UNIT

14

RESPIRATION

KEY CONCEPTS

Energy is the most important requirement of life. All systems require energy to w ork. The various processes carried out by body, such as movement, growth and reproduction, all require the expenditure of energy. In animals this energy can be obtained only from the food they eat. In the processes of cellular respiration this food energy is made available for the body activities. Aerobic respiration involves the use of oxygen and the production of carbon dioxide. Oxygen enters into animal's body from air or water surrounding it. In the less complex animals the oxygen is absorbed over the entire exposed surface of the body. In higher animals, however, there are special respiratory organs such as gills or lungs. Excess carbon dioxide is usually eliminated from the same organ.

14.1 PROPERTIES OF RESPIRATORY SURFACES

The area where gaseous exchange with the environment actually takes place is called the respiratory surface. Gaseous exchange takes place in all organisms by the physical process of diffusion. For effective diffusion the respiratory surface must have the following properties.

- It must be permeable, so that gases can pass through it.
- It must be thin for efficient diffusion, because diffusion is only efficient over distance of 1 mm or less.
- It should possess a large surface area so that sufficient amounts of gases are able to be exchanged according to the organism's need.
- It should possess a good blood supply.
- There should be a good ventilation mechanism to maintain a steep diffusion gradient across the respiratory surface.

14.2 HUMAN RESPIRATORY SYSTEM

Respiratory system provides the fundamental ability to breath. This system consists of nose and nasal cavities, pharynx, larynx, trachea, bronchi, bronchioles, and alveoli in the lungs.

14.2.1 Nose

The nose is only externally visible part of the respiratory system. The structure of a human nose is composed of bones, cartilage and fibro fatty tissues. The external feature of a nose depends upon the ethmoid bone and the cartilages.

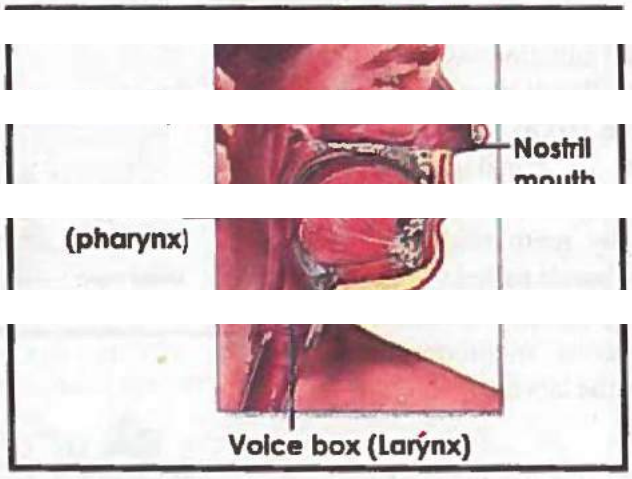


Fig:14.1 Nasal passage through face

Hairs are present inside the nostrils that help in the filtration of air. Hence, nose hair serve as a defense mechanism against the harmful pathogens and solid particulate matter present in the air. Both the nostrils and nasal cavities are lined by mucous membranes along with cilia. The mucous membrane secretes a sticky substance called mucus. The mucus and cilia filter the air and prevent the entry of foreign particles such as microorganisms, dust and particulate matter inside the respiratory system. The mucus also helps in moistening the air. Cilia move the trapped substances to the pharynx for their removal. Underneath the mucous membrane, there are blood capillaries that help to warm the air to about 30 °C, depending upon the external temperature.

14.2.2 Pharynx

Pharynx is cone-shaped passageway leading from the oral and nasal cavities to the oesophagus and larynx. The pharynx is part of both the digestive and respiratory systems.

For Your Information

The interconnection of the oral and nasal regions is extremely beneficial in humans. It allows them to breathe through either the nose or the mouth and, when medically necessary, allows food to be passed to the esophagus by nasal tubes.

14.2.3 Larynx

Larynx is an organ of complex structure that serves as a dual function: as an air canal to the lungs and controller of its access, and as the organ of voice. The **larynx** is composed of an external skeleton of cartilage plates that prevents collapse of the structure. The plates are fastened together by membranes and muscle fibers. Two fibrous bands called vocal cords are located in the larynx. The vocal cords are composed of mucous membrane stretched horizontally across the larynx.

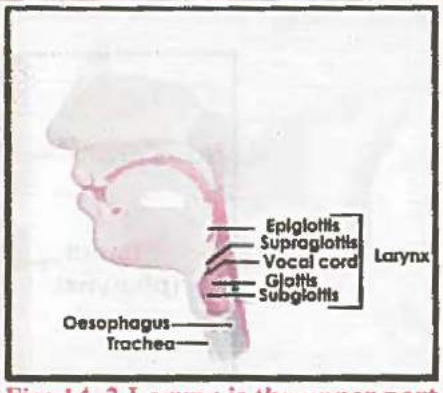


Fig: 14. 2 Larynx is the upper part of the respiratory system.

14.2.4 Trachea

Below the larynx lies the trachea, a tube of 10 to 12 cm long and 2cm wide. Its wall is stiffened by 16 to 20 characteristic horse shoe shape incomplete rings that open towards the back and are embedded in a dense connective tissue.Trachea is lined with ciliated mucus membrane. The trachea serves as passage for air, moistens and warms it while it passes into the lungs, and protects therespiratory surface from an accumulation of foreign particles.

tidbit

Men and women have different vocal cord sizes. This difference in size causes a difference in vocal pitch. Adult males have larger cords and usually low pitched voices.

14.2.5 Bronchi

The trachea divides into two stem bronchi, one each for the left and right lung. The right bronchus has a larger diameter, and is shorter than the left bronchus. Structure of bronchi closely resembles that of the trachea; however they have small cartilaginous plates to support their walls. The bronchi divide and re-divide forming an air way network in the lungs.

Skills

Analyzing and Communicating

Draw and label a diagram to illustrate microscopic features of human lung with the help of slides.

14.2.6 Bronchioles

The bronchioles are located at the end of the bronchi and terminate in the alveoli. The bronchioles are approximately 1mm or less in diameter and their walls consist of ciliated cuboidal epithelium and a layer of smooth muscle.

The bronchioles are the first airway branches that do not contain cartilage. They are responsible for controlling air distribution in the lungs. The bronchioles change diameter to either increase or reduce air flow. The bronchioles continue to divide and subdivide deep into the lungs. Eventually the terminal bronchioles open into small collections of air sacs known as alveoli, where the actual exchange of carbon dioxide and oxygen occur.

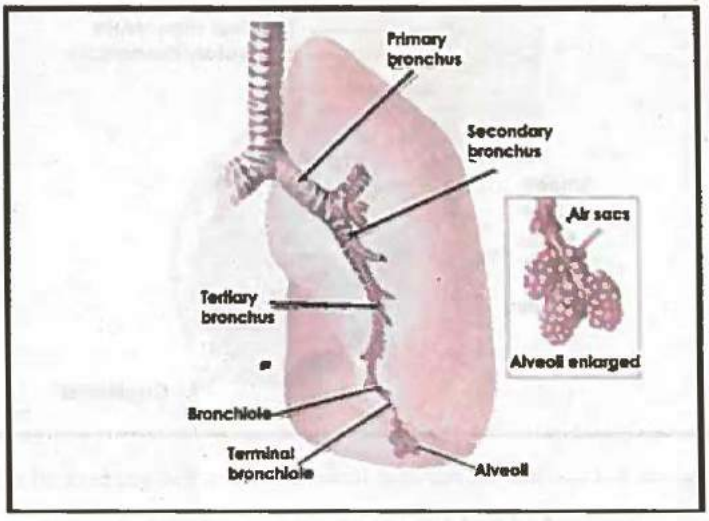


Fig:14.3 Branching of trachea leads to a netwok of airway passages.

14.2.7 Alveoli

The alveoli form the gas exchange surface. The wall of each alveolus is only 0.1 μm thick. On its outsides is a dense network of blood capillaries. Lining each alveolus is moist squamous epithelium.

tidbit

There are over 700 million alveoli present in the lungs, representing a total surface area of 70-90m.

This consists of very thin, flattened cells, reducing the distance over which diffusion must occur. Collagen and elastic fibres are also present which allow the alveoli to expand and recoil easily during breathing.

14.2.8 Lungs

Human have two lungs, a right and a left, which are located in the thoracic cavity. Together, the lungs occupy most of the intra thoracic space. The

right and left lungs are slightly unequal in size. The right lung represents 56% of the total lung volume and is composed of three lobes, a superior, middle, and inferior lobe. The left lung, smaller in volume because of the asymmetrical position of the heart, has only two lobes. In the thorax the two lungs rest with their bases on the diaphragm, while their apexes extend above the first rib.

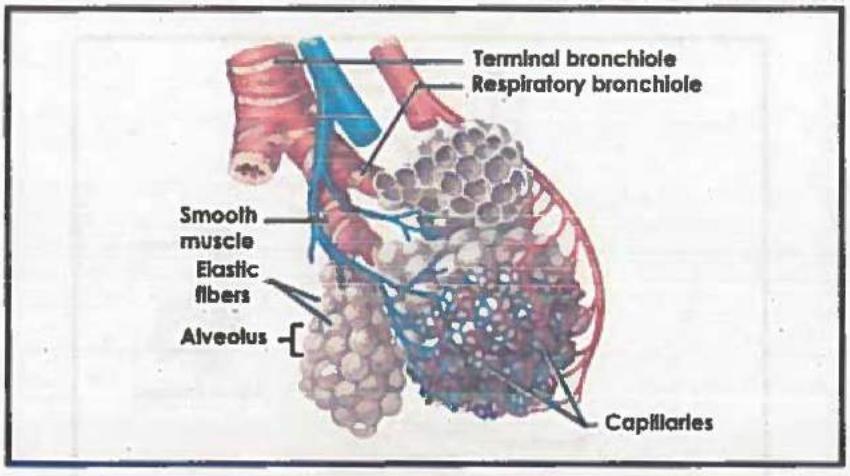


Fig:14.4 Capillaries form a network over the surface of alveoli.

Skills

(Analyzing and Interpreting)

Trace the path of air through different parts of human respiratory tract.

For Your Information

Special cells in the alveolus wall secrete a detergent like chemical on to the inside lining of the alveolus. This is called a surfactant. It lowers the surface tension of the fluid layer lining the alveolus, and thereby reduces the amount of effort needed to breathe in and inflate the lungs. Surfactants also help to kill any bacteria which reach the alveoli.

Each lung is encased in a thin membranous sac called the pleura. It consists of two tough, flexible, transparent pleural membranes. These protect the lungs, stop them leaking air into the thoracic cavity and reduce friction between the lungs and the wall of the thorax.

14.3 LUNG VOLUMES AND CAPACITIES

Lung volumes and lung capacities refer to the volume of air associated with different phases of the respiratory cycle. The average adult human has a lung capacity of approximately 5 liters but only a small amount of this capacity is used during normal breathing.

- Tidal volume is the volume of air exchanged during one breath in and out in quiet breathing. This is about 500 ml
- Residual volume is the volume of air remaining in the lungs even after a forcible expiration. This is about 1.5 liter.

14.4 CONTROL OF BREATHING

Normally breathing is an involuntary process and is not controlled consciously. However, some voluntary control is also possible.

14.4.1 Involuntary control

Involuntary control of breathing is carried out by a breathing centre located in the medulla oblongata. The ventral portion of the breathing centre acts to increase the rate and depth of inspiration and is called inspiratory centre. The dorsal and lateral portions inhibit inspiration and stimulate expiration and form the expiratory centre.

For Your Information

Oxygen concentration also has an effect on the breathing rate. However, under normal circumstances there is an abundance of oxygen available, and its influence is relatively minor. About 20% decrease in oxygen concentration in the air produce a doubling in breathing rate. Oxygen concentration also has an effect on the breathing rate. However, under normal circumstances there is an abundance of oxygen available, and its influence is relatively minor. About 20% decrease in oxygen concentration in the air produce a doubling in breathing rate.

Skills

(Analyzing and Interpreting)

Identify different parts of the respiratory system of a dissected frog (dissection would be done by the teacher).

The breathing centre communicates with the intercostal muscles by the intercostals nerves and with the diaphragm by the phrenic nerves. Rhythmic nerve impulses to the diaphragm and intercostal muscles bring about breathing movements. We know that breathing consists of two phases namely breathing in or inspiration and breathing out or expiration.

Inspiration (Inhalation)

In human, inspiration is an active process. During inspiration, the intercostal muscles between the ribs contract and pull the ribs forward and outward, pushing the sternum farther away from the vertebral column. By the contraction of the intercostal muscles and of the diaphragm the size of the thorax as a whole is increased and the pleural cavities within it are, therefore enlarged. Since the pleural cavities are closed, their enlargement tends to create a partial vacuum within them. The lungs are elastic and communicate with the atmosphere through the air passages (trachea, bronchi). As soon as the pressure around the lungs is lowered, the air rushes into them through the trachea by its own pressure and dilated them. In this way the lungs expand to fill the pleural cavities and the pressure on the inside and outside of the thorax are equalized. Thus the mechanism of human breathing is a suction –pump mechanism. The lungs are made to expand and contract by movements of the ribs and diaphragm.

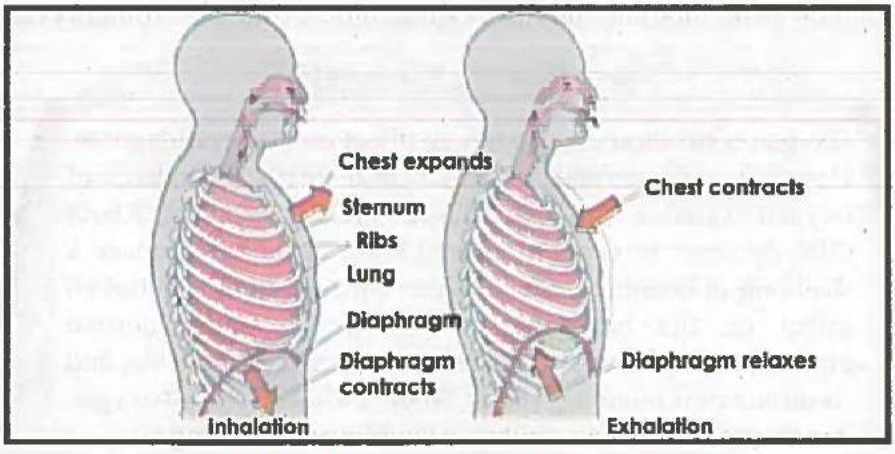


Fig:14.5 Inhalation and exhalation mechanism.

Expiration (Exhalation)

Expiration in human is normally passive. In severe muscular exercise however, the expiration also becomes active. During expiration, the intercostal muscles of the ribs relax, the ribs move down ward and inward. Thus the size of the chest cavity is reduced from side to side. The sternum comes to its original position, decreasing the size of the chest cavity from front to back or dorso –ventrally. At the same time muscles of the diaphragm relax and so the diaphragm assumes its dome shaped position. Thus the relaxation of the muscles of diaphragm and of the intercostals muscles the size of the thorax as a whole is decreased and the pleural cavities within are, therefore, reduced. This reduction in the size of the thorax exerts pressure on the lungs. The lungs themselves are very elastic and tend to return to their original size. When the lungs are pressed, the foul air inside them is expelled or expiration occurs.

14.4.2 Voluntary control

Within limits, the rate and depth of breathing are also under voluntary control as is evident by the ability to hold the breath. Voluntary control is also used during forced breathing, speech, singing, sneezing and coughing. During voluntary control impulses originate from the cerebral hemispheres and pass to the breathing centre.

14.5 MECHANISM OF TRANSPORT OF GASES

Like other materials, respiratory gases are also transported in various regions of the body by means of blood. The blood transports oxygen from the lungs to different tissues and carbon dioxides from tissues to the lungs.

14.5.1 Transport of oxygen in blood:

Approximately 97% of oxygen is carried by the red blood cells as **oxyhaemoglobin**, while 3% is transported as dissolved oxygen in the **plasma**.

At high partial pressure of oxygen, oxygen binds with haemoglobin. This binding is a rev[illegible] of the lungs in the presence of enzyme carbonic anhydrase. Each molecule of haemoglobin can bind with four molecules of oxygen to form oxyhaemoglobin.

$$Hb + 4O_2 \xrightarrow{\text{Carbonic anhydrase}} Hb4O_2$$

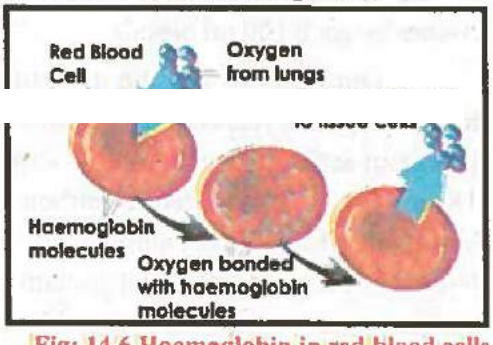


Fig: 14.6 Haemoglobin in red blood cells carry oxygen in the blood.

The ability of haemoglobin to bind with oxygen is called **oxygen carrying capacity** of blood. The oxygen carrying capacity of blood is directly proportional to the partial pressure of oxygen (PO_2). Maximum oxygen carrying capacity of arterial blood is 20 ml/100 ml of blood (100% saturated) which is achieved at 100 mmHg PO_2.

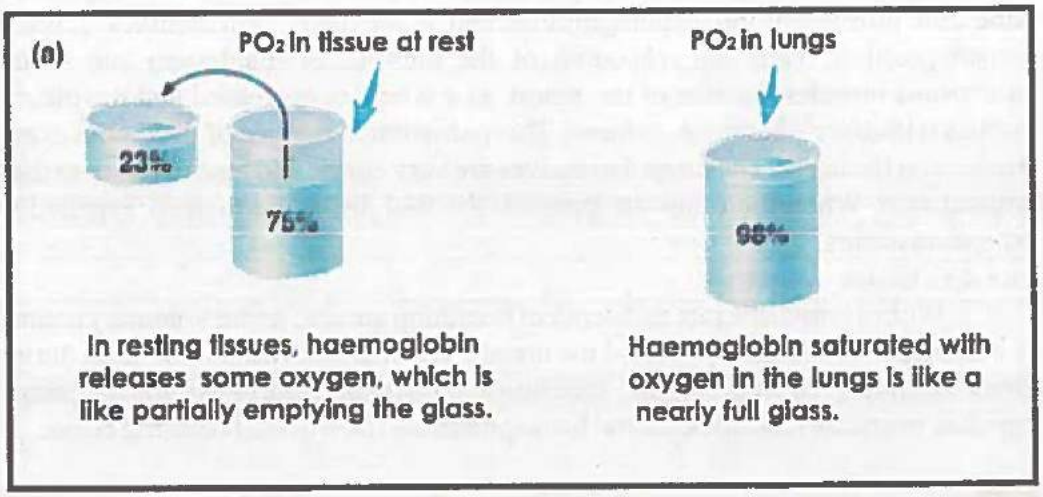


Fig: 14.7

This is because the amount of haemoglobin is 15 gms/100 ml of blood. Since 1gm Hb can combine with 1.34 ml of O_2, therefore 100 ml blood combines with 20 ml O_2 (100% saturated). Normally each 100 ml of arterial blood contains 19.4 ml O_2 (i.e. it is 97% saturated; PO_2 is 95 mmHg), while 100 ml of venous blood contains 14.4 ml O_2 (i.e. it is 75% saturated; PO_2 is 40 mmHg). Thus, 5 ml of O_2 is released to the tissues by each 100 ml blood.

During exercise, the need of oxygen is greatly increased in the tissues so more oxygen is released by the arterial blood to the tissues. The venous blood that leaves an active tissue has only 4.4 ml O_2 per 100 ml of blood (20% saturated; PO_2 is 18 mmHg). Compared to carbon dioxide, oxygen is relatively insoluble in the blood, therefore a small amount of O_2 is transported in dissolved state in the plasma. Normally each 100 ml blood contain 0.29 ml O_2 (PO_2 is 95 mmHg) and this capacity may increase up to 0.3 ml/100 ml blood at 100 mmHg PO_2.

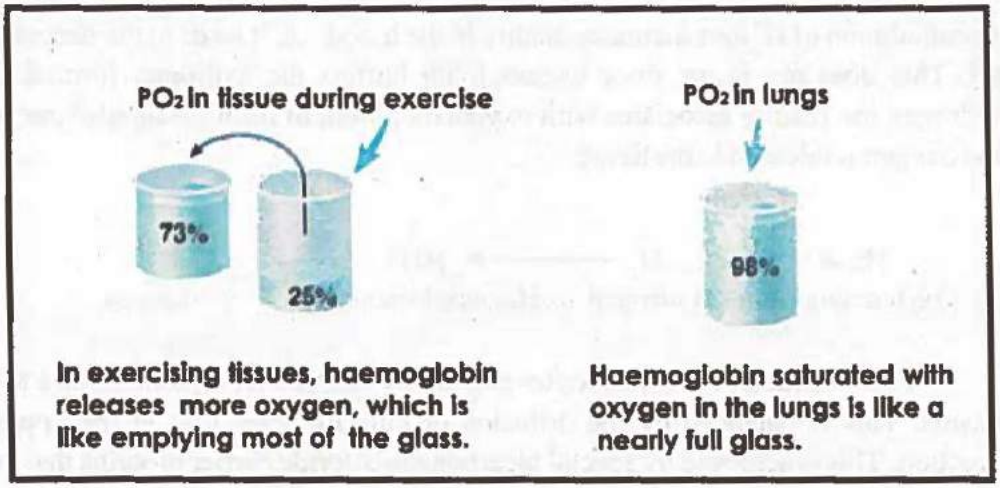


Fig: 14. 8

While the 100 ml of venous blood has 0.12 ml of dissolved O_2 (PO_2 is 40 mmHg). Thus, 0.17 ml of O_2 is transported by each 100 ml blood through the tissues per cycle in the dissolved state.

14.5.2 Transport of Carbon dioxide:

Carbon dioxide is transported in the blood in three main ways i.e. in the form of bicarbonate ions, in the form of carboxyhaemoglobin and dissolved in plasma.

(i) As bicarbonate ions:

Approximately 70% of carbon dioxide is carried in the blood as bicarbonate ions. Carbon dioxide diffuses into the blood and combines with water to form carbonic acid in the presence of enzyme carbonic anhydrase. The chemical reaction can be depicted as follows:

$$CO_2 + H_2O \underset{\text{Carbonic anhydrase}}{\rightleftharpoons} H_2CO_3$$

Carbonic acid, H_2CO_3 is an unstable compound and dissociate to form hydrogen ions and bicarbonate ions.

$$H_2CO_3 \underset{\text{Carbonic anhydrase}}{\rightleftharpoons} H^+ + HCO_3^-$$

Accumulation of H^+ ions increases acidity in the blood, i.e. it leads to the decrease in pH. This does not occur since haemoglobin buffers the hydrogen formed. The hydrogen ion readily associates with oxyhaemoglobin to form haemoglobinic acid and oxygen is released to the tissue.

$$\underset{\text{Oxyhaemoglobin}}{Hb.4O_2} + \underset{\text{Hydrogen}}{H^+} \longrightarrow \underset{\text{Haemoglobinic acid}}{HHb} + \underset{\text{Oxgen}}{4O_2}$$

From inside of the erythrocytes negatively charged HCO_3^- ions diffuse to the plasma. This is balanced by the diffusion of chloride ions, Cl-, in the opposite direction. This is achieved by special bicarbonate-chloride carrier proteins that exist in the RBC membrane. This protein moves the two ions in opposite directions, maintaining the balance of ions on either side. This is called the **chloride shifts** or **Hamburger's phenomenon.**

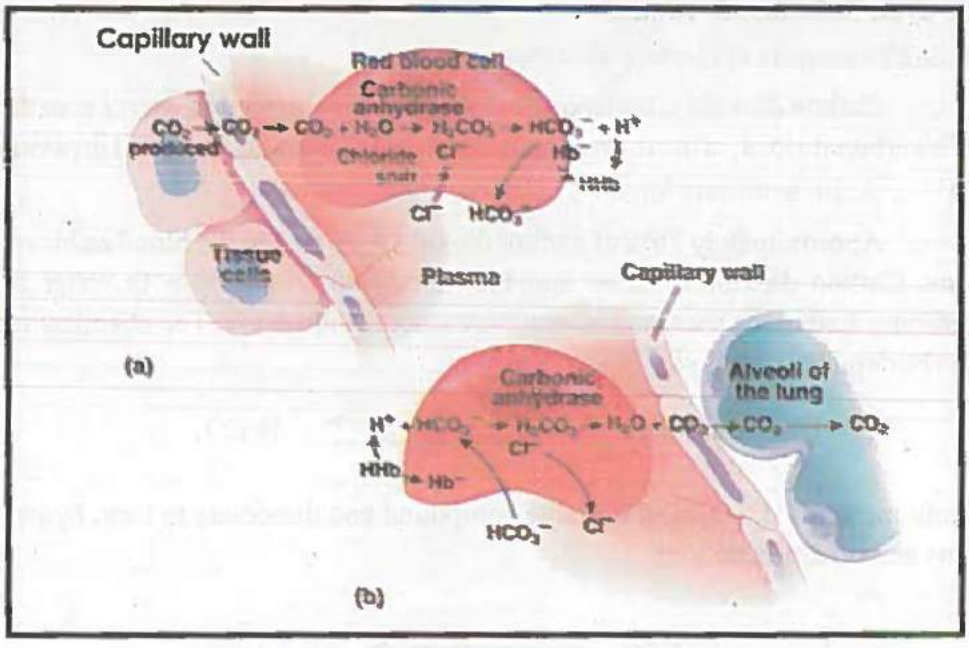


Fig: 14. 9 Mechanism of transport of carbondioxide.

The chloride ions that enters the RBC combine with potassium (K+) to form potassium chloride, whereas bicarbonate ions in the blood plasma combines with Na+ to form sodium bicarbonates.

Skills
(Initiating and Planning)

Examine some sheep's lungs obtained from butcher's shop.

For Your Information

All vertebrates use the haemoglobin as respiratory pigment that transports gases in the body, whereas invertebrates have respiratory pigments like haemocyanin (in Molluscs), haemoerythrin (in some marine animals) and chlorocruorin (in annelids). Haemoglobin is bright red when oxygenated, and dark red when deoxygenated, oxygenated haemocyanin is blue in color, deoxygenated is almost colourless. Oxygenated chlorocruorin turns green where oxygenated haemoerythrin is a violet to pink colour, and colourless when deoxygenated. **Do you think why human blood is of red colour?** In colored diagrams of human circulatory system, venous blood is generally represented by blue color. **Do you think our venous blood is really of blue color?**

The blood pH is thus maintained at approximately 7.4 by the buffer mechanism that exists in blood. Transport of CO_2 depends on the partial pressure of CO_2. In case the partial pressure of CO_2 is higher in tissues than blood, the reaction proceeds as drawn above. However, in case the partial pressure of CO_2 is higher in the blood than outside of the blood (as in case of the lungs), the equation reverse and bicarbonate ions with hydrogen ion to release carbon dioxide and water.

(ii) As Carbaminohaemoglobin:

About 23% of carbon dioxide is carried as carbaminohaemoglobin. CO2 combines with the globin part of haemoglobin. The reaction depends upon the partial

pressure of CO_2. When the PCO_2 is higher in the tissues than blood, formation of carbaminohae[illegible] in case of lungs, carbaminohaemoglobin releases its CO_2.

(iii) As dissolved CO_2 in plasma:

Only 7% of carbon dioxide is carried this way. This is rather inefficient way to carry carbon dioxide, but it does occur.

14.6 RESPIRATORY PIGMENTS

A respiratory pigment is a molecule that involves in transport or storage of respiratory gases. In human, haemoglobin that increases the oxygen-carrying capacity of the blood and myoglobin that stores oxygen in muscles are referred as respiratory pigments.

14.6.1 Haemoglobin:

Haemoglobin is the iron-containing oxygen-transport metalloprotein in the red blood cells of almost all vertebrates. Haemoglobin in the blood carries oxygen from the respiratory organs (lungs or gills) to the rest of the body (i.e., the tissues). Here it releases the oxygen to burn nutrients to provide energy. This energy is used to power the functions of the organism, and collects the resultant carbon dioxide to bring it back to the respiratory organs to be dispensed from the organism.

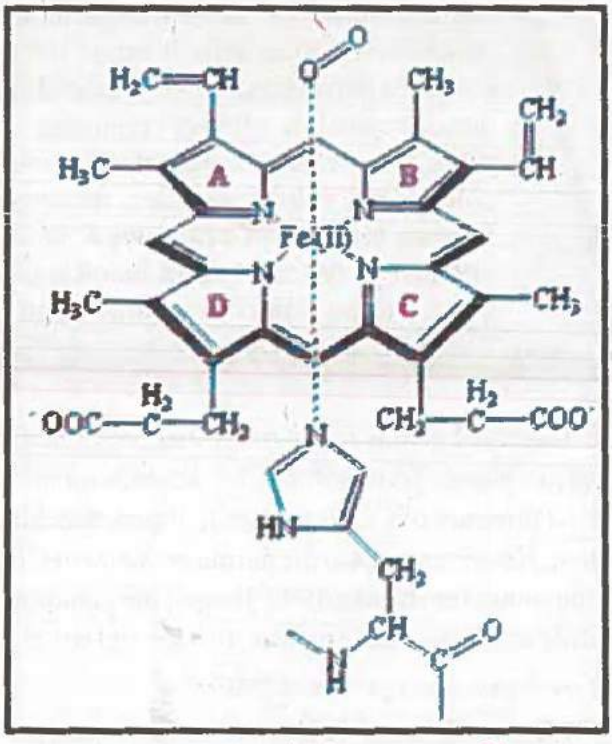


Fig: 14.10 Chemical structure of haeme group is haemoglobin

14.6.2 Myoglobin

Myoglobin (Mb) is an O_2 carrying protein that binds and releases O_2 with changes in the cytoplasm of muscle cells.

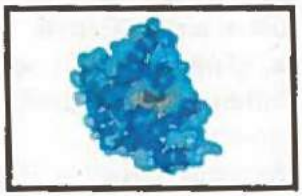


Fig:14. 11 Myoglobin

14.7 RESPIRATORY DISORDERS

Whenever respiratory tract is exposed to an unhealthy atmosphere, it is likely to become infected by various organisms. The infections may occur in upper as well as in lower respiratory tract. Most common problems of upper and lower respiratory tract are given below.

Upper Respiratory Disorders

14.7.1 Sinusitis:

Sinusitis is an inflammation of the nasal sinuses that may be acute (symptoms last 2 - 8 weeks) or chronic (symptoms last much longer). The sinuses are holes in the skull between the facial bones. There are four large sinuses: two inside the cheekbones (the maxillary sinuses) and two above the eyes (the frontal sinuses). The sinuses are lined with membranes that secrete antibody-containing mucus, which protects the respiratory passages from the irritants in the air we breathe.

Causes and Risk Factors of Sinusitis

It is usually caused by infection (bacterial or viral), but can also be caused by allergic reactions dust, pollen etc. Environmental agents, such as excessive dryness in homes and offices from dry-air heating and air-conditioning systems can also inflame the sinuses.

Symptoms of Sinusitis

The classic symptoms of acute (short lasting) sinusitis are:

- fever
- nasal obstruction

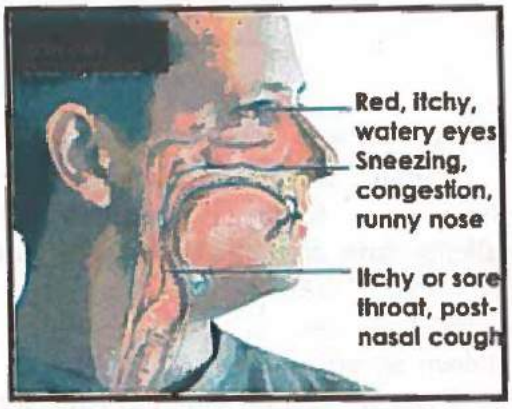


Fig:14. 12 Some of the symptoms of sinusitis

- pus-like (purulent) nasal discharge
- loss of sense of smell
- facial pain or headache
- Entering of nasal fluid into pharynx)

Treatment of Sinusitis

If a bacterial infection is present, antibiotics, or sulfa drugs, are usually prescribed.

Antiallergic and decongestants are also used for treatment of sinusitis.

14.7.2 Otitis Media

Otitis media is an inflammation of the middle ear. The eustachian tubes equalize the pressure between the middle ear cavity and the outside mucus to drain out of the middle ear cavity.

Inflammation of the middle ear causes the tubes to close causing the fluid to become trapped. Bacteria travel from the back of the nose through the fluid in the eustachian tube directly into the middle ear cavity and multiply in the fluid.

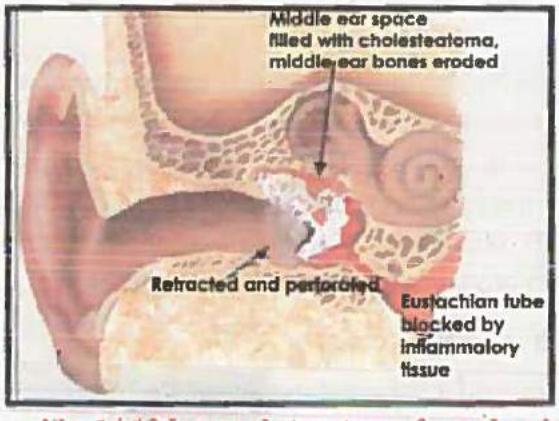


Fig: 14.13 Internal structure of ear showing region of middle ear.

Causes and Risk Factors of Otitis Media

Children are more commonly affected than adults because of the small size and horizontal position of their eustachian tube. The four main causes of otitis media are allergy, infection, blockage of the eustachian tube and nutritional deficiency.

Symptoms of Otitis Media

Otitis media causes

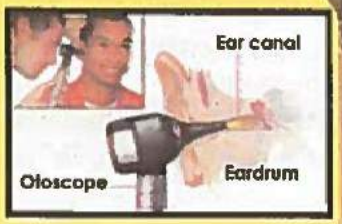
- sudden, severe earache
- deafness, and tinnitus (ringing or buzzing in the ear)
- sense of fullness in the ear
- irritability

- fever, headache, a change in appetite or sleeping patterns
- fluid leaking from the ear, nausea
- difficulty in speaking and hearing

Occasionally, the eardrum can burst, which causes a discharge of pus and relief of pain.

For Your Information

An Otoscope or auriscope is a medical device which is used to look into the ears. Otoscope consists of a light source and a simple low-power magnifying lens.



Treatment of Otitis Media

Around 80% of cases of otitis media clear up within three or four days without treatment. Perforated eardrums also usually heal on their own without the need for treatment. However, for complicated cases, following treatment options may be taken into consideration.

- Antibiotics may be prescribed to treat severe cases of middle ear infection or cases that get worse after two or three days.
- Painkillers, may be used to control the main symptoms of middle ear infection (pain and fever).

For Your Information

For children with recurrent, severe middle ear infections, tiny tubes may be inserted through the eardrum to help drain fluid. These tubes are called grommets or tympanostomy tubes.Sometime a small hole is made in the eardrum surgically to allow fluid to drain out. This surgical operation is called myringotomy

Lower Respiratory track Infections

14.7.3 Pneumonia

Pneumonia is a serious disorder of lower respiratory tract which is characterized by inflammation of alveolar wall and the presence of fluid and pus in

alveolar sacs of one or both lungs.

Causes and Risk Factors of Pneumonia

There are over 30 different causes of pneumonia, but usually pneumonia is caused by bacterial infection (including mycoplasma) and viruses, which can enter the body through the mouth, nose and eyes. If the body's resistance is down, the natural immunity against diseases is weakened then microorganisms are free to spread into the lungs. Thus, alveoli become filled with fluid and pus from the infectious agent, making it more difficult for the body to get the oxygen it needs, and the person may become sick.

The bacteria that cause bacterial pneumonia are *Streptococcus pneumonia*, *Hemophilus influenzae*, *Legionella pneumophilia*, *Staphylococcus aureus*, and *Mycoplasma*.

If pneumonia is not treated timely, some complications may arise that include pleural effusion (fluid around the lung), empyema (pus in the pleural cavity), hyponatremia (low blood sodium) and rarely, an abscess in the lung.

Symptoms of Pneumonia

Symptoms vary, depending on the type of pneumonia and the individual.

- With bacterial pneumonia, the person may experience shaking, chills, chattering teeth, severe chest pain, very high fever, sweating, rapid breathing, rapid pulse rate
- With viral pneumonia, the person may experience fever, dry cough, headache, muscle pain and weakness. These flu-like symptoms may be followed within one or two days by increasing breathlessness, dry cough becomes worse and produces a small amount of mucus, higher fever, bluish color to the lips
- With mycoplasma pneumonia, the person may experience violent coughing

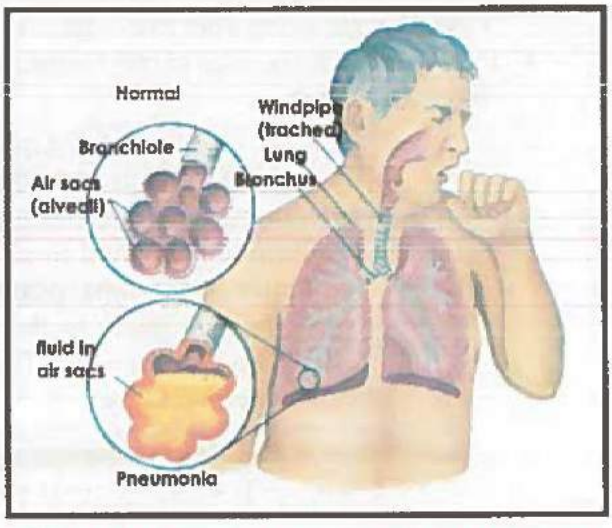


Fig: 14.14 In pneumonia body is unable to get proper amount of oxygen due to Fluid in the air sacs.

attacks, chills, fever, nausea, vomiting, slow heartbeat, and breathlessness, bluish color to lips and nail beds, diarrhoea and muscle aches.

Treatment of Pneumonia

Tre

causing the infection. Mostly antibiotics are prescribed.

14.7.4 Tuberculosis

Tuberculosis (TB) is a highly contagious chronic bacterial infection of lungs. TB infection begins when the mycobacteria reach the alveoli, where they invade and replicate within the phagosomes (vacuole formed as a result of phagocytosis) of alveolar macrophages, but they are unable to digest the bacterium.

Causes:

TB is caused by the *Mycobacterium tuberculosis* that is transmitted from person to person by airborne droplets. Usually this infection is passed on as a result of very close contact, so family members of an infected person are in dangered if the person continues to live in the same household and has not undergone proper treatment.

tidbit

About 15 percent of TB patients may develop the disease in an organ other than the lung, such as the lymph nodes, GI tract, bones and joints.

Risk factors for TB include the following:

HIV infection, low socioeconomic status, alcoholism, homelessness, crowded living conditions, diseases that weaken the immune system, migration from a country with a high number of cases, and health-care workers.

Symptoms of Tuberculosis

You may not notice any symptoms of illness until the disease is quite advanced. Loss of weight, loss of energy, poor appetite, fever, a productive cough, and night sweats -- might easily be blamed on another disease.Only about 10% of people infected with *M. tuberculosis* ever develop tuberculosis disease. Many of those who suffer TB do so in the first few years following infection, but the bacillus may lie dormant in the body for decades.

Treatment of Tuberculosis

Tuberculosis can be cured by a course of antibiotics taken over several months. Isoniazid and rifampin are the most common drugs used for TB. Inexpensive, effective and easy to take, these can prevent most cases of TB.

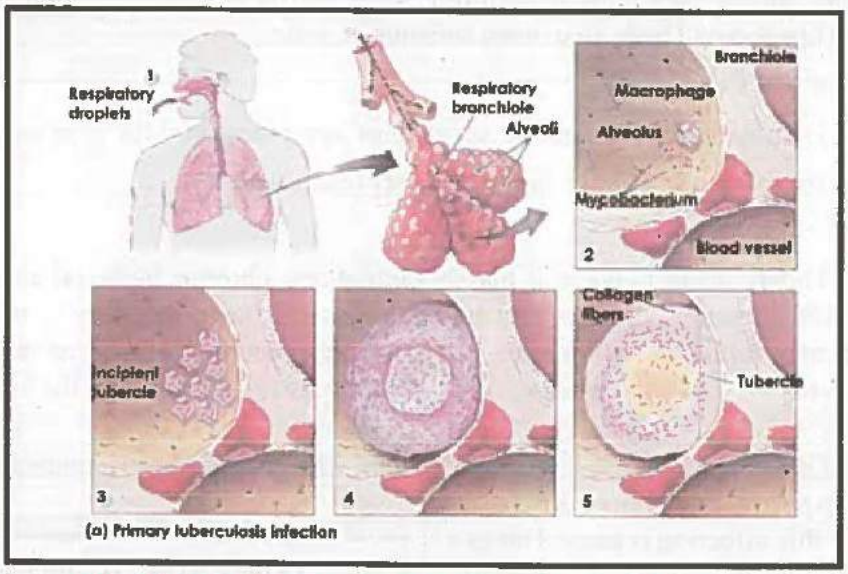


Fig: 14.15 Steps in the primary tuberculosis infection.

The disease can also be prevented by:

1) Vaccinating infants with BCG vaccine.
2) Isolating infectious patients.
3) Improving hygienic condition and housing.
4) Using pasteurized and properly boiled milk.

14.8 Disorders of Lungs

14.8.1 Emphysema

Emphysema is a lung disease which is characterized by

- shortness of breath with exertion, eventually breathlessness all the time
- Coughing
- Fatigue
- Cyanosis (a blue tinge to the skin) due to lack of oxygen

The exchange of oxygen and carbon dioxide takes place in the small air sacs of the lungs (alveoli). In a person with emphysema, the alveoli are damaged. The main tubes leading into the lungs (the bronchi) are also damaged and narrowed. The airways of the lungs are elastic. After repeated exposure to chemical irritants, such as cigarette smoke, the alveoli and bronchioles lose their elasticity.

The movement of oxygen from the air to the blood becomes more difficult. Emphysema is generally caused by cigarette smoking or long-term exposure to certain industrial pollutants or dust.

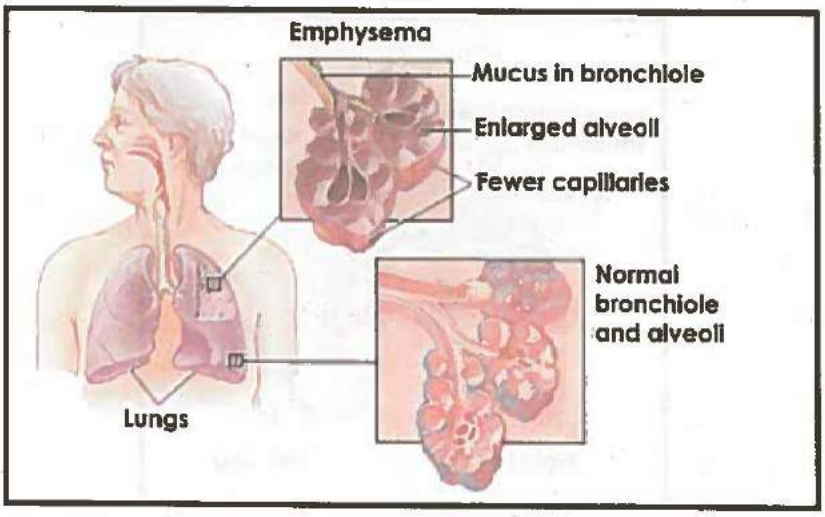


Fig: 4.16 Emphysema results in damaging the bronchiole and alveoli.

14.8.2 Lung cancer

Lung cancer is one of the most common cancers in the world. Cigarette smoking is one of the major causes of most lung cancers. The more cigarettes you smoke per day and the earlier you started smoking, the greater is the risk of lung cancer. High levels of pollution, radiation and asbestos exposure may also increase risk.

Common symptoms of lung cancer include

- A cough that doesn't go away and gets worse over time
- Constant chest pain
- Coughing up blood
- Shortness of breath,
- Repeated problems with pneumonia or bronchitis
- Swelling of the neck and face
- Loss of appetite or weight loss
- Fatigue

There are many types of lung cancer. Each type of lung cancer grows and spreads in different ways and is treated differently. Treatment also depends on the stage, or how advanced it is. Treatment may include chemotherapy, radiation and surgery.

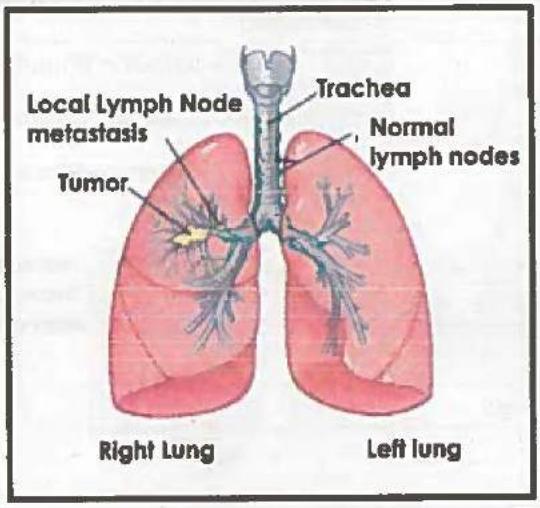
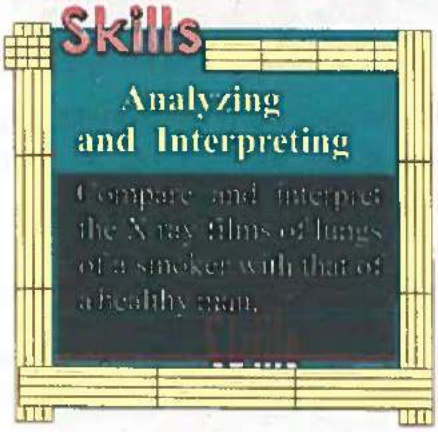


Fig: 4.17 Tumor in the lungs can develop at any place causing lung cancer.

14.8.3 Effects of smoking on the respiratory system

The effects of tobacco smoke on the respiratory system include:

- Irritation of the trachea (windpipe) and larynx (voice box)
- Reduced lung function and breathlessness due to swelling and narrowing of the lung airways and excess mucus in the lung passages
- Impairment of the lungs' clearance system, leading to the build-up of poisonous substances, which results in lung irritation and damage
- Increased risk of lung infection and symptoms such as coughing and wheezing
- Permanent damage to the air sacs of the lungs.



KEY POINTS

- For effective diffusion the respiratory surface must be permeable, thin, possess a large surface area with good blood supply and good ventilation mechanism to maintain a steep diffusion gradient across the respiratory surface.
- Respiratory system consists of nose and nasal cavities, pharynx, larynx, trachea, bronchi, bronchioles, and alveoli in the lungs.
- Lung volumes and lung capacities refer to the volume of air associated with different phases of the respiratory cycle.
- Normally breathing is an involuntary process and is not controlled consciously. However, some voluntary control is also possible. During voluntary control impulses originate from the cerebral hemispheres and pass to the breathing centre.
- Breathing consists of two phases namely breathing in or inspiration and breathing out or expiration.
- The blood transports oxygen from the lungs to different tissues and carbon dioxides from tissues to the lungs. Approximately 97% of oxygen is carried by the red blood cells as oxyhaemoglobin, while 3% is transported as dissolved oxygen in the plasma.
- Carbon dioxide is transported in the blood in three main ways i.e. in the form of bicarbonate ions, in the form of carboxyhaemoglobin and dissolved in plasma.
- Approximately 70% of carbon dioxide is carried in the blood as bicarbonate ions.
- About 23% of carbon dioxide is carried as carboxyhaemoglobin
- Only 7% of carbon dioxide by the plasma.
- In human, haemoglobin that increases the oxygen-carrying capacity of the blood and myoglobin that stores oxygen in muscles are referred as respiratory pigments.

KEY POINTS

- Sinusitis is an inflammation of the nasal sinuses and it is usually caused by infection (bacterial or viral), but can also be caused by allergic reactions dust, pollen etc.
- Otitis media is an inflammation of the middle ear.
- Pneumonia is a serious disorder of lower respiratory tract which is characterized by inflammation of alveolar wall and the presence of fluid and pus in alveolar sacs of one or both lungs.
- Tuberculosis begins when the mycobacteria reach the alveoli, where they invade and replicate within the phagosomes of alveolar macrophages, but they are unable to digest the bacterium.
- Emphysema is a lung disease in which the alveoli are damaged. It is generally caused by cigarette smoking or long-term exposure to certain industrial pollutants or dust.
- Lung cancer grows and spreads in different ways and its treatment depends on the stage, or how advanced it is. Treatment may include chemotherapy, radiation and surgery.

EXERCISE

1. Multiple Choice Questions

i. ***The wall of the trachea (windpipe) and bronchi of man is furnished with a series of incomplete:***

(a) cartilaginous plates (b) chitinous rings
(c) cartilaginous rings (d) muscular rings

ii. ***What does not happen during inspiration in man?***

(a) intercostals muscles contract (b) ribs are elevated
(c) diaphragm becomes dome-shaped (d) ribs move forwards

iii. ***The lateral walls of the chest cavity of man are composed of the:***

(a) ribs
(b) intercostals muscles
(c) ribs & Intercostals muscles
(d) ribs, Intercostals muscles & diaphragm

iv. ***When the human blood leaves the capillary bed of the tissue, most of the carbon dioxide is in the form of:***

(a) carbonic acid (b) bicarbonate ions
(c) carboxylic acid (d) none of them

v. ***Which sequence of organs is correct in air passageway of man?***

(a) nasal cavities larynx pharynx trachea bronchi
(b) nasal cavities pharynx trachea larynx bronchi
(c) nasal cavities pharynx larynx bronchi trachea
(d) nasal cavities pharynx larynx trachea bronchi

vi. ***Which part of the air passage way possesses cartilage plates in its wall?***

(a) bronchioles (b) distal region of bronchi
(c) proximal region of bronchi (d) trachea

vii. ***Human lungs are spongy due to the presence of million of:***

(a) bronchi (b) alveoli
(c) bronchioles (d) trachea

EXERCISE ?

viii. ***Which event is not associated with the activity of expiration?***

(a) contraction of diaphragm

(b) more dome like shape of diaphragm

(c) back ward & down ward movement of rib cage

(d) relaxation of intercostals muscles

ix. ***Oxygen carrying capacity of blood does not depend upon:***

(a) partial pressure of CO_2 (b) partial pressure of O_2

(c) height from sea level (d) quantity of blood

x. ***When haemoglobin of the blood is fully saturated with oxygen, the 100cc ofblood contains.***

(a) 15cc of oxygen (b) 20cc of oxygen

(c) 25cc of oxygen (d) 10cc of oxygen

2. Short Questions

i. What are the risk factors and causes of TB?

ii. State the signs and symptoms of otitis media.

iii. List two differences between haemoglobin and myoglobin.

iv. Give any two factors that affect the oxygen carrying capacity of blood.

3. Long Questions

i. Describe the structure of human respiratory system.

ii. Describe the mechanism of breathing in man.

iii. Describe the role of respiratory pigments in transport and storage of respiratory gases.

iv. State the causes, symptoms, and treatment of any one disorder of lower respiratory tract.

4. Science, Technology, and Society Connections

- Describe the development and working of artificial breathing apparatus (for use under water and at high altitude and by fireman)
- Justify why birds perform much better than man at high altitude.

EXERCISE ?

- Describe the purpose of mouth to mouth method for artificial respiration in First Aid.
- Relate the transportation of gases to hiccup, sneezing, and snoring.
- Describe the carbon monoxide poisoning (caused by gas heaters left on over-night in close environment).

Online Learning

- www.abc-of-yoga.com
- www.studentnurseconnections.com
- www.normalbreathing.com
- www.neok12.com/Respiratory-System
- www.cliffsnotes.com/.../Human-Respiratory-System

UNIT

15

HOMEOSTASIS

KEY CONCEPTS

Animals have really two environments: an **external environment** in which the organism is situated, and an **internal environment** in which the tissue of the body live. The external environment consists of varying conditions of environment. The internal environment is formed by the circulating organic liquid called lymph or plasma which surrounds and bathes all the tissues. **Homeostasis** is the tendency of an organism or cell to regulate its internal conditions, such as the chemical composition of its body fluids, so as to maintain health and functioning, regardless of outside conditions. The organism or cell maintains homeostasis by monitoring its internal conditions and responding appropriately when these conditions deviate from their normal state.

15.1 MECHANISM OF HOMEOSTASIS

Homeostatic mechanism operates just like physical control system having three components; receptors, control center and effectors.

Receptor (sensor) detects changes in variable and feeds that information back to the control center (integrator).

Control center (integrator) integrates (puts together) data from sensor and stored "set point" data.

Effector is the mechanism (heating coil in this example) that has an "effect" on the variable.

In a common lab incubator, if temperature is decreased from set point, the thermometer (receptor) detects the change in temperature and signals the thermostat (control center), which in turn activates the heating coil (effector). Similarly if temperature is increased from the set point again thermometer detects the change and signals the thermostat to switch off heating. Likewise, in human body thermoreceptors are involved in the detection of temperature change. Hypothalamus in fore brain is a body thermostat.

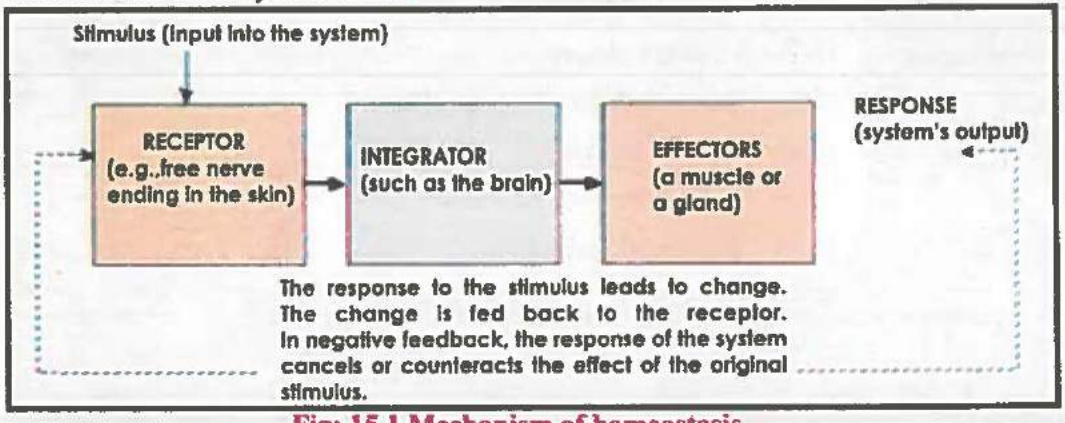


Fig: 15.1 Mechanism of homeostasis.

Stimulated once, hypothalamus acts on effectors for cooling (e.g. sweat glands) or heating (e.g. muscles) the body to reverse the change to the set point. After receiving the signal, a change occurs to correct the deviation either by depressing it with negative feedback or enhancing it with positive feedback.

15.1.1 Negative Feedback

Negative feedback is mainly how homeostasis is maintained. This feedback results in a reversal of the direction of change. Negative feedback tends to stabilize a system, correcting deviations from the normal state. In example, negative feedback mechanism is applied to control water content in the body. When body is deficient in water, hypothalamus stimulates posterior pituitary lobe to release antidiuretic hormone (ADH). ADH makes collecting tubules and distal convoluted tubules of nephrons permeable to water, thus more water is absorbed, and maximum amount of water is retained in the body. The blood water content rises, which is sensed by hypothalamus, so ADH secretion slows down.

15.1.2 Positive Feedback

In contrast to negative feedback, **positive-feedback** involves a change in some variable that triggers mechanisms that amplify rather than reverse the change. During childbirth, for instance, the pressure of the baby's head against sensors near the opening of the uterus stimulates; uterine contractions, which cause greater pressure against the uterine opening, heightening the contractions which causes still greater pressure. Positive feedback brings childbirth to completion, a very different sort of process from maintaining a physiological steady state.

15.1.3 Harmful Positive Feedback

Although Positive Feedback is needed within homeostasis, it also can be harmful at times. When you have a high fever it causes a metabolic change that can push the fever higher and higher. In rare cases the body temperature reaches 113^{0} F and the cellular proteins stop working and the metabolism stops, resulting in death. If a person breathes air that has very high carbon dioxide content, this produces a high concentration of carbon dioxide in blood.

This is sensed by carbon dioxide receptors, which cause the breathing rate to increase. So the person breathes faster, taking in more carbon dioxide, which stimulates the receptors even more, so they breathe faster and faster.

Skills

Interpreting and Communicating

Draw a flow chart to show negative feedback of homeostasis mechanisms by taking an example of hormone

15.2 OSMOREGULATION

A type of homeostasis in which water and ions (electrolytes) concentration is maintained in the cells and in the intercellular fluids is called **osmoregulation**. Balance of water and electrolytes is very critical to the health of animals. The mechanisms involved in regulating water and electrolytes balance vary widely among the animal groups as different habitats present different challenges.

15.2.1 Water and solutes Relation to the Cells:

Animal body is composed of 70% of water. However the quantity of water may vary from cell to cell. Water has a number of physiological properties that are of significance to the life. It is also the medium in which biochemical reactions occur. So it is very important to have a proper balance of water in the body. Osmoregulation involves the movement of water by osmosis. Therefore a proper balance of solutes is also important in order to maintain water movement.
Animals may be either osmoregulators or osmoconformers with respect to their osmoregulatory characteristics.

15.2.2 Osmoregulators

Some animals like all land animals and most marine vertebrates have body fluids whose solute concentration is different from that of the external environment. Therefore they must use energy in controlling water loss or gain to keep the balance of water and solutes. Such animals are called osmoregulators. Whether an animal inhabits land, fresh water or salt water, its cells cannot survive without water.

15.2.3 Osmoconformers

Some aquatic animals that live in the sea have the body fluids with a solute concentration equal to that of external environment. Such animals do not undergo a net gain or loss of water because equal amounts of water move back and forth between two solutions with equal solute concentration i.e. the animal body fluids are kept isotonic. Such animals are called osmoconformers.

15.3 OSMOREGULATION IN ANIMALS OF DIFFERENT ENVIRONMENTS

15.3.1 Fresh Water animals:

Almost all of the fresh water animals are osmoregulators. These animals are generally hypertonic to their outer environment.

These animals face the problem of swelling up by the passive movement of water into their bodies from the surrounding environment. Therefore these animals have no need to drink water. They also face the continual loss of body salts to the surrounding fresh water environment which has low salt concentration.

These animals deal with these problems by producing large volume of diluted urine. Their kidney reabsorbs the salts that are required. Salts are also obtained from the food they eat.

These animals also actively transport salts from the external dilute medium with the help of special salt cells called ionocytes. Ionocytes are found in the Amphibian's skin and gills of fishes.

15.3.2 Marine animals:

As described earlier that marine environment has both osmoconformers and osmoregulators, osmoregulatory adaptations of these animals are very different from each other. Cartilaginous fishes such as sharks, rays and skates and some cyclostomes like Myxine (Hag fishes), have plasma that is approximately isotonic to sea water.

On the other hand most of the marine teleosts (bony fishes) are hypotonic to sea water. So these fishes have tendency to lose water to the environment, especially across the gill's epithelium.

For Your Information

Osmolarity of sea water is very high and is about 1000 mosm/L while the blood osmolarities of marine animals range between 200-300 milli mole/litre.

They also have problem of excess of salts in the body due to drinking of sea water. In order to replace the water loss these fishes usually drink large amount of water unlike fresh water fishes. Among the excess salts, Na^+, Cl^- and some amount of K^+ are removed across the gill's epithelium while divalent ions like Mg^{++}, Ca^{++} are excreted by the kidney.

Some fishes also have special salt secreting glands in the wall of rectum called rectal glands that remove salts into the digestive tract which are then eliminated from the body during egestion.

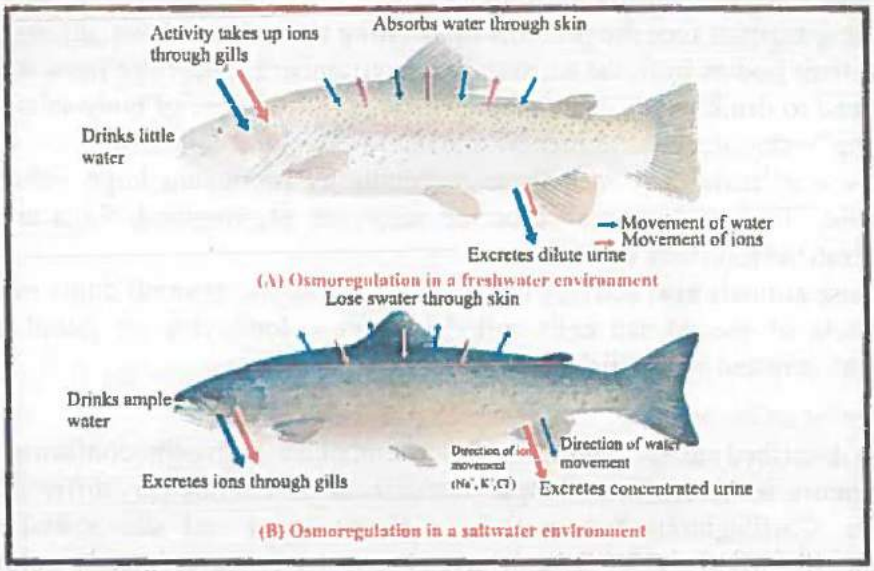


Fig: 15.2 Osmoregulation in maine animals.

15.3.3 Terrestrial animals:

In terrestrial animals evaporation of water leads to the dehydration which is the major problem faced by these animals. The successful groups of land animals are arthropods among the invertebrates and reptiles, birds and mammals among the vertebrates. The presence of chitinous exoskeleton in arthropods and dead keratinized skin in vertebrates are adaptation to reduce water loss by their bodies.

Desert mammals are very much resistant in this regard. They can tolerate against strong degree of dehydration by special **metabolic and behavioral adaptation**. This characteristic is called **anhydrobiosis**. Actually these animals feed upon seeds of desert plants in which large amount of carbohydrate is stored, during the breakdown of these compounds, water is produced as by-product that is utilized by these animals. Best example of such animals is kangroo rat. Desert animals avoid day time heat, and emerge at night. 90% of the water that they use is metabolic water derived from cellular oxidation.

Skills

(Initiating and Planning)
List some of the behavioral responses of the animals to maintain homeostasis.

Fig: 15.3 Kangroo rat; master of water conservation in the desert.

15.4 EXCRETION

Metabolism of food and other chemicals in the body produces large amount of toxic by-products. Water and Carbon dioxide are produced in metabolism of all, sugars, lipids and even proteins. The most troublesome is the nitrogen-containing waste from the metabolism of proteins and nucleic acids. Nitrogen is removed from these nutrients when they are broken down for energy or when they are converted to carbohydrates or fats. The primary nitrogenous waste product is ammonia, a small and very toxic molecule. Some animals excrete their ammonia directly; others first convert it to less toxic wastes such as urea or uric acid and then excrete it.

The form of nitrogenous waste an animal excretes depends on its habitat.

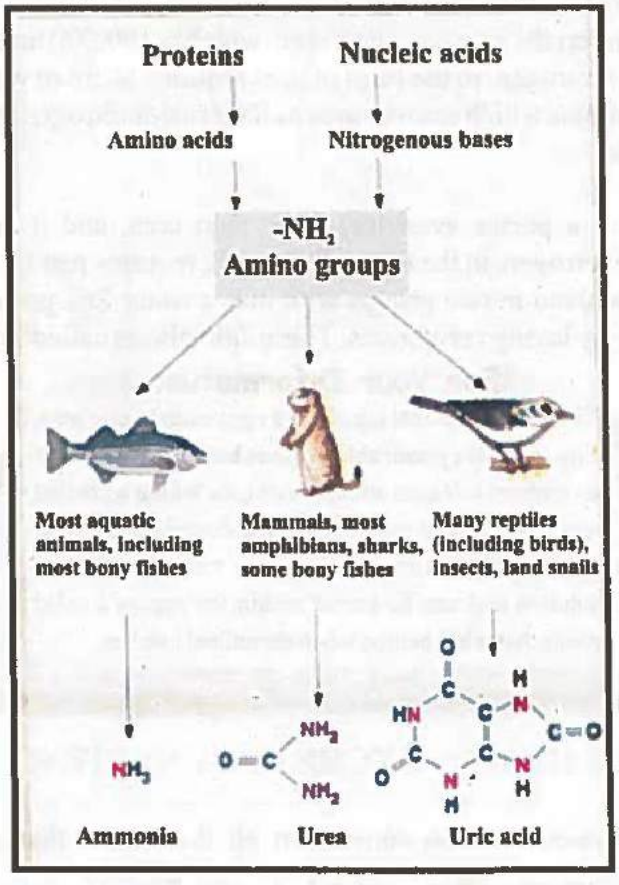


Fig: 15.4 Different types of nitrogenous wastes excreted by animals according to their habitat.

15.4.1 Ammonia

Ammonia is highly toxic and highly soluble in water. 1 g of nitrogen, in the form of ammonia, requires 500 ml of water to dissolve it to nontoxic level. If the organism has a sufficient source of water, ammonia can simply be excreted out. This is the course taken by many aquatic organisms, particularly those in fresh water.

Animals which excrete ammonia as their major nitrogenous waste product are called **ammonotelic** e.g. most fishes, protozoans, sponges, coelenterates, echinoderms.

15.4.2 Urea

Organisms with less fresh water available, such as some marine organisms and all terrestrial organisms, could not afford to waste water. They will often invest some energy to convert the ammonia into *urea*, which is 100,000 times less toxic than ammonia. One g of nitrogen, in the form of urea requires 50 ml of water to dilute it to nontoxic level. Animals which excrete urea as their major nitrogenous waste product are called **ureotelic.**

15.4.3 Uric Acid

Uric acid is a purine even less toxic than urea, and it precipitates from solution. 1 gram of nitrogen, in the form of uric acid, requires just 1 ml of water for its excretion. It has evolved in two groups with major water loss problems, terrestrial invertebrates and egg-laying vertebrates. These animals are called as **uricotelics.**

For Your Information

The vertebrates that lay shelled eggs excrete uric acid. Egg shells are permeable to gases but not to liquids. If an embryo released ammonia or urea within a shelled egg, the soluble waste would accumulate to toxic concentrations. Uric acid, however, precipitates out of solution and can be stored within the egg as a solid waste that is left behind when the animal hatches.

15.5 HUMAN EXCRETORY SYSTEM

Excretory system of man consists of all the organs that aid the body in removing waste products. Skin, lungs, liver and kidneys work to dispose of metabolic wastes.

15.5.1 Kidneys

The kidneys are dark-red, slightly flattened, bean shaped organs about 12 cm long, 6 cm wide and 4 cm thick each weighing about 150 gms. They are placed against the back wall of the abdominal cavity just below the diaphragm, one on either side of the vertebral column, between the last thoracic vertebra and the third lumbar vertebra.

The upper parts of the kidneys are partially protected by the eleventh and twelfth ribs. Their position is slightly asymmetrical, the right kidney being a little lower than the left one because of a liver lobe above it. The kidney has a bean-shaped structure. The outer surface is convex and the inner surface is concave. The inner surface has a deep notch called **hilus.** The renal artery and nerves enter the kidney, and the renal vein and ureter leave the kidney through hilus. The kidney is surrounded by tough membrane, **the renal peritonium.**

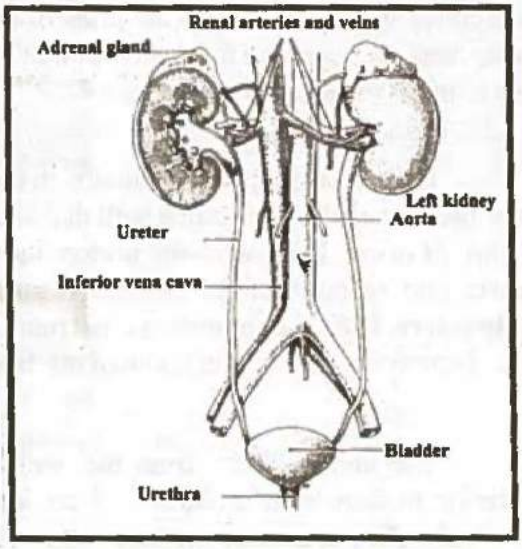


Fig: 15.5 Human urinary system

Transverse section of kidney shows two distinct regions, an outer **cortex** and an

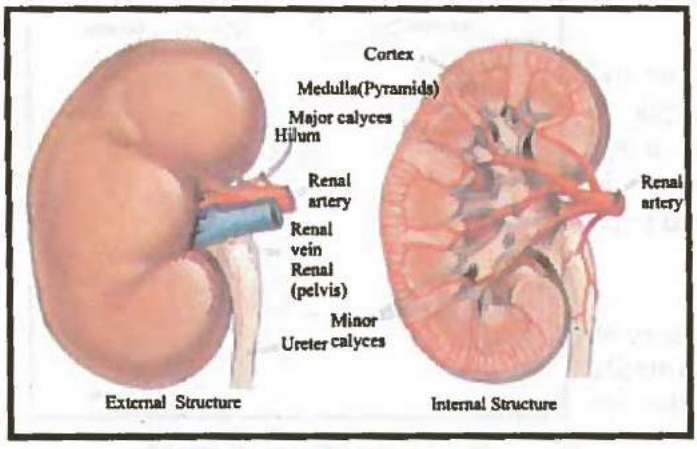


Fig:15.6 Human Kidney

tidbit

The kidney receives about 20 percent of the blood coming from the heart each time it beats. The rate of blood flows through both kidneys is approximately 1.2 liters per minute.

inner **medulla.** The cortex contains renal corpuscles and convoluted tubules of nephrons. The medulla contains conical structures called pyramids. All the pyramids project into the pelvis. The pelvis leads into the ureter.

15.5.2 Ureters

Ureters are about 28 cm long. They are a pair of narrow, muscular, tubular structures which arise from the hilus of the kidney, run backward along the dorsal body wall and open on the dorsal wall of the urinary bladder. These pass urine from the kidneys to the urinary bladder.

15.5.3 Urinary Bladder

It is a pear shaped sac situated in the pelvic region of the abdominal cavity. It has thick muscular distensible wall that allows its expansion. It can store about 0.5 to 1 litre of urine. It receives the ureters through the lower part of its back wall. The lower part or neck of the bladder is guarded by 2 rings of muscle fibres called **sphincters.** Both the sphincters must relax to let urine pass out from the bladder. The act of emptying the bladder is called **micturition.**

15.5.4 Urethra

The urethra starts from the neck of the urinary bladder and leads to the exterior. In females it is about 2 - 3 cm long and carries only urine. It opens by the urethral orifice or urinary aperture in the vulva in front of the vaginal aperture.

In male, urethra is about 20 cm long and carries urine as well as the spermatic fluid. It passes through the penis and opens out at the tip of the penis by a urinogenital aperture.

15.5.5 Nephron

The basic unit of structure and function of the kidney is the nephron. Each human kidney contains about one million nephrons. Each nephron is composed of renal corpuscle and renal tubule

15.5.6 Renal Corpuscle

Renal corpuscle is composed of a **glomerulus** and the **Bowman's capsule.** It is the initial filtering component of the nephron.

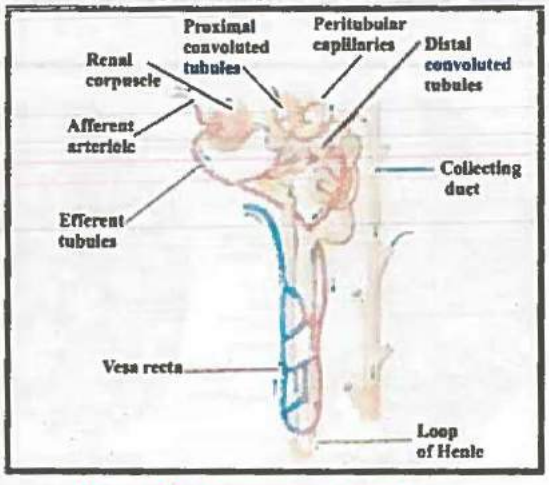


Fig: 15.7 Structure of nephron

The glomerulus is a capillary tuft that receives its blood supply from an afferent arteriole of the renal circulation. Bowman's capsule is a cup shaped structure that encloses glomerulus. The cells of Bowman's capsule in the kidneys that wrap around the capillaries of the glomerulus are called **podocytes.** The pores in the capillary endothelium and the gaps in between podocytes are quite large, and make it easy for any substance dissolved in the blood plasma to get through from the blood into the capsule. However, basement membrane of blood capillaries stops large protein molecules from getting through.

15.5.7 Renal Tubule

The components of the renal tubule are:

Proximal convoluted tubule: It is the portion of the duct system of the nephron of the kidney which leads from Bowman's capsule to the loop of Henle. It is the longest part of the nephron. The proximal tubule is lined by epithelial cells having brush boarder composed of microvilli. It increases surfa ce area for reabsorption.

Loop of Henle: It is a long U shaped tube of the nephron. The loop of Henle is more prominent in juxtamedullary nephrons where it descends down to the tips of pyramids in medulla. It is an important part of the whole system, as it allows the kidneys to filter out salt and maintain the correct balance of water in the body.

Distal convoluted tubule: The distal convoluted tubule is the most distal portion of the nephron

Collecting ducts: Each distal convoluted tubule leads to a system of collecting ducts, the first segment of which is the collecting tubule. The collecting duct system begins in the renal cortex and extends deep into the medulla. Finally it delivers urine to renal pelvis.

15.5.8 Types of Nephron

Two general classes of nephrons are **cortical nephrons** and **juxtamedullary nephrons,** both of which are classified according to the location. Cortical nephrons are found in the cortex. They have their renal corpuscle in the superficial renal cortex and have relatively short loops of Henle. 70 to 80% nephrons in human kidney are cortical. Under normal conditions of water availability the cortical nephrons deal with the control of blood volume. Juxtamedullary nephrons have their renal corpuscle close to the junction of the cortex and medulla. They have long loop of Henle which extends deep into the medulla.

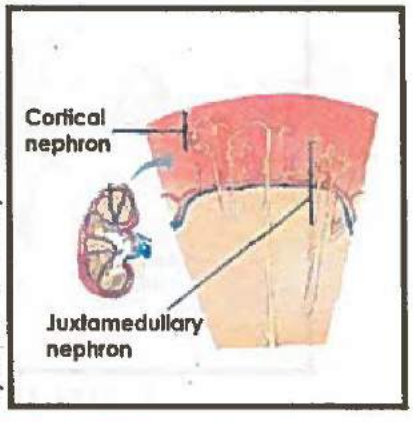


Fig: 15.8 Types of nephron.

This type of nephron is relatively rare, and only comprise 20-30% of the nephrons in the human kidney. The greater gradient in the deep medulla make this type of nephron do more work than cortical nephrons. It is these nephrons which are responsible for the development of the osmotic gradients in the renal medulla, which are used to concentrate urine. When water is in short supply, increased water retention occurs through juxtamedullary nephrons.

Blood enters the kidney by the renal artery which branches into finer and finer arteries before entering the glomerulus as an **afferent arteriole**. Filtered blood leaves the the glomerulus by an **efferent arteriole**. It flows to form a network of **peritubular capillaries** around the proximal and distal convoluted tubules in the cortex region. The capillaries of **vasa recta** run antiparallel to the loops of Henle and the collecting ducts in the medulla.

5.5.9 Excretory Function of Nephron

The human kidneys perform a variety of functions; nearly all are carried out by nephrons. The nephrons filter blood; remove wastes which are passed out as urine. Formation of urine involve three key processes, ultrafiltration, selective reabsorption and tubular secretion.

Ultrafiltration:

It is filtration under pressure. The diameter of efferent arteriole is half as compared to the afferent arteriole. It results in a high blood pressure in glomerulus. About 20% of the plasma is filtered into Bowman's capsule. This filtered fluid is called **glomerular filtrate**.

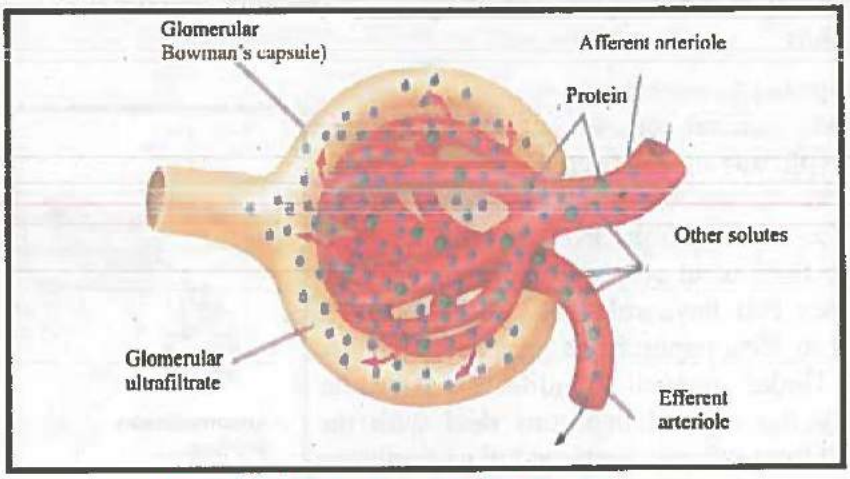


Fig: 15.9 Mechanism of ultrafiltration.

This filtrate has to cross endothelium of the glomerular capillaries, basement membrane of capillaries, and endothelium of Bowman's capsule.

It has chemical composition similar to that of blood plasma. It contains glucose, amino acids, vitamins, ions, nitrogenous wastes, some hormones and water.

Selective reabsorption

Ultrafiltration produces about 125 ml of glomerular filtrate per minute in humans. This is equivalent to about180 liters per day. In fact, of the 125 ml of filtrate produced per minute 124 ml is reabsorbed on average. The reabsorption process in the nephron is very selective. The useful substances for the body are reabsorbed.

Over 80% of the glomerular filtrate is reabsorbed in proximal convoluted tubules. Here all of the glucose, amino acids, vitamins, hormones and about 80% of the sodium chloride and water are reabsorbed.

The function of loop of Henle is to conserve water. The wall of ascending limb is impermeable to water, however, sodium, chloride, potassium and other ions are absorbed actively here. The plasma becomes concentrated and fluid in the ascending limb becomes very dilute. The descending limb is highly permeable to water. **The counter current multiplier system here results in reabsorption of a lot of water and solutes.**

The distal convoluted tubules have osmoregulatory role and also control blood pH by secreting hydrogen ions. The collecting ducts are impermeable in nature. ADH opens water channels in collecting ducts to allow water to move out of the filtrate. It reduces the volume of urine making it more concentrated.

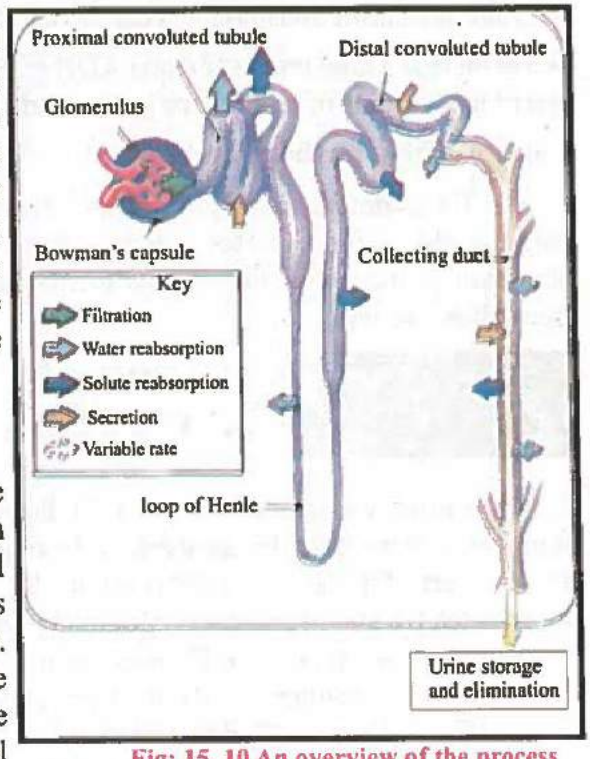


Fig: 15. 10 An overview of the process of urine formation

Tubular Secretion

Tubular secretion is the transfer of materials from peritubular capillaries to renal tubular lumen. Tubular secretion is caused mainly by active transport. Usually only a few substances are secreted. These substances are present in great excess, or are natural poisons.

Most important substances secreted by the tubules are hydrogen ions, potassium ions, and organic ions which are foreign to the body. Many drugs are eliminated by tubular secretion. Hydrogen ion secretion is important in acid-base balance of the body.

15.5.10 Kidney as Osmoregulatory Organ

Control of water level:

Body maintains the solute potential of blood at an approximately steady state. It is done by balancing water uptake from the diet with water lost in evaporation, sweating, egestion and urine. The solute potential is primarily achieved by the effect of antiduretic hormone.

ADH is secreted by the posterior lobe of pituitary gland. When body is deficient in water, hypothalamus detects a fall in blood solute potential and directs pituitary to release ADH. This hormone increases the permeability of the distal convoluted tubules and collecting ducts to water. More water is absorbed, reducing the volume of urine and making it more concentrated.

When there is a high intake of water ADH release is inhibited. Less water is absorbed and a large volume of dilute urine is excreted.

Control of blood sodium level

The maintenance of sodium level at a steady state is controlled by the steroid hormone aldosterone. It is secreted by adrenal cortex. Aldosterone activates sodium-potassium pumps in the distal convoluted tubules. Sodium is pumped back to blood from filtrate actively.

15.6 URINARY TRACT INFECTIONS (UTIs)

A urinary tract infection, or UTI, is an infection that can happen anywhere along the urinary tract. Urinary tract infections have different names, depending on what part of the urinary tract is infected. Almost all parts of the urinary tract are affected by the infection except ureters which are rarely the site of infection. Following are the types of UTIs depending upon the site.

(i) Pyelonephritis (kidney infection)
(ii) Cystitis (bladder infection)
(iii) Urethritis (urethral infection)

15.6.1 Causes

The bacterial and fungal strains that cause most common type of UTIs include:

- *Escherichia coli*
- *Staphylococcus saprophyticus*
- *Klebsiella*, *Enterococci* bacteria, and *Proteus mirabilis*
- Fungal organisms, such as *Candida albicans* that also causes the infections in mouth, digestive tract, and vagina.)

15.7 URINARY STONES

Urinary stones are hard, crystalline mineral materials that stick together to form small "pebbles" within the kidney or urinary tract. They may stay in kidneys or travel out of the body through the urinary tract.

15.7.1 Symptoms / Indications

Kidney stones often cause no pain while they are in the kidneys, but they can cause sudden, severe pain as they travel from the kidneys to the bladder. Usually pain appears at side belly or groin and the colour of urine becomes pinkish or reddish. These are common indications of kidney stones.

Anyone may develop a kidney stone, but people with certain diseases and conditions or those who are taking certain medications are more susceptible to the stone development. Kidney stones form when there is a decrease in urine volume and/or an excess of stone-forming substances in the urine.

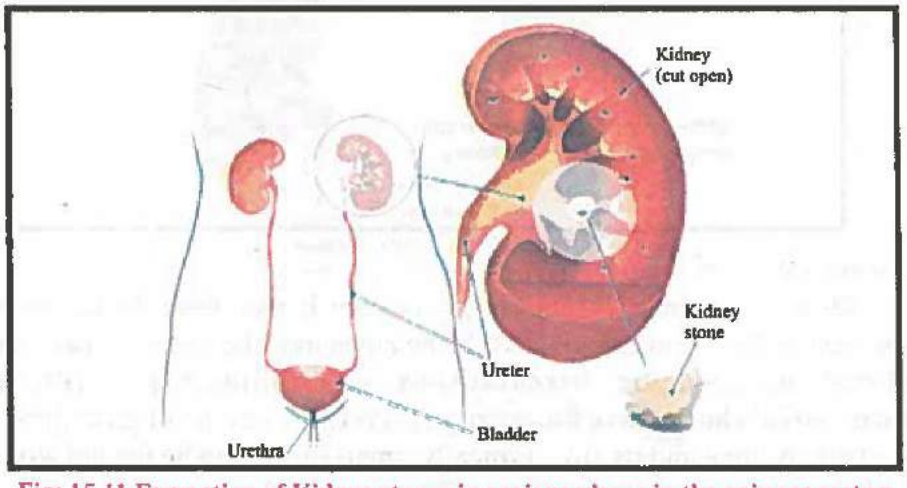


Fig: 15.11 Formation of Kidney stones in various places in the urinary system.

15.7.2 Chemical Nature of stone

The most common type of kidney stone contains **calcium** in combination with either **oxalate** or **phosphate** (70% of all stones). Other chemical compounds that can form stones in the urinary tract include **uric acid** (5-10% of all stones) and the amino acid **cystine** (1-3% of all stones). Kidney stones can also result from infection in the urinary tract; these are known as **struvite** or **infection stones** (15-20% of all stones).

15.7.3 Causes: A number of different medical and environmental conditions can lead to an increased risk for developing kidney stones:

- **Hypercalcemia: It is characterized by** increased calcium level in the blood that in turn causes **hypercalciuria** (high calcium in the urine). These conditions may also arise in case of **Hyperparathyroidism,** which is the over secretion of parathormone from parathyroid gland.

In this condition, too much calcium is absorbed from food and excreted into the urine, where it may form calcium phosphate or calcium oxalate stones.

- **Hyperoxaluria: It is characterized by** increased oxalate level in the urine. This condition is usually associated with over use of tomato and other green leafy vegetables in the diet.
- **Hyperuricemia: It is characterized by** increased amount of uric acid in the blood that can lead to the formation of uric acid stones. The level of uric acid may arise in gout(genetic disorder) or due to high intake of protein in the form of meat products.

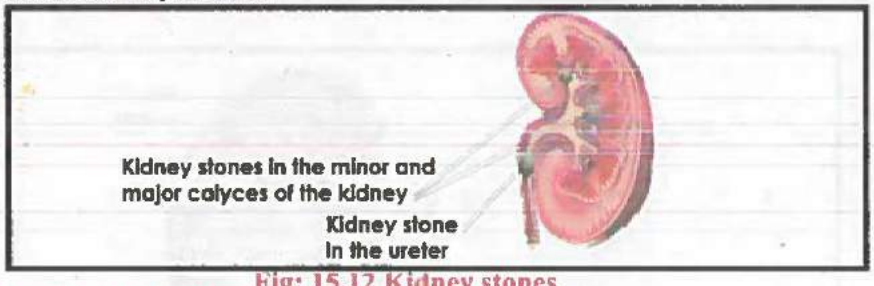


Fig: 15.12 Kidney stones

15.7.4 Treatment of urinary stones

Most stones under 0.5cm can spontaneously pass from the kidney but most stones greater than 1cm cannot pass. If the stone must be removed two commonly employed methods are **percutaneous nephrolithotrypsy (PCNL)** and **extracorporeal shock wave lithotripsy (ESWL).** The type of procedure depends on the type of stone and its size. Typically, small stones can be treated with ESWL, while larger stones require PCNL. ESWL uses sound waves to break the stone. A

PCNL procedure is more commonly used when ESWL is not successful. First a tube is inserted into the patient's back into the kidney to create a tract. A scope is run through the tract to directly see the stone inside the kidney.

Ultrasound equipment can then be inserted to break up the stone. While watching the stone through the scope, the stone fragments can be grasped with special equipment and pulled through the tract out from the kidneyBefore the advent of PCNL and ESWL, open surgical procedures were performed. This is less often necessary now, but sometimes is still performed especially for large complicated staghorn (branched) stones.

Fig: 15.13 Stagehorn stone

15.8 RENAL FAILURE/KIDNEY FAILURE

Renal failure or **kidney failure** is a medical condition in which the normal functions of kidneys (filtration of toxins and waste products from the blood) is gradually decreased. There are two forms of kidney failure:

15.8.1 Acute Kidney Failure:

Acute kidney failure occurs when kidneys suddenly become unable to filter wastes from blood. It develops rapidly over a few hours or in few days. Acute kidney failure is most common in people who are already hospitalized, particularly in critically ill people who need intensive care. Acute kidney failure can be fatal and requires intensive treatment. However, acute kidney failure may be reversible in that case, if patient otherwise in good health.

15.8.2 Causes

Acute kidney failure can occur when something damages the kidneys like blood clots or cholesterol deposits that block blood flow in the kidneys, similarly certain chemotherapy drugs, antibiotics and toxins, such as alcohol, heavy metals and cocaine can also cause kidney failure.

15.8.3 Chronic Renal Failure

Chronic kidney failure, also called chronic kidney disease is the gradual loss of kidney function. Chronic kidney failure may not become apparent until the kidney function is significantly impaired. Chronic kidney failure can progress to **end-stage renal disease (ESRD)** and **uremia**, which is fatal without artificial filtering (dialysis) or a kidney transplant.

15.8.4 Causes

Chronic renal failure develops gradually over time, often years to decades. The most common causes of chronic renal failure are diabetes and hypertension. Other causes include long-term daily use of anti-inflammatory drugs and other analgesic medications (pain relievers).

15.8.5 Renal Failure Treatment

Treatment targets the underlying cause. Acute renal failure requires immediate and intensive medical care, often including dialysis. Dietary modifications (such as reduced sodium, protein, and fluid intake) and medications to control conditions such as diabetes and hypertension allow many people to live with chronic renal failure for years to decades. When chronic renal failure progresses to ESRD, renal dialysis or kidney transplantation become necessary to sustain life.

15.9 RENAL DIALYSIS

Procedures to filter toxins from the blood when the kidneys are unable to perform this function is called renal dialysis. It can be short term or long term. Though in theory renal dialysis could sustain life indefinitely, but in practice most people experience a steady decline of overall health with long-term dialysis because artificial methods of cleansing toxins from the blood are not as effective, efficient, or thorough as the natural processes the kidneys perform. There are two general types of renal dialysis: peritoneal dialysis and haemodialysis.

15.9.1 Peritoneal Dialysis

Peritoneal dialysis makes use of a natural membrane in the body, the peritoneum, which encloses the abdominal cavity. In this process two catheters are surgically inserted into the abdominal cavity that serve as the portals through which dialysate (dialysis fluid) enters and leaves the cavity.

The molecules of the dialysate are too large to pass through the peritoneum so the solution remains contained in the abdominal cavity. During circulation, when blood passes through the blood vessels (capillary networks) within the peritoneum, the dialysate attracts certain molecules to cross the membrane into the dialysate. A second catheter carries dialysate out of the abdominal cavity. There are two stages of peritoneal dialysis, the **exchange** (draining the dialysate into and out of the abdominal cavity) and the **dwell** (the time during which the dialysate remains in the abdominal cavity)

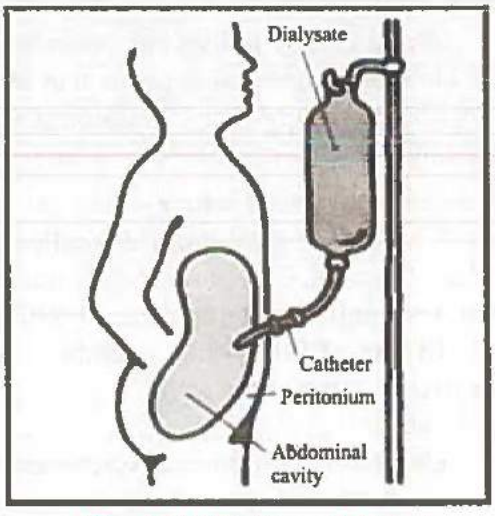


Fig: 15.14 Peritoneal dialysis

The primary advantage of peritoneal dialysis is mobility. Most people are able to participate in regular activities, including work, while peritoneal dialysis is under way and it can be performed at home. The success of peritoneal dialysis is variable than that of haemodialysis because the permeability of the peritoneum varies among individuals. Some doctors believe peritoneal dialysis is less effective than haemodialysis at clearing toxins from the body.

15.9.2 Haemodialysis

Haemodialysis removes wastes and water by circulating blood outside the body through an external filter, called a **dialyzer**, that contains a semipermeable membrane. In this process, a catheter is inserted into a blood vessel, usually in the arm, it routes the blood circulation externally through a machine that removes toxins. The cleansed blood then returns to the body through a second catheter.

Fig: 15.15 Patient being treated by haemodialysis.

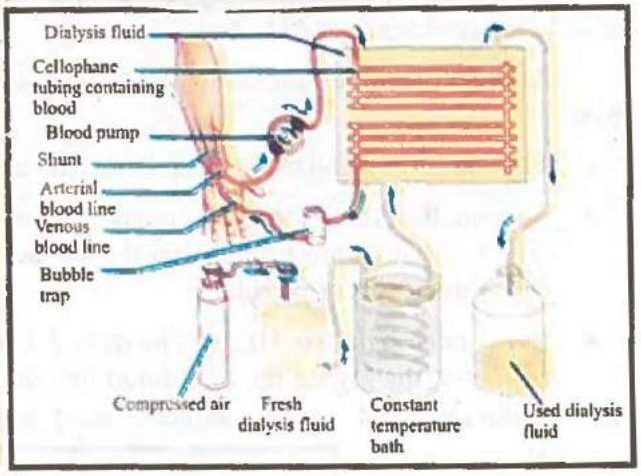


Fig:15.16 Mechanism of haemodialysis.

Many nephrologists feel that haemodialysis is more effective than peritoneal dialysis. However, haemodialysis entails significant risks like infection with hepatitis and other blood borne conditions, injury to the blood vessels used to shuttle blood between the person and the dialysis machine, and microscopic damage to the blood cells.

15.10 KIDNEY TRANSPLANTATION

Replacement of a diseased, damaged, or missing kidney with a donor kidney also called a renal transplant. Patients with end-stage renal failure are candidates for

transplantation. A successful transplant frees the patient from dialysis and provides the kidney's other metabolic functions.

For Your Information

The first successful kidney transplantation took place between identical twin brothers in 1954. However, until the discovery of the immunosuppressive drug cyclosporine in 1983, the risk of organ rejection was very high, and kidney transplantation was a treatment of last resort. With current immunosuppressive therapy the recipient of a transplanted kidney can expect to live 5 to 20 years or longer with relatively normal kidney function.

15.10.1 Donor-Recipient Match

The donor kidney must match the recipient as closely as possible in three ways.

- First, the donor and the recipient must have the same blood type.
- Second, the donor and the recipient must match Human Leukocyte Antigens (HLAs), which are proteins on the surfaces of leukocytes (white BLOOD cells), as closely as possible.
- Every person has six HLAs. The more HLAs that match between donor and recipient, the higher the likelihood that the recipient's body will accept the donor kidney Transplant surgeons like to see a match of three or more HLAs.

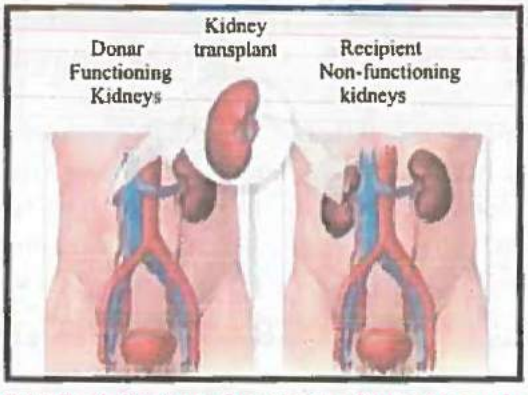


Fig: 15.14 Recipient non functioning kidney is replaced by donor functioning kidney.

- Third, the donor's blood must not initiate an antibody response with the recipient's blood (called a negative cross match), which the transplant team tests by mixing samples of blood from each in a test tube.

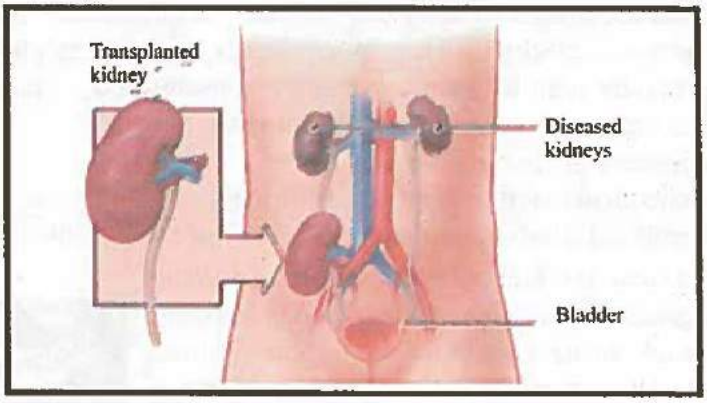


Fig: 15.18 Location where the healthy kidney is placed in the patient body.

15.10.2 Risks and Complications

The risks of transplantation surgery include bleeding during or after the operation and postoperative infection. Because the transplanted kidney is lower in the abdomen than the native kidneys it lacks the protection of the rib cage and is more vulnerable to traumatic injury. Most people recover fully from the surgery without complications, though there is always the risk of organ rejection can be treated with various medications.

Skills
(Initiating and Planning)

Hypothesize kidney stones by studying urine reports of relevant patients.

15.11THERMOREGULATION

The maintenance of body temperature by living organisms is termed as thermoregulation. The temperature influences the metabolic activity of animals in a number of ways. The main effect is on the rate of enzyme activity and the rate of movement of atoms and molecules. This directly affects the health and growth of animals. Temperature may also affect the geographical distribution of animals through its influence on plants as primary producers in the food chain.

The effect of hyperthermia on organ system of animals may be profound, and if heat stress has been severe or prolonged it may alter organ function and even kill the animals. Animals are classified into two groups on the basis of maintaining their body temperature.

Poikilotherms are unable to maintain their body temperature within narrow limits using physiological mechanism e.g. invertebrates, fishes, amphibians, and reptiles.

Homeotherms are able to maintain a fairly constant body temperature by using physiological mechanisms e.g. birds and mammals.

Animals gain heat from two sources.

- The chemical reaction of ingested nutrients
- The external environment, especially radiant energy from the sun.

The extent to which different groups of animals are able to generate and conserve this heat is variable. **Ectotherms** rely on heat derived from the environment than metabolic heat to raise their body temperature e.g. reptiles, amphibians, fishes and invertebrates. Homeothermic animals are relatively independent of external sources of heat and rely on a high metabolic rate to generate heat which is conserved. They are described as **endothermic e.g.** the great white shark, flying insects, birds and polar bear.

Fig: 15.19 Great white shark an endothermic animal.

15.11.1 Thermoregulation in Human

The ability to regulate body temperature is critical to sustain normal life. Death is the ultimate result if the body temperature strays to far from the normal. Core body temperature, the temperature of structures below the skin and subcutaneous tissue, should be maintained between 36.4 and 37.3 °C.

Respiratory metabolism is major source of heat energy in human. This energy is mainly released by breakdown of carbohydrates and fats. The process of heat production in organisms is called **Thermogenesis.** This process is regulated by nervous system and hormones. There are two types of thermogenesis , shivering thermogenesis and non-shivering thermogenesis.

Shivering thermogenesis involves repeated stimulation of voluntary muscles by motor neurons. It produces shivering response in muscles which can increase heat production by up to five times the basal level.

Non-shivering thermogenesis is the heat production caused by the high metabolic rate. Thyroxin, a thyroid hormone increases metabolic rate which result in heat production. Its effects are long term. Adrenaline produces short term increase in metabolic activity.

15.11.2 Heat loss

Heat is lost from the general body surface by a number of processes like radiation, convection, and conduction. Radiation accounts for about 50% of the total heat loss in humans. In vasodilation, certain of the arterioles beneath the epidermis dilate. Consequently more blood flows near the body surface, losing heat through the epidermis. Evaporation is another mechanism of heat loss. In humans water loss by evaporation takes place continuously through the skin even when a person is not sweating. Activation of sweat glands enhances this process. Heat loss also occurs by evaporation from the lungs. Partial control of heat loss is possible by regulating sweating.

For Your Information

The hairs in mammals act as insulating organs and reduce the heat loss. Thus the heat is retained in the body to certain extent. To increase the effect of insulation, the hairs are erected. This occurs involuntarily when the body is over cooled. In human, it produces "goose-pimples" or "goose bumps"

15.11.3 Heat conservation

There are a number of physiological and morphological adaptations in human to conserve body heat. A fatty layer in the hypodermis of skin provides insulation and is very significant to conserve heat. Additional fat insulation of vital organs like kidneys and heart helps heat conservation in respective organs. Vasoconstriction is constrictions of arterioles that supply the surface capillaries in the skin reduces the volume of blood flowing near the surface and hence diminish heat losses. Human body is covered by hair. However, distribution of hair in humans is much more restricted than in other mammals. At the base of hair follicle is a smooth muscle, the hair erector muscle. Contraction of this muscle pulls the hair upright. The hair stand on end air is trapped above the skin. It helps to conserve body heat.

15.11.4 Role of the hypothalamus

Human have a well-developed temperature control system involving receptors and effectors and an extremely sensitive control centre, the hypothalamus. Hypothalamus monitors the temperature of the blood flowing through it. This blood is at core temperature. Also skin has hot and cold thermoreceptors.

When suitably stimulated they generate nerve impulses some of which pass to the hypothalamus and others to the sensory areas of the cortex. In most cases the activity of both skin and hypothalamus receptors combine to control body temperature. This enables the body to make rapid and precise adjustment to maintain constant body temperature.

If body temperature increases the set point in hypothalamus, a set of responses is organized by hypothalamus.

- Vasodilation to increase blood flow to the skin. It increases heat loss from the skin by radiation, convection, and conduction
- Activation of sweat glands
- Decreased metabolic activity

Cold temperature responses regulated by hypothalamus are;

- Vasoconstriction to decrease blood flow to the skin, to reduce heat loss by radiation, convection, and conduction
- Inhibit sweating
- Inhibit panting
- Increased metabolism for shivering and release of thyroxin and adrenaline

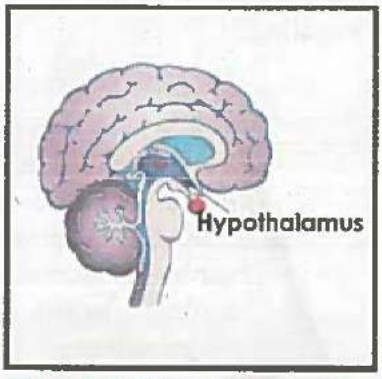


Fig: 15.20 Hypothalamus in the brain.

15.11.5 Fever

An increase in core temperature is known as fever or pyrexia. It happens in certain diseases like malaria, and typhoid. Substances known as pyrogens, which may be toxins produced by pathogenic organisms or chemicals released by neutrophils, directly affect the hypothalamus and increase the temperature set point. The raised body temperature stimulates the defence responses of the body and helps the destruction of pathogens.

