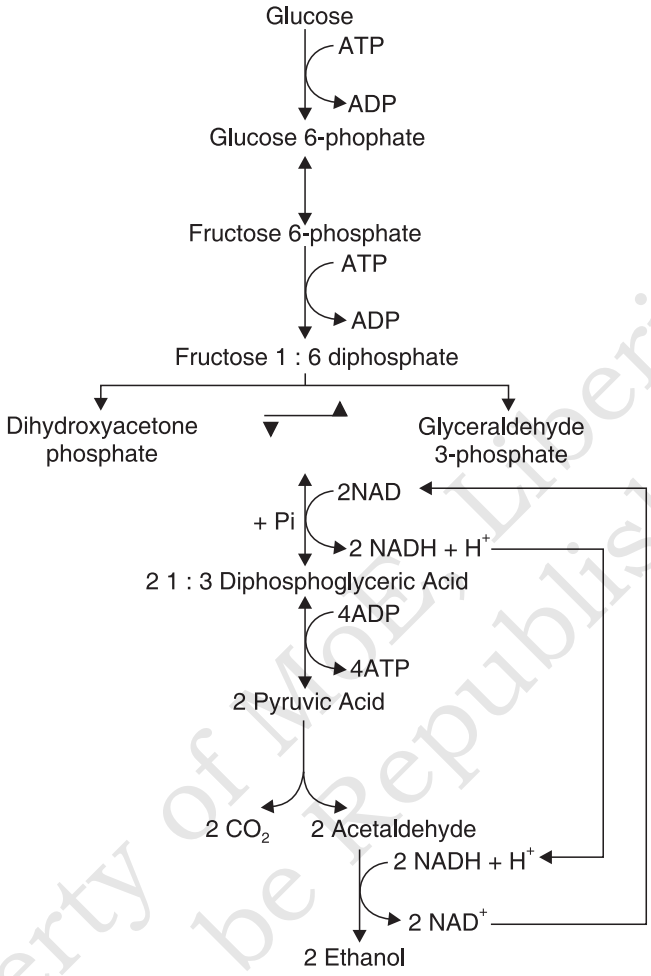


Fig. 4.20. Pathway of anaerobic respiration (fermentation) in yeast

INFOBOX

Cyanide is a deadly poison beloved of crime writers. It smells faintly of almonds and once you have taken it, you quickly die. Cyanide kills because it stops the reactions of respiration in your mitochondria. If you give individual cells cyanide, all active transport stops as their energy supply dries up. But if you supply the cells with energy in the form of ATP, even though the mitochondria are still poisoned, active transport starts again.

4.2.21. Anaerobic Respiration in Muscles and Oxygen Dept

Anaerobic Respiration in Muscles

Generally, we obtain energy by aerobic respiration. But under certain conditions (when extra energy is needed), anaerobic respiration can take place in our muscles for a short time. When the oxygen supplied by the blood, use up faster in our muscle cells, then a temporary deficiency of oxygen occurs in the muscle cells. For example, when we do a heavy physical exercise (fast running, cycling or weight lifting), our muscles need a lot of energy, but the supply of oxygen to produce the energy is limited. In other words, during heavy exercise, demand of energy is more but the supply of energy is less. To fulfill the demand of extra energy anaerobic respiration takes place in our muscle cells in the absence of oxygen. Then, the food breaks down into lactic acid and releases some energy. This extra energy helps us in doing hard physical exercise. The breaking down of glucose (food) during anaerobic respiration in muscles to release some energy. This extra energy helps us in doing hard physical exercise. The breaking down of glucose (food) during anaerobic respiration in muscles to release energy can be represented by a word equation is follows:

$$\text{Glucose (food)} \xrightarrow[\text{(Anaerobicrespiration in muscles)}]{\text{No oxygen}} \text{Lactic acid + Energy}$$

After a heavy exercise (very fast running, cycling, etc), we sometimes get muscle cramps. The muscle cramps occur when muscle cells respire anaerobically. The partial breakdown of glucose produces lactic acid. The accumulation of lactic acid in the muscle cells causes muscle cramps. We get relief from cramps after a hot water bath or a massage. Hot water bath or massage increases the circulation of blood in these muscles. As a result, the supply of oxygen results in the complete breakdown of lactic acid into carbon dioxide and water and hence, gives us relief from cramps.

Oxygen debt occurs when the body reaches a state of anaerobic respiration during intense exercise. When a person engages in high levels of physical activity, the body cannot distribute oxygen to the cells at a sufficiently rapid pace to keep up with the oxygen demand. This results in an oxygen deficit as the cells continue to produce energy but need additional oxygen to process the lactic acid produced during the process.

4.2.22. Distinguish Oxidation and Reduction with Regards to Oxygen, Hydrogen and Electrons

	Oxidation	Reduction
1.	Losing electrons	Gaining electrons
2.	For a given compound losing hydrogen	For a given compound gaining hydrogen
3.	Gain of oxygen	Loss of oxygen

4.2.23. Interpret the Balanced Chemical Equation for Respiration

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Explanation:

It is important to know that the equation listed above is a summary equation. The process of cellular respiration involves many different steps (reactions) to break down glucose using oxygen to produce carbon dioxide, water and energy in the form of ATP.