DO YOU KNOW?

Antipyretic drugs such as aspirin and paracetamol lower the set point and provide relief from the unpleasant symptoms of fever, but probably slow down the normal defence mechanism.

KEY POINTS

- **Homeostasis** is the tendency of an organism or cell to regulate its internal conditions, such as the chemical composition of its body fluids, so as to maintain health and functioning, regardless of outside conditions.
- Homeostatic mechanism operates just like physical control system having three components; receptors, control center and effectors.
- Negative feedback results in a reversal of the direction of change. Negative feedback tends to stabilize a system, correcting deviations from the normal state.
- **Positive-feedback** involves a change in some variable that triggers mechanisms that amplify rather than reverse the change.
- A type of homeostasis in which water and ions (electrolytes) concentration is maintained in the cells and in the intercellular fluids is called **osmoregulation.**
- Aquatic animals that live in the sea have the body fluids with a solute concentration equal to that of external environment so that animal body fluids are kept isotonic. Such animals are called osmoconformers.
- Desert mammals are very much resistant in this regard. They can tolerate against strong degree of dehydration by special **metabolic and behavioral adaptation**. This characteristic is called **anhydrobiosis**.
- The primary nitrogenous waste product is ammonia. Some animals excrete their ammonia directly; others first convert it to less toxic wastes such as urea or uric acid and then excrete it.
- Animals which excrete ammonia as their major nitrogenous waste product are called **ammonotelic.**
- Animals which excrete urea as their major nitrogenous waste product are called **ureotelic.**
- Animals which excrete uric acid as their major nitrogenous waste product are called **uricotelics.**
- Skin, lungs, liver and kidneys work to dispose off metabolic wastes.
- The act of emptying the bladder is called **micturition.**
- Formation of urine involve three key processes, ultrafiltration, selective reabsorption and tubular secretion.
- A urinary tract infection can happen anywhere along the urinary tract. Types of UTIs depending upon the site includes: pyelonephritis (kidney infection), cystitis (bladder infection) and urethritis (urethral infection).

KEY POINTS

- The most common type of kidney stone contains **calcium** in combination with either **oxalate** or **phosphate** (70% of all stones). Other chemical compounds that can form stones in the urinary tract include **uric acid** (5-10% of all stones) and the amino acid **cystine** (1-3% of all stones).

- Two commonly employed methods for kidney stones removal are **percutaneous nephrolithotripsy (PCNL)** and **extracorporeal shock wave lithotripsy (ESWL).**
- **Renal failure** or **kidney failure** is a medical condition in which the normal functions of kidneys (filtration of toxins and waste products from the blood) are gradually decreased.
- Procedures to filter toxins from the blood when the kidneys are unable to perform this function is called renal dialysis.
- The maintenance of body temperature by living organisms is termed as *thermoregulation.*
- **Poikilotherms** are unable to maintain their body temperature within narrow limits using physiological mechanism e.g. invertebrates, fishes, amphibians, and reptiles. **Homeotherms** are able to maintain a fairly constant body temperature by using physiological mechanisms e.g. birds and mammals.
- The process of heat production in organisms is called **Thermogenesis.**

EXERCISE ?

1- Multiple choice questions.

(i) ***Shifts in water-solute balance are managed primarily by***

(a) respiratory system **(b)** the urinary system
(c) endocrine adjustments **(d)** the circulatory system

(ii) ***Which is the most important mechanism for water loss from the body?***

(a) excretion in urine **(b)** sneezing
(c) sweating **(d)** elimination in feces

(iii) ***The process that normally exerts the greatest control over the water balance of an individual is***

(a) sweating. **(b)** kidney function.
(c) evaporation through the skin. **(d)** respiratory loss.

(iv) ***Which of the following does NOT dispose off a type of waste directly to the environment?***

(a) digestive system **(b)** respiratory system
(c) circulatory system **(d)** urinary system

(v) ***The most toxic substances routinely found in the blood are metabolites of what type of molelcules?***

(a) proteins **(b)** carbohydrates
(c) nucleic acids **(d)** Fats

(vi) ***Which of the following is the last structure that urine passes through during its excretion from body?***

(a) distal tubule **(b)** urethra
(c) urinary bladder **(d)** ureter

(vii) ***The process during which potassium and hydrogen ions and some toxic substances are put into urine is called***

(a) tubular secretion. **(b)** reabsorption.
(c) filtration. **(d)** countercurrent multiplication.

EXERCISE ?

(viii) ***Kidney health is described in terms of***

(a) the number of kidney stones. (b) rate of filtration.
(c) water retention. (d) blood clot

(ix) ***Why is there no glucose present in the filtrate in the distal tubule of a nephron?***

(a) its molecules are too large to pass across the basement membrane
(b) it is removed by osmosis from the tubule
(c) it is passively absorb by the cells lining the descending the loop of Henle
(d) it is actively absorb by the proximal tubule cells

(x) ***In case of overheating, the body temperature is regulated by:***

(a) more sweating and more urination
(b) more sweating and less urination
(c) less sweating and more urination
(d) less sweating and less urination

(xi) ***An animal that warms itself mainly by absorbing heat from its surroundings is known as:***

(a) homoiotherm (b) ectotherm
(c) endotherm (d) none of them

2- Short Questions.

(i) Why it is necessary for a living being to maintain its internal environment at a fairly constant level?

(ii) How positive feedback can be harmful at times?

(iii) Describe mechanism of ultrafiltration.

(iv) How regulation of blood flow to skin is meaningful to maintain body temperature?

EXERCISE ?

(v) Why Juxtamedullary nephrons are more important in osmoregulation?

(vi) How ADH controls concentration of urine?

(vii) Why do marine fishes drink water unlike fresh water fishes?

(viii) How do some terrestrial mammals become so resistant that they are able to survive without drinking water?

(ix) What is the benefit of Extracorporeal Shock Wave Lithotripsy (ESWL) over Per Cutaneous Nephro Lithotrypsy (PCNL).

(x) Why is the excretion of uric acid advantageous to birds and reptiles?

3- Extensive Questions

(i) Explain the working of feedback system in a living body and compare it with a non-living physical feedback system.

(ii) Describe different parts of urinary system of human with main emphasis on their role in excretion.

(iii) Describe the challenges and osmoregulatory adaptations of osmoconformers and osmoregulators in marine environment.

(iv) Describe the role of kidney as osmoregulatory organ.

(v) What is renal failure? Describe its types and causes.

(vi) Explain the procedure of peritoneal and hemodialysis.

(vii) Describe various type of kidney stones and their causes.

4- Science, Technology, and Society Connections

- Describe the importance of kidney donation for the benefit of kidney failure patients.

EXERCISE ?

- Name the important kidney transplant centers in your province.

5- **Online Learning**

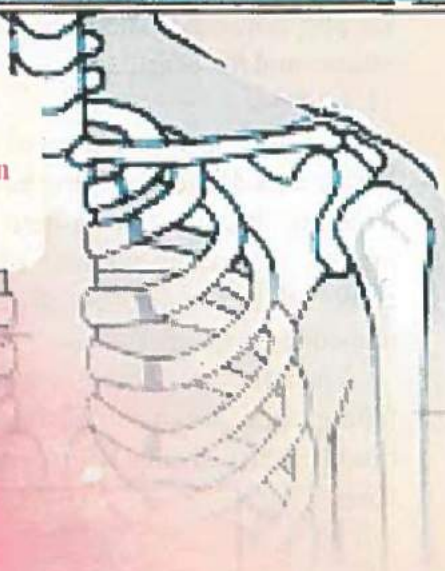
- **http://www.emedicinehealth.com**
- **http://www.medicinenet.com**
- **https://www.nyu.edu**
- **http://www.webmd.com**

UNIT

16

SUPPORT AND MOVEMENT

KEY CONCEPTS



Some support in living organisms is necessary to uphold and sustain the body against gravity and other external forces. As the living organisms increased in size through the process of evolution, the need for support became greater. This was particularly true once living organisms left water and colonized land. The skeleton in animals contributes to this support.

16.1 HUMAN SKELETON

The vertebrate skeleton is composed either of cartilage or bone. Both tissues provide an internal supporting framework of the body. Human adults have bony skeleton, but cartilage is also present in some regions.

16.1.1 Cartilage:

Cartilage is a type of connective tissue consisting of cells called chondrocytes and a tough, flexible matrix made of type II collagen. Unlike other connective tissues, cartilage does not contain blood vessels and the chondrocytes are supplied by diffusion. Because of this, it heals very slowly.

Although the human skeleton is initially made up of cartilages and fibrous membranes, most of these early supports are soon replaced by bones. A few cartilages that remain in adults are found mainly in regions where flexible skeletal support is needed. There are three types of cartilage tissue in human body: hyaline, elastic, and fibrocartilage.

16.1.2 Bone

Bone is a rigid form of connective tissue, which forms the endoskeleton of vertebrates. Bone is a living hard (resists compression) and strong (resists bending) structure. It consists of a hard ground substance or matrix and cells. In the adult human, the matrix consists of about 65% inorganic matter (calcium phosphate, carbonate etc) and about 35% organic substances (protein, collagen). The cells are embedded in the matrix.

The structure of bone is specially designed to withstand the compression strains falling upon it and to resist pressure. Bones are composed of cells for example; **osteoblasts** (cells that help **form** bone), and **osteoclasts** (cells that help **eat away** old bone).

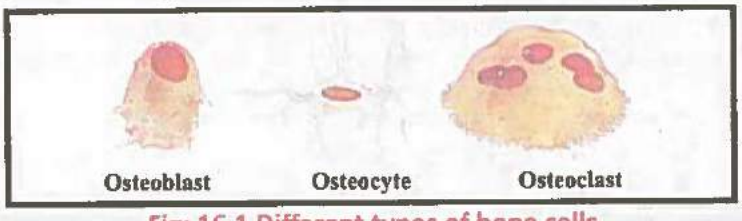


Fig: 16.1 Different types of bone cells.

In addition, bone contains cells called **osteocytes**, which are mature osteoblasts that have ended their bone-forming capacity. These cells engage in metabolic exchange with the blood that flows through the bones.

Osteoblasts:

The osteoblasts are mononucleate cells. Osteoblasts produce a matrix which is composed mainly of Type I collagen. They are also responsible for mineralization of this matrix. Osteoblasts are the immature bone cells, and eventually become entrapped in the bone matrix to become osteocytes- the mature bone cell.

Osteocytes:

They are mature bone cells. They cease to generate mineralized matrix. Osteocytes have many extensions that reach out to meet osteoblasts and other osteocytes for the purposes of communication. They are responsible for the maintenance of bone and calcium . They also regulate the bone's response to stress and mechanical load.

Osteoclast:

Osteoclasts are large, multinucleated cells that remove bone tissue by removing its mineralized matrix and breaking up the organic bone. This process is known as bone resorption. They are equipped with phagocytic-like mechanisms similar to circulating macrophages.

Composition of Bone

Bone is a dynamic tissue that is being reshaped by the activity of osteoclasts and osteoblasts. Cells are embedded in a firm calcified matrix. 30% matrix is composed of organic material, chiefly of collagen fibers (90%) and glycoproteins. 70% matrix is composed of inorganic salts. The chief inorganic constituent of bone is needle like crystals of hydroxyapatite, a form of calcium phosphate. Sodium, magnesium, potassium, chloride, fluoride, bicarbonate and citrate ions are also

Table: 16.1 Comparison between bone and cartilage

BONE	CARTILAGE
(i) Mature cells are osteocytes.	(i) Mature cells are chondrocytes
(ii) Bone matrix contains type I collagen.	(ii) Cartilages mostly contain type II collagen
(iii) Strengthen by inorganic calcium salts.	(iii) No inorganic salts
(iv) Bones are constantly reshaped by osteoblasts, and osteoclasts.	(iv) Cartilages are not reshaped
(v) Bones have rich blood supply.	(v) No blood circulation in cartilages

present in variable amounts. Calcium and phosphate may be released into the blood as needed, under the control of two hormones, **parathormone** and **calcitonin**.

16.1.3 Main divisions of human skeleton

A skeleton of cartilage supports human body, but by the time of birth much of the cartilage had been transformed into 350 bones. As one grows many of these bones fuse with one another so that at adult stage, skeleton consists of 206 individual bones which are grouped into two general divisions; axial skeleton, the basic framework of the body and appendicular skeleton, the extremities. Axial skeleton consists of skull, vertebrae and ribs. Appendicular skeleton includes pectoral girdle with forelimbs and pelvic girdle with hind limbs. Numbers and distribution of bones in human body is given in the table 16.2.

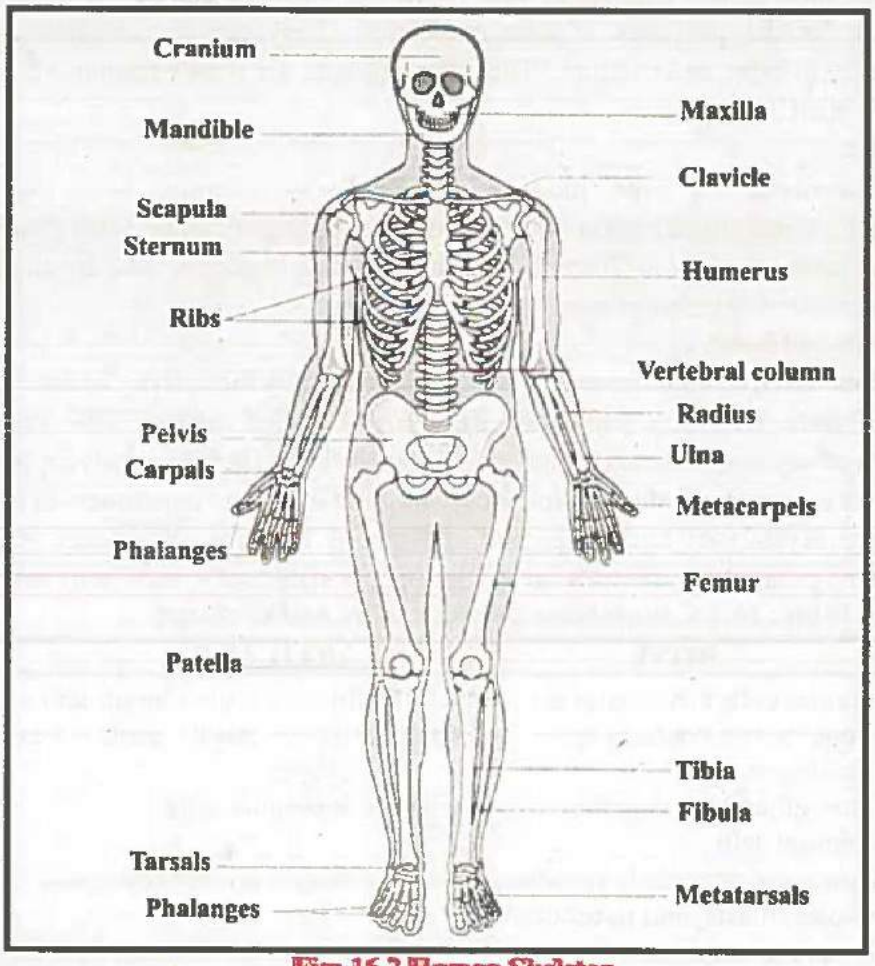


Fig: 16.2 Human Skeleton

Table: 16.2 Distribution of bones in human body.

Main part	*Subdivision*		*Total bones*
Skull	Cranium Ears Face	8 bones 6 bones 14 bones	28
Neck Trunk	Hyoid Vertebral column Chest bone Ribs	bone 1 26 bones 1 24 bones	1 51
Limbs	Upper limbs Lower limb	64 62	126

Table: 16.3 The 28 bones of the skull are tabulated here.

Skull	*Unpaired bones*	*Paired bones*
Cranium 8 bones	Frontal Occipital Sphenoid Ethmoid	Parietal Temporal
Facial bones (face) 14 bones	Mandible Vomer	Maxilla Zygomatic Lacrimal Nasal Inferior concha Palatine
Auditory ossicle (ear bones) 6 bones		Malleus Incus Stapes

Axial Skeleton

Axial skeleton consists of skull, vertebral column and ribs.

1. ***Skull*** The skull consists of cranium (or facial bones), ear bone (or auditory ossicles) and hyoid bone. The primary function of skull is the protection of brain. The human skull is composed of 22 bones, besides 6 tiny ear bones and one hyoid bone.

At the time of birth several of the bones of the cranium are not completely formed. If the bones of cranium were completely formed at the time of birth, great difficultly would have been experienced in the birth canal.

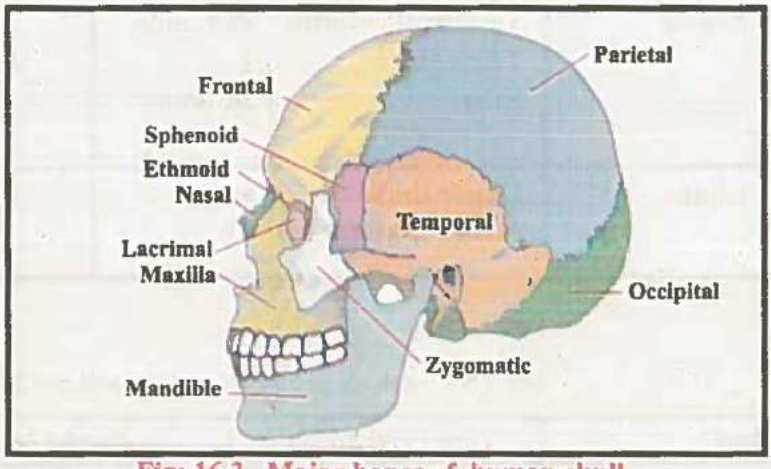


Fig: 16.3 Major bones of human skull.

2. ***Vertebral Column***

The vertebral column forms a more or less rigid rod. It extends through the length of the trunk on the dorsal side and form the backbone. It houses and protects the spinal cord. It is a place of attachment of pelvic and pectoral girdle.

In man, there are 33 vertebrae. Seven cervical vertebrae in the neck region; in the thorax region 12 thoracic vertebrae; in the lower back region 5 lumber vertebrae; in the sacral region 5 sacral vertebrae (to which the pelvic girdle is attached) and at the end of the vertebral column is the coccyx or tail bone which consists of 4 small fused vertebrae. The coccyx is man's vestige of a tail.

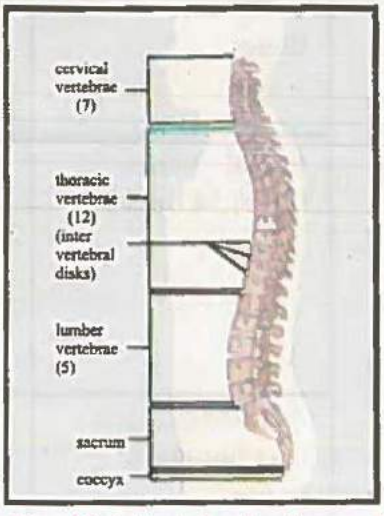


Fig: 16.4 Vertebral column of the human skeleton (side view)

3. *Ribs*

In man there are twelve pairs of ribs, one pair articulating with each of the thoracic vertebrae forming a cage that encloses the heart and lungs. Ten pairs of ribs are connected anteriorly with the sternum. Seven pairs out of these ten pairs are directly connected with the sternum and are known as 'true ribs, while the other three pairs are indirectly connected with the sternum through costal arch and are known as 'false ribs'. The lower two pairs of ribs are not attached in front and are known as the "floating ribs".

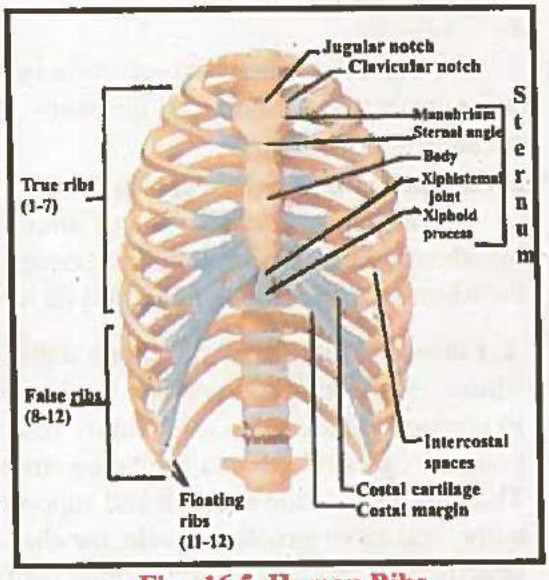


Fig: 16.5 Human Ribs

Appendicular Skeleton

The appendicular skeleton consists of pectoral girdles with forelimbs and pelvic girdle with hind limbs.

Pectoral Girdle

The bones of the pectoral girdle consists of a ventral coracoid, which meets the sternum medially; a scapula, extending dorsally; and a clavicle, which lies on the ventral side between the scapula and sternum and anterior to the coracoid.

Forelimbs

The forelimbs consist of a humerus in the upper arm region; a radius and an ulna in the lower arm region; 8 carpels in the wrist and 5 metacarpels in the palm of the hand and 14 phalanges.

Pelvic Girdle

Hind limbs are attached to the vertebral column through pelvic girdle, which is made of two coxal bones. Each of these bones are found by the combination of three bones; ischium, illium and pubis.

Hind limbs

Each hind limb consists of thigh, shank, ankle and foot. In the hind limb there is a single femur in the thigh, a pair of bones, the tibia and fibula, in the shank, 8 anklebones, followed by five longer metatarsals in the foot and finally five rows of fourteen phalanges in the toe.

16.1.4 Joints

The sites where two or more bones meet are called joints or articulations. Joints have two fundamental functions: they give mobility to the skeleton and hold the skeletal parts together.

Structural classification of joints

Structural classification of joints is based on the material binding the bones together and whether or not a joint cavity is present. There are three types of joints, the fibrous, cartilaginous, and synovial joints.

1. Fibrous joints: In fibrous joints, a thin layer of fibrous connective tissue holds the bones firmly in position. There is no joint cavity between the bones. In general fibrous joints are immovable. These joints provide strength and support for the body, and have protective role for the delicate structures. Fibrous joints are formed between the bones of skull, between sacrum and iliac of pelvic girdles, and between the bones of pelvic girdle.

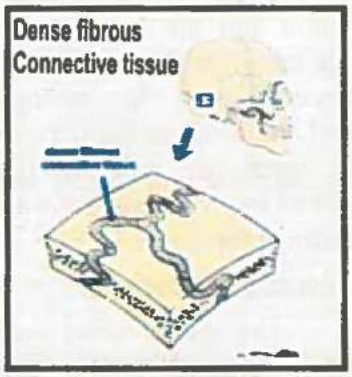


Fig: 16.6 Fibrous joints in skull.

ii. Cartilaginous joints: Cartilaginous joints are connected entirely by fibrocartilage or hyaline cartilage. Joint cavity is absent. Bones can glide over each other to a limited extent. Cartilage forms a flexible connection so that these joints allow slight movement. Such joints are formed between vertebrae, and between wrist and ankle bones.

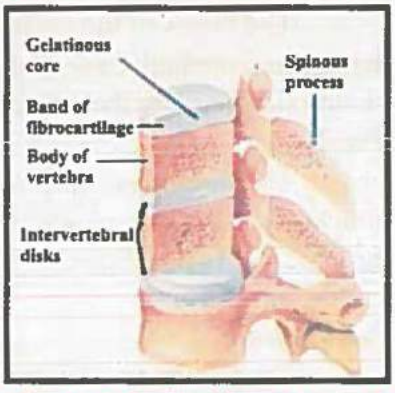


Fig: 16.7 Cartilaginous joints in vertebral column.

Synovial joints: Synovial joints are those in which the articulating bones are separated by a fluid-containing joint cavity (synovial cavity). This arrangement permits freedom of movement, and all synovial joints are freely movable.

Synovial joints are reinforced and strengthened by a number of bandlike **ligaments**. These ligaments hold the bones in position. Based on the shape of their articular surfaces, the synovial joints have different structural plan. This structural plan determines the type of movement allowed.

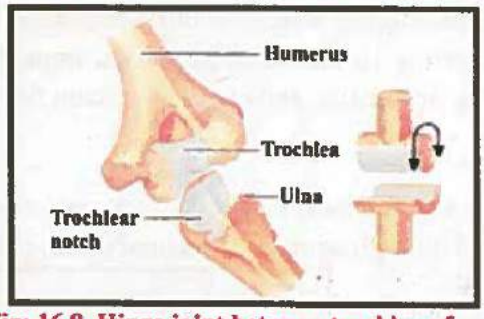


Fig: 16.8 Hinge joint between trochlea of humerus and trochlear notch of ulna at the elbow.

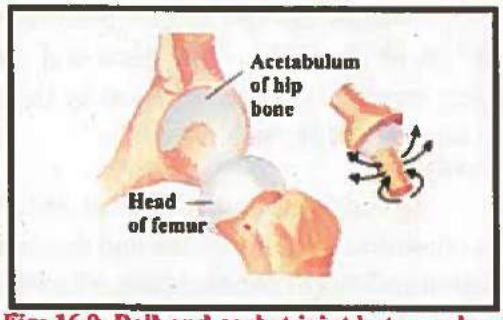


Fig: 16.9 Ball-and-socket joint between head of the femur and acetabulum of the hip bone.

The synovial joints can be classified into two major categories; hinge and ball and socket joints.

Hinge joints: In hinge joints, a cylindrical projection of one bone fits into a trough-shaped surface on another. These joints permit movement in one plane that is, permit flexion and extension only. Hinge joints are capable of bearing heavy loads. Examples are elbow and knee joint.

Ball-and-Socket Joints: In ball-and-socket joints the spherical or hemispherical head of one bone articulates with the cuplike socket of another. These joints are the most freely moving synovial joints. The shoulder and hip joints are examples.

16.2 DISORDERS OF SKELETON

16.2.1 Disorders of human skeleton:

Although human skeleton is hard and strong, yet deformities do occur resulting in reduced movement or complete immovability. Deformities of skeleton may be genetic, hormonal or due to the effects of nutrient deficiency

Disc slip:

The discs are protective shock-absorbing pads between the bones of the spine (vertebrae). The discs of the spine are also referred to as intervertebral discs. Although they do not actually "slip," a disc may split or rupture. This can cause the disc cartilage and nearby tissue to fail (herniate), allowing the inner gel portion of the disc to escape into the surrounding tissue. This leaking jelly-like substance can place pressure on the spinal cord or on an adjacent nerve to cause symptoms of pain either around the damaged disc or anywhere along the area controlled by that nerve. This condition is also known as a herniated disc. The most frequently affected area is in the lower back, but any disk can rupture, including those in the neck.

Factors that lead to a slipped disc include aging with associated degeneration and loss of elasticity of the discs and supporting structures; injury from improper lifting, especially if accompanied by twisting or turning; and excessive strain forces associated with physical activities.

Spondylosis:

Spondylosis (spinal osteoarthritis) is a degenerative disorder that may cause loss of normal spinal structure and function. Although aging is the primary cause, the location and rate of degeneration is individual.

The degenerative process of spondylosis may affect the cervical (neck), thoracic (mid-back), or lumbar (lower back) regions of the spine.

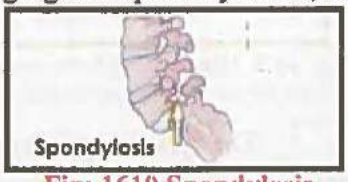


Fig: 1610 Spondylosis.

Sciatica:

Sciatica refers to pain, weakness, numbness, or tingling in the leg. It is caused by injury to or pressure on the sciatic nerve. This nerve starts in the lower spine and runs down the back of each leg. Common causes of sciatica include: Slipped disc, piriformis syndrome (a pain disorder involving the narrow muscle in the buttocks), pelvic injury or fracture and tumors.

Arthritis:

The arthritis is joint inflammation and it can affect joints in any part of the body. Arthritis is the leading cause of disability in those over the age of 65. Some of the symptoms of arthritis are:

- Joint pain and swelling.
- Stiffness particularly in the mornings.
- The feeling of warmth around a joint.
- Redness of skin around the joint.
- Inability to move the joint easily.

Some of the causes of arthritis are broken bone, infection in the area, an autoimmune disease and general wear and tear on joints.

16.2.2 Bone fractures

A fracture is the medical term for a broken bone. They occur when the physical force exerted on the bone is stronger than the bone itself. So bones break when they cannot withstand a force or trauma applied to them.

- **Simple fracture: Closed (simple) fractures** are those in which the skin is intact.

- **Compound fracture:** The fracture is an open (compound) fracture if the bone ends penetrate the skin and form a wound.

Repair of a fractured bone:

A fracture is treated by reduction, the realignment of the broken bone ends. In closed or external reduction, the bone ends are coaxed into position by the physician's hands. In open (internal) reduction, the bone ends are secured together surgically with pins or wires. After the broken bone is reduced, it is immobilized by a cast to allow the healing process to begin. For a simple fracture the healing time is six to eight weeks for small or medium-sized bones in young adults, but it is much longer for large, weight-bearing bones and for bones of elderly people (because of their poorer circulation). Repair in a simple fracture involves four major stages;

- **Hematoma formation:** When a bone breaks, blood vessels in the bone, and perhaps in surrounding tissues, are torn and hemorrhage occur. As a result, a hematoma, a mass of clotted blood, forms at the fracture site. Soon, bone cells deprived of nutrition die, and the tissue at the site becomes swollen, painful, and inflamed.
- **Fibrocartilaginous callus formation:** Within a few days, several events lead to the formation of soft granulation tissue, also called the soft callus. Capillaries grow into the hematoma and phagocytic cells invade the area and begin cleaning up the debris. Meanwhile, fibroblasts and osteoblasts invade the fracture site and begin reconstructing the bone.

The fibroblasts produce collagen fibers that span the break and connect the broken bone ends, and some differentiate into chondroblasts that secrete cartilage matrix.

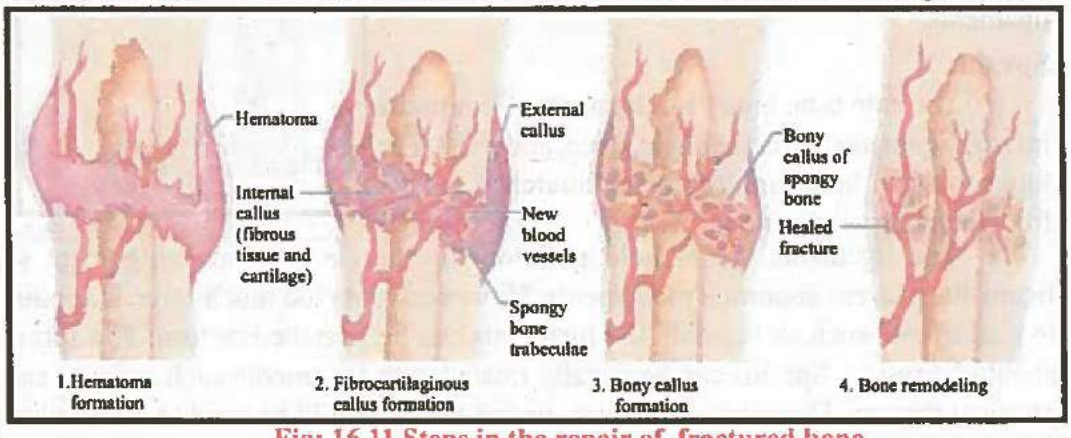


Fig: 16.11 Steps in the repair of fractured bone.

Within this mass of repair tissue, osteoblasts begin forming spongy bone, but those farthest from the capillary supply secrete an externally bulging cartilaginous matrix that later calcifies. This entire mass of repair tissue, now called the fibrocartilaginous callus, splints the broken bone.

- **Bony callus formation:** Within a week the fibrocartilaginous callus is gradually converted to a bony (hard) callus of spongy bone. Bony callus formation continues until a firm union is formed about two months later.
- **Bone remodeling:** Beginning during bony callus formation and continuing for several months after, the bony callus is remodeled. The compact bone is laid down to reconstruct the shaft walls. The final structure of the remodeled area resembles that of the original unbroken bony region because it responds to the same set of mechanical stressors.

16.2.3 Joint injuries:

Joint dislocation:

A dislocated joint is a joint that slips out of place. It occurs when the ends of bones are forced away from their normal positions. When a joint is dislocated, it no longer functions properly. A severe dislocation can cause tearing of the muscles, ligaments and tendons that support the joint. Symptoms include; swelling, intense Pain, and immobility of the affected joint. The most common causes are a blow, fall, or other trauma to the joint. In some cases, dislocations are caused by a disease or a defective ligament.

Rheumatoid arthritis can also cause joint dislocation. A dislocated joint usually can only be successfully 'reduced' into its normal position by a trained medical professional. Surgery may be needed to repair or tighten stretched ligaments.

Sprain:

A sprain is an injury to a ligament. Commonly injured ligaments are in the ankle, knee, and wrist. The ligaments can be injured by being stretched too far from their normal position.

Fig: 16.12 Ligaments in the ankle.

The ligaments are to hold skeleton together in a normal alignment so ligaments prevent abnormal movements. However, when too much force is applied to a ligament, such as in a fall, the ligaments can be stretched or torn. The sprain should be rested. Sprains can be usually treated with treatments such as icing and physical therapy. Dressings, bandages, or ace-wraps should be used to immobilize the sprain and provide support.

16.3 MUSCLES

Muscle is a specialized tissue of mesodermal origin. Muscle tissue makes up nearly half the human body mass. The most distinguishing functional characteristic of muscles is their ability to transform chemical energy (ATP) into mechanical energy. In doing so, they become capable of exerting force.

16.3.1 Types of muscles

Based on their location, three types of muscles are skeletal, cardiac, and smooth.

i. Skeletal Muscles

Skeletal muscles are attached to and cover the bony skeleton. Skeletal muscle fibers are multinucleated, the longest muscle cells having obvious stripes called striations and are under voluntary control. They can contract rapidly, but get tire easily and must rest after short periods of activity, or fatigued. Nevertheless, it can exert tremendous power.

Skeletal muscles are also remarkably adaptable. For example, hand muscles can exert a force of a fraction of an ounce to pick up a dropped paper clip and the same muscles can exert a force of many pounds to pick heavy loads like a bucket full of water. Skeletal muscles are primarily involved in locomotory actions and changes of body postures.

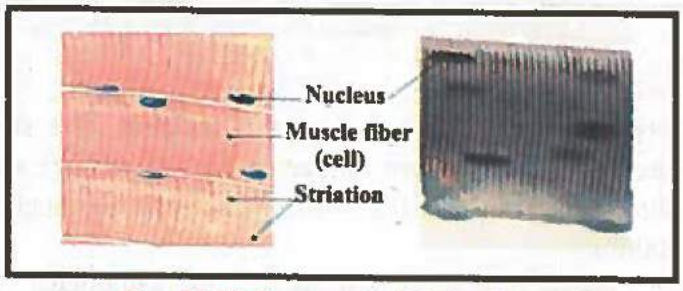


Fig: 16.13 Structure of skeletal muscle.

ii. Cardiac Muscles

Cardiac muscles occur only in the heart where they constitute the bulk of the heart walls. Cardiac muscle cells are arranged in a characteristic branching pattern. Like skeletal muscle cells, cardiac muscle cells are striated, but are involuntary and have single nucleus.

Cardiac muscles usually contract at a fairly steady rate set by the heart's pacemaker, but neural controls allow the heart to "shift into high gear" for brief

periods.

Rhythmic contraction of cardiac muscles in atria and ventricles of the heart pump blood throughout the body.

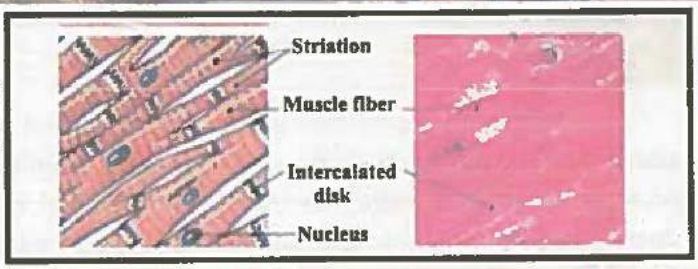


Fig: 16.14 Structure of cardiac muscle

iii. Smooth Muscles

Smooth muscles are found in the walls of hollow visceral organs, such as the stomach, urinary bladder, respiratory passages, and blood vessels. Smooth muscle cells are spindle shaped. They have one centrally placed nucleus per cell. They have no striations, and are not subjected to voluntary control.

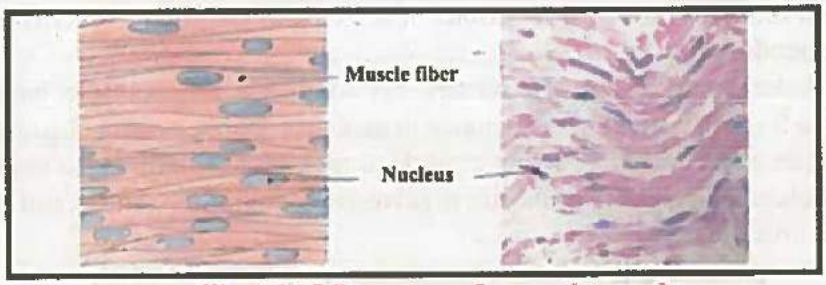


Fig: 16.15 Structure of smooth muscle.

16.3.2 Structure of Skeletal Muscles

The skeletal muscles are attached to the skeleton. The skeletal muscle consists of muscles bundle, which are further composed of huge elongated cells called muscles fibre. These muscles fibres are cylindrical, unbranched and with a diameter of 10–100μm.

Each fibre consists of a semi fluid matrix, the sarcoplasm or cytoplasm, containing many nuclei and a large number of mitochondria. The nuclei are located near the periphery of each fibre.

Each fibre is surrounded by a membrane sarcolemma. The sarcolemma of muscle fibre cell penetrates deep into the cell to form hollow elongated tube, the transverse tubule, T-tubule. The lumen of which is continuous with the extracellular fluid. The T-tubule and terminal portion of the adjacent envelope of sarcoplasmic reticulum (a modified type of endoplasmic reticulum that store calcium) form triads at regular intervals along the length of the fibril.

The nerve impulse is carried through the T-tubule to the adjacent sarcoplasmic reticulum. Fibre may be red, due to the presence of the myoglobin- an oxygen storing pigmented protein. It also contain large amount of stored glycogen.

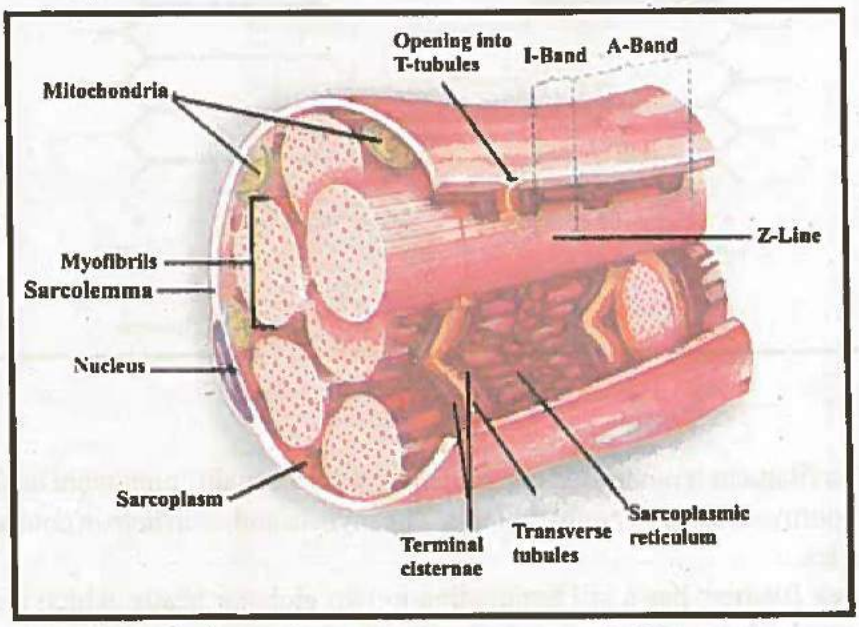


Fig: 16.16 Section through a muscle fibre.

The sarcoplasm of the fibre contains many contractile elements called myofibrils, which are 1 –2μm in diameter. Each myofibril has alternate light and dark bands, which give the fibre its "striped" appearances. It is because of this, that the skeletal muscles are also called striated or striped muscles.

Myofibrils consist of smaller contractile units called sarcomere. In each sarcomere a series of dark and light bands are evident along the length of each myofibril. The dark bands are A band (anisotropic) and the light band are I band (isotropic). Each A band has a lighter strip in its midsection called H-zone (hele for bright) which inturn is bisected by M –line (medial line). The I band have midline called Z –line (zwish meaning between). A sarcomere is the region of a myofibril between two successive Z –line. The region of myofibril is the sarcomere, which is the functional unit of the contraction process in the muscles.

Each myofilament is made up of central thick filament surrounded by thin filament, which are linked together by cross bridges. The thick filament contains a protein, myosin.

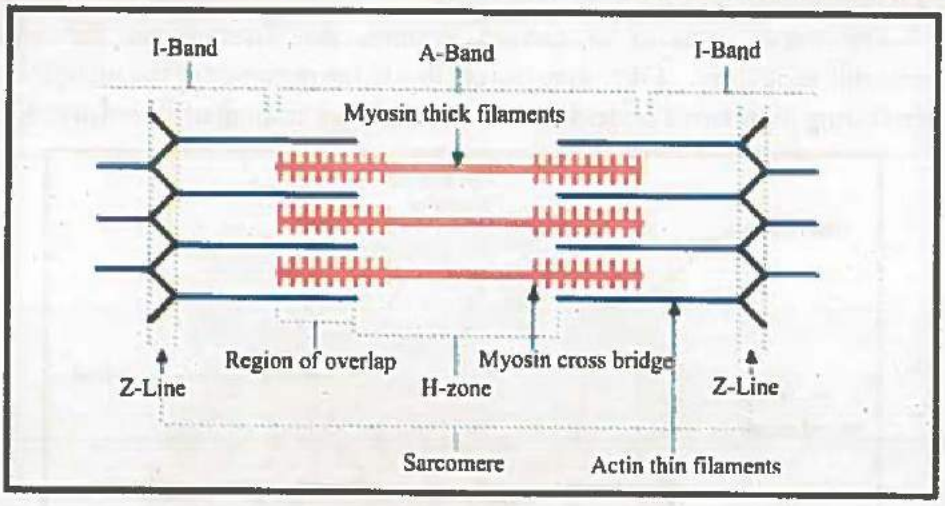


Fig: 16.17 Composition of sarcomere.

Thin filament is composed of a protein actin as its main component besides it also has tropomyosin and troponin proteins. The myosin and actin help in contraction of the muscles.

Thick filament has a tail terminating in two globular heads, which are also called as cross bridges and these link thin and thick filaments during contraction.

Muscles Contraction

Contractility or the ability to contract is a fundamental characteristic of living substance. It is essential to all kinds of movements, except growth and cytoplasmic streaming.

The currently popular model of muscle fiber contraction is called the **sliding filament hypothesis** proposed by H .E. Huxely and A. F. Huxely. They observed that when the muscle contracts, the thick and thin filaments of the muscles fibre slide past each other but are not changed in length.

According to this model, the release of calcium ions from the sarcoplasmic reticulum causes a reorientation of certain components in the thin actin filaments, permitting them to bind with extensions (heads) from the thick myosin filaments.

Each myosin head then binds and splits an ATP molecule and the energy released powers the head forward to the next binding component on the actin filament.

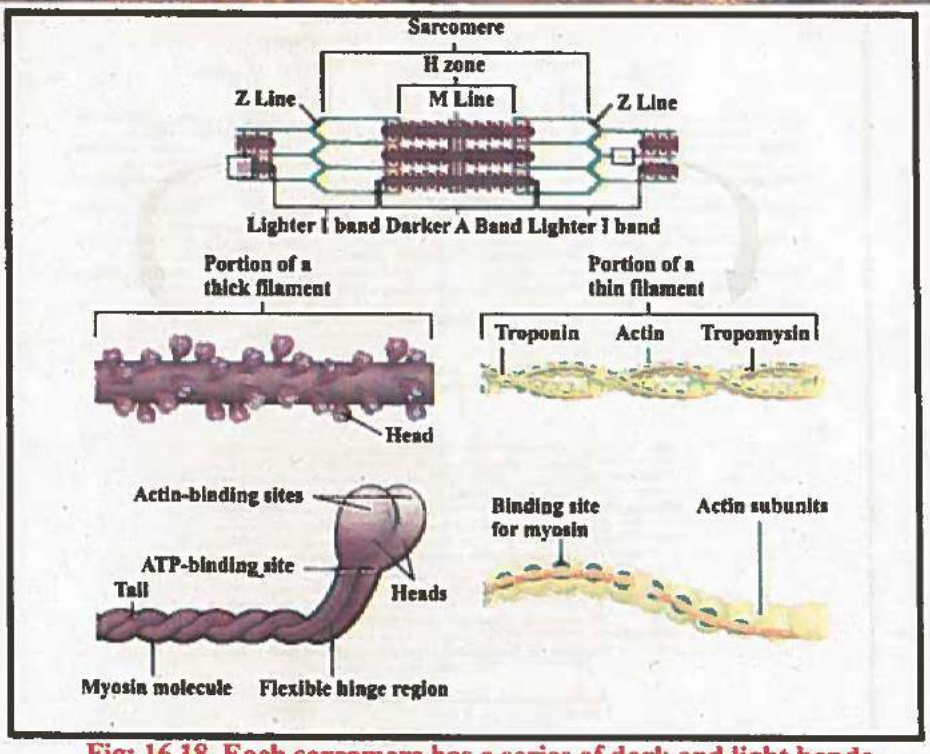


Fig: 16.18 Each sarcomere has a series of dark and light bands which are evident along the length of each myofibril.

As this occurs, the actin filament moves one "notch" past the myosin filament. As long as calcium ions and ATP are available in the cytoplasm, the myosin heads continue to "crawl" along the actin filaments, thereby contracting the sarcomere and muscle.

Recovery: Muscle Fibre Relaxation

When the electrical impulses reaching a muscle fibre cease, the sarcoplasmic reticulum begins to re-accumulate the calcium ions by active transport. Once most of the calcium is sequestered in the sarcoplasmic reticulum sacs, which takes only milliseconds, the binding between the myosin heads and the actin filaments can no longer occur. As a result, the thick and thin filaments slide past one another, returning to their relaxed state of minimal overlap. The sarcomeres (and muscle fibres) once again achieve their maximal length and stretchability.

Control of Muscle Contraction

The contraction of a muscle fibre is normally an all-or- none phenomenon. Once it is stimulated, a muscle fibre will contract to a set length, regardless of intensity of the stimulus above the threshold level.

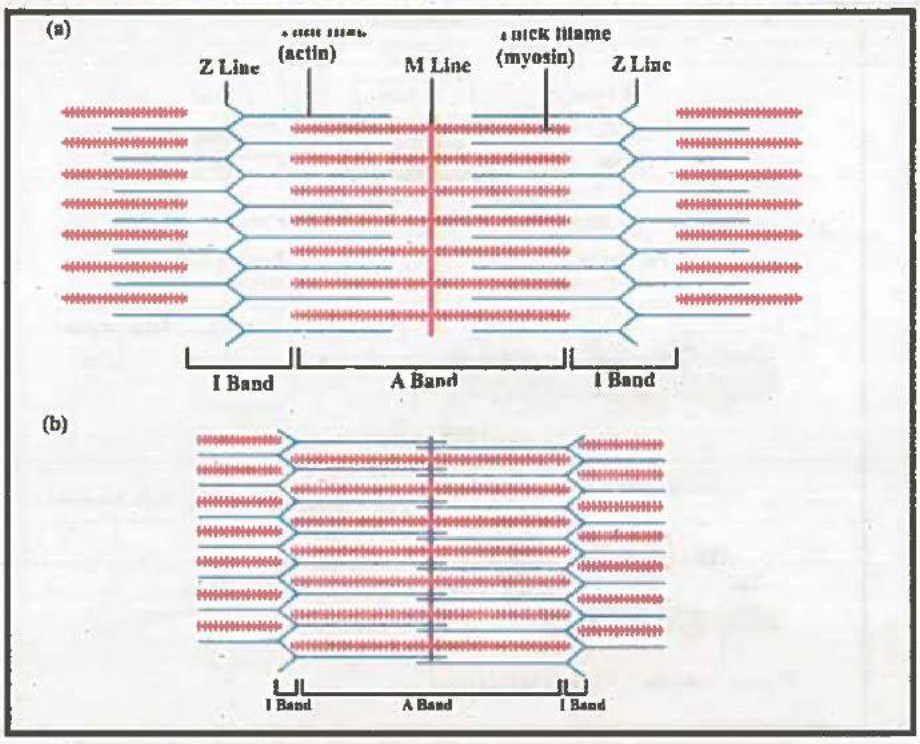


Fig: 16.19 Sarcomere exhibiting contraction movement.

The question then arises: If fibre contraction is an all-or- none phenomenon, how do we manage the fine control of muscular activity that permits us to lift a pencil on one occasion and a bowling ball on another?

Part of the answer has to do with the physical relationship between motor neurons and muscle fibres. The axon of a motor neuron has many branches, each branch terminating at a single muscle fibre. Thus, depending on how many branches it has, one neuron can stimulate several to many different muscle fibres. All the muscle fibres triggered by a single neuron contract simultaneously as a single **motor unit.** Since a particular muscle may consist of many motor units, the total amount of muscle contraction depends on the number of motor neurons conducting impulses to their motor units in that muscle. If many neurons carry impulses at once, many motor units within the muscle will contract. This causes a stronger over all contraction of the muscle than if only a few motor units are activated.

Energy of Muscle Contraction

Muscle contraction needs energy. The immediate source of energy for the muscle contraction is ATP, stored in the muscle cells. An enzyme ATPase, in the muscle cells breaks ATP to ADP, thus releasing energy for muscle contraction. But much part of the energy comes from carbohydrates or glucose, stored as glycogen in the muscle cells. When muscle contraction begins, glycogen is converted into glucose, which is then broken down to form ATP. The muscle contraction then uses this ATP.

We know that in violent exercise, such as running, much energy is needed. Is the normal rate of formation of ATP in muscles fibers adequate for this? Apparently not, but the muscles cells of all vertebrates have a reserve of high-energy phosphate compound, called phosphocreatin. During periods of intensive muscular activity, the phosphocreatin is broken into creatin and a high-energy phosphate group. This group then unites with ADP to form ATP.

Of the total energy expended in muscles contraction, only about35% is utilized for the performance of work; the remaining is liberated in the form of heat, which is employed to maintain body temperature. In cold weather the production of heat can be increased through voluntary muscular activity (walking, rubbing hand together etc) or involuntary by shivering. Conversely, in warm weather, muscular activity is deliberately decreased to reduce heat production.

16.3.5 Muscle problems

I. Cramps: Muscle cramps are sudden, involuntary contractions or spasms in one or more muscles. They often occur after exercise or at night, lasting a few seconds to several minutes. Writer's cramp is a familiar example of temporary contractures. Muscle cramps can be caused by nerves that malfunction. Other causes are, straining or overusing a muscle, dehydration, lack of minerals in diet or the depletion of minerals in body, and not enough blood getting to muscles.

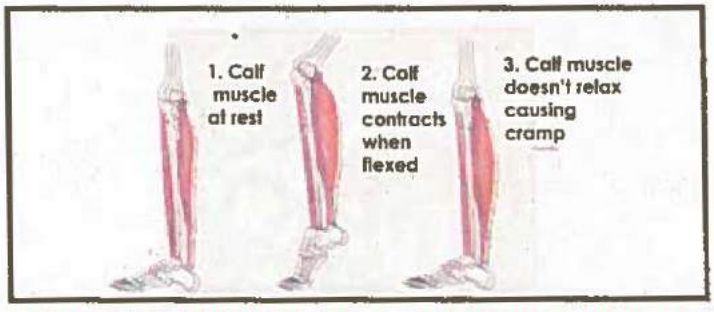


Fig: 16.20 Cramps are involuntary contractions or spasms in one or more muscles.

ii. Muscle fatigue:

Muscle fatigue is a condition of the muscle in which its capacity to produce maximum contraction is reduced even though the muscle still may be receiving stimuli. Availability of ATP declines during contraction and a total lack of ATP results in contractures, states of continuous contraction because the cross bridges are unable to detach. Although excessive intracellular accumulation of lactic acid (which causes the muscles to ache and raises H^+) alters contractile proteins, other ionic imbalances also contribute to muscle fatigue. In general, intense exercise of short duration produces fatigue rapidly via ionic disturbances, but recovery is also rapid. In contrast to short-duration exercise, the slow-developing fatigue of prolonged low-intensity exercise may require several hours for complete recovery.

iii. Tetany:

Tetany is a symptom characterized by muscle cramps, spasms or tremors. These repetitive actions of the muscles happen when muscle contracts uncontrollably. Tetany may occur in any muscle of the body, such as those in face, fingers or calves. The muscle cramping associated with tetany can be long lasting and painful. A common cause of tetany is very low levels of calcium in the body.

Tetanus:

Tetanus is infection of the nervous system with the potentially deadly bacteria *Clostridium tetani*. Spores of the bacteria *C. tetani* live in the soil and are found around the world. In the spore form, *C. tetani* may remain inactive in the soil, but it can remain infectious for more than 40 years. Infection begins when the spores enter the body through an injury or wound. The spores release bacteria that spread and make a poison called tetanospasmin. This poison blocks nerve signals from the spinal cord to the muscles, causing severe muscle spasms. The spasms can be so powerful that they tear the muscles or cause fractures of the spine.

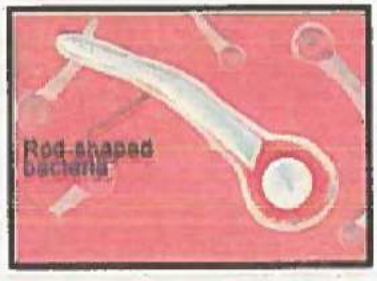


Fig: 16.21 *Clostridium tetani*

KEY POINTS

- The skeleton in animals contributes in upholding and sustaining the body against gravity and other external forces.
- The vertebrate skeleton is composed either of cartilage or bone.
- **Cartilage consists of cells called chondrocytes and a tough, flexible matrix made of type II collagen and it is without** blood vessels.
- Bone is a living hard and strong structure consisting of a hard ground substance or matrix and cells.
- Bones are composed of **osteoblasts** (cells that help **form** bone), and **osteoclasts** (cells that help **eat away** old bone) and **osteocytes** which are mature osteoblasts.
- Human skeleton consists of 206 individual bones which are grouped into two general divisions; axial skeleton, the basic framework of the body and appendicular skeleton, the extremities.
- The human skull is composed of 22 bones, besides 6 tiny ear bones and one hyoid bone.
- In human, there are 33 vertebrae. Seven cervical vertebrae, 12 thoracic vertebrae; 5 lumber vertebrae; 5 sacral vertebrae and at the end of the vertebral column is the coccyx or tail bone which consists of 4 small fused vertebrae.
- In human there are twelve pairs of ribs, one pair articulating with each of the thoracic vertebrae forming a cage that encloses the heart and lungs.
- The appendicular skeleton consists of pectoral girdles with forelimbs and pelvic girdle with hind limbs.
- The sites where two or more bones meet are called joints or articulations.
- Deformities of skeleton may be genetic, hormonal or due to the effects of nutrient deficiency.
- A fracture means broken bone.
- **Simple fractures** are those in which the skin is intact.
- Compound fracture is an open fracture: if the bone ends penetrate the skin and form a wound.
- A dislocated joint is a joint that slips out of place.
- Based on location, three types of muscles are skeletal, cardiac, and smooth.
- The skeletal muscle consists of muscles bundle, which are further composed of huge elongated cells called muscles fibre..

KEY POINTS

- The immediate source of energy for the muscle contraction is ATP, stored in the muscle cells. An enzyme ATPase, in the muscle cells breaks ATP to ADP, thus releasing energy for muscle contraction.
- Muscle fatigue is a condition of the muscle in which its capacity to produce maximum contraction is reduced even though the muscle still may be receiving stimuli.
- Muscle cramps are sudden, involuntary contractions or spasms in one or more muscles.
- Tetany is a symptom characterized by muscle cramps, spasms or tremors.
- Tetanus is a infection of the nervous system caused by a deadly bacteria *Clostridium tetani*.

EXERCISE ?

1- Multiple Choice Questions

(i) ***The disorder in which bones are porous and thin but bone composition is normal is;***

(a) osteomalacia (b) osteoporosis
(c) rickets (d) arthritis

(ii) ***The organic portion of bone's matrix is important in providing all but;***

(a) tensile strength (b) hardness
(c) to resist stretch (d) flexibility

(iii) ***The remodeling of bone is a function of which cells?***

(a) chondrocytes and osteocytes (b) osteoblasts and osteoclasts
(c) chondroblasts and osteoclasts (d) osteoblasts and osteocytes

(iv) ***In skeletal muscle, calcium facilitates contraction by binding to***

(a) tropomyosin (b) actin.
(c) troponin. (d) myosin.

(v) ***Which of the following statements concerning the role of*** Ca^{+2} ***in the contraction of skeletal muscle is correct?***

(a) The mitochondria act as a store of Ca^{++} for the contractile process
(b) Ca^{+2} entry across the plasma membrane is important in sustaining the contraction of skeletal muscle
c) A rise in intracellular Ca^{+2} allows actin to interact with myosin
d) The tension of a skeletal muscle fibre is partly regulated by G proteins
muscle

(vi) ***The function of the T tubules in muscle contraction is to***

(a) make and store glycogen
(b) release Ca^{+2} into the cell interior and then pick it up again
(c) make the action potential deep into the muscle cells
(d) to hamper the the nerve impulse

(vii) ***The sites where the motor nerve impulse is transmitted from the nerve endings to the skeletal muscle cell membranes are the:***

(a) neuromuscular junctions (b) sarcomeres
(c) myofilaments (d) Z discs

EXERCISE ?

(viii) ***Myoglobin has a special function in muscle tissue.***

(a) it breaks down glycogen
(b) it is a contractile protein
(c) it holds a reserve supply of oxygen in the muscle
(d) none of these

2- **Short Questions**

(i) Name the cranial and facial bones
(ii) What is the function of the intervertebral discs?

(iv) Briefly describe the impairment of function seen in cleft palate.

3- **Long Questions**

(i) Describe the structure of bone.
(ii) Describe major divisions of human axial skeleton
(iii) What are types of fractures? Describe the repair process of a simple fracture.
(iv) Compare smooth, cardiac, and skeletal muscles.
(v) Explain the ultra-structure of human skeletal muscles.
(vi) Explain the sliding filament theory of contraction using appropriately labeled diagrams of a relaxed and a contracted sarcomere.
(vii) Describe the structure of a sarcomere and indicate the relationship of the sarcomere to the myofilament

Analyzing and Interpreting

- Identify the bones of the pelvic girdle, pectoral girdle, arms and leg by using the model of human skeleton.
- Compare the structure of skeleton, smooth and cardiac muscles with the help of prepared slides.
- Draw a diagram of sarcomere and label its parts.
- Justify how the main functions of the skeleton are to act as a system of rods and levers, which are moved by the muscles.
- Justify why do the muscles pull but do not push.

EXERCISE

Initiating and Planning

- Relate the bipedal posture of man with his skeleton and musculature.

Science, Technology, and Society Connections

- Name the techniques for joint transplantation.
- Justify the use of calcium in teenage and twenties can be a preventive action against osteoporosis.
- Reason out the rigor mortis.
- Relate improper posture to bone/joint problems.

Online Learning

- www.muscleandfitness.com
- www.muscleandstrength.com
- www.getbodysmart.com/ap/muscles/musclesystem
- muscle.ucsd.edu
- www.innerbody.com

UNIT

17

NERVOUS COORDINATION

KEY CONCEPTS

17.1 Steps involved in nervous coordination

17.2 Neurons

17.3 Nerve impulse

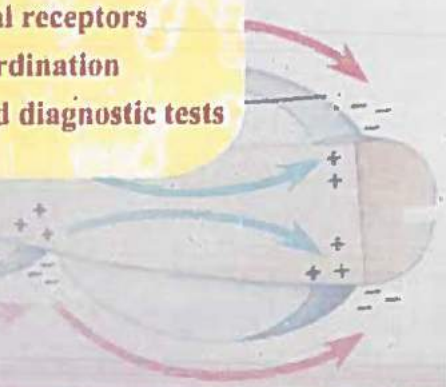
17.4 Synapse

17.5 Basic organization of human nervous system

17.6 Structure and function of special receptors

17.7 Effects of drugs on nervous coordination

17.8 Disorders of nervous system and diagnostic tests



The body of an animal frequently exposed to variety of stimuli in its daily life. For an appropriate response to a particular stimulus, usually more than one body parts are involved, their activities are coordinated either by nervous system or endocrine system or both. These two types of coordination you also have studied in class 10 to some extent, but in this chapter we are mainly focusing the human nervous system.

17.1 STEPS INVOLVED IN NERVOUS COORDINATION

Nervous coordination mainly comprises highly specialized cells, called the neurons. The function of a neuron is to detect and receive stimuli from different sensory organs (receptors) and then, integrate them to determine the mode of response of the living organism, and then commands for an appropriate response are transmitted to the other organ (effectors). Nervous coordination in higher animals is therefore consists of following steps.

- **Reception of stimulus:**
- **Processing/analysis of information:**
- **Response to stimulus:**

17.1.1 Reception of stimulus:

Those parts of the body that receive stimuli from internal or external environment are called receptors or transducers. A receptor may be a complete organ or a cell or just neuron endings. The information collected by the receptor is transmitted to the central nervous system (CNS) through sensory neurons.

Classification of receptors:

Receptors are classified into different types on the basis of stimuli.

- **Photoreceptors** detect light stimuli. For example rods and cone cells in the retina of eye
- **Chemoreceptors** detect ions or molecules (chemical). For example receptors found in nasal epithelium for detection of smell (olfaction) and those, found in tongue for taste (gustation). Chemoreceptors are also found in hypothalamus, called **osmoreceptors** that detect changes in osmotic pressure of blood.

Fig: 17.1 Photoreceptors present in the eye.

- **Mechanoreceptors** detect changes in pressure, position, or acceleration; include receptors for touch (Meissner's corpuscles in skin), stretch or pressure (Pacinian's corpuscle in skin & baroreceptor in the wall of blood vessels), hearing, and equilibrium (ear).

- **Thermoreceptors** detect temperatures stimuli. They are mostly found in the skin.
- **Nociceptors** detect pain.

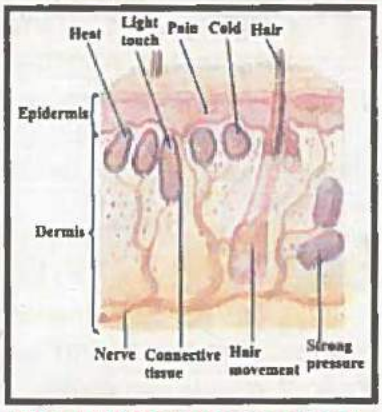


Fig: 17.2 Receptors present in the skin.

17.1.2 Processing/analysis of information:

Sensory inputs from various receptors are received by CNS (brain & spinal cord) that act as coordinating center of the body. This collected information is further processed/analyzed for an appropriate response by special type of neurons called associative or intermediate neurons.

17.1.3 Response to stimulus:

Those parts of the body which produce an appropriate response are called effectors (muscles and glands). An effector organ, on receiving signal from CNS by motor neuron, provides an appropriate response either by producing movements (muscles) or secretions (glands).

17.2 NEURONS

Although more than 50% of nervous system consists of neuroglial (neuroglia) cells, but the neuron is considered as chief structural and functional unit of nervous system. These specialized cells are the information-processing units of the nervous system responsible for receiving and transmitting information from receptors and effectors. A typical neuron consists of a cell body (soma) and fibrous structures called dendrites and axons.

Dendrites are cytoplasmic extensions at the beginning of a neuron that help to increase the surface area of the cell body. Dendrites are usually very thin fibers and have no association of Schwann cells hence they are non myelinated. These fibers receive information from receptors and transmit them to the cell body.

The soma or cell body is where the signals from the dendrites are collected and pass to the axon. The cell body contains single nucleus, many mitochondria, microtubules, neurofibrils and Nissl's granules (collection of group of ribosomes associated with rough ER and Golgi apparatus).

The axon is the elongated fiber that extends from the cell body to the terminal endings and transmits the neural signal to the next neuron. Axons are thick fibers and comparatively have more cytoplasm (axoplasm) than dendrites. Usually axons are covered by Schwann cells (neuroglia), which are strip like cells wrapped around axon fibers.

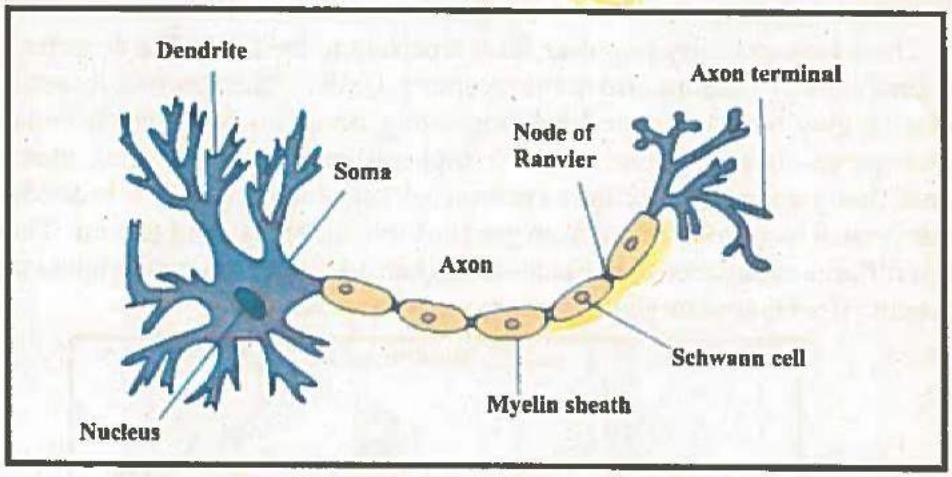


Fig: 17.3 Structure of a typical neuron.

These cells are also covered by a fatty substance called myelin sheath that acts as an insulator. This is why axons are called myelinated fibers. A non myelinated part of axon between two Schwann cells is called node of Ranvier. Velocity of impulse in axon fiber depends upon the diameter, length and myelin sheath.

The larger and thicker the axon, the faster it transmits information. The myelinated axons transmit information much faster than other neurons.

However, all neurons vary somewhat in size, shape, and characteristics depending on the function and role of the neuron.

Some neurons have few dendritic branches, while others are highly branched in order to receive a great deal of information.

Some neurons have short axons, while others can be quite long. Neuron having only one fiber radiating from cell body is called unipolar neuron, while those having two fibers called bipolar and those having many fibers are called multipolar. Based upon function neurons are three types.

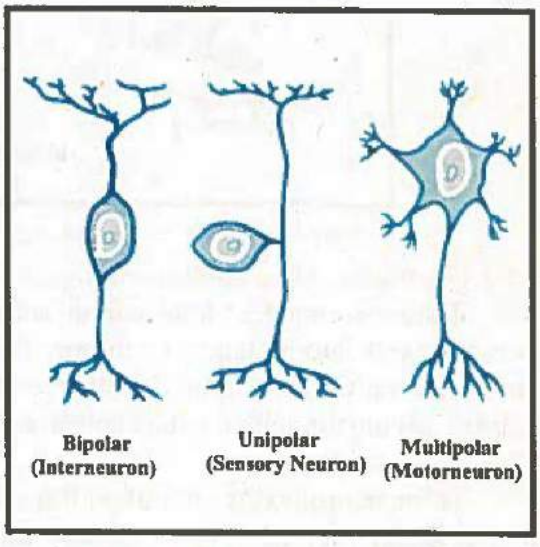


Fig: 17.4 Basic neuron types

17.2.1 Sensory Neuron:

These neurons carry impulses from receptors to the CNS. The dendrite endings of some sensory neurons also act as receptors. Unlike other neurons, these are mono polar i.e they have only one fiber originating from cell body which immediately gives rise two branches, one branch (peripheral) running between receptor site and dorsal root ganglion (collection of neuron cell) in which cell body is located, and the other branch (central) running from ganglion into the spinal cord or brain. There is no clear difference between dendrite and axon because, except for its terminal portions, the entire fiber is structurally and functionally of axon type.

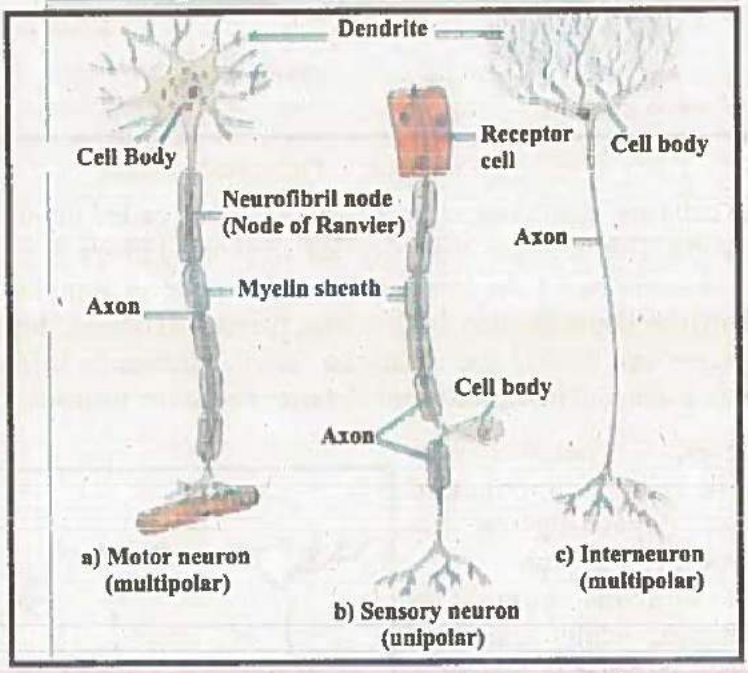


Fig: 17.5 Three types of neurons based upon functions.

17.2.2 Associative/intermediate neuron:

These neurons are found in brain and spinal cord (CNS). They are involved in processing and interpretation of information coming from receptors. Associative neurons are multipolar and unlike other neurons have highly branching network of dendrites, giving the cell a tree like appearance.

17.2.3 Motor neuron:

These neurons carry impulses from CNS to the effectors. Motor neurons are also multipolar but have long axons that run from the CNS to the effectors.Flow of information in nervous coordination can be explained with the help of a reflex arc.

17.2.4 Reflex Arc

The pathway of nerve impulse during reflex action is called reflex arc. Reflex actions are spontaneous involuntary activities performed unconsciously. For example, if you touch a hot or sharp pointed object by your hand, you will experience that your hand moves back at once before you think about it. Reflex activities have no involvement of brain; therefore the pathway of nerve impulse is slightly modified and quick than the general pathway.

A reflex arc consists of all the basic components of nervous coordination like receptor, sensory neuron, associative neuron, motor neuron and effectors. In the above example of reflex action, when your hand touches the sharp pointed object, pain sensitive endings of sensory neurons present in the skin are stimulated.

Peripheral branch of sensory neuron transmit impulse to the dorsal root ganglion from where impulse is carried to the spinal cord by central branch of sensory neuron. An associative neuron in the spinal cord is stimulated, which in turn stimulates the motor neuron, .

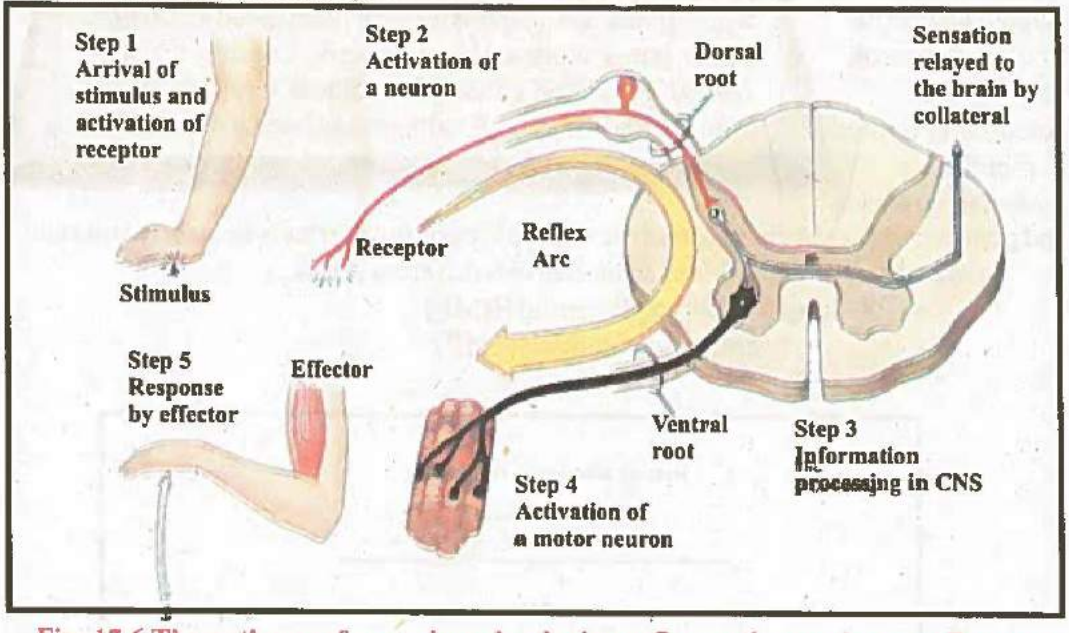


Fig: 17.6 The pathway of nerve impulse during reflex action makes a reflex arc.

The axon of the motor neuron carries impulse to the bicep muscles (effectors), causing them to contract and withdraw the body part from damaging stimulus. The sensory neuron also make a synapse on associative neuron not involved in the reflex that carry signals to the brain, inform it to the danger.

17.3 NERVE IMPULSE

Nerve impulse is information about a stimulus that is transmitted from receptors to the CNS and from CNS to the effectors. In technical terms a nerve impulse can be defined as a wave of electrochemical change that travels along the length of neuron, from one end to the other. In nerve impulse conduction, electrochemical means that it uses electricity made with chemical ions and molecules (Na^+, K^+, and charge bearing organic molecules).

A neuron possesses electrical potential which is a sort of stored (potential) energy which is manifested during separation of charges across the barrier. In case of neuron the electrical potential is termed as membrane potential, negative and positive ion act as charges and the charge separating barrier is neuron membrane.

For Your Information

The transmission of impulse along the neuron requires the movement of ions across the membrane. This is carried out by tiny holes called channels. These channels basically are of two different types i.e. pumps and gates. Pumps perform active transport while gates are responsible for facilitated diffusion. Some gates work only in specific condition called voltage regulated gates while others function all the time are known as non-voltage regulated gates.

Membrane potential is exhibited in two different forms:

- Resting Membrane Potential (RMP)
- Active Membrane Potential (AMP)

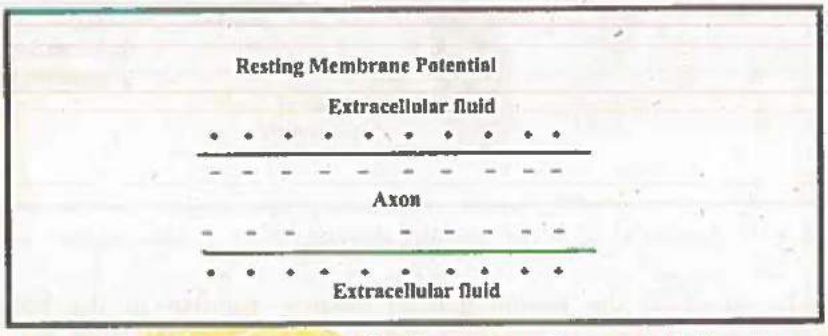


Fig: 17.7 Negative and positive ion act as charges and the charge separating barrier is neuron membrane.

17.3.1 Resting membrane potential:

It is characterized by more positive outer surface of neuron membrane than inner surface. This state is also referred as polarized state and the neuron is supposed to be at rest. This means that there is an unequal distribution of ions on the two sides of the nerve cell membrane. This potential generally measures about 70 millivolts (with the inside of the membrane negative with respect to the outside). So, the resting membrane potential is expressed as -70 mV, and the minus means that the inside is negative relative to (or compared to) the outside. It is called a resting potential because it occurs when a membrane is not being stimulated or conducting impulses. Resting membrane potential is established by the following factors:

17.3.2 Distribution and active movement of Na^+ and K^+ ions:

The concentration of potassium (K^+) is 30 times greater in the fluid inside the cell than outside and the concentration of sodium ions (Na^+) is nearly 10 times greater in the fluid outside the cell than inside.These ions are continuously moved against their concentration gradient through active transport pumps by the expenditure of energy. For every two K^+ that are actively transported inward, three Na^+ are pumped out. So inside becomes more negative than outside of the neuron membrane.

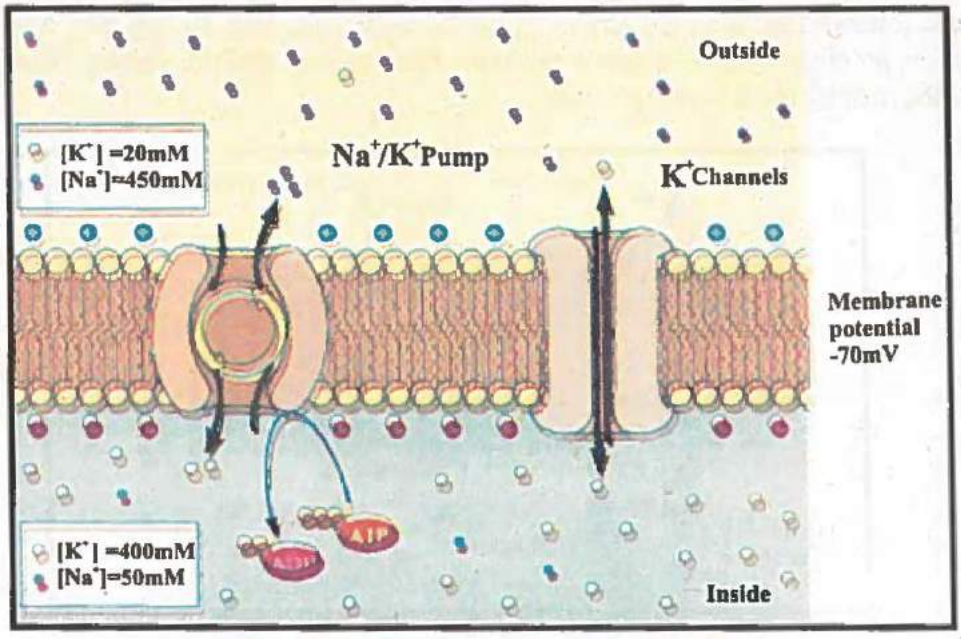


Fig: 17.8 Resting membrane potential.

17.3.3 Negative organic ions:

There are many types of organic compounds in the neuron cytoplasm that also have negative charges. These ions include some amino acids, many proteins, RNA and DNA. Presence of these ions in the neuron cytoplasm makes inside of neuron more negative than outside.

17.3.4 Leakage of K+ ions:

Cell membrane of neuron also has many channel proteins called gates. K+ ions are continuously moved out of the neuron through some non-voltage regulated gates. This also makes more positive outside of neuron than inside.

Overall there are more positive charges on the outside than on the inside. This is known as resting membrane potential. This potential will be maintained until the membrane is disturbed or stimulated by a sufficiently strong stimulus (threshold), then action potential will occur.

17.3.5 Development of active membrane potential:

Active membrane potential (also called as action potential) is characterized by more positive inside of neuron than outside (depolarized state). This happens when positive charges tend to move inside of neuron on receiving a particular stimulus. This electrochemical change appears on a short region of neuron for a brief period of time followed by the recovery of pervious polarized state. In this way a wave of action potential begin to move towards other end of neuron. Action potential is established by the following factors.

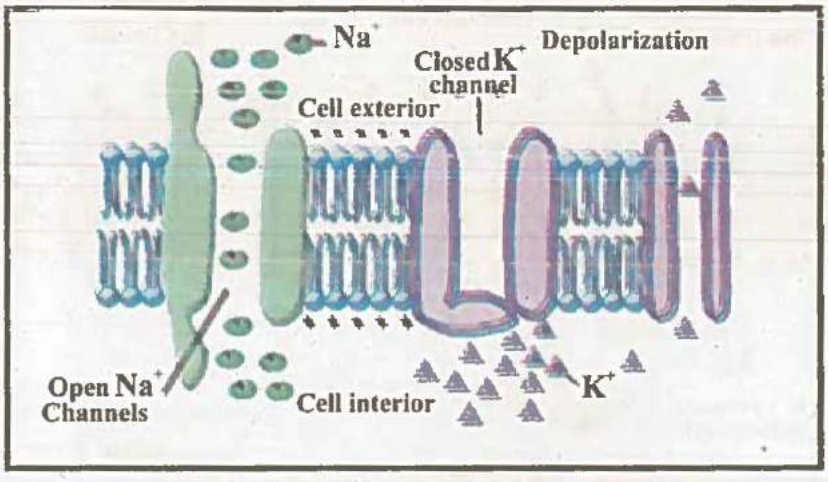


Fig: 17.9 Active membrane potential

17.3.6 Threshold stimulus:

If a stimulus is capable to bring an electrochemical change on neuron or to excite a given tissue, it is called threshold stimulus or adequate stimulus. If stimulus is not capable to excite or fails to arise any response, it is called sub threshold or inadequate stimulus.

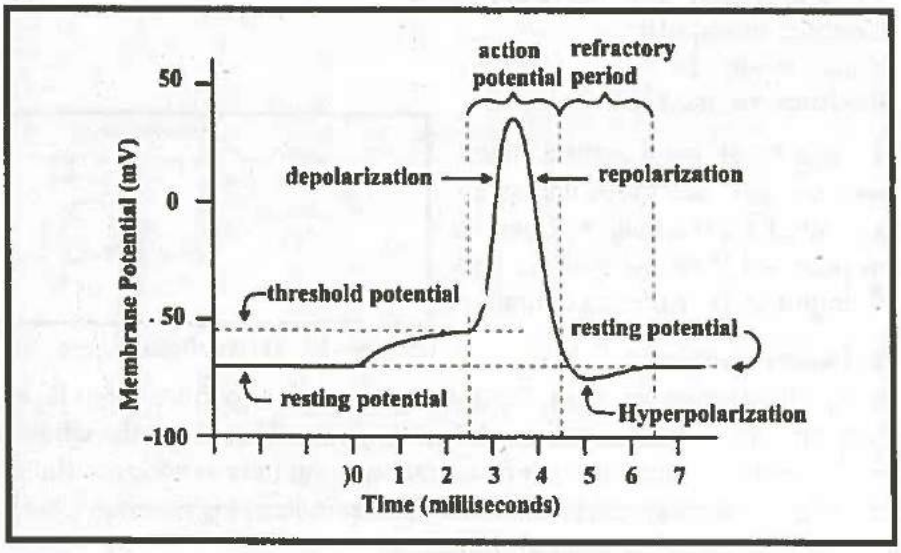


Fig: 17.10 Action Potential in a Neuron.

17.3.7 Influx of Na^+ ions:

When a neuron fiber is stimulated by a stimulus of adequate strength (threshold stimulus), the stimulated area of the fiber becomes several times more permeable to Na^+ than to the K^+ due to the opening of voltage regulated Na^+ gates. As a result Na gates permit the influx of Na^+ ions by diffusion. Since there are more Na^+ ions entering than leaving, the electrical potential of the membrane changes from -70 mV towards zero and then reach to the 50 mV. This reversal of polarity across two sides of membrane is called depolarization. This electropositive inside and electronegative outside lasts for about one milli second till the Na^+ gates are not closed.

After the peak of action potential, called the spike potential, the permeability of the membrane to Na^+ decreases, while it becomes more permeable to K^+ which rapidly diffuses out from cytoplasm to extracellular fluid due to the opening of K^+ gates. Now Na^+ gates are closed. Soon this part of neuron membrane regains its original polarity and becomes electropositive on outside and electronegative on inside. This is called repolarization.

17.3.8 Refractory period:

After an action potential, nerve fiber undergoes a period of recovery in which it regains its original ionic distribution and polarity and prepares itself for the next stimulation. This period of recovery of nerve fiber is called refractory period.

17.3.9 Types of Nerve Impulse:

There are two types of nerve impulses:

i. Continuous impulse
ii. Saltatory impulse

I. Continuous impulse:

In non myelinated neuron fibers, the K^+ and Na^+ ions can move across the membrane all along the length of neuron so action potential flows as a wave. This type of impulse is called continuous impulse.

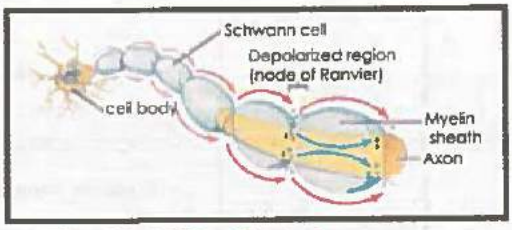


Fig: 17. 11 Myelinated neuron

II. Saltatory impulse:

In myelinated neuron fiber, the myelin sheath is impermeable to K^+ and Na^+ ions, so prevents the ionic exchange and depolarization fiber along the whole length of neuron. The ionic exchange and depolarization occur only at nodes of Ranvier. So the action potential is conducted from node to node in jumping manner. This kind of jumping impulse is called saltatory impulse.

Speed of nerve impulse: Speed of nerve impulse is different in different neuron fibers and depends upon the morphology of nerve fibers. Average speed of nerve impulse is 100 to 120 meter per second.

- The speed of nerve impulse is faster (about 20 times) in myelinated neuron fiber due to salutatory conduction. Another reason that myelinated fibers conduct faster impulse is that myelin sheath acts as an insulating sheath and prevents loss of energy, so myelinated neuron fibers require less energy.
- Speed of nerve impulse also depends upon diameter of neuron fibers. Thick neuron fibers conduct faster impulse than thin fibers because resistance to electrical current flow is inversely proportional to the cross sectional area of the conductor (such as wire or a neuron fiber), so with the increase in thickness of neuron fibers there is decrease in resistance of fiber to nerve impulse.

17.4 SYNAPSE

In most cases, action potentials are not transmitted from one neuron to another or from neuron to other cells. However, information is transmitted, and this transmission occurs at synapses. This is the junction between axon terminal of one

neuron and the dendrite of another neuron, where information from one neuron is transmitted or relayed (handed over) to another neuron, but there is no cytoplasmic connection between the two neurons instead a microscopic gap is present.
There are two types of synapses:

- Electrical synapses
- Chemical synapses

17.4.1 Electrical synapses:

In electrical impulses, which are specialized for rapid signal transmission, the cells are separated by a gap, the synaptic cleft, of only 0.2 nm, so that an action potential arriving at the pre synaptic side of cleft, can sufficiently depolarize the post synaptic membrane to directly trigger its action potential.

17.4.2 Chemical synapses: The majority of synapses are chemical synapses where synaptic cleft has gap of more than 20 nm. Through these synapses, information of impulse from one neuron is transmitted to another by means of chemical messengers, the neurotransmitters.

17.4.3 Transmission of nerve impulse across synapse:

The axon terminals of pre synaptic neurons have expanded tips called synaptic knobs.The cytoplasm of synaptic knob contains numerous tiny spherical sacs called synaptic vesicles.

Each of these vesicles has as many as 10,000 molecules of a neurotransmitter substance. The arrival of action potential at the pre synaptic terminal depolarizes the plasma membrane, opening voltage gated channels that allow Ca^{2+} to diffuse into the synaptic knob. The resulting rise in Ca^{2+} concentration in the cytoplasm of synaptic knob causes some of the synaptic vesicles to fuse with the pre synaptic membrane, releasing the neurotransmitters. The neurotransmitters then diffuse across the synaptic cleft, and bind to the receptors on post synaptic membrane.

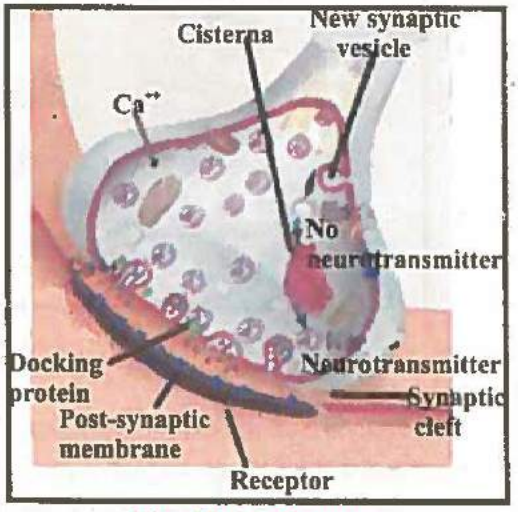


Fig: 17. 12 Synapse

Binding of neurotransmitters to the post synaptic neuron receptors opens some channels and allows Na+ ions to diffuse across the post synaptic membrane as a result post synaptic membrane depolarizes and an action potential is generated. Since this depolarization brings the membrane potential towards threshold level, it is called

excitatory postsynaptic potential (EPSP). At other synapses, different neurotransmitters bind to channels that are selectively permeable for only K^+ or Cl^-. When these channels open, the post synaptic membrane hyperpolarizes. Hyperpolarization produced in this manner is called **inhibitory postsynaptic potential (IPSP)**

Various mechanisms rapidly clear neurotransmitters from the synaptic cleft, terminating their effect on postsynaptic cells. Certain neurotransmitters may be actively transported back into the presynaptic neuron, to be repackaged into synaptic vesicles, or they may be transported into the neuroglia, to be metabolize as fuel. Other neurotransmitters are removed from synaptic cleft by enzymes that catalyze the hydrolysis of the neurotransmitters, like acetylcholine is hydrolyzed by **acetylcholinestrase** and adrenalin by **monoamine oxidase.**

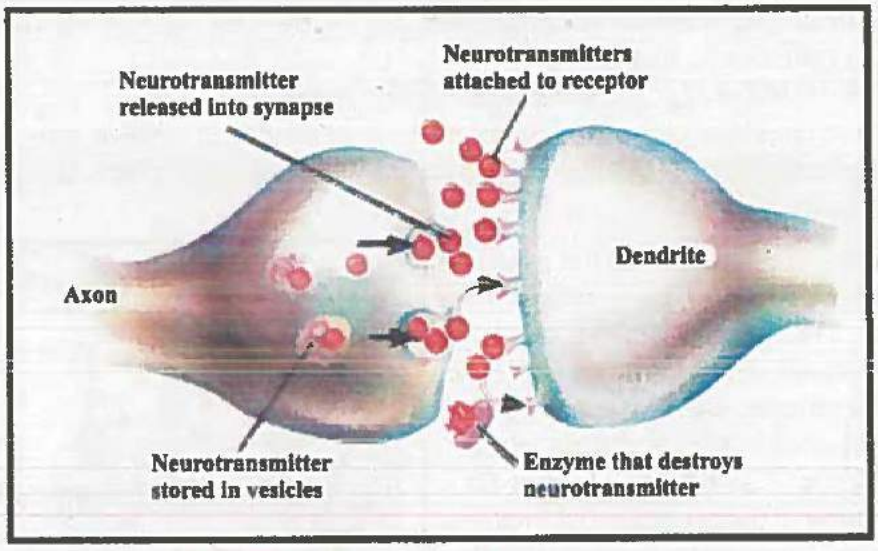


Fig: 17. 13 Neurotransmitters at synapse.

17.4.4 Neurotransmitters:

These are chemical messengers of nervous system. There are more than 100 known neurotransmitters. However, nearly all of these fall into one of a few groups based on chemical structure. Major classes of neurotransmitters are acetylcholine, biogenic amine, amino acid, neuropeptides, and gases. Some neurotransmitters that produce excitation on postsynaptic neuron receptors are called **excitatory neurotransmitters e.g acetylcholine** while other inhibits the postsynaptic action potential are called **inhibitory neurotransmitters e.g Serotonin.**

17.5 ORGANIZATION OF HUMAN NERVOUS SYSTEM

Human nervous system is a typical centralized nervous system. However, centralized nervous system is the characteristic of most animals, from flat worm to chordates, but human nervous system is the most advanced among them.

17.5.1 Divisions of human nervous system:

Human nervous system is primarily divided into central nervous system (CNS) and peripheral nervous system (PNS). CNS acts as a coordinating center while PNS provides communication among receptors, CNS, and effectors. Further division of nervous system are given in the following table.

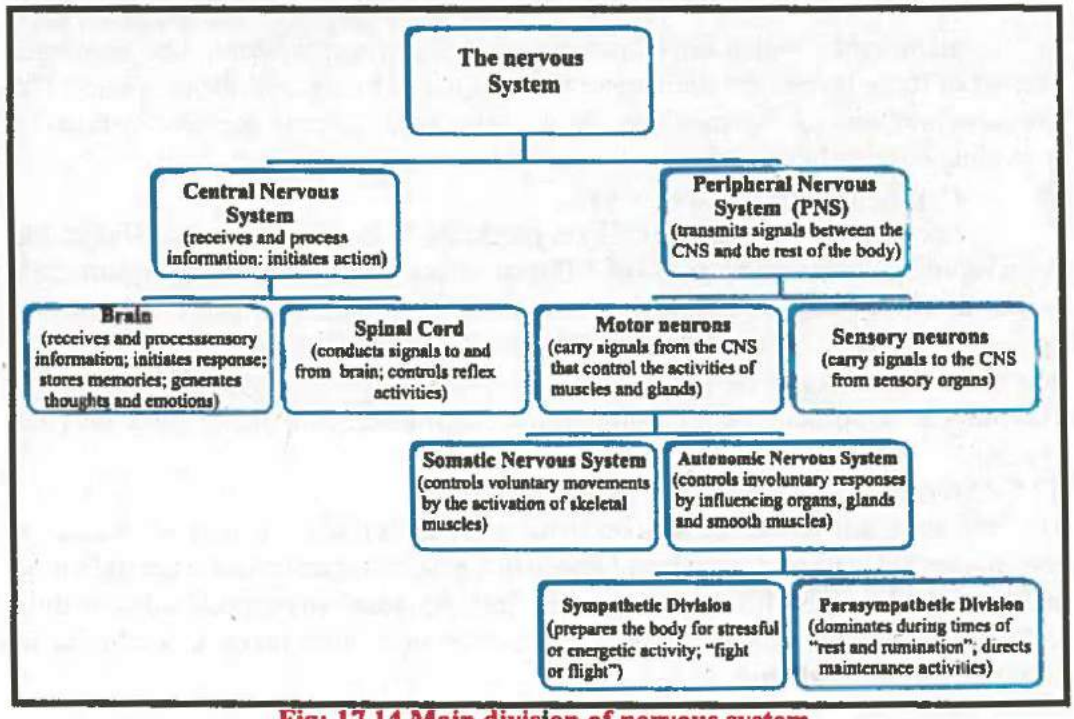


Fig: 17.14 Main division of nervous system

17.5.2 Central Nervous System:

Central nervous system consists of brain and spinal cord, both act as coordinating centers, but brain is involved more in coordination than spinal cord. Spinal cord also acts as a link between PNS and brain.

17.5.3 Protection of brain and spinal cord:

As brain and spinal cord are highly sensitive parts of human body so their protection from mechanical stresses is very important. They are protected in three different ways.

i. Skeleton:

The parts of skeleton that protect the brain and spinal cord are cranium and vertebral column. Cranium is the part of skull that covers the brain. Vertebral column consists of 33 vertebrae that encloses the spinal cord. These parts protect the brain and spinal cord from accidents or other physical traumas.

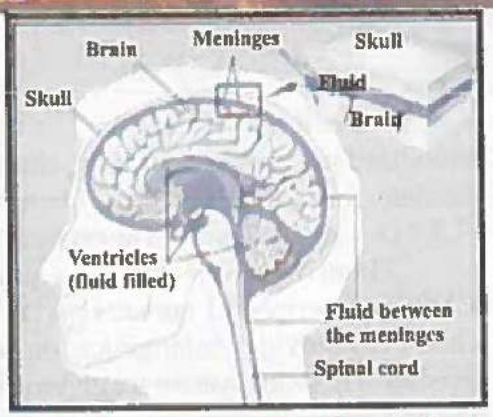


Fig: 17.15 Side way view of human brain.

ii. Meninges:

The meninges is the system of membranes which envelopes the central nervous system. The meninges consist of three layers: the dura mater, the arachnoid mater, and the pia mater. The primary function of the meninges is to protect the central nervous system by providing cushion like matrix.

iii. Cerebrospinal Fluid or CSF:

The cerebrospinal fluid (CSF) is produced from blood vessels of brain and spinal cord by a combined process of diffusion, pinocytosis and active transport. CSF is found in between pia mater and arachnoid mater, around the surface of brain and spinal cord, in the ventricles of brain and in the central hollow canal of spinal cord. It acts as a cushion that protects the brain and spinal cord from mechanical shocks. It also plays an important role in the homeostasis and metabolism of the central nervous system.

17.5.4 Structure and function of brain:

The human brain is the most wonderful and mysterious creation of nature. It coordinates the actions, so that they happen in the right sequence and at the right time and place. It also stores information, so that the behaviour can be modified according to the past experience. Human brain is divided into three parts: i. forebrain, ii. midbrain and iii. hindbrain.

i. Fore Brain

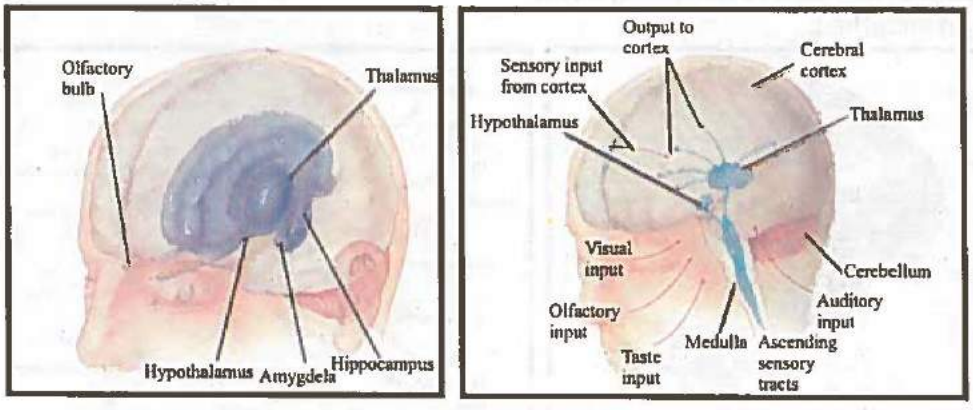
Forebrain is massively developed and contains the most sophisticated integrating centers. It has two subdivision; **telencephalon** and **diencephalon.** The telencephalon consists of a pair of olfactory bulbs and cerebrum.

The olfactory bulbs are concerned with the sense of smell. The cerebrum has many folds or convolutions that may be related to intelligence. The cerebrum is the largest portion of the brain.

It is divided into two cerebral hemispheres, connected together by a bridge of nerve fibres - the corpus callosum, which carries memory available on one side of the brain to the other side.

Cerebrum is the control center of many sensory areas like sight, speech, smell, taste and hearing. It is also concerned with conscious sensations, voluntary movements, learning,memory, thinking, decision-making, reasoning and judgment.

The **Diencephalon region** harbours limbic system, collectively representing parts of **thalamus, hypothalamus, amygdala** and **hippocampus**. Thalamus serves as a relay station between the body and the cerebrum. It receives impulses coming from different sensory areas of the body and carries them to the cerebrum. The function of hypothalamus range from hormones production to the regulation of body temperature, hunger, thirst, sexual response, the flight or fight response and biorhythms. Amygdala produces sensation of pleasure, punishment or sexual arousal when stimulated. Hippocampus plays an important role in the formation of long terms memory and is thus required for learning.



(a) The limbic system extends through several brain regions. (b) The reticular formation.

Fig: 17.16

ii. **The midbrain functions** in the coordination and relay of visual and auditory information. It is reduced in human and contain reticular formation which is a network of neurons running through **medulla** in the **hindbrain,** through the midbrain and up into the thalamus and hypothalamus of the forebrain. It receives input from most of the senses and sends outputs to higher brain centers, filtering the sensory information.

iii. The hindbrain consists of **pons, cerebellum** and **medulla oblongata.** Pons is small and lies above the medulla oblongata. Pons acts as a bridge for the conduction of impulses between cerebellum, medulla oblongata and cerebrum. It is also concerned with rate of breathing, sleep and wakefulness. Cerebellum is the second largest portion of the brain. It consists of a central lobe and two lateral lobes. Cerebellum coordinates muscle activity and guides smooth and accurate motion. If it is destroyed, the movements become jerky, shaky and disturbed.

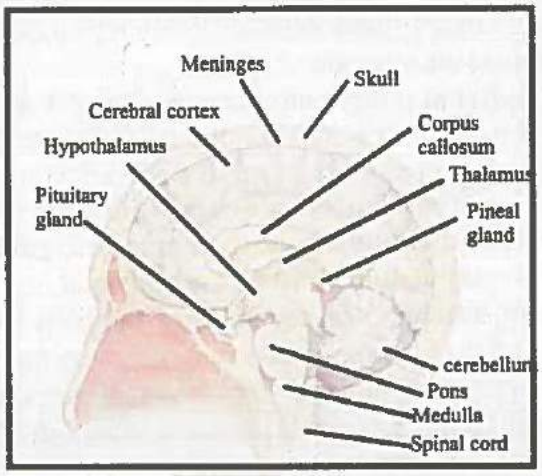


Fig: 17.17 Cross Section of human brain.

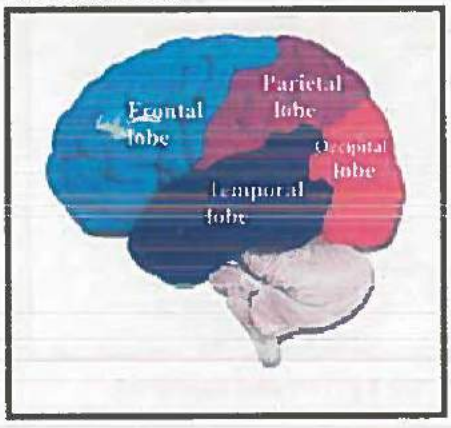


Fig: 17.18 Different lobes of brain.

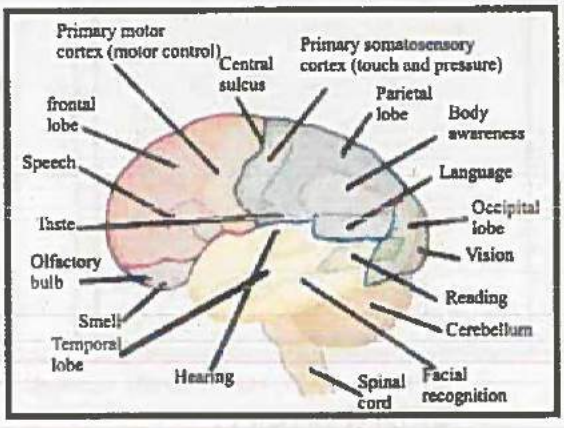


Fig: 17.19 Location of various sensations perceived by different parts of brain.

Medulla oblongata is the posterior most portion of the brain. It is broad in front and narrows behind, where it is continuous with the spinal cord. Medulla oblongata is the highway of communication between the body and the brain. Special reflexes such as heart beat, respiratory movements, salivary secretions, swallowing, vomiting, coughing and sneezing are located in the medulla oblongata.

Spinal Cord

Spinal cord is a central cable of nervous system. It is about 18 inches long and about half an inch in width. It is an elongated, hollow and cylindrical structure, lying in the neural canal of vertebral column.

It is continuous in front with the brain and tapers posteriorly, lying in the canal of urostyle. It is made up of a very large number of neurons. In cross section, the spinal cord shows an inner gray matter and the outer white matter. The gray matter surrounds a central canal, containing cerebrospinal fluid.

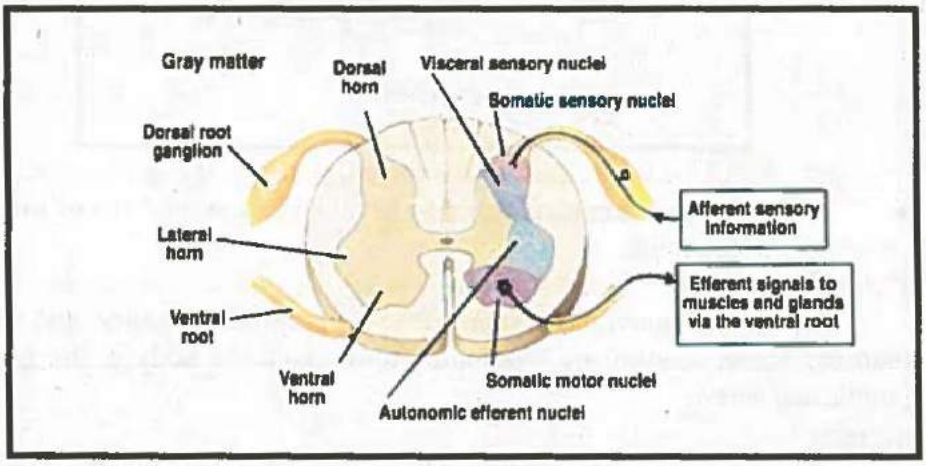


Fig: 17. 20 Spinal cord

The central canal of the spinal cord is continuous in front with the cavities of the brain, but ends blindly behind. The gray matter consists of cell bodies and white matter is made up of nerve fibres.

The spinal cord is covered with a thin pigmented membrane, the pia mater and the neural canal is lined with a thick, tough membrane, the dura mater, the space between the two membranes is filled with a lymphatic fluid which protects the cord from shocks.

Functions of Spinal Cord

Spinal cord is concerned with:

- Many reflex actions involving body structures below the neck region.
- Conducting sensory impulses from the skin and muscles to the brain.
- Carrying motor impulses from the brain to the muscles of the neck and limbs.

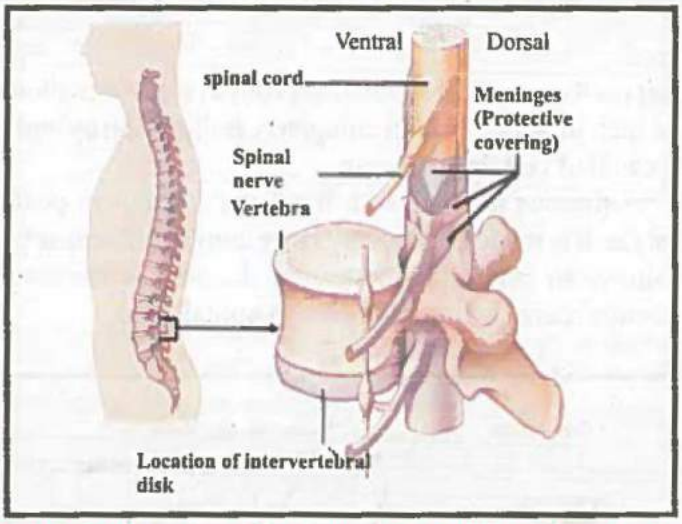


Fig: 17. 21 Location of intervertebral disk in the spinal cord.

- Receiving commands from the brain so it controls parts of the body in the trunk.

17.5.4 Peripheral Nervous System:

Peripheral nervous system (PNS) comprises sensory and motor neurons. These neurons are distributed throughout the body in the form of ganglia and nerves.

Ganglia

The collections of neuron cell bodies are called ganglia (singular ganglion). They provide relay points and intermediary connections between different neurological structures in the body, such as the peripheral and central nervous systems. Ganglia often interconnect with other ganglia to form a complex system of ganglia known as a plexus.

Nerves (Tracts):

The bundles of neuron fibers (dendrite or axons) covered by connective tissues are called nerves. All the communication between receptor to the CNS and from CNS to the effectors is carried out by the nerves. Nerves can be classified on the basis of function and origin. With respect to the functions nerves are of three types:

- **Sensory nerves:** These nerves carry impulses from receptors to the CNS.
- **Motor nerves:** These nerves carry impulses from CNS to the effectors.
- **Mixed nerves:** These nerves are the groups of sensory and motor nerves.

With respect to the origin nerves are of two types:

Spinal nerves: These nerves originate from and lead to the spinal cord. There are thirty-one pairs of spinal nerves, which are grouped as follows: Cervical, 8; Thoracic, 12; Lumbar, 5; Sacral, 5; Coccygeal, 1.

Cranial or Cerebral nerves: Those nerves that originate from or lead to the brain are called cranial or cerebral nerves. There are twelve pairs of cranial nerves which pass through the foramen (an opening) of the skull and mainly supply the peripheral tissues in the head except vagus nerve which extends event up to the abdomen.

Functionally, three pairs of cranial nerves are sensory in nature (I, II, VIII), five pairs are motor in nature (III, V, VI, XI, XII), and four pairs are mixed in nature (IV, VII, IX, X).

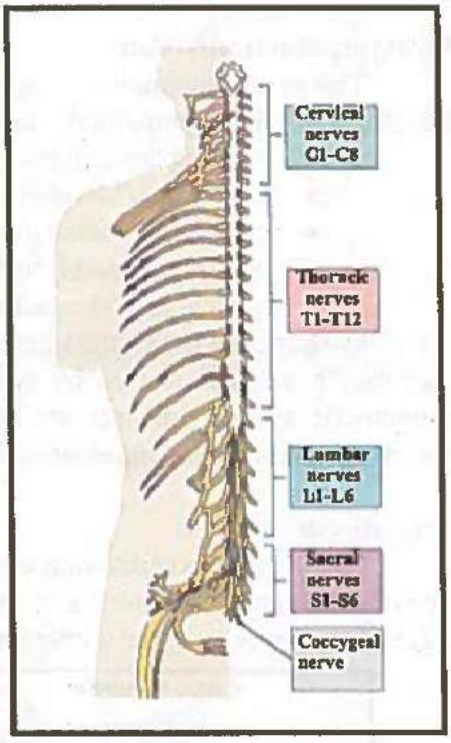


Fig: 17. 22 Spinal nerves.

17.5.5 Somatic Nervous System:

The somatic system is the part of the peripheral nervous system responsible for carrying sensory and motor information between CNS and voluntary parts of the body. The somatic nervous system controls skeletal muscle as well as external sensory organs such as the skin. This system is said to be voluntary because the responses can be controlled consciously. Reflex reactions of skeletal muscle however are an exception. These are involuntary reactions to external stimuli.

17.5.6 Autonomic Nervous System (ANS):

The autonomic nervous system consists of sensory neurons and motor neurons that run between the central nervous system (especially the hypothalamus and medulla oblongata) and various internal organs such as heart, lungs, viscera, glands (both exocrine and endocrine). The contraction of both smooth muscle and cardiac muscle is controlled by motor neurons of the ANS. The actions of the autonomic nervous system are largely involuntary (in contrast to those of the sensory-somatic system). The autonomic nervous system can further be divided into the parasympathetic and sympathetic divisions.

For Your Information

Pain receptors are the most numerous types of receptors of skin. Every square centimeter of your skin contains around 200 pain receptors but only 15 receptors for pressure, 6 for cold and 1 for warmth.

17.7 EFFECTS OF DRUGS ON NERVOUS COORDINATION

There are many drugs which are being used to treat nervous disorders, but abuse/misuse of these drugs can produce ill effects on the nervous coordination. One should be aware of uses and abuses of some common drugs used in our society.

17.7.1 Heroine:

Heroin is an illegal, highly addictive drug. Heroin is processed from morphine, a naturally occurring substance extracted from the seed pod of certain varieties of poppy plants.

Medical use:

Under the chemical name diamorphine, diacetylmorphine, the heroine is prescribed as a strong analgesic, where it is given via subcutaneous, intramuscular, or intravenous route. Its use includes treatment for acute pain, such as in severe physical trauma, myocardial infraction, post-surgical pain, and chronic pain, including end-stage cancer and other terminal illnesses.

Abuses/Misuses

Heroin is usually injected, sniffed/snorted, or smoked. With heroin, short term effects include warm flushing of the skin, dry mouth, depressed respiration, and suppression of pain, nausea, vomiting, severe itching, and spontaneous abortion. Long term effects of heroin use include addiction, infectious diseases, for example, HIV/AIDS and hepatitis B and C, collapsed veins, bacterial infections, abscesses, infraction of heart lining and valves, and arthritis.

Fig: 17.26 Poppy plant

17.7.2 Cannabis

Cannabis *(Cannabis sativa)*, also known as marijuana refers to preparations of the Cannabis plant which is being used as a psychoactive drug.

Hashish (commonly called as Chars) is another form of cannabis which is a concentrated resin produced from the flowers of the female cannabis plant. It can often be more potent than marijuana and can be smoked or chewed.

Fig: 17.27 *Cannabis sativa*

Medical use

Cannabis has very beneficial effects as medicine. Among these are: the amelioration of nausea and vomiting, stimulation of hunger in chemotherapy and AIDS patients, lowered intraocular eye pressure (shown to be effective for treating glaucoma), as well as general analgesic effects.

Abuses / Misuses:

The most common adverse effect due to the abuse of cannabis is anxiety (restlessness, feelings of loss of control, panic, fear of impending death), depression, suicidal thoughts and psychosis (a severe mental disorder in which contact with reality is lost or highly distorted).

17.7.3 Nicotine

Nicotine is an alkaloid, mainly found in tobacco leaves but also found in many other plants of family Solanaceae.

Medical use:

The primary therapeutic use of nicotine is in treating the patients habitual of smoking. It stimulates the release of many chemical messengers including acetylcholine, norepinephrine, epinephrine, serotonin, vasopressin, dopamine, and beta-endorphin. so it acts as a nerve stimulant. At higher doses, nicotine enhances the effect of serotonin and beta-endorphin activity, producing a calming, pain-killing effect. Nicotine is unique in comparison to most drugs, and acts both as nerve stimulant and sedative/pain killer.

Abuses / Misuses:

Unfortunately, many people do not know that nicotine is also sold commercially in the form of a pesticide. It is fact that nicotine is an extremely toxic poison Sixty milligrams of nicotine (about the amount in three or four cigarettes if all of the nicotine were absorbed) will kill an adult, but consuming only one cigarette's worth of nicotine is enough to make a child severely ill. **Nicotine poisoning** causes vomiting and nausea, headaches, difficult breathing, and stomach pains. In smoker mothers, nicotine damages the placenta, increasing the likelihood of miscarriages, pre mature births and damages to the foetus.

17.7.4 Alcohols:

The alcohol is among the most harmful of drugs particularly in view of the frequency of its use. It is absorbed quickly into the blood from digestive tract after drinking.

Medical uses:

It stimulates the body when taken in a small quantity as medicine to improve health conditions. Since it is an excellent solvent so many drugs are delivered into the body by dissolving in it. Alcohol is also used as a component of many medicines like cough syrups. Due to its antiseptic nature, it is also used to wash wounds during bandages and while administering injections.

Abuses / Misuses:

When people take alcohol in large quantities for non-medical purposes, it will be called as abuse of the drug. In small quantities it can suppress the cellular activity in brain. In large doses, it can kill them. Alcohol reduces levels of serotine and dopamine and act as a depressant.

Driving, after only drinking a small amount of alcohol, is dangerous because alcohol affects your reaction time and judgment of speed. This can result in an accident which may hurt you or other people. People who have drunk too much lose control of speech and movement. Extreme drunkenness can result in people becoming unconscious and even dying from choking on their own vomit or of alcohol poisoning. Alcohol addiction also causes memory loss, damage (cirrhosis or hardening) of the liver, **hallucinations** (where people imagine they are in a magical world and see enemies everywhere, this disease called paranoia), **depression** and anxiety which can result in suicide. Alcohol in gut also destroys certain vitamins and interferes with absorption of others leading to severe vitamin deficiencies.

17.7.5 Common inhalants like Nail Polish Removers & Glue:

Inhalants are chemical vapours or gases that produce psychoactive (mind-alerting) effects when abused or misused by concentrating and intentionally inhaling these fumes. These include volatile organic solvents, fuel gases, nitrites, and anesthetic gases, which are commonly found in glue, paint thinner, gasoline, and nail polish remover.

Effects of abuses:

Inhalants provide an instant "rush" and, like alcohol, cause euphoria followed by central nervous system depression. Deep breathing may result in loss of self-control, violent behavior, nausea, vomiting, unconsciousness, giddiness, loss of appetite, and, at higher doses, hallucinations, loss of motor skills, slurred speech, and heart palpitations.

17.8 NERVOUS DISORDERS AND DIAGNOSTIC TESTS

Diseases of nervous system are also called neurological disorders. They can be categorized according to the primary location affected, the primary type of dysfunction involved, or the primary type of cause. The broadest division is between central nervous system (CNS) disorders and peripheral nervous system (PNS) disorders. Neurological disorders are classified into following categories:

- Vascular (Stroke)
- Infectious (Meningitis)
- Structural (Brain Tumor)
- Functional (Headache)
- Degenerative (Alzheimer's disease)

17.8.1 Stroke:

Brain cell function requires a constant delivery of oxygen and glucose from the bloodstream. A stroke, or cerebrovascular accident (CVA), occurs when blood supply to part of the brain is disrupted, causing brain cells to die. There are two kinds of stroke. The more common kind, called ischemic stroke, is caused by a blood clot that blocks or plugs a blood vessel in the brain. The other kind, called hemorrhagic stroke, is caused by a blood vessel that breaks and bleeds into the brain. "Mini-strokes" or transient ischemic attacks (TIAs), occur when the blood supply to the brain is briefly interrupted.

Symptoms of stroke:

- numbness or weakness of the face, arm or leg (especially on one side of the body)
- confusion, trouble speaking or understanding speech
- trouble seeing in one or both eyes
- trouble walking, dizziness, loss of balance or coordination
- severe headache with no known cause

Treatment:

A stroke is a medical emergency. Immediate treatment can save lives and reduce disability, so it is very important for people who are having stroke symptoms to get to a hospital as quickly as possible (within 3 hours after symptoms begin). Treatment depends on the severity and cause of the stroke. In the hospital a CT scan or MRI scan must be done to see whether the stroke is from a clot or from bleeding.Clot-busting drugs (thrombolytic therapy) and blood thinners such as heparin are prescribed for the treatment.

17.8.2 Meningitis:

Meningitis is characterized by inflammation of the protective membranous covering of the brain and spinal cord, the meninges. The inflammation may be the result of infection with viruses, bacteria, or other microorganisms, and less commonly by certain drugs. Meningitis can be life-threatening because the location of inflammation is very close to the brain and spinal cord; therefore the condition is classified as a medical emergency.

Symptoms:

Symptoms usually come on quickly, and may include: fever and chills, mental status changes, nausea and vomiting, sensitivity to light (photophobia), severe headache, stiff neck, agitation, decreased consciousness, poor feeding or irritability in children, rapid breathing, and unusual posture, with the head and neck arched backwards.

Fig: 17.28 Patient with head and neck arched backwards in meningitis attack.

Treatment:

Treatment for meningitis depends on the organism causing the infection. Antibiotics and corticosteroids are used as general treatment.

17.8.3 Brain Tumors:

A brain tumor is a mass or growth of abnormal cells due to uncontrolled cell division in the brain. A brain tumor may be benign (noncancerous) or malignant (cancerous). A tumor can originate in brain (primary brain tumors), or it can be originated in other parts of the body and spread to the brain (secondary, or metastatic brain tumors).

Symptoms:

The signs and symptoms of a brain tumor vary greatly and depend on the brain tumor's size, location and rate of growth. General signs and symptoms caused by brain tumors may include: new onset or change in pattern of headaches that gradually become more frequent and more severe, unexplained nausea or vomiting, vision problems, such as blurred vision, double vision or loss of peripheral vision, gradual loss of sensation or movement in an arm or a leg, difficulty with balance, speech difficulties, confusion in everyday matters, personality or behavior changes, and hearing problems

Treatments and drugs:

Treatment for a brain tumor depends on the type, size and location of the tumor, as well as overall health and preferences. Surgery, radiotherapy and chemotherapy is the general treatment for tumors.

Headache:

A headache or cephalalgia is pain anywhere in the region of the head or neck. It can be a symptom of a number of different conditions of the head and neck. It is one of the most common locations of pain in the body and has many causes. The brain tissue itself is not sensitive to pain because it lacks pain receptors. Rather, the pain is caused by disturbance of the pain-sensitive structures around the brain. Several areas of the head and neck have these pain-sensitive structures, which are the cranium (the periosteum of the skull, muscles, nerves, arteries and veins, subcutaneous tissues, eyes, ears, sinuses and mucous membranes etc.

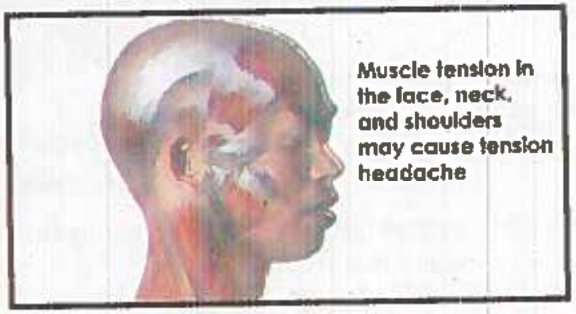


Fig: 17.29 Headaches

Alzheimer's disease:

Alzheimer's disease (AD) is a slowly progressive disease of the brain that is characterized by impairment of memory and eventually by disturbances in reasoning, planning, language, and perception.

Signs & Symptoms:

Most prominent symptom of Alzheimer's disease is dementia which is characterized by the loss of memory, particularly for recent events (short-term memory). In addition to this mild personality changes, such as less spontaneity, apathy (absence of emotion or enthusiasm), and a tendency to withdraw from social interactions, may occur early in the illness.As the disease progresses, problems in abstract thinking and in other intellectual functions develop. The person may begin to have trouble with figures when working on bills, with understanding what is being read, or with organizing the day's work.

Further disturbances in behavior and appearance may also be seen at this point, such as agitation, irritability, quarrelsomeness (having different point of view than others), and a diminishing ability to dress appropriately.

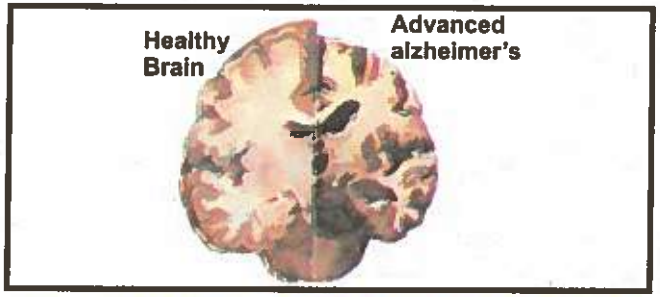


Fig: 17.30 Massive cell loss changes the whole brain in advanced Alzheimer's disease.

Causes and risk factors:

The likelihood of having Alzheimer's disease increases substantially after the age of 70 and may affect around 50% of persons over the age of 85. Nonetheless, Alzheimer's disease is not a normal part of aging and is not something that inevitably happens in later life. For example, many people live to over 100 years of age and never develop Alzheimer's disease.

Many scientists believe that Alzheimer's disease results from an increase in the production or accumulation of a specific protein (beta-amyloid protein) in the brain that leads to nerve cell death. The onset of Alzheimer's disease is usually gradual, and it is slowly progressive.

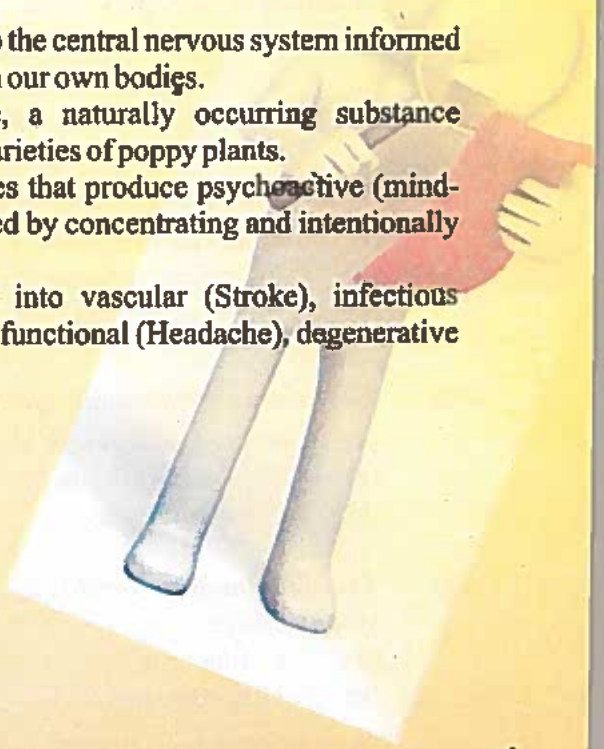
KEY POINTS

- Nervous coordination in higher animals consists of reception of stimulus, processing/analysis of information and response to stimulus.
  Receptors are classified into different types on the basis of stimuli.
- Those parts of the body which produce an appropriate response are called effectors (muscles and glands).
- Although more than 50% of nervous system consists of neuroglial (neuroglia) cells, but the neuron is considered as chief structural and functional unit of nervous system.
- Neuron having only one fiber radiating from cell body is called unipolar neuron, while those having two fibers called bipolar and those having many fibers are called multipolar.
- The pathway of nerve impulse during reflex action is called reflex arc
- Nerve impulse is a wave of electrochemical change that travels along the length of neuron, from one end to the other. Fp conduction it uses electricity made with chemical ions and molecules (Na^+, K^+, and charge bearing organic molecules).
- Nerve impulses are of two types: continuous impulse and saltatory impulse.
- Synapsess is the junction between axon terminal of one neuron and the dendrite of another neuron, where information from one neuron is transmitted or relayed (handed over) to another neuron.
- Some neurotransmitters that produce excitation on postsynaptic neuron receptors are called **excitatory neurotransmitters e.g acetylcholine** while other inhibits the postsynaptic action potential are called **inhibitory neurotransmitters e.g Gluamate.**
- Human nervous system is primarily divided into central nervous system (CNS) and peripheral nervous system (PNS).
- Human brain coordinates the actions, so that they happen in the right sequence and at the right time and place.
- Spinal cord is a central cable of nervous system.
- The somatic system is the part of the peripheral nervous system responsible for carrying sensory and motor information between CNS and voluntary parts of the body.
- The autonomic nervous system consists of sensory neurons and motor neurons that run between the central nervous system (especially the hypothalamus and medulla oblongata) and various internal organs such as heart, lungs, viscera, glands (both exocrine and endocrine).

KEY POINTS

ensory receptors receive stimuli and keep the central nervous system informed of any change in the surroundings and in our own bodies.

- Heroin is processed from morphine, a naturally occurring substance extracted from the seed pod of certain varieties of poppy plants.
- Inhalants are chemical vapours or gases that produce psychoactive (mind-alerting) effects when abused or misused by concentrating and intentionally inhaling these fumes.
- Neurological disorders are classified into vascular (Stroke), infectious (Meningitis), structural (Brain Tumor), functional (Headache), degenerative (Alzheimer's disease).



EXERCISE ?

1- Multiple choice questions.

(i) ***Which of the following is common to all neurons?***

(a) A cell body which contains a nucleus (b) A thick myelin sheath
(c) Presence of nodes of Ranvier (d) Presence of Schwann cells

(ii) ***What will occur if a drug at the neuromuscular junction blocks the receptor sites on the post-synaptic membrane?***

(a) Inhibition of Acetylcholine release (b) Muscle contraction
(c) Muscle paralysis (d) Release of calcium ions

(iii) ***The groups of ribosomes present in the cell body of the neuron, which are associated with rough endoplasmic reticulum are called:***

(a) Meissner's corpuscles (b) Pacinian corpuscles
(c) Nissl's granules (d) Lysosome granules

(iv) ***The mammalian forebrain is differentiated into the thalamus, limbic system and the:***

(a) Cerebellum (b) Cerebrum
(c) Hippocampus (d) Hypothalamus

(v) ***Information back from the control center to the effectors as done by _____ nerve path way.***

(a) afferent (b) efferent
(c) both (d) none

(vi) ***The number of human spinal nerves is:***

(a) 24 (b) 50
(c) 62 (d) 64

(vii) ***The electrical potential of cell membrane of neuron when it is not transmitting any signal is called _____.***

(a) resting membrane potential (b) action potential
(c) propagation of impulse (d) synapse

EXERCISE ?

2- Short questions.

(i) Give the structure of a typical neuron.

(ii) What do you know about the distribution and pumping of Na^+ and K^+ ions across the neuron membrane during resting membrane potential?

(iii) How the K^+ ions are moved across the neuron membrane during resting membrane potential?

(iv) Differentiate between resting membrane potential and active membrane potential.

(v) Give a graphical representation of nerve impulse.

(vi) How does an impulse move from one neuron to another neuron across the synapse?

(vii) Name the part of human brain concern with storage of memories.

(viii) Differentiate between sympathetic & parasympathetic nervous system.

(ix) Differentiate between gray mater & white mater.

(x) Differentiate between medulla & pons.

3- Extensive questions

(i) Compare the structure and function of three types of neuron.

(ii) Describe the mechanism of conduction of nerve impulse.

(iii) Explain the structure and function of human fore brain

(iv) Critically discuss the use and abuse of any one narcotic drug.

(v) Give in detail the cause symptoms and treatment of any one nervous disorder

4- Skills (Initiating and Planning)

- Predict from every day experience what various kind of receptos can be found in human body.

5- Interpreting and Communicating

- Draw a labeled diagram of human brain
- Identify different components in the diagram of CNS and PNS.
- Conceptualize the activity of brain as a electrical activity, which can be recorded using magnet and tomography.
- Compare MRI scan of a sleeping human with that of fully awaked individual.

EXERCISE 2

6- Science, Technology, and Society Connections

- Justify the way nervous system coordinate complex and intricate movements of hand to play a piano, or write alphabets.
- Ascertain the effect of nerve gas as an inhibiter of acetylcholinesterase.
- Justify that development of modern computer is in fact a product of the understanding of the way nervous coordination occurs in complex organisms like human.

7- Online Learning

- *www.free-ed.net/free-ed/HealthCare/Physiology*
- www.nlm.nih.gov/medlineplus/degenerativenervediseases
- www.ninds.nih.gov
- *www.*kidshealth.org

UNIT

18

CHEMICAL COORDINATION

KEY CONCEPTS

18.1 Hormones: the chemical messengers

18.2 Endocrine system of man

18.3 Feedback mechanism

The cellular functions need to be continuously regulated. The nerve fibers do not innervate all the cells of the body; a special kind of coordination system is thus required. The **endocrine system** serves the role to coordinates most body cells. The hormonal system is concerned with control of the different metabolic functions of the body, such as the rate of chemical reactions, the transport of substances through the cell membranes, growth, and secretions. This coordination is called **chemical coordination.**

18.1 HORMONES: THE CHEMICAL MESSENGERS

The glands are structures made up of one or more cells that make and release some product called secretion. These glands are classified as exocrine glands and the endocrine glands. **Exocrine glands** (exo = outside; crine = to secrete), secrete their products onto the target surface directly or through ducts. Liver, salivary glands, sweat glands, and the tear glands have ducts; the unicellular goblet cells on the other hand directly release mucin on the target surface by exocytosis.**Endocrine glands** (endo = within; crine = to secrete) are ductless glands. They produce hormones, and secrete by exocytosis directly into the extracellular spaces. From there the hormones enter the blood or lymphatic fluid and travel to specific target site.

18.1.1 Chemical nature of hormones:

Chemically, hormones are of three basic types i.e. steroids, amino acids or their derivatives, and proteins or polypeptides.

Steroid hormones:

These are derivatives of cholesterol. Different steroidal hormones are secreted by, the adrenal cortex (cortisol and aldosterone), the ovaries (estrogen and progesterone), the testes (testosterone) and the placenta (estrogen and progesterone).

Derivatives of amino acid tyrosine:

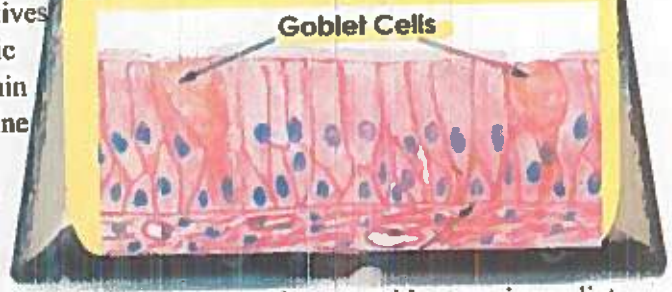
Two groups of hormones are derivatives of amino acid tyrosine. The metabolic hormones thyroxin and triiodothyronin from thyroid glands and epinephrine and norepinephrine from adrenal medullae are all derived from amino acid tyrosine.

Proteins or peptides:

Many important endocrine hormones are proteins, peptides or immediate derivatives of these. Growth hormone and prolactin are protein while antidiuretic

For Your Information

The goblet cell is a unicellular exocrine gland. Goblet cells are scattered in the epithelial linings of the intestinal and respiratory tracts. In humans, all such glands produce mucin. The mucin is a complex glycoprotein that dissolves in water when secreted, to form mucus, a slimy



hormone and oxytocin are peptides of nine amino acids each. Insulin, glucagon and parathormone are large polypeptides.

18.2 ENDOCRINE SYSTEM OF MAN

Endocrine system is the type of glandular system, consists of some 20 ductless glands lying in different parts of the body.

18.2.2 Pituitary gland:

Pituitary gland is located in the brain under the hypothalamus. It is red grey in colour, about the size of a pea, pituitary gland weighs about 0.5 g. It is attached to hypothalamus by a stalk called infundibulum.

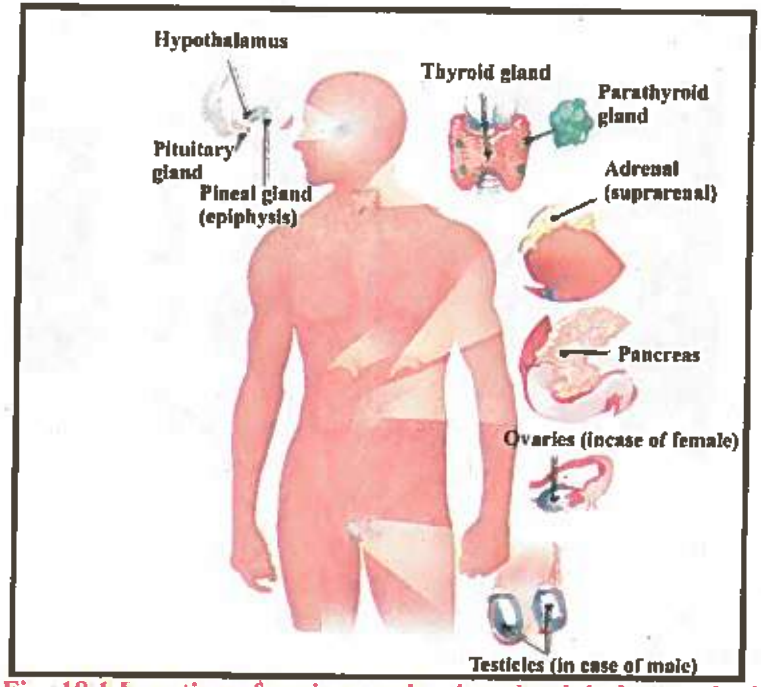


Fig: 18.1 Location of various endocrine gland in human body

It is divided into three lobes, the anterior pituitary, posterior pituitary and the intermediate pituitary.

Anterior pituitary:

Classically, the anterior pituitary is considered the master gland of the endocrine system because it secretes numerous hormones, many of which regulate the activity of other endocrine glands. Four out of six anterior pituitary hormones (thyroid stimulating hormone, adrenocorticotropic hormone, follicle stimulating

hormone, and luteinizing hormone) are tropic hormones (tropi = turn on, change), which are hormones that regulate the secretory action of other endocrine glands.

Growth hormone (GH) or somatotropin has a direct effect on growth and development of all the body parts, particularly skeleton and skeletal muscles during childhood and adolescence. GH stimulates cell growth and cell division. It also stimulates uptake of amino acids into cells and increase rate of protein synthesis.

Deficiency of GH results in dwarfism. Development is much slower and individual has short stature, however, the body parts stay in proportion and brain development and IQ are unaffected.

Gigantism is resulted by over secretion of GH during childhood. As the bones are still capable of growth, person becomes a giant. Over secretion of GH in adult life causes acromegaly. Bones are no longer capable of increasing in length but grow in thickness. Acromegaly is characterized by enlarging the hands, feet, skull, nose and jawbone.

Fig: 18.2 a. Gigantism makes a person look like a giant.

Fig: 18.2 b. Acromegaly results in abnormal thickness of bones

Thyrotrophin releasing factor (TRF) from hypothalamus stimulates the synthesis and release of thyroid stimulating hormone (TSH) from the anterior pituitary. TSH regulates the endocrine function of the thyroid gland. TSH release is regulated by the negative feedback of thyroxin acting on hypothalamus and anterior pituitary.

- **Adrenocorticotrophic hormone (ACTH):** Its secretion is stimulated by adrenocorticotrophin releasing factor (CRF) from the hypothalamus. ACTH acts on adrenal cortex and stimulates the secretion of glucocorticoids and androgens.
- **Follicle stimulating hormone (FSH):** FSH is a gonadotroph. Its secretion is stimulated by GnRH from the hypothalamus. In females it stimulates maturation of ovarian follicle and estrogen production. In males it stimulates the development of germinal epithelium and sperm production in the testes.

- **Luteinizing hormome (LH):** Its secretion is controlled by GnRH. In females its target site is ovary. It triggers ovulation and ovarian production of estrogen and progesterone. It also causes the luteinization i.e. converts ruptured follicle to a glandular structure called corpus luteum and maintains it. In males LH is also known as interstitial cell stimulating hormone (ICSH). It promotes testosterone production in interstitial cells of the testes.
- During pregnancy, secretion of prolactin cause enlargement of the mammary glands and prepare for the production of milk (lactation). It inhibits menstrual cycle in lactating women.

Intermediate (median) lobe:

In humans, intermediate pituitary is a thin layer of cells between the anterior and posterior pituitary. It produces melanocyte stimulating hormone (MSH). Melanocyte stimulating hormone increases in humans during pregnancy also. It stimulates the production and release of melanin by melanocytes in skin and hair which darken the colour of the skin especially during pregnancy.

Posterior lobe:

Posterior pituitary stores antidiuretic hormone (ADH or vasopressin) and oxytocin. These hormones are released in response to nerve impulses from hypothalamus.

- **Antidiuretic hormone:** Diuresis means urine production. Antidiuretic is any substance which inhibits urine formation. Osmoreceptors in hypothalamus monitor the solute concentration of blood.

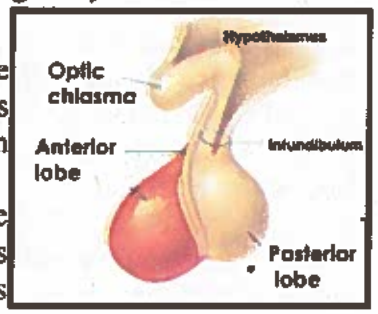


Fig: 18.3 Lobes of pituitary gland.

ADH is released when solute concentration increases as a result of water loss. It acts on kidney tubules to enhance water reabsorption. More water is reabsorbed, concentrated urine is produced. Blood volume increases and solute concentration become normal.

- **Oxytocin:** (ocytocia=childbirth); oxytocin is released during child birth and in nursing women. Stretching of the uterus and cervix during parturition is a strong stimulus for the release of oxytocin. Low level of progesterone in blood to the end of pregnancy and neural stimuli of mother during child birth also stimulate release of oxytocin. During birth it is released in waves, and results in labour contractions.

In lactating women, suckling causes the release of oxytocin. **The letdown reflex, also known as the milk ejection reflex, is set off by this hormone.**

18.2.3 Thyroid gland:

Thyroid gland is composed of two lobes which are located on either side of the trachea inferior to the larynx. Thyroid gland produces three active hormones, tri iodothyronine (T_3), thyroxin (T_4), and calcitonin.

Tri & Tetra iodothyronine (T_3 and T_4):

T_3 and T_4 are iodine containing hormones. Tri iodothyronine contains three iodine atoms in structure and thyroxin contains four, hence the names T_3 and T_4. TSH from anterior pituitary stimulates production and release of both hormones of the thyroid. The level of thyroxin circulating in the blood regulates the secretion of these hormones from the thyroid gland by negative feedback mechanisms involving the hypothalamus and anterior pituitary. These hormones show a variety of physiological effects.

Promote basal metabolic rate of the body enhance glucose catabolism and synthesis of cholesterol in the liver and promote development of nervous system in feotus and infants. They act on muscles for their development and functioning and promote growth and maturation of skeleton. These hormones also promote normal motility of the gastrointestinal tract.

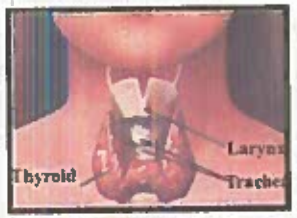


Fig: 18.4 Thyroid Gland

Hyperthyroidism:

Overactivity of thyroid causes Graves' disease. Graves' disease is believed to be an autoimmune disease. The serum of patients contains abnormal antibodies that mimic TSH and continuously stimulate thyroxin release.

The symptoms include high metabolic rate, rapid and irregular heartbeat, nervousness, increased ventilation rate, increased body temperature, sweating, and weight loss despite adequate food intake. **Mostly exophthalmia** (protrusion of the eyeballs) results from Graves's disease and is a classic symptom of hyperthyroidism. Thyroid related exophthalmia results from swelling of the tissues around the eye and within the orbit that develops in reaction to the high levels of thyroxin.


Fig: 18.5 Exophthalmia is a classic symptom of hyperthyroidism.

Hypothyroidism:

The underactivity of the thyroid gland may be due to the lack of TSH production by the anterior pituitary, iodine deficiency in the food, or failure of the enzyme system involved in thyroxin production.

Thyroid hormones cannot be synthesized without iodine, and this can cause problems in regions where farm soil and drinking water have little or no iodine. In the absence of iodine, thyroid hormone levels in the blood decrease. The anterior pituitary detects the decrease and secretes more TSH-excessively. So excess TSH over stimulates the thyroid gland and causes it to enlarge. (Since thyroid hormones are not being synthesized, the outcome is hypothyroidism.)

Fig: 18.6 Patient suffering from goiter.

The resulting tissue enlargement is a form of *goiter*. Goiter caused by iodine deficiency is no longer common in countries where iodized salt is widely used. Elsewhere, hundreds of thousands of people still suffer from the disorder, which is easily preventable.

If there is a deficiency of thyroxin at birth, it results in a severe hypothyroidism in infants called cretinism. Child is mentally retarded with poor physical growth and disproportionate body size. Bone maturation and puberty are severely delayed and infertility is common.

In adults, the full-blown hypothyroid syndrome is called myxedema (means "mucous swelling" as body weight increases due to the formation and storage of a semifluid material under the skin). Symptoms include a low metabolic rate, feeling chilled, puffy eyes, thick and dry skin with hair lost from the scalp and eyebrows, edema, tongue swelling, constipation; lethargy, and mental sluggishness (but not mental retardation). Myxedema may result from lack of iodine; the thyroid gland enlarges and protrudes. This condition is called endemic or colloidal goiter.

Calcitonin:

The thyroid gland also secretes calcitonin. This hormone plays a minor but direct role in controlling extracellular levels of calcium ions (Ca^{++}). When the levels rise, calcitonin promotes calcium deposition into bones. When the levels return to normal, thyroid cells decrease their secretion of calcitonin.

Calcitonin inhibits Ca^{2+} absorption by the intestines and decreases its reabsorption by the kidney tubules allowing its excretion in urine. It also inhibits potassium ions reabsorption in kidney tubules.

Calcitonin appears more important in childhood, when the skeleton grows quickly and the bones are changing dramatically in mass, size, and shape. If deficient, Ca^{2+} are not deposited in bones and high blood Ca^{2+} level causes disturbance in the functioning of muscles and nervous system and may lead to kidney stones.

18.2.4 Parathyroid:

In human there are four parathyroid glands. All four glands are located on the thyroid gland. They are small, light coloured lumps that stick out from the ventral surface of the thyroid gland.

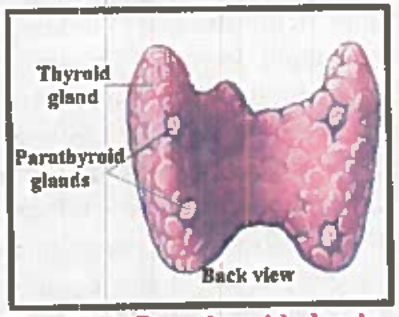


Fig: 18.7 Parathyroid glands are present on the thyroid gland.

The parathormone is the single most important hormone of parathyroids controlling the calcium balance of the blood. Its release is triggered by low blood Ca^{2+} levels and inhibited by high blood calcium levels. Parathormone stimulates osteoclasts to reabsorb bone mineral and liberating calcium into blood. It stimulates absorption of calcium in the small intestine and also its reabsorption in the kidney tubules.

Over secretion of parathormone is usually a result of a parathyroid gland tumor. Calcium is released from the bones, and bones get soften and tend to fracture spontaneously. Blood calcium level elevates (hypercalcemia) which depresses nervous system and causes weakness of muscles. Excess calcium salts precipitate in the kidneys leading to stone formation.

Under secretion of parathormone causes hypocalcemia. This increases the excitability of neurons. Also it can lead to tetany in which muscles remain in contracted state. If untreated, it can be fatal.

18.2.5 Pancreas (Islets of Langerhans)

The pancreas is a double gland as it serves both as exocrine and endocrine gland. The bulk of the gland is exocrine and is formed of acinar cells which synthesize pancreatic juice rich in digestive enzymes. Pancreatic juice is delivered to the duodenum by pancreatic duct during food digestion.

Endocrine pancreas consists of islets of Langerhans. In human pancreas has about one million islets scattered among the acinar cells. Each islet is a small mass of cells with two major types of cells; glucagon producing α cells and insulin producing β cells.

Insulin:

It is released by β cells in response to a rise in blood glucose level. Its overall effect is to:

- Reduce blood glucose level to the normal level.
- Increases the rate of glucose uptake by most body cells especially skeletal muscles and fat cells.
- Promotes glycogenesis in liver and muscle cells.

- Increases the use of glucose in cellular respiration.
- Promotes the conversion of excess glucose to fats.
- Inhibits gluconeogenesis (glucose synthesis).
- Increases the rate of uptake of amino acids into the cells and the rate of protein synthesis.

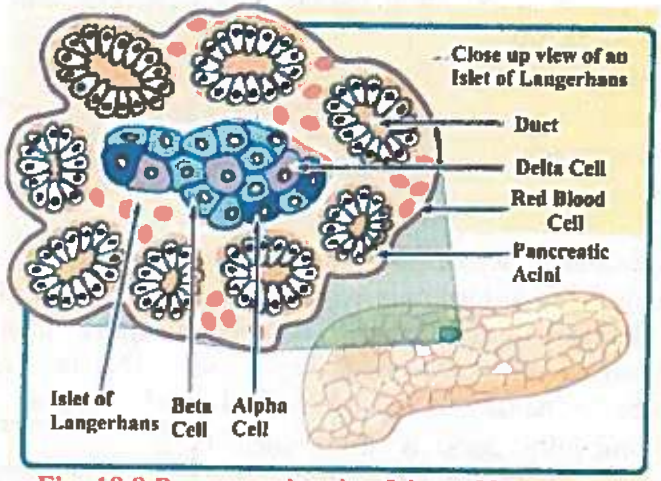


Fig: 18.8 Pancreas showing Islets of Langerhans

If insulin is deficient or is hypoactive, blood glucose level after meal remains high (hyperglycemia). Kidneys cannot reabsorb such high volume of glucose from the filtrate and excess of glucose begins to be lost from the body in the urine (glycosuria). This metabolic disease is known as diabetes mellitus. The three cardinal signs of diabetes mellitus are:

- Polyuria; a condition in which abnormally large volume of urine is produced.
- Polydipsia; a condition of excessive thirst.
- Polyphagia; a condition of excessive hunger ingestion of food.

Low blood glucose level causes breakdown of the muscle tissue, loss of weight and tiredness. If untreated diabetes finally leads to the disruption of the heart activity and oxygen transport, and severe depression of the nervous system leads to coma and death. Hypersecretion (a rare disorder) of insulin results in hypoglycemia. Other effects include hunger, sweating, irritability, double vision, unconsciousness, and even death.

Glucagon:

Glucagon is a hyperglycemic agent. It is released by α cells when blood glucose level is low. Sympathetic nervous system also stimulates its secretion. High blood glucose levels, insulin, and somatostatin suppress its secretion.

Its role is to increase the blood glucose level.

- It promotes glycogenolysis
- It promotes gluconeogenesis; synthesis of glucose from lactic acid and other non-carbohydrate compounds like proteins and fats.
- Promotes release of glucose to the blood by liver cells, which causes blood glucose levels to rise.

18.2.6 Adrenal glands:

Human body has a pair of adrenal glands one above each kidney. Each adrenal gland is composed of two types of tissues: Outer adrenal cortex and the adrenal medulla.

Adrenal cortex:

It produces many steroid hormones, collectively called corticosteroids or corticoids. Among them Aldosterone is chief mineralocorticoid. It is secreted in response to low blood pressure, and low level of Na^+ and high K^+ in blood. ACTH had also some effect in its secretion. It works to increase blood Na^+ level especially acting on kidney tubules to enhance sodium and thus water reabsorption.

Adrenal medulla consists of modified ganglionic sympathetic neurons that synthesize epinephrine and norepinephrine. The two hormones exert the same effects. Epinephrine is the more potent stimulator of metabolic activities, bronchial dilation, and increased blood flow to skeletal muscles and the heart, but norepinephrine has the greater influence on peripheral vasoconstriction and blood pressure. Epinephrine is used clinically as a heart stimulant and to dilate the bronchioles during acute asthmatic attacks

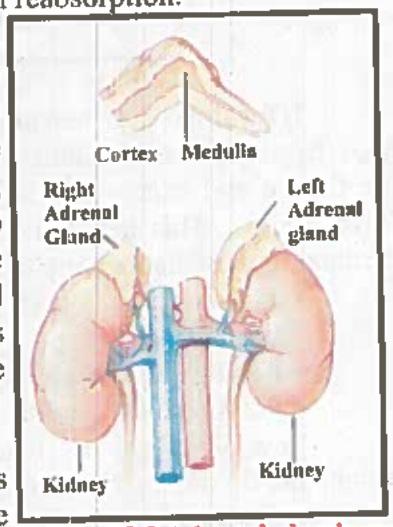


Fig: 18.9 Adrenal glands are located on the top of each kidney.

18.2.7 The Gonads:

Gonads are special type of endocrine glands which beside hormone secretions also produce gametes. Female gonads are ovaries while male gonads are testes..

Ovaries: Besides producing ova, the ovaries produce several hormones, most importantly estrogens and progesterone. The estrogens are responsible for maturation of the reproductive organs and the appearance of the secondary sex characteristics of females at puberty.

Acting with progesterone, estrogens promote breast development and cyclic changes in the uterine mucosa in the menstrual cycle. Progesterone promotes further thickening and vascularization of the uterus for the implantation of zygote, maintains pregnancy and causes the development of breasts during pregnancy.

- **Testes:** The male testes, located in an extra-abdominal skin pouch called the scrotum, produce sperm and male sex hormones, primarily testosterone. During puberty, testosterone initiates the maturation of the male reproductive organs and the appearance of secondary sex characteristics and sex drive. In addition, testosterone is necessary for normal sperm production and maintains the reproductive organs in their mature functional state in adult males.

18.3 FEEDBACK MECHANISM

It is a type of interaction in which a controlling mechanism is itself controlled by the product of reactions it is controlling. After receiving the signal, a change occurs to correct the deviation by depressing it with negative feedback or enhancing it with positive feedback.

18.3.1 Negative feedback:

Negative feedback is a mechanism to maintain homeostasis. This feedback results in a reversal of the direction of change. Negative feedback tends to stabilize a system, correcting deviations from the set point. A good example of negative feedback is with the hormone, insulin. Insulin is produced by the pancreas. Insulin is released by the pancreas in response to consumption of glucose. The amount of glucose in the blood rises and the pancreas detects this increase. It then secretes insulin into the blood. Insulin increases glucose uptake in target cells. Glucose uptake by cells decreases blood glucose levels - this decrease is detected by the pancreas and in response, it stops secreting insulin in to the bloodstream.

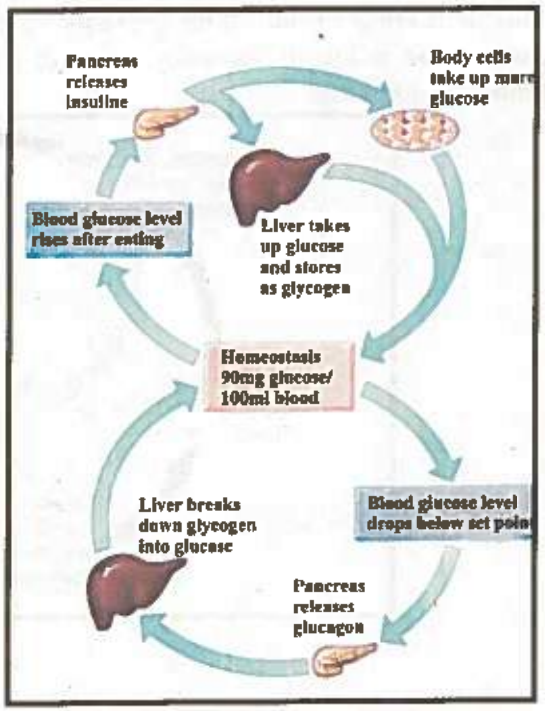


Fig: 18.10 Feedback Mechanism

If blood glucose levels fall below normal levels insulin secretion is inhibited. At the same time, the alpha cells of the pancreas respond by secreting glucagon. It accelerates the breakdown of glycogen to glucose in liver and skeletal muscle cells. It increases the breakdown of fats to fatty acids and glycerol in adipose tissue and, consequently, the release of these substances into the bloods. Glucagon also stimulates liver cells to increase glucose synthesis (from glycerol absorbed from the blood) and glucose release into the blood. These effects collectively cause an increase in blood glucose levels back to normal levels.

18.3.2 Positive feedback

Positive feedback response is to amplify the change in the variable. This has a destabilizing effect, so does not result in homeostasis. Positive feedback is less common than negative feedback, but it has its applications.

Positive feedback enables childbirth. The hormone oxytocin stimulates and enhances labor contractions. As a baby moves towards the birth canal, it presses against the pressure receptors in the muscular part of the uterus. These receptors evoke a release of oxytocin from the pituitary gland. When the oxytocin reaches responsive receptors in the muscles of the uterus it further increases muscular tension thus increasing stimuli to the pressure receptors. This goes on as "labour" until the pressure is relieved: the baby is born; oxytocin is no longer evoked and labor contractions cease.

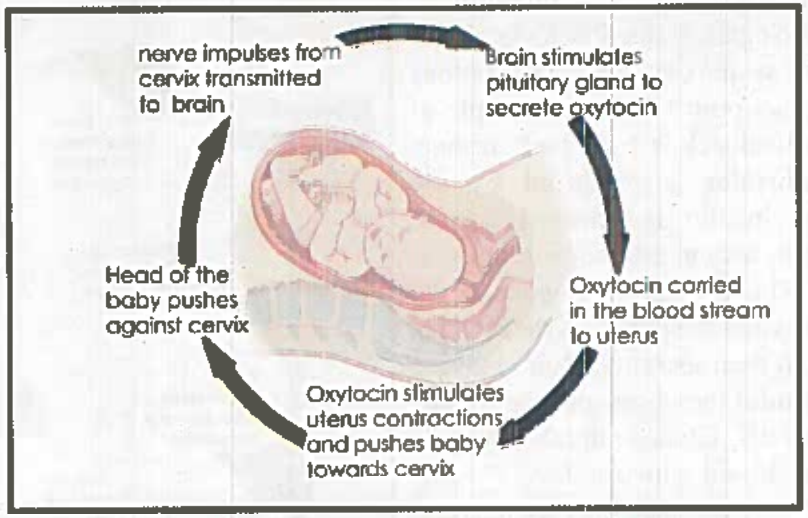


Fig: 18.11 Positive Feedback Mechanism

KEY POINTS

- The endocrine system serves the role to coordinate most body cells
- Endocrine glands are structures made up of one or more cells that make and release hormones. These glands are classified as exocrine glands and the endocrine glands.
- Chemically, hormones are of three basic types i.e. steroids, amino acids or their derivatives, and proteins or polypeptides.
- Pituitary gland signals other glands to put forth hormones. The pituitary also secretes growth hormone, and anti-diuretic hormone, prolactin, and oxytocin, a hormone which causes contractions of the uterus during labor.
- Thyroid gland produces the hormones thyroxin, triiodothyronine and calcitonin, which stimulate metabolism, body heat production and bone growth.
- Parathyroid glands regulate the use and function of calcium and phosphorus in the body.
- Pancreas: The abdominal organ which secretes insulin and glucagon, which control the utilization of sugar, the body's chief source of energy.
- Adrenal glands are two small glands which are present on top of each kidney. They release hydrocortisone, which effects metabolism. They also produce androgens and aldosterone, which maintains blood pressure and the body's salt and potassium balance.
- Ovaries are female glands which produce the hormones estrogen and progesterone, produce eggs in the ovaries and influence female characteristics.
- Testes are male glands which secrete testosterone, which stimulates sperm production and development of male characteristics.
- It is a type of interaction in which a controlling mechanism is itself controlled by the product of reactions it is controlling. After receiving the signal, a change occurs to correct the deviation by depressing it with or enhancing it with positive feedback .

EXERCISE 2

1- Multiple Choice Questions

(i) Which one of the following condition is resulted from excess GH in adults?

(a) *Cushing's disease* (b) *acromegaly*
(c) *hyperthyroidism* (d) *diabetes mellitus*

(ii) _____ regulates the kidney's retention of water.

(a) prolactin (b) oxytocin
(c) thyroxine (d) vasopressin (ADH)

(iii) Which of the following hormones is not released by the anterior pituitary?

(a) melanocyte-stimulating hormone
(b) gonadotropin-releasing hormone
(c) thyroid-stimulating hormone
(d) growth hormone

(iv) Parathyroid hormone acts to ensure that

(a) calcium levels in the blood never drop too low
(b) sodium levels in urine are constant
(c) potassium levels in the blood don't escalate
(d) the concentration of water in the blood is sufficient

(v) The adrenal cortex produces _____.

(a) *adrenaline* (b) *calcitonin*
(c) *epinephrine* (d) *aldosterone*

(vi) Oxytocin is secreted by the endocrine gland named:

(a) pituitary gland (b) thyroid gland
(c) parathyroid gland (d) adrenal gland

(vii). Deficiency of vasopressin or ADH by the pituitary gland leads to a disorder in which the patients kidneys have lessened ability to absorb water is:

(a) diabetes mellitus (b) diabetes insipidus
(c) goiter (d) exophthalmic goiter

EXERCISE 2

(viii) The function(s) of oxytocin is/are to _____.

(a) cause the uterus to contract
(b) induce labor
(c) stimulate the release of milk from the mother's mammary glands when her baby is nursing.
(d) all of the above

(ix) In humans, MSH (melanocyte-stimulating hormone) _____.

(a) regulates primary skin color (b) causes the thyroid to produce thyroxin
(c) governs the rate of tanning (d) concentration is very low

2- Short Questions

(i) Differentiate between endocrine and exocrine glands.
(ii) Why anterior pituitary gland is called master gland?
(iii) List down the effects of Hyperthyroidism.
(iv) Why pancreas is known as double gland?
(v) Why insulin is so vital for normal survival?

3- Long Questions

(i) Describe the chemical nature of hormone by giving the examples of important hormones.
(ii) Explain the role of hormones secreted by anterior lobe of pituitary.
(iii) Discuss the regulation of calcium level in the body also discuss the effects of hypercalcemia and hypocalcemia.
(iv) Describe the hormone involve in the regulation of reproductive functions.
(v) Analyze the phenomenon of feedback mechanism by taking an appropriate example from chemical coordination.

4- Interpreting and Communication

- State the role of artificially synthesized steroids in sports and their long term effects on its user.
- Explain on what grounds some companies claim the growth is possible in people having short heights.

5- Online Learning

- www.tutorvista.com › Biology
- www.cliffsnotes.com/.../Hormones-and-Glands
- www.nos.org/secscicour/CHAPTER28.pdf
- www.hormone.org

UNIT

19

BEHAVIOUR

KEY CONCEPTS

19.1 Nature of behavior
19.2 Innate behavior
19.3 Learning behavior
19.4 Social behaviors

Behaviour is the response of an organism to stimulus or stimuli. The stimuli may originate outside the organism or within the organism (secretions change the chemical state). Behaviour is what animal does and how it does it. For example walking, sitting, sleeping, eating, mating and rearing young ones are all different types of behaviour. The study of animal behaviour is called ethology. Behavior is defined as the aggregate of responses to stimuli for given situation. All living organisms exhibit a variety of forms of behavioural activity determined by the extent to which they are able to respond to stimuli.

19.1 NATURE OF BEHAVIOR

19.1.1 Behavior and stimuli:

The ability of an organism to respond against particular stimuli varies from the relatively simple action of the growth of a plant stem towards a light source, to the complex sexual behavior patterns of territory defense, courtship and mating seen in birds and mammals. In other words, what a person, animal, plant, or any organism does after being stimulated, is part of its behavior. In order to cause that response, the stimulus must be sensed, processed, and interpreted.

19.1.2 Effect of genetics on behavior:

Francis Galton

Fig: 19.1

Charles Darwin, who originated the theory that natural selection is the basis of biological evolution, was persuaded by Francis Galton that the principles of natural selection applied to behavior as well as physical characteristics. Members of a species vary in the expression of certain behaviors because of variations in their genes and these behaviors have survival value in some environments. One example of such a behavior is curiosity—some organisms are more curious than others, and in some settings curiosity is advantageous for survival. Heredity has important role in intelligence, moodiness, impulsiveness, shyness, and all other psychological characteristics.

19.1.3 Biological rhythms:

There are cyclic phenomena in biology, which recurs each year, each lunar month, each day or with the tides. A number of biological characteristics of animals fluctuate in some regular fashion.

Intrinsic "biological clocks" may be involved in regulating such cyclic phenomenon. The organisms living in the temperate zones of the world typically show marked seasonal cycles of activity. Most animals have a breeding season at one time of the year, usually in the spring; some show a decrease in activity and metabolism during the winter - a phenomena termed as hibernation.

Fig: 19.2 Sleepy bear emerges from hibernation after snoozing all through winter.

The adult forms of many plants and animals especially insects, die at the end of each summer season and the species is carried over the winter in the form of seeds, eggs or pupae. In tropics there is usually a period of heavy rain, which alternates with a period of little or no rain. The plants and the animals in such regions have cycles that are geared to these changes in the environment.

Organisms and even several parts of the organisms usually do not function at a constant rate over the entire twenty-four hours of the day. Frequently, there appear to be repeated sequences of events, which occur at about 24 hours intervals. These have been termed as "circadian rhythms" (circa =about; dies=days).

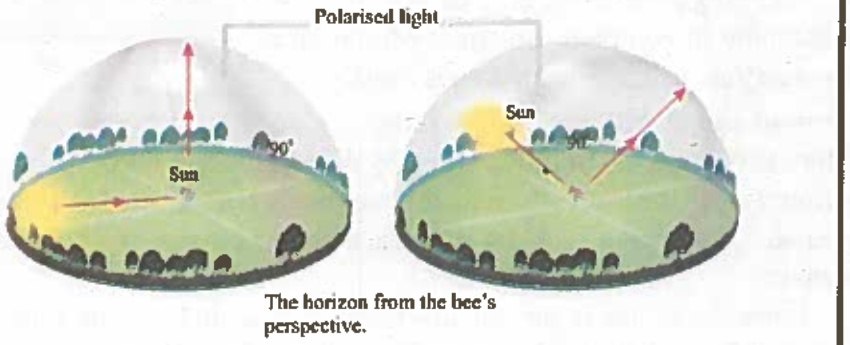
Some animals are diurnal, having their greatest degree of activity during the day. Others are corpuscular and have their greatest activity during the twilight hours. And still others are nocturnal and show their greatest degree of activity during darkness. Certain insects exhibit diurnal variations in pigmentation. There is diurnal deposition and utilization of glycogen in the liver of rabbit and mouse. Man also has circadian rhythms. Many marine organisms living in intertidal zone show marked differences in their activity. Some being active only when the tide is in, others when the tide is out. The vertical distribution of many small marine organisms subject to the diurnal cycle - tend to concentrate near the surface at night and go to the deeper water during the day. Since many fishes feed on them, so the fishes in turn also tend to move nearer the surface at night and to swim farther down in the water during the day.

Many different kinds of animals have evolved "biological clocks" by means of which their activities are adapted to the regularly recurring changes in the external conditions.

These 'clocks' together with other signals received from the external environment; indicate to the organisms the time of the day which is most appropriate for some particular activity.

In a few animals, such as birds and bees, these timing devices have been highly evolved. Bees are not only able to find their way from hive to feeding ground but they can make suitable corrections for the sun's position as the day advances. In an experiment, four feeding tables were setup 50 meters to the north west, north east, south west and south east. The bees were released in the morning. Majority of them flew to the feeding table to the north west.

This shows that bees navigate using the sun as a guide. This also enables the bee to know the best time of the day to visit a plant whose nectar is secreted only during certain hours of the day. Biological rhythms may enable the organism synchronize its activities.



Air molecules in the atmosphere scatter photons to create a circle of strongly polarised light at 90^0 to the sun. This band moves with the sun throughout the day, allowing bees to use this information to navigate, even when the sun is obscured.

Fig: 19.3 Mechanism followed by bees to navigate using sun.

19.2 INNATE BEHAVIOR

Innate behaviour is inherited or in-born. It does not involve parental sign, training or experience or even of contact with member of the same species. It is sometime called instinctive. There are many characteristics of innate behaviour e.g.

(i) Innate responses are built in nervous system during development.
(ii) This behaviour is automatic and machine-like in nature.
(iii) Innate responses are not forgotten.
(iv) Innate behaviour has survival value for the species.

The honeybee, for example, inherits the tendency to fly towards flowers to seek nectar. A young duck starts swimming without any experience.

A young spider will spin and weave a web in its first attempt. In a similar way a caterpillar will form a cocoon characteristic of its species. Also a pair of young bird will build a nest without getting any training. A day old chick will peck at objects on the ground. It does not have to learn this behaviour. Although, learning is important in the songs of some birds, other sing even when they have been raised from hatching in complete isolation. Migration of birds is also innate. Innate behaviour is usually in the form of simple reflexes such as removing one's hand from a hot stove and the withdrawal of an acid - stimulated leg by a fresh brainless frog. Not all unlearned behaviours are in the form of simple reflexes many complicated activities in man are also innate. The human suckling reflex is a good example of a complex unlearned behaviour.

Fig: 19.4 A young spider weaving its web.

Innate behavior is genetically programmed. Individuals inherit a suite of behaviors (often called an **ethogram**) just as they inherit physical traits such as body colour and wing venation. In general, innate behaviors will always be:

1. **Heritable** -- encoded in DNA and passed from generation to generation
2. **Intrinsic** -- present in animals raised in isolation from others
3. **Stereotypic** -- performed in the same way each time by each individual
4. **Inflexible** -- not modified by development or experience
5. **Consummate** -- fully developed or expressed at first performance

Since innate behavior is encoded in DNA, it is subject to genetic change through mutation, recombination, and natural selection. Just like physical traits, innate behaviors are phylogenetic adaptations that have an evolutionary history.

19.2.1 Reflexes:

The most basic unit of innate behavior is a simple reflex. A simple reflex is an involuntary stereotyped response of part of an organism to a given stimulus. It is determined by the presence of an inherited pattern of neurons forming reflex arcs. The reflex arc is a neural pathway that may involve as few as two neurons: a sensory neuron detects a stimulus and is linked with a motor neuron that sets off a response in an effector cell (such as a muscle or a gland cell). More commonly, reflex arcs also include an association neuron spliced between the sensory and motor neurons. A knee jerk, coughing, yawning, blinking of eyes, sneezing, salivation, movement of diaphragm during breathing are all examples of reflex actions.

In Patellar Reflex (knee jerk) when the patellar tendon is tapped just below the knee, the patellar reflex is initiated and the lower leg kicks forward (via contraction of the quadriceps). The tap initiates an action potential in a specialised structure known as a muscle spindle located within the quadriceps. This action potential travels to the spinal cord, via a sensory axon which chemically communicates by releasing glutamate (see synapse) onto a motor nerve. The result of this motor nerve activity is contraction of the quadriceps muscle, leading to extension of the lower leg at the knee.

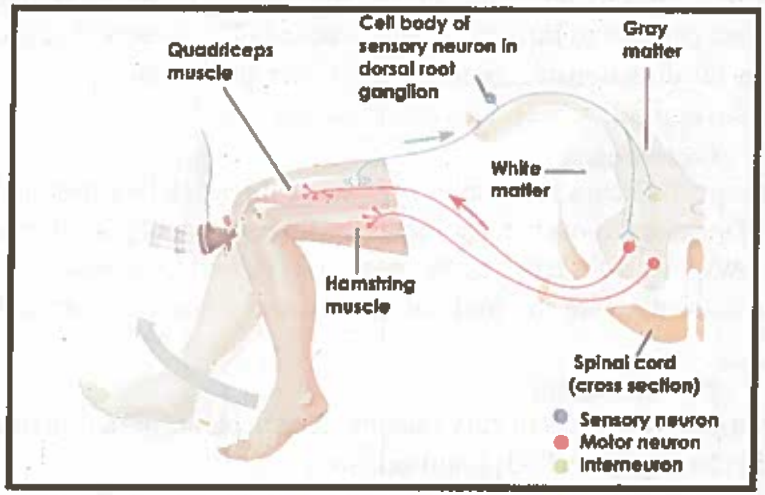


Fig: 19. 5 Patellar Reflex (knee jerk).

Most insects have simple "startle" reflexes triggered by small disturbances as well as more comprehensive "escape" reflexes triggered by larger disturbances.

19.2.2 Orientation Behaviors

Orientation Behaviors are coordinated movements (walking, flying, swimming, etc.) that occur in response to an external stimulus. These behaviors have adaptive value for survival by helping the organism locate (or avoid) the source of a stimulus. There are two types of orientation behaviour:

i. Kinesis:

Kinesis is a change in the speed of movement (orthokinesis) or a change in the rate of turning (klinokinesis) which is directly proportional to the intensity of a stimulus. A kinesis is non-directed orientation, that is, the animal exhibits a random walk. The change in speed or rate of turning increases the probability of locating the stimulus but does not guarantee it.

ii. Taxis:

It is a movement of whole organism directly toward (positive) or away from (negative) a stimulus. Stimulus intensity increases with movement toward the source and decreases with movement away from the source.

Fig: 19.6 A kinesis is non-directed orientation.

19.2.3 Tropic Movements

These are induced movement of curvature shown by the plant organ (shoot or root), which are capable of turning in any direction. The direction of movements is determined by the direction of stimulus (light, water, gravity etc).

Tropism or tropic movements are classified as under:

(i) Geotropism

Geotropism occurs in radially symmetrical organs like root and stem. The orientation of stem and roots in response to the force of gravity is called geotropism. The roots grows towards the force of gravity and are said to be positively geotropic, the stem grows away from the force of gravity and is there fore called negatively geotropic.

(ii) Phototropism

The tropic movement of curvature induced in plants organs in response to the unilateral effect of light is called phototropism.

Young stems are positive phototropic, turn towards light. The curvature is due to the greater growth on the shaded side then on the side on which the light acts.

Roots are usually indifferent to stimulus of light, their orientation being determined chiefly by the gravity.

19.3 LEARNING BEHAVIOR

Learning can be defined as a persistent change in behavior that occurs as a result of experience. Since a newborn nymph or larva has no prior experience, its first behaviors will be entirely innate. Each individual starts life with a "clean slate": it acquires new skills and knowledge through trial and error, observation of other individuals, or memory of past events. In general, learned behaviors will always be:

1. **Nonheritable** -- acquired only through observation or experience
2. **Extrinsic** -- absent in animals raised in isolation from others
3. **Permutable** -- pattern or sequence may change over time
4. **Adaptable** -- capable of modification to suit changing conditions
5. **Progressive** -- subject to improvement, or refinement through practice

19.3.1 Habituation:

Habituation is learning not to respond to some unimportant stimulus. It is an extremely simple form of learning, in which an animal, after a period of exposure to a stimulus, stops responding. Sensory systems may stop, after a while, sending signals to the brain in response to a continuously present or often-repeated stimulus. Habituation allows animals' nervous system to focus on stimuli that signal the presence of food, a mate, or real danger, rather than waste time or energy on stimuli that are irrelevant to animals' survival and reproduction. Lack of continued response to strong odours is a common example of sensory habitation.

19.3.2 Imprinting:

Imprinting behavior includes both innate and learned components. Imprinting is an amazing example of genetic and environmental influences on animal behavior. It involves a brief sensitive period, also called critical period. Sensitive period is a limited developmental phase when certain behavior can be learned. In 1930s, Konard Lorenz showed that the principal imprinting stimulus in grayleg geese (Anser anser) is a nearby object that is moving away from the young.

Fig: 19. 7 Grayleg geese exhibiting imprinting behaviour.

When incubator hatched goslings spent their first few hours with Lorenz rather than with a goose, they imprinted with him and followed him from then on. Furthermore, they showed no recognition of their biological mother or other adults of their own species.

19.3.3 Classical conditioning (Type I learning)

In a series of experiments, Pavlov set out to provoke a conditioned response to a previously neutral stimulus. He opted to use food as the unconditioned stimulus, or the stimulus that evokes a response naturally and automatically. The sound of a metronome was chosen to be the neutral stimulus. The dogs would first be exposed to the sound of the ticking metronome, and then the food was immediately presented.

After several conditioning trials, Pavlov noted that the dogs began to salivate after hearing the metronome. A stimulus which was neutral by itself had been superimposed upon the action of the inborn alimentary reflex. It was observed, after several repetitions of the combined stimulation, the sounds of the metronome had acquired the property of stimulating salivary secretion. In other words, the previously neutral stimulus (the metronome) had become what is known as a that then provoked a conditioned response (salivation)

.19.3.4 Instrumental Learning (Operant learning):

It is learning by consequences. Operant behavior can foster adjustment of organism to certain situation. Operant conditioning helps to explain the acquisition and maintenance of more complex voluntary behaviors. Through the process of operant conditioning, organism learns to perform behavior that produces certain rewarding effect on the environment. These behaviors are called operant responses because they operate on the environment to produce rewarding consequences. The organism acquires responses or develops skills that lead to reinforcement. Reinforcement is a change in the environment (stimulus) that increases the frequency of the behavior that precedes it. A reward is defined as a pleasant stimulus that increases the frequency of behavior.

It depends on the animal's ability to remember the outcome of past events and modify future behavior accordingly. Good consequences (positive feedback) reinforce the behavior and increase its likelihood of occurrence in the future. Bad consequences (negative feedback) have the opposite effect. Cockroaches learn to run through a simple maze to find food is a simple example of instrumental learning (also known as operant conditioning).

While working with his rats in the cumulative recorder box (i.e., Skinner box) he discovered that the rate of responding did not depend on what occurred prior to the behaviour but on what occurred after the behaviour. Skinner's work with rats in his Skinner box led him to discover a process he called *shaping*.

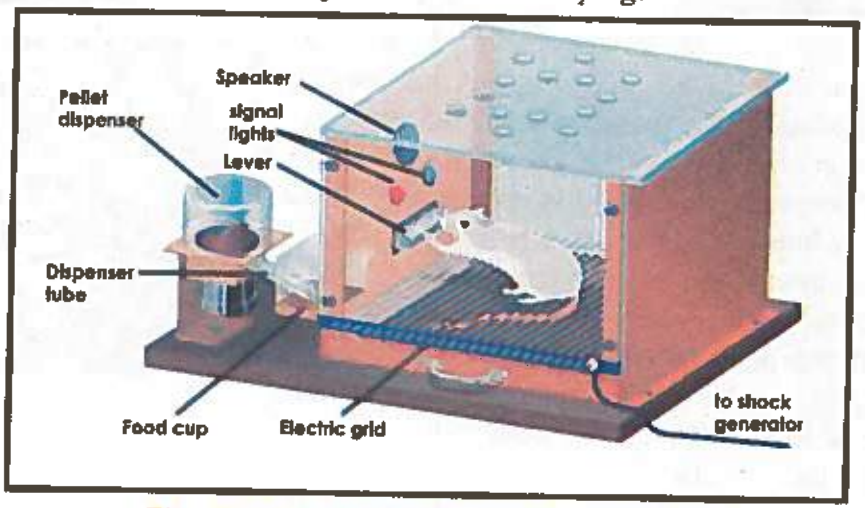


Fig: 19. 8 Rats in the cumulative recorder box.

When the rat is initially put in the Skinner box it does not know that it has to push the lever to get food. Whenever the rat pressed down on this, it received a pellet of dried food. Of course, the rat didn't know this from the outset and only triggered feeding when it happened to touch the lever by accident. But after scoring several such lucky strikes, it appeared to have learned the connection, and consequently the time that elapsed between pushes on the lever became ever shorter.

19.3.5 Insight learning:

A type of learning that uses reason, especially to form conclusions, inferences, or judgments, to solve a problem. Unlike learning by trial-and-error, insight learning is solving problems not based on actual experience (like trial and error steps) but on trials occurring mentally. Often the solution is learned suddenly, such as when a person is in a problem for a period of time and suddenly learns the way to solve it.

This was observed in the Kohler found that chimpanzees could use insight learning instead of trial-and error to solve problems. In one example, a banana was placed high out of reach that the chimpanzees found a way to reach it.

Fig: 19. 9 Experiments of Wolfgang Kohler involving chimpanzees.

The chimpanzees first tried to knock them down by using a stick. Then, the chimpanzees learned to stack boxes on top of one another to climb up to the bananas.

19.4 SOCIAL BEHAVIOURS

Social behavior consists of a set of interactions among individuals of the same species. A wide range of sociality occurs among animals. Some animals rarely if ever interact with one another, even when it comes to issues of parental care. Examples of relatively asocial animals include mosquitoes and polar bears. Highly social organisms live together in large groups, and often cooperate to conduct many tasks. Examples of social groups include packs of wolves and schools of fish. The most highly social animals form tightly knit colonies and include all ants and termites, some bees and wasps, and a few other organisms.

Fig: 19. 10 Honey bees make hives which is a result of social interaction.

19.4.1 Hostile and helpful intraspecific interaction:

Many species of insects and most vertebrates show a variety of (hostile or friendly) group behavioural activities associated with numbers of individuals living together. The cooperation achieved as a result of social behavior which has adaptive significance. It increases the efficiency and effectiveness of the species over that of the other species. In social group a system of communication is essential. The efficiency of the organization is further increased by individuals carrying out particular roles within the society. The roles include members specialized for finding food, reproduction, rearing and defense. Cooperation between members of a society sharing division of labour depends upon stereotyped patterns of behavior and effective means of communication.

Ants, termites and bees are social insects that live in colonies and have an organization based on a cast system. In the honey bee colony there is a single fertile female queen, several thousand sterile female workers and a few hundred fertile male drones. Each type of honey bee has a specific role.

19.4.2 Aggression:

Aggression is a group of behavioural activities including threat posture, rituals and occasionally physical attacks on other organisms. They are usually directed towards members of the same sex and species.

Aggressions have various functions including the displacement of other animals from an area, usually a territory or a source of food, defense of a mate or offspring and establishment of ranking a social hierarchy. **Agnostic behavior** is an

Fig: 19. 11 Agnostic behavior exhibited by two domestic cats threatening each other. Note the more flattened ears of the cat on the right.

aggressive behavior between conspecifics (of the same species) usually involves fighting over a limiting resource such as food, water, space, or mates. Depending on the importance of the resource as well as its scarcity, agonistic behavior can range from all-out fighting to the death to much safer ritualistic behavior. Most species channel their agonistic behavior into ritual contests of strength and threat postures which are universally recognized by the species.

19.4.3 Territorial behavior:

Territory is an area held and defended by an organism or group of organisms against organisms of the same or different species. The exact function of territory formation varies from species to species. However, in all cases it ensures that each mating pair of organisms and their offspring are adequately spaced to receive a share of the available resources, such as food and breeding space.

Prior to breeding, usually males found territory. Defense of the area is greatest at the time of breeding and fiercest between males of the same species. There are a variety of behavioral activities associated with territory formation and they involve threat displays between owners of adjacent territories.

Spider monkeys form loose groups of 15 to 25 animals. They break up into small groups of 2 to 8 animals that travel together and feed throughout the day within a core area of their territory.

When two different troops of spider monkeys come together, the males in each troop display agonistic and territorial behavior such as calling and barking. These interactions happen with much distance between the two groups and do not involve physical contact, indicating that groups respect distinct territorial boundaries.

19.4.4 Dominance hierarchies:

In dominance hierarchies (pecking orders), animals within a group are arranged according to the status. Position in the hierarchy is usually decided by some agonistic form of behavior other than fighting.

The advantage of pecking order is that it decreases the amount of individual aggression associated with feeding, mate selection and breeding site selection. It also avoids injury to the stronger animals which may occur if fighting was necessary to establish the hierarchy. Also it ensures that resources are shared out so that the fittest survive.

19.4.5 Altruistic behavior:

It is the behavior in which certain organisms expend time and energy in caring for other members of the species. It is a form of social behavior whereby one organism puts itself either at risk or personal disadvantage for the good of other members of the species.

In case of activities associated with mating and parental care, altruism is not so difficult to comprehend since the action is clearly in the interests of the parents, offspring and species.

The female baboon protects and cares for its offspring for almost six years and most bird species feed and protect their demanding offsprings until they are capable of feeding for themselves. But why some organisms support to organisms which are not their offspring, for example, birds and monkeys that call out warnings to others in danger and female monkeys who carry and care for the babies of other monkeys.

Fig: 19. 12 Bird species feed and protect their demanding offsprings.

Fig: 19. 13 Altruistic behaviour in honeybees.
Queen Bee ensures the continuity of the hive.

Altruistic behavior is seen in the social insects such as honeybees, wasp and ants. In honeybees, female workers are sterile, never produce offspring, yet they spend their lives looking after their brothers and sisters. Especially by helping their sister, queen bee, to reproduce they are aiding in the production of new workers, drones and queen.

KEY POINTS

- Behaviour is the response of an organism to stimulus or stimuli which may originate outside the organism or within the organism. Behaviour is what animal does and how it does it?
- Members of a species vary in the expression of certain behaviors because of variations in their genes, and these behaviors have survival value in some environments.
- Biological rhythms are cyclic phenomena in biology, which recurs each year, each lunar month, each day or with the tides.
- Some animals are diurnal, having their greatest degree of activity during the day. Others are corpuscular and have their greatest activity during the twilight hours.
- Innate behaviour is inherited or in-born and it does not involve parental sign, training or experience or even of contact with member of the same species.
- Innate behavior is genetically programmed. Individuals inherit a suite (**ethogram**) of behaviors.
- Reflex is an involuntary stereotyped response of part of an organism to a given stimulus which is determined by the presence of an inherited pattern of neurons forming reflex arcs.
- Orientation Behaviors are coordinated movements that occur in response to an external stimulus.
- Taxis is a movement of whole organism directly toward (positive) or away from (negative) a stimulus.
- Learning can be defined as a persistent change in behavior that occurs as a result of experience.
- Habituation is learning not to respond to some unimportant stimulus.
- Imprinting behavior includes both innate and learned components. **Genetic and environmental factors influences animal behavior.**
- Insight learning that uses reason, especially to form conclusions, inferences, or judgments, to solve a problem.
- Social behaviour consists of a set of interactions among individuals of the same species.
- In dominance hierarchies (pecking orders), animals within a group are arranged according to the status. Position in the hierarchy is usually decided by some agonistic form of behavior other than fighting.
- Altruistic behavior is the behavior in which certain organisms expend time and energy in caring for other members of the species.

EXERCISE 2

1- Multiple Choice Questions

(i) ***Innate behavior is all but;***

(a) Heritable (b) Intrinsic
(c) Stereotypic (d) Flexible

(ii) ***Innate behavior is all except:***

(a) Coded in DNA
(b) Modified in individuals' life span
(c) Modified with species evolution
(d) Programmed responses to external stimuli

(iii) ***Which one is non-directed orientation?***

(a) Taxis (b) Kinesis
(c) Tropism (d) Imprinting

(iv) ***Trial and error learning has no role in***

(a) Operant learning (b) Classical conditioning
(c) Insight (d) Imprinting

(v) ***Advantage of pecking orders is to***

(a) avoids injury to the stronger animals
(b) protect territory
(c) find suitable mate
(d) Assign specific role to individual subordinates.

2- Short Questions

(i) How innate behavior ensures the survival of individuals in a population
(ii) What is territorial behavior?
(iii) How insight learning is different from other learnings?
(iv) Write a brief note on altruism in honeybees.
(v) Give the characteristics of innate behavior

3- Analyzing and Interpreting

- Give examples to interpret that hormones and brain control instincts.
- Relate different examples of learning of human with habituation, conditioning, latent learning and insight learning.

EXERCISE 2

4- Performing and Recording

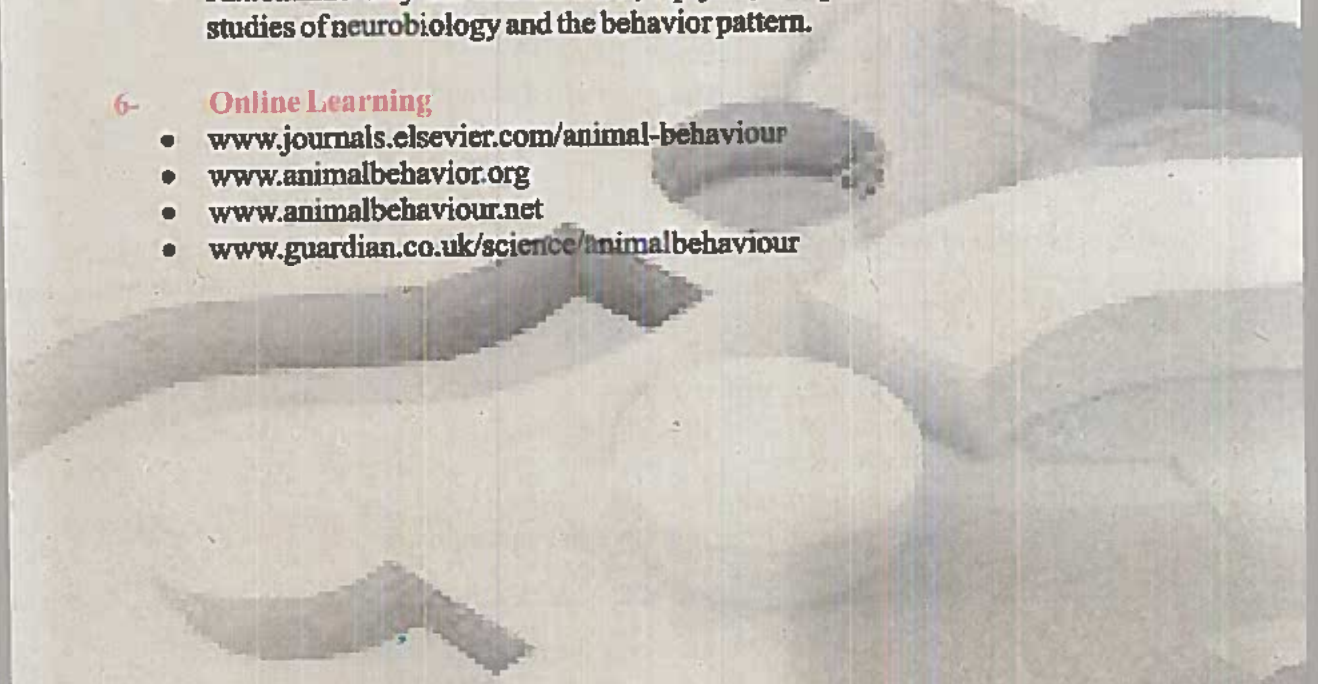
- Observe spider's web and record the instincts by providing it various stimuli

5- Science, Technology, and Society Connections

- State the role of research in neurobiology in the understanding of behavior.
- Rationalize why the marine snail, Aplysia, has proved very helpful in the studies of neurobiology and the behavior pattern.

6- Online Learning

- www.journals.elsevier.com/animal-behaviour
- www.animalbehavior.org
- www.animalbehaviour.net
- www.guardian.co.uk/science/animalbehaviour

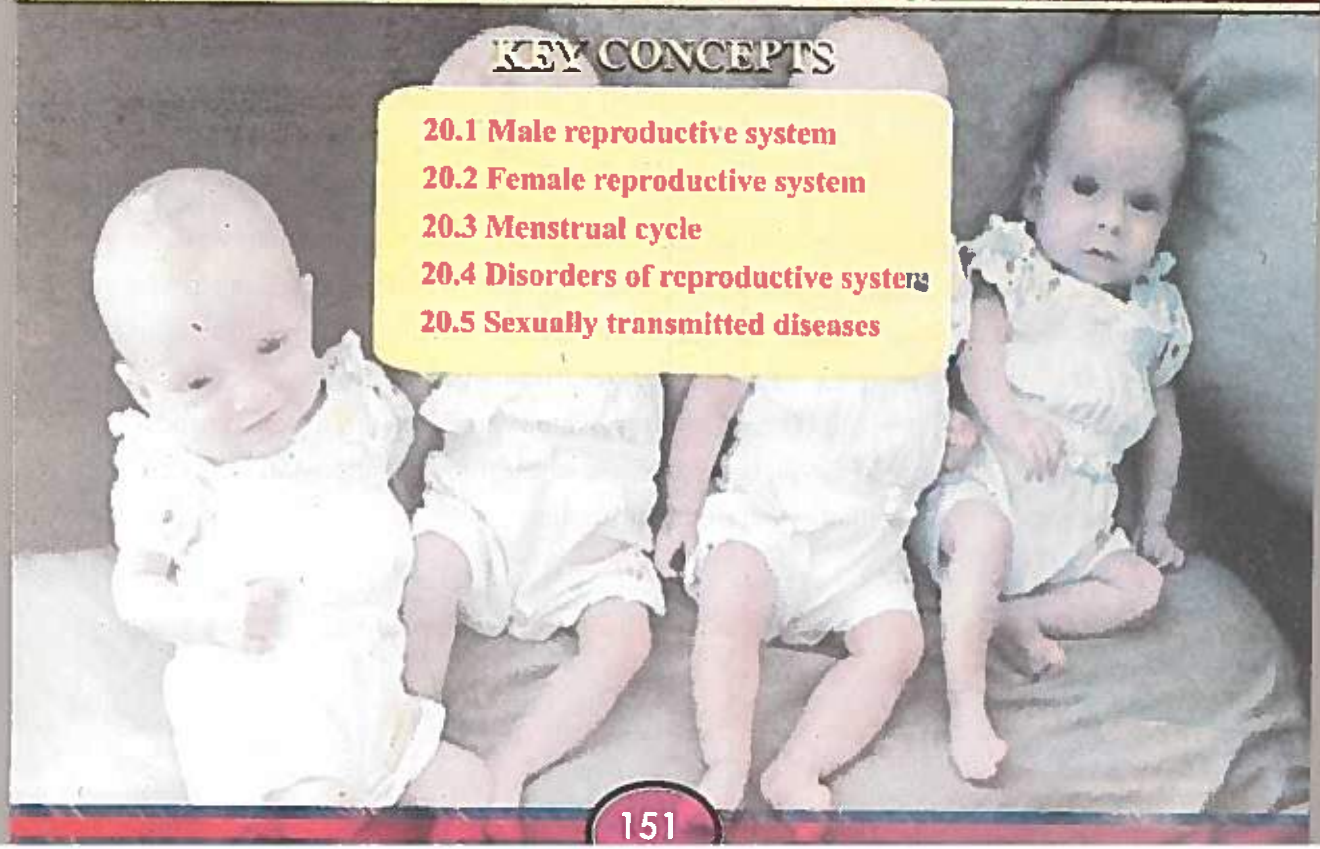


UNIT

20

REPRODUCTION

KEY CONCEPTS



Reproduction is important for the survival of all living things. Without a mechanism for reproduction, life comes to an end. Reproduction guarantees the transmission of one generation's genetic material into the next generation. Without this transmission, the species will cease to exist after all of the members of the current generation have died out. Thus, reproduction is essential to the continued survival of a species over time.

HUMAN REPRODUCTIVE SYSTEM

The humans are the most advanced mammals and correspondingly show a reproductive pattern, which is most efficient, especially in the sense of protection of the embryo within the female body as well as its care after its birth. The male and female reproductive system in humans is as follows.

20.1 MALE REPRODUCTIVE SYSTEM

Male reproductive system consists of a pair of testes, ducts, glands, and external genitalia.

20.1.1 Testes:

The testes are male gonads which are situated outside the abdomen within a skin pouch called scrotum. Each testis is divided into 250 to 300 lobules. Each lobule contains one to four tightly coiled seminiferous tubules. The process of spermatogenesis takes place here in the seminiferous tubules. Leyden cells are present between the seminiferous tubules which produce male sex hormone testosterone. The accessory ducts include the vasa efferentia, the epididymis, the ductus deferens, the ejaculatory duct, and the urethra.

20.1.2 Vasa efferentia:

About 10 to 20 vasa efferentia collect sperms from inside the testes and transfer them to the epididymis.

The epididymis rests on the backside of each testis. Most of the epididymis consists of the highly coiled duct of the epididymis with an uncoiled length of about 6 m (20 feet). Its functions are the transport and storage of the sperms. Here the sperms are stored temporarily, nourished, and they gain the ability to swim.

20.1.4 Vas deferens:

It starts from the epididymis moves deep into the pelvic cavity and then joins with the duct of the seminal vesicle to form the short ejaculatory duct. Each ejaculatory duct enters the prostate; there it empties into the urethra.

20.1.5 Urethra:

The urethra is the terminal portion of the male duct system. It opens to the outside at the external urethral orifice and conveys both urine and semen.

20.1.6 Accessory glands:

The Seminal Vesicles provide an alkaline fluid containing fructose sugar, ascorbic acid, and a coagulating enzyme called vesiculase, as well as other substances that enhance sperm motility thus improve their fertilizing power.

DO YOU KNOW?

Why the testes are located outside the abdominal cavity? The testes work best at temperatures slightly less than core body temperature. The optimum temperature for sperm development is about 35 °C.

The Prostate encircles the urethra just below the bladder. Its secretion is a milky, slightly acidic fluid that contains citrate as a nutrient source and several enzymes especially hyaluronidase.Cowpers' gland secretes mucus and an alkaline fluid into the urethra. The alkaline fluid neutralizes the acidity of urine in the urethra.The Bulbourethral Glands produce thick and clear mucus.

Semen is a white, sticky mixture of sperm and secretions of accessory glands. The liquid substance in the semen provides nutrients and protection to sperms and acts as a transport medium for sperms. Prostaglandins in semen decrease the viscosity of mucus guarding the entry (cervix) of the uterus and stimulate reverse peristalsis in the uterus, facilitating sperm movement through the female reproductive tract.

20.1.6 Spermatogenesis:

It is the process of sperm formation in males which involves a precise sequence of events. This process takes place in semniferous tubules. Spermatogonia are the outermost cells which make the epithelial wall of the semniferous tubules. These cells are just beneath the basal lamina. The spermatogonia divide continuously by mitosis and, each mitotic division of a spermatogonium results in two distinctive daughter cells–types A and B.

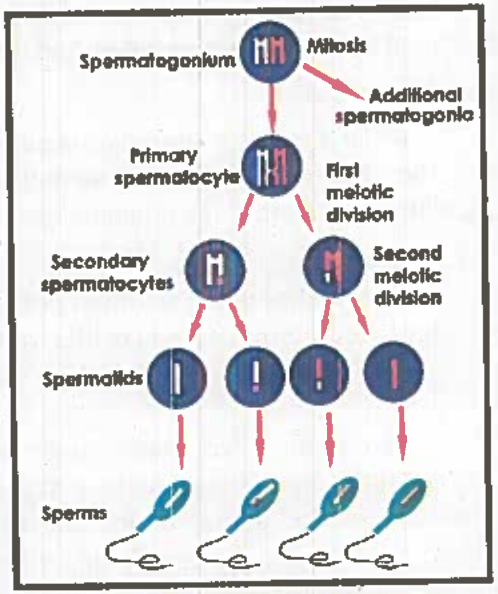


Fig: 20.3 Spermatogenesis.

The type A daughter cell remains at the basement membrane to maintain the germ cell line. The type B cell gets pushed toward the lumen, where it becomes a primary spermatocyte destined to produce four sperm.

Each primary spermatocyte undergoes meiosis I, forming two smaller haploid cells called secondary spermatocytes.

The secondary spermatocytes continue on rapidly into meiosis II, and their daughter cells, called spermatids are formed. Each spermatid is a round, nonmotile haploid cell.

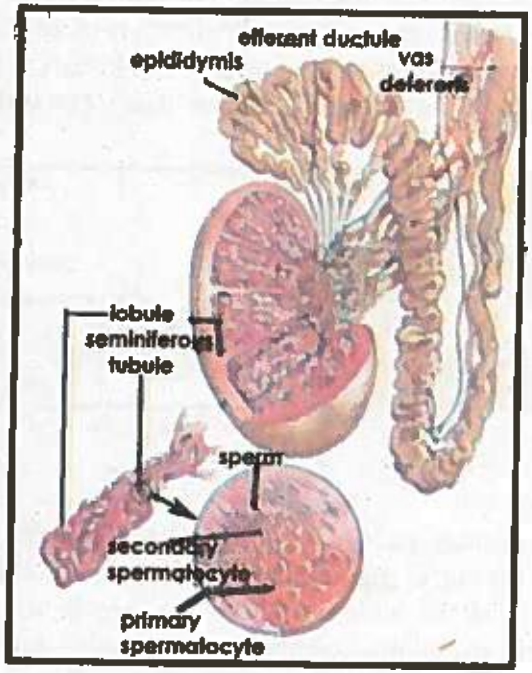


Fig: 20.4 Section through testis showing the site of sperm production.

Spermiogenesis is a process in which spermatids change into motile and active sperms. During this process a spermatid elongates, sheds its excess cytoplasm, and forms a tail.

20.1.7 Sperm:

The sperm, or spermatozoon (animal seed), is a very small haploid cell. It has a head, a neck, a midpiece, and a tail. The head contains the nucleus having haploid set of chromosome. Adhering to the top of the head is acrosome. The lysosome-like acrosome is produced by the Golgi apparatus and contains hydrolytic enzyme hyaluronidase that enables the sperm to penetrate and enter an egg. The neck of sperm is very short and contains a pair of centrioles. The microtubules of one of the

centriole elongate and run the entire length of the tail. It forms the axial filament of the tail. The middle piece contains many mitochondria arranged spirally around the axial filament. The process begins around the age of 14 years in males, and continues throughout life. Every day, a healthy adult male makes about 400 million sperm.

Fig: 20.5 Structure of a sperm

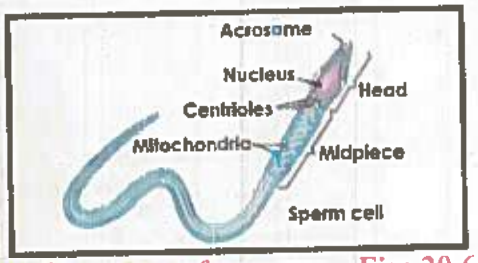


Fig: 20.6

20.1.8 Hormonal control:

Process of spermatogenesis is controlled by hormonal secretions from hypothalamus and pituitary gland. The hypothalamus releases gonadotropin-releasing hormone (GnRH), which controls the release of the anterior pituitary gonadotropins follicle-stimulating hormone (FSH) and luteinizing hormone (LH). FSH stimulates spermatogenesis by stimulating the sertoli cells (cell of the testes that is part of a seminiferous tubule) to complete the development of sperms from spermatids. LH stimulates leydig cells (found adjacent to the seminiferous tubules in the testicle) to release testosterone. Testosterone causes the growth and development of germinal epithelium to form sperms.

Inhibin hormone is produced by the sertoli cells and serves to control the spermatogenesis at normal rate. When the sperm count is high, inhibin release increases and it inhibits anterior pituitary release of FSH and hypothalamic release of GnRH. When sperm count falls, inhibin secretion declines steeply.

20.2 FEMALE REPRODUCTIVE SYSTEM

The reproductive role of the female is far more complex than that of a male. Not only must she produce gametes, but her body must prepare to nurture a developing embryo for a period of approximately nine months. Female reproductive system consists of a pair of ovaries, oviducts, uterus, cervix, and vagina.

20.2.1 Ovaries:

Ovaries are female gonads which produce ova and release hormones. The paired ovaries flank the uterus on each side and each ovary is held in place within the

peritoneal cavity by several ligaments. The ovaries are almond-shaped, measure about 3-5 cm long and 2-3 cm wide. Within the ovary are many tiny saclike structures called ovarian follicles each of which consists of an immature egg, called an oocyte. Each month in adult women, one of the ripening follicles ejects its oocyte from the ovary. This event is called ovulation. After ovulation, the ruptured follicle is transformed into a glandular structure called the corpus luteum.

20.2.2 Fallopian tubes:

Fallopian tubes or oviducts form the initial part of the female duct system. They receive the ovulated oocyte and are the site where fertilization generally occurs. Each oviduct is about 10 cm long and extends near from the region of an ovary to empty into the uterus. The uterine tube contains sheets of smooth muscle and contains both ciliated and non-ciliated cells. The oocyte is carried toward the uterus by a combination of muscular peristalsis and the beating of the cilia. Non-ciliated cells produce a secretion that keeps the oocyte (and sperm, if present) moist and nourished.

20.2.3 Uterus:

The uterus is located in the pelvis, anterior to the rectum and posterior to the bladder. It is about the size and shape of an inverted pear. It is a hollow, thick-walled, muscular organ that functions to receive, retain, and nourish a fertilized ovum. The wall of the uterus is composed of three layers. The **perimetrium** is the outermost thin covering layer of the uterus. The **myometrium** is the middle thick muscular layer composed of bundles of smooth muscle, that contracts rhythmically during childbirth to expel the baby from the mother's body.

The **endometrium** is the inner spongy lining of the uterine cavity. If fertilization occurs, the young embryo takes root into the endometrium (implants) and resides there for the rest of its development.

20.2.4 Cervix:

It is a narrow entrance to the uterus from the vagina. It is normally blocked by a plug of mucus.

20.2.5 Vagina:

The vagina is a thin-walled 8–10 cm long tube and extends from the cervix to the body exterior.

It is often called the birth canal as it provides a passageway for delivery of an infant and for menstrual flow. The urethra is embedded in its anterior wall.

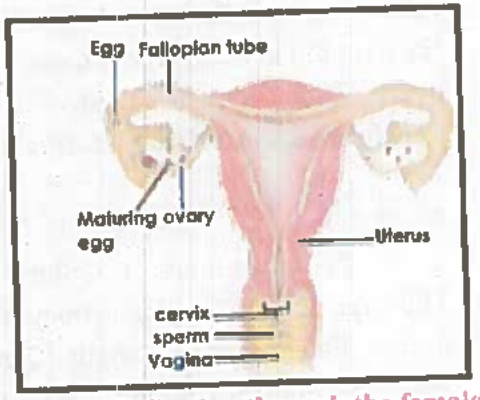


Fig: 20.7 Section through the female reproductive system.

20.2.6 Oogenesis:

The process of egg formation in females is called oogenesis. The process of oogenesis takes years to complete. First, in the fetal period the oogonia, the diploid stem cells of the ovaries, multiply rapidly by mitosis and then enter a growth phase and lay in nutrient reserves. Gradually the oogonia are transformed into primary oocytes and become surrounded by a single layer of follicle cells. The primary oocytes begin the first meiotic division, but become "stalled" late in prophase I and do not complete it. They remain in their state of suspended animation all through childhood; the wait is a long one–10 to 14 years at the very least!

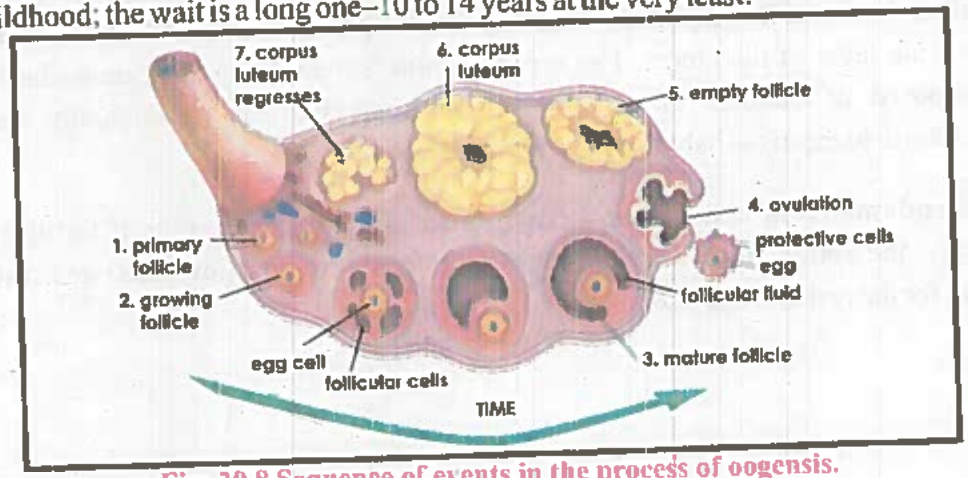


Fig: 20.8 Sequence of events in the process of oogensis.