The **6 carbon** atoms present in a glucose molecule make it possible to form **6 carbon dioxide** molecules.

The **12 hydrogen** atoms in the glucose make it possible for form **6 water** molecules.

To balance the oxygen atoms for the reactant side, you need to count 6 atoms from the glucose. In order to form the 6 molecules of carbon dioxide and 6 molecules of water you will have a total of 18 oxygen atoms on the product side (6 × 2) + (6 × 1) = 18. In order to get 18 oxygen atoms on the reactant side you need an additional 12 oxygen atoms from oxygen O_2 to balance the numbers.

The process of cellular respiration will produce 36 ATP molecules in Eukaryotes (plant/animal etc.) for every one glucose molecule. The process will produce 38 ATP molecules for every one glucose in Prokaryotes (bacteria).

4.2.24. Elecron Carriers

A **flavoprotein** located on the matrix face of the inner mitochondrial membrane and functions as a specific electron acceptor for primary dehydrogenases, transferring the electrons to terminal respiratory systems such as electron-transferring-flavoprotein dehydrogenase.

In these electron transport systems, the **quinones** act as an electron carrier when they diffuse across membranes after being reduced by an

external electron donor and then oxidized by an encapsulated electron acceptor.

Cytochromes are the electron carriers present in the electron transport chain. Cytochrome c acts as a mobile carrier and shuttles electrons between immobile integral membrane macromolecule complex. Complex III and IV contain cytochromes within macromolecules, which are embedded in the membrane.

Activity 3

If you carry out a single repetitive action such as stepping up and down or lifting a weight or a book from the bench to your shoulder time after time, you will soon feel the effect of a build-up of lactic acid in your muscles.

You will need:

- book, or other weight that can be held easily in one hand
- stopwatch or clock with clear second hand

Method:

1. Work in pairs.
2. One member of the pair takes the weight in one hand, with their lower arm flat on the surface of the bench or desk. During the investigation lift the weight regularly from the desk to your shoulder and back down again, taking about one second for each movement. Wait to be told when to start.
3. The other member of the pair starts the stopwatch and gives the instruction to start lifting at the same time.
4. Record how long it takes before the first aching in the muscles start - indicating the beginning of fatigue and the production of lactic acid in the muscles - and how long it takes before you can no longer continue lifting.
5. Swap roles and then repeat the investigation.
6. Collect data from the whole class on the time taken for the first awareness of fatigue to develop and the total time before lifting stops and produce graphs or bar charts to help you analyse the information. What is the range of times for the class? What are the average and the mean times before fatigue develops and before exercise stops? What factors might be affecting the time exercise continues?

Do it Yourself

1. In anaerobic respiration, organic food is oxidised incompletely. (True/False)
2. During anaerobic respiration water is not produced. (True/False)
3. Fermentation is often used in aerobic respiration. (True/False)
4. During oxidation, electrons are lost. (True/False)
5. Loss of oxygen occurs in reduction. (True/False)

KEY GLOSSARY

- **Metabolism:** It is the process by which your body converts you eat and drink into energy.
- **Homeostasis.** It is the maintenance of a constant internal environment.
- **Coenzyme.** A coenzyme is a molecule that helps an enzyme to carry out its function.
- **Oxidation.** Gain of oxygen is called oxidation.
- **Reduction.** Loss of oxygen is termed as reduction.
- **Fermentation.** It is a metaboli process that produces chemical changes in organic substances by the action of enzymes.
- **Micturition.** The act of expulsion of urine from the urinary bladder.
- **Vigourous.** Heavy exercises.

SUMMARY

- Excretion is the removal of **metabolic waste products** from the body of living organisms.
- Kidneys are reddish brown, bean shaped structures situated between the levels of last thoracic and third lumber vertebra close to the dorsal inner wall of the abdominal cavity.
- The primary function of the kidneys is the elimination of excess water and wastes from the bloodstream by the production of the liquid waste known as urine.

- Internally, the urinary bladder has a triangular area, the **trigone**, between the three openings—two openings through which the ureters enter the bladder and one opening through which urethra leaves the bladder.
- The epithelial cells of colon transfer certain inorganic ions such as calcium, magnesium and iron from the blood into the cavity of colon for removal with faeces.
- Excretion refers to the process of the body eliminating toxins or waste products. The excretory system consists of numerous organs in the body that all contribute to the removal of waste products and toxins.
- The process of excretion may be divided into three stages—filtration, selective reabsorption and tubular secretion.
- The human respiratory system consists of lungs, pharynx, larynx, alveoli, bronchi and bronchioles.
- Homeostasis is the maintenance of a constant internal environment. The cells in the body of multicellular organisms are able to carry out their metabolic functions perfectly.
- Cocaine is a controlled substance that is typically snorted or smoked. This type of use can result in numerous respiratory issues.
- The exchange of gases (*i.e.*, O_2 and CO_2) between lung alveoli and pulmonary capillaries is called external respiration.
- The exchange of gases (*i.e.*, O_2 and CO_2) between tissue blood capillaries and tissue cells is called **internal respiration**.