At puberty, a small number of primary oocytes are recruited each month, however, only one is selected each time to continue meiosis I, ultimately producing two haploid cells (that are quite dissimilar in size. The larger cell, which contains nearly all the cytoplasm of the primary oocyte, is the secondary oocyte. The smaller cell is called the first polar body.

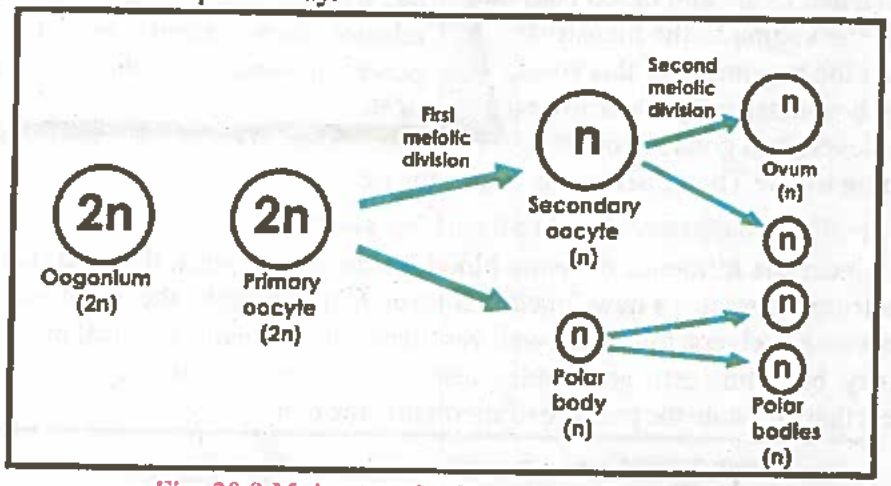


Fig: 20.9 Main steps in the process of oogensis.

In humans, the secondary oocyte arrests in metaphase II and it is this cell that is ovulated. If an ovulated secondary oocyte is not penetrated by a sperm, it simply deteriorates. But, if sperm penetration does occur, it quickly completes meiosis II, yielding one large ovum and a tiny second polar body. The unequal cytoplasmic divisions that occur during oogenesis ensure that a fertilized egg has ample nutrients for its six- to seven-day journey to the uterus. Without nutrient-containing cytoplasm the polar bodies degenerate and die.

20.3 MENSTRUAL CYCLE

The reproductive cycle in human and other primates is called menstrual cycle. The first menstruation begins at puberty. The uterine or menstrual cycle is a series of cyclic changes that the uterine endometrium goes through each month as it responds to the waxing and waning of ovarian hormones in the blood. These endometrial changes are coordinated with the phases of the ovarian cycle, which are controlled by gonadotropins released by the anterior pituitary.

Various phases of menstrual cycle are as follows:

20.3.1 Menstrual phase (Days 1–5): In this menstruation phase, the uterus sheds all but the deepest part of its endometrium.

The thick, hormone-dependent functional layer of the endometrium detaches from the uterine wall, a process that is accompanied by bleeding for 3–5 days. The detached tissue and blood pass out through the vagina as the menstrual flow. At the beginning of this stage, ovarian hormones are at their lowest normal levels and gonadotropins are beginning to rise. Then FSH levels begin to rise.

For Your Information

It has been assumed that a female's total supply of eggs is already determined by the time she is born, and the time span during which she releases them extends only from puberty to menopause, about the age of 50.

20.3.2 Proliferative/preovulatory phase (Days 6–14):

Under the influence of rising blood levels of estrogens, the basal layer of the endometrium generates a new functional layer. Consequently, the endometrium once again becomes velvety, thick, and well vascularized. Normally, cervical mucus is thick and sticky, but rising estrogen levels cause it to thin and become crystalline, forming channels that facilitate the passage of sperm into the uterus.

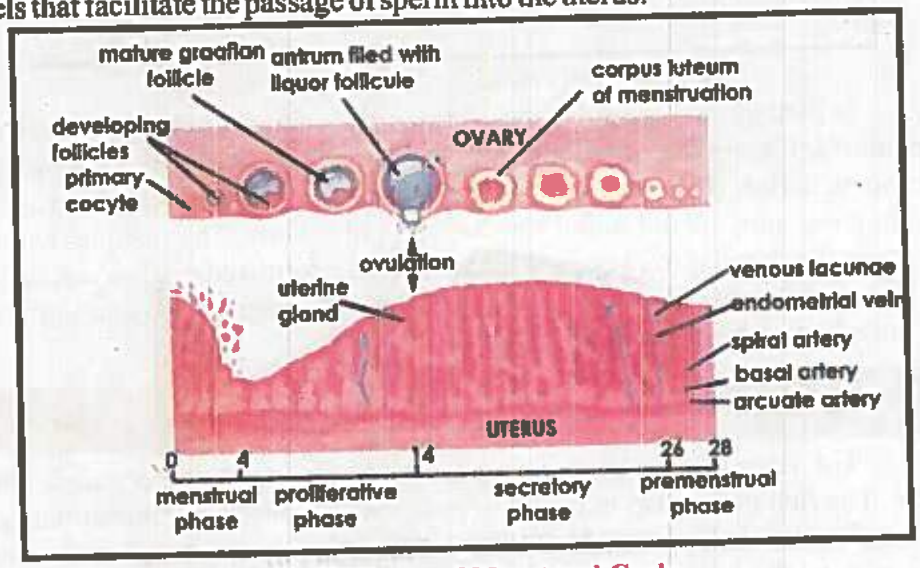


Fig: 20.10 Phases of Menstrual Cycle.

Ovulation, which takes less than five minutes, occurs in the ovary at the end of the proliferative stage (day 14) in response to the sudden release of LH from the anterior pituitary. LH also converts the ruptured follicle to a corpus luteum.

20.3.3 Secretory/postovulatory phase (Days 15–28):

This 14-day phase is the most important. During the secretory phase the

endometrium prepares for implantation of an embryo. Rising levels of progesterone from the corpus luteum act on the estrogen-primed endometrium, causing the arteries to elaborate and converting the functional layer to a glandular secretory layer. The uterine glands enlarge, coil, and begin secreting nutritious glycogen into the uterine cavity. These nutrients sustain the embryo until it has implanted in the blood-rich endometrial lining.

If fertilization has not occurred, the corpus luteum begins to degenerate toward the end of the secretory phase as LH blood levels decline. Progesterone levels fall, depriving the endometrium of hormonal support, and endometrial cells die, setting the stage for menstruation to begin on day 28.

In female menstrual cycle ceases around 50 year of age and it is termed as menopause. Cyclic menstruation is an indicator of normal reproductive life of females.

Fig: 20.11

For Your Information

In 1–2% of all ovulations, more than one oocyte is ovulated. This phenomenon, which increases with age, can result in multiple births. Since, in such cases, different oocytes are fertilized by different sperm, the siblings are fraternal, or nonidentical, twins. Identical twins result from the fertilization of a single oocyte by a single sperm, followed by separation of the fertilized egg's daughter cells in early development

20.4 DISORDERS OF REPRODUCTIVE SYSTEM

20.4.1 Female infertility

Infertility means not being able to get pregnant. Women who can get pregnant but are unable to stay pregnant may also be infertile.

Pregnancy is the result of a process that has many steps. To get pregnant:

- A woman's body must release an egg from one of her ovaries (ovulation).
- The egg must go through a fallopian tube toward the uterus.
- A man's sperm must join with (fertilize) the egg along the way.
- The fertilized egg must attach to the inside of the uterus (implantation).
- Infertility can happen if there are problems with any of these steps.

Most cases of female infertility are caused by problems with ovulation. Without ovulation, there are no eggs to be fertilized. Some signs that a woman is not ovulating normally include irregular or absent menstrual periods.

Less common causes of fertility problems in women include:

- Blocked fallopian tubes due to pelvic inflammatory disease, endometriosis
- Physical problems with the uterus
- Uterine fibroids, which are non-cancerous clumps of tissue and muscle on the walls of the uterus.

20.4.2 Male Infertility:

Infertility in men is most often caused by a problem called varicocele. This happens when the veins on a man's testes are too large. This heats the testicles. The heat can affect the number or shape of the sperm. Other factors that cause a man to make too few sperm or none at all.

Movement of the sperm is yet another cause infertility. This may be caused by the shape of the sperm. Sometimes injuries or other damage to the reproductive system block the sperm. Sometimes a man is born with the problems that affect his sperm. Other times problems start later in life due to illness or injury. For example, cystic fibrosis often causes infertility in men.

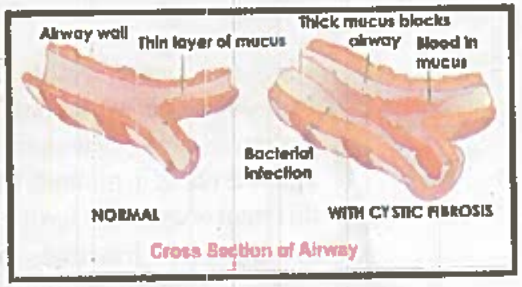


Fig:20.12 Cystic Fibrosis, is an autosomal recessive genetic disorder that affects most critically the lungs, and also the pancreas, liver, and intestine.

20.4.3 In vitro fertilization (IVF):

IVF means fertilization outside of the body. IVF is the most effective types of assisted reproductive technology. It is often used when a woman's fallopian tubes are blocked or when a man produces too few sperm. Doctors treat the woman with hormones that causes the ovaries to produce multiple eggs. Once mature, the eggs are removed from the woman. They are put in a dish in the lab along with the man's sperm for fertilization. After 3 to 5 days, healthy embryos are implanted in the woman's uterus.

20.4.4 Miscarriage:

A miscarriage is the spontaneous loss of a foetus before the 20th week of pregnancy. (Pregnancy losses after the 20th week are called preterm deliveries.) A miscarriage may also be called a "spontaneous abortion." This refers to naturally occurring events, not medical abortions. Most miscarriages are caused by chromosome problems that make it impossible for the baby to develop. Usually, these problems are unrelated to the mother or father's genes.

Other possible causes for miscarriage include: Drug and alcohol abuse, exposure to environmental toxins, hormone problems, infections, obesity, physical problems with the mother's reproductive organs, problem with the body's immune response, serious body-wide diseases in the mother such as uncontrolled diabetes and smoking. It is estimated that up to half of all fertilized eggs die and are lost (aborted) spontaneously, usually before the woman knows she is pregnant. Among those women who know they are pregnant, the miscarriage rate is about 15-20%. Most miscarriages occur during the first 7 weeks of pregnancy.

Abortion is defined as the termination of pregnancy by the removal or expulsion of a foetus or embryo from the uterus before it is viable. An abortion can occur spontaneously, in which case it is usually called a miscarriage, or it can be purposely induced. The term abortion most commonly refers to the induced abortion of a human pregnancy.

20.5 SEXUALLY TRANSMITTED DISEASES

20.5.1 Gonorrhea:

The causative agent of gonorrhea is *Neisseria gonorrhoeae*, which invades the mucosae of the reproductive and urinary tracts.The most common symptom of gonorrhea in males is urethritis, accompanied by painful urination and discharge of pus from the penis.

Symptoms vary in women, ranging from none (about 20% of cases) to abdominal discomfort, vaginal discharge, abnormal uterine bleeding, and occasionally, urethral symptoms similar to those seen in males. Untreated gonorrhea can cause urethral constriction and inflammation of the entire male duct system. In women, it causes pelvic inflammatory disease and sterility. It can be treated by penicillin, tetracycline, and certain other antibiotics.

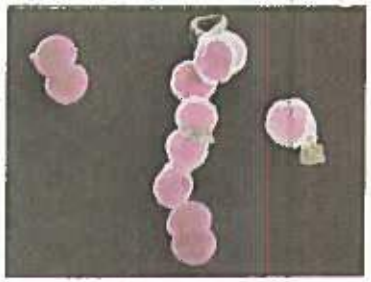


Fig:20.13 *Neisseria gonorrhoeae*,

20.5.2 Syphilis:

Syphilis is caused by *Treponema pallidum*, and is usually transmitted sexually, but it can be contracted congenitally from an infected mother. Foetuses infected with syphilis are usually stillborn or die shortly after birth. The bacterium easily penetrates intact mucosae and abraded skin.

Within a few hours of exposure, an asymptomatic body wide infection is in progress. After an incubation period of two to three weeks, a red, painless primary lesion called a chancre (shang'ker) appears at the site of bacterial invasion. In males, this is typically the penis, but in females the lesion often goes undetected within the vagina or on the cervix. The chancre ulcerates and becomes crusty; then it heals spontaneously and disappears within a few weeks.

If syphilis is untreated, its secondary signs appear several weeks later. A pink skin rash all over the body is one of the first symptoms. Fever and joint pain are common. These signs and symptoms disappear spontaneously in three to twelve weeks. Then the disease enters the latent period and is detectable only by a blood test. The latent stage may last a person's lifetime (or the bacteria may be killed by the immune system), or it may be followed by the signs of tertiary syphilis. Tertiary syphilis is characterized by gummas, destructive lesions of the CNS, blood vessels, bones, and skin. Penicillin is still the treatment of choice for all stages of syphilis.

20.5.3 AIDS

AIDS is one of the most serious, deadly diseases in human history. More than 20 years ago, doctors in the United States identified the first cases of AIDS in San Francisco and New York. Now there are an estimated 42 million people living with HIV or AIDS worldwide, and more than 3 million die every year from AIDS-related illnesses. AIDS is caused by the human immunodeficiency virus (HIV). HIV destroys a type of defense cell in the body called a CD4 helper lymphocyte.

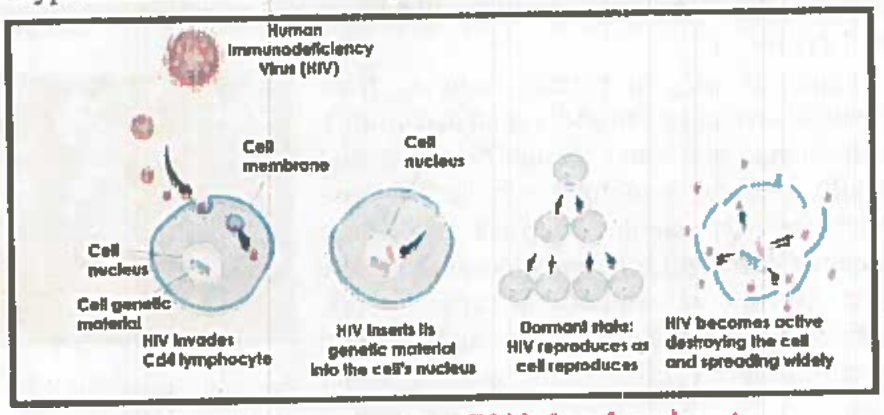


Fig:20.13 HIV invading Cd4 helper lymphocyte

These lymphocytes are part of the body's immune system, the defence system that fights infectious diseases. But as HIV destroys these lymphocytes, people with the virus begin to get serious infections that they normally wouldn't — that is, they become immune deficient. The name for this condition is acquired immunodeficiency syndrome (AIDS).

As the medical community learns more about how HIV works, they've been able to develop drugs to inhibit it (meaning they interfere with its growth). These drugs have been successful in slowing the progress of the disease, and people with the disease now live much longer. But there is still no cure for HIV and AIDS.

HIV can be transmitted from an infected person to another person through blood, semen vaginal fluids, and breast milk.

The virus is spread through high-risk behaviors including; immoral sexual behaviour, sharing needles, such as needles used to inject drugs, needles used for injecting steroids and those used for tattooing.

People who have another sexually transmitted disease, such as syphilis, genital herpes, gonorrhea, or bacterial vaginosis are at greater risk for getting HIV.

If a woman with HIV is pregnant, her newborn baby can catch the virus from her before birth, during the birth process, or from breast feeding.

Fig:20.15 Needles used in tatto art can be an agent for HIV infection.

KEY POINTS

- Reproduction guarantees the transmission of one generation's genetic material into the next generation.
- Male reproductive system consists of a pair of testes, ducts, glands, and external genitalia.
- Each testis is divided into 250 to 300 lobules. Each lobule contains one to four tightly coiled seminiferous tubules. The process of spermatogenesis takes place here in the seminiferous tubules.
- The Prostate gland produce a secretion which is a milky, slightly acidic fluid that contains citrate as a nutrient source and several enzymes.
- Cowpers' gland secretes mucus and an alkaline fluid into the urethra. The alkaline fluid neutralizes the acidity of urine in the urethra.
- The Bulbourethral glands produce thick and clear mucus. Some of the mucus drains into the urethra when a man becomes sexually excited and neutralizes traces of acidic urine in the urethra.
- Semen is a white, sticky mixture of sperm and secretions of accessory glands.
- Spermatogenesis is initiated in the male testis with the beginning of puberty. This comprises the entire development of the spermatogonia (former primordial germ cells) up to sperm cells.
- Process of spermatogenesis is controlled by hormonal secretions from hypothalamus and pituitary gland.
- Female reproductive system consists of a pair of ovaries, oviducts, uterus, cervix, and vagina.
- Within the ovary are many tiny saclike structures called ovarian follicles each of which consists of an immature egg, called an oocyte.
- Each month in adult women, one of the ripening follicles ejects its oocyte from the ovary. This event is called ovulation.
- The process of egg formation in females is called oogenesis.
- The reproductive cycle in human and other primates is called menstrual cycle.
- In female menstrual cycle ceases around 50 year of age and it is termed as menopause. Cyclic menstruation is an indicator of normal reproductive life of females.

KEY POINTS

- Most cases of female infertility are caused by problems with ovulation. Without ovulation, there are no eggs to be fertilized. Some signs that a woman is not ovulating normally include irregular or absent menstrual periods.
- IVF is the most effective types of assisted reproductive technology.
- A miscarriage is the spontaneous loss of a foetus before the 20th week of pregnancy.
- The most common symptom of gonorrhea in males is urethritis, accompanied by painful urination and discharge of pus from the penis.
- Foetuses infected with syphilis are usually stillborn or die shortly after birth.
- AIDS is caused by the human immunodeficiency virus (HIV) which destroys a CD4 helper lymphocyte. These lymphocytes are part of the body's immune system.

EXERCISE

1- Multiple Choice Questions

(i) ***Gonadotropin releasing hormone is responsible for the stimulation/release of which hormone?***

(a) LH
(b) Progesterone
(c) Secretin
(d) Insulin

(ii) ***Fertilization of the ovum normally occurs:***

(a) In the upper third of the oviduct
(b) In the uterus
(c) In the lower third of the oviduct
(d) Can take place successfully in vagina

(iii) ***The human egg is swept through the oviduct toward the uterus by***

(a) The beating of the eggs' cilia.
(b) Rhythmic contraction of the oviduct.
(c) Rhythmic contraction of the uterus.
(d) The beating of the cilia in the oviduct.

(iv) ***Embryo implants in the _____ of the uterus***

(a) Perimetrium
(b) Myometrium
(c) Endometrium
(d) Cervix

(v) ***Which will occur as a result of nondescent of the testes?***

(a) Male sex hormones will not be circulated in the body.
(b) Sperm will have no means of exit from the body.
(c) Inadequate blood supply will retard the development of the testes.
(d) Viable sperm will not be produced.

(vi) ***The corpus luteum is formed at the site of***

(a) Fertilization
(b) Ovulation
(c) Menstruation
(d) Implantation

(vii) ***Within the ovary, progesterone is produced by the***

(a) corpus albicans. (b) corpus luteum.
(c) tertiary follicles (d) primary follicles.

EXERCISE

(viii) The basic difference between spermatogenesis and oogenesis is that

(a) during spermatogenesis two more polar bodies are produced.
(b) the mature ovum is haploid while the sperm is 2n.
(c) spermatogenesis involves mitosis and meiosis, but oogenesis involves meiosis only.
(d) in oogenesis, one mature ovum is produced, and in spermatogenesis four mature sperm are produced.

(ix) The uterine layer which is shed with each monthly cycle is

(a) endometrium. (b) perimetrium.
(c) tunica albuginea. (d) myometrium.

2- Short Questions

(i) List down the functions of glands associated with the male reproductive system.
(ii) What is the role of hormones in the process of spermatogenesis.
(iii) Differentiate between the terms miscarriage and abortion.
(iv) List down control measures against HIV infection.

3- Long Questions

(i) Explain structure and function of male reproductive system.
(ii) Discuss the structure and function of female reproductive system.
(iii) Analyze hormonal control of male reproductive system.
(iv) Discuss various events of menstrual cycle.
(v) What are the causes of male and female infertility? Analyze the possible solution to this problem.

3- Initiating and Planning

- Examine the prepared slides of histology of ovary and draw its microscopic structure.
- Expose the reproductive system of a dissected frog (dissection would be done by the teacher)

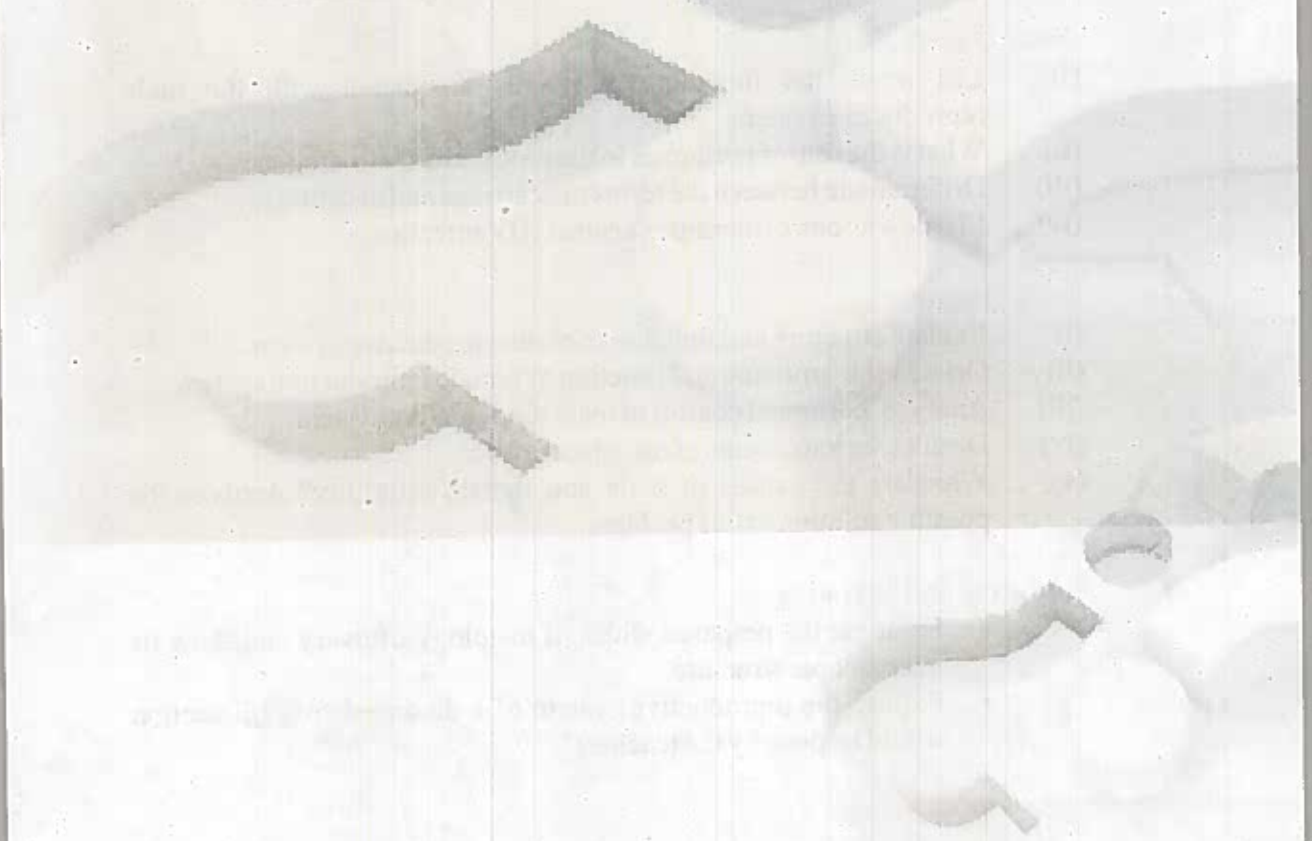
EXERCISE 2

4- Science, Technology, and Society Connections

- Realize the effect of endocrine disrupting contaminants on the reproductive abilities.
- Become aware of the ethical implications of abortion.
- List the measures that can help to prevent transmission of HIV.

5- Online Learning

- www.betterhealth.vic.gov.au
- *www.biology.clc.uc.edu/courses/bio105/reproduc.htm*
- *www.webmd.com/sex-relationships/guide/male-reproductive-system*
- www.innerbody.com



UNIT

21

DEVELOPMENT AND AGING

KEY CONCEPTS

In the course of its life an organism changes from a fertilized egg into an adult. This process of conversion from simpler to more complex form is called development. As development proceed all sort of changes take place. The most obvious change is growth. However, these positive changes become negative at some stage in the life cycle, which are termed as aging.

21.1 EMBRYONIC DEVELOPMENT

The progressive changes which are undergone before an organism acquires its adult like form constitute the embryonic development. It begins with a series of mitotic divisions in the zygote. These early divisions of the zygote are called **cleavages.**

21.1.1 Early cleavages & blastocyst formation:

Cleavage is a period of fairly rapid mitotic divisions of the zygote following fertilization. Some 36 hours after fertilization, the first cleavage division has produced two identical cells called **blastomeres.** These divide to produce four cells, then eight, and so on. As a result, a loose collection of cells that form a berry-shaped cluster of 16 or more cells called the **morula** has been formed.

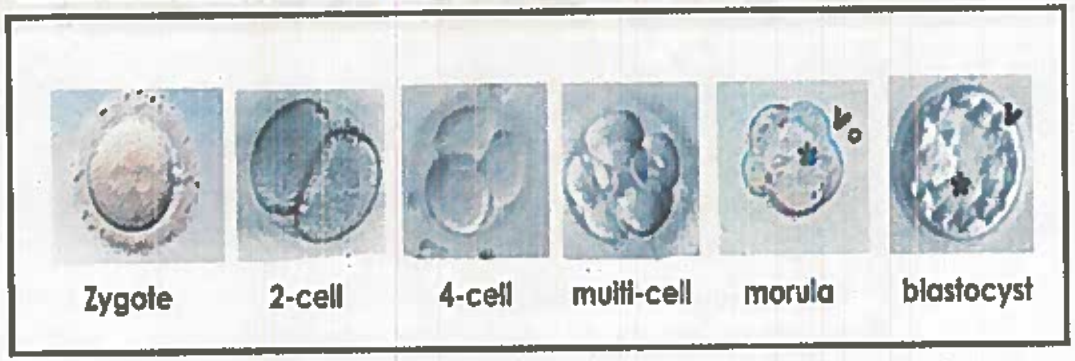


Fig: 21.1 Early cleavages & blastocyst formation.

All the while, transport of the embryo toward the uterus continues. By day 3 or 4 after fertilization, the embryo consists of about 100 cells and floats free in the uterus. By this time, it has tightened its connections between neighboring cells (a process called compaction) and begins accumulating fluid within an internal cavity. The zona pellucid the external membrane now starts to break down and the inner structure, now called a **blastocyst**, "hatches" from it. The blastocyst is a fluid-filled hollow sphere composed of a single layer of large, flattened cells called **trophoblast**

cells and a small cluster of 20 to 30 rounded cells, called the **inner cell mass**, located at one side.

Trophoblast cells begin to display L-selectin (adhesion) molecules on their surface soon after the blastocyst hatching. They also take part in placenta formation, and secrete and display several factors with immunosuppressive effects that protect the trophoblast (hence the developing embryo) from attack by the mother's cells. The inner cell mass becomes the embryonic disc, which forms the embryo proper (and the extra embryonic membranes except the chorion, a trophoblast derivative).

21.1.2 Implantation of early embryo

The extra embryonic membranes that form during the first two to three weeks of development include the amnion; yolk sac, allantois, and chorion. The amnion develops when cells of the epiblast fashion themselves into a transparent membranous sac. This sac, the amnion, becomes filled with amniotic fluid.

Later, as the embryonic disc curves to form the tubular body, the amnion curves with it. Eventually, the sac extends all the way around the embryo, broken only by the umbilical cord.

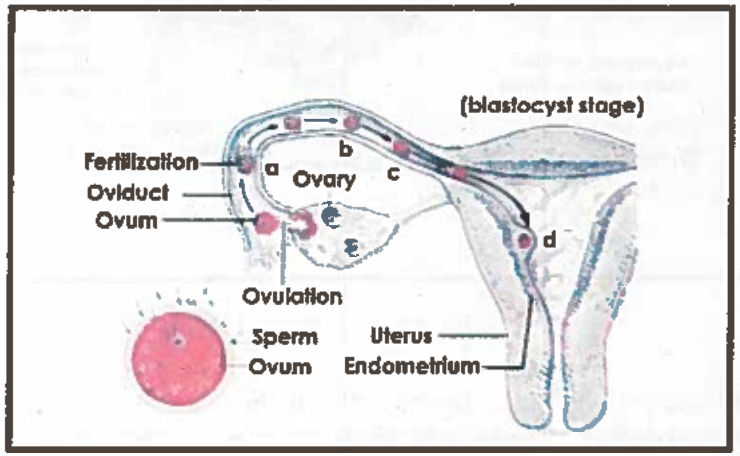


Fig: 21.2 Implantation of early embryo.

21.1.3 Gastrulation:

During week 3, the two-layered embryonic disc transforms into a three-layered embryo in which the primary germ layers—ectoderm, mesoderm, and endoderm present. This process, called gastrulation, involves cellular rearrangements and migrations.Gastrulation begins when a groove with raised edges

called the **primitive streak** appears on the dorsal surface of the embryonic disc and establishes the longitudinal axis of the embryo.

Surface (epiblast) cells of the embryonic disc then migrate medially across other cells and enter the primitive streak. The first cells to enter the groove displace the hypoblast cells of the yolk sac and form the most inferior germ layer, the endoderm. Those that follow push laterally between the cells at the upper and lower surfaces, forming the mesoderm.

The cells that remain on the embryo's dorsal surface are the ectoderm. The mesodermal cells immediately beneath the early primitive streak aggregate, forming a rod of mesodermal cells called the notochord, the first axial support of the embryo. At this point, the embryo is about 2 mm long.

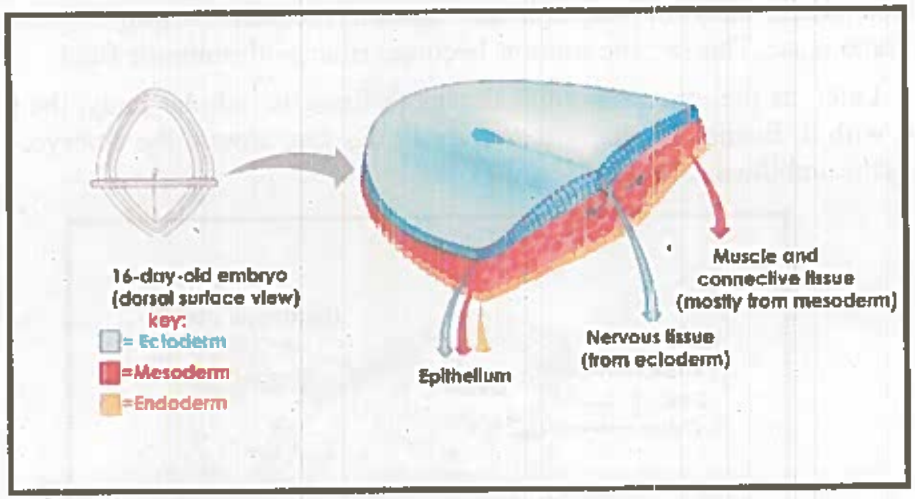


Fig: 21.3 Three germinal layers

The three primary germ layers serve as the primitive tissues from which all body organs will derive. Ectoderm fashions structures of the nervous system and the skin epidermis. Endoderm forms the epithelial linings of the digestive, respiratory, and urogenital systems, and associated glands. Mesoderm forms virtually everything else.

Gastrulation lays down the basic structural framework of the embryo and sets the stage for the rearrangements of organogenesis, formation of body organs and organ systems.

21.1.4 Neurulation:

The formation of organs and systems during embryonic development is called organogenesis. The first major event in organogenesis is neurulation, the differentiation of ectoderm that produces the brain and spinal cord.

For Your Information

By the end of the embryonic period, when the embryo is about 22 mm (slightly less than 1 inch) long from head to buttocks (referred to as the crown-rump measurement), all the adult organ systems are recognizable. It is truly amazing how much organogenesis occurs in such a short time in such a small amount of living matter.

This process is induced by chemical signals from the notochord, the rod of mesoderm that defines the body axis.

The ectoderm overlying the notochord thickens, forming the neural plate, and then starts to fold inward as a neural groove, which forms prominent neural folds as it deepens. By day 22, the superior margins of the neural folds fuse forming a neural tube. It soon pinches off and becomes covered by surface ectoderm.

The anterior end of the neural tube becomes the brain and the rest becomes the spinal cord. The associated neural crest cells migrate widely and give rise to the cranial, spinal, and sympathetic ganglia (and associated nerves), to the medulla of the adrenal gland, and to pigment cells, and contribute to some connective tissues.

By the end of the first month of development, the three primary brain vesicles (fore-, mid-, and hindbrain) are obvious. By the end of the second month, all brain flexures are evident; the cerebral hemispheres cover the top of the brain

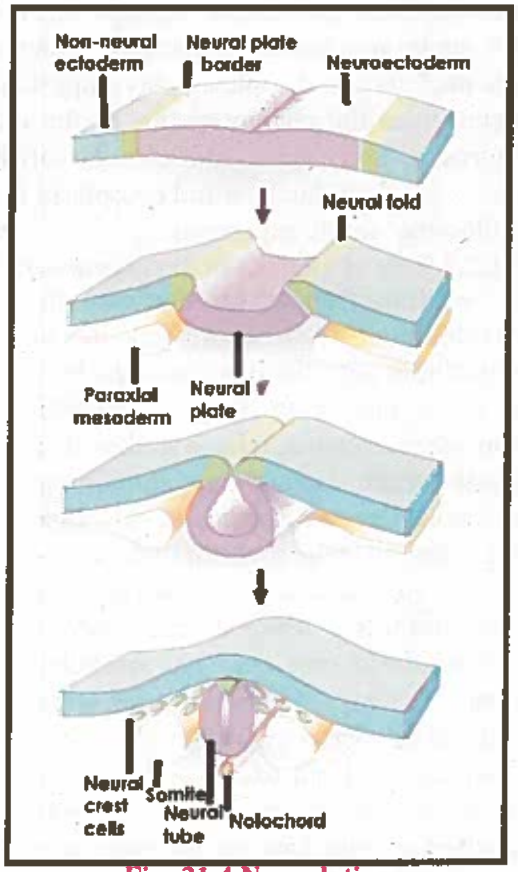


Fig: 21.4 Neurulation

stem, and brain waves can be recorded. Most of the remaining ectoderm forming the surface layer of the embryonic body differentiates into the epidermis of the skin.

21.2 CONTROL OF DEVELOPMENT

We know that every gene is present in every cell of developing embryo. Mitosis guarantees that every daughter cell of the zygote will have full set of chromosomes with all of their genes. As the development proceeds further, we find that different cells differentiate along different lines and perform different functions. For example, one enzyme produced by the cells of stomach is useful in digestion of food. Another enzyme produced in the cell of fingers and toes forms the protein keratin of the finger nails and toe nails. We are quite sure that the genes governing the production of both these enzymes are present in the cells of stomach and those of the fingers and toes. Why one kind of cells forms one sort of enzyme while the other kind of cells forms a different enzyme? The most logical answer to this question is that if the nuclei are identical in these cells then perhaps the cytoplasm may vary. Thus both the nucleus and cytoplasm play important role in normal development. The nucleus determines the characteristics of the individual, while the cytoplasm selectively "turns on" some genes and "switches off" others.

Role of nucleus and cytoplasm in development is shown with the help of the following simple experiments.

21.2.1 Role of nucleus in development

Importance of nucleus in development was expressed in a unicellular alga, the *Acetabularia*. It is 2 to 3 inches in length, inhabits European seawater. It has a stalk with a characteristic cap and base containing nucleus. The two species of this alga are different in the shape of their cap.

Acetabularia mediterranea has umbrella shaped cap, while *Acetabularia crenulata* has irregular head. The caps of both species were cut and thrown away. Their stalks were also removed but exchanged. i.e. the stalk of *Acetabularia crenulata* was grafted on the base of *Acetebularia mediterranea*

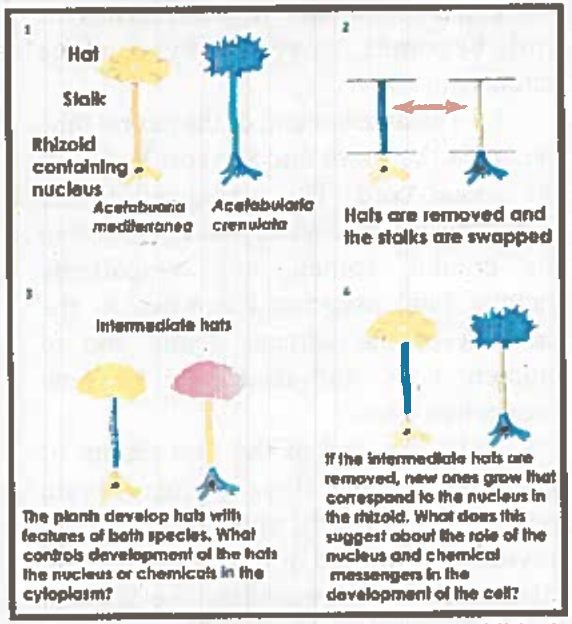


Fig: 21.5 Role of nucleus in development exhibited in *Acetabularia*

and vice versa. A whole new alga forms from the jointed pieces. It was found that the new caps regenerated according to the type of nucleus present in the base. The nucleus exerts a strong influence on the development of cap through the messenger RNA. This is the evidence for nuclear control in developmental process.

21.2.2 Role of cytoplasm:

The gray crescent is the cytoplasmic director of cell destiny. This experiment demonstrates that the cytoplasm in the crescent -shaped gray area of a fertilized frog zygote helps direct embryonic development. Normal cleavage divides the zygote through the gray crescent, so each daughter cell receives an equal share of the components in the cytoplasm. If these two cells are experimentally separated, each grows into a normal tadpole. However, if the first division is altered so it doesn't bisect the gray crescent equally, only the cell containing the gray crescent develops normally and the one lacking gray crescent develops into an undifferentiated ball of cells. It is known that different cytoplasmic components contain different morphogenetic determinant that are responsible for cell differentiation.

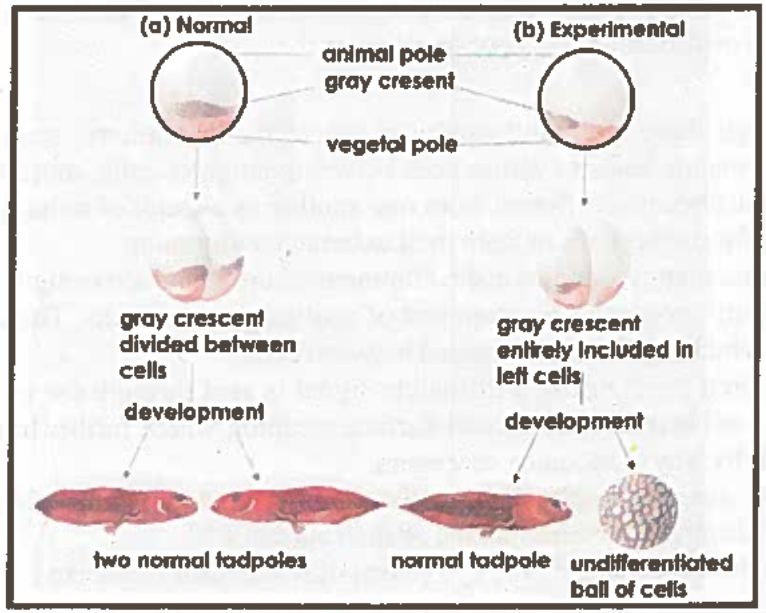


Fig: 21.6 Role of cytoplasm in development.

These determinants are present in blastomeres. For example the fertilized egg of an ascidian contains cytoplasm of four different colors that are segregated into different blastomeres.

- **Clear cytoplasm: produces larval epidermis.**
- **Yellow cytoplasm: gives rise to muscle cells**
- **Grey vegetal cytoplasm: gives rise to gut**
- **Grey equatorial cytoplasm: produces notochord and neural tube.**

23.2.3 Mechanisms of cellular determination

How do cells become different from their parent cells? How do two identical daughter cells become different from one another? How might one daughter cell become a neuron, while the other daughter cell becomes a skin cell? In some cases, determination results from the **asymmetric segregation of cellular determinants**. However, in most cases, determination is the result of **inductive signaling between cells**.

Asymmetric segregation of cellular determinants is based on the asymmetric localization of cytoplasmic molecules (usually proteins or mRNAs) within a cell before it divides. During cell division, one daughter cell receives most or all of the localized molecules, while the other daughter cell receives less (or none) of these molecules. This results in two different daughter cells, which then take on different cell fates based on differences in gene expression.

Induction:

Although there are many examples where the asymmetric segregation of cellular determinants leads to differences between daughter cells, more frequently we find that cells become different from one another as a result of inductive signals coming either from other cells or from their external environment.

There are many examples in development where an inductive signal from one group of cells influences the development of another group of cells. There are three main ways in which signals can be passed between cells.

- In the first mechanism, a diffusible signal is sent through the extracellular space, and is received by a cell-surface receptor, which further transmits the signals by way of second messengers.
- In the second mechanism, cells directly contact each other through transmembrane proteins located on their surfaces.
- In the third mechanism, the cytoplasm of two cells is connected through gap junctions, allowing the signal to pass directly from one cell to another cell. In plants, direct connections between cells are called plasmodesmata.

In the 1920s, the German zoologists Hans Spemann and Hilde Mangold discovered in an early gastrula an extremely important morphogenetic field with amazing properties. Their experiments involved dissecting a small piece of tissue from the dorsal lip of the blastopore in an early gastrula of a newt and transplanting it to the opposite side of another gastrula.

The result was the formation of a second notochord and neural tube during gastrulation and neurulation in the host embryo, and ultimately the formation of an entirely new body axis—the resulting embryo developed two bodies.

Though technically difficult because the gastrulas were only about 2 mm wide, these experiments yielded clear results because the researchers used two very closely related species of newts.

Triton taeniatus, which is pigmented, served as the tissue donor, and *Triton cristatus*, which is nonpigmented, served as the host embryo. By transplanting pigmented tissue from the donor embryo into a nonpigmented host embryo, Spemann and Mangold were able to visually track the origin of the newly developed tissue.

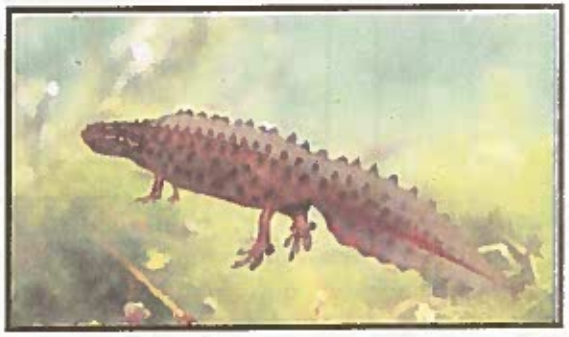


Fig: 21.7 *Triton*

The results showed that the secondary notochord and neural tube were composed in large part of host (nonpigmented) cells, with some pigmented cells remaining from the transplanted tissue. This indicated that the transplanted tissue—which they named the organizer—had induced cells in the host to differentiate into neural tissue on the transplanted side of the embryo. More recent work has shown that the organizer secretes morphogens.

21.3 HUMAN EMBRYONIC DEVELOPMENT

A normal pregnancy lasts nine months. Each three-month period of pregnancy is called a trimester. During each trimester, the fetus grows and develops.

21.3.1 Fetal development: The first trimester; week one to twelve

Soon after fertilization, the zygote travels down the fallopian tube toward the uterus. At the same time, it will begin dividing rapidly to form a cluster of cells resembling a tiny raspberry. The inner group of cells will become the embryo. The outer group of cells will become the membranes that nourish and protect it.

Implantation takes place in the fourth week of pregnancy. By the time it reaches the uterus, the rapidly dividing ball of cells — now known as a blastocyst — has separated into two sections. The inner group of cells will become the embryo. The outer group of cells will become the membranes that nourish and protect it. On contact, it will burrow into the uterine wall for nourishment. This process is called implantation. The placenta, which will nourish the foetus throughout the pregnancy, also begins to form.

The fifth week of pregnancy marks the beginning of the embryonic period. This is when the baby's brain, spinal cord, heart and other organs begin to form.

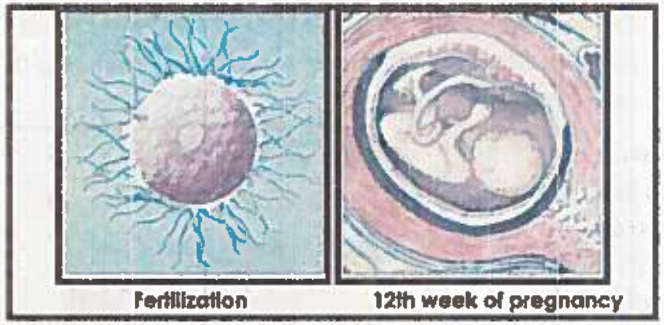


Fig: 21.8 First trimester

The embryo is now made of three layers. The top layer — the ectoderm — will give rise to the baby's outermost layer of skin, central and peripheral nervous systems, eyes, inner ear, and many connective tissues. Now baby's heart and a primitive circulatory system will form in the middle layer of cells — the mesoderm. This layer of cells will also serve as the foundation for the baby's bones, muscles, kidneys and much of the reproductive system.

Growth is rapid in coming weeks. The neural tube along fetal back is closing and heart is pumping blood. Basic facial features will begin to appear, including passageways that will make up the inner ear and arches that will contribute to the jaw. The foetal body begins to take on a C-shaped curvature. Small buds will soon become arms and legs. Tiny nostrils become visible, and the eye lenses begin to form. The arm buds now take on the shape of paddles. The arms and legs are growing longer, and fingers have begun to form.

Fig: 21. 9

For Your Information

Ectopic pregnancy: A pregnancy in which the embryo implants in any site other than the uterus; most often the site is a uterine tube (tubal pregnancy). Since the uterine tube (as well as most other ectopic sites) is unable to establish a placenta or accommodate growth, the uterine tube ruptures unless the condition is diagnosed early, or the pregnancy spontaneously aborts.

The external parts of the baby's ears also are forming, and eyes are visible. The upper lip and nose have been formed. The trunk of body is beginning to straighten. To the end of first trimester the embryo can be now technically described as a foetus. Foetus is developing fingernails and face now has a human profile.

Fig: 21. 10

21.3.2 Foetal development: The second trimester

During the second trimester, the foetal sex becomes apparent and possibly identified during an ultrasound. In the second trimester uterus and ovaries are in place for a girl and the testes are beginning to descend for a boy. The foetal ears begin to stand out at the side of the head and the nerve endings from the brain connect to the ears allowing the foetus to hear. The head is about half of the overall size of the fetus. The foetus grows rapidly during the fifth month and internal organs continue to mature. Foetal muscle and body fat is being stored under the skin and body hair starts to appear. Fingers have developed fingerprints that are unique to every individual.

23.3.3 Foetal development: The third trimester

Final weight gain takes place, which is the most weight gain throughout the pregnancy. The foetus will be growing the most rapidly during this stage, gaining up to 28 g per day. The foetus begins to move regularly, and is felt by the woman. Movement of the foetus becomes stronger and more frequent and via improved brain, eye, and muscle function the foetus is prepared for ex utero viability. There is head engagement in the third trimester, that is, the foetal head descends into the pelvic cavity.

Forty weeks into pregnancy, or 38 weeks after conception, baby might be about 18 to 20 inches long and weighs 6 to 9 pounds, however, that healthy babies born in different sizes. It's just as normal to deliver a baby a week or two late — or early — as it is to deliver on due date.

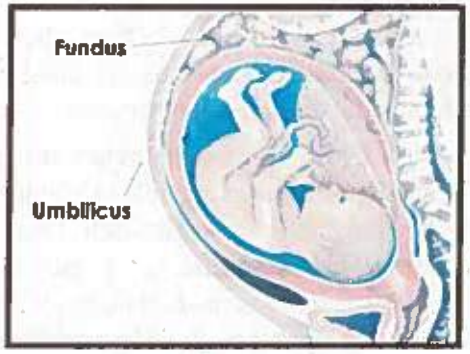


Fig: 21. 11

21.3.4 Twins and quadruplets

Apregnancy of two or more foetuses is called a multiple fetuses. Multiple fetuses can be the same (identical) or different (fraternal). Identical twins or triplets come from a single egg that has been fertilized by one sperm. For unknown reasons, the fertilized egg splits into two or more embryos during the first stage of development. Fraternal multiples come from multiple fertilized eggs.

Some identical multiples share the same placenta. However, they usually grow within separate amniotic sacs in the uterus. In rare cases, identical multiples share one amniotic sac. Fraternal foetuses have separate placentas and amniotic sacs.

Fig: 21. 12 Multiple pregnancy resulting in quadruplets.

23.3.5 Placentation:

Some cells of the embryo grow into a disk like structure called placenta. The placenta closely attached to the embryo by a tube called umbilical cord. The umbilical cord connects the embryo to the placenta. The blood vessels of the placenta are close to those of uterus so that oxygen, glucose, amino acids and salts can pass from the mother's blood to the embryo's blood. In a similar way carbon dioxide and urea in the embryo's blood escape in the placenta and are carried away by mother's blood in uterus.

The placenta can prevent some harmful substances in the mother's blood from reaching the embryo. It also produces hormones like estrogen and progesterone which helps in maintaining the pregnancy and prepare the mother for delivery. It also helps in the periodic contractions of uterus during delivery.

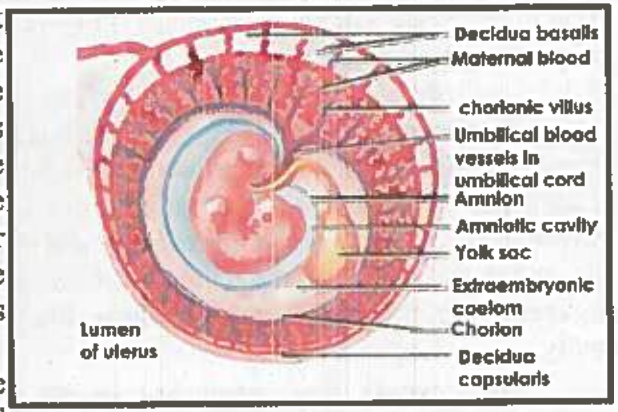


Fig: 21. 13 Placenta attached to the embryo by a tube called umbilical cord.

A few weeks before the birth, the head of the fetus is turned down in the uterus, just above the cervix. Childbirth begins when the muscular layers of uterus start to contract and relax. These actions are felt as labour pains. Opening of the cervix widens enough to let the baby head pass through. Head of the baby acts as a wedge to, assist cervical dilation. The amniotic sac breaks at some stage in labour and the fluid escapes. Finally the baby is pushed through the vagina (now called birth canal) into the outer world and birth occurs .The umbilical cord is cut and tied. After the birth of baby, contraction of uterus continues during which the placenta is expelled.The sudden fall in temperature felt by the newly born baby stimulate it to take its first breath and thus usually cries. In a few days, the remains of the umbilical cord attached to the baby's abdomen shrivel and fall away, leaving a scar in the abdominal wall, called the navel.

Lactation

The newborn baby is supplied with maternal milk soon after its birth. The mammary glands of the mother are especially prepared during the period of pregnancy under well-defined hormonal control. The secretory ducts within the mammary glands branch further and undergo enormous development and start producing milk by the end of the pregnancy.

The milk produced initially by the mammary glands contains special lymph like fluid known as colostrum which is quite rich in antibodies. Usually, the baby is fed on the maternal milk for upto two years. However, depending upon the general health condition of the mother as well as other physiological conditions, maternal milk may not be available for so long.

The baby is then fed on other sources of milk. As soon as the mother stops feeding the baby, her reproductive cycle begins again. However, sometimes the reproductive cycles can initiate even when the mother is breast feeding.

21.4.4 Breast Feeding Vs Bottle Feeding: There are advantages and disadvantages to both breastfeeding and bottle-feeding.

Advantages of Breast feeding:

- Breast milk has perfect balance of nutrient.
- It is easily digested and absorbed.
- Breast milk is always at perfect temperature.
- Milk is readily available at any time and any place.

Advantage of Bottle feeding

- The only advantage is anyone can feed the baby. Presence of mother is not necessary.

Disadvantages of Bottle feeding

- It can create unhygienic circumstances for the baby.
- It is vulnerable to carry various types of infections.
- It can cause indigestion and several stomach disorders.
- Not as efficiently utilized as breast milk.
- Some babies have difficulty in utilizing certain nutrients of the bottle milk.
- Bottle fed babies also have the risk of developing an allergy to a particular formula. When a baby develops an allergy to formula, he or she may have symptoms that include irritability, crying after feedings, nausea, vomiting, diarrhea, or a skin rash.

21.5 DISORDERS DURING EMBRYONIC DEVELOPMENT

21.5.1 Rubella: **Rubella**, commonly known as **German measles**, is a disease caused by the rubella virus. Rubella virus during pregnancy can be serious; if the

mother is infectedwithin the first 20 weeks of pregnancy, the child may be born with congenital rubella syndrome (CRS). The syndrome (CRS) follows intrauterine infection by Rubella virus and comprises cardiac, cerebral, ophthalmic and auditory defects. It may also cause prematurity, low birth weight, anaemia and hepatitis

Fig: 21. 14 Rubella virus

21.5.2 Abnormal neural tube:

Neural tube defects (NTDs) are serious birth defects with symptoms that range from mild to severe impairment. They are caused by incomplete development of the brain, spinal cord and/or their protective coverings. This occurs when the foetus' spine fails to close properly during the early stages of pregnancy.

21.5.3 Thyroid gland:

In newborn infants with congenital hypothyroidism frequently have hyperbilirubinemia, and delayed skeletal maturation, reflecting immaturity of liver and bone, respectively, and they are at risk of permanent mental retardation if thyroid hormone therapy is delayed or inadequate; their size at birth, however, is normal.

21.5.4 Limb abnormalities:

The upper and lower limbs have a large number of different genetic and environment derived abnormalities, some of which can be surgically repaired. Among them partial or complete absence of limbs or digits are common.

21.5.5 Genetic abnormalities related to spontaneous abortions:

Approximately 50% of first trimester miscarriages are due to a chromosome abnormality in the fetus. An extra chromosome or a missing chromosome can cause miscarriage, usually in the first or second trimester of pregnancy, or can lead to a child with learning difficulties or mental retardation and birth defects. Chromosome abnormalities involving a missing or extra chromosome are not inherited or caused by an exposure during pregnancy. Instead, they result from a chance mistake in cell division soon after the time of conception. This error is a random event that can occur in anyone's pregnancy.

An inherited problem with the chromosomes can also cause miscarriage. A parent can have a rearrangement (a "translocation") of his or her chromosomes, in which the chromosomes are structured differently. Another genetic cause of miscarriage is a change in a single gene or several genes on the chromosomes. This can cause specific genetic diseases or birth defects.

Foetal surgery and detected foetal developmental problems

Recent developments and improvements in prenatal diagnostic methods, and in particular ultrasonography, have made detection of fetal abnormalities possible. Most defects are best treated after birth, only a few disorders are potentially treated surgically inside the mother body. Prerequisites for foetal surgery include the selection of those fetuses who might benefit from intrauterine treatment, counselling of the family concerned, and a highly experienced multidisciplinary team including a perinatal obstetrician, an ultrasonographer, a pediatric surgeon and a neonatologist. In human beings intrauterine treatment has been performed in erythroblastosis foetalis, urinary tract obstruction with encouraging results.

21.6 POSTNATAL DEVELOPMENT

21.6.1 Allometric growth:

The term means differential growth and refers to developmental patterns of growth which are not uniform, that is, not all parts of the organism develop at the same rate. An example of allometry is leg length in humans. The foetal and newborn baby has short, chubby, and ineffectual legs. The proportion of leg length to body length is low. About half of the adult height is accounted for by leg length. Obviously, legs acquire length disproportionately compared with body length.

21.7 AGING

Usually aging refers to the physiologic changes that occur in all individuals due to age. The sequence of the changes is consistent among all people, the rate, however, can differ greatly. Both genetics and environment impact age-related changes. Siblings with the same genetic background can have marked differences in longevity due to environmental factors or secondary aging. The causes of secondary aging may be preventable.

21.7.1 Process of Aging:

Aging is a progressive physiological process that is characterised by degeneration of organ systems and tissues with consequent loss of functional reserve of these systems. Loss of these functional reserves impairs an individual's ability to cope with physiological challenges such as anaesthesia and surgery.

Fig: 21. 15 Aging is a natural process.

Individuals of the same chronological age may differ significantly in the rate and severity of functional decline. Persons who maintain greater than average functional capacity are considered 'physiologically young' and those whose function declines at an earlier age appear to be 'physiologically old'.

21.7.2 Signs and symptoms:

There are many different signs and symptoms of aging. Most of these develop gradually and are very diverse, but it should be remembered that it is not possible to diagnose aging based on isolated signs and symptoms alone. Different people possess widely varying degrees of these signs and symptoms. Some of these include:

- An overall decrease in energy and vigour
- Changes in sleeping patterns
- Decreased memory
- Skin and hair changes such as wrinkles, brown spots on the skin, loss of skin elasticity, and hair loss
- A loss or decrease in vision and hearing
- Sexual dysfunction
- Urinary problems such as incontinence, dribbling, and changes in frequency of urination
- Changes in menstrual cycle
- Abdominal obesity and inability to lose weight

Secondary aging processes result from disease and poor health practices (e.g. no exercise, smoking, excess fat and other forms of self-damage) and are often preventable, whether through lifestyle choice or modern medicine.

Stop smoking it even leads to early aging process.

21.7.3 Cell level changes in aging:

All cells change as they age. Cells become larger. Their capacity to divide and reproduce tends to decrease. Normal cells have built-in mechanisms to repair minor damage, but the ability to repair declines in aging cells.

DNA is damaged through the aging process and changes occur:

- in cellular membranes;
- in enzymes;
- in the transport of ions and nutrients;
- in the nucleus chromosomes undergo such changes as clumping, shrinkage, and fragmentation.

Other changes occur in such organelles as the mitochondria and lysosomes where numbers are reduced, causing cells to function less efficiently. This effect also ties in with a decrease in hormonal secretions.

A decrease in metabolism has several effects:

- toleration of cold is less;
- a tendency to gain weight increases;
- there is a decreased efficiency in the body's use of glucose.
- Collagen and elastin decrease in connective tissue formation
- Lipid and fat content of tissues change.
- The total amount of water in the body gradually decreases

21.7.4 System level changes in aging:

The GI tract in general maintains its functional level well into old age. There are three areas that are the exceptions: altered taste decreased stomach acid and decreased blood flow to the liver. In the mouth, there is a decrease in saliva which affects chewing and swallowing. Also, altered taste makes food less palatable.

Osteopenia and osteoporosis both deal with bone loss; the difference is the degree of loss. Between the ages of 30 and 40, men and women start to lose bone mass and enter a condition called osteopenia, a decreased or lower mineral content of the bone. Osteoporosis then is a greater degree of osteopenia and involves both a decrease in bone minerals and a decrease in bone matrix.

Usual aging is accompanied by a lower production of neurotransmitters, but only when the drop approaches 50% will dementia ensure. About 15% of the elderly have severe dementia.

The heart of an elderly person could be smaller than normal due to malnutrition, larger than normal due to severe high blood pressure, or unchanged in size. Usual aging causes the left ventricular wall to thicken and the diameter and length of the aorta, a major artery leaving the heart, to increase. Fat will accumulate in the heart muscle as a response an increase in total body fat.

Infections occur more frequently in the elderly and are more often severe due to low degree working of immune system.

KEY POINTS

- An organism changes from a fertilized egg into an adult. The progressive changes which are undergone before an organism acquires its adult like form constitute the embryonic development.
- Early divisions of the zygote are called **cleavages**.
- The extraembryonic membranes that form during the first two to three weeks of development include the amnion; yolk sac, allantois, and chorion.
- During week 3, the two-layered embryonic disc transforms into a three-layered embryo in which the primary germ layers—ectoderm, mesoderm, and endoderm present. This process, called gastrulation, involves cellular rearrangements and migrations.
- The formation of organs and systems during embryonic development is called organogenesis.
- The first major event in organogenesis is neurulation, the differentiation of ectoderm that produces the brain and spinal cord.
- Every gene is present in every cell of developing embryo.
- The nucleus determines the characteristics of the individual, while the cytoplasm selectively "turns on" some genes and "switches off" others.
- A normal pregnancy lasts nine months.
- Each three-month period of pregnancy is called a trimester. During each trimester, the foetus grows and develops.
- Implantation takes place in the fourth week of pregnancy.
- A pregnancy of two or more foetuses is called a multiple pregnancy.
- Multiple fetuses can be the same (identical) or different (fraternal). Identical twins or triplets come from a single egg that has been fertilized by one sperm.
- The placenta is closely attached to the embryo by a tube called umbilical cord. The umbilical cord connects the embryo to the placenta.
- Rubella virus during pregnancy can be serious; if the mother is infected within the first 20 weeks of pregnancy.
- Allometric growth means differential growth and it refers to developmental patterns of growth which are not uniform. An example of allometry is leg length in humans.
- Aging is a progressive physiological process that is characterised by degeneration of organ systems and tissues with consequent loss of functional reserve of these systems.

EXERCISE

1. Multiple Choice questions

i. ***The protective coat which surrounds the embryo is known as:***

(a) amnion (b) chorion
(c) allantosis (d) chorio allantoic

ii. ***The outer layer of the blastocyst, which later attaches to the uterus, is the***

(a) Deciduas (b) Trophoblast
(c) Amnion (d) inner cell mass

iii. ***Identical twins result from the fertilization of;***

(a) one ovum by one sperm (b) one ovum by two sperms
(c) two ova by two sperms (d) two ova by one sperm

iv. ***The most important hormone in initiating and maintaining lactation after birth is;***

(a) estrogen (b) FSH
(c) Prolactin (d) Oxytocin

2. Short questions

i. The life span of the ovarian corpus luteum is extended for nearly three months after implantation, but otherwise it deteriorates.
(a) Why this is so.
(b) Why it is important that the corpus luteum remain functional following implantation.

ii. What factors are believed to bring about uterine contractions at the termination of pregnancy?

iii. The placenta is a marvelous, but temporary, organ. How it is an intimate part of both fetal and maternal anatomy and physiology during the gestation period?

iv. What is importance of cleavage?

3. Long Questions

i. Describe the process of early cleavage and blastocyst formation.

ii. Explain the role of nucleus in the control of development by demonstrating the work of Hammerling.

iii. Give a brief over view of the work done by Hans Spemann in the discovery of embryonic induction.

EXERCISE

iv. Discuss the major events of human embryonic development during first trimester.

v. Elaborate the role of feotal and maternal hormones initiating labour pain and culminating in the birth of baby.

4. **Analyzing and Interpreting**
   - Identify the group of vertebrates through diagrams of different blastula.
   - Identify the different stages in chick development through observation of prepared slides.
   - Using the knowledge of about the postnatal growth of brain and jaws; interpret why a six month old baby have the same jaw skull proportions as it had at the time of birth.

5. **Initiating and Planning**
   - Explain why proper nourishment of the mother is imperative during the third trimester of pregnancy.
   - Why oxytocin is involved in the secretion of milk, hypothesize why new mothers often experience cramps in uterus while nursing.

6. **Communication**
   - Draw a table to list the events of human development in the first, second and third trimester.

7. **Science, Technology, and Society Connections**
   - Draw how a blastula is divided into two (by using micromanipulator) to produce twins of animals for biological research.
   - Rationalize that nursing is an important bonding time between mother and child, as it provides the child with protection by mother's immune system while its own develops.
   - List some of the diseases due to aging and what medical science is doing to treat these diseases.

8. **Online Learning**
   - www.nchd.org.pk
   - www.hdf.com
   - www.embryocd.ch
   - www.embryo.chronolab.com
   - www.med.uc.edu/embryology

UNIT

22

INHERITANCE

KEY CONCEPTS

The capacity to reproduce is one of the fundamental characteristic of living organisms. It results in the formation of offspring which resembles the parental generation. This tendency of individuals to resemble their parents is known as **heredity**. The resemblance, however is not complete, offspring differ from each other and their parents in many respects. These differences are known as **variations**. Heredity and variations play a significant role in the formation of new species. The science which deals with mechanism of the heredity and variation is called **genetics**. Since the heredity and variation characteristics are controlled by genes, so the term genetics is also referred to the study of genes.

22.1 MENDEL'S LAWS OF INHERITANCE

The science of genetics originated in the year 1900 with the rediscovery of an article originally published in 1866 by an Augustinian monk named Gregor John Mendel. Early philosophers, thinkers and workers had also put forward speculations and theories to explain the mechanism of inheritance but they had not been succeeded in their efforts. Mendel was the first who successfully explained the mechanism of inheritance during his research work on pea plant.

22.1.1 Gregor John Mendel & his work:

Mendel was the pioneer of classical geneticists. Gregor Mendel (1822-1884) was an Austrian monk and is popularly known as the 'Father of genetics'. His experimental work became the basis of modern heredity theory. Mendel was born on July 22, 1822 in Czech Republic. He entered the Augustinian monastery at Brunn, Czech Republic and become actively engaged in investigating variation, heredity and evolution in plants.

Fig: 22.1 Gregor Mendel (1822-1884)

Between 1856 and 1863 he cultivated and tested at least 28,000 pea plants carefully analyzing seven pairs of seed and plant characteristics. He delivered his first lecture on pea experiments in the year 1865 and published his paper 'Experiments on plants hybridization' in the year 1866. His experiments resulted in the formation of the laws of heredity or Mendel's laws. Unfortunately his work made no impression for the next 34 years. Later on in 1900 his work was recognized by three investigators, a Dutch botanist Hugo de Vries, De Correns of Germany and Tschmarck of Austria. He died in Brunn on January 6, 1884.

The reasons why Mendel's work was neglected during his time are as follows:

- The biologists were preoccupied with Darwin's theory of evolution which appeared in the year 1859.

- The journal in which Mendel's work was published was not recognised.
- The scientists of early times were not familiar with the statistical analysis of experimental data.

22.1.2 Mendel's Experiment:

Mendel was very careful about the selection of the plant for his hybridization experiments. He selected the garden pea (*Pisum sativum*) as experimental plant because of the following reasons:

- The plant was easy to grow in pots or in open ground.
- It had a short life cycle.
- The plant has self-pollinating flowers.
- Cross-pollination was also possible.
- The plant possesses distinct contrasting heritable characters.
- Mendel chose seven pairs of characters for his study which is summarized in following table.

Table: 22.1 Seven pairs of contrasting characters in pea plant.

Character	Dominant Trait	Recessive Trait	Character	Dominant Trait	Recessive Trait
Seed Shape	Spherical	Wrinkled	Flower position	Axial	Terminal
Seed colour	Yellow	Green	Stem height	Tall	Dwarf
Flower colour	Purple	White			
Pod shape	Inflated	Constricted			
Pod colour	Green	Yellow			

22.1.3 Inheritance of single trait:

One of the reasons of Mendel's success was that he confined to the study of limited traits in pea. In his hybridization (crosses) experiments, first he studied the inheritance of single trait, and then added in his study more traits one by one.

A cross between two individuals that differ with one particular trait is called monohybrid cross. For example, Mendel crossed a true bred round seed shape plant with true bred wrinkled seed shape plant. Such plants are referred as first parental generation (P_1). In first filial generation (F_1) he observed all the offspring with round seed shape.

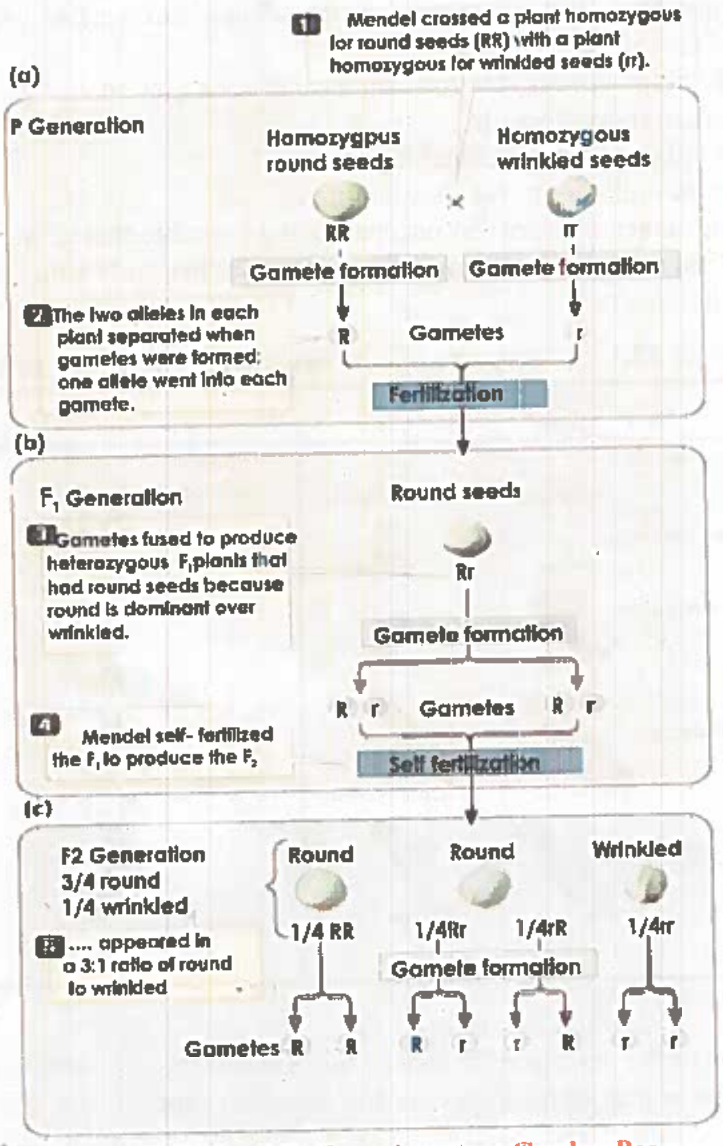


Fig: 22.2 Mendel's Experiment on Garden Pea.

He supposed round seed shape as dominant trait. Next, he allowed the hybrids of F_1 generation to be self-fertilized. In F_2 generation he noticed that both the parental characters appeared. The character that appeared in F_1 was called the dominant character, while hidden character that made its appearance in F_2 was known as the recessive character. The dominant character (in this case round) expressed in approximately 75% offspring whereas recessive (wrinkled in this case) appeared in only 25% of the offspring. He also noticed that the dominant character remained the same even when he conducted reciprocal cross. He tested each of the seven pairs of contrasting characters (given in the table) for the phenomenon of dominance and recessiveness. Mendel observed that the recessive character appeared in the F_2 offsprings in an average ratio of 3:1.

Mendel's predictions:

The science of cytology was in its primitive state during Mendel's time. However, Mendel visualized the cause of inheritance as factors or elements, which were later named as genes by Johannsen in 1909. According to Mendel, each male and female parent contains a pair of factors and each parent passed only one factor of a pair to their offspring. He also predicted that each factor retained its individuality from generation to generation. The factors contributed united randomly to produce the characters of the hybrid. Thus, he indirectly predicted the reduction in chromosome number during gametogenesis and the physical hereditary mechanism.

22.1.4 Mendel's Principles of Inheritance

Mendel did not publish any law as erroneously described in the various books. The rediscoverers of Mendel's work were responsible for our understanding of Mendel's principles. They left that Mendel's work could be represented by laws of heredity. These laws are the law of dominance, law of segregation and the law of independent assortment.

Symbols Used to Represent Mendel's Laws:

According to the classical method of symbolism, the dominant allele is represented by the capital letter while the recessive allele by the small letter. Thus tallness will be represented as 'TT' and recessive character by 'tt'. In the modified method, according to the abnormal recessive allele the symbol is chosen. For example the condition of albinism is characterized by the lack of melanin pigment in the skin, hair, eyes etc. this condition is a rare condition caused by the recessive allele in homozygous condition. The symbol in this case is 'a' for recessive allele and 'A' for the normal allele.

Another method is followed in wild plant bacteria and viruses. When out of two phenotypes, one is more common in the population than its alternative form, it is referred to as the wild phenotype. The rare form is called the mutant phenotype. The symbol "+" is used to indicate the normal allele for wild type and the base letter is borrowed from the name of the mutant type.

Law of Dominance

According to the law of dominance, different characters are controlled by units called factors; factors occur in pairs, of a pair, one factor dominates the other.

Law of Segregation

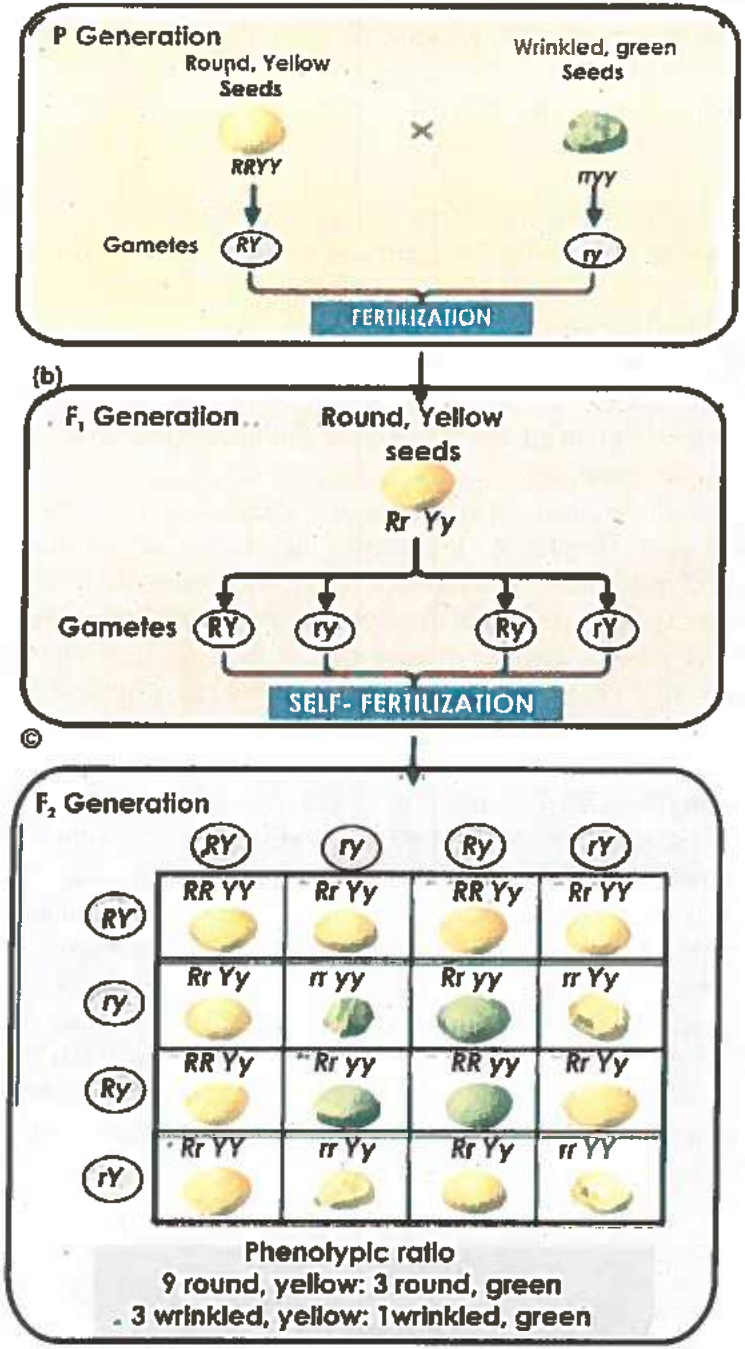
According to the law of segregation or law of purity of gametes, in a heterzygote the dominant and recessive allele remain together without mixing with each other. The alleles separate or segregate from each other during gametogenesis, so that each gamete receives only one allele, either dominant or recessive. During his experiments, Mendel encountered some traits that did not follow the law he had encountered. These traits did not appear independently but always together with at least one other trait. Mendel could not explain what happened and chose not to mention it in his work. Today, it is understood that these traits are because of alleles located on the same chromosome.

22.1.5 Inheritance of two traits:

A dihybrid cross describes a mating experiment between two organisms that are particularly different for two traits. The offspring of such cross is called dihybrid which is heterozygous at two different genetic loci. After understanding the inheritance of single trait, next Mendel decided to study inheritance of two traits simultaneously. For this purpose he performed dihybrid crosses on pea plants and discovered a fundamental law of genetics called the Law of Independent Assortment. Mendel began his experiments by first crossing two homozygous parental organisms that differed with respect to two traits. An organism that is homozygous for a specific trait carries two identical alleles at a particular genetic locus.

Mendel chose to cross a pea plant that was homozygous and dominant for round (RR), yellow (YY) seeds with a pea plant that was homozygous and recessive for wrinkled (rr), green (yy) seeds, represented as RRYY x rryy

The offspring of the RRYY x rryy cross, which is called the F1 generation, were all heterozygous plants with round, yellow seeds and the genotype RrYy. Next, Mendel crossed two plants from the F1 generation. This step is represented as RrYy x RrYy


P Generation
Round, Yellow Seeds
Wrinkled, green Seeds
RRYY
rryy
Gametes
RY
ry
FERTILIZATION
(b)
F1 Generation
Round, Yellow seeds
Rr Yy
Gametes
RY
ry
Ry
rY
SELF- FERTILIZATION
©
F2 Generation
RY
ry
Ry
rY
RR YY
Rr Yy
RR Yy
Rr YY
Rr Yy
rr yy
Rr yy
rr Yy
RR Yy
Rr yy
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Rr Yy
Rr YY
rr Yy
Rr Yy
rr YY
Phenotypic ratio
9 round, yellow: 3 round, green
3 wrinkled, yellow: 1wrinkled, green

Mendel observed that the F2 progeny of his dihybrid cross had a 9:3:3:1 ratio and produced nine plants with round, yellow seeds, three plants with round, green seeds, three plants with wrinkled, yellow seeds and one plant with wrinkled, green seeds.

Conclusion:

From his experiment, Mendel concluded that the pairs of traits in the parental generation assorted independently from one another, from one generation to the next.

22.1.6 Law of Independent Assortment:

The law of Independent Assortment states that two pairs of contrasting traits when followed in a cross, the alleles of one pair assort independently with the alleles of other pair. It implies that alleles of one gene pair have equal probability to with any of the allele of other gene pair.

Independent assortment of genes and their corresponding traits was first observed by Gregor Mendel in 1865 during his studies of genetics in pea plants. Mendel was performing dihybrid crosses, which are crosses between organisms that differ with regard to two traits. He discovered that the combinations of traits in the offspring of his crosses did not always match the combinations of traits in the parental organisms. From his data, he formulated the Principle of Independent Assortment.

We now know that this independent assortment of genes occurs during meiosis in eukaryotes. Meiosis is a type of cell division that reduces the number of chromosomes in a parent cell by half to produce four reproductive cells called gametes. In humans, diploid cells contain 46 chromosomes, with 23 chromosomes inherited from the mother and a second similar set of 23 chromosomes inherited from the father. Pairs of similar chromosomes are called homologous chromosomes. During meiosis, the pairs of homologous chromosome are divided in half to form haploid cells, and this separation, or assortment, of homologous chromosomes is random. This means that all of the maternal chromosomes will not be separated into one cell, while the all paternal chromosomes are separated into another. Instead, after meiosis occurs, each haploid cell contains a mixture of genes from the organism's mother and father.

22.1.7 Scope of independent assortment in variation:

Another feature of independent assortment is recombination. Recombination occurs during meiosis and is a process that breaks and recombines pieces of DNA to produce new combinations of genes. Recombination scrambles pieces of maternal and paternal genes, which ensures that genes assort independently from one another. It is important to note that there is an exception to the law of independent assortment for genes that are located very close to one another on the same chromosome because of genetic linkage

22.1.8 Statistics and Probability Relevant to Genetics

Two basic rules of probability are helpful in solving genetics problems: the rule of multiplication and the rule of addition.

Rule of multiplication (Product rule):

Rule of multiplication is that the probability that independent events will occur simultaneously is the product of their individual probabilities. For example:

Question:

In a Mendelian cross between pea plants that are heterozygous for flower colour (*Pp*), what is the probability that the offspring will be homozygous recessive?

Answer:

- Probability that an egg from the F_1 (*Pp*) will receive a *p* allele = 1/2.
- Probability that a sperm from the F_1 will receive a *p* allele = 1/2.
- The overall probability that two recessive alleles will unite, one from the egg ***and*** one from the sperm, simultaneously, at fertilization is: 1/2 X 1/2 = 1/4.

Rule of addition (Sum rule):

Rule of addition is that the probability of an event that can occur in two or more independent ways is the sum of the separate probabilities of the different ways. For example:

Question:

In a Mendelian cross between pea plants that are heterozygous for flower colour (*Pp*), what is the probability of the offspring being a heterozygote?

Answer:

- There are two ways in which a heterozygote may be produced: the dominant allele (*P*) may be in the egg and the recessive allele (*p*) in the sperm, ***or*** the dominant allele may be in the sperm and the recessive in the egg. Consequently, the probability that the offspring will be heterozygous is the sum of the probabilities of those two possible ways:
- Probability that the dominant allele will be in the egg with the recessive in the sperm is 1/2 X 1/2 = 1/4.
- Probability that the dominant allele will be in the sperm and the recessive in the egg is 1/2 X 1/2 = 1/4.

- Therefore, the probability that a heterozygous offspring will be produced is 1/4 + 1/4 = 1/2.

The Statistical Nature of Inheritance

- If a seed is planted from the F_2 generation of a monohybrid cross, we cannot predict with certainty that the plant will grow to produce white flower (*pp*).
- We can say that there is a 1/4 chance that the plant will have white flowers.
- Stated in statistical terms: among a large sample of F_2 plants, approximately 25% will have white flowers.
- The larger the sample size, the more likely it will be that the percentage of the results will approximate the prediction.

Statistics and Probability

Probability (p) is the chance that an event will occur. Probability equals the case (a) divided by the total number of cases (n) or p = a/n, assuming all cases are equally likely events.

- p for heads? heads/heads plus tails. 1/2
- p for tails? tails/heads and tails. 1/2
- p for heads or tails? 1/2 + 1/2 = 1
- p for heads and tails? These are mutally exclusive. But heads and then tails is possible. 1/2 X 1/2 = 1/4
- **The sum rule:** if ***either/or*** then add the probabilities.
- Die: What is the probability that the die will fall on either 1 or 2 spots? = 1/6 + 1/6.
- **Product rule:** the ***and*** rule, multiply the probabilities.
- What is the probability that die will fall on 1 and next throw, 2? 1/6 X 1/6.

22.2 EXCEPTIONS TO MENDELIAN INHERITANCE

Since Mendel's time, our knowledge of the mechanisms of genetic inheritance has grown immensely. For instance, it is now understood that in how many different ways, alleles interact with their contrasting partner alleles at the same locus. These relationships between the contrasting alleles at the same locus in heterozygous state are called dominance relations. Although Mendel had observed only one form of dominance relation (complete dominance) but later on many geneticists became able to explain several exception to the Mendelian inheritance that could not be explained on the basis of complete dominance. These exceptions are said to have non-Mendelian inheritance patterns. Overall, dominance relations are of following types:

- Complete dominance
- Incomplete dominance

- Co-dominance
- Over dominance

22.2.1 Complete dominance:

When one allele (R) completely dominates the other (r) in heterozygous state is called complete dominance. In this case the heterozygotes (Rr) have the same phenotype as the homozygotes (RR) have. The contrasting pair of alleles for all the seven characters chosen by Mendel showed complete dominance.

22.2.2 Incomplete dominance:

When neither of the two alleles expresses independently in heterozygous state, rather a blend of expression of both alleles is appeared is called incomplete dominance. In 1899 Carl Correns was working on a flowering plant named 4 O'clock. When he crossed a true breeding red flowered plant with a true breeding white flowered 4 O'clock, all the F_1 hybrids had pink flowers. This novel phenotype had a shade intermediate between those of the parents due to an intermediate amount of pigment in petals. When Correns self-fertilized F_1 pink, the F_2 showed all three phenotypes of flower in the ratio of 1 red : 2 pink : 1 white. Red was homozygous for red alleles. and white was homozygous for white alleles. But when allele for red and allele for white were present together in the same plant. neither of them masked the effect of other, rather these alleles showed incomplete dominance in the form of pink colour. As there is no truly dominant allele, the usual capital and small letter distinction for dominant and recessive trait is not necessary. Both the alleles are represented by the same letter "R" but are numbered differently to distinguish white from red.

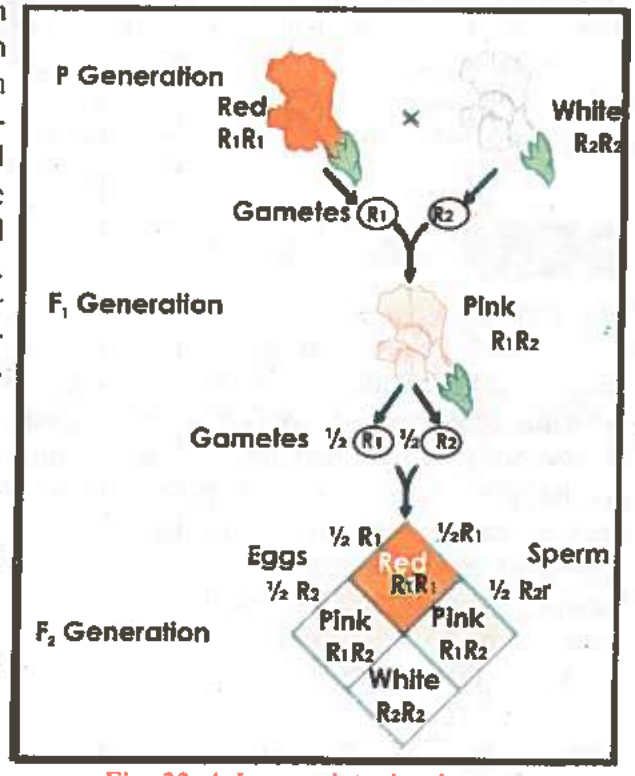


Fig: 22. 4 Incomplete dominance

Allele for red is designated as R_1 and the allele for white as R_2. Punnett square indicates that the phenotypic ratio is the same as the genotypic ratio.

There is absolutely no need of test cross.

22.2.3 Co-dominance:

It is not an intermediate quantitative expression like incomplete dominance but in this case different alleles of a gene that are both expressed in a heterozygote condition are called co-dominant. For example, in case of blood group AB both antigen A and antigen B are expressed and the group is named as blood group AB.

22.2.4 Over dominance:

When the phenotypic expression of heterozygotes (w^+/w) become more intense than the homozygous (w^+/w^+) state of the dominant allele, is called over dominance. For example, in fruit fly (*Drosophila*) the heterozygote (w^+/w) has more quantity of florescent pigments in eyes than wild (w^+/w^+) or white eye (w/w) homozygote.

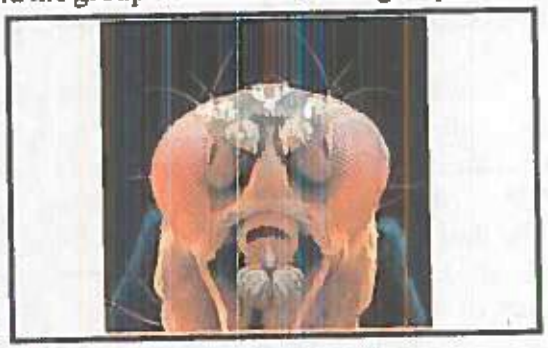


Fig: 22. 5 Coloured scanning electron micrograph (SEM) of the head of a fruit fly (Drosophila sp.). Its two compound eyes (red) are seen on either side of its head.

22.3 ABO BLOOD GROUP SYSTEM

22.3.1 Multiple Alleles:

Allele is the form of a gene which codes for one possible outcome of a phenotype. For example, in Mendel's pea investigations, he found that there was a gene that determined the colour of the pea pod. One form of it (one allele) creates yellow pods, & the other form (allele) creates green pods. It indicates that two possible phenotypes of one trait (pod colour) are determined by two alleles (forms) of the one "colour" gene. If a trait exists in three different phenotypes, there must be some sort of interactions like incomplete dominance or co-dominance is found between the two alleles. Now, if there are 4 or more possible phenotypes for a particular trait, then more than 2 alleles for that trait must exist in the population. All of such alleles are called "multiple alleles".

Multiple alleles are produced by gene mutation. Some genes may have as many as 300 alleles, but individuals have only two of those alleles. Why? Because individuals have only two biological parents. We inherit half of our genes (alleles) from mother, & the other half from father, so we end up with two alleles for every trait in our phenotype.

An excellent example of multiple allele inheritance is human ABO blood group system. It is the most well-known blood group system which was discovered in 1901 at the University of Vienna by Karl Landsteiner in the process of trying to learn why blood transfusions sometimes cause death and at other times save a patient. In 1930, he received the Nobel Prize for his discovery of blood types.

22.3.2 ABO blood groups:

ABO blood groups are found in all humans and in many other primates such as apes chimpanzees, baboons, and gorillas. There are four principal types: A, B, AB, and O, there are two antigens and two antibodies that are mostly responsible for the ABO types. The specific combination of these four components determines an individual's type in most cases.

Table: 22.2 ABO blood groups

ABO Blood type	Antigen (A or B)	Antibodies (Anti-A or Anti-B)	Donors
A	A	Anti-B	A,O
B	B	Anti-A	B, O
AB	Both A&B	None	A,B,AB,O
O	None	Both Anti-A or Anti-B	Only O

For example, people with type A blood will have the A antigen on the surface of their red blood cells (as shown in the table below). As a result, anti-A antibodies will not be produced by them because they would cause the destruction of their own blood.

However, if B type blood is injected into their systems, anti-B antibodies in their plasma will recognize it as alien and burst or agglutinate the introduced red cells in order to cleanse the blood of alien protein.Individuals with type O blood do not produce AB antigens. Therefore, their blood normally will not be rejected when it is given to others with different ABO types. As a result, type O people are universal donors for transfusions, but they can receive only type O blood themselves.

Those who have type AB blood do not make any antibodies. Their blood does not discriminate against any other ABO type. Consequently, they are universal recipients for transfusions, but their blood will be agglutinated when given to people with every other type because they produce both kinds of antigens.

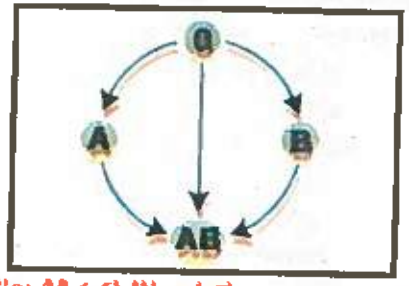


Fig: 22.6 O Blood Group people are universal donors for transfusions

22.3.3 Genetic basis of ABO blood groups:

Bernstein explained the genetic basis of ABO system in 1925. It is a multiple allelic trait that is encoded by a single polymorphic gene "I" on chromosome 9. This gene exists in three multiple alleles that have been produced through mutation.

Gene "I" → Mutation 1 → I^A (antigen-A producing allele)
Gene "I" → Mutation 2 → I^B (antigen-B producing allele)
Gene "I" → Mutation 3 → i (non-antigen producing allele)

Table: 22.3 Genetic basis of ABO blood groups

ABO Blood Type	Genotypes
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

Their dominance relations are very interesting, alleles I^A and I^B are completely dominant over the allele i, while I^A and I^B are co-dominant to each other because each expresses in equally in heterozygous (I^AI^B) state to produce AB phenotype. Therefore I^AI^A or I^Ai genotypes will produce phenotype A. Similarly I^BI^B or I^Bi produces phenotype B. The homozygous ii will produce phenotype O.

The blood groups alleles start their expression at early embryonic stage and keep on expressing themselves till death. Therefore the blood group phenotype of a person never changes throughout life.

22.3.4 Occurrence of some other blood group systems:

There are a number of different blood group systems found in human. The International Society of Blood Transfusion has recognized up to 30 major group systems. These systems are characterized by the presence or absence of specific molecules, called antigens that are situated on the surface of the red blood cells. Most antigens are protein molecules. Two main blood group systems are ABO system and Rh (Rhesus) system. These two systems are more significant because incompatibility between donor and recipient's blood with respect to these two systems may become dangerous to life.

In the "ABO" system, all blood belongs to one of four major groups: A, B, AB, or O; and in "Rh" system, there are two groups i.e. Rh positive or Rh negative. But there are more than two hundred minor blood groups (belong to the rest of blood group system other than ABO & Rh systems) that usually do not complicate the blood transfusions. These are known as rare blood types.

Table: 22.3 Physiology of Rh blood group.

Rh Blood Type	Rh-factor or antigen	Anti-Rh Antibodies	Donors	Genotypes
Rh^+	Present	Absent	Rh^+/Rh	DD/ Dd
Rh^-	Absent	Present	Only Rh	dd

Examples of blood group systems other than "ABO" and "Rh" are MNS, P, Lutheran, Kell, Lewis, Duffy, Kidd, Diego, etc.

22.4 Rh BLOOD GROUP SYSTEMS

The Rh (Rhesus) blood group system (including the Rh factor) is one of the currently 30 human blood group systems. It is clinically the most important blood group system after ABO. The name of this system (Rh) is derived from *Rhesus* monkey, because its antigen was first discovered in it by Landsteiner in 1930s.The Rh blood group system currently consists of 50 defined blood-group antigens, among which the 5 antigens D, C, c, E, and e are the most important ones.

The commonly-used terms Rh factor, Rh positive and Rh negative refer to the D antigen only. So the persons having this antigen are called Rh positive and those in which it is absent are called Rh negative. Other antigens of Rh blood group system have no significant role in blood transfusion.

On the other hand the D antigen incompatibility between donor and recipient can cause problem not only during blood transfusion but it is also a relevant cause of the hemolytic disease of the newborn or erythroblastosis foetalis.

For Your Information

ABO Blood type antigens are not only found on the surface of red cells. They are also normally secreted by some people in their body fluids, including saliva, tears, and urine. Such persons are called secretors. Whether someone is able to secrete them is genetically controlled by a dominant secretor gene "Se" presents on chromosome 19.

22.4.2 Genetic basis of Rh blood group system:

Rh blood group system is encoded by three genes *C*, *D*, and *E*, which occupy two tightly linked loci. Alleles of gene *D* occupy one locus called locus D, while genes *C* and *E* alternatively occupy the other locus. The D locus is of prime importance, because it is associated with the formation of D antigen (commonly known as Rh factor).

Gene *D* has two alleles, *D* and *d*. *D* is completely dominant over *d*. persons having genotypes *"DD"* or *"Dd"* have D antigen (Rh factor) on their RBC and are Rh positive. Persons with genotype *"dd"* don not have Rh factor and are Rh negative.

22.4.3 Maternal-foetal Rh incompatibility:

The Rh factor is notorious in cases where antibodies produced by a pregnant woman react with the red blood cells of her developing foetus. The situation arises if the mother is Rh-negative but the foetus is Rh-positive, having inherited the factor from the father. The mother develops antibodies against the Rh factor when small amounts of fetal blood cross the placenta and come in contact with her lymphocytes, usually late in pregnancy or during delivery of the baby. Typically, the mother's response to this first exposure is mild and without medical consequences for the baby. The real danger occurs in subsequent pregnancies, when the mother's immune response against the Rh factor has already been exposed and her antibodies can cross the placenta and destroy the red blood cells of an Rh-positive foetus. This condition is referred as erythroblastosis foetalis. To prevent this, the mother may be injected with anti- Rh antibodies after delivering her first Rh-positive baby.

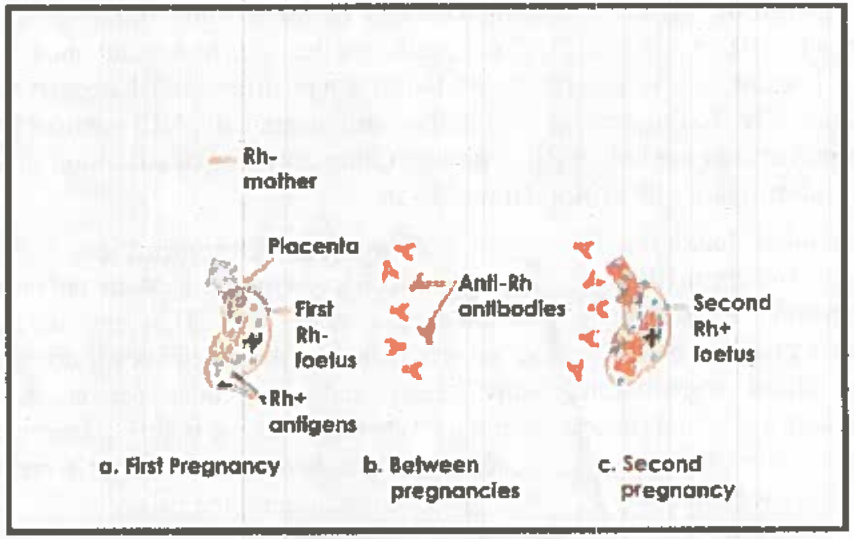


Fig: 22.6 Erythroblastosis foetalis

The antibodies destroy the Rh-positive red cells that have entered the mother's circulation before her own immune system has been stimulated by the Rh antigen.

DO YOU KNOW?

An **erythroblast** is a type of red blood cell which still retains a cell nucleus. It is the immediate precursor of a normal erythrocyte.

22.5 GENE INTERACTIONS

During the study of Mendelian experiments, you have learnt about the phenomenon of dominance which is an interaction between the contrasting alleles of same locus. Now you are going to understand the interaction between the alleles of different gene pairs located on different loci of same or different chromosomes. These are known as **non- allelic interactions** or **inter-genic interactions**.

22.5.1 Epistasis:

An example of non- allelic interactions is **epistasis**, which can be defined as the phenomenon in which the effect caused by the genes at one locus interferes with or hides the effect caused by another gene at another locus. In such interactions, the gene which suppresses or masks the effect of action of a gene at another locus is known as **epistatic gene** and the gene which is suppressed is known as **hypostatic gene**.

Epistasis must not be confused with dominance. Dominance is the relationship between alleles of the same gene occupying the same locus, but epistasis is the interaction between different genes occupying different loci. Following table further illustrate the difference between epistasis and dominance.

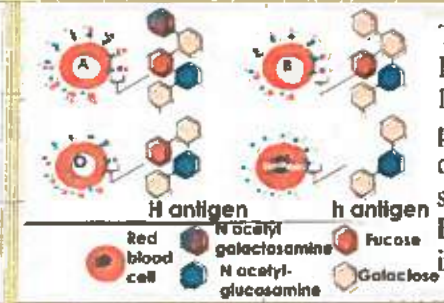
22.5.2 Bombay phenotype:

The Bombay phenotype in humans is an example of epistasis. This is an altered and very rare blood group phenotype in which individuals are phenotypically O but genotypically they may be like A, B, or AB. Actually the production of A or B antigen also dependent upon H-substance, which is synthesize by another gene *"H"* on chromosome 19. Its recessive allele *"h"* does not synthesize this substance.

DO YOU KNOW?

This blood phenotype was first discovered in Bombay, now known as Mumbai, in India, by Dr. Y.M. Bhende, as published in 1952. It is present in about 0.0004% (about 4 per million) of the human population generally, though in some places such as Mumbai (formerly Bombay) local populations can have occurrences in as much as 0.01% (1 in 10,000) of inhabitants.

Bombay



The H-substance is a precursor to the A and B antigens. For instance, the *B* allele must be present to produce the B enzyme that modifies the H-substance to become the B antigen. It is the same for the *A* allele. However, if only recessive alleles for the H-substance are inherited *(hh)*, as in the case of Bombay phenotype,

the H-substance will not be produced. Subsequently, the A and B antigens also will not be produced.The result is an O phenotype by default since a lack of A and B antigens is the O type. This means that the ABO genotypes also require *HH* or *Hh* genotypes for their correct expression.

So the individuals who are homozygous recessive at the H-locus *(hh)* will be blood type O regardless of the genotype at the *I*-gene where the alleles for ABO blood types reside.

ACTIVITY

Consider a child from a type AB male and a type O female who are both heterozygous carriers of the recessive h-allele. What is the probability that this couple will have a type O child?

22.5.3 Polygenic Inheritance:

Genotypes interact with environment to produce phenotypes. Phenotypic expressions of the traits are of two different types i.e. qualitative and quantitative. **Qualitative traits** have few phenotypes that have sharp and more obvious differences among them so they show discontinuous variations.

On the other hand **quantitative traits** comparatively have large number of phenotypes that have small and less striking difference so they have continuous variations.

For instance, some traits like pea seed shape exists in two sharply distinct phenotype, round and wrinkled; others like 4 O'clock flower colour can have three phenotypes, red, pink and white; still others like ABO blood group system have four qualitatively different phenotypes, A, B, AB, and O.

But there are number of traits such as height, weight, intelligence, and skin colour in human; and grain colour in wheat exhibit continuous quantitative variations over the wide range of many phenotypes from one extreme to another.

Mendel focused on traits that showed only two qualitatively different phenotypes which could be determined by just two alternate alleles of a single gene. But a wide range of phenotypes of a quantitative trait cannot be encoded by a single gene with two alleles.

Even a few multiple alleles of a single gene cannot make a large number of phenotype. In fact, a continuously varying trait is encoded by alleles of two or more different gene pairs found at different loci, all influencing the same trait in an **additive way**. These quantitative traits are therefore called **polygenic traits.**

All the genes that control a quantitative trait are called **polygenes** which have a small positive or negative effect on the character. Polygenes supplement each other and sum of positive and negative effect of all individual polygenes produce quantitative phenotype of a continuous varying traits.

22.5.4 Wheat grain colour:

Wheat grain colour is a good example of polygenic (multiple gene) inheritance. Wheat grains show a continuous variation in colour from white to dark red.

Approximately seven different phenotypes are found in wheat population all over the world. Some grains are white, some are deep red but most grains have shades in between from light pink to moderately dark red. Nilsson Elle studied the genetics of wheat grain colour. When he crossed a true breeding dark red grain plant with a true breeding white grain plant, all F_1 grains had light red colour intermediate between two parental shades.

It seemed as if it was a case of incomplete dominance. But when F_1 grains were grown to mature plants and crossed with each other, F_2 grains had exactly seven shades of colour in the following ratio:

Dark red	Moderately dark red	Red	Light red	Pink	Light Pink	White
1	6	15	20	15	6	1

Three different gene pairs, Aa, Bb, Cc at three different loci contribute to the wheat grain colour. Each individual would contain six alleles for the trait. Alleles A, B and C codes for an equal amount (dose) of red pigment, which is a positive effect. But none of a, b and c encode red pigment, which is a negative effect.

If all the six allele code for red pigment (AABBCC), the grain is dark red; when none of the six allele encodes red pigment (aabbcc), the grain is white. When a grain has one allele for red pigment (Aabbcc or aaBbcc or aabbCc) its colour is light pink; if it has two alleles for the pigment (AaBbcc or aaBbCc or AabbCc) it is pink, if it has three pigment alleles (AaBbCc or AABbcc or AabbCC), it will be light red. Similarly four alleles colour dose (AABBcc or aaBBCC or AAbbCC) will make red and five alleles colour dose (AABBCc or AABbCC or AaBBCC) will produce moderately dark red grain.

Thus colour phenotypes of grains depend upon the number of pigment producing alleles (A, B, and C). Environmental factors like light, water and nutrients also influence the amount of grain colour.

22.5.5 Human skin colour:

Human skin colour is a good example of polygenic (multiple gene) inheritance. Skin colour is largely determined by the amount of melanin the skin produces. Dark-skinned individuals produce more melanin than light-skinned individuals. At least three genes regulate the amount of melanin produced.

- Gene A is involved in the permanent survival, proliferation and migration of melanocytes.
- Gene B encodes the enzyme tyrosinase which is involved in the production of melanin from tyrosine.

- Gene C is primarily responsible for determining whether pheomelanin or eumelanin is produced in humans.

Each gene has two forms: dark-skin allele represented by capital case letters (A, B, and C) and light-skin allele represented by small case letters (a, b, and c). No allele is completely dominant to the other, and heterozygotes exhibit an intermediate phenotype (incomplete dominance).

A, B, and C act as dark-skin alleles in the genotype, because they add pigment by increasing melanin production. On the other hand a, b, and c act as light-skin alleles in the genotype because they inhibit melanin production.

There are seven different shades of skin colour ranging from very light (aabbcc) to very dark (AABBCC); most individuals have the intermediate skin colour (AaBbCc). This latter genotype would be characteristic of a mulatto (an offspring of a black and a white parent). In the cross between two mulatto genotypes (AaBbCc X AaBbCc), each parent produces eight different types of gametes and these gametes combine with each other in 64 different ways resulting in a total of seven skin colours. The skin colours can be represented by the number of capital letters, ranging from zero (no dark skin alleles) to six (all dark skin allele). The approximate shades of skin colour corresponding to each genotype are shown in Table 22.4

Table: 22.4 Different shades of skin colour.

Pigment alleles colour shade	6	5	4	3	2	1	0
	Dark Brown	Moderately dark brown	Brown	Light Brown	Pinkish Brown	Very pale brown	Pure white
Ratio	1	6	15	20	15	6	1

22.6 GENE LINKAGE AND CROSSING OVER

22.6.1 Gene linkage:

The number of genes in a cell is far greater than the number of chromosomes; in fact each chromosome has hundreds and thousands of genes. Genes located on the same chromosome that tend to be inherited together in genetic crosses are said to be **linked genes**, and the phenomenon of staying together of more than one gene on the same chromosome is called **gene linkage**. If genes are linked on autosomes, their linkage is called autosomal linkage. Similarly, if they are linked on sex chromosome, their linkage is called sex linkage.

All the linked genes found on the same homologous pair of chromosome form a group, known as **linkage group**, so the number of linkage groups in an organism are equal to the number of homologous pair of chromosomes in that organism.

For instance, in human, the genes for sickle cell anaemia, leukemia, and albinism are found on chromosome 11, so these traits are supposed to be in the same linkage group.

As it is mentioned earlier, that linked genes tend to be inherited together (*en bloc* inheritance) in the offspring, so usually they do not show recombination and do not assort independently in the offspring. So the ideal Mendelian ratio of independent assortment is deviated.

22.6.2 Detection of gene linkage:

Gene linkage can easily be detected by performing a test cross between two gene pairs (dihybrid test cross). In such type of test cross, a heterozygous individual for two traits (F_1) is back crossed with its recessive parent (P_1). If all four phenotypic combinations (parental & recombinants) are produced in equal 1:1:1:1 ratio, then there would be no linkage between the genes. If this ratio is deviated i.e. more parental types and less recombinant types, this indicates the **incomplete or partial linkage**; but if only parental types are produced, **complete or tight linkage** is believed.

To see how linkage between genes affects the inheritance of two different characters, let's take an example from T. H. Morgan's experiments on Drosophila. In Drosophila, the shape of wings exists in two forms; normal wing shape is dominant over vestigial wing.

Similarly, body colour also exists in two forms; the grey body colour is dominant over black body colour. When Morgan made a cross between the individual having grey body and normal wings with another individual having black body and vestigial wings, all the F_1 progeny inherited grey body and normal wing phenotypes. When these flies were test crossed with their P_1 recessive, following results were observed:

- Grey body and normal wings (parental type) = 965
- Black body and vestigial wings (parental types) = 944
- Grey body and vestigial wings (recombinant types) = 206
- Black body and normal wings (recombinant types) = 185

Since most offspring had a parental phenotype (incomplete / partial linkage), Morgan concluded that the genes for body colour and wing size are located on the same chromosome. However, the production of a relatively small number of offspring with nonparental phenotypes indicated that some mechanism occasionally breaks the linkage between the genes on same chromosome.

Later on it was discovered that crossing over at the time of meiosis (gamete formation in animals and spore formation in plants) is the mechanism that occasionally breaks the linkage between the genes on same chromosome.

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22.6.3 Crossing over:

Subsequent experiments demonstrated that the process which is responsible for the recombination of linked genes is crossing over. In crossing over, an exchange of maternal and paternal chromatid parts occurs while homologous chromosomes are paired during prophase of meiosis I. The recombinant chromatids resulting from crossing over may bring alleles together in new combinations, so when they are distributed in different gametes, a wide variety of gametes are produced.

Let's recall Morgan's experiment in which a female fly having grey body and normal wings was crossed by a male fly having black body and vestigial wings. Although most of the eggs had a chromosome with either the b^+ vg^+ or b vg parental genotypes for body colour and wing size, but some eggs had a recombinant chromosome with b^+ vg or b vg^+ genotypes. Fertilization of these various classes of eggs by homozygous recessive sperms (b vg) produced an offspring population in which 17% exhibited nonparental, recombinant phenotypes. These recombinants were the products of crossing over.

22.6.4 Recombination frequency & Genetic Map of chromosome:

Discovery of linked genes and recombination due to crossing over led one of Morgan's students, Alfred H. Sturtevant, to a method of constructing a **genetic map** or **linkage map**, an ordered list of genetic loci along a particular chromosome.

Sturtevant hypothesized that recombination frequencies, which are the result of crossing over, depend upon the distance between the linked genes on chromosomes. So he assumed that the farther apart two genes are, the higher the probability that a crossover will occur between them and therefore the higher the recombination frequency. The recombination frequency is determined as follows:

$$\text{Recombination Frequency \%} = \frac{\text{Sum of recombinants}}{\text{Sum of all combination (Parental + Recombinants)}} \times 100$$

Using recombination data from various fruit fly crosses, Sturtevant assign relative positions of several genes along the length of chromosome. For instance, figure 22.8 shows the Sturtevant's linkage map of three genes: the body colour *(b)*, wing size *(vg)*, and a third gene, called cinnabar *(cn)*. Cinnabar is one of many Drosophila genes affecting eye colour. Cinnabar eyes, a mutant phenotype, are a brighter red than the wild type colour. The recombination frequency data is given below:

- $cn-b = 9\%$
- $cn-vg = 9.5\%$
- $b-vg = 17\%$

With the help of these data, the only assumption about the location of these three genes can be made is that *cn* is located midway to the *b* and *vg*. Sturtevant expressed the distances between genes in **map units.**

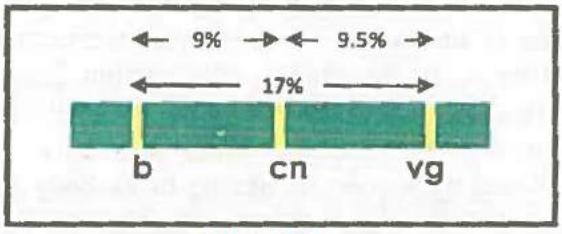


Fig:22.8

The map units are arbitrary, so they are not related to any physical units of length, however, one map unit is supposed to equal to 1% recombination frequency. Today map units are often called ***centimorgans (cM)*** in honor of Morgan.

The b-vg recombination frequency (17%) is slightly less than the sum of the b-cn and cn-vg frequencies (9 + 9.5 = 18.5%) because of the few times that crossover occurs between b and cn and an additional crossover occurs between cn and vg. The second crossover would "cancel out" the first, reducing the observed b-vg recombination frequency while contributing to the frequency between each of the closer pair of gene. The value of 18.5% (18.5 map units) is closer to the actual distance between the genes, so a geneticist would add the smaller distances in constructing a map.

22.7 SEX DETERMINATION

Whether we are male or female is one of our more obvious phenotypic characters. Although the anatomical and physical differences between women and men are numerous, the chromosomal basis for determining sex is rather simple. The search for mechanism of inheritance of sex started after discovery of Mendel's work in 1900. A clear picture of the genetic basis of sex determination emerged after the discovery of sex chromosome.

22.7.1 Patterns of Sex Determination:

There is a wide variety of sex determining mechanisms but three patterns are more common.

XO – XX Type:

This pattern of sex determination is found in grasshopper and Protenor bug. Male is XO because it has only one X chromosome. The other sex chromosome is missing entirely. Male is heterogametic because it forms two types of sperms; half the sperms have X chromosome and the other half without any sex chromosome. A gamete without any sex chromosome is called nullo gamete.

Female is XX, because it has two X chromosomes. It is homogametic, as it forms only one type of eggs. Every egg carries an X chromosome. Sex of the offspring depends on the kind of sperm that fertilizes the egg. If an X-carring sperm fertilizes the egg, an XX female offspring is produced. If the nullo sperm fertilizes the egg, an XO male offspring is produced. Sex ratio between male and female offspring is 1:1.

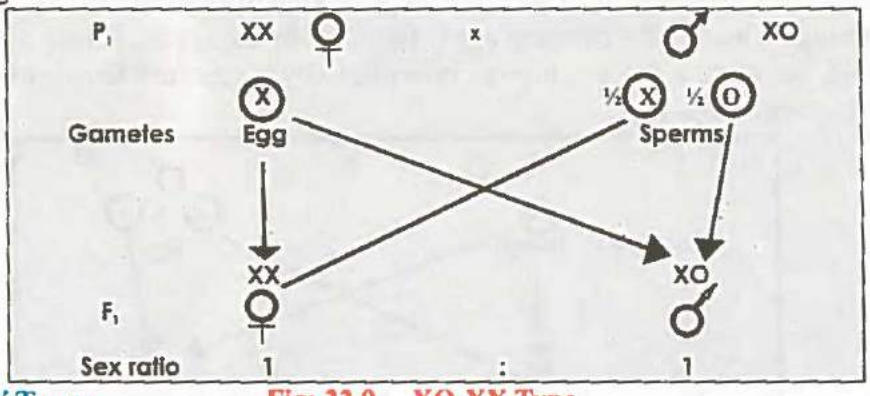


Fig: 22.9 XO-XX Type

XY – XX Type:

This pattern of sex determination is found in Drosophila, human and many other organisms. Male is XY and female is XX. Male being heterogametic produces two types of sex-determining sperms. Half the sperms carry X-chromosome and the other half carry Y – chromosome. Chances for both types of sperms are equal.

Female being homogametic produces only one type of eggs, each with an X chromosome. Sex of the offspring is determined by the type of sperm. If an X – carrying sperm fertilizes the egg, the zygote will be XX, and a female offspring is produced. If a Y – carrying sperm fertilizes the egg, the zygote will be XY, and a male offspring will be produced. The sex-ratio between male and female offspring is 1:1. Sex ratio indicates chances of the sex of the offspring. Chances for a son or daughter in human birth are equal.

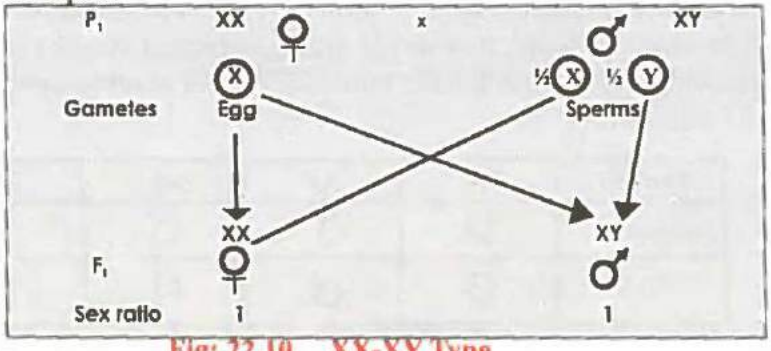


Fig: 22.10 XX-XY Type

XX – XY type or WZ – ZZ Type:

This type of sex – determination pattern is common in birds, butterflies and moths. It was discovered by J. Seiler in 1914 in moth. It is the reverse of XY – XX system. Here the female is heterogametic XY but the male is homogametic XX. Female produces two kinds of eggs X and Y in equal proportions. All sperms are alike, each carrying an X – chromosome. It is the kind of egg that determines the sex of offspring. When an X – carrying egg is fertilized by the sperm, a male offspring is produced, but when a Y – carrying egg is fertilized by the sperm a female offspring is produced. Sex ratio is 1:1

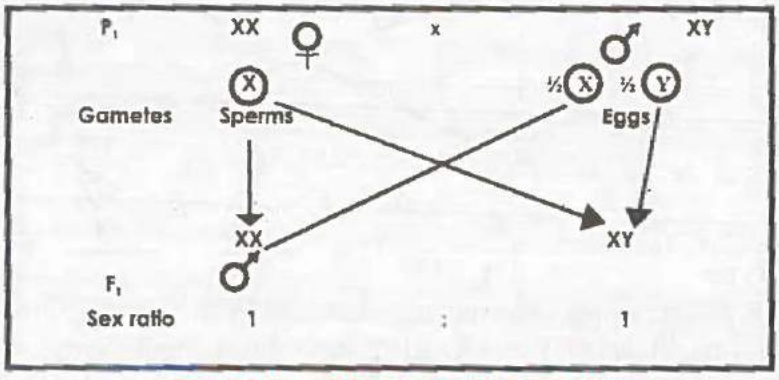


Fig: 22.11 XX-XY or WZ-ZZ Type

22.7.2 Comparison of chromosomal determination of sex between Drosophila and Humans:

Although both *Drosophila* and humans follow the same XY – XY sex determining pattern, yet there is a basic technical difference between the two. Presence of 'SRY' gene on Y chromosome is essential for triggering the development of maleness in humans. Absence of Y chromosome simply leads to the female development path. XO Turner's syndrome in humans produced through non-disjunction is a sterile female. But in *Drosophila* XO is a sterile male. Similarly XXY individual produced through non disjunction gametes in humans is a sterile male called Klinefelter's syndrome, but the same XXY set of chromosomes in Drosophila produces a fertile female.

Species	XX	XY	XO	XXY
Drosophila	♀	♂	♂	♀
Humans	♀	♂	♀	♂

There is a close genic balance between genes of different chromosomes. *Drosophila* has an X chromosome-autosome balance system. Its Y chromosome appears to have little influence on sex.

Here actually the X chromosome is female determining and the autosomes are male determining. Sex of an individual depends more on the number of X chromosomes relative to the number of sets of autosomes.

An X : A ratio of 1.00 or higher produces female whereas an X : A ratio of 0.5 or lower produces males.

22.8 SEX LINKAGE

22.8.1 Sex Linkage in Drosophila

T. H. Morgan made the first demonstration of a sex-linked trait in 1910. Through his experiments on *Drosophila*, the common fruit fly, Morgan showed that the inheritance of eye colour and sex occurs in a coordinate fashion. He reasoned correctly that the eye colour gene is located on the X chromosome but is not present on the Y chromosome. This meant that the recessive allele specifying white eyes is always expressed in males but could be masked by the presence of a dominant red eye colour allele in heterozygous females.*Drosophila melanogaster* eye colour turned out to be a most informative trait. At first, all the flies Morgan raised were wild type for eye colour; they had brick –red eye (wild type).

In 1910, a white-eyed male appeared in a laboratory bottle. Apparently the variant form arose through a spontaneous mutation in a gene controlling eye colour. Morgan established true breeding traits of white-eyed males and females. Then he did a series of reciprocal crosses represented in the following figures.

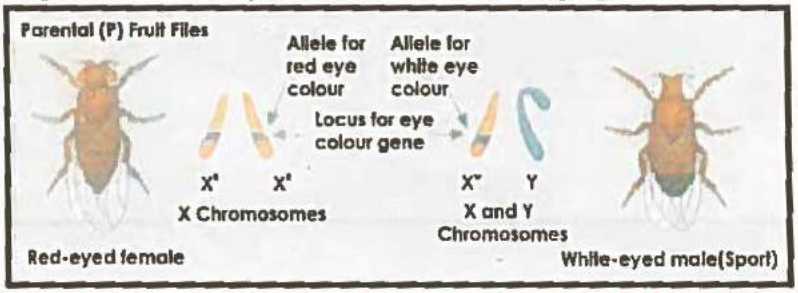


Fig 22.12 X and Y = sex chromosomes, R = the dominant allele for red eye colour, w = the recessive allele for white-eye colour; X^R indicates that the X chromosomes carries the allele for red eyes; X^w indicates that the X chromosomes carries alleles for white eyes. The Y-chromosomes has no locus for eye colour genes. These are the phenotypes, sex chromosomes and alleles for eye colour in Morgan's experimental fruit flies in the P generation.

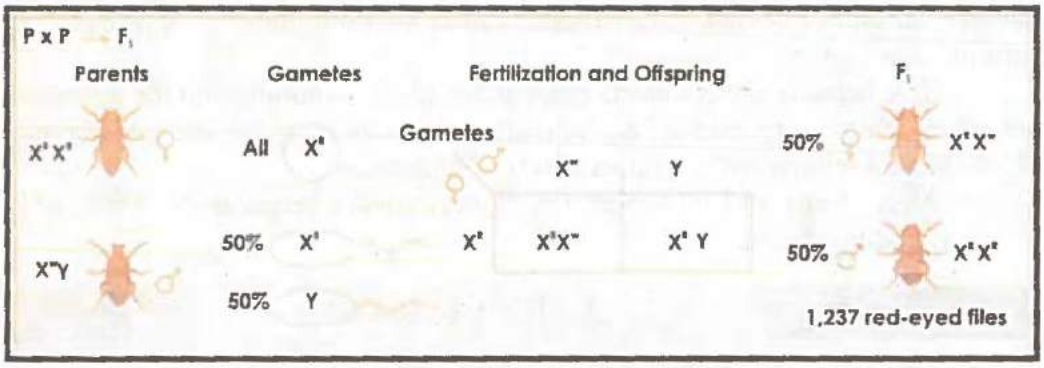


Fig: 22.13 In Morgan's first preliminary experiment (PxP), homozygous red-eyed females were mated with the white-eyed males. The female could produce gametes containing only X^R. The sperm of the male could contain either a Y chromosome or an X^w. A Punnett square is used to describe the offspring produce by the fertilization of parental gametes. The phenotypes and genotypes and ratios of the F_1 are also shown.

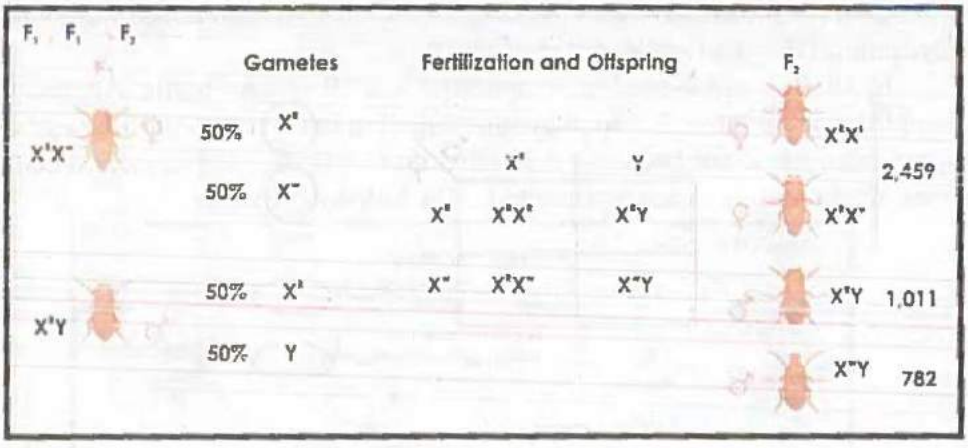


Fig 22.14 In Morgan's second preliminary experiment, F_1 females were mated with F_1 males. Morgan hypothesis explained clearly why all the white eyed flies in F_2 generation were only males.

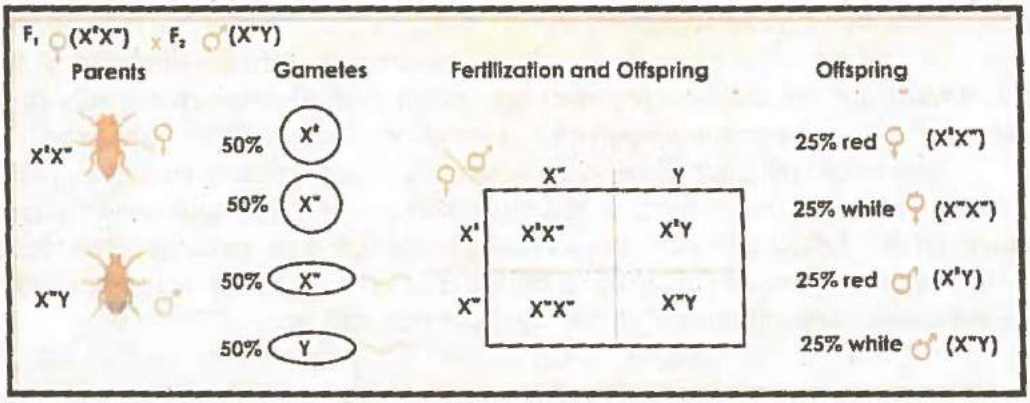


Fig 22.15 Morgan wanted to test his hypothesis .he crossed F_1 females heterozygous for white-eyes with white-eyed male. The four combinations of offspring resulted (25 percent red-eyed females, 25 percent white-eyed females, 25 percent red-eyed males and 25 percent white-eyed males).White eyed female provided an opportunity for a further confirmatory test .For this a cross was made between white eyed female (X^rX^r) with a red eyed male (X^RY). All the females' offspring's had red eyes and all male offspring had white eyes (Fig: 22.16).

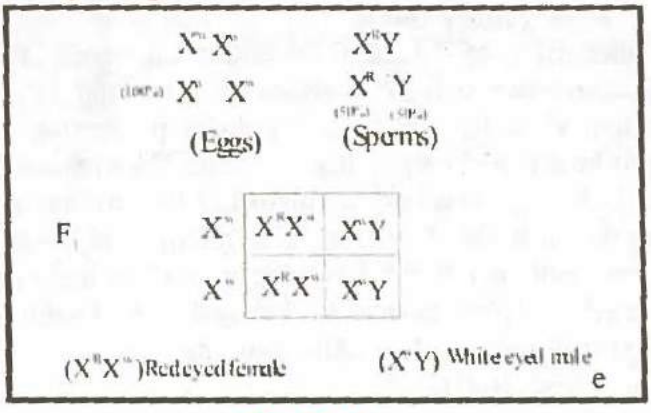


Fig: 22.16

Morgan experiments were designed to test prediction derived from his hypothesis that factor for eye colour is associated with X chromosomes. A trait whose gene is present on X-chromosome is called X-linked trait and a gene which is present on X- chromosomes with no counter part on Y –chromosome is called X-linked gene. Same is the case with Y –linked genes. Y-chromosome do carry some gene having no counter part on X chromosome e.g SRY genes on Y chromosome of man determines maleness. Y-linked genes directly pass through Y chromosome from father to son.

22.8.3 Types of sex linked traits:

A trait whose gene is present on X chromosome is called X – linkage trait. X – linked traits are commonly referred as sex-linked trait. A gene present only on X chromosome, having no counterpart on Y chromosome, is called X – linked gene.

Sex-linked inheritance follows a very specific pattern. As a son inherits his X chromosome only from his mother, and a daughter gets as X chromosome from each parent, an X – linked trait passes in a crisscross fashion from maternal grandfather (P1) through his daughter (F1) to the grandson (F2). It never passes direct from father to son because a son inherits only Y chromosome from father.

22.8.4 Sex – Linkage in Humans

Humans have many X – linked traits of which some like haemophilia and colour blindness are recessive while others like hypophosphatemic or vitamin D resistant rickets are dominant. X – linked dominant is a trait which is determined by an X linked dominant gene, while X – linked recessive is a trait that is determined by as X – linked recessive gene. Their patterns of inheritance are very different from each other.

Experimental matings are not practically possible in humans. Mode of inheritance of human traits can be traced through pedigrees.

X-Linked Recessive Inheritance

Characteristics of X-Linked Recessive Inheritance: Females possessing one X-linked recessive mutation are considered carriers and will generally not manifest clinical symptoms of the disorder. All males possessing an X-linked recessive mutation will be affected (males have a single X-chromosome and therefore have only one copy of X-linked genes). All offspring of a carrier female have a 50% chance of inheriting the mutation. All female children of an affected father will be carriers (daughters posses their fathers' X-chromosome). No male children of an affected father will be affected (sons do not inherit their fathers' X-chromosome).

Some examples of X-linked Recessive Disorders:

- Hemophilia A and B
- Colour Blindness
- Diabetes Insipidus

X-Linked Dominant Inheritance:

Characteristics of X-Linked Dominant Inheritance: A male or female child of an affected mother has a 50% chance of inheriting the mutation and thus being affected with the disorder. All female children of an affected father will be affected (daughters possess their fathers' X-chromosome). No male children of an affected father will be affected (sons do not inherit their fathers' X-chromosome).

Some examples of X-Linked Dominant disorders:

- Alport's syndrome
- Coffin - Lowry syndrome (CLS)
- Idiopathic hypoparathyroidism
- Vitamin D resistant rickets

Y-linked inheritance:

In mammals, Y-linkage refers to when a phenotypic trait is determined by an allele (or gene) on the Y chromosome. It is also known as **holandric inheritance.**

The Y-chromosome is small and does not contain many genes, therefore few traits are Y-linked, and Y-linked diseases are rare. Because the only humans which have a Y chromosome are males, the genes are simply passed from father to son, with no interchromosomal genetic recombination.

Chromosome Y deletions are a frequent genetic cause of male infertility. Another example in humans of a Y-linked trait was thought to be hairy ears (it may also be sex-limited). However, this has been discredited.

22.8.5 Genetics of Haemophilia:

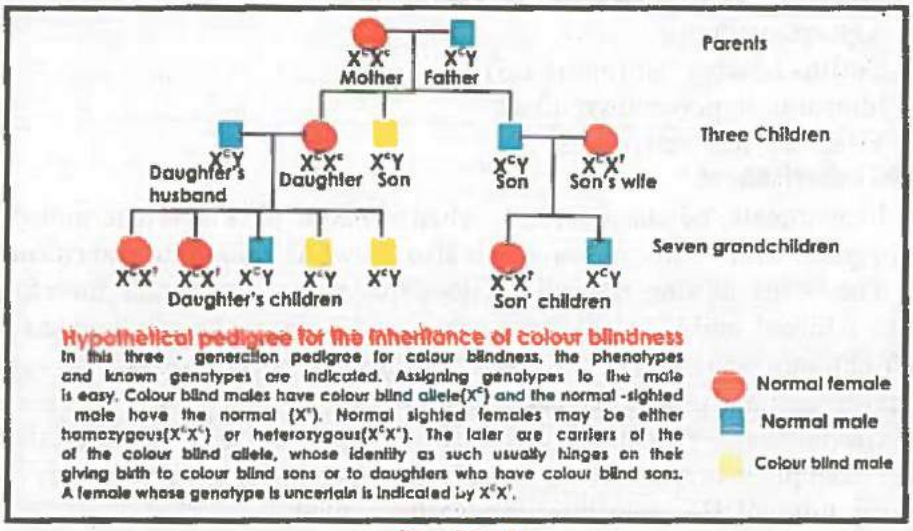
A well-studied sex-linked trait in humans is hemophilia, a disorder that renders the individual less able to form blood clots. This is a serious medical problem because in hemophiliacs, or bleeders, even a minor injury can result in a major loss of blood. Because the hemophilia allele is recessive and carried on the X chromosome, hemophilia is predominantly a male disorder. In fact, hemophilia is extremely rare in females because there are so few hemophiliac males that survive to marry and reproduce. Largely the phenotypically normal female carrier maintains the faulty allele in human population

.22.8.6 Genetics of colour-blindness:

Red green colour blindness is a recessive sex linked trait that renders individuals unable to distinguish shades of red or green and both appear gray.

To understand why colour blindness occurs much more frequently in males, let us examine the types of parental combinations that can produce colour blindness in sons and daughters.

A son inherits the colour- blind allele from his mother, who may be either colour- blind herself or, more likely, a normal- sighted carrier. There is a 50% chance that a son will inherit the colour blind trait from a carrier mother. Whether or not the father is colour-blind (X^cY or X^cY) has no bearing because a son receives only the Y chromosome from his father.



Hypothetical pedigree for the inheritance of colour blindness

In this three - generation pedigree for colour blindness, the phenotypes and known genotypes are indicated. Assigning genotypes to the male is easy. Colour blind males have colour blind allele(X^c) and the normal -sighted male have the normal (X^+). Normal sighted females may be either homozygous(X^+X^+) or heterozygous(X^cX^+). The later are carriers of the of the colour blind allele, whose identity as such usually hinges on their giving birth to colour blind sons or to daughters who have colour blind sons. A female whose genotype is uncertain is indicated by X^cX^+.

Fig: 22.17

For a daughter to be colour-blind, however, not only her mother must have at least one allele for colour blindness, but her father must be colour-blind. As this combination of parents occurs rather infrequently, there are few colour-blind females in the human population.

22.8.7 Sex Related Traits:

Sex related traits are those which are associated with maleness or femaleness. These traits are not necessarily being sex linked. These traits may be controlled by sex linked or autosomal genes.

Sex limited traits:

A sex limited trait is a type of sex related trait which is confined to only one sex due to anatomical differences. Such traits affect a structure or function of the body present in only males or in only female.

For example: Genes for milk yield in dairy cattle affect only cows. Similarly beard growth in human is limited to men. A woman does not grow a beard herself but she can pass the genes specifying heavy beard growth to her son.

Sex influenced trait:

Sex influenced traits are also the type of sex related traits. These occur in both males and females but they are more common in one sex. Such traits are controlled by an allele that is expressed as dominant in one but recessive in the other. This difference in expression is due to hormonal difference between the sexes.

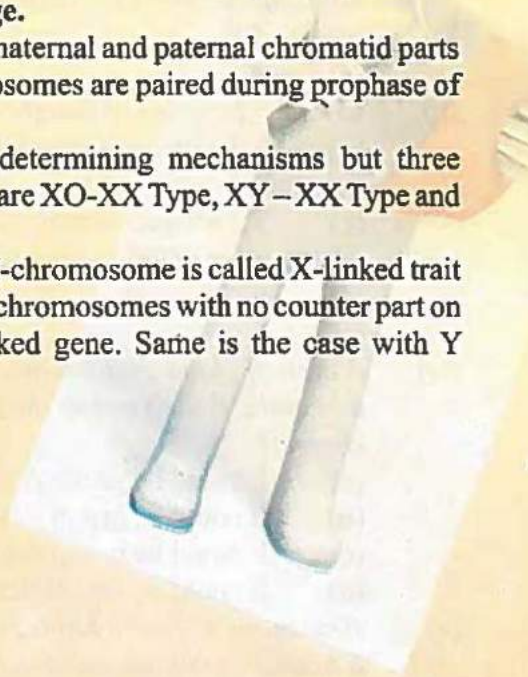
For example: Baldness is a sex influenced trait. Many more men than women are bald. It is inherited as an autosomal dominant trait in males but as an autosomal recessive trait in females. A heterozygous male is bald but a heterozygous female is not. A woman can be bald only when she is homozygous recessive.

KEY POINTS

- The tendency of individuals to resemble their parents is known as **heredity**.
- The science which deals with mechanism of the heredity and variation is called **genetics.**
- Mendel was the first who successfully explained the mechanism of inheritance during his research work on pea plant.
- According to the law of dominance, different characters are controlled by units called factors; factors occur in pairs, of a pair, one factor dominates the other.
- A dihybrid cross describes a mating experiment between two organisms that are particularly different for two traits. The offspring of such cross is called dihybrid which is heterozygous at two different genetic loci.
- Overall, dominance relations are: complete dominance, incomplete dominance, co-dominance and over dominance.
- ABO blood groups are found in all humans and in many other primates such as apes chimpanzees, baboons, and gorillas. There are four principal types: A, B, AB, and O, there are two antigens and two antibodies that are mostly responsible for the ABO types.
- The Rh blood group system currently consists of 50 defined blood-group antigens, among which the 5 antigens D, C, c, E, and e are the most important ones.
- **Epistasis is** defined as the phenomenon in which the effect caused by the genes at one locus interferes with or hides the effect caused by another gene at another locus.
- A continuously varying trait is encoded by alleles of two or more different gene pairs found at different loci, all influencing the same trait in an **additive way**. These quantitative traits are **polygenic traits.** All the genes that control a quantitative trait are called **polygenes** which have a small positive or negative effect on the character.
- Human skin colour is a good example of polygenic (multiple gene) inheritance.

KEY POINTS

- The phenomenon of staying together of more than one gene on the same chromosome is called **gene linkage.**
- In crossing over, an exchange of maternal and paternal chromatid parts occurs while homologous chromosomes are paired during prophase of meiosis I.
- There are wide variety of sex determining mechanisms but three patterns are more common which are XO-XX Type, XY – XX Type and XX – XY type or WZ – ZZ Type.
- A trait whose gene is present on X-chromosome is called X-linked trait and a gene which is present on X- chromosomes with no counter part on Y –chromosome is called X-linked gene. Same is the case with Y –linked genes.



EXERCISE ?

1- Multiple Choice Questions

(i) ***Blood group B phenotype contains anti-A antibodies in the serum and agglutinates any RBC with antigen:***

(a) AB (b) O
(c) A (d) B

(ii) ***Chances for a son or daughter in human birth are:***

(a) 3:1 between son and daughter (b) 1:3 between son and daughter
(c) 1:1 between son and daughter (d) None of them

(iii) ***The number of linkage group in man is:***

(a) 02 (b) 23
(c) 46 (d) 92

(iv) ***A man of blood group A marries a woman of blood group B and they have one child. Which one of the following statements about the child's blood is correct?***

(a) It could be group A only
(b) It could be group AB only
(c) It could be group A or Group B only
(d) It could be any of the groups A, B, AB, O.

(v) ***How many different kinds of gametes will be formed by an individual, who is heterozygous for four gene pairs:***

(a) 8 (b) 16
(c) 20 (d) 30

(vi) ***A woman with normal colour vision, whose father was red-green colour blind, married a red-green colour-blind man. What is the probability of her first-born child being red-green colour blind?***

(a) 1.0 (b) 0.75
(c) 0.50 (d) 0.025

(vii) ***Two parents, each of blood groups A, have a daughter of blood group O. What is the probability that their next child who has blood group O?***

(a) 0.125 (b) 0.25
(c) 0.50 (d) 0.75

(viii) ***What are the phenotypes of the parent of a colour-blind son and non-carrier daughter with normal colour vision?***

EXERCISE ?

	Father	*Mother*
(a)	Carrier	Normal
(b)	Colour-blind	Carrier
(c)	Normal	Carrier
(d)	Normal	Colour-blind

(ix) ***When expression of a biological character is observed in variable intensity it is due to the affect of:***

(a) multiple alleles (b) codominance
(c) epistasis (d) polygenic inheritance

(x) ***Inheritance of skin colour in man is controlled by eight pairs of genes, which are:***

(a) linked (b) codominent
(c) multiple alleles (d) assorting independently

2- Short Questions

(i) Why pea was the most suitable plant for Mendel's experiments.
(ii) Differentiate between dominance and epistasis.
(iii) State the dominance relations among the alleles of ABO blood group system
(iv) What were the Mendel's observations about the phenotypes and genotypes in F_2 generation of monohybrid cross.
(v) Differentiate between sex limited and sex influenced traits

3- Long Questions

(i) Define and explain the law of segregation.
(ii) How Mendel performed dihybrid cross? What he did proposed on the basis of his observations in this cross.
(iii) Describe the genetic basis of ABO blood group system.
(iv) What is polygenic inheritance? Explain its mode of inheritance by taking an example in human.
(v) Describe Morgan's historic work on sex linkage in Drosophila.

4- Genetic Problems

(i) A woman with Type O blood and a man with Type AB are expecting a child. What are the possible blood types of the kid?

EXERCISE ?

(ii) What are the possible blood types of a child whose parents are both heterozygous for "B" blood type?

5- **Analyzing and Interpreting**

- Collect data from class or the school to see how many individuals have AB blood group and construct a pie chart and histogram for collected data.

6- **Initiating and Planning**

- Hypothesize that in dihybrid inheritance pattern of colour and texture of pea seed, the two traits are not inter dependent.

7- **Performing and Recording**

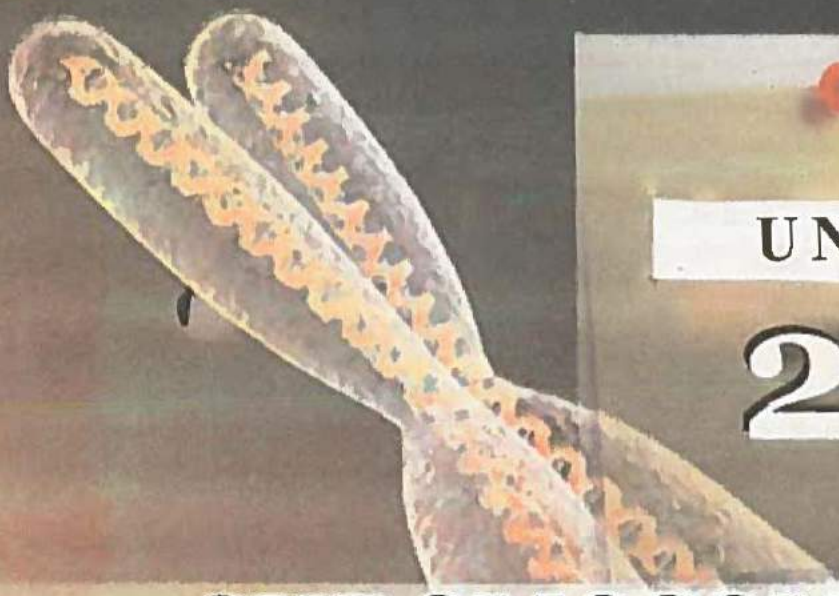
- Build a thematic chart for blood groups for his/her class fellows and identify the antigens present in blood.
- Test his/her blood group using antisera and explain which antigens and antibodies he/she has?

8- **Science, Technology, and Society Connections**

- Evaluate incomplete and co-dominance as variation of Mendel's research.
- Drive an idea to get alternative of blood transfusion. (reference could be made to synthesize plasma and serum)
- Justify why the recessive blood group allele ""i" is more frequent in the population.
- Justify blood donation as a service to suffering humanity.
- Name and explain the techniques employed for embryonic screening, e.g. Amniocentasis.
- Suggest ways to solve lives through the knowledge gained in this chapter.
- Describe how the field of genetics has progressed to more applied science.
- Justify the effectiveness of some of the treatments of haemophilia.

6- **Online Learning**

- *www.phschool.com/science/biology*
- *www.ncbi.nlm.nih.gov*
- *www.nature.com*
- biology.clc.uc.edu/courses/bio105/geneprob.htm
- www.sciencedaily.com



UNIT

23

CHROMOSOME AND DNA

KEY CONCEPTS

Gregor Mendel's "hereditary factors" were purely an abstract concept when he proposed their existence in 1865. At that time, no cellular structures were known that could house for these imaginary units. Today we can show that genes - Mendel's "factors" are located along chromosome and we can see the locations of a particular gene by tagging chromosome with a florescent dye that highlights that gene.

23.1 CHROMOSOMES

Chromosomes are thick thread like structures that appear in nucleus during cell division. In an interphase cell chromosome become uncondensed and look like very fine network called chromatin network.

Chromosomes were first observed by German embryologist Walther Fleming in 1882, when he was examining the rapidly dividing cells of salamander larvae. The term **"chromosome"** was proposed by Waldeyer, which literally means coloured bodies. Since their discovery, chromosomes have been found in the cells of all eukaryotes. However, in prokaryotic cell, its single DNA molecule is also referred as chromosome.

23.1.1 Number of chromosome:

The number of chromosome varies from species to species and usually it is a characteristic feature of many species. ***Penicillium***, a fungus, has only one pair of chromosome, while some ferns have more than 500 pairs. Many species have two sets of chromosomes in their somatic cells, hence called **diploid**, while some may have more than two sets of chromosomes; they are called polyploids (tetraploid, hexaploid). The term **"haploid"** is referred to the number of chromosome exactly half than the somatic number of chromosome. Gametes and spores are usually haploid cells. A haploid cell may be monoploid (one set), diploid (two sets), triploid (three sets), and etc.

Table: 23.1 Number of chromosomes in human and wheat.

Name of Species	Somatic Number	Haploid	Monoploid (n)
Human	46(2n)	23(n)	23
Wheat	42 (6n)	21(3n)	7

23.1.2 Structure of chromosome:

A typical chromosome consists of two strands called **chromatids**; each is made up of a long DNA molecule which is highly coiled along with histone proteins. Generally both chromatids are attached with each other at a point known as

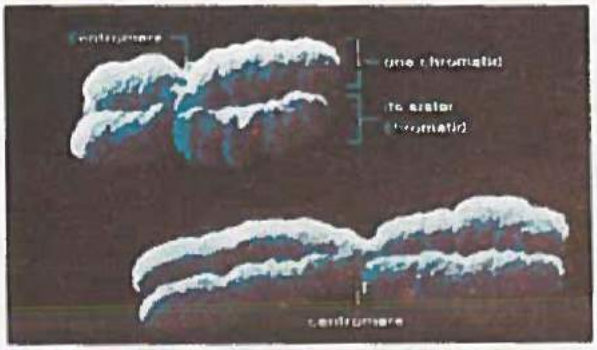


Fig: 23.1 Chromosomes showing chromatids and centromere.

centromere or **primary constriction**, so each chromosome shows two **arms** (region from centromere to an end). Some chromosomes may have another point of union along the length of chromatids, called **secondary constriction** or **nucleolar organizer**. It gives rise to nucleoli during interphase.

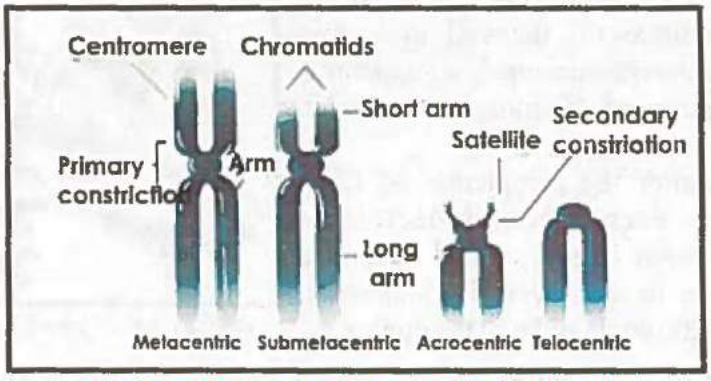


Fig: 23.2 General structure of Chromosome.

At least one pair of homologous chromosomes possesses nucleolar organizer region. Beside secondary constriction the end becomes a knob like structure called **satellite**. This region has a useless sequence of DNA called **junk DNA**. The terminal ends of chromosomes are called **telomeres** which prevent the two chromosomes to attach with each other from their ends.

On the basis of position of centromere along the length, a chromosome may be called **metacentric** (centromere located in the center), **submetacentric** (centromere located slightly away from the center), **acrocentric** (centromere located near the end), and **telocentric** (centromere located at an end).

23.1.3 Composition and organization of chromosome:

Generally a chromosome is made up of 40% DNA and 60% protein. In the cell, which is ready to divide, the chromosome has two identical DNA molecules i.e. each chromatid has one DNA molecule. An average sized human chromosome has approximately 5 cm long DNA which consist of about 140 million nucleotides. So can you imagine how such a huge molecule fit into a tiny chromosome? DNA is a negatively charged molecule because of phosphate groups; therefore it has strong affinity to histone proteins, which are positively charged unlike many other proteins due to the abundance of some basic amino acid such as arginine and lysine. There are five types of histone proteins (H_1, H_2A, H_2B, H_3, and H_4) found in the chromosome.

During S phase of cell cycle DNA and histones are completely disorganized from each other, but after DNA is replicated, both DNA and histones begin to organize again and the process of condensation remains continue till the cell undergoes division and the chromosome's are appeared. The organization of chromosomes occurs in four levels:

Just after the completion of DNA replication, each DNA molecule of enormous length begins to coil around a histones core. In this level of organization about every 200 nucleotides of the duplex

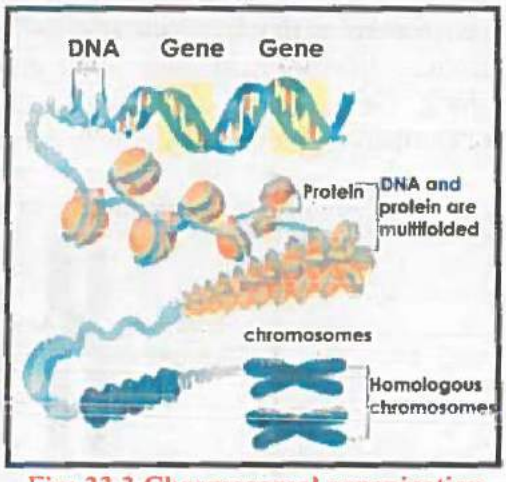


Fig: 23.3 Chromosomal organization.

DNA wrap twice around the core of eight histones (two of each H_2A, H_2B, H_3, and H_4), thus forming a complex known as nucleosome, while H_1 is associated with a small segment of DNA (linker DNA) between every two nucleosome. In this way the whole DNA (2nm thick) is turned to a chain of beads like appearance called nucleosome string (10 nm thick).

Immediately the nucleosome string begins to coil again about its axis to form yet another thick fiber of 30 nm, called chromatin fiber or solenoid. During G_1 and G_2 phases, chromosomes are found in this level of organization. The chromatin fiber shows two regions i.e. heterochromatin and euchromatin. Heterochromatin is highly condensed and unexpressed region while euchromatin is non-condensed and the genes of this region are also expressed. When cell undergoes division, euchromatin is also condensed so that a uniform chromatin fiber is established.

When cell division begins, the higher order coiling of chromatin fiber gives rise supercoil which has diameter of 200 nm. Immediately supercoil establish into the chromatid of 700nm as result of further coiling around itself.

23.2 CONCEPT OF GENE

23.2.1 Historical Background:

Charles Darwin first conceived the idea of hereditary units when he published his theory of **pangenesis** in 1868. In this model, circulating units called **gemmules** are accumulated in the gonads and transmitted to the off-spring. This theory was discredited by experimental tests performed by Francis Galton in the 1870s. Galton used blood transfusions in rabbits to show that the alleged gemmules in one rabbit's blood did not alter the heredity of the recipient rabbit's blood. In the 1890s **Hugo de Vries** took the term "pangenesis" and trimmed it to **"pangene"** for the assumed units of inheritance. He argued that pangenes remained inside the cell and did not migrate. It was this theory of intracellular pangenesis that led de Vries to independently find what **Gregor Mendel** had discovered thirty years earlier in his work with contrasting traits in garden peas—there are units of inheritance that are transmitted by reproduction. **Wilhelm Johansson** introduced the term **"gene"** to replace several contending and misleading terms for the basic unit of heredity in 1909. The term **"genetics"** came earlier, when **William Bateson** coined the word in 1906 to represent the new field that studied heredity, variation, and evolution.

23.2.2 Modern concept of gene:

It is believed that the modern concept of gene was given by the Mendel while his experimentation on pea plant. *According to the Mendel, each trait in the pea plant is controlled by the discrete units,* what he referred as **elementen** or **factors**. In modern terminology Mendel's factors are called **genes**. Since the rediscovery of Mendelian work in 1900, the nature and expression of gene is being explored by various geneticists in all over the world and this job is still continued. But now we know that ***a gene is composed of nucleotide sequence of a short segment of DNA which encodes the sequence of amino acid of a particular polypeptide.***

23.2.3 Where do genes reside?

These genes are found in the chromosome. The position on a chromosome where a gene is located is often referred to as a **locus**. Most genes exist in alternative versions, or **alleles**, with differences at one or more nucleotide positions in the DNA. The alleles related to the same trait are occupied on the same locus. For example, gene of ABO blood group i.e. *"I"* exist in three different alleles *(I^A, I^B, i)* that are found on the same locus at chromosome 9.

23.2.4 Structure of a gene:

We have already discussed that a gene is a particular segment of DNA in which nucleotide sequence determines the sequence of amino acid of a polypeptide. A gene usually has regulatory regions and a structural region. The regulatory region located to the 5' end of coding strand of the gene is called **promoter** that controls the binding RNA polymerase during transcription. Other regulatory region, the **terminator**, is located to the 3' end of coding strand of the gene. The terminator region causes RNA polymerase to stop transcription. The region between promoter and terminator is **structural region** of the gene that comprises information (genetic code) for a particular polypeptide or functional RNA. In eukaryotic genes the information of structural region is interrupted by the non-functional sequences called **introns** whereas the functional sequences are called **exons**. There is no such pattern of introns and exons in prokaryotic DNA. In prokaryotes many adjacent structural gene that synthesize different polypeptides are regulated by same promoter and terminator regions. Such a group of genes is called **operon.**

23.3 CHROMOSOME THEORY OF INHERITANCE

The chromosomal theory of inheritance is the idea that genes, the units of inheritance, which are physical in nature, are found in the chromosomes, so chromosomes act as carriers of heredity.

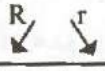
First time this idea was put forward in 1900 by a German geneticist Karl Correns, in one of the paper announcing the rediscovery of Mendel's work, but he had no supportive evidences for this idea. Therefore, actual credit of this theory goes to both Walter Sutton (an American who at that time was a graduate student) and Theodor Boveri (a German biologist). In 1902, these scientists recognized independently that the behavior of Mendel's factors (genes) is parallel to the behavior of chromosome at meiosis, which is pointed out in the following table:

In addition to the above evidences based on parallel behavior between genes and chromosome during meiosis, we can also analyze the mechanism of sexual reproduction, which involves the initial union of two cells, egg and sperm. If Mendel's model is correct, then these two gametes must make equal hereditary contributions.

Sperm, however, contains little cytoplasm and during fertilization it only contribute nucleus to the zygote. Therefore the hereditary units must reside within the nucleus of the gametes, whereas, chromosomes are also found in the nucleus. Beside above mentioned parallel behavior between genes and chromosome during meiosis, this observation also indicates that genes would be present in chromosomes.

Many investigators of that time pointed out a serious objection on Sutton's theory. According to that, let we accept that Mendelian traits are determined by the factors / genes located on chromosome, and if the genes are segregated due to segregation of chromosome and independent assortment of genes is reflected by the independent assortment of chromosome in meiosis, why is it that number of genes that assort independently of one another in a given kind of organism is often much greater than the number of chromosome pairs that the organism possesses. But later on this objection was cleared after the discovery of linkage by the historical experimentation of **T. H. Morgan** in 1910 on *Drosophila*.

Parallel behavior of genes and chromosomes during meiosis.

Behavior of chromosomes	Behavior of genes
1. Diploid cells (before meiosis) have two copies of each chromosome (homologous pairs) while gametes (after meiosis) have only one. e.g. In pea plant diploid cells have 7 pairs of homologous chromosomes while gametes have single 7 chromosomes.	1. According to the Mendel, diploid cells have two copies of each gene (pair of alleles) while gametes have only one, e.g. In pea plat, diploid cells have a pairs of alleles for each gene like *Rr, Yy,* and *Tt,* while gametes have single *R* or *r*, *Y* or *y* and *T* or *t*.
2. Homologous pairs of chromosomes segregate during meiosis.	2. According to the Mendel, pair of gene for each trait also segregates form each other during meiosis, e.g. Rr 
3. During meiosis, each pair of homologous chromosomes orient on the metaphase plate independently of any other pair so that in anaphase each pair assort independently of the other.	3. According to the Mendel, alleles of one gene pair also assort independently to the alleles of other gene pair during meiosis, e.g. RrYy genotype as a result of independent assortment can form four type of gametes i.e. RY, rY, and ry.

Morgan's work with respect to the gene linkage and inheritance of eye color in drosophila, you have already been studied in the previous chapter.

23.4 DNA AS HEREDITY MATERIAL

When the chromosome theory of inheritance was confirmed in 1910, geneticist started think over the issue that, in which form, the heredity units are found in the chromosome. It was known that chromosomes contain both DNA and protein.

On which of these was the heredity information written? Over a period of 30 years, starting in the late 1920s, a series of investigators addressed this issue, resolving it clearly. Here, we are going to learn three experiments, each of which yields a clear answer in a simple and elegant manner.

23.4.1 Griffith's Experiment:

In 1928, British microbiologist Fredrick Griffith made a series of unexpected observations while experimenting with *Streptococcus pneumonae* which are found in two types. One of its types has a polysaccharide capsule, its colony appears as smooth or shiny, and hence it is called S-type. The other type forms a rough colony due to the absence of polysaccharide capsule; this is referred as R-type.When Griffith injected healthy mice with a strain of S-type, all the mice died, but when he injected similar mice with a strain of R-type, the mice showed no ill effect. On the basis of these observation, Griffith made a hypothesis that virulent effect of S-type might be associated with polysaccharide capsule as the R-type that lack a capsule, appeared non virulent.

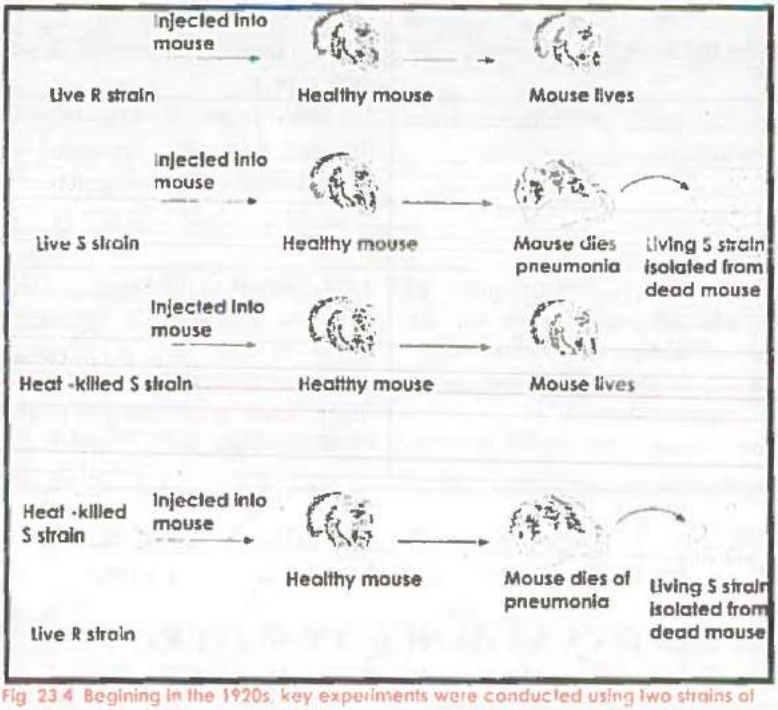


Fig. 23.4 Begining in the 1920s, key experiments were conducted using two strains of *Diplococcus* bacteria, a smooth (S) from and a rough (R) form. In Griffith's first experiment, mice were injected with either the S or R *Diplococcus*. Those injected with the R strain were unaffected, but those receiving the S strain died of pneumonia. In later experiments, mice injected with heat killed S bacteria lived, however, if those S form were first mixed with live R bacteria and then injected into a mouse, it died and was found to contain live S forms.

As a final control, he blended living R-type with heat killed S-type, both of these strains were already confirmed as non-virulent. When he injected this mixture into the healthy mice, unexpectedly, the injected mice developed disease symptoms and many of them died. The blood of the dead mice was found to contain large number of living S-type virulent bacteria.

On the basis of these unexpected observations, Griffith concluded that somehow the information specifying the polysaccharide capsule and virulence had passed from the heat killed S-type bacteria to the live R-type once in the control mixture, transforming them into live S-type virulent bacteria that killed the mice. This transfer of genetic material from one organism to another, by which genetic make-up of recepient is altered, is called **transformation.**

23.4.2 Avery's Experiment:

The agent responsible for transforming R-type to S-type went undiscovered until 1944. In a classic series of experiments, Oswald Avery along with Colin Macleod and Maclyn McCarty characterized what they referred to as the "transforming principle". They first prepared mixture of dead S-type and live R-type *Streptococcus pneumonae* that Griffith had used in his last experiment. Then they removed as much of the protein as they could from the preparation by treating it with protease enzyme, eventually achieving 99.98% purity. Despite removal of nearly all protein, the transforming activity was not reduced. In the second attempt, all the RNA contents were removed with the help of RNAase enzyme, but transformation remained continue. Finally, when, mixture was treated with DNAase enzyme in order to remove DNA contents of S-type. The mice injected with such a mixture in which DNA contents of S-type had removed, developed no ill effect because no transformation occurs. In this way it was confirmed that the transforming agent in the Griffith's experiment was DNA.

23.4.3 Hershey & Chase Experiment:

Soon after the Avery's results, another very convincing experiment on bacteriophages was performed by Alfred Hershey and Martha Chase in 1952, which was difficult to ignore.

Bacteriophages are the viruses that attack upon bacteria, their body consists of DNA and protein, during infection they multiply in the host and their many copies emerged within 20-25 minutes. It was not known till 1952 that either DNA or protein which possesses hereditary information of bacteriophages. Even, scientists were not sure that during infection, the whole viral particle entered the host body or only its DNA or protein get entry.

In 1952, Hershey and Chase set out an experiment to identify the viral part that is injected into the host body at the start of infection. For this purpose they labeled the DNA of bacteriophages with a radioactive isotope of phosphorus, ^{32}P, and also labeled their protein coats with radioactive isotope of sulfur, ^{35}S. The labeled viruses were permitted to infect bacteria. Soon after the infection bacterial cells were separated from media contents with the help of centrifugation technique. Then media contents and bacterial cells were analyzed for the activity of ^{32}P and ^{35}S. In this analysis, ^{32}P was found in the bacterial cells while ^{35}S was found in the medium. These observations clearly showed that during infection, ^{32}P labeled DNA of bacteriophage was injected into the bacterial cell while its ^{35}S labeled protein coat remained outside. Subsequently, many viral particles released outside the host. Based on these observations, Hershey & Chase claimed that the virus DNA, not the virus protein, was responsible for directing the production of new viruses.

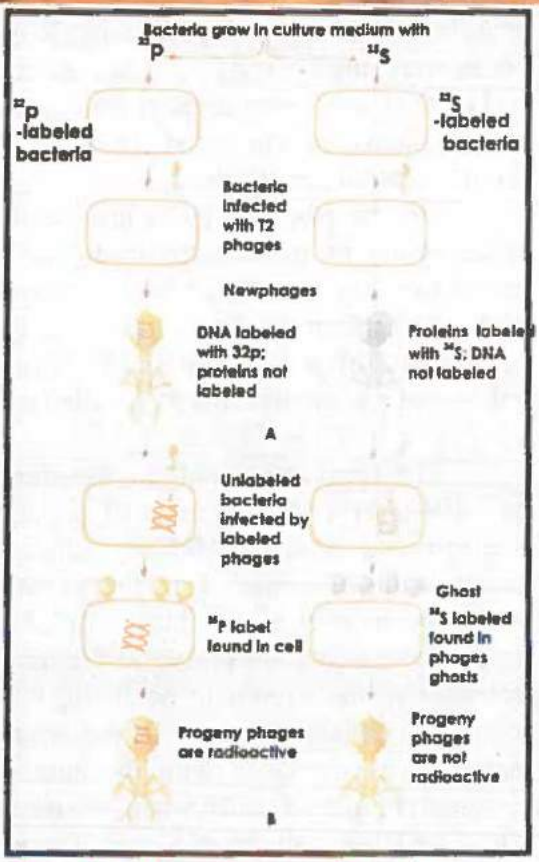


Fig: 23.5 Hershey and Chase famous phage experiment finally settled the question of whether protein or DNA was the genetic material

23.5 DNA REPLICATION

The process of self-synthesis of DNA molecule is called DNA replication. This process occurs only once in S-phase during the life cycle of a cell. The molecule of DNA which is replicated is called parent DNA, while the molecules, produced in this process are called daughter DNA. A parent DNA molecule after replication gives rise two daughter DNA molecule. How duplex DNA can replicate? Scientists started struggle to find the answer of this by the discovery of DNA structure.

Over all three different models to explain the replication process were come forward:

23.5.1 Semi-conservative Model:

This model was given by the Watson and Crick, who also proposed that structure of DNA. According to this model the parent DNA molecule becomes unwind and lost its base pairs (unzipping), both strands act as template that allow the formation of new strands, as a result two daughter DNA molecules are formed with one old and one new strand (hybrid DNA). In this way the parental strands are partially conserved in both daughter DNA molecules.

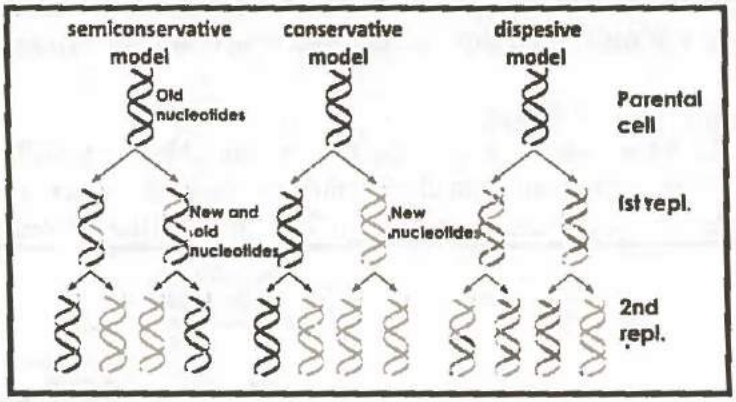


Fig: 23.6 Replication models of DNA.

23.5.2 Conservative Model:

According to this model the parental DNA remains intact in its duplex state, while a daughter DNA molecule with both new strands is established. In this way the parental DNA is fully conserved in the next generation.

23.5.3 Dispersive Model:

This model predicted that the parental DNA would become completely dispersed into fragments, which will be mixed with new nucleotide fragments.

In this way the daughter DNA molecules would be mixture of old and new fragments.

23.5.4 Meselson-Stahl Experiment:

The three models of DNA replication were evaluated by Mathew Meselson and Franklin Stahl of the California Institute of technology in 1958. In this experiment, it was concluded finally that the replication of DNA occurs according to semi-conservative model.

Culturing of bacteria

They grew bacteria in a medium containing heavy isotope of nitrogen, ^{15}N, which became incorporated into the bases of bacterial DNA. After several generations, the bacteria were shifted to three separate plates, which were already contained ^{14}N medium.

Sampling of DNA

Three DNA samples were taken from bacteria shifted from ^{15}N medium to the ^{14}N medium. First sample was obtained from first plate just after the transfer of culture; called sample at 0 minute, the second sample was taken from second plate after 20 minutes, called sample at 20 minutes, and third sample was taken from third plate after another 20 minute, called sample at 40 minute. In addition to these, a control sample was also taken from the bacteria which were grown separately in ^{14}N medium.

Centrifugation of DNA samples:

The DNA samples were dissolved in cesium chloride (CsCl) solution and then spun at a very high speed in an ultra-centrifuge for many hours. The cesium and chloride ions tend to be pushed by centrifugal force towards the bottom of the tube.

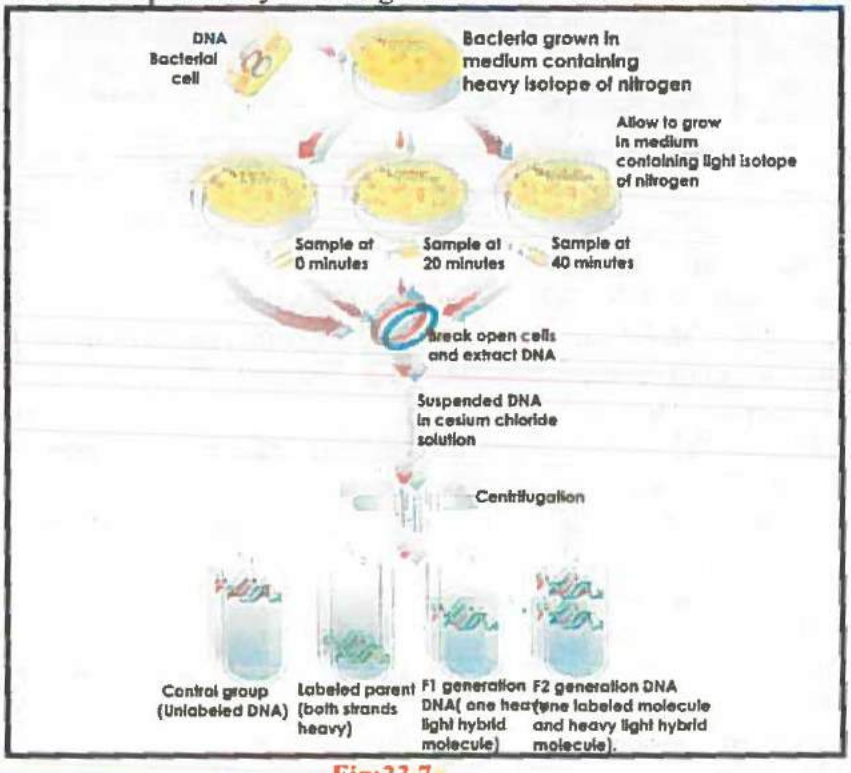


Fig:23.7

Results of centrifugation:

DNA of control sample was appeared lightest as formed sediment at the top of test tube, while DNA of sample at 0 minute was appeared heaviest as it formed sediment at the bottom of test tube. The DNA of sample at 20 minute formed sediment intermediate level to that of control sample and sample at 0 minute whereas sample at 40 minute had two sediments, one at the top and other at intermediate level.

Interpretations of results:

Meselson-Stahl interpreted their results as follows: the DNA of control sample appeared lightest because it had both strands of ^{14}N, whereas DNA of sample at 0 minute appeared heaviest because it had both strand of ^{15}N, but after first round of replication each daughter duplex was a hybrid possessing one strand of ^{14}N and one of ^{15}N, so it formed sediment at intermediate level.

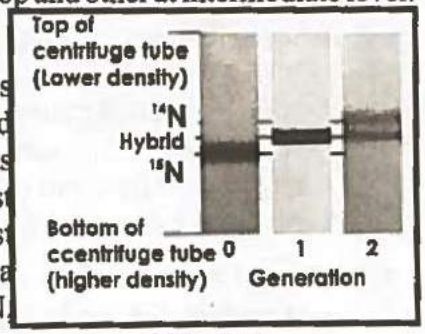


Fig: 23.8

When this hybrid duplex replicated in second round of replication, it contributed ^{15}N strand to form another hybrid duplex and ^{14}N strand to form a light duplex containing both ^{14}N strands that is why this sample formed two sediments. On the basis of above mentioned results, they claimed that the DNA replication is sem iconservative.

23.5.5 Process of DNA replication:

Although DNA replication is a continuous process but here we are going to discuss it in different phases for our convenience.

Initiation phase:

The initiation phase is characterized by the formation of replication bubble and replication fork, which are formed at a particular site, called **origin of replication** site. It is a specific sequence of nucleotides along the length of DNA from where process of replication begins. In eukaryotic DNA there may be more than one origin of replication sites but in prokaryotic DNA there is only one origin of replication.Replication bubble is formed when **DNA gyrase (topoisomerase)** and **DNA helicase** enzymes work at origin of replication. DNA gyrase opens the turns of DNA duplex so the DNA is converted from spiral ladder like form to straight ladder like form. At the same time DNA helicase breaks down the base pairs of DNA so the two strands gradually separate from each other and give a bubble like appearance at origin of replication.

After the breakdown of base pairs, the single strands of DNA are prevented to pair up again by specific proteins called **single stranded binding (SSB)**

proteins. Both single strands of DNA will act as template strand in the next phase and direct the synthesis of daughter strands along themselves. Each side of replication bubble is now termed as **replication fork.**

Extension / Polymerization phase:

Extension or polymerization is referred to the formation of daughter strands (leading or lagging strands) along the template strands. The daughter strands are actually synthesized by **DNA polymerase** enzyme but this enzyme cannot work unless some nucleotides are arranged on template. For this purpose **primase** enzyme is involved to arrange some nucleotides on template stands. Such short fragments of few nucleotides are called **primers**. Each primer is short oligonucleotide strand of RNA, acts as start site for the activity of DNA polymerase.

After the establishment of primers, synthesis of daughter strands begins by the DNA polymerase enzyme. There are three different forms of this enzyme:

- **DNA polymerase-I:** it performs an important role in termination phase of replication so it provides a support to the DNA polymerase-III in the main replication process.
- **DNA polymerase-II:** it involves in the repairing process of DNA damages during the life time of a cell.
- **DNA polymerase-III:** it is the main enzyme that synthesizes both daughter strands along the template during replication process.

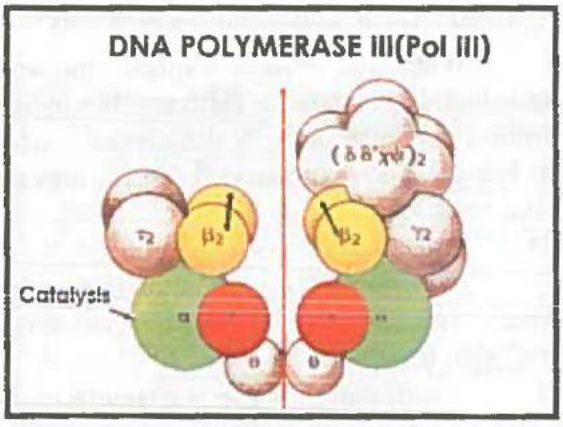


Fig: 23.9

Mechanism of DNA polymerase-III activity:

This enzyme is a huge dimer molecule i.e. it consists of two units that further consist of several sub units. DNA polymerase-III cannot initiates replication process, it can add a nucleotide onto only a preexisting 3'-OH group, and, therefore, needs a primer to perform its polymerase activity. It always adds nucleotide at 3' end of primer so the direction of replication becomes 5' to 3' end. One of its subunit also possesses ability to remove wrong nucleotide if it is added mistakenly. This ability is called proofreading.

Both units of DNA polymerase-III are interlinked by a small polypeptide chain, first unit work on one template and continuously synthesize a daughter strand towards replication fork, this continuously growing daughter strand is called **leading strand,** while the second unit work on other template and synthesize another daughter strand away from replication fork. As the two units are interlinked so the second unit is allowed to polymerize daughter

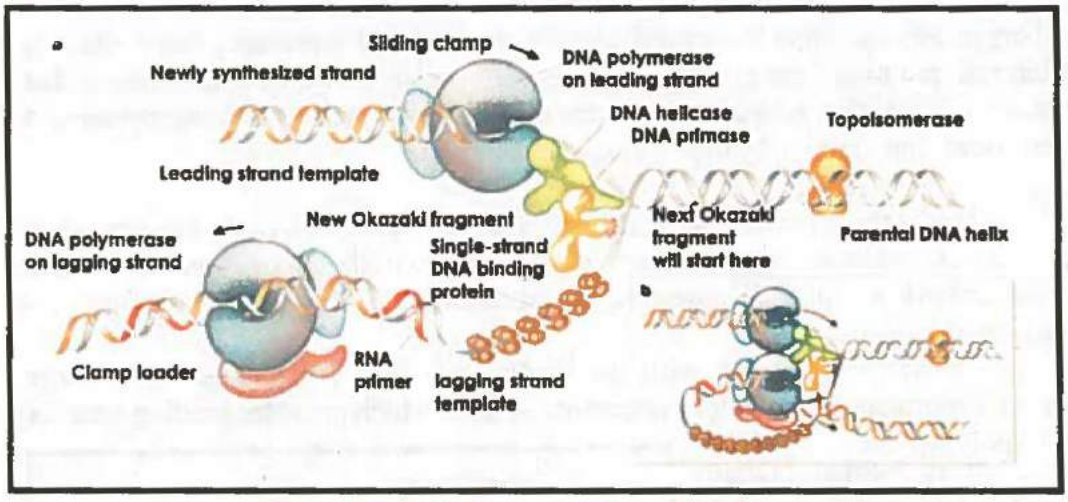


Fig: 23.10 Mechanism of DNA replication.

strand up to a specific length then it has to jump back (100 to 200 nucleotides in prokaryotes and 1000 to 2000 nucleotides in eukaryotes) to a new primer to perform polymerization again. Therefore, this daughter strand grows discontinuously away from the replication fork by forming short fragments interrupted by primers, called **Okazaki' fragments.** This discontinuously growing strand is called **lagging strand.**

Termination phase:

Termination phase is characterized by the replacement of primers by DNA nucleotides and joining of Okazaki's fragments in lagging strand to form a continuous strand.

The replacement of primers by DNA nucleotides is carried out by **DNA polymerase-I** that has dual function i.e. beside **polymerase** it also acts as **exonuclease.** It is attached to the 3' end of Okazaki's fragment where it adds DNA nucleotide so that it can extend while on the other hand it cleaves nucleotide from 5' end of primer. In this way primers are removed and each Okazaki's fragment is extended up to the next Okazaki's fragment but they do not join together.

The joining of Okazaki's fragments is carried out by **DNA ligase** enzyme that finally constructs phosphodiester bonds between Okazaki's fragments so a continuous strand is formed.

23.6 GENE EXPRESSION

23.6.1 Central Dogma of gene expression:

All organisms use same basic mechanism of reading and expressing genes which is often referred to as central dogma. In this mechanism the genetic information that resides in DNA, first flows down into the mRNA by the process of transcription and then convert into protein by the process of translation.

23.6.2 Transcription:

This is the process in which an mRNA copy of the DNA sequence encoding the gene is produced with the help of an enzyme, RNA polymerase. Process of transcription is completed in three phases: initiation, elongation and termination.

Initiation phase:

Transcription begins with the binding of RNA polymerase at promoter region. Promoter is a regulatory region of the gene which provides binding sites for RNA polymerase.

It is located towards the 5' end of coding strand. In prokaryotes, there are two binding sites are located in promoter i.e. TATAAT also called -10 sequence and TTGACA also called -35 sequence, whereas in eukaryotes, TATA (TATA box) also called -25 sequence and CAAT (CAAT box) also called -70 sequence. Names of these sequences (-10, -35 or -25, -70) refer to position that these sequences are located before the initiation site of structural region of the gene.

RNA polymerase consists of four subunits:

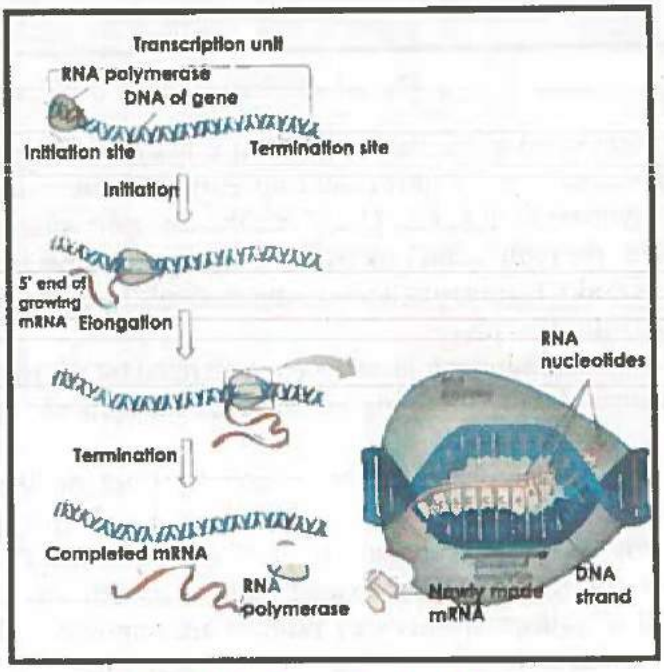


Fig: 23. 11 Transcription Process

beta, beta' and sigma; only the first three subunits are required for polymerase activity and are considered the core enzyme while the sigma factor is required for RNA polymerase to bind to the promoter. It is similar to the DNA polymerase in that it also adds nucleotides to the 3' end of the growing polypeptide chain but unlike DNA polymerase it does not require primer to perform polymerase activity.

In prokaryotes, only one type of RNA polymerase is found while in eukaryotes, there three types of RNA namely RNA polymerase-I, which synthesize rRNA, RNA polymerase-II, which synthesize mRNA, RNA polymerase-III which synthesize tRNA.

As the RNA polymerase binds to the promoter, DNA duplex become unwind, base pairs are broken down, and a bubble like structure, the transcription bubble is appeared.

Elongation phase:

As the RNA polymerase binds to promoter, sigma factor is released and remaining core enzyme extends the polymerization of ribonucleoside triphosphates (rNTP). It does not require primer to initiate polymerization. One of the two strand of the gene acts as template for transcription. This template strand is also called antisense because mRNA is complementary to this strand. The other strand of the gene is called coding or sense strand. In elongation phase RNA polymerase keep on moving from 5' to 3' direction towards the terminator region, beside it transcription bubble also moves along the DNA, leaving the growing RNA strand protruding from the bubble. This event continues till the RNA polymerase reaches the terminator region of the gene.

Termination phase:

The sequence of terminator region of the gene stops the synthesis of mRNA. The terminator region consists of a series of GC base pairs followed by a series of AT base pairs. The part of mRNA which is transcribed in this region, project to form a loop likes structure called GC hairpin followed by a small tail of AU nucleotides. The GC hairpin causes the RNA polymerase to stop the synthesis of RNA.

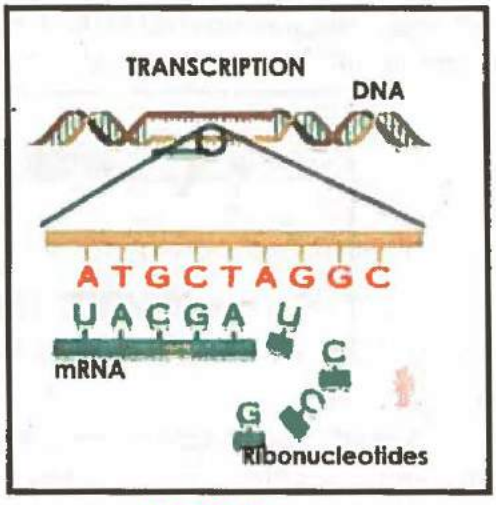


Fig: 23.12

23.6.3 Post Transcriptional Modifications of mRNA:

Post-transcriptional modification is a process by which primary mRNA transcript is converted into mature RNA or functional RNA.

This process is only associated with eukaryotic transcription because in prokaryotes, the mRNA that is synthesized during transcription is ready for translation into a protein due to the absence of a definite nucleus. On the other hand eukaryotic mRNA is produced inside the nucleus, is not immediately ready for translation because it has to pass comparatively long distance to reach ribosomes in the cytoplasm. During this journey, some enzymes like **phosphatases** and **nucleases** can degrade mRNA before its translation.

Another problem is that a newly formed eukaryotic mRNA comprises many non-protein coding sequences. As described earlier in this chapter that eukaryotic genes have a pattern of **exons** (protein coding sequence) and **introns** (non-protein coding sequence). So these non-protein coding sequences from a primary mRNA transcript are to be removed. Post transcriptional modification is therefore involved two events, addition of a cap and tail to protect it from degradation and RNA splicing to remove non-protein coding sequences.

Addition of Cap and Tail:

A cap and a tail are added to both ends of primary mRNA so that the molecule may remain stable and cannot be degraded by phosphatases and nucleases during long journey to ribosome. A cap is in the form of **7-methyl GTP**, which is liked from its 5′ to the 5′ end of mRNA. A modification also takes place at the opposite end of the RNA transcript in the form of a small chain of 30-500 adenine nucleotides, called poly-A tail, which is attached to the 3' end of the mRNA. These two modifications prevent the mRNA to be degraded by phosphatases and nucleases.

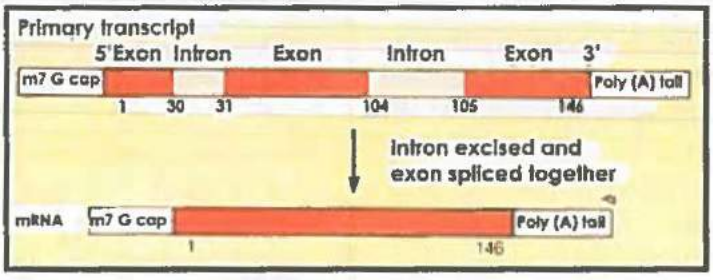


Fig: 23.13

RNA Splicing:

A newly emerged eukaryotic mRNA is very long as it contains both exon and intron sequences. Introns are non-protein coding sequences, which are to be removed form primary mRNA before its translation on ribosome.

This removal of introns and maturation of primary mRNA to secondary or functional mRNA is called **RNA splicing.**

23.6.4 Genetic Code:

The sequence of nucleotides in DNA or RNA that determines the specific amino acid sequences of the proteins is called genetic code. It is the biochemical basis of heredity and nearly universal in all organisms. The Genetic Code is stored on one of the two strands (the coding or sense strand) of a DNA molecules as a linear, non-overlapping sequence of the nucleotides.

The genetic code is a coded language, which is based on an "alphabet" consisting of only four types of nucleotides Adenine (A), Guanine (G), Cytosine (C) and Thymine (T), which are variously arrange to form code words called **codons.** Usually, a codon specifies an amino acid so the order in which codons are arranged in mRNA, determines the order in which the amino acids are arranged in a protein

Each code word (codon) is a unique combination of three letters that will eventually be interpreted as a single amino acid in a polypeptide chain. There are 64 code words possible from an 'alphabet' of four letters.

One of these code words, the start codon (AUG) begins all the sequences that code for amino acid chains. Three of these code words act as stop codons (UGA, UAG, and UAA) that indicate that the message is over. Since, these three codons do not encode any amino acid, hence called non sense codon, while all the other sequences that encode specific amino acids are called sense codons.

Second letter

First letter	U	C	A	G	
U	UUU, UUC Phenyl-alanine UUA, UUG Leucine	UCU, UCC, UCA, UCG Serine	UAU, UAC Tyrosine UAA, UAG Stop codon Stop codon	UGU, UGC Cytosine UGA Stop codon UGG Tryptophan	U C A G
C	CUU, CUC, CUA, CUG Leucine	CCU, CCC, CCA, CCG Proline	CAU, CAC Histidine CAA, CAG Glutamine	CGU, CGC, CGA, CGG Arginine	U C A G
A	AUU, AUC, AUA Isoleucine AUG Methionine	ACU, ACC, ACA, ACG Threonine	AAU, AAC Asparagine AAA, AAg Lysine	AGU, AGC Serine AGA, AGG Arginine	U C A G
G	GUU, GUC, GUA, GUG Valine	GCU, GCC, GCA, GCG Alanine	GAU, GAC Aspartic acid GAA, GAG Glutamic acid	GGU, GGC, GGA, GGG Glycine	U C A G

Some amino acids are only coded for by a single codon; while some others are coded for by up to four codons and amino acids leucine and serine are encoded by six codons.

Degeneracy of the genetic code is an important characteristic which refers that an amino acid can be encoded by more than one codons but a particular codon does not specify more than one amino acid. So the genetic code has redundancy but no ambiguity. For example, although codons GAA and GAG both specify glutamic acid (redundancy), neither of them specifies any other amino acid (no ambiguity).

The genetic code is universal. It is the same in almost all the organisms. For example AGA specifies arginine in bacteria, in humans and all other organisms whose genetic code has been studied. Because of the universality of codon the genes can be transferred from one organism to another and be successfully transcribed and translated in their new host.

The study of genetic code of mitochondrial DNA however, showed that genetic code is not that universal. For example:

Codon	Nuclear DNA	Mitochondrial DNA
UGA	Stop codon	Tryptophan
AUA	Iso leucine	Methionine
AGA & AGG	Arginine	Stop Codon

Thus it appears that genetic code is not quite universal.

23.6.5 Translation:

Translation is the second stage of protein synthesis (gene expression). In translation, messenger RNA (mRNA) produced by transcription is decoded by the ribosome to produce a specific amino acid chain, or polypeptide, that will later fold into an active protein. In Bacteria, translation occurs in the cell's cytoplasm, where the large and small subunits of the ribosome are located, and bind to the mRNA. In Eukaryotes, translation occurs across the membrane of the endoplasmic reticulum.

Although translation is a continuous process but for convenience we will discuss it in four phases: activation, initiation, elongation and termination. After that the product of translation in the form of amino acid chain, or polypeptide is formed.

I. Activation of amino acids:

Activation of amino acids refers to the binding of free amino acids dispersed in cytoplasm to the 3' end of particular tRNA molecules, in this way a complex is formed called aminocyl tRNA complex is formed. This binding is catalyzed by aminocyl tRNA synthase (activation enzyme). Various amino acids that are to be take part in polypeptide formation have been continuously activated throughout the process of translation.

ii. Formation of initiation complex:

Process of translation actually begins with the formation of initiation complex. It is formed by the combination of ribosomal subunits, mRNA and first aminocyl tRNA complex. First a tRNA molecule carrying a chemically modified methionine (called N-formyl methionine) binds to the smaller ribosomal subunit. This binding is controlled by an enzyme called initiation factor. At the same time 5′ end of mRNA molecule also binds to the ribosome with the help of another initiation factor. Initiation complex is completed when larger subunit of ribosome is also placed upon smaller subunit.

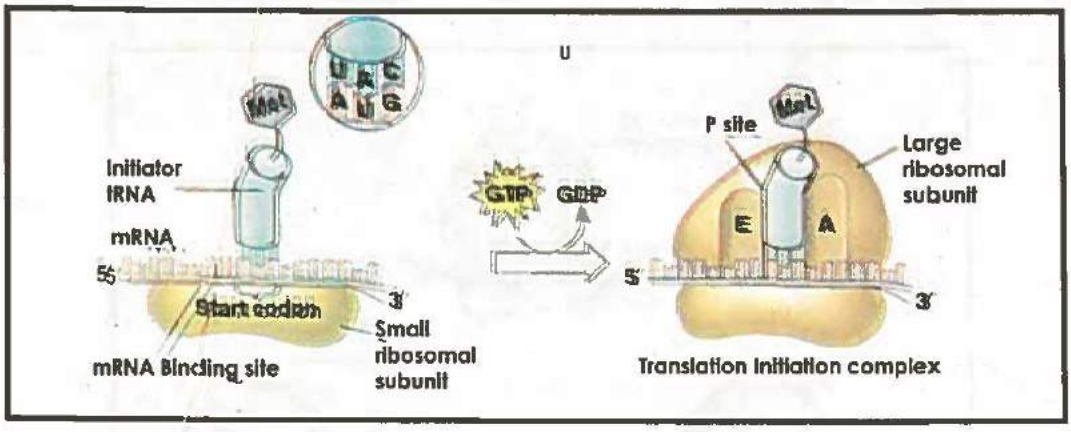


Fig: 23.14 Translation Process

The region of smaller ribosomal subunit where first aminocyl tRNA complex is attached is called P site (peptidyl site), here peptide bonds will be formed between successive amino acids during elongation phase. Nearby two other sites are also established. A site (aminocyl site) where successive tRNAs bearing amino acids will be attached and E site (exit site) where empty tRNAs will leave ribosome during elongation phase.

iii. Polypeptide elongation:

In this phase ribosomal units move along mRNA, amino acids are brought by tRNAs, which are joined together to form a polypeptide chain. This is accomplished by three steps which are repeated again and again throughout this phase.

- Whichever codon of mRNA is exposed at A site, its anticodon bearing aminocyl tRNA complex binds to it with the help of an enzyme, the elongation factor.

- Then an enzyme peptidyl transferase is emerged from P site. It removes the amino acid (may be a chain) from tRNA present on P site and binds it to the newly coming amino acid with the help of peptide bond.
- Then ribosomal sub units slightly move along mRNA from 5′ to 3′ direction so that a new codon is exposed at A site. This movement is called translocation. As a result, the empty tRNA is reached at E site to leave the ribosome, while the other tRNA bearing a chain of amino acid is shifted from A site to P site, and another codon is exposed to A site.
- These three steps are repeated again and again until the stop codon is reached at A site.

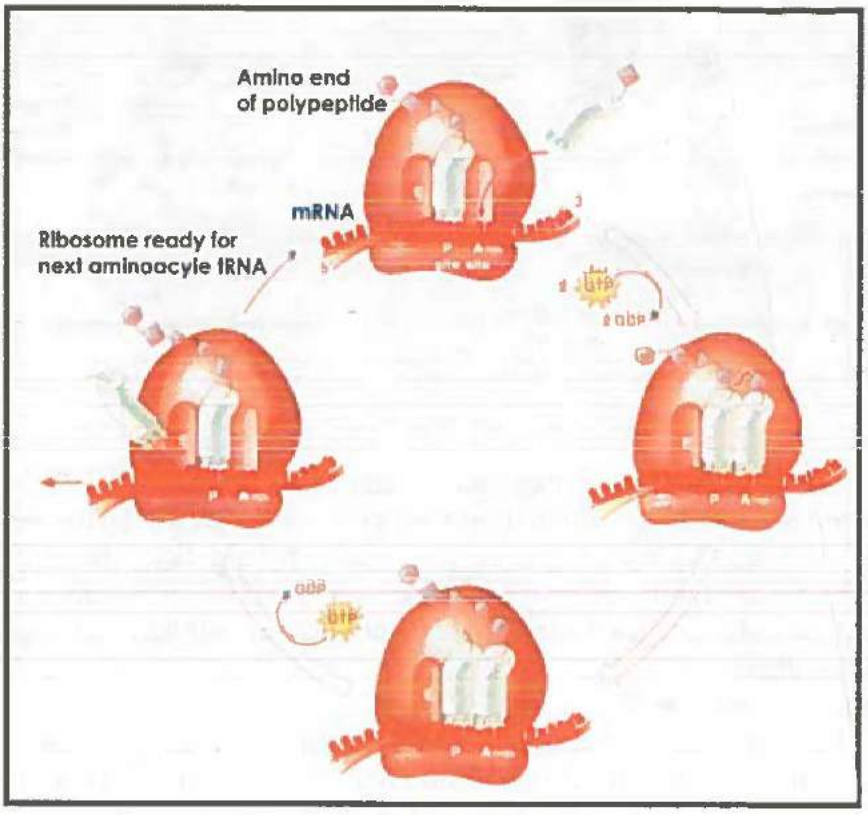


Fig: 23.15

iii. Termination:

Elongation continues in this fashion until a chain-terminating non sense codon is exposed at A site.

Non sense codons do not bind to any tRNA, but they recognize by release factors that terminate the process of translation and the polypeptide is released from the tRNA, the tRNA is released from the ribosome, and the two ribosomal subunits separate from the mRNA.

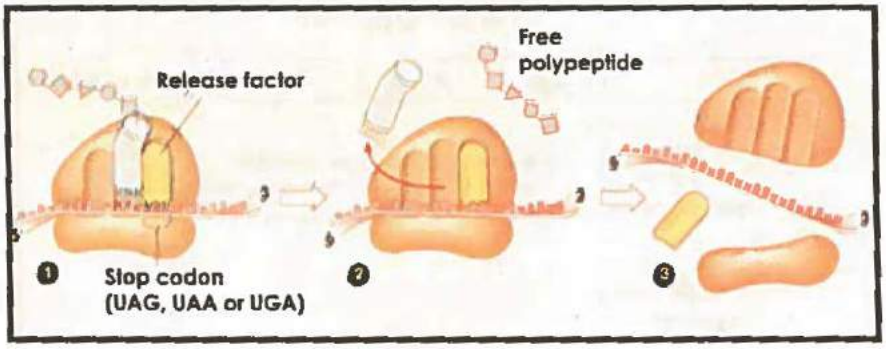


Fig: 23.16 Termination process.

23.7 REGULATION OF GENE EXPRESSION

23.7.1 Importance of gene regulation:

Regulation of gene expression (or gene regulation) is essential for prokaryotes and eukaryotes as it increases the versatility and adaptability of an organism by allowing the cell to express protein when needed. Furthermore, gene regulation drives the processes of cellular differentiation and morphogenesis, leading to the creation of different cell types in multicellular organisms where the different types of cells may possess different gene expression profiles though they all possess the same genome sequence.

23.7.2 Methods of gene regulation:

There are two possible ways of regulation of gene expression, positive regulation and negative regulation. When the expression of genes is quantitatively increased by the presence of specific regulatory protein (**the activator**) is called **positive gene regulation**. Whereas, when the expression of genes is diminished by the presence of specific regulatory protein (**the repressor**) is called **negative gene regulation**.

23.7.3 *Lac* Operon (Dual Positive and Negative Control of gene expression):

A classic example of a positive regulation in bacteria is the *lac* operon, responsible for obtaining energy from β-galactosides such as lactose.

In bacteria, genes are clustered into operons which are gene clusters that encode the proteins necessary to perform coordinated function, such as catabolism of a substrate obtained from outside (***lac* operon**) or biosynthesis of a given amino acid (***trp* operon**).

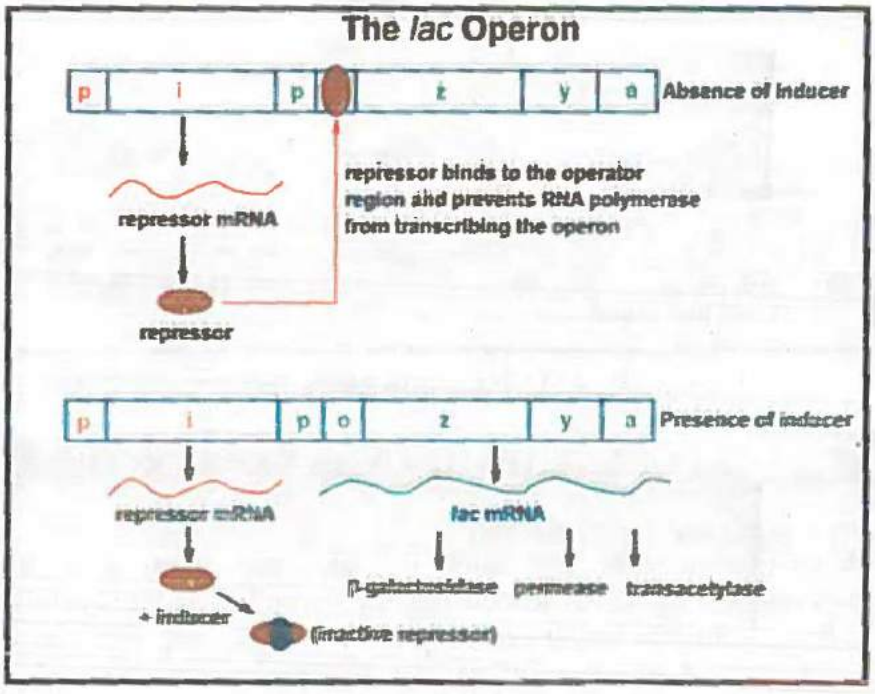


Fig: 23.17

RNA that is transcribed from prokaryotic operons is **polycistronic** a term implying that multiple proteins are encoded in a single transcript.

The *lac* operon (see diagram below) consists of one regulatory gene (the *i* gene) and three structural genes (*z*, *y*, and *a*). The *i* gene codes for the repressor of the *lac* operon. The *z* gene codes for **β-galactosidase (β-gal),** which is primarily responsible for the hydrolysis of the disaccharide, lactose into its monomeric units, galactose and glucose. The *y* gene codes for **permease**, which increases permeability of the cell to β-galactosides. The *a* gene encodes a **transacetylase**, an enzyme that transfers an acetyl group from acetyl-CoA to β-galactosides. Its precise function as part of the *lac* operon is not understood currently.

23.8 MUTATION

A gene mutation is a permanent change in the DNA sequence that makes up a new allele in the population. Mutations range in size from change in a single DNA nucleotide to a large segment of a chromosome or whole chromosome or some times changes in the number of chromosome. Mutations are caused by radiation, viruses, transposons and mutagenic chemicals, as well as errors that occur during meiosis or DNA replication. These agents that cause mutations are called **mutagens** while the organism in which mutation is occurred is called **mutant.**

Some mutations are very rare; others are common in the population. Mutations that occur in more than one percent of the population are called **polymorphisms**. They are common enough to be considered a normal variation in the DNA. Polymorphisms are responsible for many of the normal differences between people such as eye color, hair color, and blood type. Although many polymorphisms have no negative effects on a person's health, some of these variations may influence the risk of developing certain disorders.

23.8.1 Origin of Mutation:

Gene mutations occur in two ways: they can be inherited from a parent or acquired during a person's lifetime. Mutations that are passed from parent to child are called **hereditary mutations** or **germ line mutations** (because they are present in the egg and sperm cells, which are also called germ cells). This type of mutation is present throughout a person's life in virtually every cell in the body.

Mutations that occur only in an egg or sperm cell, or those that occur just after fertilization, are called **new (de novo) mutations**. De novo mutations may explain genetic disorders in which an affected child has a mutation in every cell, but has no family history of the disorder.

Acquired (or somatic) mutations occur in the DNA of individual cells at some time during a person's life. These changes can be caused by environmental factors such as ultraviolet radiation from the sun, or can occur if a mistake is made as DNA copies itself during cell division. Acquired mutations in somatic cells (cells other than sperm and egg cells) cannot be passed on to the next generation.

23.8.2 Types of mutation:

Mutations are of two types on the basis of how mutation occurs in cells. The mutations which occur naturally and automatically due to internal factors are called **spontaneous mutations**, whereas the mutations which are produced by external factors are called **induced mutations.**

Mutations are of two types on the basis of where the mutations occur and to what extent. A mutation that causes change of single or few nucleotides in the DNA is called **point mutation,** whereas the mutation that causes change in the structure or number of chromosome is called **chromosomal mutation or aberration.**

Point mutations involve a sudden change in the sequence of nucleotides of a gene that causes change in the phenotype of an organism. Such mutations occur in following ways:

- **Deletion:** It is the removal of one or few nucleotide from a particular segment of DNA. For example:

ATTAGCCTTAGAACT

↓ Deletion

ATTAGCCTAGAACT

- **Insertion:** It is the addition of one or few nucleotide in a particular segment of DNA. For example:

ATTAGCCTTAGAACT

↓ Insertion

ATTAGCC AA TTAGAACT

- **Base substitution:** It is the replacement of one or few nucleotide in a particular segment of DNA. For example:

ATTAGCCTTAGAACT

↓ Base substitution

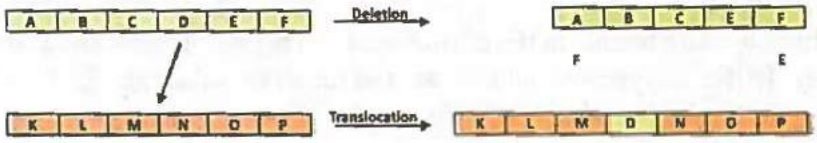
ATTAGCC A TAGAACT

Structural changes in chromosome are the type of chromosomal mutations or aberrations. Such changes in chromosomes take place during meiosis when due to certain mutagen chromosome is split down into several fragments but later on when these fragments reunite, its new pattern become changed from original one . Structural changes in chromosome are of following type:

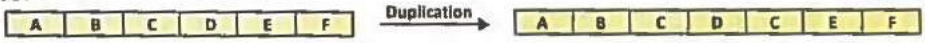
Deletion: It is the removal of a segment of chromosome comprising single of few genes. For example:

Inversion: In this case a portion of a chromosome breaks off, turns around and joins again in such a way that the sequence of genes gets reversed. For example:

Translocation: It involves shifting of a segment of one chromosome to another non homologous chromosome. Thus both the chromosomes are affected. The donor chromosome suffers a deletion, while the recepient chromosome becomes longer than normal. For example:



Duplication: It is the repetition of one or few genes in the same chromosome. For example:



Another aspect of chromosomal aberration is the change in the number of chromosome which occurs due to chromosomal non disjunction during meiosis. Change in the number of chromosome due to addition or loss of one or more chromosome is called **aneuploidy**, whereas change in the number of chromosome due to addition or loss of one or more complete set of chromosome is called **euploidy.** Aneuploidy may be of following type:

- **Monosomy (*2n - 1*):** It is the result of loss of single chromosome from the diploid set.
- **Nullisomy (*2n - 2*):** It is the result of loss of a pair of homologous chromosome from the diploid set.
- **Trisomy (*2n + 1*):** It is the result of addition of single chromosome in the diploid set. For example: Down's syndrome and Klinfelter's syndrome.
- **Tetrasomy (*2n + 2*):** It is the result of addition of a pair of homologous chromosome in the diploid set.