EXERCISES

A. Multiple Choice Questions.

1. This process is the removal of metabolic wastes from the body of living organisms.

(a) Excretion (b) Respiration

(c) Circulation (d) Digestion

2. Our lungs remove about 18 litres of

(a) CO_2 (b) O_2

(c) NaCl (d) NaOH

3. The sweat glands secrete an aqueous fluid called
(a) sweat (b) water
(c) urine (d) oil

4. The colour of urine is due to pigment
(a) cytochrome (b) urochrome
(c) chlorophyll (d) none of these

5. Inspiration is initiated by the contraction of
(a) diaphragm (b) lungs
(c) kidneys (d) liver

6. The exchange of gases between lungs and alveoli is called
(a) external respiration (b) Internal respiration
(c) both (a) and (b) (d) None of these

7. Phosphorylation is step of this
(a) Kreb's cycle (b) glycolysis
(c) digestive systems (d) excretion

8. Sucrose is converted into glucose and fructose by the enzyme.
(a) Convertase (b) Vertase
(c) Invertase (d) None of these

9. The process of oxidation of food by using oxygen is called
(a) aerobic respiration (b) anaerobic respiration
(c) both (a) and (b) (d) none of these

10. Functional unit of kidney is
(a) nephron (b) neuron
(c) nephritis (d) loop of Henle

B. Fill in the Blanks.

1. _____ are reddish brown, bean shaped structure.

2. _____ _____ help to protect the kidney.

3. Urethra carries only _____ .

4. _____ contains water, some inorganic salts, and traces of urea.

5. The _____ regulate the water and salts balance in the body.

6. The glottis bears a leaf like cartilaginous flap, the _____ at its anterior margin.

7. _____ is often used in place of anaerobic respiration.

8. _____ is common to both aerobic and anaerobic modes of respiration.

9. Reduction is _____ of oxygen.
10. Oxidation is _____ of oxygen.

C. Match the following.

	Column A		Column B
1.	Kidney	a.	Respiratory organ
2.	Urethra	b.	Store urine
3.	Skin	c.	Nephron.
4.	Liver	d.	Bilirubin
5.	Pharynx	e.	Sweat
6.	Oxidation	f.	Hexokinase
7.	Reduction	g.	Gain of oxygen
8.	Fermentation	h.	Glycolysis
9.	Common pathway	i.	Yeast
10.	Phosphorylation	j.	Loss of oxygen

D. Very Short Answer Questions.

1. Name one organ of excretory system.
2. Write function of urethra.
3. Name two bile pigments.
4. Define homoeostasis.
5. What is pleurae?
6. What are the types of respiration?
7. Write chemical formula of aerobic respiration.

E. Short Answer Type Questions.

1. What do you understand by aerobic respiration?
2. Write one function of each of following.
   a. Kidney b. Urethra
   c. Liver d. Lungs
3. Define Internal Respiration.
4. Write chemical equation of anaerobic respiration.
5. Give two differences between oxidation and reduction.
6. What is the role of diaphragm muscles in respiration, intercostal.

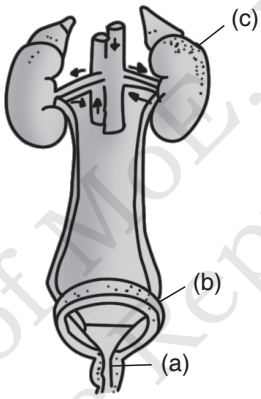
F. Long Answer Type Questions.

1. Describe the process of excretion.

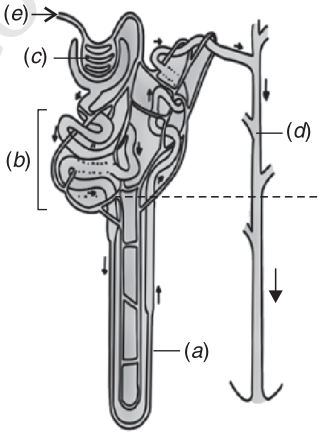
2. Differentiate aerobic and anaerobic respiration.
3. Describe external and internal respiration.
4. What are the effects of substance abuse on the organs of two systems.
5. Explain the process of urination.
6. What are the role of coenzymes in respiration?

G. Diagram Based Questions

1. Answer the following questions related to the given figure.
(i) Identify the given figure.
(ii) Name the parts labelled as (b), (c) and (a).
(iii) Give one major function of each of these parts.



2. Answer the following question related to the given figure.
(i) Identify the given figure.



(ii) Name the parts labelled as (*a*), (*b*), (*c*), (*d*) and (*e*).
(iii) Give one major function of each of these parts.