Euploidy is the state of a cell or organism having an integral multiple of the **monoploid** (single set) number of chromosome. It is also called **polyploidy**. It exist in various forms like **triploidy** (three sets), **tetraploidy** (four sets), **pentaploidy** (five sets), **hexaploidy** (six sets) and so on. As a general rule polyploids can be tolerated in plants, but are rarely found in animals. One reason is that the sex balance is important in animals and variation from the diploid number results in sterility.

23.8.3 Types of Mutagens:

Mutations can be artificially produced (induced mutation) by certain agents called mutagens or mutagenic agents. Following are two major types of mutagens.

Physical Mutagens:

Short wave radiations are the most important physical mutagens. H. J. Muller was the first to induce mutations using X rays in drosophila. Other than X rays, gamma rays and ultra violet radiation can be used to induce mutations. The main source of spontaneous mutations is the natural radiations coming from cosmic rays of the sun. They occur in small amounts in the environment and are known as background radiations.

Radiation cause breaks in the chromosome. These cells then show abnormal cell divisions. Different types of cancers are the result of radiations. UV rays affect the structure of DNA helix and also affect the replication process.

Chemical Mutagens:

A number of chemicals act as mutagens such as nitrous acid, formaldehyde, mustard gas, 5-bromouracil; acridines etc. chemicals such as colchicine induce polyploidy in cells. Caffeine, nicotine, food preservatives and pesticides are also mutagenic. The first chemical mutagen discovered was mustard gas that was used as chemical weapon during 1st world war.

23.8 DISEASES INDUCED BY MUTATION

23.8.4 Sickle Cell Anemia (Drepanocytosis):

Sickle-cell anaemia is an autosomal recessive genetic blood disorder characterized by abnormal, rigid, sickle shape red blood cells. Sickle shape decreases the cells' flexibility due to which they can also get stuck more easily in small blood vessels, and break into pieces that interrupt healthy blood flow.

Signs and Symptoms:

Signs and symptoms of sickle cell disease usually begin in early childhood. Characteristic features of this disorder include a low number of red blood cells (anemia), repeated infections, and periodic episodes of pain. Anemia can cause shortness of breath, fatigue, and delayed growth and development in children. The rapid breakdown of red blood cells may also cause yellowing of the eyes and skin, which are signs of jaundice. Almost all patients with sickle cell anemia have painful episodes (called crises), which can last from hours to days. These crises can affect the bones of the back, the long bones, and the chest.

Cause & Risk Factor:

Sickle cell anemia is caused by a recessive allele *HbS* which encode defective β globin chain as a result abnormal haemoglobin is formed called **haemoglobin S.** HbS is originated from HbA (normal haemoglobin gene) due to a point mutation. The patients inherit two such alleles from both parents. The parents of an individual with an autosomal recessive condition each carry one copy of the mutated gene, but they typically do not show signs and symptoms of the condition. Sickle cell disease is much more common in people of African and Mediterranean descent. It is also seen in people from South and Central America, the Caribbean, and the Middle East.

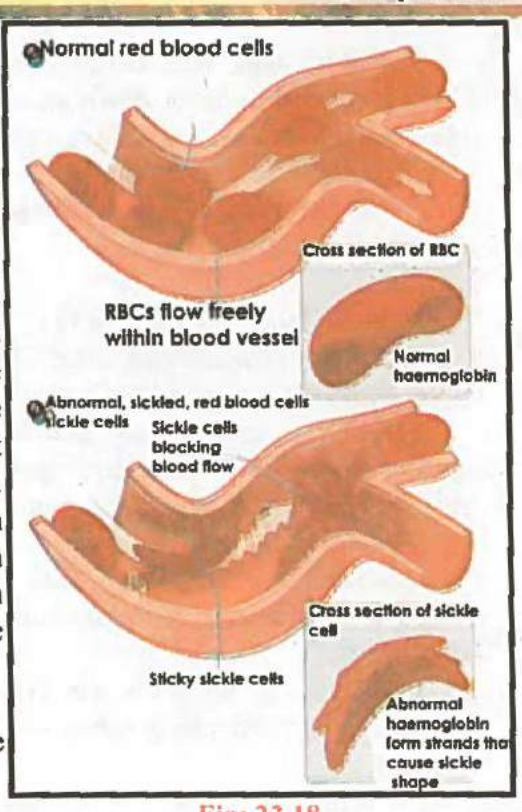


Fig: 23.18

Treatment:

The goal of treatment is to manage and control symptoms, and to limit the number of crises. Folic acid supplements should be taken. Folic acid is needed to make red blood cells.

Treatment for a sickle cell crisis includes: blood transfusions (may also be given regularly to prevent stroke), pain medicines, plenty of fluids

Other treatments for sickle cell anemia may include: hydroxyurea (Hydrea), a medicine that may help reduce the number of pain episodes (including chest pain and difficulty breathing) in some people, antibiotics to prevent bacterial infections, which are common in children with sickle cell disease.

23.8.5 Phenylketonuria:

Phenylketonuria (PKU) is a rare condition in which a baby is born without the ability to properly break down an amino acid called **phenylalanine.**

Causes, incidence, and risk factors:

Phenylketonuria (PKU) is inherited, which means it is passed down through families. Both parents must pass on the defective gene in order for a baby to have the condition. This is called an autosomal recessive trait.

Babies with PKU are missing an enzyme called ***phenylalanine hydroxylase***, which is needed to break down an essential amino acid called phenylalanine. The substance is found in foods that contain protein.

Without the enzyme, levels of phenylalanine and two closely-related substances build up in the body. These substances are harmful to the central nervous system and cause brain damage.

Symptoms:

Phenylalanine plays a role in the body's production of melanin, the pigment responsible for skin and hair color. Therefore, infants with the condition often have lighter skin, hair, and eyes than brothers or sisters without the disease.

Other symptoms may include: delayed mental and social skills, head size significantly below normal, hyperactivity, jerking movements of the arms or legs, mental retardation, skin rashes, tremors, and unusual positioning of hands.

If the condition is untreated or foods containing phenylalanine are not avoided, a "mousy" or "musty" odor may be detected on the breath and skin and in urine. The unusual odor is due to a buildup of phenylalanine substances in the body.

Treatment:

PKU is a treatable disease. Treatment involves a diet that is extremely low in phenylalanine, particularly when the child is growing. The diet must be strictly followed.

Phenylalanine occurs in significant amounts in milk, eggs, and other common foods. The artificial sweetener Nutra Sweet (aspartame) also contains phenylalanine. Any products containing aspartame should be avoided.

A special infant formula called Lofenalac is made for infants with PKU. It can be used throughout life as a protein source that is extremely low in phenylalanine and balanced for the remaining essential amino acids.

23.8.6 Down syndrome:

Down syndrome (also called trisomy 21) is a chromosomal condition characterized by the presence of an extra copy of 21st chromosome, either in whole or part (such as due to translocations). So these individuals generally have 47 chromosomes (2n + 1).

Sign and Symptoms:

Although the severity of Down syndrome ranges from mild to severe, most individuals with Down syndrome have widely recognizable physical characteristics. These include:

Fig: 23.19

- α flattened face and nose, a short neck, a small mouth sometimes with a large, protruding tongue, small ears, upward slanting eyes that may have small skin folds at the inner corner (epicanthic fold) and inner corner of the eyes may be rounded instead of pointed;
- white spots (also known as Brushfield spots) may be present on the colored part of the eye (iris);
- the hands are short and broad with short fingers, and with a single crease in the palm;
- poor muscle tone and loose ligaments are also common; and
- development and growth is usually delayed and often average height and developmental milestones are not reached

For Your Information

Down syndrome is named after **Doctor Langdon Down**, a British physician, who in 1866 first described the syndrome as a disorder. Although Doctor Down made some important observations about Down syndrome, he did not correctly identify what causes the disorder. It wasn't until 1959 that **Dr. Jérôme Lejeune** discovered the genetic origin of Down syndrome

Causes & risk factor:

It is the consequence of **autosomal non-disjunction** during which 21st chromosome fail to segregate, resulting gamete with 24 chromosomes. This gamete fertilizes normal gamete the new individual will have 47 ($2n + 1$) chromosomes.

The incidence of Down syndrome is estimated 1 per 800 births before the age of 30, although it is statistically more common with older parents (especially mothers), for example, a woman has risk of Down syndrome up to about 1 in 350 by age 35. By 40 the risk rises to about 1 in 100.

For Your Information

The average IQ of children with Down syndrome is around 50, compared to normal children with an IQ of 100. A small number have a severe to high degree of intellectual disability.

Treatment:

Although the genetic cause of Down syndrome is known, there is no specific treatment available currently. But it can be managed to some extent by taking few measures like:

- Corrective surgery for heart defects, gastrointestinal irregularities, and other health issues is necessary for some individuals.
- Regular health checkups should be scheduled to screen for other conditions such as visual impairments, ear infections, hearing loss, hypothyroidism, obesity, and other medical conditions.
- Individuals with Down syndrome should be fully included in family and community life because many children with Down syndrome who have received family support, enrichment therapies, and tutoring have been known to graduate from high school and college, and enjoy employment in the work force.

23.8.7 Klinefelter's Syndrome:

Klinefelter syndrome (also called XXY syndrome) is a condition in which human males have an extra X chromosome. Klinefelter syndrome is named after **Dr. Henry Klinefelter**, who in 1942, first described a group of symptoms found in some men. In 1959, these men with Klinefelter syndrome were discovered to have an extra sex chromosome (XXY) instead of the usual male sex complement (XY).

Signs & Symptoms:

All affected males with the condition do not have the same symptoms or to the same degree.

- As babies, many XXY males have weak muscles and reduced strength. They may sit up, crawl, and walk later than other infants.
- As XXY males enter puberty, they often don't make as much testosterone as other boys. This can lead to a taller, less muscular body, less facial and body hair, and broader hips than other boys.
- As teens, XXY males may have larger breasts, weaker bones, and a lower energy level than other boys. They tend to be quiet and shy meaning they may have more trouble "fitting in" with other kids
- By adulthood, XXY males look similar to males without the condition, although they are often taller. XXY males can have normal sex lives, but they usually make little or no sperm. Between 95 percent and 99 percent of XXY males are infertile
- They may have some kind of trouble using language to express thoughts and needs, problems reading, and trouble processing what they hear.

Cause & Risk:

Klinefelter's syndrome is caused by non-disjunction of sex chromosome during oogenesis in mothers. These persons inherit two X chromosome from mother and a Y chromosome from father, so they have sex chromosome trisomy (XXY).

Klinefelter's syndrome affects 1 in 500 to 1,000 males. Most variants of Klinefelter syndrome are much rarer, occurring in 1 in 50,000 or fewer male births. Klinefelter syndrome does not occur in females.

Treatment:

The XXY chromosome pattern cannot be changed. But, there are a variety of ways to treat the symptoms of the XXY condition.

Testosterone replacement therapy (TRT) can greatly help XXY males get their testosterone levels into normal range to develop more masculine appearance and identity. Having a more normal testosterone level can help develop bigger muscles, deepen the voice, and grow facial and body hair. With treatment, most boys grow up to have normal sex lives, successful careers and normal social relationships. Educational services and physical, speech and occupational therapy may also increase their confidence level.

23.8.8 Turner's syndrome:

Turner's syndrome is chromosomal disorder which is characterize by the missing of one X chromosome (44 + X). In 1938, Henry Turner first described Turner syndrome. Since these persons do not have Y chromosome so they always develop as female.

Signs & Symptoms:

- More than 95% of adult women with Turner syndrome exhibit short stature.
- They have non-functioning ovaries which do not produce sex hormones (estrogen and progesterone) so they do not start menstruation or dev elop breasts without hormone treatment at the age of puberty.
- Even though many women who have Turner have non-functioning ovaries and are infertile, their other genitalia are totally normal so pregnancy with donor embryos may be possible.
- In early childhood, these girls may have frequent middle ear infections. Recurrent infections can lead to hearing loss in some cases.
- These girls have normal intelligence with good verbal skills and reading skills. Some girls, however, have problems with mathematics, memory skills and fine-finger movements.

Cause and Risk:

Turner's syndrome is caused by sex chromosomal non-disjunction that may occur during oogenesis in mother. As a result mother produces an egg lacking X chromosome (nullo gamete). When such egg is fertilized by an X chromosome containing sperm, the female baby is developed with 44 autosomes and one X chromosome (monosomy). This condition occurs in about 1 in 2,500 female births worldwide, but is much more common among pregnancies that do not survive to term (miscarriages and stillbirths).

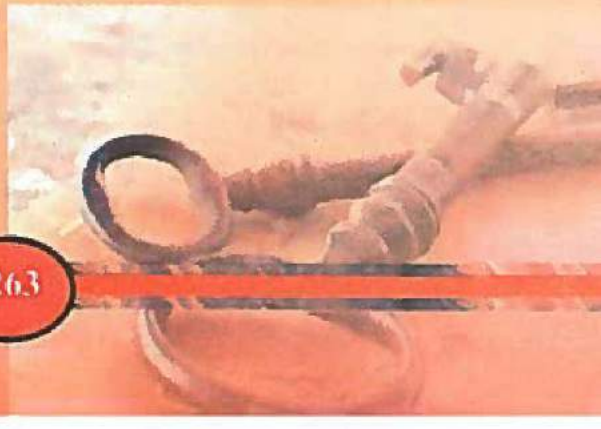
Treatment:

Having appropriate medical treatment and support allows a woman with Turner syndrome to lead a normal, healthy and happy life. Treatments include:

- Growth hormone injections are beneficial to increase final adult height by a few inches.
- Estrogen & progesterone replacement therapy can help in breast development and start of menstruation which is necessary to keep the womb healthy; it also prevents osteoporosis.

KEY POINTS

- All animals and plant cells have nuclei.
- Nucleus contains chromosomes.
- Chromosomes are composed of DNA and protein.
- The number, shape and size of chromosomes is same for a particular species.
- DNA is stable molecule and capable of self-duplication with full conservation of its specificity.
- DNA is polynucleotide chain of four different kinds of nucleotide. The difference in the type of nucleotide lies in the type of nitrogen bases, adenine, guanine called purine and cytosine, thymine called pyrimidine.
- Two strands of double helix molecule of DNA are formed of sugar and phosphate group bounded in linear sequence and held together by hydrogen bonds between specific kinds of bases.
- Two strands of DNA molecule separate from each other during DNA replication, each serving as a model for the synthesis of new complimentary strand
- Sometime errors occur in replication resulting in alteration in base sequence along DNA molecule.
- Change in the base sequence result in mutation.
- Proteins are long polypeptide chains of amino acids.
- Each gene directs the synthesis of a particular polypeptide chain.
- Three kinds of RNA take part in the synthesis of protein and these are mRNA, tRNA, rRNA.
- Code lying in chromosomal DNA is transcribed in mRNA, which is translated by tRNA in ribosome into polypeptide chain.
- Change at gene level or change in the structure or number of chromosomes result in mutation.



EXERCISE

1- Multiple Choice Questions

(i) ***A chromosome with unequal length of its arms is called:***

(a) Metacentric (b) Sub metacentric
(c) Acrocentric (d) Telocentric

(ii) ***In Hershey & Chase experiment, ^{32}P labeled bacteriophages allowed to infect the bacteria. During analysis ^{32}P activity was detected:***

(a) In culture medium
(b) On the surface of bacterial cell
(c) Inside the bacterial cell
(d) Both a & b

(iii) ***In Meselson & Stahl experiment, the DNA from sample at 20 minutes, after centrifugation it made sediments at the:***

(a) Top (b) Bottom
(c) Intermediate (d) Top & intermediate

(iv) ***Which of the following act as a stop codon?***

(a) UGG (b) UGC
(c) UAG (d) UGU

(v) ***In mitochondria UGA codon act to specify ------- instead stop codon:***

(a) Argenine (b) Valine
(c) Glutamic acid (d) Trytophan

(vi) ***If the amount of adenine in DNA of a bacterial cell is 36% of the total nitrogenous bases, what will be the amount of guanine in the DNA of a cell in next generation:***

(a) 14% (b) 28%
(c) 36% (d) 64%

(vii) ***If an mRNA is synthesized with all the different codons, what is the minimum number of amino acids in the protein that is formed by mRNA:***

(a) 64 Amino acids (b) 62 Amino acids
(c) 60 Amino acids (d) None of them

(viii) ***In eukaryotic mRNA molecule there are 90 nucleotide involved in translation process. What is the number of amino acid in the protein formed by this mRNA molecule?***

(a) 29 amino acids (b) 30 amino acids
(c) 45 amino acids (d) 90 amino acids

EXERCISE ?

(ix) In Griffith experiment mice developed pneumonia when they were injected with:

(a) R-type bacteria
(b) heat killed S-type bacteria
(c) heat killed R-type bases
(d) heat killed S-type bacteria along with live R-type bacteria.

(x) If the codon consisted of only two nucleotides, there would be how many possible codons?

(a) 4 (b) 8
(c) 20 (d) 16

2- Short Questions

(i) Differentiate the concept of monoploid and haploid.
(ii) List are the types and role of histone proteins in chromosome?
(iii) Give any two evidences provided by Sutton in favour of chromosome theory of inheritance.
(iv) What was the conclusion of Avery's experiment?
(v) Differentiate between conservative and semiconservative models of DNA replication.
(vi) Give a brief comparison between RNA polymerase and DNA polymerase.
(vii) "Genetic codes are universal but not quite universal". Analyze this statement.
(viii) Summarize the structure of a eukaryotic gene?
(ix) Define RNA splicing?
(x) What is the structure of *Lac* Operon?

3- Long Questions

(i) Critically analyze the history of chromosome theory of inheritance.
(ii) Prove that an evidence of DNA as heredity material.
(iii) Eloborate the work of Meselson & Stahl to justify the semi conservative replication as a correct model of replication.
(iv) Describe the events of the process of DNA replication.
(v) Describe post transcriptional modification of mRNA.
(vi) Explain the process of translation of mRNA into polypeptide.
(vii) Discuss the regulation of gene expression with help of *lac* operon model.
(viii) Describe cause, symptoms, and treatment of Down's syndrome.

EXERCISE ?

4- **Analyzing and Interpreting**

- Interpret an experiment in which a radio isotope labeled DNA can be traced in the progeny of an organism.
- Interpret how DNA conserves one strand during replication.
- Interpret that how many types of tRNA molecules are necessary for a living cell, if the genetic code is a triplet code.

5- **Initiating and Planning**

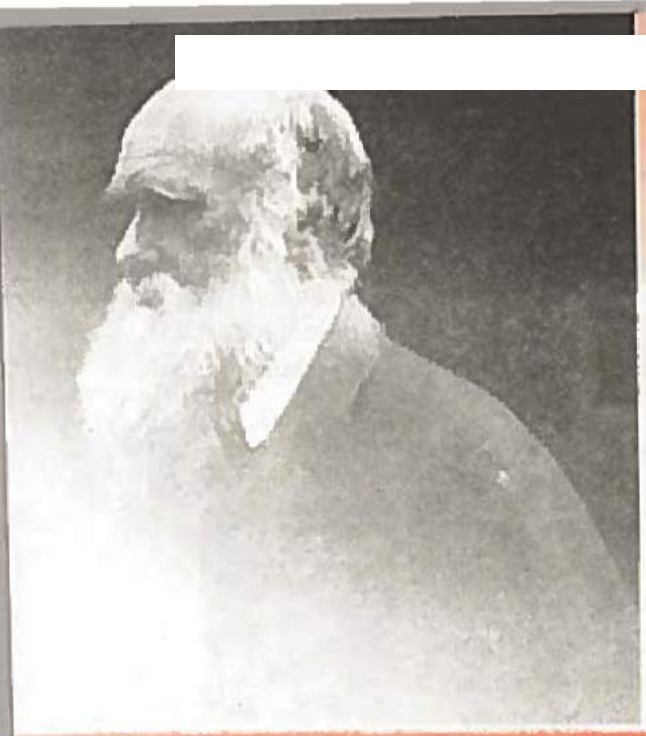
- Make a list of all the proteins that have been studied or referred to till now.
- Make list of some commonly occurring minor mutation in human.
- Justify why mutations prevail in a population and are inherited.

6- **Science, Technology, and Society Connections**

- Describe the paradoxical nature of DNA, as a tool of geneticists and forensics
- Describe how various scientists in the field of biotechnology and genetic engineering have used the DNA replication.
- Suggest possible ways to solve lives or treat genetic diseases (like diabetes) through the knowledge gained under this heading.
- Explain how harmful mutations have been eradicated by nature.

7- **Online Learning**

- www.johnkyrk.com/DNAreplication
- www.genome.wellcome.ac.uk
- www.scienceblogs.com
- www.ghr.nlm.nih.gov
- www.biobase-international.com.



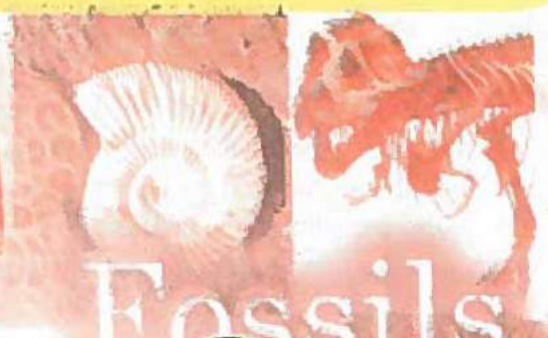
UNIT

24

EVOLUTION

KEY CONCEPTS

24.1 The concept of evolution
24.2 Evolution of eukaryotes from prokaryotes
24.3 Lamarckism
24.4 Darwinism
24.5 Neo-Darwinism



Fossils

Man has always been curious to know how, when and where life originated; and how the diverse forms of animals and plants came into existence. Many scientific and non-scientific theories have been put forth so for regarding the origin of life on earth like special creation, spontaneous generation, cosmozoan, and biochemical evolution. Widely regarded are special creation and biochemical evolution.

24.1 THE EVOLUTION OF THE CONCEPT OF EVOLUTION

Fig: 24.1 Aristotle

Aristotle (384-322 B.C), one of the first great naturalists, categorized all the living things that he encountered. Aristotle thought that all organisms fit into an orderly scheme, later called the *Scala Naturae,* or Ladder of Nature. The ladder stood, so to speak, upon nonliving matter climbed rung by rung from fungi and mosses to higher plants through primitive animals such as mollusks and insects and was finally terminated in human beings. The *Scala Naturae* was considered to be permanent and never changing; each organism has its place on the ladder ordained by God during creation.

Creationism, the idea that each species was created individually by God and never changed thereafter, reigned unchallenged for nearly 2000 years. As European naturalists explored the newly discovered lands of Africa, Asia, and America, they found that the diversity of living things was much greater than anyone had suspected. Some of these exotic species closely resembled one another yet also displayed variations in characteristics. This unpredicted expansion of information led some naturalist to consider that perhaps species could change after all and that some of the similar species might have developed from a common ancestor. Later on, the discoveries of fossils added credibility to this view. The fossil remains also showed a remarkable progression in form. Fossils found in the lowest and oldest rock layers were usually very different from modern forms with a gradual advancement to greater resemblance to modern species in younger rocks, as if there were a *Scala Naturae* stretching back in time.George Cuvier (1769-1832) proposed the theory of catastrophism. Cuvier hypothesized that a vast supply of species was created in the beginning. Successive catastrophes produced the layers of rock and destroyed many species, fossilizing some of their remains in the process. The reduced flora and fauna of the modern world are the species that survived the catastrophes. Louis Agassiz

(1807-1873) proposed that there was a new creation after each catastrophe and that modern species result from the most recent creation.Geologists James Hutton (1726-1797) and Charles Lyell (1797-1875) contemplated the forces of wind, water, earthquake and volcanism as agents for creating layered pattern. These layers of rocks are evidence of ordinary natural processes, occurring repeatedly over a long periods of time. This concept is called uniformitarianism. If slow natural processes alone are enough to produce layers of rock thousands of feet thick then earth must be old indeed, many millions of years old. Hutton and Lyell in fact concluded that earth was a eternal: "No vestige of a beginning, no prospect of an end". Thus, Hutton and Lyell provided the time for evolution but there was still no convincing mechanism.

One of the first to propose a mechanism for evolution was the French Biologist Lamarck (1744 –1829). He hypothesized that organisms evolved through the inheritance of acquired characteristics. Lamarck proposed that all organisms possess an innate drive for perfection, and urge to climb the ladder of nature.

By the mid 1800 some biologists were beginning to realize that the fossil record and the similarities between fossil forms and modern species could be best explained if present day species had evolved from pre-existing forms. The question remains: But how? In 1858 Charles Darwin and Alfred Russell Wallace independently provided convincing evidence that the driving force behind evolutionary change was natural selection.

Fig: 24.2 Lamarck

24.2 EVOLUTION OF EUKARYOTES FROM PROKARYOTES

Fossil records indicate that eukaryotes evolved from prokaryotes somewhere between 1.5 to 2 billion years ago. Two proposed pathways describe the invasion of prokaryote cells by two smaller prokaryote cells. They subsequently became successfully included as part of a now much larger cell with additional structures and capable of additional functions. The process involved in the evolution of eukaryotes are Endosymbiosis and Membrane infolding.

24.2.1 Endosymbiosis:

Research conducted by Lynn Margulis at the University of Massachusetts supports the hypothesis that two separate mutually beneficial invasions of a prokaryote cell produced the modern day mitochondria and chloroplast as eukaryotic organelles. In this model, ancestral mitochondria were small heterotrophs capable of using oxygen to perform cellular respiration and thereby create useful energy.

They became part of a large cell either by direct invasion as an internal parasite or as an indigestible food source. Later, a second invasion brought ancestral chloroplasts, which are thought to be small, photosynthetic cyanobacteria.

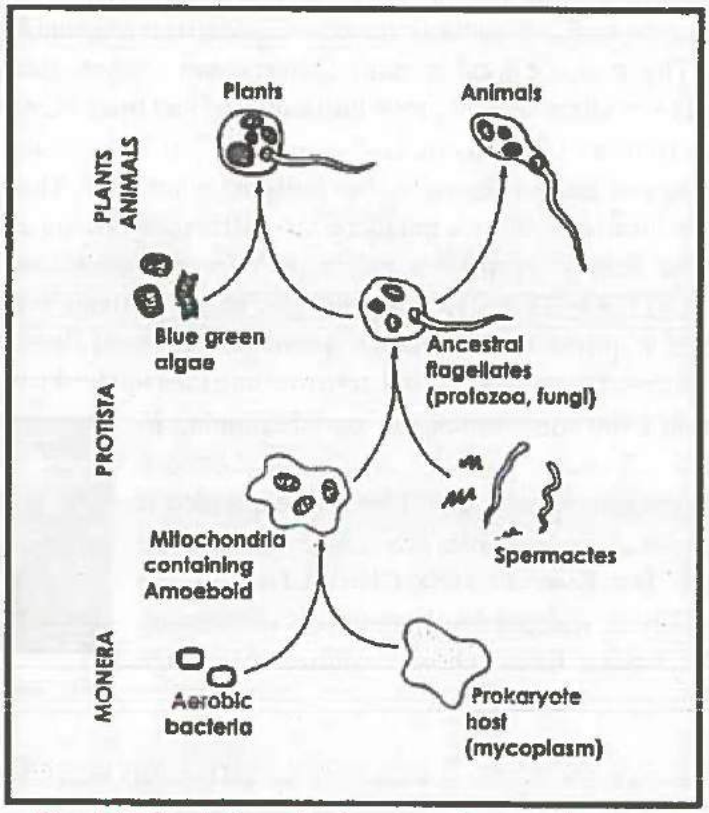


Fig: 24.3 Evolution of eukaryotes from prokaryotes.

Modern day supporting evidence for endosymbiosis shows that both the mitochondria and chloroplasts have their own genes, circular DNA and RNA, and reproduce by binary fission independent of the host's cell cycle. They therefore appear to be more similar to prokaryotes than eukaryotes.

24.2.2 Membrane Infolding:

The invasions of the host prokaryote cell probably were successful because the host cell membrane infolded to surround both invading prokaryote cells and thereby help transport them into the cell. The membrane did not dissolve but remained intact, and thereby created a second membrane around the protomitochondria and protochloroplast.

It is also known that in modern-day eukaryotes the inner membrane of both the mitochondria and chloroplast contain structures more similar to prokaryotes than eukaryotes, whereas the outer membrane retains eukaryote characteristics! It is also suggested that continued membrane infolding created the endomembrane system. It can be said that possibly the first eukaryotic cell type was miraculously born from prokaryotic, symbiotic, multicellular interactions.

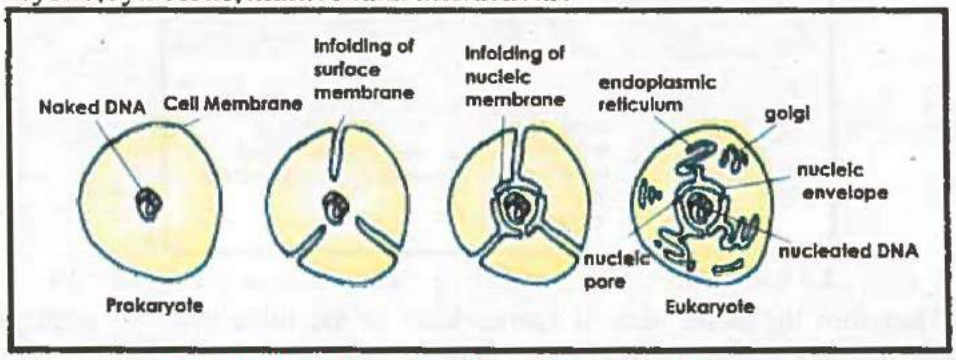


Fig: 24.4 Evolution of eukaryotes from prokaryotes.

24.3 LAMARCKISM

The earliest theory of organic evolution, was that of the French Jean Baptiste de Lamarck (1744-1829), first a soldier, then botanist and finally a professor of zoology in Paris, whose *Philosophic Zoologique* was published in 1809. Lamarck gave an explanation of evolution, based on the inheritance of acquired characters. An acquired character may be defined as a structural change in the body of organism involving a deviation from normal, induced in the life time of an individual due to certain change in the environment or in function i.e. use or disuse of an organ.

Lamarck gave many examples to prove his theory. For example

1. The ancestors of giraffe were forced to live in conditions where there was not enough grass to eat, so they started browsing upon the foliage trees and this effort resulted in elongation of their forelimbs and neck. This increase was passed on from generation to generation.
2. The loss of limbs in snakes is the result of crawling and concealing habit. The snakes e.g. pythons were provided with limbs but when mammals e.g. weasel arose; these snakes began to live in burrows so as to conceal themselves. The result was a gradual reduction and eventually loss of limbs, which were not needed in the new habitat.

Bodily modifications, whether brought through use or disuse or directly by environment cannot lead to the formation of new species unless they are inherited.

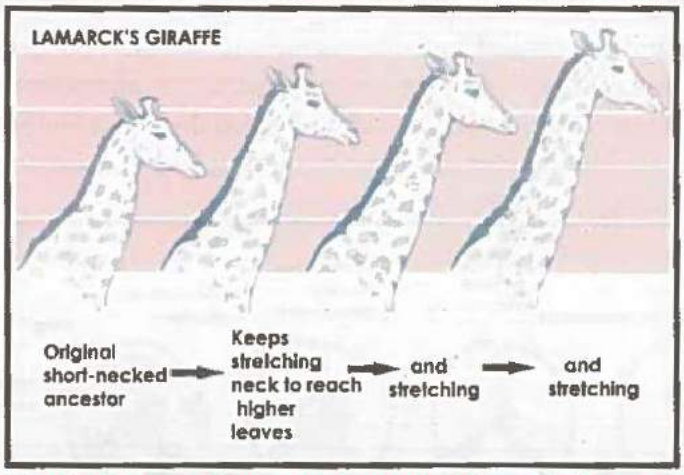


Fig: 24.5 Evolution of long neck of giraffe according to Lamarck.

Therefore the basic idea of Lamarckism is the inheritance of acquired characters, which is wrong in terms of principles of genetics.

24.4 DARWINISM

24.4.1 Darwin's voyage of HMS Beagle and his observations:

Charles Darwin (1809 –1882), was an English naturalist and is regarded as the pioneer of evolutionary idea for his theory of "Origin of species by natural selection" published in the book "Origin of species". After graduation from Cambridge, Darwin was appointed as a naturalist by professor Henslow, on the ship Beagle, which had to make a five year cruise round the world, preparing navigation charts for British navy.

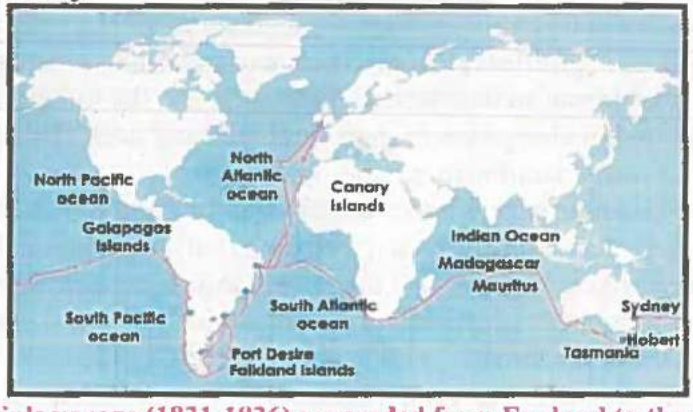


Fig: 24.6 Darwin's voyage (1831-1836) proceeded from England to the coast of South Amer... ...ross the pacific to Australia and back around the South Africa to England.

24.3.2 Darwin's theory of evolution

Darwin started the voyage, believing in the fixity of species or theory of special creation. He spent most of his time in collecting and studying thousands of animals and plants. Strange animals greeted his eye and he was impressed by the unique adaptation of these organisms.

. He was surprised to see the diversity of giant tortoises and Finches (13 types) in Galapagos Islands, west of Ecuador. He noticed that fauna and flora of South America was distinct from the life forms of Europe. Darwin was impressed by the peculiar geographical distribution and distinctive interrelationship among species

This experience eventually led him to the idea that new species originate from ancestral forms by gradual accumulation of adaptations. The long delayed publication of Darwin's "On the origin of species by means of natural selection" 1859 was catalyzed by Alfred Wallace, who independently arrived at the theory of natural selection.

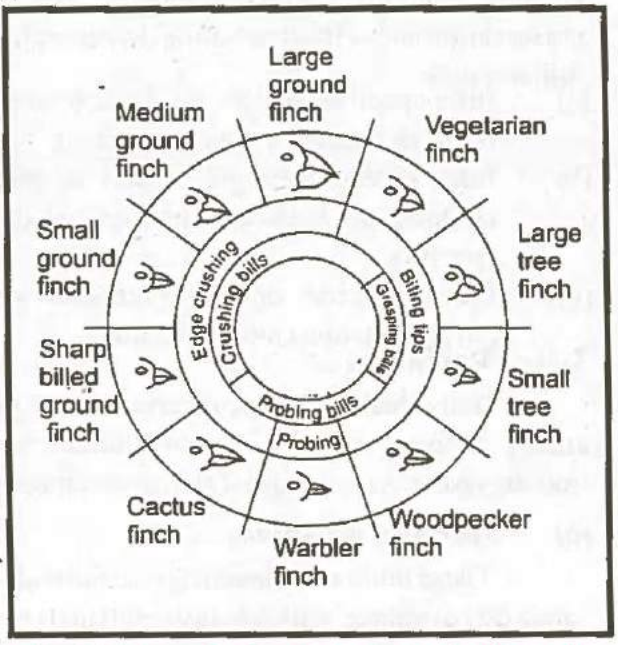


Fig: 24.7 A result of nature selection is adaptation as illustrated by thevarious beaks of Galapagos finch species. The diagram relates the beaks of some finches to their food supply.

Salient features of Darwin –Wallace theory are:

1. Over production.
2. Struggle for existence.
3. Variation.
4. Natural selection or survival of the fittest.
5. Speciation or origin of new species.

1. Over Production

Each population of organisms has the potential to reproduce large numbers of off springs. Since environmental resources (food, space, nutrients etc.) are generally limited so limited numbers of offspring survive, due to competition on these resources.

2. Struggle for existence

Since more individuals are born then can survive, there is a severe competition, termed by Darwin as "struggle for existence". Such competition may involve struggle for food, space, mates and other necessities of life or against adverse climatic conditions of environment. The struggle for existence aims at self preservation and self perpetuation. In general, the struggle for existence may be three fold in nature:

(a) Intra specific struggle or rivals (competition between members of same species)

(b) Inter specific struggle or prey or predation (competition between members of different species).

(c) Extra specific or environmental struggle (struggle against forces of nature).

Fig: 24.8 Wolves defending their kill.

3. Variation

Individuals show great variation of form, size, colour, habit and physiology among themselves. No two individuals are alike. Not even identical twins (monozygote). According to Darwin variation is heritable, and is of two kinds:

(a) Harmful variations

These hinder and handicap the individuals in the struggle and place them at a great disadvantage, which many result in its extermination.

(b) Useful variations

These provide an advantage to the possessor over other and therefore increase the chances of survival.

4. Natural selection or survival of the fittest

Darwin argued that in the struggle for existence only those individuals survive, which possess advantageous variation over the unfortunate counterparts, the unfit perish. Darwin called it "natural selection", while Herbert Spencer used the term "survival of the fittest". Thus the fittest are automatically selected and the unfit are eliminated by nature.

5. Speciation or origin of species

The selected or the surviving individuals transmit their useful or successful variation to the succeeding generations. These resulting generations may produce descendants, which are quite different from their ancestors, different enough to be declared as a separate species.

This is the formation of new species or descent with modification or evolution.

24.5 NEO-DARWINISM

Neo - Darwinism and the Modern Synthesis

Since natural selection was proposed, advances in genetics, biochemistry, ecology and paleontology have enable scientists to identify mutation, genetic drift and gene flow as other natural forces of evolutionary change. The pioneering work of Cheverikov, Mayr, Simpson and many other led to what become known as the modern synthesis. Neo Darwinism, which emphasizes the role of genetics in explaining how evolution works. The modern theory accepts five major causes of evolution.

1. Gene and Chromosomal mutation.
2. Genetic recombination.
3. Natural selection.
4. Genetic drift.
5. Reproductive isolation

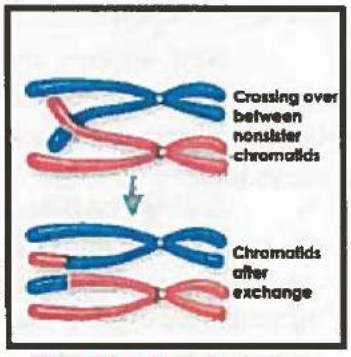


Fig: 24.9 Crossing over

1. Gene mutation and Chromosomal mutation

As you know, that both gene and chromosomal mutation can bring about variations. These variations can lead to evolution.

2. Genetic Recombination

Reshuffling of genes occurs during sexual reproduction. Meiosis causes random assortment of genes during synapsis and rearrangement of paternal and maternal chromosomes in both kinds of gametes. Such reassortment of genes is one of the bases for the appearance of new genetic recombinations in the organisms. Crossing over of genes during meiosis also adds to the variations. Thus new combination of characteristics in the organism adds to genetic variability.

3. Natural selection

Natural selection uses the variations and mutations as the raw materials for better survivors. Thus natural selection due to environment always exerts a selective influence and molds the species to fit in its changed environment

4. Genetic drift

Genetic drift is concerned with changes in gene frequencies in small populations by chance. The gene frequencies will continue to fluctuate until a new

mutation is either lost or is fixed. When a species moves from its original home into a new area, the individuals are not fully suited to the new environment. They are thus exposed to mutations with their gene pool markedly different from the parent population. Moreover when a species is expanding continuously, the populations invade new areas and become more different genetically after establishing themselves in those areas. This finally results in the modification of these populations into new species. Therefore genetic drift determines evolution.

5. *Reproductive isolation*

Reproductive isolation is regarded as one of the most important factors of evolution. It does not permit the interbreeding among the individuals of different species. It helps in splitting of the species and in the establishment of new species, which is responsible for bringing about evolution.

24.4.1 Evidences of Evolution

New species are evolved by descent with modification from a common ancestor. There are many facts and evidences from almost all subdivisions of biological science, which prove that evolution has occurred. Some of these evidences are as follows.

1. Evidence from comparative anatomy

Studies in comparative anatomy provide many evidences of evolution. In such study we are concerned with homologous structures - structures that have the same general arrangement of parts and similar mode of development but different functions. This condition is homology.

For example, human hand (grasping) a bat's wing (flying), cat's paw and horse front leg (running) and the front flipper of whale (swimming), all consists of the same number of bones, muscles, nerves and blood vessels arranged in the same pattern with similar mode of developments.

The conclusion drawn from this evidence is that groups of organisms have diverged sufficiently from ancestral type to constitute new species.

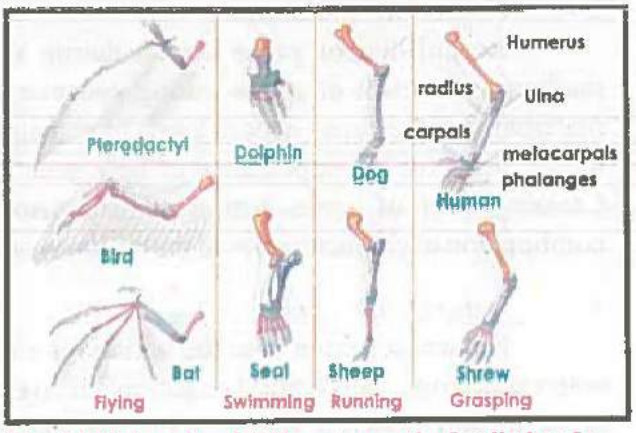


Fig: 24.10 In spite of different uses, the forelimbs of a number of very different vertebrates, all have the same framework of bone structure.

Evolution is therefore a conservative process and tends to remodel the existing ones. In the study of comparative anatomy, structures are often found that have the same function and are superficially alike, such as wings of bird, wings of butterfly and that of a flying lizard, yet they are quite different in origin and structural design. Such structures are said to be analogous. In short the analogous organs provide evidence for convergent evolution.

2. Fossil Evidence

Fossils are the remains of members of species that are ancestral to modern species. So a progressive series of fossils leading from an ancient, primitive organism, through several intermediate stages and end in modern form, provide a strong evidence of evolution.Fossil horses represent such a series. Giraffes, elephants and several mollusks show a gradual evolution of body form over time suggesting that species evolved from previous species. Another example is that of *Archeopteryx,* the fossil bird, discovered from rocks in East Germany. This bird possessed both reptilian as well as avian characters.

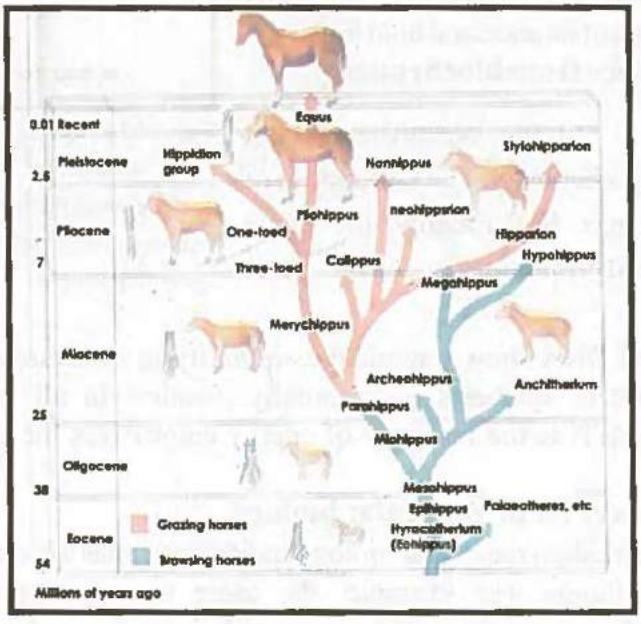


Fig: 24.11 The evolution of modern horse (*Equs*). A progression of fossils can be traced back over 60 million years to the "dawn horse" called *Eohippus*. This small ancestor had four toes in its front feet and three in its hind feet. The evolutionary pattern that lead to the modern horse included a reduction in the number of toes, the development of more complex teeth, and an increase in size. All species become extinct except the ancestral line that ended with *Equus*.

It shows that birds are evolved from reptiles and proves the truth of the statements that birds are glorified reptiles.

3. Evidence from vestigial organs

In evolution, sometimes an organ becomes reduced and may even lose its function. Such organs are vestigial organs. It is believed that once such organs were function able in the ancestors. Presence of vestigial organs is the most convincing evidence of evolution.

Some of the examples of vestigial organs in human beings are nictitating membranes of eye, appendix, coccyx or tail bone and mammary glands of male. Vestigial organs are not confined to man only. Whale has vestiges of hind limbs buried in the flesh, where its tail begins. Python (a snakes) has tiny bony structures beneath the skin, which are the remains of its ancestral hind limb.

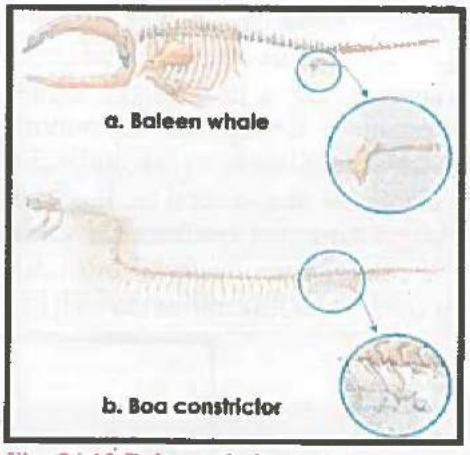


Fig: 24.12 Baleen whales and boa constrictors have no functional legs but still develop the vestigial pelvic bones and even miniature leg bones buried in their sleek sides.

4. Evidence from biochemistry

Living organisms exhibit similarity in biochemistry. The protoplasm of all living beings has roughly the same composition and properties.

The DNA and RNA show remarkable similarity in structure and function. The process of protein synthesis is essentially identical in all living beings. The occurrence of ATP as the reservoir of energy emphasizes the aspect of common origin.

5. Evidences from Molecular biology

The modern molecular biology indicates there is a biochemical similarity in all living things. For example, the same mechanisms for trapping and transforming energy and for building proteins from amino acids are nearly identical in almost all living systems. DNA and RNA are the mechanisms for inheritance and gene activity in all living organisms. The structure of the genetic code is almost identical in all living things. This uniformity in biochemical organization underlies the diversity of living things and points to evolutionary relationships.

6. Evidences from Embryology

The embryologist Karl Von Baer was the first to consider the fact that, no matter how great adult vertebrates may differ from each other in structure and habit, their embryos resemble one another and provides an evidence of evolution. For example, all multicellular animals begin their life as unicellular fertilized egg or zygote, which by the cell division forms hollow blastula, followed by gastrula. The cleavage, blastula and gastrula are almost fundamentally similar in all metazoan groups including man. In the development of frog, there is fish like stage of tadpole.

Haeckle was impressed by the striking similarity that exists between the embryonic development of higher organisms and evolutionary history of the race. This led to the belief that organism during its development repeat its ancestral history. Recapitulation theory of Von Baer or Biogenetic law of Hackle state that ontogeny (embryonic development of individual) recapitulates phylogeny (evolutionary history of the race) or "in development each individual tends to climb to its own family tree". In this way zygote can be supposed to be the unicellular ancestor and the gastrula a diploblastic ancestor in many organisms.

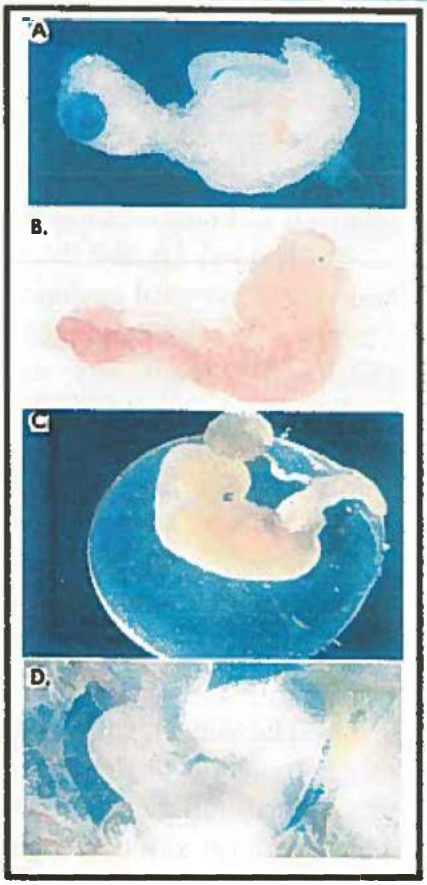


Fig: 24.13 Embryological stages reveal evolutionary relationship early embryonic stages of (A) turtle (B) mouse (C) human (D) chicken showing strikingly similar anatomical features.

24.5.2 Divergent and Convergent Evolution:

Adaptive radiation is one example of divergent evolution. Divergent evolution is the process of two or more related species becoming more and more dissimilar. If species have diverged while adapting to different environmental conditions, they should do so only in certain features, retaining ancestral traits unmodified by this adaptive process. The result should be that species resemble each other in many traits, leaving clues to their history of ancestry in the fine structure of their adaptations.

The term homology means "similarity due to shared developmental pathways." Homology can thus be recognized when structures evolve from the same precursor cells in embryos. Darwin argued that the most logical explanation for this sharing of pathways among different organisms was (1) that organisms had diverged from common ancestors, and (2) that early developmental stages had changed relatively less than later stages during evolution.

The red fox and the kit fox provide an example of two species that have undergone divergent evolution. The red fox lives in mixed farmlands and forests, where its red color helps it blend in with surrounding trees. The kit fox lives on the plains and in the deserts, where its sandy color helps conceal it from prey and predators. The ears of the kit fox are larger than those of the red fox. The kit fox's large ears are an adaptation to its desert environment. The enlarged surface area of its ears helps the fox get rid of excess body heat. Similarities in structure indicate that the red fox and the kit fox had a common ancestor. As they adapted to different environments, the appearance of the two species diverged.

Fig: 24.14 Kit fox and red fox.

The convergent evolution is the process whereby organisms not closely related (not monophyletic), independently evolve similar traits as a result of having to adapt to similar environments or ecological niches. Some animals have organs which perform similar functions and yet they are different in their origin and structure. Such organs are called analogous organs. So in convergent evolution, unrelated species become more and more similar in appearance as they adapt to the same kind of environment. The Cactus, which grows in the American desert resemble to the Euphorbia, which grows in the African deserts. Both have fleshy stems armed with spines. These adaptations help the plants store water and ward off predators. An example of convergent evolution is the similar nature of the flight/wings of insects, birds, pterosaurs, and bats. All four serve the same function and are similar in structure, but each evolved independently. Some aspects of the lens of eyes also evolved independently in various animals.

24.5.3 Hardy Weinberg theorem:

In 1908, two scientists, Godfrey H. Hardy, an English mathematician, and Wilhelm Weinberg, a German physician, independently worked out a mathematical relationship that related genotypes to allele frequencies. Their mathematical concept, called the Hardy-Weinberg principle, is a crucial concept in population genetics.

It predicts how gene frequencies will be inherited from generation to generation given a specific set of assumptions. The Hardy-Weinberg principle states that in a large randomly breeding population, allelic frequencies will remain the same from generation to generation in the absence of following conditions.

i. mutation
ii. natural selection
iii. infinite large population
iv. all members of the population breed
v. all mating is totally random
vi. everyone produces the same number of offspring
vii. there is no migration in or out of the population

Fig: 24.15

In other words, if no mechanisms of evolution are acting on a population, evolution will not occur--the gene pool frequencies will remain unchanged. However, since it is highly unlikely that any of these seven conditions, let alone all of them, will happen in the real world, evolution is the inevitable result. Godfrey Hardy and Wilhelm Weinberg went on to develop a simple equation that can be used to discover the probable genotype frequencies in a population and to track their changes from one generation to another. This has become known as the Hardy-Weinberg equilibrium equation. In this equation $(p^2 + 2pq + q^2 = 1)$, p is defined as the frequency of the dominant allele and q as the frequency of the recessive allele for a trait controlled by a pair of alleles (*A* and *a*). In other words, *p* equals all of the alleles in individuals who are homozygous dominant (*AA*) and half of the alleles in people who are heterozygous (*Aa*) for this trait in a population. In mathematical terms, this is

$$p = AA + \tfrac{1}{2}Aa$$

Likewise, q equals all of the alleles in individuals who are homozygous recessive *(aa)* and the other half of the alleles in people who are heterozygous *(Aa)*.

$$q = aa + \tfrac{1}{2}Aa$$

Because there are only two alleles in this case, the frequency of one plus the frequency of the other must equal 100%, which is to say

$$p + q = 1$$

Since this is logically true, then the following must also be correct:

$$p = 1 - q$$

There were only a few short steps from this knowledge for Hardy and Weinberg to realize that the chances of all possible combinations of alleles occurring

randomly is

$$(p + q)^2 = 1$$

or more simply

$$p^2 + 2pq + q^2 = 1$$

In this equation, p^2 is the predicted frequency of homozygous dominant *(AA)* people in a population, *2pq* is the predicted frequency of heterozygous *(Aa)* people, and q^2 is the predicted frequency of homozygous recessive (aa) ones.

From observations of phenotypes, it is usually only possible to know the frequency of homozygous recessive people, or q^2 in the equation, since they will not have the dominant trait. Those who express the trait in their phenotype could be either homozygous dominant (p^2) or heterozygous *(2pq)*. The Hardy-Weinberg equation allows us to predict which ones they are. Since $p = 1 - q$ and q is known, it is possible to calculate p as well. Knowing p and q, it is a simple matter to plug these values into the Hardy-Weinberg equation $(p^2 + 2pq + q^2 = 1)$. This then provides the predicted frequencies of all three genotypes for the selected trait within the population.

24.5.4 Genetic Drift

Allele frequencies in small populations do not generally reflect those of larger populations since too small of a set of individuals cannot represent all of the alleles for the entire population. Genetic drift occurs when the population size is limited and therefore by chance, certain alleles increase or decrease in frequency. This can result in a shift away from Hardy-Weinberg equilibrium (HWE). Unlike natural selection, genetic drift is random and rarely produces adaptations to the environment.

Although population genetics by itself is important, one of the objectives of this field is to assess how changes in allele frequencies affect the evolution of a population. Evolution in its modern form was first explored by Charles Darwin in 1859. In his book *On the Origin of Species*, Darwin outlined what he called "descent with modification" and what we now refer to as evolution. He speculated that all species evolved from a common ancestor. Over time, faced with new environments and habitats, populations of species acquired modifications, which allowed them to better adapt to their environment.

Darwin termed these changes within populations, natural selection, and he proposed the idea of "survival of the fittest." Individual variations which proved beneficial would be preserved within a population, whereas variations that were

lethal to the organism would be destroyed. Under natural selection, some individuals in a population have modifications that allow them to more successfully survive and reproduce, making their adaptations more common as a whole due to their increased reproductive success. Over a long period of time, this change in the characteristics of a population can lead to the production of a new species.

24.5.5 Speciation:

Speciation is the evolutionary process by which new biological species arise. Speciation is among the most fundamental events in the history of life. It has occurred millions, if not billions, of times since life originated some 3.5 billion years ago.

How speciation works; starts from an initial step that isolates populations, a second step that results in traits such as mating system or habitat use to diverge, and a final step that produces reproductive isolation. According to this model, the isolation and divergence steps were thought to take place over time and to occur while populations were located in different geographic areas.

Polyploidy, dispersal, and variance only create the conditions for speciation. For the event to continue, genetic drift and natural selection have to act on mutations in a way that creates divergence in the isolated populations.

Sympatric speciation:

Sympatric speciation occurs when populations of a species that share the same habitat become reproductively isolated from each other. This speciation phenomenon most commonly occurs through polyploidy, in which an offspring or group of offspring will be produced with twice the normal number of chromosomes. Where a normal individual has two copies of each chromosome (diploidy), these offspring may have four copies (tetraploidy). A tetraploid individual cannot mate with a diploid individual, creating reproductive isolation.

Sympatric speciation is rare. It occurs more often among plants than animals, since it is so much easier for plants to self-fertilize than it is for animals. A tetraploidy plant can fertilize itself and create offspring. For a tetraploidy animal to reproduce, it must find another animal of the same species but of opposite sex that has also randomly undergone polyploidy.

Allopatric speciation:

Allopatric speciation, the most common form of speciation, occurs when populations of a species become geographically isolated.

When populations become separated, gene flow between them ceases. Over time, the populations may become genetically different in response to the natural selection imposed by their different environments. If the populations are relatively small, they may experience a founder effect: the populations may have contained different allelic frequencies when they were separated. Selection and genetic drift will act differently on these two different genetic backgrounds, creating genetic differences between the two new species.

Parapatric Speciation:

Parapatric speciation is extremely rare. It occurs when populations are separated not by a geographical barrier, such as a body of water, but by an extreme change in habitat. While populations in these areas may interbreed, they often develop distinct characteristics and lifestyles. Reproductive isolation in these cases is not geographic but rather temporal or behavioral. For example, plants that live on boundaries between very distinct climates may flower at different times in response to their different environments, making them unable to interbreed.

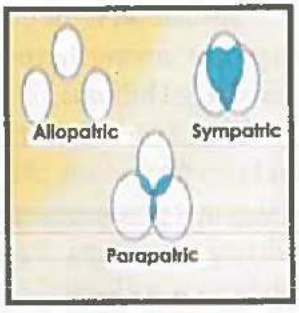


Fig: 24.16

Facts about Creation of living organisms

The theory of evolution as proposed by Charles Darwin in the 19th century, is one of the most unbelievable and irrational claims in history. Despite this, over its 150-year history the people who have accepted it have failed to produce any scientific evidence, supporting the theory. The theory puts forth the irrational claim that all living organisms, plants, animals and human beings are the result of blind, unconscious, accidental events. Evolutionists believe that millions of years ago, in the primal soup of the oceans or pools of water, mindless atoms with no knowledge, powers of reason came together in certain proportions and later, by chance, formed the proteins and cells that even today's scientists with most advanced laboratory technology have not been able to duplicate. They go so far as to say that these cells, in their turn- and again by sheer chance- formed starfish, sparrows, hawks, penguins, cats, lambs, loins, apples, apricots, pomegranates, figs and even human beings. If human efforts cannot produce any living thing by using the whole pool of human knowledge, how can life be brought into being with the aid of unconscious atoms and chance events? Any intelligent human being of conscience can certainly understand that all living things including himself cannot be the result of chance vents. Every intelligent, unprejudiced person with a conscious knows that Allah has created all these living things with His incomparable power.

The universe with all its creations both living and non-living has a flawless design, unique systems and an ordered balance that provide all the conditions necessary for living things to survive. Scientific discoveries, especially in the 20th and 21st centuries, have shown that the flawless design of the universe is clearly the work of supreme intelligence, The Allah, with

His supreme intelligence, limitless knowledge and eternal power created the universe. How is it possible to think that the balance in the ecosystem and the universe as a whole came about by mere coincidence when the extraordinary harmony of nature is observable even with the naked eye? It is the most unreasonable claim to say that the universe, each point of which suggests the existence of its Creator, has come into being on its own.The fact about the creation is that there is a mighty force in the universe that has created all different types of living things once by special creation and in them have put the ability to reproduce their next generations. This mighty force is Allah the Almighty Who is the Creator and Who sustains life on earth. The hypothesis that two prokaryotes cells invaded another prokaryote cell resulting in the evolution of a eukaryote cell is as baseless as some ones claim that two rakshas invaded a third one and in this way a motor car was evolved. The above hypothesis suggests that one of the invading prokaryote cell was changed into mitochondria and another invading prokaryote cell was modified into chloroplast. Thousands of questions arise from the above hypothesis.

Some of the questions, the proponents of blind evolution need to answer, are given below:

1. The first and foremost question is how prokaryote cells came into being?
2. How it started division?
3. How proteins, the most complicated organic compounds formed of units called amino acids, were formed?
4. How nucleic acids, which are also complicated organic compounds formed of units called nucleotides, were formed?
5. What is the probability of formation of these two essential organic compounds together? As for the synthesis of one, the other is required. If for example both of the above organic compounds were formed by chance factor, which is practically impossible, at different places then the evolution of a cell and its further division would not have been possible.
6. How autotrophic cyanobacteria developed chlorophyll?
7. The chromosome of prokaryotes is circular in shape while the chromosomes of eukaryotes are of different shapes and size. How these differences developed?
8. How other membranous structures such as Golgi bodies, endoplasmic reticulum, lysosomes, peroxisomes etc were evolved?
9. If billions of prokaryotes are cultured together for a hundred years what will be the probability of evolution of a eukaryotic cell like the one claimed at the beginning?
10. What is the probability of developing a living cell from the material (components) of cell putting together?
11. The most important question is what is life? How is it originated?
12. If evolution is a blind process for example why is it stopped on human being? If not what type of organisms will evolve from humans and when will it start?
13. What about the Universe? Who created it?
14. How the high degree of discipline present in the universe can be explained?
15. What kind of forces are responsible for the movements of earth in its axis and orbit

around the sun?

16. The matter as a whole is inorganic. Organic compounds are produced by the green plants which are producers in the ecosystem. Heterotrophic prokaryote use organic compounds for energy source. Wherefrom the heterotrophic cells obtained these organic compounds?

17. The structure of both mitochondria and chloroplasts are totally different from heterotrophic prokaryote and autotrophic cyanobacteria.

18. How nucleus came into existence because prokaryote cell does not contain a membrane bounded nucleus characteristic of eukaryotic cell?

Therefore there should be a Creator of the universe and an Owner of the balance visibly everywhere from our body to the farthest corners of the vast universe. Who is that Creator? That Almighty Creator is one. He is Allah. He brought into existence everything and Whose existence is without any beginning or end.

KEY POINTS

- Descent with modification is evolution.
- Creationism, the idea that each species was created individually by God and never changed thereafter, reigned unchallenged for nearly 2000 years.
- George Cuvier proposed the theory of catastrophism.
- Geologists James Hutton and Charles Lyell contemplated the forces of wind, water, earthquake and volcanism as agents for creating layered pattern. These layers of rocks are evidence of ordinary natural processes, occurring repeatedly over a long periods of time. This concept is called uniformitarianism.
- The process involved in the evolution of eukaryotes are: endosymbiosis and membrane infolding.
- The earliest theory of organic evolution, was that of the French Jean Baptiste de Lamarck first a soldier, then botanist and finally a professor of zoology in Paris, whose *Philosophic Zoologique* was published in 1809.
- Lamarck gave an explanation of evolution, based on the inheritance of acquired characters.
- Charles Darwin is regarded as the pioneer of evolutionary idea for his theory of "Origin of species by natural selection" published in the book "Origin of species".
- Salient features of Darwin –Wallace theory are: Over production, struggle for existence, variation, natural selection or survival of the fittest and speciation or origin of new species.

EXERCISE ?

1- Multiple Choice Questions

(i) ***The random loss of alleles in a population is called***

(a) Mutation **(b)** Selection
(c) Gene flow **(d)** Genetic drift

(ii) ***Human appendix, coccyx and nictitating membrane of the eye are:***

(a) vestigial organs **(b)** homologous organs
(c) analogous organs **(d)** embryonic organs

(iii) ***The existing species are the modified descendants of pre- existing ones according to:***

(a) Theory of special creation **(b)** theory of organic evolution
(c) uniformitarianism **(d)** theory of catastrophe

(iv) ***Using the Hardy-Weinberg Principle, which expression represents the frequency of the homozygous recessive genotype?***

(a) P^2 **(b)** 2pq
(c) q^2 **(d)** q

(v) ***Which one of the following would cause the Hardy-Weinberg principle to be inaccurate?***

(a) The size of the population is very large.
(b) Individuals mate with one another at random.
(c) Natural selection is present.
(d) There is no source of new copies of alleles from outside the population.

(vi) ***The study of birds is:***

(a) ornithology **(b)** ichthyology
(c) herpetology **(d)** **entomology**

(vi) ***Similarity in characteristics resulting from common ancestry is known as:***

(a) Analogy **(b)** Homology
(c) Evolutionary relationship **(d)** Phylogeny

(vii) ***The parts of the body use extensively to cope with the environment become larger and stronger, while those that are not used deteriorate was argued by:***

(a) Charls Darwin **(b)** Alfred Wallace
(c) Carolus

EXERCISE ?

(viii) ***Which one of the following pairs represents analogous features?***

(a) Elephant tusks & Human incisors

(b) Insects wings & bat wings

(c) Mammal fore limb & bird wing

(d) Reptilian heart & mammalian heart

(ix) ***In which of the following situations would evolution be slowest for an inter breeding population?***

	Migration	Selection Pressure	Variation due to Mutation
(a)	Absent	Low	Low
(b)	Absent	High	High
(c)	High	Low	High
(d)	High	High	Low

(x) ***Which of the following ideas was not part of Charles Darwin's theory of evolution by natural selection?***

(a) Organisms produce more offspring than the environment can support.

(b) Variation between individuals arises by gene mutation.

(c) Only those individuals that are best adapted to the environment survive and reproduce.

(d) Individuals compete for space and resources.

2- Short Questions

(i) Differentiate between special creation and evolution.

(ii) Why flora and fauna of Australia is different is different from the other world?

(iii) What is the endosymbiosis view of eukaryotic origin

(iv) Define Hardy Weinberg theorm and name conditions necessary to keep population in equilibrium.

(v) Define speciation.

3- Long Questions

(i) Analyze the divergent evolution and convergent evolution in light of evidences from comparative anatomy.

(ii) Describe the mechanism of evolution as proposed by Lamarck.

(iii) Explain Darwin's theory of evolution by natural selection

EXERCISE ?

(iv) Discuss Hardy-Weinberg principle as an evidence of evolution.

(v) Define and explain the mechanism of speciation.

4- **Analyzing and Interpreting**

- Interpret different homologous and analogous structure through observations in plants
- Solve problems related to gene frequencies using Hardy-Weinberg equation.

5- **Initiating and Planning**

- Identify questions that arise from concept of evolution and diversity (e.g. what factors have contributed to the dilemma that pharmaceutical companies face in trying to develop new antibiotics because so many microorganisms are resistant to existing antibiotics?)
- Hypothesize whether Lamarck was criticized in his day for advocating the ideas of evolution or for the mechanism he proposed.

6- **Science, Technology, and Society Connections**

- List the vestigial structure found in man and categorizes them in homologous or analogous organs.
- Describe and analyze examples of technology that have extended or modified the scientific understanding of evolution (e.g. the contribution of radiometric dating to the paleontological analysis of fossils).

7- **Online Learning**

- www.evolution.berkeley.edu
- www.imdb.com
- www.projects.gnome.org/evolution
- www.conservapedia.com/Evolution

UNIT

25

MAN AND HIS ENVIRONMENT

KEY CONCEPTS

25.1 Biogeochemical cycles

25.2 Energy flow through an ecosystem

25.3 Ecological succession

25.4 Population dynamics

25.5 Human impacts on environment

25.6 Environmental resources & their depletion

Environment is defined as the surroundings in which the organism lives. The environment may be the physical environment, the chemical environment or the biological environment. Organisms are dependent on the environment to fulfill their needs; man is also constantly interacting with the environment in order to fulfill his needs. These needs include the basic needs of oxygen, food and shelter etc. The things that man requires for his survival and comfort are called the resources. The environment is a reservoir of resources. Maintaining the natural resources of the environment and their careful use is called conservation. The conservation of environment involves the conservation of the natural resources. A healthy environment is an absolute necessity for the well-being of all organisms, including man. All our needs, big and small are being met by the environment. However, man having reached the pinnacle of evolution is trying to bring about changes in the environment to suit his convenience. Unfortunately, this convenience is temporary. In the long run, man is losing out on a healthy environment.

25.1 BIOGEOCHEMICAL CYCLES

The flow of chemical elements and compounds between living organisms and the physical environment is called **biogeochemical cycle.** Chemicals absorbed or ingested by organisms are passed through the food chain and returned to the soil, air, and water by such mechanisms as respiration, excretion, and decomposition. As an element moves through this cycle, it often forms compounds with other elements as a result of metabolic processes in living tissues and of natural reactions in the atmosphere, hydrosphere, or lithosphere. Of the 92 elements produced in nature, only six are critical to the life of organisms: hydrogen, carbon, nitrogen, oxygen, phosphorus, and sulfur. Though these elements account for 95% of the mass of all living things, their importance extends far beyond the biosphere. Hydrogen and oxygen, chemically bonded in the form of water, are the focal point of the hydrosphere, while oxygen and nitrogen form the bulk of the atmosphere. All six are part of complex biogeochemical cycles in which they pass through the biosphere, atmosphere, hydrosphere, and aerosphere. These cycles circulate nutrients through the soil into plants, microbes, and animals, which return the elements to the earth system through chemical processes that range from respiration to decomposition.

25.1.1 Water Cycle

Water is an integral part of life on this planet. It is an odorless, tasteless, substance that covers more than three-fourths of the Earth's surface. Most of the water on Earth, 97% to be exact, is salt water found in the oceans. We can not drink

salt water or use it for crops because of the salt content. We can remove salt from ocean water, but the process is very expensive. Only about 3% of Earth's water is fresh. Two percent of the Earth's water (about 66% of all fresh water) is in solid form, found in ice caps and glaciers. Because it is frozen and so far away, the fresh water in ice caps is not available for use by people or plants. That leaves about 1% of all the Earth's water in a form useable to humans and land animals. This fresh water is found in lakes, rivers, streams, ponds, and in the ground (a small amount of water is found as vapor in the atmosphere).

The hydrologic cycle begins with the evaporation of water from the surface of the ocean. As moist air is lifted, it cools and water vapour condenses to form clouds. Moisture is transported around the globe until it returns to the surface as precipitation. Once the water reaches the ground, one of two processes may occur; 1) some of the water may evaporate back into the atmosphere or 2) the water may penetrate the surface and become groundwater. Groundwater either seeps its way to into the oceans, rivers, and streams, or is released back into the atmosphere through transpiration.

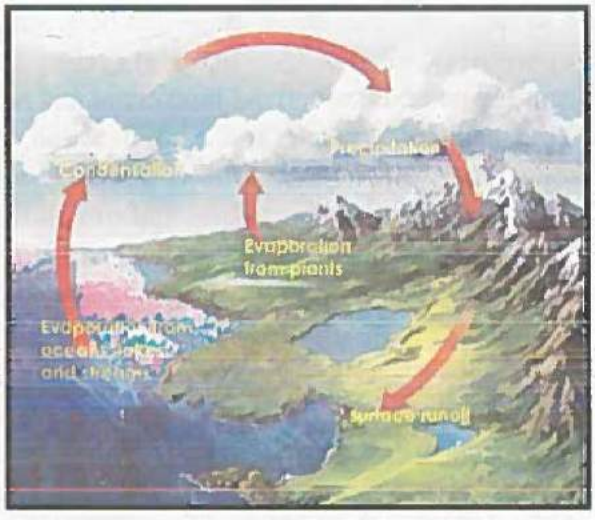


Fig: 25.1 Water Cycle in nature.

The balance of water that remains on the earth's surface is runoff, which empties into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.

25.1.2 The Nitrogen Cycle

Various processes are responsible for recycling the chemicals necessary for life on Earth. The nitrogen cycle is the most complex of these. Carbon, sulfur and phosphorus are the other main cycles. We are going to explore how nitrogen is cycled and the important role of microbes in this cycle.

Nitrogen:

Nitrogen is required by all living organisms for the synthesis of organic molecules such as amino acids, nucleic acids and proteins. The Earth's atmosphere contains almost 80 % nitrogen gas. It cannot be used in this form by most living organisms until it has been fixed, that is reduced (combined with hydrogen), to ammonia. Green plants, the main producers of organic matter, use this supply of fixed nitrogen to make proteins that enter and pass through the food chain. Micro-organisms (the decomposers) break down the proteins in excretions and dead organisms, releasing ammonium ions. These two processes form part of the nitrogen cycle.

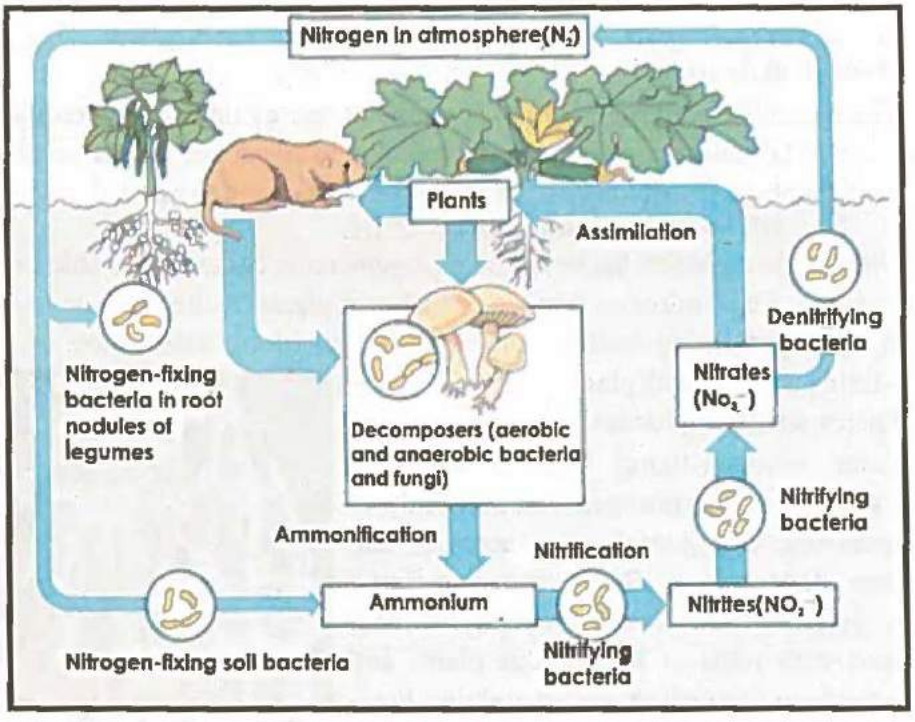


Fig: 25.2 Nitrogen cycle

The nitrogen cycle is the movement of nitrogen between the earth and the atmosphere. It consists of a series of processes that convert nitrogen gas to organic substances and these back to nitrogen in nature. It is a continuous cycle maintained by the decomposers and other bacteria. The nitrogen cycle can be broken down into four types of reaction and micro-organisms play roles in these entire.

i. Nitrogen fixation:

Nitrogen gas is composed of two atoms of nitrogen linked by a very strong triple bond. This makes it chemically non reactive and large amounts of energy are required to break the bond. Nitrogen gas can be fixed in three ways.

- **Atmospheric fixation:** This occurs spontaneously by lightning; a small amount (5–8 %) only is fixed this way. Lightning allows nitrogen and oxygen to combine to produce various oxides of nitrogen. These are carried by the rain into the soil where they can be used by plants.
- **Industrial fixation:** The Haber process is used to make nitrogen-containing fertilizers. This is a very energy inefficient process.
- **Biological fixation:** Nitrogen-fixing bacteria fix 60 % of nitrogen gas in the atmosphere.

ii. Biological fixation:

The reduction of nitrogen gas to ammonia is energy intensive. It requires 16 molecules of ATP and a complex set of enzymes to break the bonds so that the nitrogen can combine with hydrogen. Its reduction can be written as:

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

Only a relatively few bacteria (the nitrogen-fixing bacteria) are able to carry out this reaction. Fixed nitrogen is made available to plants by the death and lysis of free-living nitrogen-fixing bacteria or from the symbiotic association of some nitrogen-fixing bacteria with plants.

Types of nitrogen-fixing bacteria:

Some nitrogen-fixing bacteria are free-living in the soil, fixing nitrogen independently of other organisms, e.g. *Azotobacter* (aerobic) and *Clostridium* (anaerobic). Some nitrogen-fixing bacteria (e.g. *Rhizobium*) form symbiotic associations with roots of leguminous plants and appear in the form of swellings called nodules. Free-living rhizobia invade the legume through an infection thread formed in the root hair of the plant.

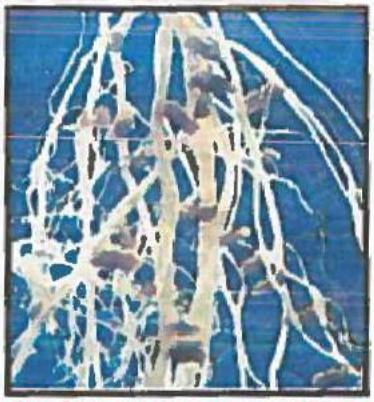


Fig: 25.3 Nodules of leguminous Plant.

The infection thread is constructed by the root cells and not the bacteria and is formed only in response to infection. The infection thread grows through the root hair cells and penetrates other root cells nearby, often with branching of the thread. The root cells then proliferate to form a root nodule. Within a week of infection small nodules are visible to the naked eye. Each root nodule is packed with thousands of living *Rhizobium* bacteria. Root-nodulated non-legume is a diverse group of woody species such as alder with e.g. Frankia. These filamentous bacteria infect the roots of plants forming actinorhizal root nodules.

Anabaena azollae is a cyanobacterium that infects new leaves of *Azolla* as they develop from the stem. Strings of *Anabaena* get caught in tiny leaf hairs that grow from a dimple on the developing leaf. The dimple grows larger into a pouch-like structure that eventually closes up, locking the *Anabaena* inside the leaf.

Fig: 25.4 *Anabaena azollae*

Adapting to their environment

Nitrogen-fixing bacteria contain an enzyme complex called nitrogenase which catalyses the conversion of nitrogen gas to ammonia. It supplies hydrogen as well as energy from ATP. The nitrogenase complex is sensitive to oxygen, becoming inactivated when exposed to it. This is not a problem with the free-living anaerobic bacteria such as Clostridium. Free-living aerobic bacteria have a variety of different mechanisms for protecting the nitrogenase complex, including high rates of metabolism and physical barriers. Azotobacter overcomes this problem by having the highest rate of respiration of any organism, thus maintaining a low level of oxygen in their cells.

For Your Information

Rhizobium contains leghaemoglobin. Leghaemoglobin functions similarly to hemoglobin, i.e. it binds to oxygen. This provides sufficient oxygen for the metabolic functions of the bacteroids, but prevents the accumulation of free oxygen that would destroy the activity of nitrogenase. Frankia and Anabaena are able to exclude oxygen by carrying out the fixation in specialized structures known respectively as a vesicle and a heterocyst. The thick walls of the vesicle and heterocyst form an oxygen diffusion barrier.

ii. Nitrification:

This is the oxidation of ammonium compounds to nitrites and then to nitrates by the nitrifying bacteria. During these oxidation reactions energy is released. The nitrifying bacteria are chemoautotrophs and are able to use this source of energy to produce organic compounds from inorganic ones. (Photoautotrophs use light energy to produce organic compounds from inorganic ones.) Nitrification is a two-step process:

- Bacteria of the genus *Nitrosomonas* convert ammonium ions to nitrites (NO_2^-). (Nitrite is toxic to plants and animals in high concentrations.)
- Bacteria of the genus *Nitrobacter* convert nitrites to nitrates (NO_3^-). The nitrates can then be taken in by plants.
- Nitrification occurs in well drained and aerated soils at neutral pH.

iii. Denitrification:

This is the conversion of nitrates into primarily nitrogen gas but also nitrous oxide gas by the denitrifying bacteria, e.g. Pseudomonas.

$$NO_3^- \longrightarrow N_2 + NO_2$$

Denitrifying bacteria transform nitrate in extremely wet soils and swampy grounds, where there is very little oxygen, i.e. the conditions are anaerobic.

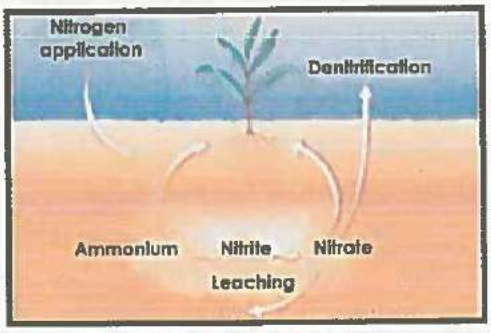


Fig: 25.5 Denitrification

The bacteria get the oxygen they need for respiration from the breakdown of nitrates. The gases that are formed escape into the atmosphere completing the nitrogen cycle. This can be a harmful process as fixed nitrogen is removed from the soil making it less fertile.

iv. Ammonification

This is the conversion of organic forms of nitrogen (e.g. in dead organisms and their excretions) into inorganic nitrogen. A wide range of soil fungi and bacteria called the decomposers carry out the ammonification process. The decomposers consume the organic matter and the nitrogen contained in the dead organism is converted to ammonium ions. The ammonium is then converted to nitrates by the nitrifying bacteria.

25.2 ENERGY FLOW THROUGH AN ECOSYSTEM

Ecosystems maintain themselves by cycling energy and nutrients obtained from external sources. At the first trophic level, primary producers (plants, algae, and some bacteria) use solar energy to produce organic plant material through photosynthesis. Herbivores—animals that feed solely on plants—make up the second trophic level. Predators that eat herbivores comprise the third trophic level; if larger predators are present, they represent still higher trophic levels. Organisms that feed at several trophic levels (for example, grizzly bears that eat berries and salmon) are classified at the highest of the trophic levels at which they feed. Decomposers, which include bacteria, fungi, molds, worms, and insects, break down wastes and dead organisms and return nutrients to the soil.

Decomposers process large amounts of organic material and return nutrients to the ecosystem in inorganic form, which is then taken up again by primary producers. Energy is not recycled during decomposition, but rather is released, mostly as heat.

On average about 10 percent of net energy production at one trophic level is passed on to the next level. Processes that reduce the energy transferred between trophic levels include respiration, growth and reproduction, defecation, and nonpredatory death (organisms that die but are not eaten by consumers). The nutritional quality of material that is consumed also influences how efficiently energy is transferred, because consumers can convert high-quality food sources into new living tissue more efficiently than low-quality food sources.The low rate of energy transfer between trophic levels makes decomposers generally more important than producers in terms of energy flow.

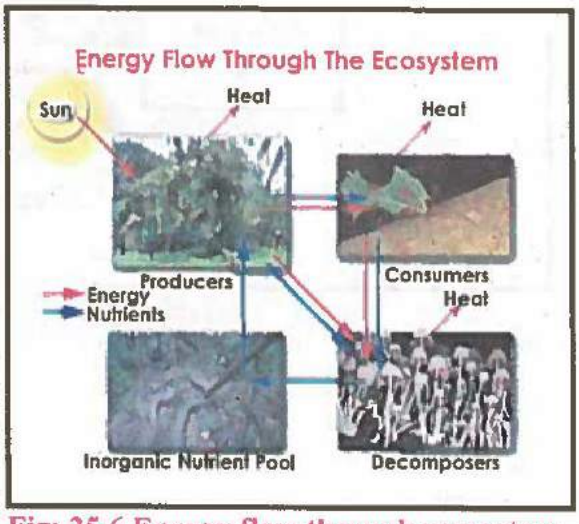


Fig: 25.6 Energy flow through ecosystem.

25.2.1 Gross & Net primary productivity:

An ecosystem's gross primary productivity (GPP) is the total amount of organic matter that it produces through photosynthesis. **Net primary productivity**

(NPP) describes the amount of energy that remains available for plant growth after subtracting the fraction that plants use for respiration. Productivity in land ecosystems generally rises with temperature up to about 30°C, after which it declines, and is positively correlated with moisture. On land primary productivity thus is highest in warm, wet zones in the tropics where tropical forest biomes are located. In contrast, desert scrub ecosystems have the lowest productivity because their climates are extremely hot and dry.

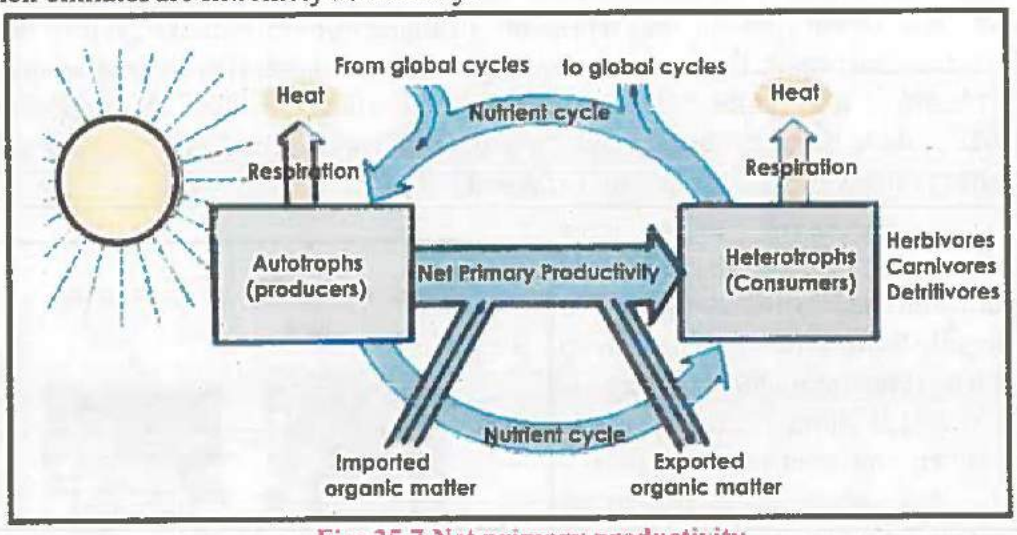


Fig: 25.7 Net primary productivity.

In the oceans, light and nutrients are important controlling factors for productivity. "Oceans," light penetrates only into the uppermost level of the oceans, so photosynthesis occurs in surface and near-surface waters. Marine primary productivity is high near coastlines and other areas where upwelling brings nutrients to the surface, promoting plankton blooms. Runoff from land is also a source of nutrients in estuaries and along the continental shelves. Among aquatic ecosystems, algal beds and coral reefs have the highest net primary production, while the lowest rates occur in the open due to a lack of nutrients in the illuminated surface layers.In contrast to land, where vascular plants carry out most primary production, most primary production in the oceans is done by microscopic algae.

25.2.2 Ecological pyramids:

An ecological pyramid is a graphical representation designed to show the number of organisms, energy relationships, and biomass of an ecosystem. They are also called Eltonian pyramids after Charles Elton, who developed the concept of ecological pyramids.

Producer organisms (usually green plants) form the base of the pyramid, with succeeding levels above representing the different trophic levels (respective position of the organisms within ecological food chains).

Succeeding levels in the pyramid represent the dependence of the organisms at a given level on the organisms at lower level. There are three types of pyramids: of numbers, of biomass, and of energy.

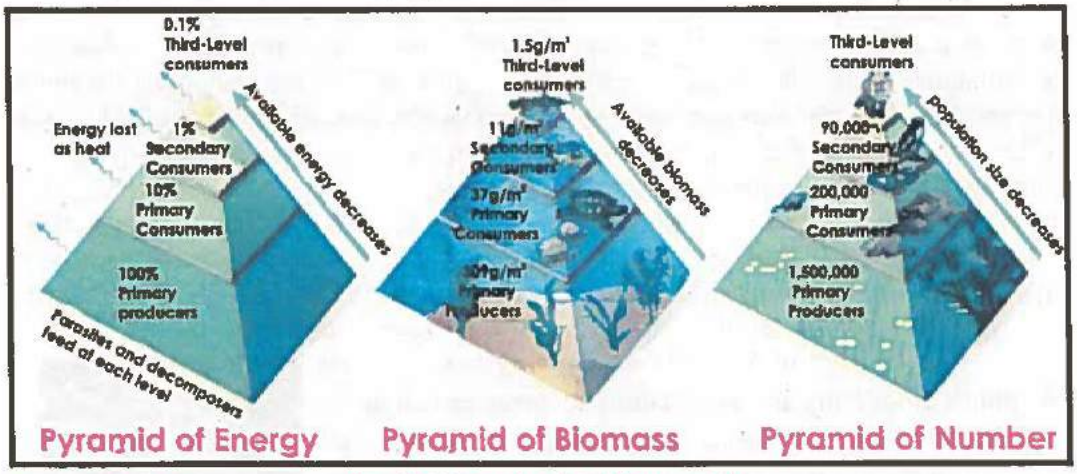


Fig: 25.8 Ecological Pyramids

Pyramid of Biomass:

Biomass is renewable organic (living) material. A pyramid of biomass is a representation of the amount of energy contained in biomass, at different trophic levels for a particular time. It is measured in grams per meter^2 or calories per meter^2. This demonstrates the amount of matter lost between trophic levels. Each level is dependent on its lower level for energy; hence the lower level determines how much energy will be available to the upper level. Also, energy is lost in transfer so the amount of energy is less high up the pyramid.

Pyramid of Numbers:

The pyramid of numbers represents the number of organisms in each trophic level. This pyramid consists of a plot of relationships between the number herbivores (primary consumers), first level carnivore (secondary consumers), second level carnivore (tertiary consumers) and so forth. This shape varies from ecosystem to ecosystem because the number of organisms at each level is variable

Pyramid of Energy:

The pyramid of energy represents the total amount of energy consumed by each trophic level. An energy pyramid is always upright as the total amount of energy

available for utilization in the layers above is less than the energy available in the lower levels. This happens because during energy transfer from lower to higher levels, some energy is always lost.

25.3 ECOLOGICAL SUCCESSION

Succession is a directional, non-seasonal cumulative change in the types of plant species that occupy a given area through time. It involves the processes of colonization, establishment, and extinction which act on the participating plant species. Most successions contain a number of stages that can be recognized by the collection of species that dominate at that point in the succession. Succession begins when an area is made partially or completely devoid of vegetation because of a disturbance. Some common mechanisms of disturbance are fires, wind storms, volcanic eruptions, logging, climate change, severe flooding, disease, and pest infestation. Succession stops when species composition changes no longer occur with time, and this community is said to be a climax community.

The concept of a climax community assumes that the plants colonizing and establishing themselves in a given region can achieve stable equilibrium. The idea that succession ends in the development of a climax community has had a long history in the fields of biogeography and ecology. One of the earliest proponents of this idea was Frederic Clements who studied succession at the beginning of the 20th century.

Fig: 25.9 lichens on a rock

25.3.1 Types of Succession:

On the basis of origin, ecological succession may be of following two types

- **Primary succession** – It is the establishment of plants on land that has not been previously vegetated. It begins with colonization and establishment of pioneer species.
- **Secondary succession** – It is the invasion of a habitat by plants on land that was previously vegetated. Removal of past vegetation may be caused by natural or human disturbances such as fire, logging, cultivation, or hurricanes.

Whereas on the basis of location, ecological succession may be xerarch or hydrarch:

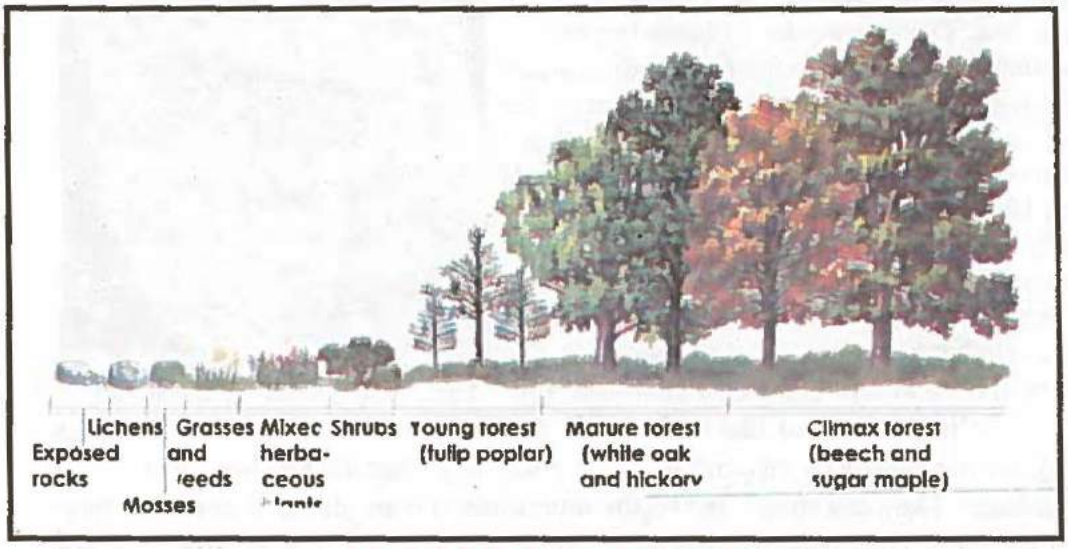


Fig: 25.10 Ecological succession

Xerarch Succession:

Plant succession starting on bare ground or rock and culminating in a mature climax forest is called xerarch succession. The pioneer species, such as lichens and mosses, result in the gradual accumulation of soil.

The lichen colonies on these boulders are the first step in xerarch succession. Along with mosses, they trap dust particles and form a layer of soil on the rock surface that allows other plants, such as grasses and herbs, to become established.

Hydrarch:

Plant succession starting on relatively shallow water, such as ponds and lakes, and culminating in a mature forest is termed as hydrarch.

25.3.2 Xerosere

The term xerosere refers to changes in community structure during xerarch succession. It includes the different stages in a xerarch succession of ecological communities originated in extremely dry conditions such as sand deserts, sand dunes, salt deserts, rock deserts etc. A xerosere may include lithoseres on rocks and psammoseres on sand. Following are the stages of lithosere:

Stage 1: Crustose Lichen Stage:

A bare rock consists of solid surface or very large boulders and there is no place for rooting plants to colonize. The crustose lichens can adhere to the surface of rock and absorb moisture from atmosphere.

Therefore these colonize the bare surfaces of rock fast. The propagules of these lichens are brought by the air from the surrounding areas. These lichens produce acids which corrode the rock and their thalli collect windblown soil particles among them that help in formation of thin film of soil. When these lichens die their thalli decomposed to humus. This promotes soil building and the environment becomes suitable for growth of foliose and fruiticose type of lichens.

Fig: 25.11 Crustose Lichen Stage.

Stage 2: Foliose and Fruiticose Lichen Stage:

Foliose have leaf like thalli while the fruiticose lichens are small bushes. They are attached by the substratum at one point only. Therefore do not cover the soil completely. They can absorb and retain more water and are able to accumulate more dust particles. Their dead remains are decomposed to humus which mixes with soil particles and help building substratum and improving the soil moisture contents further. The shallow depreciation in the rocks and crevices become filled with sold and top soil layers increase further. These autogenic changes favor growth and establishment of mosses. This community includes Parmelia and Dermatocarpon etc which have large leaf like thalli.

Stage 3: Moss Stage

The spores of xerophytic mosses are brought to the rock where they succeed lichens. Their rhizoids penetrate soil among the crevices, secretes acids and corrode the rock. The bodies of mosses are rich in organic and inorganic compounds. When they die they add these compounds to the soil to increase the fertility of the soil. Since mosses develop in patches they catch soil particles from air and help increasing substratum. The changing environment leads to migration of lichens and help invasion of herbaceous vegetation.

Stage 4: Herb Stage:

Herbaceous weeds mostly annuals such as asters and evening primroses invade the rock. Their roots penetrate deep down, secrete acids and enhance the process of weathering. Leaf litter and death herbs add humus to the soil. Shading of soil results in decrease in evaporation and there is slight increase in temperature. As a result the xeric conditions begin to change and biennial and perennials herbs and xeric grasses begin to inhabit. These climatic conditions favor growth of bacterial and fungal populations resulting in increase in decomposition activity.

Stage 5: Shrub Stage:

Herb and grass mixture is invaded by shrub species such as Rhus and others. Early invasion of shrub species is slow but once a few bushes have become established birds invade this area and help dispersal of shrub seeds. This results in dense shrub growth shading the soil and making conditions unfavorable for the growth of herbs which begin to migrate. The soil formation continues and its moisture contents enhance. The environment becomes mesic or moderately moist.

Fig: 25.12 *Rhus typhina*

Stage 6: Tree Stage:

Changes in environment favor colonization of tree species. The tree saplings begin to grow among the shrubs and establish themselves. The kind of tree species inhabiting this area depends upon the nature of the soil. In poorly drained soils oaks establish themselves. The trees form canopy and shade the area. Shade loving shrubs continue to grow as secondary vegetation. Leaf litter and decaying roots weather the soil further and add humus to it making the habitat more favorable for growth of trees. Mosses and ferns make their appearance and fungi population grows abundantly.

Stage 7: Forest or Climax Stage:

The succession culminates in a climax community, the forest. Many intermediate tree stages develop prior to establishment of a climax community. The forest type depends upon climatic conditions.

25.4 POPULATION DYNAMICS

Population dynamics is the branch of life sciences that studies short-term and long-term changes in the size and age composition of populations, and the biological and environmental processes influencing those changes. Population dynamics deals with the way populations are affected by birth and death rates, and by immigration and emigration, and studies topics such as aging populations or population decline.

25.4.1 Characteristics of Population:

A population ecologist studies the interaction of organisms with their environments by measuring properties of populations rather than the behavior of individual organisms. Properties of populations include;

- Population size
- Population density
- Patterns of dispersion

- Demographics
- Population growth Limits on population growth

Population size:

A population's size depends on how the population is defined;

- If a population is defined in terms of some degree of reproductive isolation, then that population's size is the size of its gene pool.
- If a population is defined in terms of some geographical range, then that population's size is the number of individuals living in the defined area.

Ecologists typically are more concerned with the latter means of defining a population since this is both easier to do and is a more practical measure if one is interested in determining the impact of a given population on a given ecosystem, or vice versa. Although we can determine an average population size for many species, the average is often of less interest than the year-to-year or place-to-place trend in numbers.

Population density:

Population density may be defined as number of individual organism per unit area. Different species, of course, exist at different densities in their environments, and the same species may be able to achieve one density in one environment and another in a different environment. Population densities may additionally be determined in terms of some measure other than population size per unit area such as population mass per unit area.

Population Distribution:

Individual members of populations may be distributed over a geographical area in a number of different ways including

- Clumped distribution (attraction)
- Uniform distribution (repulsion)
- Random distribution (minimal interaction/influence)

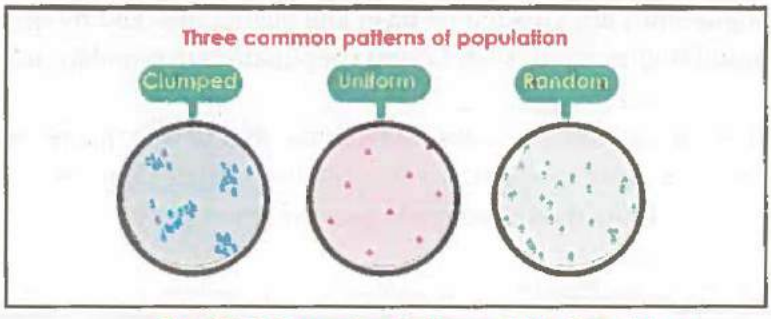


Fig: 25.13 Dispersion Patterns within Population

Clumping may result either from individual organisms being attracted to each other, or individual organisms being attracted more to some patches within a range than they are to other patches; the net effect is that some parts of the range will have a large number of individuals whereas others will contain few or none.

Fig: 25.14 Clumping bamboo

A uniform distribution means that approximately the same distance may be found between individual organisms; uniform distributions result from individual organisms actively repelling each other.

A random distribution means that where individual organisms are found is only minimally influenced by interactions with other members of the same population, and random distributions are uncommon; "Random spacing occurs in the absence of strong attractions or repulsions among individuals of a population."

Population Growth:

The simplest case of population growth is that which occurs when there are no limitations on growth within the environment. In such situations two things occur;

1. The population displays its intrinsic rate of increase
2. The population experiences exponential growth

Intrinsic rate of population increase (rmax):

The intrinsic rate of population increase is the rate of growth of a population when that population is growing under ideal conditions and without limits, i.e., as fast as it possibly can.

A population with a higher intrinsic rate of increase will grow faster than one with a lower rate of increase. The value of rmax for a population is influenced by life history features, such as age at the beginning of reproduction, the number of young produced, and how well the young survive.

Exponential growth

Exponential growth simply means that a population's size at a given time is equal to the population's size at an earlier time, times some greater-than-one number

For example, if a population increased in size per unit time in the following manner: 1, 2, 4, 8, 16, 32, 64, 128, etc. (or, e.g., 1, 3, 9, 27, or 1, 5, 25, 125, etc.) then the population is displaying exponential growth, each unit time the population is increasing by a factor of 2 (or 3 or 5 in the other examples; note that exponential growth is occurring so long as the rate of increase per unit time is greater than a factor of 1, e.g., 2 or 4 or 10 or 1.2, etc.)

Limits on population growth:

Exponential growth cannot go on forever; sooner or later any population will run into limits in their environment.

25.4.2 Carrying capacity (K): Populations subsist on a finite amount of available resources, and as the population becomes more crowded, each individual has access to an increasingly smaller share. Ultimately, there is a limit to the number of individuals that can occupy a habitat. Ecologists define carrying capacity as the maximum stable population size that a particular environment can support over a relatively long period of time. Carrying capacity, symbolized as K, is a property of the environment, and it varies over space and time with the abundance of limiting resources. Generally, as population size approaches carrying capacity, the amount of some key resource declines per capita to the point where individuals experience either a higher death rate or a lower fecundity; thus, as population size approaches carrying capacity, the rate of population growth declines towards zero.

25.4.3 Problems Related to Rapid Growth in Human Population:

As the world population continues to grow geometrically, great pressure is being placed on arable land, water, energy, and biological resources to provide an adequate supply of food while maintaining the integrity of our ecosystem. According to the World Bank and the United Nations, from 1 to 2 billion humans are now malnourished, indicating a combination of insufficient food, low incomes, and inadequate distribution of food. This is the largest number of hungry humans ever recorded in history.

In China about 80 million are now malnourished and hungry. Based on current rates of increase, the world population is projected to double from roughly 6 billion to more than 12 billion in less than 50 years.

Fig: 25.15 Malnutrition leads to millions of death each year.

More than 99 per cent of the world's food supply comes from the land, while less than 1 per cent is from oceans and other aquatic habitats. The continued production of an adequate food supply is directly dependent on ample fertile land, fresh water, energy, plus the maintenance of biodiversity. As the human population grows, the requirements for these resources also grow. Even if these resources are never depleted, on a per capita basis they will decline significantly because they must be divided among more people.At present, fertile crop land is being lost at an alarming rate. For instance, nearly one-third of the world's cropland (1.5 billion hectares) has been abandoned during the past 40 years because erosion has made it unproductive. Solving erosion

and recombinant plasmids into the same medium.

Bacterial cells take up recombinant plasmid, especially, if they are treated with calcium chloride to make them more permeable. Thereafter, as the cell reproduces, a bacterial clone forms and each new cell contains at least one plasmid. Therefore, each of the bacteria contains the gene of interest, which will express itself and make a product.

26.2.3 Identification of transformed clone:

The transformed clone can be identified by adding a particular antibiotic (for which resistant gene is found in plasmid) into the medium. As the transformed clone has got resistance against the antibiotic, so it remains alive and continues to grow, because the gene of interest is inserted inside the other antibiotic resistant gene.whereas all the untransformed clones are killed by the antibiotic. From this transformed bacterial clone, the cloned gene can be isolated for further analysis or its protein product can be separated.

26.3 POLYMERASE CHAIN REACTION

The polymerase chain reaction (PCR) is a revolutionary technique in molecular biology to amplify (cloning) a single or a few copies of a piece of DNA, to generate thousands to millions of copies. It was originally invented by Kary Mullis in 1983; later on he was awarded the Nobel Prize in Chemistry in1993. PCR is a process that 'amplifies' or 'copies' a piece of DNA repeatedly until there is an amount which is great enough to observe visually. It is based upon *in vitro* replication process which is carried out by DNA polymerase enzyme. In this technique DNA polymerase is compelled to polymerize a given piece of DNA again and again, so that multiple copies are produced, thus, the technique is known as **polymerase chain reaction (PCR).**

26.3.1 Components of PCR technique:

The following are the components required for carrying out a PCR reaction:

1. Template DNA
2. Deoxyribo-nucleoside tri-phosphates (dNTPs)
3. Primers
4. *Taq* polymerase

Fig: 26.8 PCR Machine

1- Template DNA or Target DNA: It is the piece of DNA to be cloned or amplified. It may be a useful gene found in the genomic DNA or the piece of DNA of infecting organisms.

2- Deoxyribo-nucleoside tri-phosphates (dNTPs): These are free nucleotides that act as raw material for the synthesis of new DNA fragments. There are four different types of dNTPs (dATP, dGTP, dCTP, dTTP) required in this process.

3- Primers: DNA polymerase is unable to initiate polymerization unless primers are attached. Two sets of primers—forward primer and the backward primer are used in this technique that select 3' ends of target DNA fragment by annealing with its complementary sequences.

4- *Taq* polymerase: The Taq DNA polymerase is a temperature-tolerant enzyme isolated from *Thermus aquaticus*, a bacterium found in hot springs. It catalyzes the synthesis of DNA. This enzyme is stable and active at near-boiling temperatures. Therefore, it is well suited for carrying out PCR reactions. These are basic components required for the assembly of a PCR reaction. They form a mixture called **PCR mixture** or **reaction mixture**. The PCR mixture is placed in an instrument called **thermal cycler** or **PCR machine**. Thermal cycler regulates the temperature during various steps of PCR reaction according to the need.

26.3.2 Mechanism of PCR reaction:

A PCR-amplification cycle consists of three basic steps. They are **denaturation**, **primer annealing**, and **extension or polymerization**. Its time duration, temperatures and sequence of the steps have to be programed in the thermal cycler.

Fig: 26. 9 A hot spring in Yellowstone National Park, the habitat for *Thermus aquaticus*.

Denaturation: In the denaturation step, the template is heated to 94°C for one minute or up to five minutes. At this high temperature the DNA undergoes complete denaturation and the double-stranded DNA (dsDNA) becomes single-stranded (ssDNA). Each single ssDNA can act as the template for the *in vitro* DNA synthesis.

Primer annealing: The next step is the primer annealing. In this step the two primers, the forward primers and the backward primers, anneal or hybridize to the single-stranded template DNA at its complementary regions. Annealing is usually carried out at a lower temperature depending on the length and sequence of the primers. In standard cases it is 54°C and approximate time required for this step is 2 minutes.

Extension or Polymerization: The final step in each cycle is the primer extension or polymerization in which the Taq DNA polymerase synthesizes new DNA strands to the 3' ends of primers using dNTPs. The optimum temperature for carrying out the primer

extension reaction or polymerization of dNTPs is standardized at 72°C. This step takes just one minute to be completed.

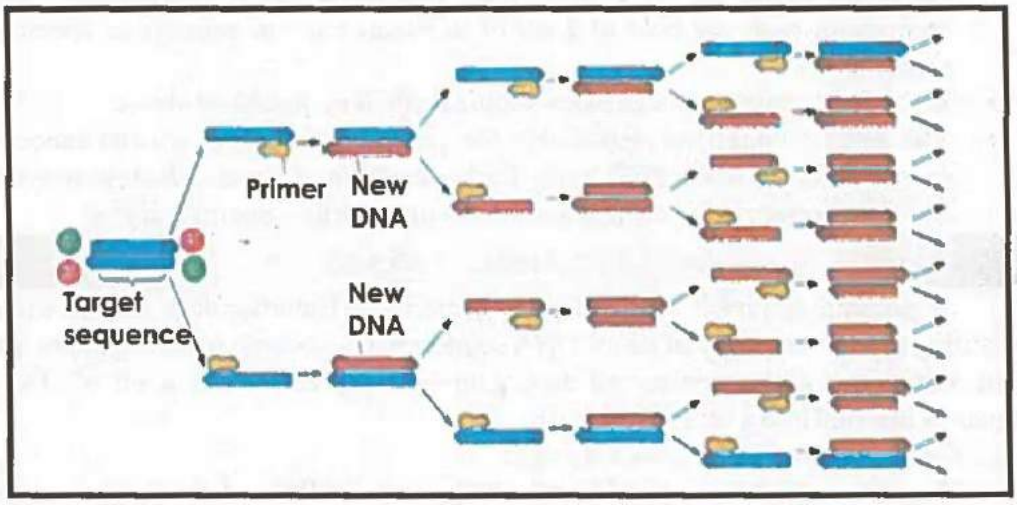


Fig: 26.10 Mechanism of PCR reaction

At the end of first cycle one target DNA molecule is converted in to two molecules. The second cycle immediately starts with the denaturation by heating at 94°C, so that all the newly synthesized DNA are also denatured to single strands, which again act as templates. It will again be followed by the primer annealing and extension and thus the cycle of denaturation, primer annealing, and extension continues resulting in the amplification of the selected DNA sequence at an exponential rate i.e. the number of existing DNA molecules become doubled after each cycle.

26.3.3 Applications of PCR:

PCR has application in almost all areas of molecular biology, genetics, and in clinical areas.

- PCR is an efficient diagnostic technique used for the detection of specific infectious agents e.g HBV, HCV, HIV.
- It is also used for the detection of microorganisms in food samples, water, and in the environment with the help of species-specific primers.
- PCR can also be used for genome analysis and for generating markers for the construction of genetic and physical maps of organisms.
- There is the PCR-based cDNA synthesis known as RT-PCR (reverse transcriptase- PCR), which can be directly carried out with purified mRNA.
- Reactions for DNA sequencing are also simplified by introducing the PCR method.

- PCR has also shown its impact in criminology. The DNA of the suspects and the DNA sample recovered from the crime scene can be analyzed by PCR techniques with the help of a set of identical random primers or specific primers.
- DNA fingerprinting is also made simple by PCR as described above.
- The genetic mutations responsible for certain genetic diseases and cancers can be detected using PCR tools. Early detection of genetic disease is even possible in embryonic conditions or even in sex cells—sperm and egg.

26.4 GENOMEIC LIBRARY

A genomic library is a collection of bacterial or bacteriophage clones, each containing at least one copy of every DNA sequence in a genome of an organism. In single library the entire genome of an organism is represented as a set of DNA fragments inserted into a vector molecule.

26.4.1 Construction of Genomic Library:

To construct a genomic library, the genomic DNA of the organism is extracted and is cut into fragments of suitable sizes by any of the following three methods.

- The genomic DNA is digested completely by a restriction enzyme that converts it into fragments of suitable sizes. The restriction enzyme cuts at all relevant restriction sites and produces a large number of short fragments with sticky ends. The disadvantage of this is that genes containing restriction sites within the reading frame may be cut into two or more fragments and may be cloned separately.
- The genomic DNA can be fragmented un-enzymatically by means of mechanical shearing such as **sonication**, which produces longer DNA fragments. The disadvantage in this case is that the ends of the fragments produced are not uniform and need enzymatic modification for insertion into a cloning vector.
- The third method for fragmenting genomic DNA is by partial enzymatic digestion with a restriction enzyme.

26.4.2 Locating gene of interest from DNA libraries:

A DNA probe is a small, fluorescently or radioactively labeled DNA molecule that is used to locate similar or complementary sequences among a long stretch of DNA molecule or bacterial colonies such as genomic or cDNA libraries or in a genome.

Fig: 26.11 DNA Probe is added to locate similar sequences of DNA.

26.5 DNA SEQUENCING

To understand the complexities of gene structure, its expression, its regulation, protein interactions, and molecular mechanisms of genetic diseases—the detailed and exact sequences of the bases in DNA is very essential. The main principle of any DNA sequencing method is:

1. To generate piece of DNA of different sizes all starting from the same point and ending at different points.
2. Separation of these different sized pieces of DNA by gel electrophoresis.
3. Reading of sequence from the gel.

For generation of different sized DNA fragments, two different sequencing methods were developed during the late 1970s. They are: Sanger method and Maxam-Gilbert method.

26.5.1 Sanger's method:

This method is widely used and similar to the natural process of DNA replication. It was developed by Frederick Sanger along with Andrew Coulson in 1977. They have awarded Nobel Prize in 1980 on this achievement. Sanger's method now became the standard because of its practicality.

Procedure:

Before the DNA can be sequenced, it has to be denatured into single strands using heat because only one strand that acts as template is required in this procedure. Now the template strand is tagged with a known sequence at 3' end, so that a complimentary primer can bind on the known sequence. Once the primer is attached to the DNA, the solution is divided into four tubes labeled "G", "A", "T" and "C". Then reagents are added to these samples as follows:

"G" tube: all four dNTP's, ddGTP and DNA polymerase
"A" tube: all four dNTP's, ddATP and DNA polymerase
"T" tube: all four dNTP's, ddTTP and DNA polymerase
"C" tube: all four dNTP's, ddCTP and DNA polymerase

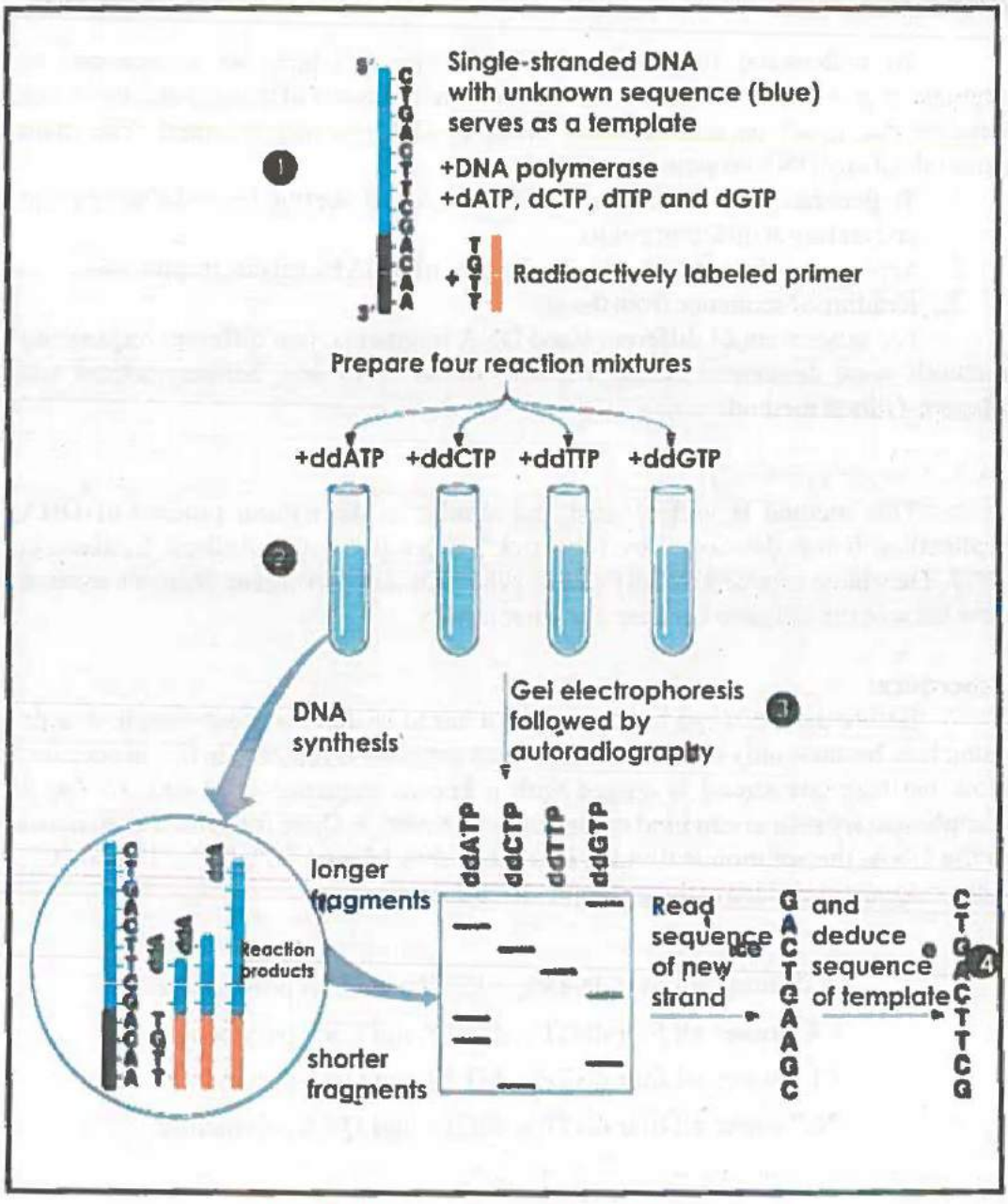


Fig: 26.12 Sanger's method of DNA sequencing

As shown above, all of the tubes contain a different ddNTP present, and each at about one-hundredth the concentration of the normal precursors. Now all these test tubes are placed in PCR machine so that sequencing reaction can start. As the DNA is synthesized, nucleotides are added on to the growing chain by the DNA polymerase. However, on occasion a dideoxynucleotide is incorporated into the chain in place of a normal nucleotide, which results in a chain-terminating event. For example if we looked at only the "G" tube, we might find a mixture of the following products:

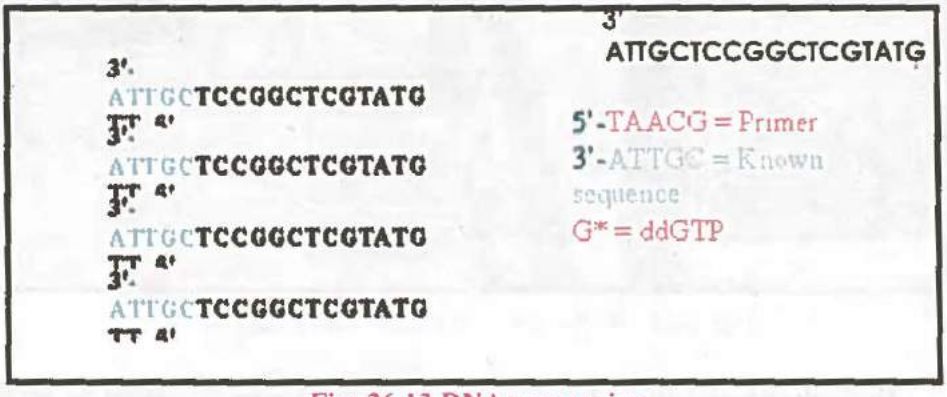


Fig: 26.13 DNA sequencing

The key to this method is that all the reactions start from the same nucleotide and end with a specific base. Thus in a solution where the same chain of DNA is being synthesized over and over again, the new chain will terminate at all positions where the nucleotide has the potential to be added because of the integration of the dideoxynucleotides. In this way, bands of all different lengths are produced. Once these reactions are completed, the DNA is once again denatured in preparation for electrophoresis. The contents of each of the four tubes are run in separate lanes on a polyacrylmide gel in order to separate the different sized bands from one another. After the contents have been run across the gel, the gel is then exposed to either UV light or X-rays, depending on the method used for labeling the DNA.

26.5.2 Gel electrophoresis:

Gel electrophoresis is a technique used in molecular biology to separate charge bearing polymers (proteins, RNA or DNA) under the influence of electric field. DNA electrophoresis is used to separate DNA fragments primarily by size. The types of gels most commonly used for DNA electrophoresis are agarose (for relatively large DNA molecules) and polyacrylamide (for high resolution of short DNA fragments). The freshly prepared gel is in liquid form but when it is poured in a gel caste to form a thin slab of gel and is allowed to be cooled, it turns into solid state.

At one end of the gel slab some partial holes are made which are called "wells", they are partial in the sense that they are not opened from other side of the slab. Later on various samples of mixture of different sized DNA fragments are poured into these wells.

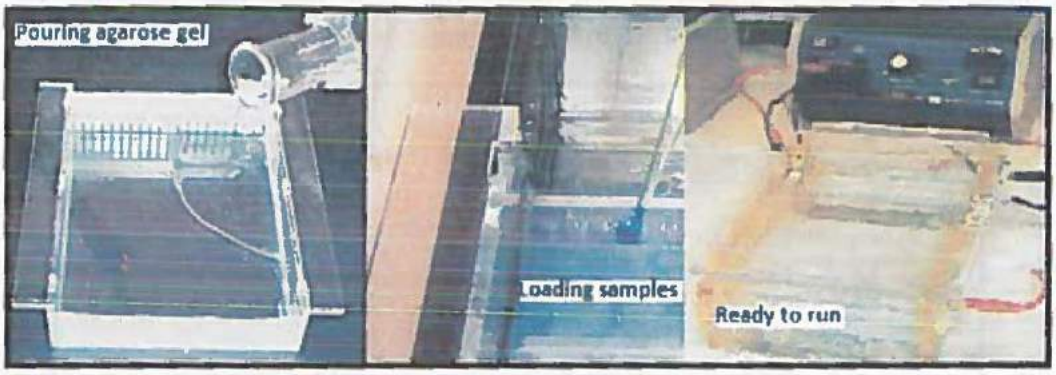


Fig: 26.14 Steps in Gel Electrophoresis technique.

The gel slab is suspended in a buffer solution which is used to establish electric field. The buffers used for the separation are Tris-Borate-EDTA or Tris-Acetate-EDTA. To establish an electric field, a positive electrode at one end and a negative electrode at another end of buffer solution are inserted. As the electric current run between the electrodes, the DNA fragment of different length present in the wells begin to move from negative pole to positive pole because DNA molecules have negative charges due to the phosphate groups.

The DNA fragments migrate relative to its size because the distance a DNA fragment travels is inversely proportional to its length so the smaller fragments move faster through the gel matrix than larger fragments.

Although, the movements of the fragments also depend upon charges, number of strands (single or double), shape of the molecules (linear or circular) and the concentration of the gel (pore size).

When the movement of fragments is stopped, the DNA molecules are appeared as band at different positions of gel but still bands cannot be viewed until they are labeled with florescent dyes or radioactive probes.

Following the separation, the gels can be stained by DNA binding florescent dyes that bind to the DNA molecules and are typically viewed under UV illumination. DNA bands can also be transferred from gel to the nitrocellulose membrane for autoradiography (X ray imaging).

In the image of gel pattern, some bands are appeared thick and some are thin, thick bands represent the high concentration of same sized fragments while thin bands show low concentration. If a particular sized fragment is to be used for further analysis, the piece of gel containing that band can be cut and its DNA can be purified again.

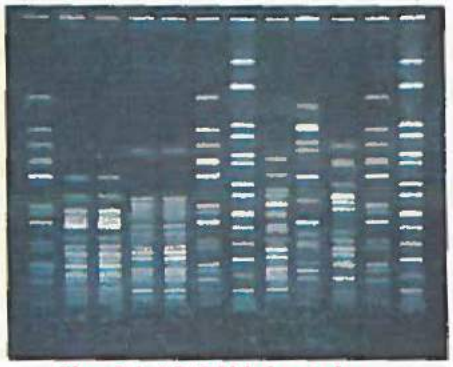


Fig: 26.15 DNA bands

26.5.3 Automated DNA Sequencing

Automatic sequencing machines have greatly improved the quality as well as the speed of the sequencing process. The basic principle sequencing is quite same in manual and automated DNA sequencing except few differences.

There is no need for radiolabeling and autoradiography. The use of fluorescently labeled ddNTPs (dideoxynucleotide triphosphates) has made the reading very easy, convenient, and automatic with the help of UV laser detectors. Thus, it has greatly improved the speed of sequencing. Each of the four types of ddNTPs can be labeled with a specific dye, so that a specific color can be attributed to the presence of a particular nucleotide or base.

After electrophoresis, we don't even have to 'read' the sequence from the gel. The computer does that for us. After electrophoresis the colored bands can be monitored using UV-laser beams. The laser beams excite the fluorescent dyes and result in the emission of specific spectral waves (colored light), which are recorded by a specific photoelectric device. The data thus generated is fed to a computer, where the emission data from the gel is converted into a corresponding nucleotide sequence of the DNA sample. The nucleotide sequence is also represented in specific peaks indicating each nitrogen base.

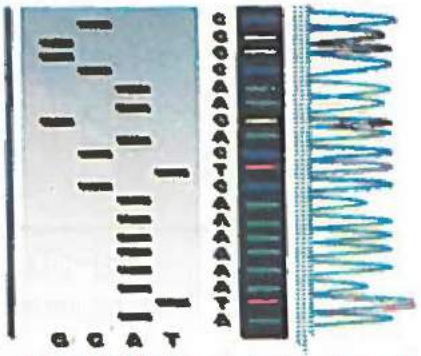


Fig: 26.16 After electrophoresis the colored bands can be monitored using UV-laser beams.

26.5.4 Maxam-Gilbert Method:

In 1976-1977, **Allan Maxam** and **Walter Gilbert** developed a DNA sequencing method which is also called as **chemical cleavage method** because it is based on chemical modification of DNA and subsequent cleavage at specific bases.

Procedure:

The DNA to be sequenced must first be end labeled, at one end only. This is accomplished by kinase treatment with 32P ATP, which transfers radioactive phosphorus from ATP to 5' end of each strand. Dimethylsulphoxide (DMSO) is then added and the labeled DNA samples heated to 90°C. This results in the breakdown of base pairing and dissociation of DNA molecules into its two component strands.

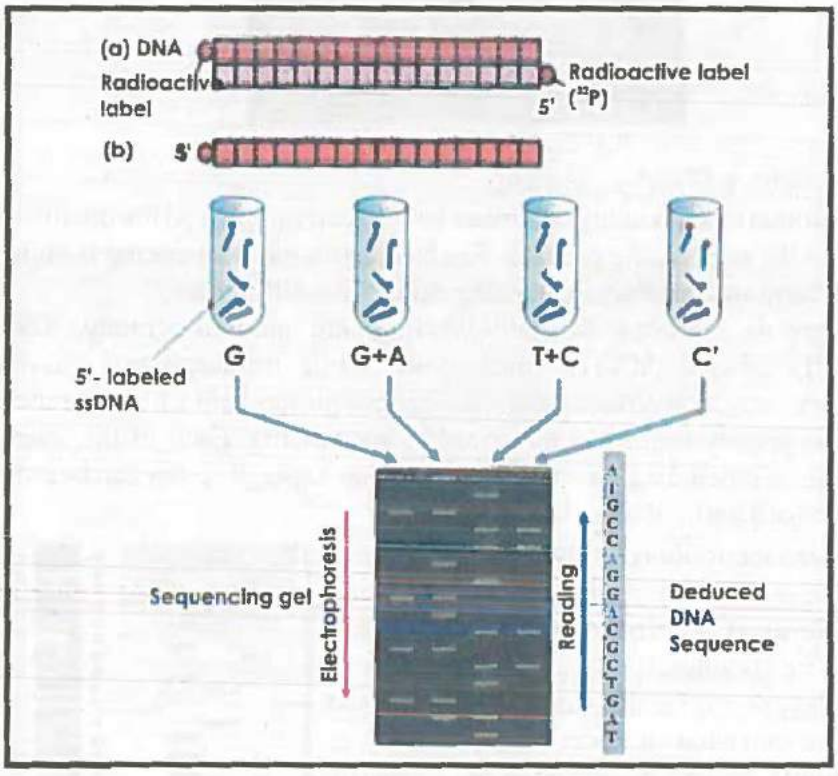


Fig: 26.17 Maxam and Walter Gilbert developed a DNA sequencing method.

The two strands are separated from one another by gel electrophoresis, one strand is purified from the gel and divided into four samples (G, A+G, T+C, and C), each of which is treated with one of the cleavage reagents and modifying chemical reagents.

The former are used to cut DNA strand at specific point while the later cause a chemical modification in the nucleotides they are specific for, making them to susceptible to cleavage.

26.6 DNA ANALYSIS

DNA analysis or DNA fingerprinting is an examination method that emerged in the 1980s and is credited to **Alec Jeffrey**, an English geneticist who made first DNA fingerprint in 1985. Every species has unique genetic sequences. DNA analysis allows any type of organism to be identified by analyzing its genetic sequences. This method can also clarify questions of identification within a species. Identification within a species can present more of a challenge than determining between two different species. For example, it is much easier to determine whether a victim was attacked by a bear or human than it is to determine which human perpetrated an attack.

Human DNA not only has a record of each person's individuality but also a shared history of the evolution of our species, and the code that can provide insight into a person's future health. So Today, DNA analysis has become a standard practice for defining paternity or maternity, predisposition to disease, embryonic health, criminal guilt or innocence, and so on. DNA can be analyzed in various ways for these purposes.

26.6.1 Procedure:

There are several techniques that can be used for DNA analysis. **Restriction fragment length polymorphism (RFLP)** was one of the first methods used in DNA analysis. Following are the key steps to make a DNA fingerprint by using this method.

Fig: 26.18

Collection of DNA samples:

For DNA analysis, very small fraction of DNA is sufficient because it can be amplified several times with the help of PCR. Therefore it can be collected even from a small trace of blood or from the cells of single hair root.

DNA samples can also be collected from mummified organisms or from fossils when evolutionary relationship has to be studied.

Placement of RFLP:

RFLP refers to the different sized fragments of DNA produced by a particular restriction enzyme. Every person has a unique set of RFLPs because the restriction site of a particular enzyme is always different in number and distribution in all human on earth except the monozygotic (identical) twins. Therefore RFLPs of any two persons, when compared, one can easily analyze their individuality. However, the entire human have 99% similarity in nucleotide sequence of their genomes, this is the only 1% difference in genome sequence that establishes the individuality of every person.. Placement of RFLP is the digestion of DNA samples by a particular restriction enzyme, which produces a set of different sized DNA fragments (RFLPs)

Separation of RFLPs:

The DNA fragments are then electrophoresed on an agarose gel to separate them by size. The mixture of RFLPs is loaded in polyacrylamide gel and run for electrophoresis; fragments of various lengths begin to move at different rate from negative to positive pole within the gel. When the movement is stopped, the gel is proceeded for further treatments in order to observe banding pattern.

Southern Blotting:

A Southern blot is a method routinely used in molecular biology for detection of a specific DNA sequence in DNA samples. Southern blotting is the combinations of two steps i.e. transfer of electrophoresis-separated DNA fragments to a filter membrane and subsequent fragment detection by probe hybridization. The method is named after its inventor, the British biologist Edwin Southern.

Autoradiography:

After hybridization, excess probes are washed from the membrane, and the pattern of hybridization is visualized on X-ray film by exposing the membrane to an X-ray source. This technique is known as autoradiography. The banding pattern, which was originally obtained in the gel due to the separation of RFLPs, is now developed on an X-ray film.

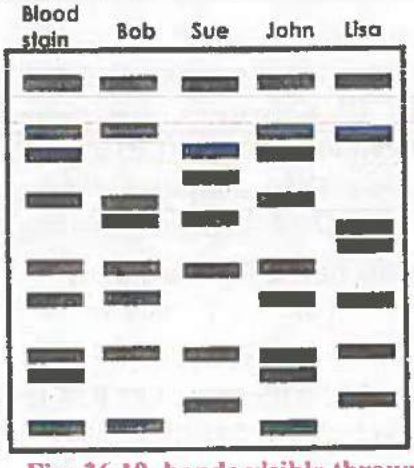


Fig: 26.19 bands visible through autoradiography.

26.6.2 Applications of DNA analysis:

Today DNA analysis has wide range of application in different fields of life. It can be used to:

- Identify potential suspects whose DNA may match evidence left at crime scenes

- Exonerate persons wrongly accused of crimes
- Identify crime and catastrophe victims
- Establish paternity and other family relationships
- Identify endangered and protected species as an aid to wildlife officials (could be used for prosecuting poachers)
- Detect bacteria and other organisms that may pollute air, water, soil, and food
- Match organ donors with recipients in transplant programs
- Determine pedigree for seed or livestock breeds

26.7 GENOME MAPS

The genome is a collection of all the genes found in one complete set of chromosome. So a diploid organism has two copies of genome while egg or sperm has one.

26.7.1 Genome maps:

Just like the road maps and street maps of a city, which guide us to reach a specific location, the genome maps are used by the scientists searching for a specific gene somewhere within the vast human genome.

They have available to them two broad categories of maps: genetic maps and physical maps, which are being used for genome analyses. A genetic map, like an interstate highway map, provides an indirect estimate of the distance between two locations (loci). On the other hand, physical maps mark an estimate of the true distance, in measurements called base pairs, between locations (loci) interest. To continue our analogy, physical maps would then be similar to street maps, where the distance between two sites of interest may be defined more precisely.

For Your Information

In his marvelous book, Genome, Matt Ridley wrote: "Imagine that the human genome is a book. There are 23 chapters, called chromosomes. Each chapter contains several thousand stories, called genes. Each story is made up of paragraphs called exons, which are interrupted by advertisements called introns. Each paragraph is made up of words called codons. Each word written in letters are called bases, which are Cytosine, Guanine, Adenine, Thiamine or shortly A,G,T,C."

26.7.2 Genetic markers:

Just like interstate maps have cities and towns that serve as landmarks, genetic maps have landmarks known as genetic markers, or "markers" for short. The term marker is used very broadly to describe any observable variation that results from an alteration, or mutation, at a single genetic locus.

A marker may be used as one landmark on a map if, in most cases, that stretch of DNA is inherited from parent to child according to the standard rules of inheritance. Markers can be within genes that code for a noticeable physical characteristic such as eye color, or a not so noticeable trait such as a disease. DNA-based reagents can also serve as markers. These types of markers are found within the non-coding regions of genes and are used to detect unique regions on a chromosome. DNA markers are especially useful for generating genetic maps when there are occasional, predictable mutations that occur during meiosis—the formation of gametes such as egg and sperm that, over many generations, lead to a high degree of variability in the DNA content of the marker from individual to individual.

26.7.3 Commonly Used DNA Markers

- **RFLPs, or restriction fragment length polymorphisms**
- **VNTRs, or variable number of tandem repeat polymorphisms**
- **Microsatellite polymorphisms**
- **SNPs, or single nucleotide polymorphisms**

26.7.4 Genome Analysis:

Due to rapid development of genome studies, a new branch of biotechnology has emerged called genomics which deals with exploration and analysis of complete DNA sequence of an organism's genome. This field was not really possible until the publication of the genome of Haemophilus influenzae in 1995. Before this Fred Sanger also had sequenced the first bacteriophage genome for which he later won the Nobel Prize. Beside it human genome project was also launched in 1990.

26.7.5 Human Genome Project (HGP)

The Human Genome Project (HGP) is an international scientific research project which is based on the exploration and analysis of human genome. It was originally founded by the U.S. Department of Energy and the National Institutes of Health in 1990. They have established National Human Genome research Institute (NHGRI), who has completed this task in 2003. James D. Watson was appointed as first director of this institute but at the time of completion of the project, the institute was being led by Dr. Francis Collin. Although this project was funded initially by the US government but later on Welcome Trust (U.K.) became a major partner; additional contributions came from Japan, France, Germany, China, and others.

26.7.6 Major Goals of HGP:

Major goals and objective of this project were to

- identify all the approximately 20,000-25,000 genes in human DNA,
- determine the sequences of the 3 billion chemical base pairs that make up human DNA,
- store this information in databases,

- improve tools for data analysis,
- transfer related technologies to the private sector, and
- address the ethical, legal, and social issues (ELSI) that may arise from the project.

26.7.7 Benefits of HGP

Some potential benefits from human genome project are expected in the following fields:

Molecular Medicine:

- Improved diagnosis of disease
- Earlier detection of genetic predispositions to disease
- Rational drug design
- Gene therapy and control systems for drugs
- Pharmacogenomics "custom drugs"

Bioarchaeology, Anthropology, Evolution, and Human Migration:

- Study evolution through germ line mutations in lineages
- Study migration of different population groups based on female genetic inheritance
- Study mutations on the Y chromosome to trace lineage and migration of males
- Compare breakpoints in the evolution of mutations with ages of populations and historical events.

26.8 TISSUE CULTURE

The propagation of a plant by using a plant part or single cell or group of cells in a test tube under very controlled and hygienic conditions is called "Tissue Culture". Tissue culture is often a generic term that refers to both organ culture and cell culture. The initial plant part which is used to develop tissue culture is called **explant**. It may be complete organ (seed, leaf, and twig) or single cell (protoplast) or a piece of tissue. On the basis of explant tissue culture is variously called as **cell culture** or **organ culture**.

26.8.1 Procedure of Tissue Cultures:

A typical tissue culture method consists of following steps:

Sterilization:

Tissue culture is performed under aseptic conditions. Sterilization refers to the decontamination because living plant materials from the environment are naturally contaminated on their surfaces (and sometimes interiors) with

microorganisms, so surface sterilization of starting materials (explants) in chemical solutions (usually Sodium or calcium hypochlorite or mercuric chloride) is required. The glassware which is to be used in the procedure should also be sterilized.

Media preparation:

Soil is a natural medium of plant growth which is supposed to be very complex for a tiny explant, so in tissue culture technique, explants are grown on artificial media in which composition is kept under control. Solid or liquid media are used depending upon the need, which are generally composed of inorganic salts plus a few organic nutrients, vitamins and plant hormones.

Inoculation:

Inoculation refers to the placement of explant onto the surface of a solid culture medium, but is sometimes placed directly into a liquid medium, particularly when cell suspension cultures are desired. This is done in laminar flow, a sterile chamber. After the placement of explant, it is ensured that petri plates or test tube should be air tight. Next, these glass wares are shifted to the growth room or incubator.

Development of callus:

First the explant is allowed to grow into and unorganized mass of cells, callus, which is then shifted to the new media for the development of shoots and roots. A balance of both auxin and cytokinin will often produce an unorganized mass of cells, the callus.

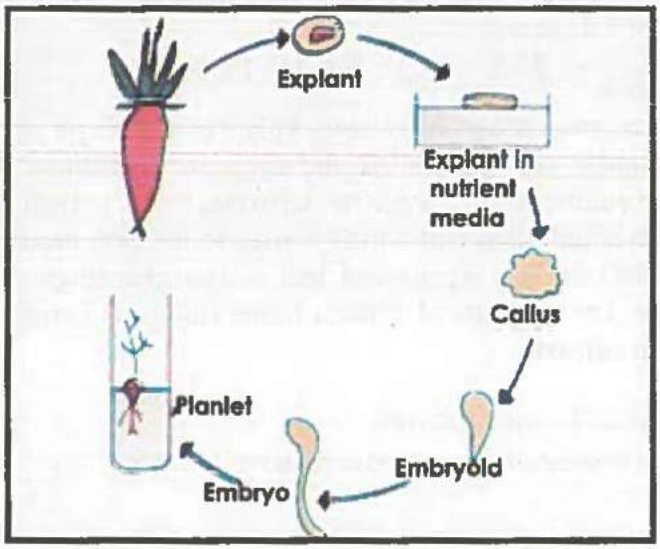


Fig: 26.20 Major steps in tissue culture technique.

Development of plantlets:

As the callus grows, pieces are typically sliced off and transferred to new media (sub cultured) to allow for growth or to alter the morphology of the callus. The skill and experience of the tissue culturist are important in judging which pieces to culture and which to discard.

As shoots emerge from a culture, they may be sliced off and rooted with auxin to produce plantlets which, when mature, can be transferred to potting soil for further growth in the greenhouse as normal plants.

26.8.2 Types of tissue culture:

There are several types of tissue cultures which are primarily based upon type of explant used.

i. Callus culture:

When explants are cultured on the appropriate medium, usually with both an auxin and a cytokinin, can give rise to an unorganized, growing, and dividing mass of cells. This is called callus culture. Any plant tissue can be used as an explant.

ii. Cell-suspension cultures:

Cell-suspension culture is developed from the callus, when it is placed into a liquid medium and then agitated, single cells and/or small clumps of cells are released into the medium. Under these cells continue to grow and divide, eventually producing a cell-suspension culture. It can be scaled up by repeated sub culturing into fresh medium. Large cell clumps can be removed during subculture of the cell suspension.

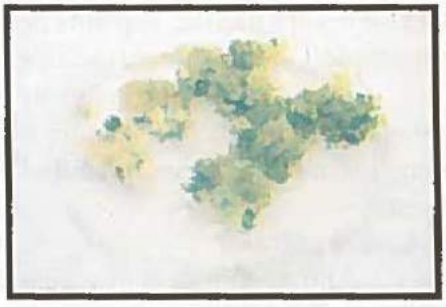


Fig: 26.21 Callus of *Nicotiana tabacum*

Cell suspension cultures are very useful to obtain some drug compound which are generally obtained from specific parts of adult plant because the cell suspension cultures produce the same chemicals as the entire plant. For example cell suspension culture of Cinchona ledgeriana produce quinine and those of Digitalis lanata produce digitoxin.

iii. Protoplasts culture:

Protoplasts are plant cells with the cell wall removed. Protoplasts are most commonly isolated from either leaf mesophyll cells or cell suspensions.

Protoplast cultures can be used to develop whole plants by organogenesis or **somatic embryogenesis** (synthetic embryos that are developed from somatic cells). Genetic variations can also be induced in these somatic embryos, if they are exposed

to chemical of physical mutagens. Such variations are called as **somaclonal variations**. Protoplasts also act as ideal targets for transformation by a variety of means.

Fig: 26.12 Callus of *Nicotiana tabacum*

iv. Meristem Culture:

Meristems are the rapidly dividing and growing tissues, especially found at the apices of roots or shoots and in some other plant parts. A tissue culture in which meristems are used as explants is called meristem culture. Generally root apical or shoot apical meristems are used for meristem culture.

Meristem culture is mostly used for micropropagation and to obtain virus or parasite free plants because the whole plant may be infected by virus, bacteria or fungi but meristems are devoid of viruses due to the absence of vascular system in them.

v. Anther culture:

Anther culture is also called as microspore culture or pollen culture. It is a technique in which mature anthers or microspores are cultured in a suitable medium, the haploid cells (tube cells) present in the microspore begin to divide and produce haploid callus.

A haploid callus can be grown into a haploid plant; a diploid plant can also be obtained if chromosomal doubling is induced by the colchicine treatment.

26.8.3 Animal Cell Culture:

An important aspect of any biotechnological processes is the culture of animal cells in artificial media. These animal cells in culture are used in recombinant DNA technology, genetic manipulations and in a variety of industrial processes. Now-a -days it has become possible to use the cell and tissue culture in the areas of research which have a potential for economic value and commercialization. The animal cell cultures are being extensively used in production of vaccines, monoclonal antibodies, pharmaceutical drugs, cancer research, genetic manipulations etc.

Techniques of animal cell culture:

Animal cells can grow in simple glass or plastic containers in nutritive media but they grow only to limited generations. A cell culture which is initiated by the cells removed from an animal's organ is called as **primary cell culture**; where as the primary culture is subcultured in fresh media to establish **secondary cultures**.

The culture of native tissue that retains most of the in vivo histological features is regarded as **organ culture** while the culturing of the cells for their re-aggregation to form a tissue-like structure represents **histotypic culture**. Another culture technique involves the recombination of different cell types to form a more defined tissue or an organ is known as **organotypic culture**.

Among the essential requirements for animal cell culture are special incubators to maintain the levels of oxygen, carbon dioxide, temperature, humidity as present in the animal's body, and, the synthetic media with vitamins, amino acids and fetal calf serum.

Synthetic media are prepared artificially by adding several organic and inorganic nutrients, vitamins, salts, serum proteins, carbohydrates, cofactors etc.

Different types of synthetic media can be prepared for a variety of cells and tissues to be cultured. Synthetic media are of two types- Serum containing media (media containing serum) and serum- free media (media without serum).

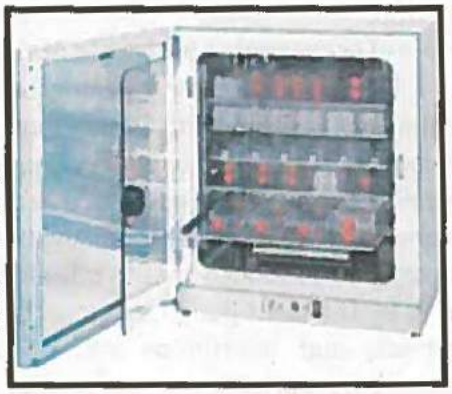


Fig: 26.23 Cell Culture Incubator

Applications of Animal Cell Culture:

The animal cell cultures are used for a diverse range of research and development. These areas are:

a) Production of antiviral vaccines.

d) Genetic manipulation, which is easy to carry out in cells or organ cultures.
e) Production of monoclonal antibodies requires cell lines in culture.
f) Production of pharmaceutical drugs using cell lines.
g) Chromosome analysis of cells derived from womb.
h) Study of the effects of toxins and pollutants using cell lines.
i) Use of artificial skin.
j) Study the function of the nerve cells.

26.9 TRANSGENIC ORGANISMS

Combining genes from different organisms is known as recombinant DNA technology, and the resulting organism is said to be **"genetically modified (GM)," "genetically engineered (GE)," or "transgenic."** In other words the free living organisms in the environment that have had a foreign gene inserted into them are called transgenic organisms. Bacteria were the first transgenic organisms, first transgenic bacterium was produced in 1973, since then many transgenic organisms such as animals, plants, and bacteria have been produced. Genetic Modification consists of a special set of techniques that alter the genetic makeup of the organisms.

26.9.1 Transgenic Bacteria:

Bacteria were the first organisms to be modified in the laboratory, due to their simple genetics. The first example of this occurred in 1978 when **Herbert Boyer** working at a University of California laboratory took a version of the human insulin gene and inserted into the bacterium *Escherichia coli* to produce synthetic "human" insulin.

Role of transgenic bacteria in making biotechnology products:

Transgenic bacteria are now being used in a variety of ways, and are particularly important in producing large amounts of pure human proteins for use in medicine. Genetically modified bacteria are used to produce the protein insulin to treat diabetes. Similar bacteria have been used to produce clotting factors to treat haemophilia, and human growth hormone to treat various forms of dwarfism. Some transgenic bacteria have been produced that synthesize tissue plasminogen activator (tPA), a protein used by the heart patients to treat thrombotic disorders as it dissolves clotted blood masses; and interferons which are used for treating viral infections. These recombinant proteins are much safer than the products they replaced, since the older products were purified from cadavers and could transmit diseases.

For Your Information

Both strains of *P. syringae* occur naturally, but recombinant DNA technology has allowed for the synthetic removal or alteration of specific genes, enabling the creation of the ice-minus strain. Modifying *P. syringae* may have unexpected consequences for climate. A study has shown that its ice nucleating proteins may play an important part in causing ice crystals to form in clouds. If humans increase the frequency of bacteria lacking these proteins then it could potentially affect rainfall.

Transgenic bacteria are also being used for bioremediation (removal of environmental pollutants by organisms). Such bacteria are also used to cleanup and recovery from an oil spill.

Ecological concerns surrounding transgenic bacteria:

Where lots of benefits are being obtained from genetically engineered bacteria, there are some ecological concerns also associated with these bacteria. One of the main issues regarding this is the possibility that hazardous new pathogens might be created.

26.9.2 Transgenic Plants:

The first field trials of genetically engineered plants occurred in France and the USA in 1986, when tobacco plants were engineered to be resistant to herbicides. In most cases the aim of developing transgenic plant is to introduce a new trait to the plant which does not occur naturally in this species. Examples include resistance to certain pests, diseases or environmental conditions, or the production of a certain nutrient or pharmaceutical agent.

Methods of gene transformation in plants:

There are many techniques of gene transformation have been developed; in all techniques gene of interest is introduced into single or few plant cells which are then allowed to regenerate in a suitable culture medium, upon a successful tissue culture procedure a transgenic plant is obtained.

Agriculturally improved transgenic crops:

During the last two decades, a tremendous progress has been made in the development of transgenic plants using the various techniques of genetic engineering. As per estimates recorded in 2002, transgenic crops are cultivated world-wide on about 148 million acres 587 million hectares) land by about 5.5 million farmers.

For Your Information

The first genes available for genetic engineering of crop plants for pest resistance were Cry genes (popularly known as Bt genes) from a bacterium ***Bacillus thuringiensis***. These are specific to particular group of insect pests, and are not harmful to other useful insects like butter flies and silk worms. Transgenic crops with Bt genes (e.g. cotton, rice, maize, potato, tomato, brinjal, cauliflower, cabbage, etc.) have been developed. This has proved to be an effective way of controlling the insect pests and has reduced the pesticide use.

Transgenic plants have many beneficial traits like:

- Tolerance against biotic stresses (viral, bacterial infections, pests and weeds) and abiotic stresses (physical actors such as temperature, humidity, salinity, drought, waterlogging etc.), weedicide or Herbicide tolerance e.g. glyphosate resistance and phosphinothricin resistance.
- Insect resistance like transgenic crops with Bt genes (e.g. cotton, rice, maize, potato, tomato, brinjal, cauliflower, cabbage, etc.)
- Delayed fruit ripening,
- Improvements in nutritional contents

Some of the commercially grown transgenic plants in developed countries are: "Roundup Ready" soybean, "Freedom II squash", "High- lauric" rapeseed (canola), "Flavr Savr" and Endless Summer" tomatoes. During 1995, full registration was granted to genetically engineered Bt gene containing insect resistant 'New Leaf' (potato), 'Maximizer' (corn), 'Boll Gard' (cotton) in USA.

DO YOU KNOW?

In July 2000, researchers from the team that produced Dolly reported success in producing transgenic lambs in which the transgene had been inserted at a specific site in the genome and functioned well.

26.9.3 Transgenic Animals:

A transgenic animal is one that carries a foreign gene that has been deliberately inserted into its genome. Transgenic animals have the potential to improve human welfare in:

- agriculture, such as larger sheep that grow more wool
- medicine, such as cows that produce insulin in their milk
- industry, such as goats that produce spider silk for materials production

Methods of creation of transgenic animals:

In comparison to that for larger vertebrates, mice have become the model animal used in the field of transgenics because of their small size and low cost of housing, short generation time, and, fairly well defined genetics.

The insertion of gene is, however, a random process, and there is a high probability that the introduced gene will not insert itself into a site on the host DNA that will permit its expression.

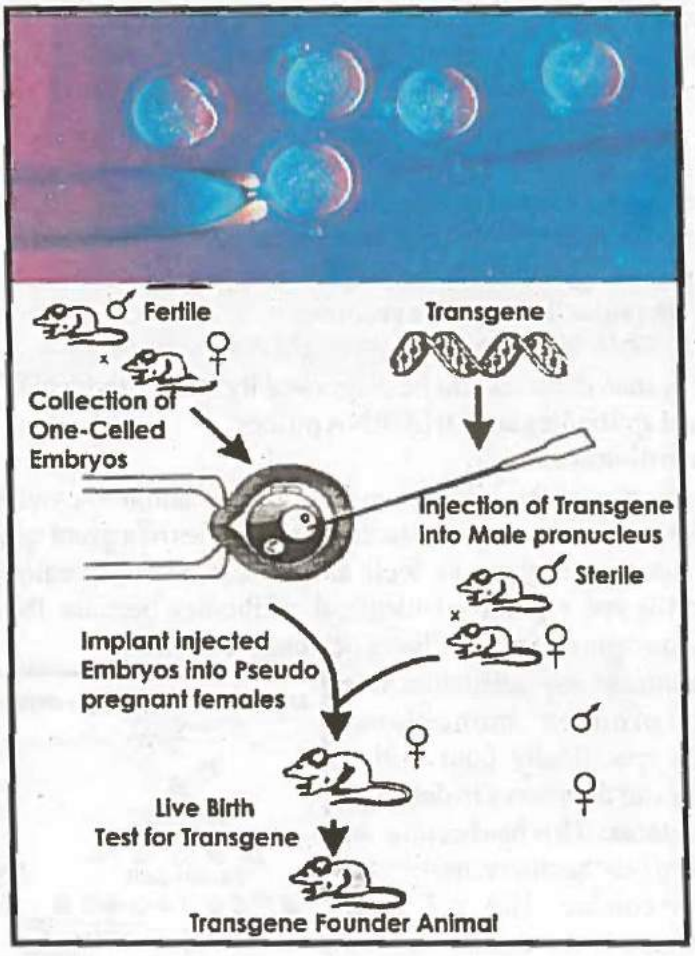


Fig: 26.24 Procedure for creation of transgenic animal.

The three principal methods used for the creation of transgenic animals are DNA microinjection, embryonic stem cell-mediated gene transfer and retrovirus-mediated gene transfer.

26.10 BIOTECHNOLOGY AND HEALTHCARE

The tools and techniques of biotechnology have opened up new doors when it comes to researching and learning more about the human body and what goes wrong with it when problems arise. Due to being able to understand the molecular base of health and disease this has lead scientists to improve methods of treating and preventing those diseases.

Biotechnology has made a huge difference in human health care and has now enabled scientists to develop products which can give quicker and more accurate tests, therapies that have a lot less side effects and vaccines which are safer than ever before.

6.10.1 Development of vaccine in biotechnology:

Biotechnology is used in three different ways in the development of vaccine:

a) Separation of a pure antigen using a specific monoclonal antibody.

b) Synthesis of an antigen with the help of a cloned gene.

c) Synthesis of peptides to be used as vaccines.

26.10.2 Role of Biotechnology in Diagnosis of diseases:

Many human diseases can be diagnosed by using products of biotechnology like monoclonal antibodies and DNA/RNA probes.

Monoclonal Antibodies:

The response of the immune system to any antigen, even the simplest, is polyclonal. That is, the system manufactures antibodies of a great range of structures both in their binding regions as well as in their effector regions. Monoclonal antibodies (mAb) are a group of identical antibodies because they are made by identical immune cells that are all clones of a unique parent cell.

Given almost any substance, it is possible to produce monoclonal antibodies that specifically bind to that substance; they can then serve to detect or purify that substance. This has become an important tool in biochemistry, molecular biology and medicine. Not only can antibodies be used therapeutically, to protect against disease; they can also help to diagnose a wide variety of illnesses, and can detect the presence of drugs, viral and bacterial products, and other unusual or abnormal substances in the blood. Monoclonal antibodies are typically made by fusing **myeloma cells** (cancerous B-lymphocytes) with the spleen cells from a mouse that has been immunized with the desired antigen. The technique is called **somatic cell hybridization**

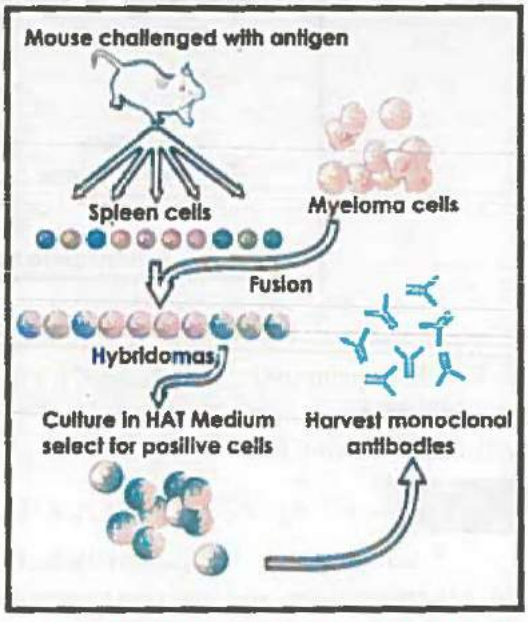


Fig: 26.25 Production of monoclonal antibodies.

DNA/RNA Probes:

In biotechnology, a probe is a florescent or radioactive labeled fragment of DNA or RNA of variable length (usually 100-1000 bases long), which is used in DNA or RNA samples to detect the presence of nucleotide sequences that are complementary to the sequence in the probe. Such probes are widely used in diagnosis of many viral and bacterial diseases.

Diagnosis of diseases caused by protozoa and helminthes

The monoclonal antibodies and DNA probes are being used as very sensitive tools in biotechnology to diagnose the diseases caused by protozoa and helminthes. Monoclonal antibodies can be used through serological tests which takes only minutes as compared to conventional methods which require some weeks as the bacteria and viruses have to be cultured e.g. in Herpes virus.

The DNA probes are more sensitive than monoclonal antibodies and the process takes hours instead of weeks. Readymade DNA probes for Herpes virus and other human, animal and plant viruses are being prepared. Probes are now available for a number of human parasites from the group protozoa and helminthes.

26.10.3 Gene Therapy:

Gene therapy is a technique for correcting defective genes responsible for disease development. Researchers may use one of several approaches for correcting faulty genes:

- A normal gene may be inserted into a nonspecific location within the genome to replace a nonfunctional gene. This approach is most common.
- An abnormal gene could be swapped for a normal gene through homologous recombination.

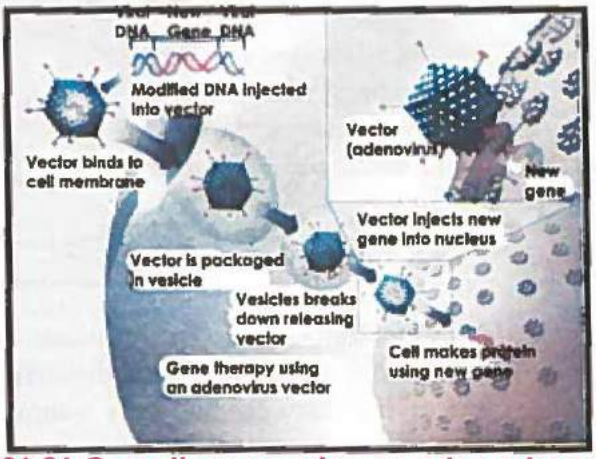


Fig: 26.26 Gene therapy using an adenovirus vector.

- The abnormal gene could be repaired through selective reverse mutation, which returns the gene to its normal function.
- The regulation (the degree to which a gene is turned on or off) of a particular gene could be altered.

Mechanism of gene therapy:

In gene therapy treatment normal gene is either delivered directly into the body ***(in vivo)*** or into the cells outside the body then these transgenic cells are again implanted into the body ***(ex vivo)***. In both cases, a "normal" gene is inserted into the genome to replace an "abnormal," disease-causing gene. A carrier molecule called a vector must be used to deliver the therapeutic gene to the patient's target cells. Currently, the most common vector is a virus that has been genetically altered to carry normal human DNA. Viruses have evolved a way of encapsulating and delivering their genes to human cells in a pathogenic manner. Scientists have tried to take advantage of this capability and manipulate the virus genome to remove disease-causing genes and insert therapeutic genes.

Target cells such as the patient's liver or lung cells are infected with the viral vector. The vector then unloads its genetic material containing the therapeutic human gene into the target cell. The generation of a functional protein product from the therapeutic gene restores the target cell to a normal state.

Besides virus-mediated gene-delivery systems, there are several non-viral options for gene delivery. The simplest method is the direct introduction of therapeutic DNA into target cells. This approach is limited in its application because it can be used only with certain tissues and requires large amounts of DNA.

Another non-viral approach involves the creation of an artificial lipid sphere with an aqueous core. This liposome, which carries the therapeutic DNA, is capable of passing the DNA through the target cell's membrane.

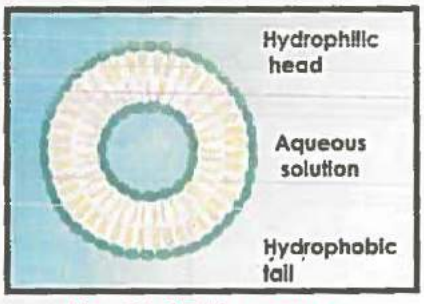


Fig: 26.27 Liposome

26.10.4 Cystic fibrosis:

An inherited disease, cystic fibrosis affects the mucus and sweat glands. People with severe symptoms can have serious lung and digestive problems, while people with a mild form of the disease may not have any symptoms until they are adolescents or young adults.

Normally, mucus is watery. It keeps the linings of certain organs moist and prevents them from drying out or getting infected. However, the cause of cystic fibrosis (CF) is a defect in the **cystic fibrosis transmembrane conductance regulator (CFTR)** gene that encodes a protein by which the movement of salt and water is controlled in and out of your cells. In people with cystic fibrosis, the gene does not work effectively. As a result, cells that line the passageways of the lungs, pancreas, and other organs produce abnormally thick, sticky mucus. This mucus obstructs the airways and glands, which causes the characteristic signs and symptoms of cystic fibrosis.

Gene Therapy of Cystic fibrosis: In 1989, experts discovered the gene that causes cystic fibrosis and identified it as the cystic fibrosis transmembrane conductance regulator or CFTR. The discovery of this defective gene posed new possibilities of a cure. Experts proposed gene therapy as a plausible method for curing the disease. Gene Therapy is the process of creating a healthy version of the flawed CFTR gene and infusing it into the affected cells in the body, particularly into the lungs of cystic fibrosis-inflicted patients.

26.11 SCOPE AND IMPORTANCE OF BIOTECHNOLOGY

During 1970s, biotechnology emerged as new discipline, as a result of marriage of biological science with technology. It has been possible due to revolutionary discoveries made in these two areas. Biotechnology is not a pure science, but an integrated effort of these two, the root of which lies in biological science. Biotechnology is defined by different organizations in different ways. It has been broadly defined as, "the development and utilization of biological processes, forms and systems for obtaining maximum benefits to man and other forms of life". Biotechnology is "the science of applied biological process". Importance of biotechnology is highlighted in the following fields.

26.11.2 Biochips & biological computers:

Biochip is the result of marriage of microchips business with biotechnology. In future, there is the possibility of developing of biological computers.

The development of biochips is a major thrust of the rapidly growing biotechnology industry, which encompasses a very diverse range of research efforts including genomics, proteomics, computational biology, and pharmaceuticals, among other activities. Advances in these areas are giving scientists new methods for unraveling

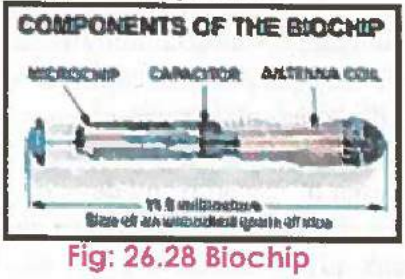


Fig: 26.28 Biochip

the complex biochemical processes occurring inside cells, with the larger goal of understanding and treating human diseases. At the same time, the semiconductor industry has been steadily perfecting the science of microminiaturization. The merging of these two fields in recent years has enabled biotechnologists to begin packing their traditionally bulky sensing tools into smaller and smaller spaces, onto so-called biochips. These chips are essentially miniaturized laboratories that can perform hundreds or thousands of simultaneous biochemical reactions. Biochips enable researchers to quickly screen large numbers of biological analytes for a variety of purposes, from disease diagnosis to detection of bioterrorism agents.

26.11.3 Mycorrhiza: Mycorrhiza is a symbiotic association between certain fungi and roots of higher plants. This association is very beneficial for the growth of plants. In most of the cases plant seedling fails to grow if the soil does not contain inoculum of mycorrhizal fungi.

In recent years, use of biotechnologically produced inoculum of mycorrhizal fungi has increased its significance due to its multifarious role in plant growth and yield, and resistance against climatic and edaphic stresses, pathogens and pests.

Fig: 26.29 Mycorrhizal roots

26.11.4 Biofertilizers: In recent years, use of microbial inoculants as a source of biofertilizers (nutrient inputs of biological origin for plant growth) has become a hope for most of countries, as far as economic and environmental viewpoints are concerned. Biologically fixed nitrogen is such a source which can supply an adequate amount of nitrogen to plants and other nutrients to some extent. It is a non-hazardous way of fertilization of field. Moreover, biologically fixed nitrogen consumes about 25 percent to 30 percent less energy than normally done by chemical process.

26.11.5 Nanotechnology: A new and exciting sub-branch requiring biotechnologists is the field of nanotechnology. Nanotechnology gives us the capability to engineer the tiniest of objects, things at the molecular level. Nanotechnology includes the study and manipulation of materials between 1 and 100 nanometers.Nanotechnologists are imparting their expertise in the development of such nano particle that can be used for efficient drug delivery at the target cells and in the diagnosis of diseases.

26.11.6 Scope of biotechnology: Biotechnology is one of the fastest growing field in the area of research and development. It is also called a technology of the future or technology of tomorrow because of its unprecedented impacts on the human mankind and the universe as a whole.

Due to its interrelation with other fields such as industry, agriculture, computers etc, it is going to create amazing opportunities for manipulating the biological systems and thereby understanding the mysteries of fundamental life processes.

Students of biotechnology after completing their studies can have scope in the following fields:

- **Communications/media** - reporting, writing, editing
- **Computer Science** - data base development, bioinformatics, web site development, etc.
- **Pharmaceutical companies,** i.e Drug development
- **Engineering** -working in bioprocess chambers, Instrumentation development, Fermentation technology
- **Research e.g.** cancer, genetically linked diseases, AIDS
- **Diagnostic laboratories** funded by public and private sectors
- **Waste management**, bio-monitoring bodies and pollution control boards
- **Medicine** - The medical genetics, genetic counseling, gene therapy and gene testing uses biotechnological tools.
- **Bio power plants.**
- **Bio-processing industry e.g.** enzyme technology, paper technology, metabolic engineering, protein engineering, food processing etc
- **Agriculture and animal husbandry**
- **Legal field** involving issues related to intellectual property rights, patency, copyrights related to the field of biotechnology. The issues related to Genetic and Paternity testing also requires the combined expertise of biotechnologist and a law expert.
- **Millitary** - With the fear of Biological warfare looming large on the human civilization, a biotechnologist is needed in pathogen identification, in the development of protection against the chemical and biological warfare, and in doing the risk assessment studies
- **Crime and law** - With the use of DNA finger printing in Forensic science it has become easy to create a data bank of the criminals and thereby catch the culprits faster

Fig: 26.30 DNA finger printing is used in crime detection.

26.11.7 Hazards and social/ethical implication of using biotechnology:

The field of biotechnology has had a lot of beneficial contribution in the area of healthcare, agriculture, food production, manufacture of industrial enzymes, and appropriate environmental management. However, the advancement in this field has also lead to some concerns and controversies raised by a number of groups, NGOs etc. ELSI is the short form to represent the ethical, legal, and social implications of biotechnology. ELSI broadly covers the relationship between biotechnology and society with particular reference to ethical and legal aspects.

26.11.8 Concerns about the genetically modified organisms (GMOs):

There are concerns regarding the biosafety, ethics and issues related to the release of GMOs in the environment. Many countries and NGOs have opposed the release of the GMOs due to these reasons. In order to address these issues, the United Nations has built up an Informal Working Group on Biosafety. In 1991, this group prepared the **"Voluntary Code of Conduct for the release of Organisms into the Environment"**. The main areas of consideration for safety aspects in biotechnology are the following:

- How to dispose-off spent microbial biomass and purify the effluents from biotechnological processes?
- The toxicity of the allergy associated with microbial production.
- How to deal with the increase in the number of antibiotic resistant pathogenic microorganisms?
- How to evaluate the pathogenicity of the genetically engineered microorganisms to infect humans, plants and animals?
- How to prevent contamination, infection or mutation of the processed strains?
- The evaluation of the interaction of the genetically engineered microbes with the elements of natural environment.

26.11.9 Biological Warfare:

Most of the countries of the world are signatories to the **Biological Weapons Conventions** of 1972.As a signatory, it is a voluntary pledge by a nation "never to produce microbial or other biological agents or toxins, whatever may be their method of production, for use in wars. However, many people have expressed their concerns about the possible use of genetic manipulations for military purposes in the near future.

Fig: 26.3 Signing ceremony of Biological Weapons Convention of 1972.

26.11.10 Intellectual Property:

With the fast pace development in the field of biotechnology, the issues related to legal characterization and the treatment of trade related biotechnological processes and products are of immense importance. These are popularly known as **Intellectual Property**. Intellectual Property includes Patents, trade secrets, copyrights, and trademarks. **Intellectual Property Rights (IPR)** is a collective term applied to a number of different types of legal rights granted by each country. The rights to protect this property prohibit others from making, copying, using or selling the proprietary subject matter.

In biotechnology, the intellectual property covers the processes and products which result from the development of genetic engineering techniques through the use of restriction enzymes to create recombinant DNA. Another example of intellectual property is the development of crop varieties which are protected through "plant breeder's rights or PBRs. The PBRs ensures that the plant breeder who developed a particular variety gets the exclusive rights for marketing the variety.

KEY POINTS

- Biotechnology refers to the use of living organisms or their processes and products for the welfare of mankind.
- Gene cloning is the act of making copies, or clones, of a single gene. There are two possible ways of cloning of gene: recombinant DNA technology and polymerase chain reaction (PCR).
- Recombinant DNA Technology is an *in vivo* method which is used when gene cloning is required at industrial scale. For this purpose the following components or tools are required: gene of interest, molecular scissors, molecular carrier or vector, molecular glue and expression system
- Plasmid could be used as vectors which are derived mostly from bacteria and are the most widely used, versatile, and easily manipulated ones.
- DNA Ligase is enzyme responsible for the formation of the phosphodiester linkage between two adjacent nucleotides and thus joins two double-stranded DNA fragments, therefore it is called molecular glue.
- The polymerase chain reaction (PCR) is a technique in molecular biology to amplify (cloning) a single or a few copies of a piece of DNA, to generate thousands to millions of copies.
- A genomic library is a collection of bacterial or bacteriophage clones, each containing at least one copy of every DNA sequence in a genome of an organism. In single library the entire genome of an organism is represented as a set of DNA fragments inserted into a vector molecule.
- The main principle of any DNA sequencing method is to generate piece of DNA of different sizes all starting from the same point and ending at different points, separation of these different sized pieces of DNA by gel electrophoresis and reading of sequence from the gel.
- Gel electrophoresis is a technique used in molecular biology to separate charge bearing polymers (proteins, RNA or DNA) under the influence of electric field.
- DNA electrophoresis is used to separate DNA fragments primarily by size.
- The genome is a collection of all the genes found in one complete set of chromosome.

KEY POINTS

- The Human Genome Project (HGP) is an international scientific research project which is based on the exploration and analysis of human genome. Major goals and objective of this project were to identify all the approximately 20,000-25,000 genes in human DNA, determine the sequences of the 3 billion chemical base pairs that make up human DNA, store this information in databases, improve tools for data analysis, transfer related technologies to the private sector, and address the ethical, legal, and social issues (ELSI) that may arise from the project.
- The animal cell cultures are being extensively used in production of vaccines, monoclonal antibodies, pharmaceutical drugs, cancer research, genetic manipulations etc.
- Combining genes from different organisms is known as recombinant DNA technology, and the resulting organism is said to be **"genetically modified (GM)," "genetically engineered (GE),"** or **"transgenic."**
- A transgenic animal is one that carries a foreign gene that has been deliberately inserted into its genome.
- Gene therapy is a technique for correcting defective genes responsible for disease development.

EXERCISE ?

x. *A totipotent cell means:*

(a) An undifferentiated cell capable of developing into a system or entire plant

(b) An undifferentiated cell capable of developing into an organ

(c) An undifferentiated cell capable of developing into complete embryo

(d) Cell which lacks the capability differentiate into an organ or system

2. Short Questions

i. Why don't the restriction enzymes destroy the DNA of the organism in which they are produced?

ii. What are the essential features of a vector?

iii. What are monoclonal antibodies?

iv. Name two conditions necessary for maintaining animal cells in culture which are different from plant cell culture

v. Give any two human proteins and their function which are produced biotechnologically.

vi. What are probes?

vii. What were the aims and objectives of human genome project?

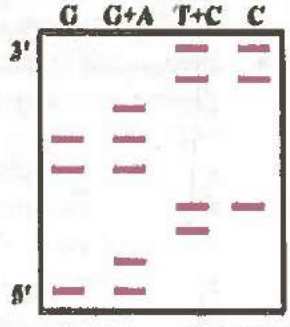
viii. Differentiate between Maxam-Gilbert method & Sanger's method of gene sequencing.

ix. What is cDNA library?

x. What are the types of vector or carrier?

xi. What are the applications of PCR?

xii. Read carefully the diagram of gel pattern obtained through Maxam-Gilbert method of gene sequencing, and predicts the sequence of target DNA.



3. Long Questions

i. What are molecular scissors? Describe their sources and mode of action.

ii. Evaluate the process of gene sequencing with the help of Sanger's Method.

iii. Explain the process of gene cloning with the help of recombinant DNA technology.

iv. Explain the process of gene cloning with the help of Polymerase Chain Reaction.

v. Describe the procedure of DNA analysis.

EXERCISE ?

v. Describe the procedure of DNA analysis.

4. **Analyzing and interpreting**

- Analyze and interpret the DNA of a child by comparing it with that of two individuals in case of disputed parenthood.

5. **Science, Technology & Society Connections**

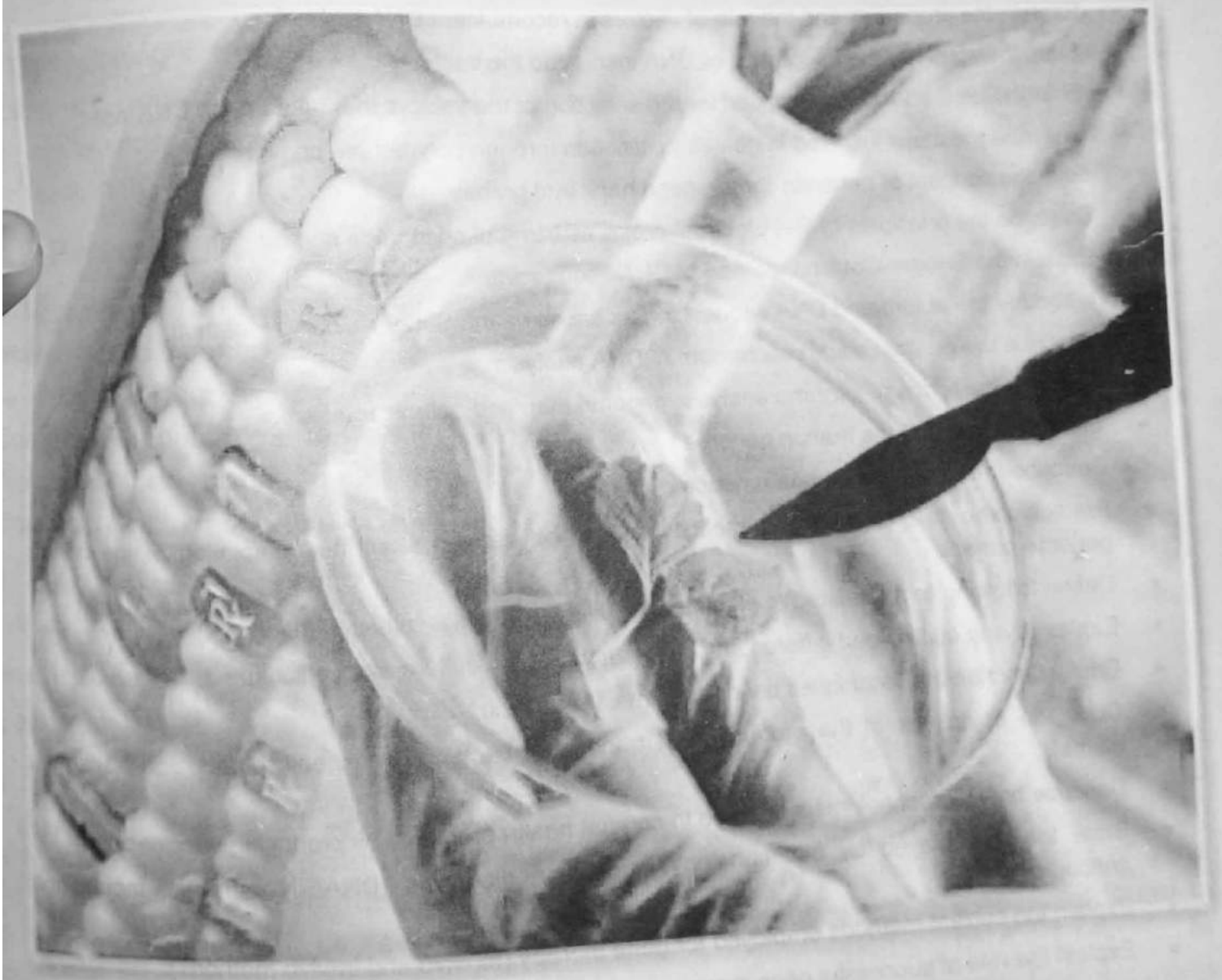
- Describe the applications of polymerase chain reaction.
- State the importance and limitations of DNA analysis in foreign sick medicine and paleontology.
- Justify why the human genome project is regarded as the most ambitious project ever undertaken by man.
- Describe the major findings that have arisen from human genome project.
- Predict the applications of genetic engineering in crop improvement.
- Describe the role of genetic screening.
- Justify the need for genetic counseling.
- Describe briefly the accomplishments of the renowned genetic engineers working in privet or public sector institutions in his/her province.
- Suggest measures he/she would take to solve related problems by using knowledge gained in this chapter.
- Describe and analyze examples of technology that have extended or modified the scientific understanding of the genetic engineering.
- Investigate careers that require an understanding of biotechnology and genetic engineering.

6. **Online learning**

- www.ncbi.com
- www.biotechnology4u.com
- www.ornl.gov/hgmis
- www.vivo.colostate.edu/hbooks/genetics/biotech
- www.genetics-and-society.org

SECTION 6

Application of Biology



Biotechnology

26

BIOTECHNOLOGY

After completing this lesson, you will be able to

This is a 15 days unit

- Define gene cloning and state the steps in gene cloning.
- Describe the techniques of gene cloning through recombinant DNA technology.
- Explain the role of restriction endonucleases and DNA ligases in gene cloning.
- Describe the selection and isolation of the gene of interest.
- Explain the properties and the role of vectors in recombinant DNA technology.
- State the steps for the integration of DNA insert into the vector.
- Briefly state the technique applied for the selection of the vectors that take up the DNA insert.
- Describe the steps involved in gene amplification through polymerase chain reaction.
- Give the concept of genomic library, gene bank and probes.
- Describe the principles of Gel Electrophoresis as being used in gene sequencing.
- Explain the Sanger-Coulson method of DNA sequencing.
- Introduce the automated DNA sequencing as based on the Sanger-Coulson method.
- Describe the purposes and mechanism of DNA analysis.
- Describe the terms of genome analysis, genome map and genetic markers.
- State the history of the human genome project
- Describe the goals of the human genome project.
- Predict some of the possible benefits that can be derived after the completion of the human genome project.
- Define following terms related to plant tissue culture; explants, callus, plantlets.
- Explain tissue culture and differentiate between the organ culture and cell culture.
- Briefly describe the techniques used for animal tissue culture.
- State the objectives of the production of transgenic bacteria, transgenic plants and transgenic animals.
- Describe how biotechnologists are able to combat health problems by producing vaccines.
- State the role played by biotechnology in disease diagnosis (DNA/RNA probes, monoclonal antibodies).
- Explain the current methods employed for gene therapy (ex-vivo and in-vivo methods).
- Explain the role of successful gene therapy for cystic fibrosis.
- Explain the scope and importance of biotechnology in promoting human welfare.
- List the hazards of using genetically modified organisms.

Reading

Biotechnology deals with the application of biology and biological concepts to science and engineering for the welfare of mankind. It is the crossroad of the biological sciences with other major disciplines of science, from organic chemistry to mechanical engineering. The history of biotechnology is as old as history of man. When the first human beings realized that they could plant their own crops and breed their own animals, they learned to use biotechnology. But the term biotechnology was introduced by the end of 20th century. Now a days the field of biotechnology becomes a vast field but this chapter touches a brief part of biotechnology, called **genetic engeering**, which deals with manipulation or alteration in genetic material of an organism.

26.1 CLONING OF GENES

Gene cloning is the act of making copies, or clones, of a single gene. Once a gene is identified and cloned, it can be used in many areas of biomedical and industrial research. There are two possible ways of cloning of gene: recombinant DNA technology and polymerase chain reaction (PCR).

26.1.1 Recombinant DNA Technology

Recombinant DNA technology is a series of procedures that are used to join DNA segments from different sources. This is an *in vivo* (in living cells) method which is used when gene cloning is required at industrial scale. The main advantage of this method is the production of product of gene beside copies of gene. It involves the selection and isolation of desired gene (gene of interest), inserting it in a suitable vector and the transformation of a suitable host by the recombinant DNA.

Components / Tools of recombinant DNA technology

The cloning of gene through recombinant DNA technology requires gene of interest, molecular scissors, molecular carrier or vector, molecular glue and expression system.

i) Gene of Interest

The gene of interest is the gene which is to be cloned. It can be obtained by one of the three possible ways: (a) artificial gene synthesis is the process of synthesizing a gene *in vitro* (in glassware) without template DNA samples with the help of DNA synthesizer machine. (b) Gene of interest can also be obtained by synthesizing it from its mRNA. Synthesis of gene from mRNA is carried out by **reverse transcriptase** enzymes which are naturally found in retroviruses. The DNA formed by this process is called **complementary DNA** (cDNA). (c) In most of the cases the gene of interest is directly cleaved from a chromosomal DNA by using particular DNA scissors called restriction endonucleases.

ii) Molecular scissors (Restriction endonuclease)

Restriction endonucleases are enzymes that cleave the phosphodiester bonds of both strands of duplex DNA at specific sequences. In 1970, the first restriction enzyme was isolated. Many different restriction endonucleases have been isolated so far.

Naturally restriction enzymes are found in bacteria, where they appear to serve as host-defence role because they chop up and inactivate **("restrict")** the DNA of infecting viruses.

Each restriction enzyme cleaves DNA at specific sequence of DNA called **recognition sites** or **restriction sites**. These sites have **palindromic sequences**. A palindromic sequence is a four to eight base pairs in DNA in which nucleotides are arranged symmetrically in reverse order.

Restriction enzymes either make **staggered cut** or **blunt cut**. A staggered cut is one in which the resulting duplex fragments show single stranded projected ends called **sticky ends**. While in blunt cut the resulting duplex fragments do not show such sticky ends. In the fig 26.1, the recognition site is boxed in yellow and the cut sites indicated by red triangles.

Critical Thinking

(i) If restriction enzymes are capable of destroy the DNA of bacteriophage, why they do not chew up their host genomic DNA? (ii) The restriction enzymes that form sticky ends are more useful in genetic engineering. Why?

Science Tibits

By convention, restriction enzymes are named after their host of origin. For example, EcoRI was isolated from *Escherichia coli*, Hind II and Hind III from *Haemophilus influenzae*, and XhoI from *Xanthomonas holcicola*.

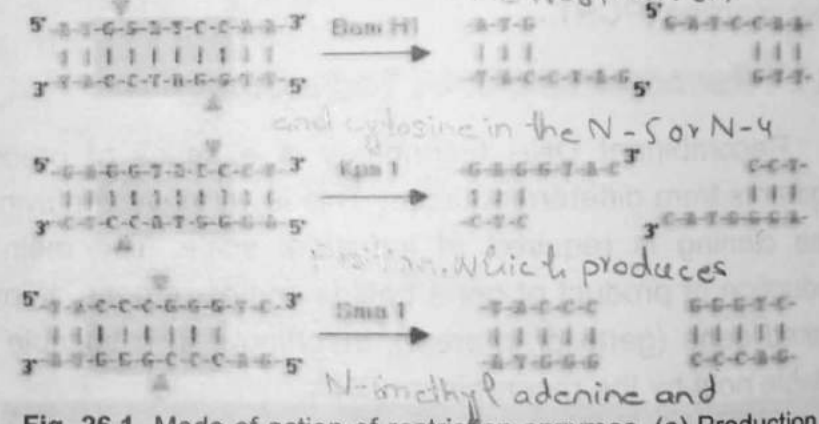


Fig. 26.1 Mode of action of restriction enzymes. (a) Production of 5′ sticky ends, (b) Production of 3′ sticky ends, (c) Production of blunt ends. Bam H-I, Kpn-I and Sma-I are different restriction enzymes

iii) Molecular carriers or vectors

Vectors are another major component required to make a recombinant DNA (rDNA) molecule for gene cloning. Vectors act as a vehicle for carrying foreign DNA into a host cell for multiplication. Usually small circular DNA molecules of bacterial origin are used as cloning vectors. A DNA molecule should possess the following essential characteristics to act as a cloning vector: (a) Origin of replication site, (b) antibiotics resistant genes, (c) restriction sites of different enzymes. Example of vectors are: Plasmid, lambda phage DNA, Cosmid (combination of plasmid and phage DNA), Yeast artificial chromosomes (YACs) etc.

iv) Molecular glue (DNA Ligase)

This enzyme is responsible for the formation of the phosphodiester linkage between two adjacent nucleotides and thus joins two double-stranded DNA fragments; therefore it is called

plasmid in the right direction. The ligation process or fusing of DNA

molecular glue. In rDNA experiments, **DNA ligase** is used to join two different DNA fragments (plasmid/vector and the foreign DNA) that are annealed by the sticky ends.

fragments, requires less DNA When the DNA has sticky ends.

v) Expression system

A suitable organism that can act as host for the recombinant vector to express (multiplication) is called **expression system**. Therefore, the selection of suitable expression system always depends upon the type of vector which is being used while making recombinant DNA. The most important character of an ideal expression system is its short generation time and simplicity of its genetic system. So bacterial cells can act as an ideal expression system.

Mechanism or procedure of recombinant DNA technology

Cloning of the desired gene through recombinant DNA technology involves the formation of recombinant DNA (gene of interest + vector DNA), transformation of a suitable expression system by the recombinant DNA, and the identification of transformed clones.

(I) Formation of recombinant DNA

The first step in the construction of a recombinant DNA, is the isolation and purification of vectors and gene of interest. First, digest the vector DNA (e.g., plasmid) with same restriction enzyme by which gene of interest is cleaved so that compatible sticky ends can be produced. Next both, vector and gene of interest are incubated together in the presence of DNA ligase

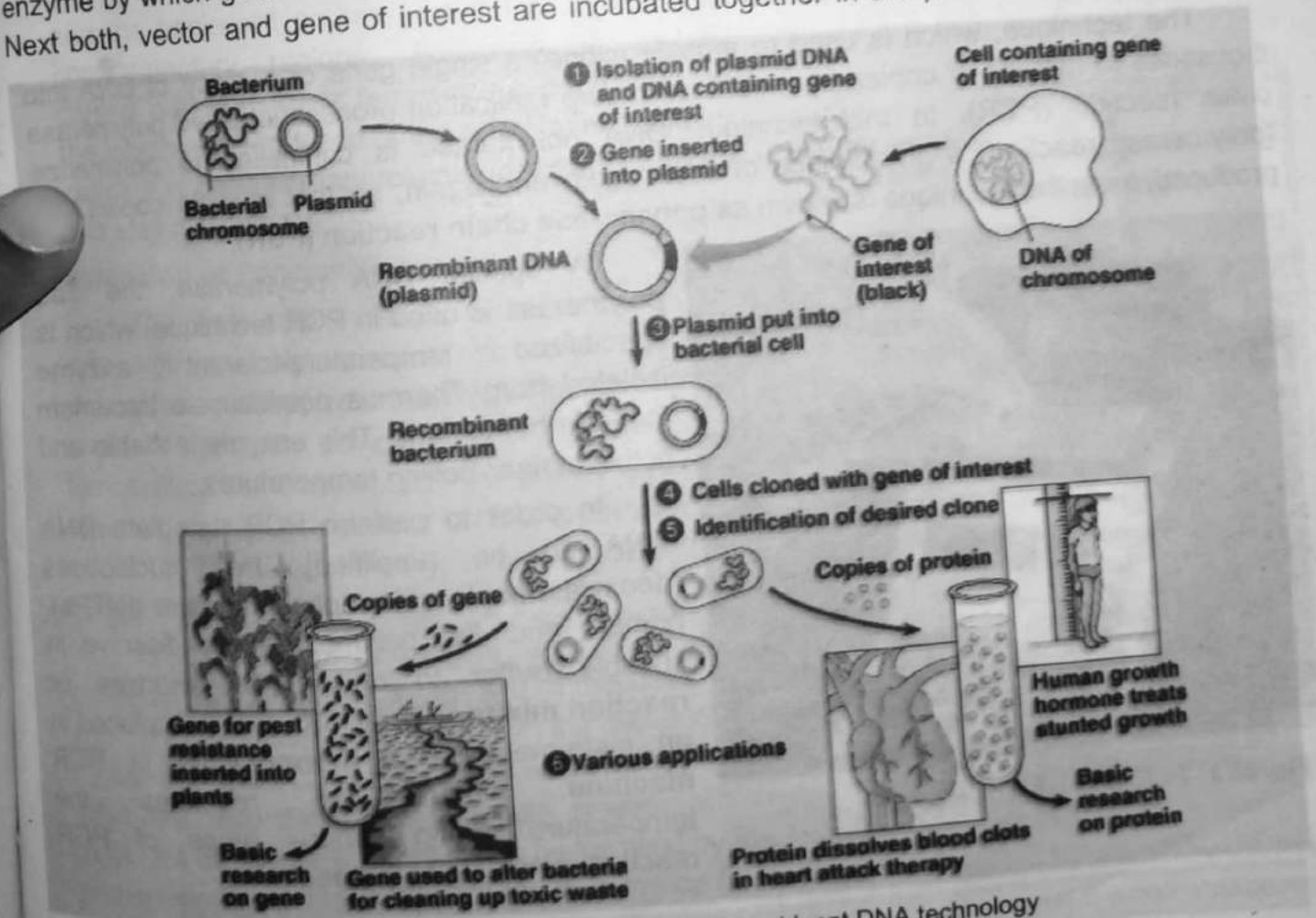


Fig. 26.2 Steps and applications of recombinant DNA technology

which connects them by forming phosphodiester linkage. This results in the formation of recombinant DNA molecule of vector and the gene of interest.

(ii) Transformation of expression system

Here transformation refers to the insertion of recombinant DNA into the expression system which can be performed by putting the expression system (bacterial cells that already contain no plasmids) and recombinant plasmids into the same medium. Bacterial cells take up recombinant plasmid, especially, if they are treated with calcium chloride which make them more permeable. Thereafter, as the cell reproduces, a bacterial clone forms and each new cell contains at least one plasmid. Therefore, each of the bacterial cell contains the gene of interest, which will express itself and make its product. ampicillin(antibiotic)

(iii) Identification of transformed clone

The transformed clone can be identified by adding a particular antibiotic (for which resistant gene is found in plasmid) into the medium. As the transformed clone has got resistance against the antibiotic, so it remains alive and continues to grow, whereas all the untransformed clones are killed by the antibiotic. From this transformed bacterial clone, the cloned gene can be isolated for further analysis or its protein product can be separated and used for various purposes.

26.1.2 Polymerase Chain Reaction (PCR)

The technique, which is used to amplify (clone) a single gene or a piece of DNA into thousands to millions of copies by means of *in vitro* replication process is called polymerase chain reaction (PCR). In this technique DNA polymerase is compelled to polymerize (polymerase reaction) a given piece of DNA again and again, so that multiple copies are produced, thus, the technique is known as **polymerase chain reaction (PCR)**.

Fig. 26.3 PCR machine (Thermocycler)

A special DNA polymerase, the *Taq* polymerase is used in PCR technique, which is specialized temperature-tolerant enzyme isolated from *Thermus aquaticus*, a bacterium found in hot springs. This enzyme is stable and active at near-boiling temperatures.

In order to perform PCR, template DNA (DNA to be amplified), free nucleotides (deoxyribo-nucleoside triphosphates or dNTPs), primers and *Taq* polymerase are dissolve in suitable buffer to make **PCR mixture** or **reaction mixture**. The PCR mixture is placed in an instrument called **thermocycler** or **PCR machine**. Thermocycler regulates the temperature during various steps of PCR reaction according to the need.

Taq polymerase
free nucleotides
Target DNA

Mechanism of PCR Reaction

PCR cycle consists of three steps: **denaturation**, **primer annealing**, and **extension** or **polymerization** each requires a specific temperature. The time duration, temperature and sequence of the steps have to be programmed in the thermocycler.

(1) · Faster process · cheap · want to go through cycles of melting and molding DNA.

Denaturation

In the denaturation step, the template is heated to 94°C for one minute. At this high temperature the DNA undergoes complete denaturation and the double-stranded DNA (dsDNA) becomes single-stranded DNA (ssDNA). Each single ssDNA can act as the template for the *in vitro* DNA synthesis.

(2) · heat-tolerant · most active around 70°C which makes it ideal for PCR. thermophilic bacterium for example: Thermus aquaticus.

Primer annealing

The next step is the primer annealing. In this step the two primers, the forward primers and the backward primers, anneal or hybridize to the single-stranded template DNA at its complementary regions. Annealing is usually carried out at a lower temperature depending on the length and sequence of the primers. In standard cases it is 54°C and approximate time required for this step is 2 minutes.

Extension or Polymerization

The final step in each cycle is the primer extension or polymerization in which the *Taq* polymerase synthesizes new DNA strands to the 3′ ends of primers using dNTPs. The optimum temperature for carrying out the primer extension reaction or polymerization of dNTPs is standardized at 72°C. This step takes just one minute to be completed.

At the end of first cycle one target DNA molecule is converted in to two molecules. The second cycle immediately starts with the denaturation by heating at 94°C, so that all the newly synthesized DNA are also denatured to single strands, which again act as templates. It will again be followed by the primer annealing and extension and thus the cycle of denaturation, primer annealing, and extension

Science Titbits

PCR Technique was invented by Kary Mullis in 1983; later on he was awarded the Nobel Prize in Chemistry in1993

Critical Thinking

(1) Why heat is used in PCR technique to denature the target DNA instead of using DNA helicase and DNA gyrase enzymes? → it works best

(2) Why human DNA polymerase cannot be used in PCR technique? at body temperature.

(3) Why already synthesized primers are used in PCR technique instead of using primase

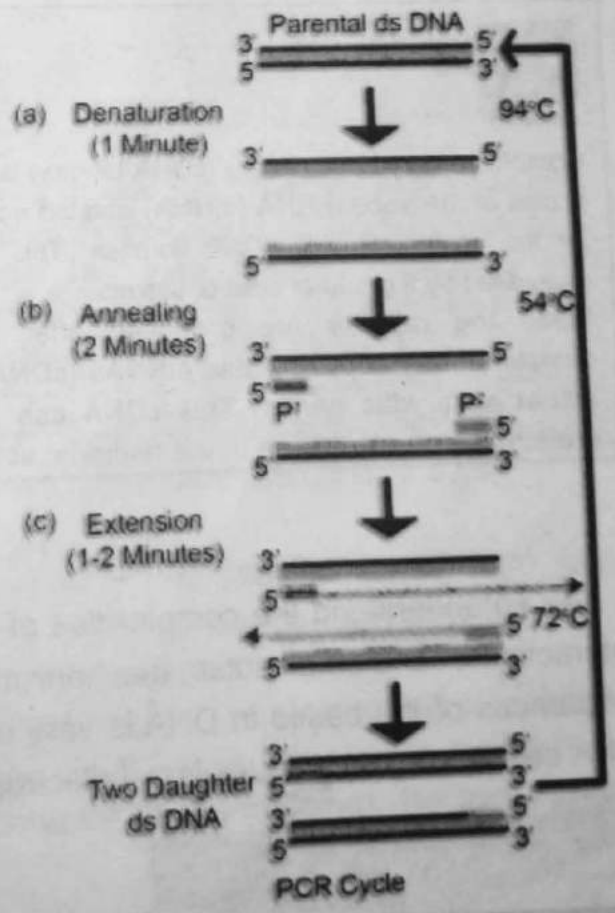


Fig. 26.4 Mechanism of PCR reaction P1 is forward primer and P2 is backward primer

continues resulting in the amplification of the selected DNA sequence at an exponential rate i.e., the number of existing DNA molecules become doubled after each cycle.

Science, Technology and Society Connections

The application of polymerase chain reaction.

PCR has application in almost all areas of molecular biology, genetics, and in clinical areas.

1) PCR is an efficient diagnostic technique used for the detection of specific genotypes of infectious agents.
2) Reactions for DNA sequencing are also simplified by introducing the PCR method.
3) DNA fingerprinting is also made simple by PCR as described above.
4) The genetic mutations responsible for certain genetic diseases and cancers can be detected using PCR tools. Early detection of genetic disease is even possible in embryonic conditions or even in sex cells—sperm and egg.

26.1.3 Genomic Library

Genome: a complete set of gene of an individual.

A **genomic library** is a collection of bacterial or bacteriophage clones, each containing at least one copy of every DNA sequence in a genome of an organism. In single library, the entire genome of an organism is represented as a set of DNA fragments inserted into a vector molecule. Collection of genomic libraries of different organisms is called gene bank.

A specific complementary **probe** is used to search a particular gene of interest from genomic library if it is required for further analysis, A DNA probe is a small, fluorescently or radioactively labelled single stranded DNA molecule.

Science Titbits

Complementary DNA Library (cDNA Library) is the collection of clones of DNA, which are the complementary copies of messenger RNA (mRNA) isolated from the particular cells. Messenger RNA is the starting material for the construction of cDNA libraries. This DNA library represents only those genes which are being expressed by a group of cells or tissues.

Since the mRNAs are produced after splicing, they are devoid of introns. Therefore, the complimentary copy of these mRNAs (cDNA) represents only the exons or the coding regions of the actual eukaryotic genes. This cDNA can be directly inserted into an expression vector and the protein can be expressed in the bacterial systems.

26.2 DNA SEQUENCING

To understand the complexities of gene structure, its expression, its regulation, protein interactions, and molecular mechanisms of genetic diseases, the detailed and exact sequences of the bases in DNA is very essential. One of the important tools used in various DNA sequencing techniques is gel electrophoresis.

Teacher's Point

The teacher would tell the students that PCR is used to make multiple copies of genes then ask "How many copies of the DNA will be after five cycles if the PCR starts with single template DNA duplex".

26.2.1 Gel Electrophoresis

Gel electrophoresis is a technique used in molecular biology to separate different sized fragments of charge bearing polymers (proteins, RNA or DNA) under the influence of electric field in a semisolid gel medium of agarose or polyacrylamide. The molecules being sorted are dispensed into a well in the gel material. The gel is placed in an electrophoresis chamber, which is then connected to a power source. When the electric current is applied, the different sized molecules begin to move to the opposite pole through the gel.

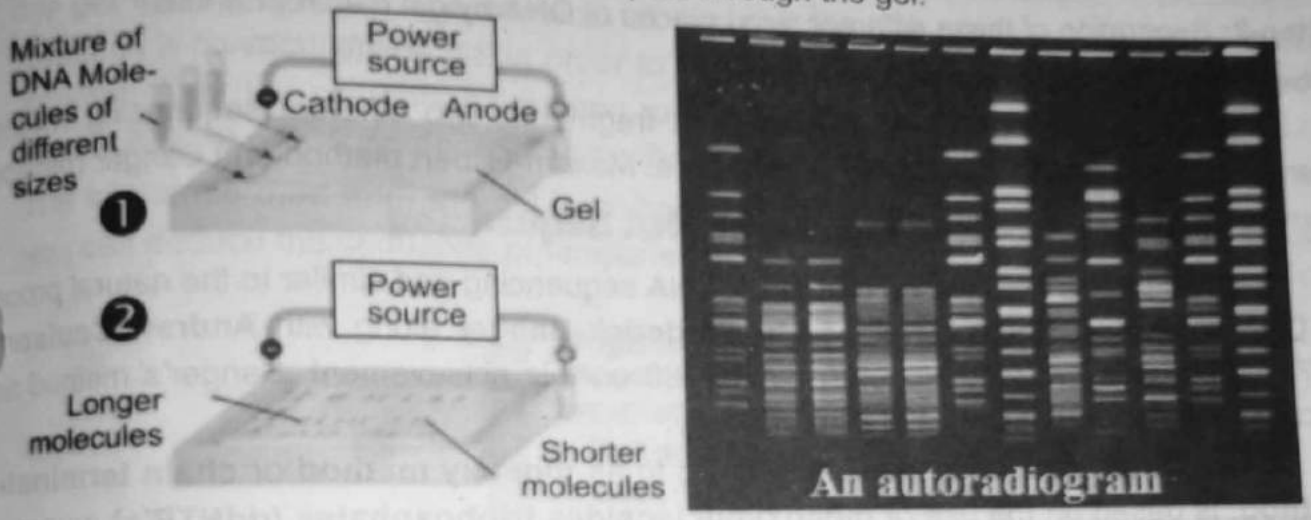


Fig.26.5 Gel electrophoresis

The movement of the fragments is primarily dependent upon size because the distance, a DNA fragment travels, is inversely proportional to its length so the smaller fragments move faster through the gel matrix than larger fragments. However, the movement of the fragments also depends upon charges, number of strands (single or double) and shape of the molecules (linear or circular) and the concentration of the gel (pore size).Therefore, after sometimes the different sized molecules have been separated into distinct bands on the gel.

Science Titbits

The types of gels most commonly used for DNA electrophoresis are agarose (for relatively large DNA molecules i.e., more than 50 nucleotide) and polyacrylamide (for high resolution of short DNA fragments i.e., less than 50 nucleotide).

To visualize DNA or RNA, the gel is placed on an ultraviolet transilluminator. Now you can observe that some bands are thick and some are thin, thick bands represent the high concentration of same sized fragments while thin bands show low concentration.

If a particular sized fragment is to be used for further analysis, the piece of gel containing that band can be cut and its DNA can be purified again. DNA bands can also be transferred from gel to the nitrocellulose membrane for autoradiography (X ray imaging). Be aware that

Teacher's Point

The teacher would ask the students that how do DNA probes help to identify individuals"?

DNA will diffuse within the gel over time, and examination or photography should take place shortly after cessation of electrophoresis.

26.2.2 Major Steps in DNA Sequencing Techniques

The mechanism of any DNA sequencing method is based upon three steps:

Step-1: To generate piece of DNA of different sizes all starting from the same point and ending at different points.

Step-2: Separation of these different sized pieces of DNA by gel electrophoresis.

Step-3: Reading of sequence from the gel.

For generation of different sized DNA fragments, two different sequencing methods were developed during the late 1970s. They are: Maxam-Gilbert method and Sanger method.

26.2.3 Sanger – Coulson Method of DNA Sequencing

This method is widely used method of DNA sequencing and similar to the natural process of DNA replication. It was developed by **Frederick Sanger** along with **Andrew Coulson** in 1977. They were awarded Nobel Prize in 1980 on this achievement. Sanger's method now became the standard because of its practicality.

Sanger's method, which is also referred to as **dideoxy method** or **chain termination method**, is based on the use of **dideoxynucleosides triphosphates (ddNTP's)** commonly known as **dideoxynucleotides** in addition to the normal nucleotides (dNTP's) found in DNA. Dideoxynucleotides are essentially the same as common nucleotides except, they contain a hydrogen group on the 3′ carbon instead of a hydroxyl group (OH). These modified nucleotides, when integrated into a sequence, prevent the addition of further nucleotides. This occurs because an OH group is required at 3′ end of growing chain in order to make phosphodiester bond with next incoming nucleotide. In this way they are used to terminate replication processes.

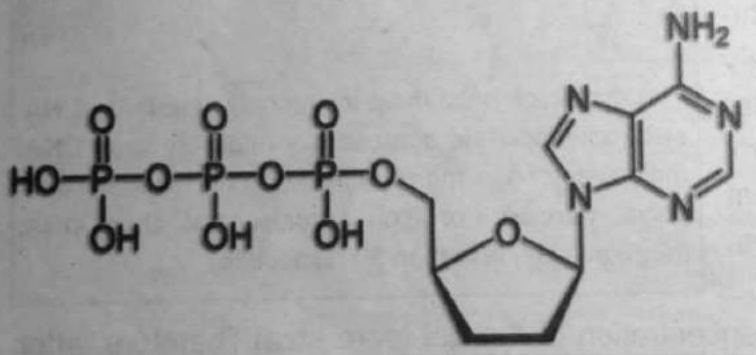


Fig.26.6 (a) Dideoxyribonucleotide

Procedure

(1) Before the DNA can be sequenced, it has to be denatured into single strands using heat because only one strand that acts as template is required in this procedure. Now the template strand is tagged with a known sequence at 3′ end, so that a complimentary primer can bind on the known sequence.

(2) Tagged target DNA, primers, normal free nucleotides and Taq polymersase dissolved in an appropriate buffer are equally added in four separate tubes each containing a different dideoxynucleotide. Now all these test tubes are placed in PCR machine so that sequencing reaction can start. As the DNA is synthesized, nucleotides are added

on to the growing chain by the DNA polymerase. However, on occasion a dideoxynucleotide is incorporated into the chain in place of a normal nucleotide which results in a chain-terminating event. For example in the tube contusing ddATP, only those fragments will be produced that will terminate on "A". Same mechanism takesplace in other tubes.

(3) Once these reactions are completed, the DNA is once again denatured in preparation for gel electrophoresis. The contents of each of the four tubes are run in separate lanes on a polyacrylamide gel in order to separate the different sized bands from one another. After the contents have been run across the gel, the gel is then exposed to either UV light or X-Ray, depending on the method used for labelling the DNA.

(4) The sequence read from the gel is complementary to the actual template DNA. Now you can deduce the sequence of template DNA.

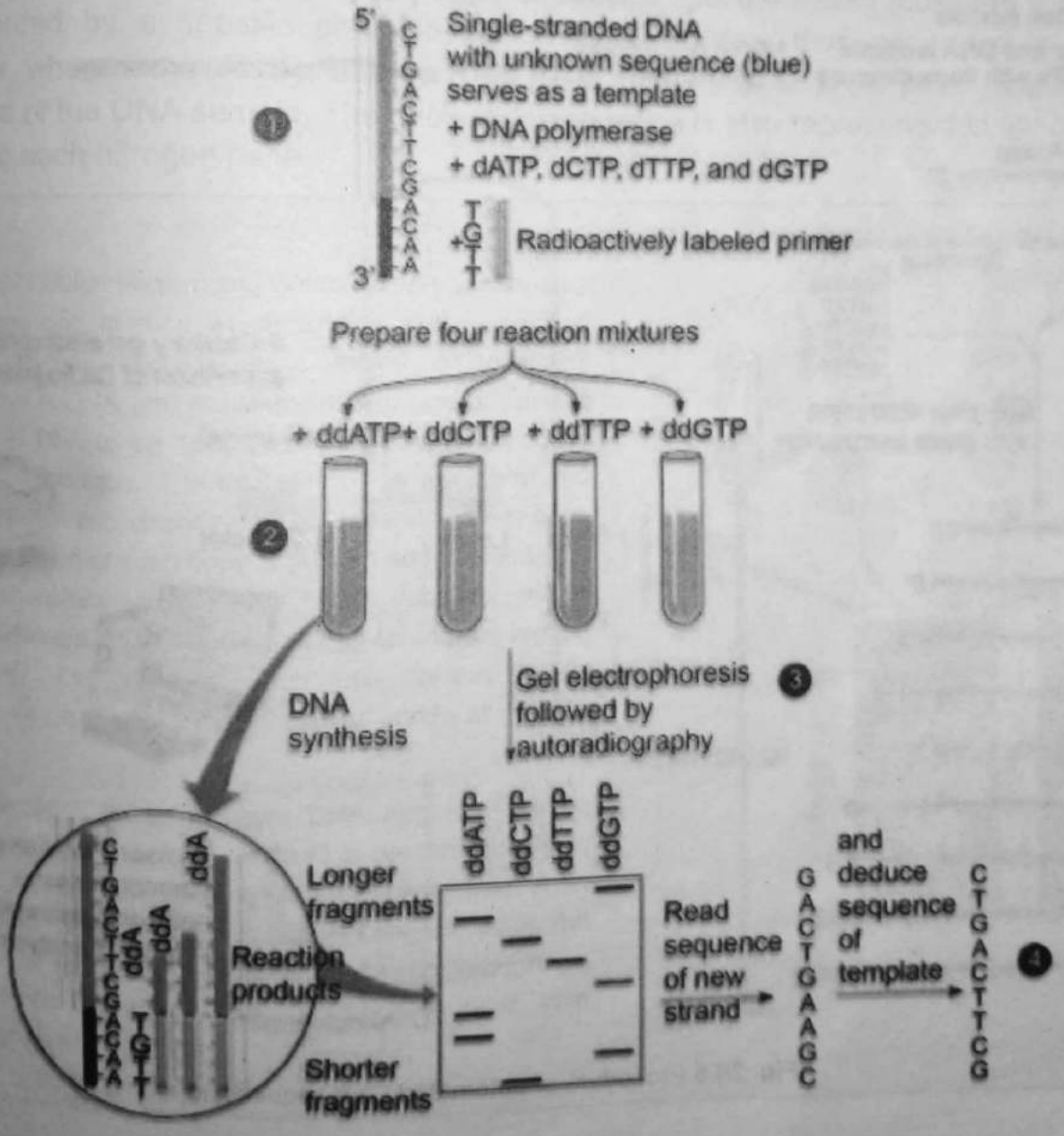


Fig. 26.7 Sanger's method

Science Titbits

Although Maxam and Gilbert published their chemical sequencing method two years after the ground-breaking paper of Sanger and Coulson on plus-minus sequencing. Maxam–Gilbert sequencing rapidly became more popular, since purified DNA could be used directly while the initial Sanger method required that each read start be cloned for production of single-stranded DNA. However, with the improvement of the chain-termination method, Maxam-Gilbert sequencing has fallen out of favour due to its technical complexity prohibiting its use in standard molecular biology kits, extensive use of hazardous chemicals, and difficulties with scale-up.

26.2.4 Automated DNA Sequencing

Automatic sequencing machines have greatly improved the quality as well as the speed of the sequencing process. The basic principle of sequencing is quite same in manual and automated DNA sequencing except few differences.

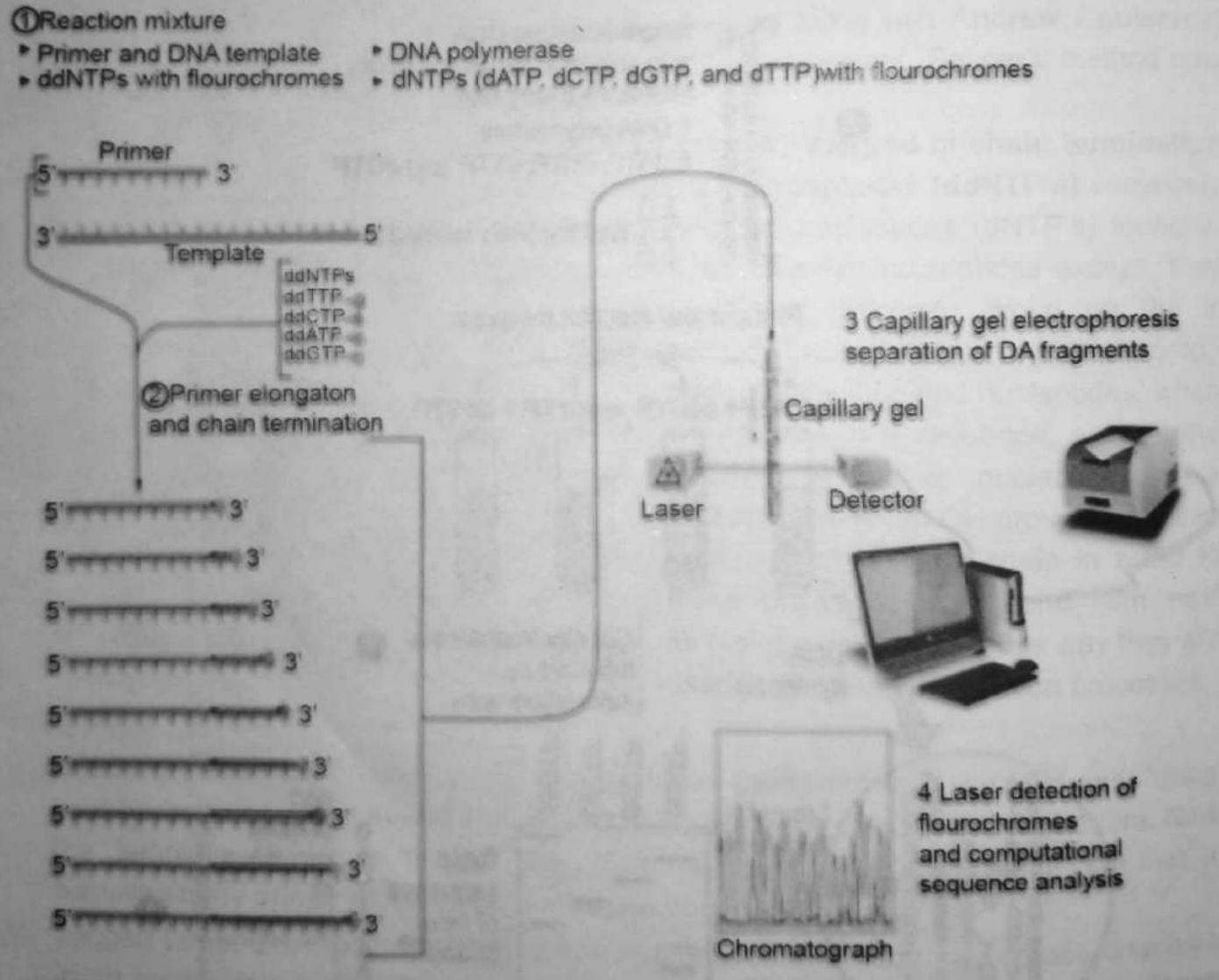


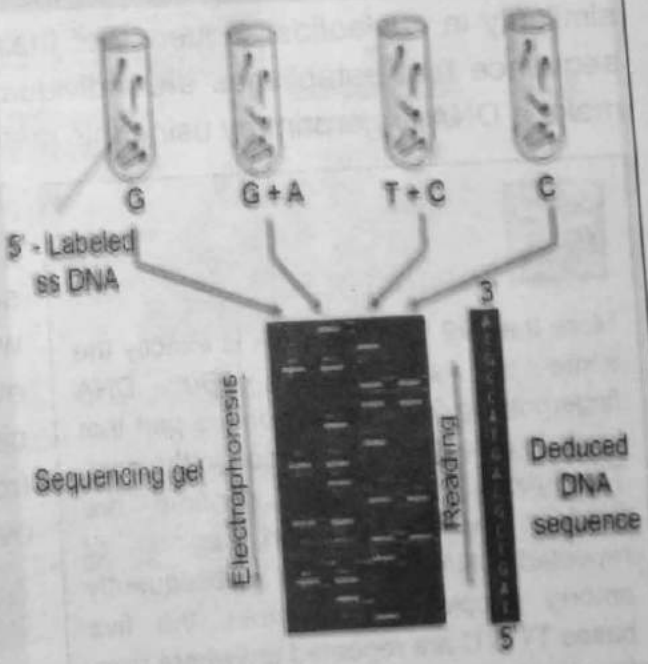
Fig. 26.8 Procedure of automated DNA sequencing

There is no need for radiolabeling and autoradiography. The use of fluorescently labelled ddNTPs (dideoxynucleotide triphosphates) has made the reading very easy, convenient, and automatic with the help of UV laser detectors. Thus, it has greatly improved the speed of sequencing. Each of the four types of ddNTPs can be labelled with a specific dye, so that a specific colour can be attributed to the presence of a particular nucleotide or base. Since fluorescent dyes of four different colours are used so there is no need to perform reaction in separate tubes, all 4 reactions can be run in the same tube which greatly increase the speed and ease of sequencing. There is no need to run the reaction mixtures in separate lanes of electrophoresis gel during the separation of different sized fragments after sequencing reaction. The reaction mixtures can be electrophoresed on a single lane instead of four by using **capillary array electrophoresis**. After electrophoresis, we don't even have to 'read' the sequence from the gel. The computer does that for us. After electrophoresis the coloured bands can be monitored using UV-laser beams. The laser beams excite the fluorescent dyes and result in the emission of specific spectral waves (coloured light), which are recorded by a specific photoelectric device. The data thus generated is fed to a computer, where the emission data from the gel is converted into a corresponding nucleotide sequence of the DNA sample. The nucleotide sequence is also represented in specific peaks indicating each nitrogen base.

Maxam-Gilbert Method of DNA Sequencing (Extra Reading Material)

In 1976-1977, Allan Maxam and Walter Gilbert developed a DNA sequencing method which is also called chemical cleavage method because it is based on chemical modification of DNA and subsequent cleavage at specific bases. The DNA to be sequenced must be amplified by using PCR technique. The multiple copies are denatured first so that the two strands can be separated from each other, one strand of each copy is purified and labelled with isotopic phosphate at 5′ end. These labelled, single stranded DNA are divided into four samples and are tagged as G, A+G, T+C, and C. Each tube contain certain chemicals which cleave phosphodiester bonds at specific point.

In the sample "G" the unknown DNA fragment will be cleaved from all those point where G is present. Similarly, in sample "A+G" the fragment will be cleaved from A as well as from G and so on in other samples. After the completion of reactions, the products are run through gel electrophoresis and finally the sequence is read from autoradiogram of gel pattern.



26.3 DNA ANALYSIS

DNA profiling (also called **DNA testing**, **DNA typing**, or **genetic fingerprinting**) is a technique employed by forensic scientists to assist in the identification of individuals by their respective nucleotide sequence of DNA. This method was emerged in the 1980s. The first DNA fingerprint was made in 1985.

26.3.1 Purposes/Applications of DNA Analysis

Today DNA analysis has wide range of application in different fields of life. It can be used to: (a) Identify potential suspects who's DNA may match evidence left at crime scenes. (b) Identify crime and catastrophe victims. (c) Establish paternity and other family relationships. (d) Detect bacteria and other organisms that may pollute air, water, soil and food. (e) Match organ donors with recipients in transplant programs.

26.3.2 Mechanism/Procedure of DNA analysis

There are several techniques that can be used for DNA analysis. **Restriction Fragment Length Polymorphism (RFLP)** was one of the first methods used in DNA analysis. RFLP (pronounced as "rif-lips") refers to the different sized fragments of DNA produced by a particular restriction enzyme. Every person has a unique set of RFLPs because the restriction site of a particular enzyme is always different in number and distribution in all human on earth except the monozygotic (identical) twins. Therefore, RFLPs of any two persons, when compared, one can easily analyse their individuality. However, the entire human have 99% similarity in nucleotide sequence of their genomes, this is the only 1% difference in genome sequence that establishes the individuality of every person. Following are the key steps to make a DNA fingerprint by using this method.

Science Titbits

More than 99 % of the DNA is exactly the same in all humans. But DNA fingerprinting focuses only on the part that tends to differ from one person to the next. Throughout the human genome are **tandem repeats** - short regions of repeated DNA- that differ subsequently among people. For example, the five bases TTTTC are repeated anywhere from four to fifteen times in tandem in different people, and the bases (CGC) are repeated five to fifty times in tandem. By examining many tandem-repeat sites, researchers found out that each person carries a unique combination of repeat numbers.

Collection of DNA samples

For DNA analysis, very small fraction of DNA is sufficient because it can be amplified several times with the help of PCR. Therefore, it can be collected even from a small trace of blood or from the cells of single hair root. DNA samples can also be collected from mummified organisms or from fossils when evolutionary relationship has to be studied.

Placement and separation of RFLP

Placement of RFLP is the digestion of DNA samples by a particular restriction enzyme which produces a set of different sized DNA fragments (RFLPs). The mixture of RFLPs is loaded in polyacrylamide gel and run for electrophoresis; fragments of various lengths begin to move at different rate from negative to positive pole within the gel. When

the movement is stopped, the gel is proceeded for further treatments in order to observe banding pattern.

Denaturation of RFLP fragments

In this step, first, the electrophoresed gel is placed into an alkaline solution (typically containing sodium hydroxide) to denature the double-stranded DNA. The denaturation may improve binding of the negatively charged DNA to a positively charged membrane and separating it into ssDNA for later hybridization to the probe.

Blotting

In this method, a sheet of nitrocellulose (or alternatively nylon) membrane is placed on top of the gel. Ion exchange interactions bind the ssDNA to the membrane due to the negative charge of the DNA and positive charge of the membrane. The membrane is then baked in a vacuum or regular oven at 80 °C for 2 hours to permanently attach the transferred DNA to the membrane.

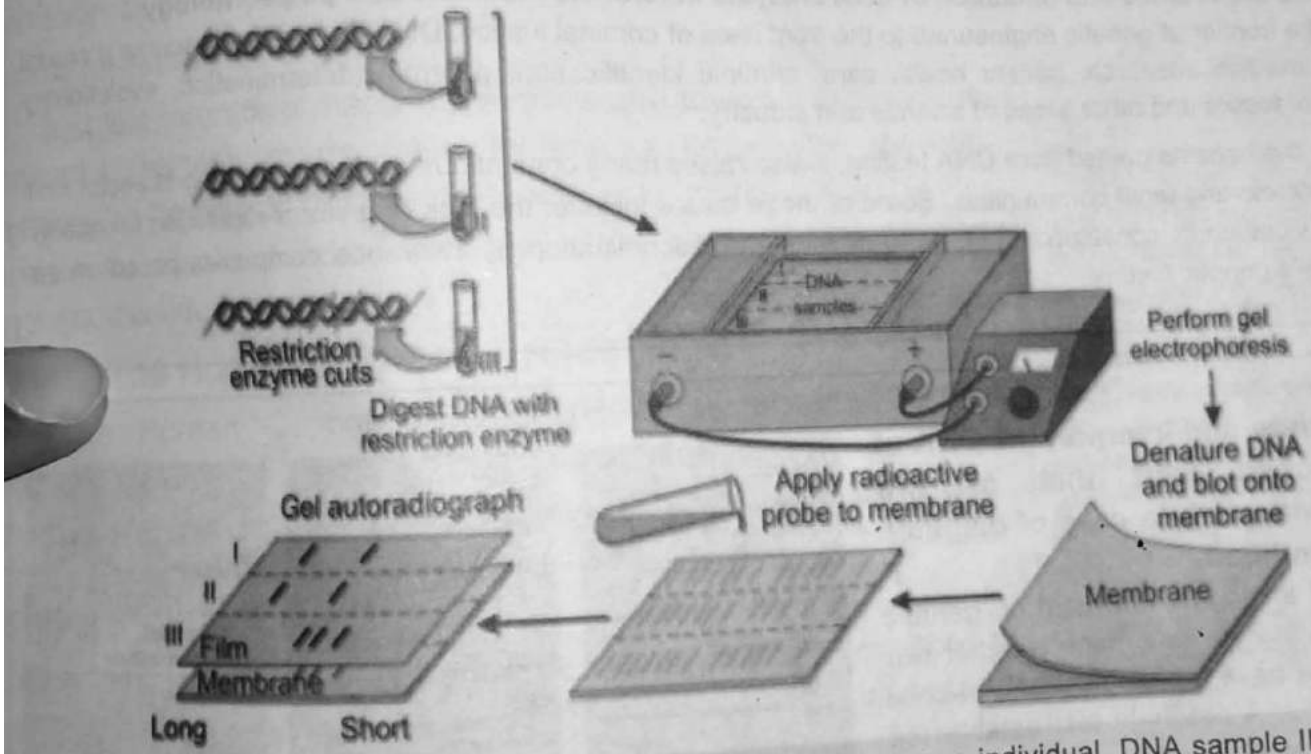


Fig. 26.9 RFLP analysis. DNA samples I and II are from the same individual. DNA sample III is from a different individual. Notice, therefore, that the restriction enzymes cuts are different for sample III. Gel electrophoresis separates the DNA fragments according to their length because shorter fragments migrate farther in an electrical field than do longer fragments. The fragments are denatured and transferred to membrane where a radioactive probe can be applied. The resulting pattern (the DNA fingerprint) can then be detected by autoradiography.

Teacher's Point

The teacher would ask the students to "Explain why RFLPs can serve as genetic markers even though they produce no visible phenotypic differences. *Hint*: RFLPs are inherited in Mendelian fashion and variation, in RFLPs among individuals can be detected by southern blotting.

Labelling of RFLP fragments

The membrane is then exposed to radioactive probes which hybridize with denatured DNA
(ssDNA) fragments in all bands. Since, the DNA probes are radioactively labelled so they can be detected by autoradiography.

Autoradiography

After hybridization, excess probes are washed from the membrane and the pattern of hybridization is visualized on X-ray film by exposing the membrane to an X-ray source. This technique is known as autoradiography. The banding pattern which was originally obtained in the gel due to the separation of RFLPs, is now developed on an X-ray film.

Science, Technology and Society Connections

State the importance and limitation of DNA analysis in forensic medicine and palaeontology

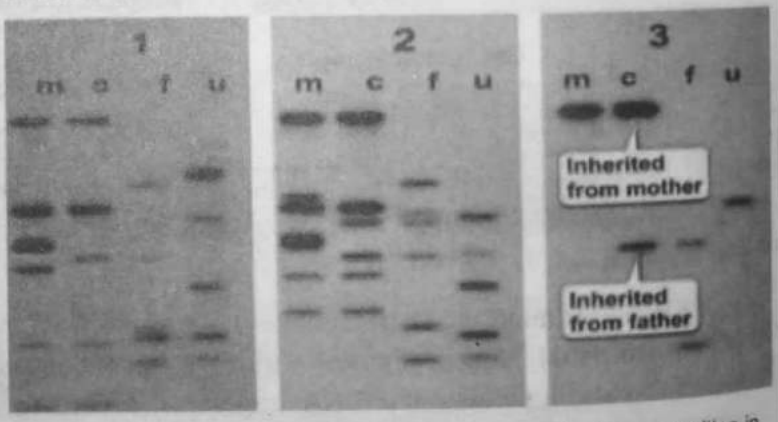
From the frontier of genetic engineering to the front lines of criminal justice, DNA testing has become a crucial tool in medical research, patient health care, criminal identification, paternity determination, evolutionary history of fossils and other areas of science and industry.

Despite the benefits gained from DNA testing, it also raises many contentious issues in the private sector and the academic and legal communities. Some of these issues include: the lack of uniform regulation for quality control, violation of constitutional rights to privacy and discrimination by insurance companies based on an individual's genetic history.

Skills: Analyzing, Interpreting and Communication

- **Analyze and interpret the DNA of a child with that of two individuals in a case of disputed parenthood.**

Parental testing is the use of genetic fingerprinting to determine whether two individuals have a biological parent-child relationship. A paternity test establishes genetic proof whether a man is the biological father of an individual, and a maternity test establishes whether a woman is the biological mother of an individual. The current techniques for paternal testing are using PCR and RFLP.



Here is a child's paternity and maternity can be clearly seen written in its DNA profile using three different restriction enzymes. Half of the child's (c) makers come from its mother (m), and half from its father (f). An unrelated individual is shown in the last lane (u)

26.4 GENOME MAPS

The **genome** is a collection of all the genes found in one complete set of chromosome. So a diploid organism has two copies of genome while egg or sperm has one.

26.4.1 Genome Analysis

Just like the road maps and street maps of a city, which guide us to reach a specific location, the **genome analyses** are used by the scientists searching for a specific gene somewhere within the vast genome.

Due to rapid development of genome studies, a new branch of biotechnology has emerged called **genomics** which deals with exploration and analysis of complete DNA sequence of an organism's genome.

Genome maps

These analyses help to develop two broad categories of maps: **genetic maps** and **physical maps**, which are being used for genome analyses. A genetic map shows the sequence of gene loci along the length of chromosomes while physical map represents the sequence of nucleotides in the DNA.

Science Titbits

VNTRs, or variable number of tandem repeat polymorphisms, occur in non-coding regions of DNA. This type of marker is defined by the presence of a nucleotide sequence that is repeated several times. In each case, the number of times a sequence is repeated may vary.

Genetic markers

Just like interstate maps have cities and towns that serve as landmarks, genetic maps have landmarks known as **genetic markers**, or **"markers"** for short. Examples of markers are RFLPs, variable number of tandem repeats, short tandem repeats and single nucleotide polymorphism.

26.4.2 The Human Genome Project (HGP)

The Human Genome Project (HGP) is an international scientific research project which is based on the exploration and analysis of human genome.It was originally founded by the U.S. Department of Energy and the National Institutes of Health in 1990.

Historical background

Due to widespread international cooperation and advances in the field of genomics (especially in sequence analysis), as well as major advances in computing technology, a **'rough draft'** of the genome was finished in 2000. On-going sequencing led to the announcement of the essentially complete genome in April 2003, 2 years earlier than planned, but the sequence of the last chromosome was published in the journal Nature in May 2006. Finally it came to know that human genome comprises **3.2 billion** nucleotides and approximately **20,000-25,000 genes**.

Science Titbits

In 1090, US government had established National Human Genome research Institute (NHGRI), who had compieted HGP in 2003. James D. Watson was appointed as first director of this institute but at the time of completion of the project, the institute was being led by Dr. Francis Collin.

James Watson

Teacher's Point

The teacher would ask the students to evaluate the potential impact on the Human Genome project on both scientific thought and society.

Major goals and benefits of HGP

Major goals and objective of this project were to (a) construct genetic and base sequence map of human genome (b) store this information in databases, (c) improve tools for data analysis, (d) transfer related technologies to the private sector, and (e) address the ethical, legal, and social issues (ELSI) that may arise from the project. Human genome project can benefit in improved diagnosis of disease, earlier detection of genetic predispositions to disease, rational drug design, gene therapy, control systems for drugs etc.

Science, Technology and Society Connections

Justify why the human genome project is regarded as the most ambitious project ever undertaken by man

Although the Human Genome Project was initially started by the U.S. government in 1990 but later on Welcome Trust (U.K.) became a major partner; additional contributions came from Japan, France, Germany, China, and others. Since the current applications of genome research address national needs in molecular medicine, waste control and environmental clean-up, biotechnology, energy sources and risk assessment. Therefore HGP is regarded as the most ambitious project ever undertaken by man.

Science, Technology and Society Connections

Describe the major findings that have arisen from the human genome project.

Some of the findings of this project are: (1) Repetitive sequences are stretches of DNA sequences that are repeated many times (2) Chromosome 1 has most genes (2968) and chromosome Y has least number of genes. (3) The function of over 50% of discovered genes are unknown.(4) The count of no. of nucleotides.(5) Number of genes (6) In light of the findings of the Human Genome Project that we actually have less genes in our genome, or on our chromosomes, than originally thought.

26.5 TISSUE CULTURE

Growth of single cell or group of cells in a glassware on artificial medium under aseptic conditions is called **tissue culture**. Many somatic plant cells, including some fully differentiated types (e.g., leaf mesophyll), contain intact nuclear, plastid and mitochondrial genomes and have the capacity to regenerate into whole plants. This phenomenon is **totipotency**.

26.5.1 Methods of Plant Tissue Culture

Tissue culture is often a generic term that refers to both organ culture and cell culture. The initial plant part which is used to develop tissue culture is called **explant**. It may be complete organ (seed, leaf, and twig) or single cell (protoplast) or a piece of tissue. **Plantlets** are young plants which are developed during tissue culturing. On the basis of explant tissue culture is variously called **cell culture** or **organ culture**.

There are several methods of tissue cultures have been developed which are primarily based upon type of explant used e.g., meristem, anther, ovary, embryo culture etc.

26.5.2 Animal Cell Culture

Unlike plant and microbial cells, the animal cells can grow only to a limited generations even in the best nutritive media. This growth also depends on the sources of tissue isolated. For example, neurons cannot divide and grow while fibroblast can divide and grow in culture to

some generations. After completing several generations they die. These animal cells cultures are used in recombinant DNA technology, genetic manipulations, cancer research and in a variety of industrial processes such as production of vaccines, monoclonal antibodies, pharmaceutical drugs etc.

There are two major techniques of animal cell cultures i.e., anchorage-dependent and anchorage-independent. Adherent cells are **anchorage-dependent** and propagate as a monolayer attached to the cell culture vessel. Most cells derived from tissues are anchorage-dependent. Since these cells grow for limited generations so they are also called **finite cell line**. Suspension cells can survive and proliferate without being attached to a substratum, therefore, called **anchorage-independent**. Hematopoietic cells (derived from blood, spleen, or bone marrow) as well as some transformed cell lines and cells derived from malignant tumours can be grown in suspension. Since these cells grow for unlimited generations so they are also called **continuous cell lines**.

26.6 TRANSGENIC BACTERIA, PLANTS AND ANIMALS

The free living organisms in the environment that have had a foreign gene inserted into them are called **"genetically modified (GM)," "genetically engineered (GE),"** or **"transgenic organisms."** Bacteria were the first transgenic organisms, first transgenic bacterium was produced in 1978. Many transgenic organisms such as animals, plants, and bacteria have been produced.

26.6.1 Transgenic Bacteria

Unlike other organisms bacteria can be easily transformed due to their simple genetics. The first example of this occurred in 1978 when a version of the human insulin gene was inserted into the bacterium *Escherichia coli* to produce synthetic "human" insulin. The transgenic bacteria are not only being used to produce different human proteins, they are also being used in improvement of plant growth, removal of environmental pollutants and extraction of metals from low grade ores.

26.6.2 Transgenic Plants

The first field trials of genetically engineered plants occurred in France and USA in 1986, when tobacco plants were engineered to be resistant to herbicides. In most cases the aim of developing transgenic plant is to

frost plus

Science Titbits

Both strains of *Pseudomonas syringae* occur naturally, but recombinant DNA technology has allowed for the synthetic removal or alteration of specific genes, enabling the creation of the ice-minus strain. Modifying *P. syringae* may have unexpected consequences for climate. A study has shown that its ice nucleating proteins may play an important part in causing ice crystals to form in clouds. If humans increase the frequency of bacteria lacking these proteins then it could effect cloud cover.

Science Titbits

The first genes available for genetic engineering of crop plants for pest resistance were known as Bt genes from a bacterium ***Bacillus thuringiensis***. These are specific to particular group of insect pests and are not harmful to other useful insects like butter flies and silk worms. Transgenic crops with Bt genes (e.g. cotton, rice, maize, potato, tomato, brinjal, cauliflower, cabbage, etc.) have been developed. This has proved to be an effective way of controlling the insect pests and

Protein toxic insect

roduce a new trait to the plant which does not occur naturally in this species. Examples clude resistance to certain pests, diseases or environmental conditions or the production of a rtain nutrient or pharmaceutical agent.

6.6.3 Transgenic Animals

A transgenic animal is one that carries a foreign gene that has been deliberately inserted to its genome. Genetic engineering has also been used to improve the traits of farm animals, addition, these animals are also used to produce drugs. Such transgenic animals which also roduce drugs are called **transpharmer animals.**

Science, Technology and Society Connections

Predict the application of genetic engineering in crop improvement.

There has been a consistent increase in the global area planted to transgenic crops from 1996 to 2005. About 90 Mha was planted in 2005 to transgenic crops with high market value such as herbicide tolerant soybean, maize, cotton, and canola; insect resistant maize, cotton, potato, and rice; and virus resistant squash and papaya. With genetic engineering, more than one trait can be incorporated into a plant. Transgenic crops with combined traits are also available commercially. These include herbicide tolerant and insect resistant maize and cotton.

26.7 BIOTECHNOLOGY AND HEALTHCARE

Biotechnology has made a huge difference in human health care and has now enabled cientists to develop products which can give quicker and more accurate tests, therapies that ave a lot less side effects and vaccines which are safer than ever before.

6.7.1 Role of Biotechnology in Treatment and Diagnosis of Diseases

Biotechnology is used in three different ways in the development of vaccine: (a) eparation of a pure antigen using a specific monoclonal antibody. (b) Synthesis of an antigen ith the help of a cloned gene. (c) Synthesis of peptides to be used as vaccines.

Many human diseases can be diagnosed by using products of biotechnology like onoclonal antibodies and DNA/RNA probes.

6.7.2 Gene Therapy

Gene therapy is a technique for correcting defective genes responsible for disease evelopment. Researchers may use one of several approaches for correcting faulty genes, like normal gene may be inserted into a nonspecific location within the genome to replace a non-nctional gene. This approach is most common.

echanism of gene therapy

In gene therapy treatment, normal gene is either delivered directly into the body *(in vivo)* into the cells outside the body then these transgenic cells are again implanted into the body

Teacher's Point

The teacher would ask the students to "Explain how a transgenic plant differs from a hybrid plant?

(ex vivo). In both cases, a "normal" gene is inserted into the genome to replace an "abnormal," disease-causing gene. A carrier molecule called a vector must be used to deliver the therapeutic gene to the patient's target cells. Currently, the most common vector is a virus that has been genetically altered to carry normal human DNA.

Some of the different types of viruses used as gene therapy vectors are Retroviruses, Adenoviruses, Herpes simplex viruses.

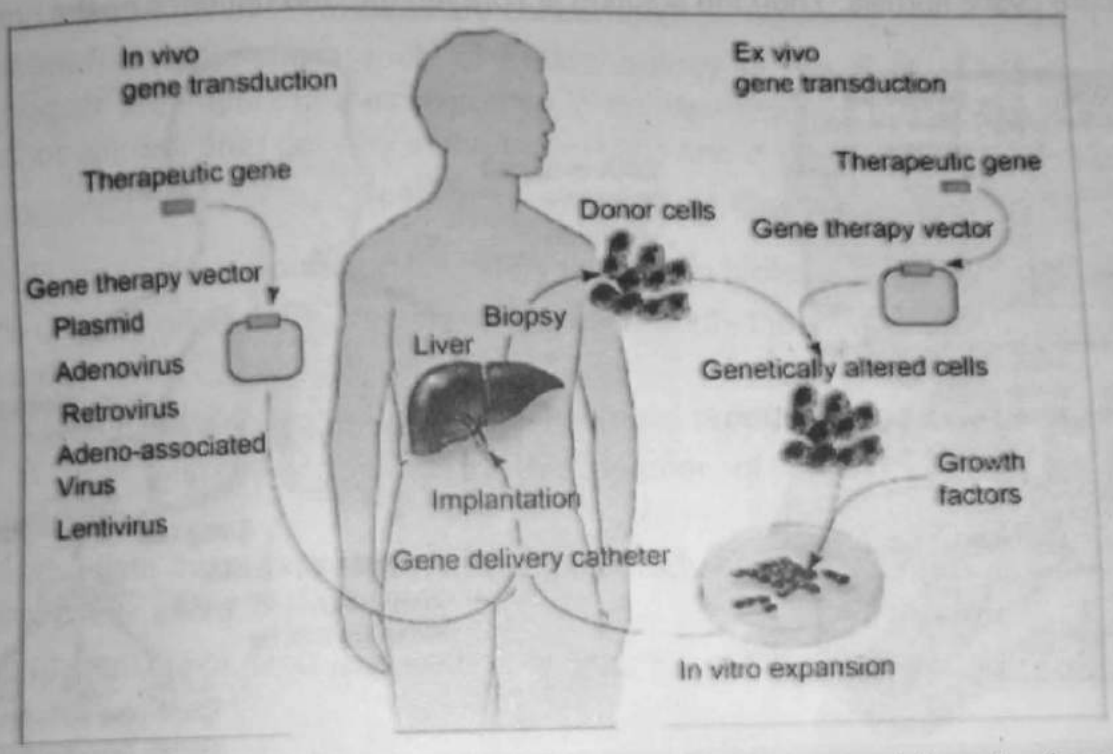


Fig. 26.10 Mechanism of gene therapy: An in vivo approach to gene therapy delivers the therapeutic nucleic acid directly to the patient. The gene is packaged in one of several vectors and delivered with a device to a target organ. In the illustration (left), the gene is incorporated into a plasmid and delivered to the liver via a catheter in the portal vein. An ex vivo approach involves harvesting cells from the tissue of interest, transducing them with a gene in vitro, and re-administering the genetically altered cells to the patient. Gene transduction in vitro may be mediated by the same vectors as those used in ' in vivo ' gene transduction.

26.7.3 Role of Gene Therapy for Cystic Fibrosis

Cystic fibrosis is an inherited disease which affects the mucus and sweat glands. People with severe symptoms can have serious lung and digestive problems.

Cystic fibrosis (CF) involves a defect in the **cystic fibrosis trans membrane conductance regulator (CFTR)** gene that encodes a protein by which the movement of salt and water is controlled in and out of body cells. In people with cystic fibrosis, the gene does not work effectively. As a result, cells that line the passageways of the lungs, pancreas and other organs produce abnormally thick, sticky mucus. This mucus obstructs the airways and glands which causes the characteristic signs and symptoms of cystic fibrosis. On the other hand, in normal persons, mucus is watery. It keeps the linings of certain organs moist and prevents them from drying out or getting infected.

Gene Therapy of Cystic fibrosis

In 1989, experts discovered the gene that causes cystic fibrosis and identified it as the cystic fibrosis trans membrane conductance regulator or CFTR. The discovery of this defective gene posed new possibilities of a cure.

An in vivo method of treatment is being tried. Liposomes-microscopic vesicles that spontaneously form when lipoproteins are put into a solution have been coated with the gene needed to cure cystic fibrosis. Then the solution is sprayed into the patient's nostril.

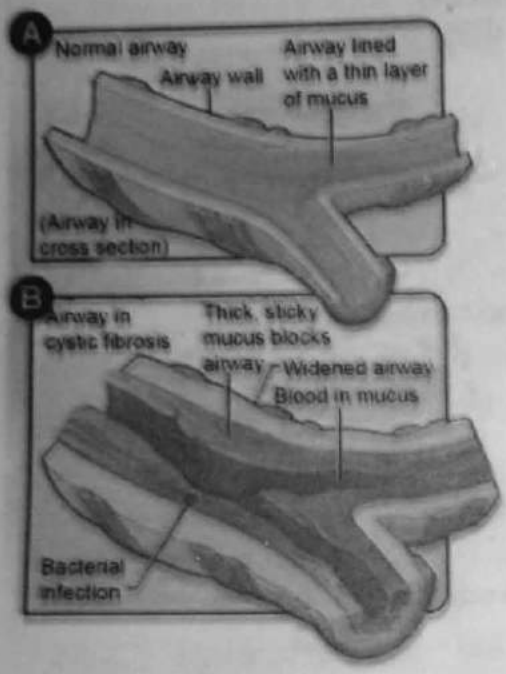


Fig. 26.11 Effects of cystic fibrosis

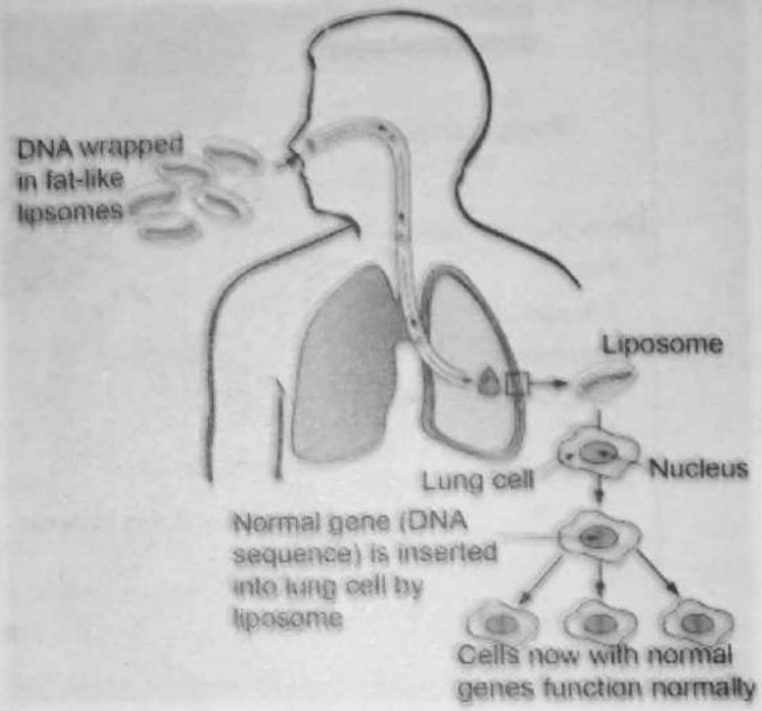


Fig. 26.12 An attempt of in vivo gene therapy for cystic

26.8 SCOPE AND IMPORTANCE OF BIOTECHNOLOGY

Biotechnology is "the science of applied biological process". It is one of the fastest growing field in the area of research and development. It is also called a **technology of the future** or **technology of tomorrow** because of its unprecedented impacts on the human and the universe as a whole.

26.8.1 Scope and Importance of Biotechnology in Promoting Human Welfare

Biotechnology is going to be very important in our daily life with the passage of time. The ultimate objective of biotechnology is to provide welfare for human being.

In future, there is the possibility of developing of **biological computers or biochips.**

Teacher's Point

The teacher would ask the students that "What is the advantage of using stem cells for gene therapy? *Hint*: stem cells continue to reproduce themselves.

These essentially miniaturized laboratories can perform hundreds or thousands of simultaneous biochemical reactions. Biochips enable researchers to quickly screen large numbers of biological analysis for a variety of purposes, from disease diagnosis to detection of bioterrorism agents.

In recent years, use of microbial inoculants as a source of **biofertilizers** (nutrient inputs of biological origin for plant growth) has become a hope for most of countries, as far as economic and environmental viewpoints are concerned.

A new and exciting sub-branch of biotechnology is the field of **nanotechnology**. Nanotechnologists are imparting their expertise in the development of such nano particle that can be used for efficient drug delivery at the target cells and in the diagnosis of diseases.

26.8.2 Concerns about the Genetically Modified Organisms (GMOs)

The main areas of consideration for safety aspects in biotechnology are the following:

(a) How to dispose-off spent microbial biomass and purify the effluents from biotechnological processes?

(b) The toxicity of the allergy associated with microbial production.

(c) How to deal with the increase in the number of antibiotic resistant pathogenic microorganisms?

(d) How to evaluate the pathogenicity of the genetically engineered microorganisms to infect humans, plants and animals?

(e) How to prevent contamination, infection or mutation of the processed strains?

Science Titbits

Most of the countries of the world are signatories to the Biological Weapons Conventions of 1972. As a signatory, it is a voluntary pledge by a nation "never to produce microbial or other biological agents or toxins, whatever may be their method of production, for use in wars. However, many people have expressed their concerns about the possible use of genetic manipulations for military purposes in the near future.

Teacher's Point

The teacher would ask the students to "List reasons you would or would not be concerned about eating genetically modified food".

Science, Technology and Society Connections

- **Justify the need of genetic counselling.**

Genetic counselling is a service that provides information and advice about genetic conditions. Counselling is conducted by healthcare professionals who have been specially trained in the science of human genetics (a genetic counsellor or a clinical geneticist). The counsellor will discuss the risks, benefits and limitations of genetic testing with you. They will also explain how the information found as a result of genetic testing could have implications for both you and your family.

- **Investigate careers that require an understanding of biotechnology and genetic engineering.**

Many careers require an understanding of biotechnology and genetic engineering. Such as: Healthcare professionals, Teachers of biological sciences, biomedical engineers, crime lab analyst, crime scene investigator, environmental impact analyst, forensic scientist, genetic engineer, molecular biologist etc.

- **Describe briefly the accomplishments of the renowned genetic engineers working in private and public sector institutions in her or his province.**

It is advised to the administration that they should arrange study tour of student to public and privet sector institutions of genetic engineering so that students can meet with renowned genetic engineers and can directly ask about their accomplishments.

- **Suggest measure she/he would take to solve related problems by using knowledge gained in this chapter.**

Students should evaluate themselves to know what they have learnt in this chapter and should apply this knowledge to solve related problems under the guidance of their class teacher.

- **Describe the role of Genetic Screening.**

Genetic screening includes all those diagnostics tests which are used to determine whether a person or a new born baby is at risk of genetic diseases or not. Generally there are two types of genetic screening, screening of children and adults, and screening of unborn children. Genetic screening of children and adults has two purposes: first it can confirm whether the person has a mutated gene of certain disease or characteristics. The second purpose is to test adults to see if their children will be at risk of certain disease. Knowing that one or both parents carries a dominant allele for a genetic disease might affect the decision parents make about having children , sometimes this kind of genetic screening is used for approval of marriage licenses in some countries, like Denmark.

Activity

1. Make a model of DNA probe and restriction enzymes.

Exercise

M.C.Qs

1. Select the correct answer

(i) Which of the following tools of recombinant DNA technology is incorrectly paired with its use?

(A) restriction enzyme --- production of RFLPs
(B) DNA ligase --- enzyme that cuts DNA, creating the sticky ends of restriction fragments.
(C) reverse transcriptase --- production of cDNA from mRNA
(D) electrophoresis --- separation of DNA fragments

(ii) Plants are more readily manipulated by genetic engineering than are animals because

(A) plant genes do not contain interon
(B) plant cells have larger nuclei
(C) a somatic plant cell can often give rise to a complete plant.
(D) genes can be inserted into plant cells by microinjection.

(iii) A paleontologist has recovered a bit of tissue from the 400 year old preserved skin of an extinct bird. the researcher would like to compare DNA from the sample with DNA from living birds. Which of the following would be most useful for increasing the amount of the bird DNA available for testing?

(A) a RFLP analysis
(B) polymerase chain reaction (PCR)
(C) electroporation
(D) Southern hybridization

(iv) Which of the following sequences in double-stranded DNA is mostly likely to be recognized as a cutting site for a restriction enzyme?

(A) AAGG / TTCC (B) AGTC / TCAG (C) GGCC / CCGG (D) ACCA / TGGT

(v) A plasmid

(A) is used as DNA vector
(B) is a type of bacteriophage
(C) is a type of cDNA
(D) is a retrovirus

(vi) DNA molecules with complementary sticky ends associate by

(A) covalent bond
(B) hydrogen bond
(C) ionic bond
(D) disulphide bond

(vii) Which technique rapidly replicates specific DNA fragments without cloning?

(A) gel electrophoresis
(B) cDNA libraries
(C) genetic probe
(D) polymerase chain reaction

(viii) The PCR technique uses
(A) heat resistant DNA polymerase (B) reverse transcriptase
(C) DNA ligase (D) restriction enzymes

(ix) RFLP is a (an):
(A) introns (B) exons
(C) anticodon (D) genetic marker

(x) The dideoxynucleotides (ddATP, ddTTP, ddGTP and ddCTP) are important in DNA sequencing because they:
(A) cause premature termination of growing DNA strand
(B) are used as prime
(C) cause the DNA fragments that contain them to migrate more slowly through the gel
(D) are not affected by high temperatures

(xi) If eukaryotic DNA contains five cleavage sites for a particular restriction enzyme, how many fragments will be produced upon complete digestion of the DNA with that enzyme:
(A) 2 (B) 4 (C) 6 (D) None

(xii) Gel electrophoresis separates nucleic acid on the basis of difference in
(A) length (molecular weight) (B) charge
(C) nucleotide sequence (D) relative proportion of adenine and guanine

(xiii) Which of the following is not the property of probe:
(A) Fluorescently labeled (B) radioactively labeled
(C) Double stranded DNA (D) Complementary to the gene of interest

(xiv) A genomic DNA library
(A) represents all the DNA in a specific chromosome
(B) is made using reverse transcriptase
(C) is stored in a collection of recombinant bacteria
(D) is a DNA copy of mature mRNAs

(xv) Which of the following is genetic marker which is useful in DNA fingerprinting
(A) Probe (B) Primer (C) RFLP (D) Exon

Short Questions

2. What is the role of restriction endonucleases in gene cloning?
3. What are molecular carriers?
4. What is the role of restriction DNA ligases in gene technology?
5. What are the three steps on which mechanism of any DNA analysis sequencing method is based?
6. What are the applications of DNA analysis?
7. What is genomics?
   What are the concerns about genetically modified organisms?

9. Define following terms:
(i) Biotechnology (ii) genetic engineering (iii) gene cloning
(iv) palindromic sequence (v) recombinant DNA technology (vi) DNA ligase,
(vii) polymerase chain reaction (viii) primers (ix) Taq polymerase
(x) genomic library (xi) DNA probe (xii) gel electrophoresis
(xiii) DNA sequencing (xiv) capillary array electrophoresis (xv) DNA profiling
(xvi) genome (xvii) genome maps (xviii) genetic markers
(xix) tissue culture (xx) explants (xxi) cell culture
(xxii) transgenic organisms (xxiii) gene therapy (xiv) biochips.

10. Write the difference between:
(a) biotechnology and genetic engineering (b) staggered and blunt cut restriction enzymes
(c) genome and chromosome (d) blotting and clotting
(e) genetic map and physical maps of genome
(f) trangenic organisms and hybrid organisms
(g) biotechnology and nanatechnology

Extensive Questions

11. Describe the components of recombinant DNA technology under the following heads:
(a) Gene of interest (b) Molecular scissors
(c) Molecular carriers (d) Molecular glue
(e) Expression system
12. Describe the mechanism or procedure of recombinant DNA technology.
13. What are polymerase chain reactions discuss its components and mechanism?
14. (a) Describe "Gel electrophoresis" as being used in gene sequencing.
(b) What is the principle of movement of in the gel?
(c) How the fragments are visualized?
15. Explain Sanger-Coulson method of DNA sequencing.
16. Explain automated DNA sequencing as based on the Sanger-Coulson method.
17. (a)Describe mechanism or procedure of DNA analysis.
(b) What are the purpose/applications of DNA analysis?
18. What is gene therapy? Explain the mechanism of gene therapy.
19. What is cystic fibrosis? What is the role of gene therapy for cystic fibrosis?
20. Discuss the scope and importance of biotechnology in promoting human welfare.
21. What are the ethical, legal and social implications of using biotechnology?

UNIT

27

BIOLOGY AND HUMAN WELFARE

KEY CONCEPTS

What we need to go for in the new world is not the application of physical science for the production of goods to get money-power, but the application of biological science to build better men and a better society. The first step in the new world must be the abolition of poverty, and we must concentrate on building men and women before we build new cities.

The age which is now passing away is largely the age of physical science, with its inventions and discoveries, which have given us power over the forces of Nature. It is to be hoped that when this War is over the age of physical science will be replaced by an age of biological science-the study of life in all its manifestations. Biology is contributing in many aspects of human life for instance human population is increasing continuously; approximately seven billion people are living on the planet earth.

All of our food and many daily useable home articles are derived from either plants or animals. The development of improved high yielding varieties of these organisms is only possible through the biological research. Due to the modern inventions, the consumption of energy has been increased many fold. Therefore many power generation plants have been installed and are being installed. These plants and the use of modern inventions in our daily life also drastically change our

27.1 INTEGRATED DISEASE MANAGEMENT

Effective control of a particular disastrous disease or all the common diseases of a population can be achieved by using all relevant, appropriate methods of disease control. Such an approach of disease control is known as integrated disease management Combating of disease by utilizing all methods as and when required and ensuring the participation of community in this program is very useful way of disease control. This requires an awareness of the community about the severity of the problem, its causes and its remedies. Public awareness can be ensured by using print and electronic media, by arranging seminars in school and colleges, or by person to person communication.

In integrated disease management, every available method of disease control is used like preventive measures, drug treatment, vaccination, and different kinds of therapies. Actually the real objective is to stop the further spread of disease and to prevent its new onset. This is proved very effective program for elimination and control of the dangerous disease from the human society.

27.2 VACCINATION

Vaccination is the administration of vaccine to stimulate the immune system of an individual to develop artificially induced active immunity against an infectious disease. Vaccines can prevent the effects of infection by many pathogens.

27.2.1 Vaccine:

A vaccine may be intact but inactivated (non-infective) or an attenuated (with reduced infectivity) form of the causative pathogens (bacteria or viruses), or purified components of the pathogen that have been found to be highly immunogenic (e.g. the outer coat proteins of a virus particle). Toxoids are produced for the immunization against toxin-based diseases, such as tetanospasmin of tetanus, by destroying the toxic but preserving the immunogenic effect.

27.2.2 How does vaccine work?

When the body is exposed to the weak or dead organisms (vaccine), the body is triggered to produce antibodies. Since the injected agents are weak or dead, the body does not actually suffer the disease, but an immune response is initiated. Now the body is fully equipped to fight against the actual causative agent like virus or bacteria that attack the body later in life. The same principle works in the body in case of natural active immunity. That is the reason why some childhood diseases occur only once in the lifetime.

27.2.3 History of vaccine:

Edward Jenner was the first scientist who developed a vaccine against small pox in 1796. He conducted an experiment on 8 year old boy, James Philip. He scratched the skin of the boy and introduced into the area a liquid of cowpox obtained from the hand of milkmaid who contracted it from cows. Later when boy was exposed to small pox, he did not suffer the disease. James Philip thus immunized against small pox.

Later Louis Pasteur discovered that aging or attenuated culture of bacteria that cause fowl cholera when introduced into healthy chickens developed immunity against that disease instead of causing the disease. Pasteur next applied this principle of inoculation with attenuated cultures to the prevention of anthrax and rabies, and again it worked. The term vaccine was proposed by the Pasteur, who honored the Edward Jenner because the term is derived from the Latin **Vacca** which means cow because the first vaccine was made from cowpox liquid.

Fig:27.1 Edward Jenner (1749-1823)

27.2.4 Types of Vaccines:

Scientists take many approaches to designing vaccines against a microbe. These choices are typically based on fundamental information about the microbe, such as how it infects cells and how the immune system responds to it, as well as practical considerations, such as regions of the world where the vaccine would be used. The following are some important types of vaccines:

- Live, attenuated vaccines
- Inactivated vaccines
- Subunit vaccines
- Toxoid vaccines

1-Live, Attenuated Vaccines:

Live, attenuated vaccines contain a version of the living microbe that has been weakened in the lab so it can't cause disease. Because a live, attenuated vaccine is the closest thing to a natural infection, these vaccines are good "teachers" of the immune system: They elicit strong cellular and antibody responses and often confer lifelong immunity with only one or two doses. Despite the advantages of live, attenuated vaccines, there are some down sides. It is the nature of living things to change, or mutate, and the organisms used in live, attenuated vaccines are no different.

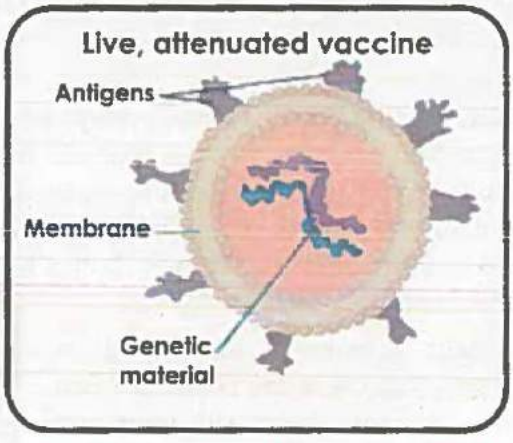


Fig: 27.2 An attenuated vaccine is a vaccine that comes from live microorganisms or viruses. These viruses are under adverse conditions that can lead to them losing virulence.

The remote possibility exists that an attenuated microbe in the vaccine could revert to a virulent form and cause disease. Examples include the viral diseases yellow fever, measles, rubella, and mumps and the bacterial disease typhoid.

2- Inactivated or killed Vaccines:

Scientists produce inactivated vaccines by killing the disease-causing microbe with chemicals, heat, or radiation. Such vaccines are more stable and safer than live vaccines: The dead microbes can't mutate back to their disease-causing state.

Inactivated vaccines usually don't require refrigeration, and they can be easily stored and transported in a freeze-dried form, which makes them accessible to people in developing countries.

Most inactivated vaccines, however, stimulate a weaker immune system response than do live vaccines. So it would likely take several additional doses, or booster shots, to maintain a person's immunity.

Examples are the influenza vaccine, cholera vaccine, bubonic plague vaccine, polio vaccine, hepatitis A vaccine, and rabies vaccine.

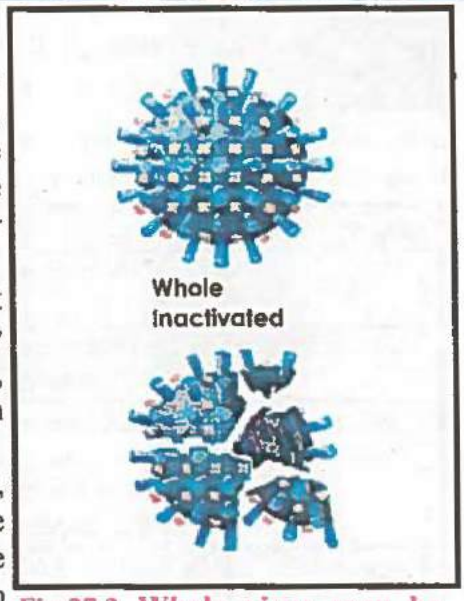


Fig:27.3 Whole virus may be inactivated by heat or chemicals, subunit vaccines may be generated by breaking open viruses or expressing specific proteins.

3- Subunit Vaccines:

Instead of the entire microbe, subunit vaccines include only the antigens that best stimulate the immune system. In some cases, these vaccines use epitopes—the very specific parts of the antigen that antibodies or T cells recognize and bind to. Because subunit vaccines contain only the essential antigens and not all the other molecules that make up the microbe, the chances of adverse reactions to the vaccine are lower. Examples include the subunit vaccine against Hepatitis B virus that is composed of only the surface proteins of the virus.

4- Toxoid Vaccines:

For bacteria that secrete toxins, or harmful chemicals, a toxoid vaccine might be the answer. These vaccines are used when a bacterial toxin is the main cause of illness.

Scientists have found that they can inactivate toxins by treating them with formalin, a solution of formaldehyde and sterilized water. Such "detoxified" toxins, called toxoids, and are safe for use in vaccines. Vaccines against diphtheria and tetanus are examples of toxoid vaccines.

27.3 SCHEDULE OF VACCINATION AGAINST COMMON DISEASES

In the following table 27.1 a general schedule of vaccination against some common diseases is given.

Table 27.1 General schedule of vaccination

Disease	Vaccine	Type	Age group
Polio	OPV (Oral Polio Vaccine)	Live vaccine	From birth to 5 years of age
Tuberculosis	BCG (Bacillus Calmette Guerin)	Live vaccine	At birth
Typhoid	Typhoid vaccine TAB vaccine (Typhoid Paratyphoid A & Paratyphoid B)	Killed vaccine	At 2 years of age
Hepatitis	Hepatitis-B Vaccine	Subunit vaccine	At any age
Diphtheria + Tetanus	Diphtheria toxoid vaccine Tetanus toxoid vaccine	Toxoid vaccine	Generally in childhood

27.4 ANIMAL HUSBANDRY

Ever since the beginning of civilization, humans have depended on animals for many requirements, such as that of food (milk, meat and egg), clothing (hide or wool), labour (pulling, carrying load) and security etc. The development of desirable qualities in all such animal species, through creating better breeds, has been an important human achievement. For this, humans have consistently tried to improve the breeds of domesticated animals to make them more useful for them.

The branch of science, which deals with the study of various breeds of domesticated animals and their management for obtaining better products and services from them, is known as **Animal Husbandry.** The term husbandry derives from the word "husband" which means 'one who takes care'. When it incorporates the study of proper utilization of economically important domestic animals, it is called **Livestock Management.**

Being a country that has a largely agriculture-based industrial system, animal husbandry plays an important role in the rural economy of Pakistan and is a major source of livelihood for many farmers. It is estimated that there are between 30 to 35 million people in Pakistan's current labor force who are engaged in livestock.

27.4.1 Different Categories of Animals (livestock):

- Wild –Those that breed better where they are free than they do when they are captivated. They have no common use for humans. Examples are Lion, Tiger, Rhinoceros, Deer etc.
- Tamed – Those, which are caught from the wild and trained to be useful to humans in some way. Elephant, Chimpanzee, Gorilla, Yak etc.
- Domesticated – Those that are of use at home and are easily bred and looked after by humans. Common domesticated animals are dog, horse, cow, sheep, buffalo, fowl etc.

For Your Information

Comparison of average milk yields across countries shows that one New Zealand dairy animal produces as much milk as three dairy animals in Pakistan; while one American cow produces as much as seven Pakistani cows.

27.4.2 Importance of domestic animals:

On the basis of utility, domestic animals are categorized into the following functional groups:

- Milk yielding animals (Cattle, buffalo, goat, sheep, and etc.).
- Draught animals (used for load Bullock, horse, donkey, mule, bearing camel, elephant, yak etc.)
- Fibre, hide and skin yielding Sheep, goat, cattle, buffalo, camel etc.
- Meat and egg yielding animals Fowl (hen) and duck, goat, buffalo, etc.

Fig: 27.4 Cattle play an important role in the rural economy.

27.4.3 Types of animal husbandry

There are several forms of animal husbandry out of them some important forms are given below.

Milk and meat yielding animals:

Depending upon the availability and regional considerations different animals are reared for the purposes of yielding milk and meat. Cattles are considered to have been one of the first animals domesticated by man for agricultural purposes.

Cattle mainly include cow, bull, oxen, goat, sheep etc. The females of the species provide milk, which in turn contribute animal protein to the diet of people. While the female species of these cattle are used for milk, the male species play an important role in the agricultural economy by providing labour, meat and hide. Milk itself is taken in many forms like ghee, curd, butter and cheese etc. The excreta of these animals used as manure, in biogas and as fuel.

For Your Information

This breed is from Holland. This is by far the best diary breed among exotic cattle regarding milk yield. On an average it gives 25 litres of milk per day, whereas a cross breed H.F. cow gives 10 - 15 lts per day.

Holstein Friesian
(Milk yield - 7200-9000 kgs)

Dairy products:

Milk as drawn from the animals is known as full cream milk. When the cream is separated and the remaining milk is called toned milk. This milk contains no fat and is known as skimmed milk. On the basis of fat contents the various milk product are as follows:

- **Cream:** It is prepared by churning milk; the fat comes on the top which is separated by draining out the liquid. It is known as cream with 10-70% fat contents.
- **Curd:** Milk is converted to curd due to bacterial activities.
- **Butter Milk:** It is the left over liquid after removal of butter.
- **Ghee:** After heating butter, the water evaporates and fat contents are almost 100%.
- **Condensed milk:** Milk is concentrated by removing water contents with or without adding sugar. It has 31% milk solids with 9% fats.
- **Powdered milk:** It is the powdered form of milk.
- **Cheese:** It is coagulated milk protein-casein with fat and water.
- **Khoya:** A desiccated milk product prepared by evaporating water contents and reducing the bulk to about 70-75%.

For Your Information

Most common breed of buffalo is Nili Ravi which constitutes 76.7% of the total buffalo population in Pakistan. Local Cattles include Sahiwal, Cholistani, Dajal, Dhani, and Rojhan. Sahiwal are a high yielding breed but the pure blood is diminishing due to cross breeding. An example of crossbred dairy animals with varying degrees of a highly productive dairy product is Australian Holstein Friesian with local Sahiwal and Cholistani.

- **Cattle Dung:** Cattle dung is mainly used to make dung cakes for burning as fuels. It is used mainly in villages. The farmers also use cattle dung to produce bio gas and the leftover residue as manure. Biogas plant (Gobar gas plant) Bio gas plant is a chamber where animal excreta (Cow dung, buffalo dung etc.) and some anaerobic bacteria are fed into airtight biogas chamber. Decomposition of excreta produces methane gas used as a smoke free gas for cooking. This gas can also be utilized for lighting. The left over solid residue serves as good manure.

Draught animals

Draught animals are animals need for carrying load. From ancient time a number of animal species have been used for special purposes by humans, utilizing their mechanical strength, endurance and speed. These include horse for riding and swift running; elephant for riding, strength and heavy load lifting, camel for riding in sandy desert and ability to survive without water for long duration, donkey and mule (a hybrid of male donkey and female horse) for carrying load.Most of the draught animals are herbivorous and survive on leaves of trees, shrubs and bushes. While raising them, they are also fed on grains, beans, cottonseeds, maize and bran besides dry/ green fodder.

Fig: 27.5 Cattle play an important role in the rural economy.

Fiber, hide and skin yielding animals:

Besides providing meat, milk and transport, livestock provide many commercially useful products such as fibre, skin and hide. Generally sheep and goat provide fibres for making of products like woolen strings, ropes, carpets, clothing and brushes etc.

Egg yielding animals:

This category consists of egg producing animals whose eggs are used as food by mankind to provide proteins. Poultry farming is defined as a term for rearing and keeping of birds such as fowl, duck and hen for egg and meat. Poultry farming has become popular because it is comparatively easy to start and maintain. It gives quick return within one to six month of investments, is easily manageable and requires less space and labour. Poultry birds and their eggs are a rich source of nutrients.

Fig: 27.6 Poultry farming is considered to be one of the profitable business.

27.4.4 Genetic improvement in animals:

The application of laws of animal health and reproduction genetics has contributed towards increase in milk, egg and meat productivity. The increase in egg production brought about the silver revolution in the area of animal husbandry. The methods being widely used are artificial insemination and embryo transplant.

Artificial insemination:

Artificial insemination involves collection of semen from a healthy bull of the desired breed, its storage at low temperatures and introduction into the females of cattle of other breeds for bringing about fertilization using sterilized (germ free) equipment. Advantages of this method are:

(a) Up to 3000 females can be fertilized from semen collected from one bull.
(b) The semen can be stored for a long period and transported over long distances.
(c) It is economical and has high success rates of fertilization.

Embryo transplant:

This method of breed improvement has been quite successful in sheep and goat. In this method, embryos (depending on their period of development) from superior breeds are removed during the early stages of pregnancy and are transferred to the other female with inferior characters, in whose body the gestation period is completed.

By this technique, quality and productivity in the livestock can be improved. Unlike artificial insemination, this method has low success rate due to greater chances of contamination.

27.5 LATEST TECHNIQUES USED FOR PLANTS

From ancient times plant breeders have been struggling for the improvement of crop plants. Traits that breeders have tried to incorporate into crop plants by using various techniques in the last 100 years include:

- Increased quality and yield of the crop
- ncreased tolerance of environmental pressures (salinity, extreme temperature, drought)
- Resistance to viruses, fungi and bacteria
- Increased tolerance to insect pests
- Increased tolerance of herbicides

Classical breeding relies largely on homologous recombination between chromosomes to generate genetic diversity.

Fig: 27.7Hercules, a "Liger", a Lion/Tiger hybrid.

The classical plant breeder may also makes use of a number of in vitro techniques such as protoplast fusion, embryo rescue or mutagenesis to generate diversity and produce hybrid plants that would not exist in nature. In addition many new techniques are also being employed by the breeders for the improvement of crop plants.These techniques may include acclimatization, selective breeding, hybridization and backcrossing. Plant improvement by genetic engineering is also becoming popular day by day.

27.5.1 Acclimatization:

Acclimatization or acclimation is the process of an individual organism adjusting to a gradual change in its environment, (such as a change in temperature, humidity, photoperiod, or pH) allowing it to maintain performance across a range of environmental conditions. Acclimatization occurs in a short period of time (days to weeks), and within the organism's lifetime (compare to adaptation). and acclimatization are different terms in the sense that acclimation is used under laboratory conditions, while acclimatization is "in the field" or in nature. In order to maintain performance across a range of environmental conditions, there are several strategies organisms use to acclimate.

In response to changes in temperature, organisms can change the biochemistry of cell membranes making them more fluid in cold temperatures and

less fluid in warm temperatures by increasing the number of membrane proteins. Organisms may also express specific proteins called **heat shock proteins** that may act as molecular chaperons (protein that assists non-covalent folding) and help the cell maintain function under periods of extreme stress. It has been shown, that organisms which are acclimated to high or low temperatures display relatively high resting levels of heat shock proteins so that when they are exposed to even more extreme temperatures the proteins are readily available.

Expression of heat shock proteins and regulation of membrane fluidity are just two of many biochemical methods organisms use to acclimate to novel environments

Many plants, such as maple trees, irises, and tomatoes, can survive freezing temperatures if the temperature gradually drops lower and lower each night over a period of days or weeks. The same drop might kill them if it occurred suddenly. Studies have shown that tomato plants that were acclimated to higher temperature over several days were more efficient at photosynthesis at relatively high temperatures than were plants that were not allowed to acclimate.

Fig: 27. 8 Acclimation is in process. In this case, shoots are removed from the sterile environment and placed in soil in a high humidity environment.

27.5.2 Selective breeding:

Selective breeding is the art and science of changing the genetics of plants in order to produce desired characteristics. Plant breeding can be accomplished through many different techniques ranging from simply selecting plants with desirable characteristics for propagation, to more complex molecular techniques.Sometimes many different genes can influence a desirable trait in plant breeding. The use of tools such as molecular markers or DNA fingerprinting can map thousands of genes. This allows plant breeders to screen large populations of plants for those that possess the trait of interest. The screening is based on the presence or absence of a certain gene as determined by laboratory procedures, rather than on the visual identification of the expressed trait in the plant.

International development agencies believe that breeding new crops is important for ensuring food security by developing new varieties that are higher-

yielding, resistant to pests and diseases, drought-resistant or regionally adapted to different environments and growing conditions.

27.5.3 Hybridization and backcrossing:

Classical plant breeding uses deliberate interbreeding (crossing) of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. This process is known as hybridization. Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background. For example, a mildew-resistant pea may be crossed with a high-yielding but susceptible pea, the goal of the cross being to introduce mildew resistance without losing the high-yield characteristics.

Progeny from the cross would then be crossed with the high-yielding parent to ensure that the progeny were most like the high-yielding parent. This type of hybridization is called backcrossing. The progeny from that cross would then be tested for yield and mildew resistance and high-yielding resistant plants would be further developed. Plants may also be crossed with themselves to produce inbred varieties for breeding.

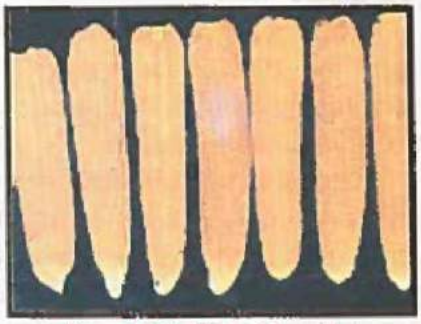


Fig: 27.9 Hybrid maize

27.5.4 Role of Genetic engineering in crop improvement:

Since last two decades, genetic engineering has been imparting a very significant role in crop improvement. Desired traits/genes can be inserted in the plant genome by genetic recombination using the bacteria Agrobacterium tumefaciens or A. rhizogenes, or by direct methods like the gene gun or microinjection.

The majority of commercially released transgenic plants are currently limited to plants that have introduced resistance to insect pests and herbicides. Insect resistance is achieved through incorporation of a gene from *Bacillus thuringiensis* (Bt) that encodes a protein that is toxic to some insects. For example, the cotton bollworm, a common cotton pest, feeds on Bt cotton it will ingest the toxin and die. Herbicides usually work by binding to certain plant enzymes and inhibiting their action.

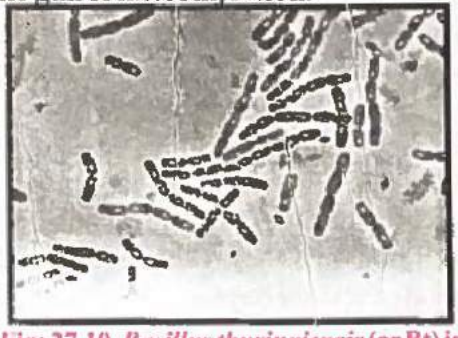


Fig: 27.10 *Bacillus thuringiensis* (or Bt) is a soil-dwelling bacterium, commonly used as a biological alternative to a pesticide; alternatively, the Cry toxin may be extracted and used as a pesticide.

Here is a seasonality chart that will help you in choice for home gardening. This chart could be slightly different in different parts of the country.

Winter January, February	Spring March, April, May	Summer June, July, August	Fall Sep, Oct, Nov
Cabbage	Asparagus	Corn	Apples
Cauliflower	Basil	Cucumbers	Cabbage
Celery Root	Beans	Dates	Cauliflower
Grapefruit	Berries	Figs	Cranberries
Mandarin	Broccoli	Grapes	Cucumbers
Oranges	Cabbage	Mangoes	Dates
Sweet Oranges	Cucumbers	Okra	Fennel
Pears	Radish	Peaches	Grapes
Spinach	Mangoes	Chile Peppers	Pears
Sweet Potatoes	Okra	Sweet Peppers	Chile Peppers
	Sweet Oranges	Plums	Sweet Peppers
	Papayas	Tomatoes	Spinach
	Peas	Watermelon	Sweet Potatoes
	Chile Peppers		
	Sweet Peppers		
	Spinach		
	Turnips		

27.7 ROLE OF MICROBES IN HUMAN WELFARE

Microorganisms or microbes are generic terms for the group of living organisms which are microscopic in size, and include bacteria, viruses, algae, fungi, and protozoa. Microorganisms have a great impact on many areas of biology and general human welfares. Some are beneficial to man while others are harmful. The beneficial functions include production of bread, cheese, antibiotics, vaccines, vitamins, enzymes and many other products. Microorganisms occupy an important position in the ecosystem. They are required for the various cycles of nature, such as carbon, nitrogen, oxygen, and Sulphur that take place in the ecosystem.

27.7.1 Role of Microbe in food processing:

There are many useful applications of microorganisms in the food processing industry. They influence the quality, availability and quantity of food. Microorganisms are used to change one substance to another which is used as food such as milk to yoghurt and cheese, sugar to wine and bread.

Yoghurt making:

Yoghurt is a dairy product which is produced by bacterial fermentation of milk. Most commonly cow's milk is used, though it can be made from any kind of milk. The milk sugar, i.e. lactose is fermented into lactic acid by the friendly bacteria, *Streptococcus salivarius*, *S. thermophiles* and *Lactobacillus bulgaricus*. These bacteria are collectively known as lactic acid bacteria or LAB. The bacteria feed on the lactose and release lactic acid as a bye product. The acid causes the curdling of the milk protein, casein into solid mass called curd. The gel like texture and taste of yoghurt is due to the fermentation of lactose to lactic acid. The increased acidity (pH=4-5) also prevents the proliferation of other potentially pathogenic bacteria.

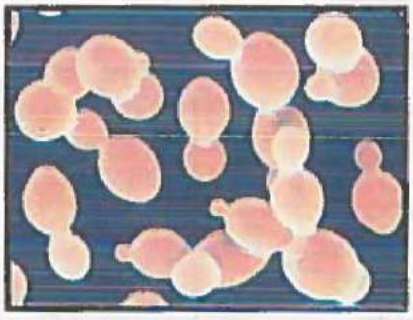


Fig: 27.12 *Saccharomyces cervisiae*

Cheese making:

Cheese is a generic term for a diverse group of milk-based food products. Cheese is solid food produced by milk of various animals throughout the world in wide-ranging flavors, textures, and forms.

As described above that fermentation of milk leads to lactic acid production which sour the milk. This leads to the coagulation of milk protein, casein. The solid part of the milk produced by coagulation is known as **curd** and the liquid is known as **whey**.

For Your Information

Coagulation can be controlled using rennet tablets, which contains the enzyme renin. Renin is an enzyme present in the stomach of calves and in human infant but now is also available through genetically engineered bacteria. In addition, coagulation can also be done by using acids such as vinegar or lemon juice.

The curds can be separated and pressed into desired shape and whey is used as food source for yeast, which in turn can be processed as cattle feed and is rich in protein and vitamins. The cheese can be matured or ripened by the addition of bacteria or fungi or both. The bacteria added reduce the pH, alters the texture and develop a flavour.

27.7.2 Role of Microbes in Alcohol industry:

Alcohol is most common solvent used in laboratories, chemical industry, and as a fuel. It is produced during anaerobic respiration of yeast, i.e. *Saccharomyces cervisiae*, which converts sugar to ethanol and carbon dioxide. This is known as alcoholic fermentation.

Depending on the type of sugar, different type of alcohol can be made.

- Beer is prepared from the fermentation of maltose by yeast.
- Wine is made from the fermentation of grape sugar by yeast.

Beer is brewed from barley grain, which is partially germinated to convert the starch to maltose. This process of conversion is known as **malting**. Gibberellins and amylase are used to speed up the process of germination and to increase the amount of sugar to produce more alcohol. The sugar is extracted by crushing the grain and adding hot water. The liquid obtained after this procedure is known as **wort.** Next the wort is fermented by the yeast to produce alcohol.

27.7.3 Role of Microbes in Pharmaceutical industry:

Insulin is a pharmaceutically important compound produced commercially by transgenic *E. coli*. In earlier times, insulin was isolated from pancreas of dead animals (cadavers). Today, human insulin gene is introduced into *E. coli* by recombinant DNA technology.

Many compounds of pharmaceutical importance are being derived from various kinds of microorganisms. Some of these compounds include insulin, penicillin, monoclonal antibodies, cyclosporine and etc.These bacteria are grown in bioreactors (large tanks containing bacterial media). The insulin can be extracted, purified and is ready to use. The two main advantages of the insulin produced by the recombinant DNA technology are as follows:

- It is chemically identical to the human insulin.
- It can be made available in unlimited quantities.

Fig: 27.13 *E. coli*

Penicillin is a group of antibiotics derived from Penicillium fungi. Penicillin is a secondary metabolite of fungus *Penicillium* that is produced when growth of the fungus is inhibited by stress. It is not produced during active growth.

Cyclosporin is an immunosuppressive agents used in organ transplant patients. It is produced by a fungus, Trichoderma polysporum.

The lovastatin produced by the yeast *Monascus purpureus*, is a blood cholesterol lowering agents, it acts as a competitive inhibitor for the enzyme which is responsible for the synthesis of cholesterol, thereby stopping its synthesis.

27.7.4 Role of Microbes in Waste Treatment:

Sewage treatment or domestic wastewater treatment is the process of removing contaminants from waste water and household sewage, both runoff (effluents) and domestic.

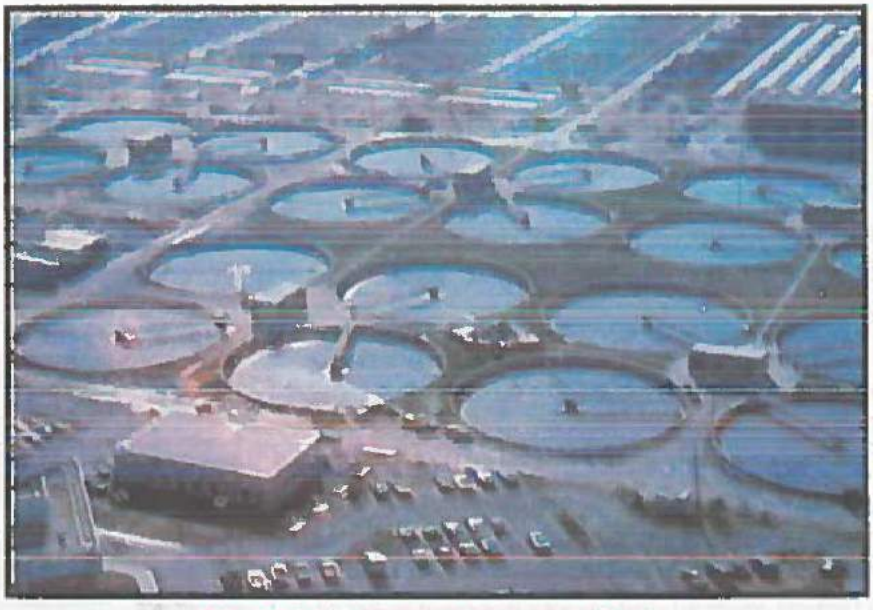


Fig: 27.14 A sewage treatment plant.

It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid waste stream (or treated effluent) and a solid waste (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer). A sewage treatment plant is nothing more than a

giant microbial culture breading facility where microbes are engaged to work for our benefit.

27.7.5 Role of Microbes in Energy generation:

The widespread use of fossil fuels has brought numerous benefits to industrialized societies. Large amounts of agricultural, domestic and industrial wastes (mainly consists of biomass) generated in these countries as a result of development, have potentially detrimental effects both on the environment and on human health. Biotechnology is one of the future-oriented technologies, and one that will play a major role in the exploitation of biomass energy. All biomass (plant, animal and microbial), originates through CO2 fixation by photosynthesis. Biomass utilization is consequently included in the global carbon cycle of the biosphere.

For Your Information

Approximately 114 kilocalories of free energy are stored in plant biomass for every mole of CO_2 fixed during photosynthesis. Solar radiation striking the earth on an annual basis is equivalent to 178,000 terawatts, i.e. 15,000 times that of current global energy consumption. Although photosynthetic energy capture is estimated to be ten times that of global annual energy consumption, only a small part of this solar radiation is used for photosynthesis.

Biomass energy in developing countries, originates from fuel wood, animal wastes, and agricultural residues. This biomass can be used to generate energy with the help of microbial activity. Some important examples are given below.

Biogas

Biogas is 50-75% methane and the remainder is carbon dioxide with traces of nitrogen and other gases. Different groups of microorganisms are used in the process of fermentation of various organic substrates to produce biogas. Methanogens are the bacteria used for the production of methane from carbon and hydrogen.

Fig: 27.15 Biogas plant in one of the village of Pakistan

Methanobacterium is an example of methanogen. Methanogens symbiotically live in the in the gut of cattle from where they are passed to sewage through their wastes.

Biogas production from activated sludge:

The solid waste that is taken out from the settling tanks at various stages in sewage treatment plants is known as activated sludge. It is alive with microbiological activity. Methane gas is given off, and this can be detected by your nose in the vicinity of sewage treatment plants. Methane produced in this way is referred as biogas.

The sludge is removed to large concrete vats that can be sealed. Excess effluent water is drained from the bottom of the vat. Anaerobic microbes (Methanobacteria) within the sewage are now allowed to work, breaking down all the organic matter. A sealed vat, though, will build up pressure and burst, from the methane given off by the microbes, so the gas is vented from the vat and in countries where energy is at a premium, is often used to power machinery in the sewage plant.

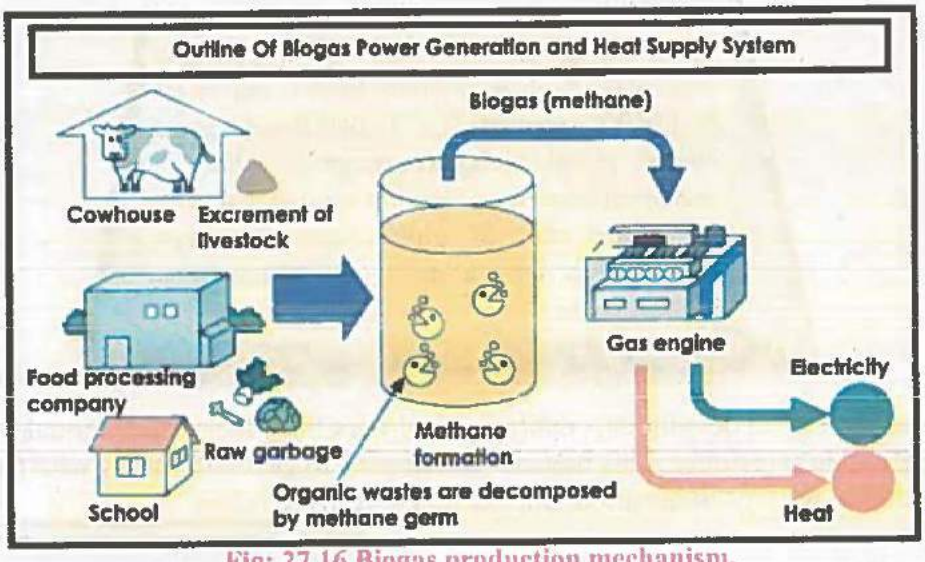


Fig: 27.16 Biogas production mechanism.

Up to 50% of the sludge can be digested in the vats, but once the process starts to wane the vats are emptied and the waste material can be spread out on the ground to dry in shallow concrete pits. Once this has happened the material can be collected, bagged, and sold as land fertilizer. It is safe to handle and extremely effective in the fields, provided it is free from industrial pollutants.

Biogas production from cattle's dung (gobar):

Methanobacteria found in the rumen of cattle help in the breakdown of cellulose which is present on the fodder of cattle.

For Your Information

Janelle Curtis of Biodesign Institute at Arizona State University has discovered certain Bacteria that have evolved to utilize almost any chemical as a food source. In the microbial fuel cell, bacteria form a biofilm, a living community that is attached to the electrode by a sticky sugar and protein coated biofilm matrix. When grown without oxygen, the byproducts of bacterial metabolism of waste include carbon dioxide, electrons and hydrogen ions. Electrons produced by the bacteria are shuttled onto the electrode by the biofilm matrix, creating a thriving ecosystem called the biofilm anode and generating electricity

Cattle's dung known as gobar is rich in these bacteria therefore dung is used for the production of biogas. This gas is also known as gobar gas. The biogas plant is a tank which is 10-15 ft. deep. The biowastes and dung are added into the tank. The gas produced is collected and sent out through an outlet while the slurry left in the tank can be used as fertilizer.

Other than animal manure and sewage sludge, food and domestic wastes, crop remains, paper wastes are also used as substrate for fermentation. Crops like maize, sugarcane, sugar beet and water plants like water hyacinth may also be used.

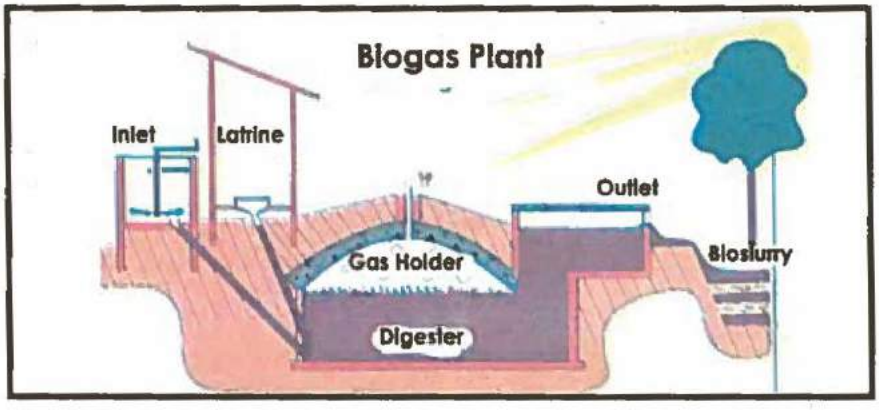


Fig: 27.17 Biogas Production plant.

Uses of Biogas:

Methane can be used as a fuel both in internal combustion engines (i.e as in car) and in gas turbines (as in an airliner). These engines can power pumps and sluices, generate electricity and even deliver the excess power into the electricity grid system. Thus your local sewage plant can be eco-friendly, by adding no net increase in greenhouse gasses or other pollutants to the environment. It also allows a certainty of power supply to the treatment plant, for it is not at the mercy of electricity grid or public gas supply.

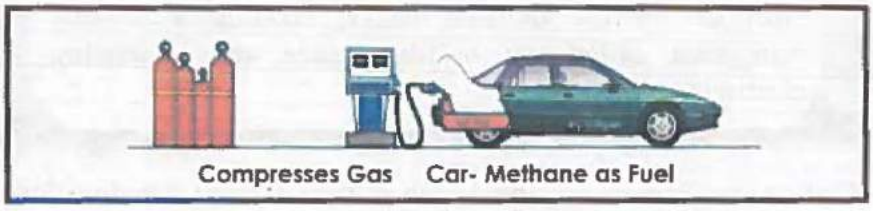


Fig: 27.18 Methane used as fuel.

KEY POINTS

- In integrated disease management, every available method of disease control is used like preventive measures, drug treatment, vaccination, and different kinds of therapies.
- Vaccination is the administration of vaccine to stimulate the immune system of an individual to develop artificially induced active immunity against an infectious disease.
- Some important types of vaccines are live, attenuated vaccines, inactivated vaccines, subunit vaccines and toxoid vaccines.
- The branch of science, which deals with the study of various breeds of domesticated animals and their management for obtaining better products and services from them, is known as **Animal Husbandry.**
- Artificial insemination involves collection of semen from a healthy bull of the desired breed, its storage at low temperatures and introduction into the females of cattle of other breeds for bringing about fertilization using sterilized (germ free) equipment.
- Selective breeding is the art and science of changing the genetics of plants in order to produce desired characteristics.
- Classical plant breeding uses deliberate interbreeding (crossing) of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. This process is known as hybridization.
- Microorganisms are used to change one substance to another which is used as food such as milk to yoghurt and cheese, sugar to wine and bread.
- Insulin is a pharmaceutically important compound produced commercially by transgenic *E. coli.* In earlier times, insulin was isolated from pancreas of dead animals (cadavers). Today, human insulin gene is introduced into *E. coli* by recombinant DNA technology.
- Sewage treatment or domestic wastewater treatment is the process of removing contaminants from waste water and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants.
- Biogas is 50-75% methane and the remainder is carbon dioxide with traces of nitrogen and other gases.

EXERCISE ?

1. Multiple choice questions

i. Which of the following is not included in integrated disease management?
(a) awareness through media (b) vaccination and medication
(c) both a & b (d) none of them

ii. BCG vaccine is a type of:
(a) live attenuated vaccine (b) killed vaccine
(c) subunit vaccine (d) conjugated vaccine

iii. Study of proper utilization of economically important domestic animals, it is called:
(a) Animal Husbandry (b) Wild life Management
(c) Livestock Management (d) none of them

iv. **Holstein Friesian was imported from** Holland. This is by far the best diary breed among exotic cattle regarding milk yield. On an average it gives:
(a) 10 liter of milk per day (b) 15 liter of milk per day
(c) 20 liter of milk per day (d) 25 liter of milk per day.

2. Short Questions

i. Differentiate between animal husbandry and livestock management.
ii. What is the importance of artificial insemination?
iii. What is biogas?
iv. Write a note on the process of cheese making.
v. What is acclimatization? Explain briefly with the help of an example.
vi. List the traits that breeders have tried to incorporate into crop plants by using various techniques?
vii. Give the importance of domestic animals?
viii. What are conjugate vaccines, give an example.
ix. How did Edward Jenner prepare the first vaccine?

3. Long Questions

i. What is vaccine? Describe its mode of action and various types.
ii. What are dairy animals? Also describe various kinds of dairy products?
iii. Describe any two methods of crop improvement.
iv. Explain the methods for the production of biogas.

4. Analyzing and interpreting

- Correlate the role of biotechnology and genetic engineering in crop improvement.

EXERCISE ?

5. Science, Technology & Society Connections

- Justify the importance of vaccination campaigns observed worldwide to curb the diseases.
- List the objectives of the institutions of the federal health department and UNO working for integrated disease management.
- Assess the impact of livestock in boosting up of national economy.

6. Online learning

- www.sciencedaily.com
- www.fas.org
- www.nespak.com
- www.environment.gov.pk
- www.czs.org

GLOSSARY

A

Adrenocorticotropic Hormone (ACTH): A hormone produced by the anterior pituitarythat stimulates the adrenal cortex to release several hormones including cortisol.

Aldosterone: A hormone secreted by the adrenal glands that controls the reabsorption of sodium in the renal tubule of the nephron.

Alleles: Alternate forms of a gene.

Alveoli: Tiny, thin-walled, inflatable sacs in the lungs where oxygen and carbon dioxide are exchanged.

Aneuploidy: Variation in chromosome number involving one or a small number of chromosomes; commonly involves the gain or loss of a single chromosome.

Anticodon: A sequence of three nucleotides on the transfer RNA molecule that recognizes and pairs with a specific codon on a messenger RNA molecule; helps control the sequence of amino acids in a growing polypeptide chain.

Assortment: A way in which meiosis produces new combinations of genetic information. Paternal and maternal chromosomes line up randomly during synapsis, so each daughter cell is likely to receive an assortment of maternal and paternal chromosomes rather than a complete set from either.

Autosomes: The chromosomes other than the sex chromosomes. Each member of an autosome pair (in diploid organisms) is of similar length and in the genes it carries.

B

Barriers to gene flow: Factors, such as geographic, mechanical, and behavioral isolating mechanisms that restrict gene flow between populations, leading to populations with differing allele frequencies.

Biochemical cycle: The flow of an element through.the living tissue and physical environment of an ; e. g., the carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus cycles.

Biomass: The total weight of living tissue in a community.

Biome: A large-scale grouping that includes many communities of a similar nature.

Blastocoels: The fluid-filled cavity at the center of a blastula.

Blastocyst: The developmental stage of the fertilized ovum by the time it is ready to implant; formed from the morula and consists of an inner cell mass, an internal cavity, and an outer layer of cells (the trophoblast).

Blastula: A ball of cells surrounding a fluid-filled cavity (the blastocoel) that is produced by the repeated cleavage of a zygote.

Bronchitis: A respiratory disorder characterized by excess mucus production and swelling of the bronchioles; caused by long-term exposure to irritants such as cigarette smoke and air pollutants.

C

Calcitonin: A hormone produced by the thyroid that plays a role in regulating calcium levels.

Carnivores: Term applied to a heterotroph, usually an animal, that eats other animals. Carnivores function as secondary, tertiary, or top consumers in food chains and food webs.

Catastrophism: Once-popular belief that events in earth history had occurred in the past a sudden events and by processes unlike those operating today. Periods of catastrophic change were followed by long periods of little change. A subgroup, the Diluvialists, contended that Noah's Flood was the last of many floods which had occurred throughout earth history.

Chemotrophs: Organisms (usually bacteria) that derive energy from inorganic reactions; also known as chemosynthetic.

Chromosomes: Structures in the nucleus of a eukaryotic cell that consist of DNA molecules that contain the genes.

Chromosome theory of inheritance: Holds that chromosomes are the cellular components that physically contain genes; proposed in 1903 by Walter Sutton and Theodore Boveri.

Clavicle: The collar bone.

Cleavage furrow: A constriction of the cell membrane at the equator of the cell that marks the beginning of cytokinesis in animal cells. The cell divides as the furrow deepens.

Climax community: The stage in community succession where the community has become relatively stable through successful adjustment to its environment.

Clone: An exact copy of a DNA segment; produced by recombinant DNA technology.

Closed community: A community in which populations have similar range boundaries and density peaks; forms a discrete unit with sharp boundaries.

Codominance: A type of inheritance in which heterozygotes fully express both alleles.

Codon: A sequence of three nucleotides in messenger RNA that codes for a single amino acid.

Community age: One of the factors that helps cause the latitudinal diversity gradient. Tropical communities have had more time to evolve because they have been less disrupted by advancing ice sheets and other relatively recent climatic changes.

Consumers: The higher levels in a food pyramid; consist of primary consumers, which feed on the producers, and secondary consumers, which feed on the primary consumers.

Continuous variation: Occurs when the phenotypes of traits controlled by a single gene cannot be sorted into two distinct phenotypic classes, but rather fall into a series of overlapping classes.

Convergent evolution: The development of similar structures in distantly related organisms as a result of adapting to similar environments and/or strategies of life. Example: wings of birds and insects, the body shape of dolphins, sharks, and the extinct marine reptiles known as ichthyosaurs.

D

Deletion: The loss of a chromosome segment without altering the number of chromosomes.

Dendrites: Short, highly branched fibers that carry signals toward the cell body of a neuron.

Deoxyribose: Five-carbon sugar found in nucleotides of DNA.

Dibetes mellitus, Types I and II: A disorder associated with defects in insulin action. Type I diabetes is characterized by inadequate insulin secretion; Type II diabetes is characterized by impaired insulin secretion in response to elevated blood glucose levels or by loss of sensitivity to insulin by target cells.

Diencephalon: Part of the forebrain; consists of the thalamus and hypothalamus.

Divergent evolution: The divergence of a single interbreeding population or species into two or more descendant species.

DNA hybridization: The formation of hybrid DNA molecules that contain a strand of DNA from two different species. The number of complementary sequences in common in the two strands is an indication of the degree of relatedness of the species.

DNA ligase: In recombinant DNA technology, an enzyme that seals together two DNA fragments from different sources to form a recombinant DNA molecule.

DNA polymerase: In DNA replication, the enzyme that links the complementary nucleotides together to form the newly synthesized strand.

Dominance: The property of one of a pair of alleles that suppresses the expression of the other member of the pair in heterozygotes.

Dominance hierarchy: A social structure among a group of animals in which one is dominant and the others have subordinate nonbreeding positions.

Ecological niche: The role an organism occupies and the function it performs in an ecosystem; closely associated with feeding.

Ecological time: A timescale that focuses on community events that occur on the order of tens to hundreds of years.

Emphysema: Lung disease characterized by shortness of breath, often associated with smoking.

Endometrium: The inner lining of the uterus.

Endothermy: The internal control of body temperature; the ability to generate and maintain internal body heat.

Epinephrine: A hormone produced by the adrenal medulla and secreted under stress; contributes to the "fight or flight" response.

Epistasis: The masking of the effects of one gene by the action of another, example: widow's peak masked by the baldness gene.

Excretion: The process of removing the waste products of cellular metabolism from the body.

Exon: The DNA bases that code for an amino acid sequence. Exons are separated by introns that code for no amino acid sequences.

Extinction: The elimination of all individuals in a group, both by natural (dinosaurs, trilobites) and human-induced (dodo, passenger pigeon,

F

Fibroblast: A term applied to a cell of connective tissue that is separated from similar cells by some degree of matrix material; fibroblasts secrete elastin and collagen protein fibers.

Follicles (ovary): Structures in the ovary consisting of a developing egg surrounded by a layer of follicle cells.

Founder effect: The difference in gene pools between an original population and a new population founded by one or a few individuals randomly separated from the original population, as when an island population is founded by one or a few individuals; often accentuates.

G

Gap junctions: Junctions between the plasma membranes of animal cells that allow communication between the cytoplasm of adjacent cells.

Gene pool: The sum of all the genetic information carried by members of a population. Note: there is ***no*** diving in the deep end of the gene pool!

Gene therapy: The insertion of normal or genetically altered genes into cells through the use of recombinant DNA technology; usually done to replace defective genes as part of the treatment of genetic disorders.

Genetic divergence: The separation of a population's gene pool from the gene pools of other populations due to mutation, genetic drift, and selection. Continued divergence can lead to speciation.

Genetic drift: Random changes in the frequency of alleles from generation to generation; especially in small populations, can lead to the elimination of a particular allele by chance alone.

Genetic maps: Diagrams showing the order of and distance between genes; constructed using crossover information.

Glial cells: Nonconducting cells that serve as support cells in the nervous system and help to protect neurons.

Gonorrhea: A sexually transmitted disease that is caused by a bacterium that inflames and damages epithelial cells of the reproductive

H

Hemizygous: Having one or more genes that have no allele counterparts. Usually applied to genes on the male's X chromosome (in humans).

Homologues: A pair of chromosomes in which one member of the pair is obtained from the organism's maternal parent and the other from the paternal parent; found in diploid cells. Also commonly referred to as homologous chromosomes.

Hypothalamus: A region in the brain beneath the thalamus; consists of many aggregations of nerve cells and controls a variety ofautonomic functions aimed at maintaining homeostasis.

I

Immovable joint: A joint in which the bones interlock and are held together by Þbers or bony processes that prevent the joint from moving; e.g., the bones of the cranium.

Implantation: The process in which the blastocyst embeds in the endometrium.

Incomplete dominance : A type of inheritance in which the heterozygote has a phenotype intermediate to those of the homozygous parents.

Inheritance of acquired characteristics: Lamarck's view that features acquired during an organism's lifetime would be passed on to succeeding generations, leading to inheritable change in species over time.

Initiation: The Þrst step in translation; occurs when a messenger RNA molecule, a ribosomal subunit, and a transfer RNA molecule carrying the Þrst amino acid bind together to form a complex; begins at the start codon on mRNA.

Initiation codon (AUG): Three-base sequence on the messenger RNA that codes for the amino acid methionine; the start command for protein synthesis.

Insertion: A type of mutation in which a new DNA base is inserted into an existing sequence of DNA bases. This shifts the reference frame in protein synthesis, resulting (sometimes) in altered amino acid sequences.

Intron: In eukaryotes, bases of a gene transcribed but later excised from the mRNA prior to exporting from the nucleus and subsequent translation of the message into a polypeptide.

K

Karyotype: The chromosomal characteristics of a cell; also, a representation of the chromosomes aligned in pairs.

Klinefelter syndrome: In humans, a genetically determined condition in which the individual has two X and one Y chromosome. Affected individuals are male and typically tall and infertile.

L

Langerhans' cells: Epidermal cells that participate in the inpammatory response by engulfing microorganisms and releasing chemicals that mobilize immune system cells.

Larynx: A hollow structure at the beginning of the trachea. The vocal cords extend across the opening of the larynx.

L-dopa: A chemical related to dopamine that is used in the treatment of Parkinson's disease.

Ligaments: Dense parallel bundles of connective tissue that strengthen joints and hold the bones in place.

Linkage: The condition in which the inheritance of a specific chromosome .is coupled with that of a given gene. The genes stay together during meiosis and end up in the same gamete.

M

Meissner's corpuscles: Sensory receptors concentrated in the epidermis of the fingers and lips that make these areas very sensitive to touch.

Messenger RNA (mRNA): "Blueprint" for protein synthesis that is transcribed from one strand of the DNA (gene) and which is translatedat the ribosome into a polypeptide sequence.

Methionine: The amino acid coded for by the initiation codon; all polypeptides begin with methionine, although post-translational reactions may remove it.

Morula: The solid-ball stage of the pre-emplantation embryo.

Mutation: Any heritable change in the nucleotide sequence of DNA; can involve substitutions, insertions, or deletions of one or more nucleotides.

Mutation rate: The average occurrence of mutations in a species per a given unit of time.

Myofibrils: Striated contractile microfilaments in skeletal muscle cells.
Myosin: Thick protein filaments in the center sections of sarcomeres

N

Negative feedback: The stopping of the synthesis of an enzyme by the accumulation of the products of the enzyme-mediated reaction.

Negative feedback control: Occurs when information produced by the feedback reverses the direction of the response; regulates the secretion of most hormones.

Net primary productivity (NPP): The rate at which producer (usually plants) biomass is created in a community.

Niche: The biological role played by a species.

Node of Ranvier: A gap between two of the Schwann cells that make up an axon's myelin sheath; serves as a point for generating a nerve impulse.

Nondisjunction: The failure of chromosomes to separate properly during cell division. The unequal segregation of chromosomes during meiosis. This forms cells with either too many (possibly one or more single or sets of chromosomes too many) or too few chromosomes. Thought to be a common cause for Down Syndrome, where sufferers often have an extra copy of chromosome 21.

Nucleotide sequences: The genetic code encrypted in the sequence of bases along a nucleic acid.

O

Oncogenes: Genes that can activate cell division in cells that normally do not divide or do so only slowly. A gene that when over-expressed leads to cancer, but which normally functions in cell division.

Oocyte: A cell that will/is undergo/ing development into a female gamete.

Osmoconformers: Marine organisms that have no system of osmoregulation and must change the composition of their body fluids as the composition of the water changes; include invertebrates such as jellyfish, scallops, and crabs.

Osmoregulation: The regulation of the movement of water by osmosis into and out of cells; the maintenance of water balance within the body.

Osmoregulators: Marine vertebrates whose body fluids have about one-third the solute concentration of seawater; must therefore undergo osmoregulation.

Osteoblasts: Bone-forming cells.

Osteoclasts: Cells that remove material to form the central cavity in a long bone.

Osteocytes: Bone cells that lay down new bone; found in the concentric layers of compact bone. Bone cell, a type of connective tissue.

Osteoporosis: A disorder in which the mineral portion of bone is lost, making the bone weak and brittle; occurs most commonly in postmenopausal women.

Oviducts: Tubes that connect the ovaries and the uterus; transport sperm to the ova, transport the fertilized ova to the uterus, and serve as the site of fertilization; also called the fallopian tubes or uterine tubes.

Ovulation: The release of the oocyte onto the surface of the ovary; occurs at the midpoint of the ovarian cycle. The release of the ovum (egg) from the ovary after the peaking of luteinizing hormone concentration in the blood during the menstrual cycle.

Ovum: The female gamete, egg.

Oxytocin: A peptide hormone secreted by the posterior pituitary that stimulates the contraction of the uterus during childbirth.

Ozone: A triatomic (O_3) form of oxygen that is formed in the stratosphere when sunlight strikes oxygen atoms. This atmospheric ozone helps filter radiation from the sun.

Pacinian corpuscles: Sensory receptors located deep in the epidermis that detect pressure and vibration.

Paleontology: The study of ancient life by collection and analysis of fossils.

Pancreatic islets: Clusters of endocrine cells in the pancreas that secrete insulin and glucagon; also known as islets of Langerhans.

Parasympathetic system: The subdivision of the autonomic nervous system that reverses the effects of the sympathetic nervous system. Part of the autonomic nervous system that controls heartbeat, respiration and other vital functions.

Pectoral girdle: In humans, the bony arch by which the arms are attached to the rest of the skeleton; composed of the clavicle and scapula.

Pedigree analysis: A type of genetic analysis in which a trait is traced through several generations of a family to determine how the trait is inherited. The information is displayed in a pedigree chart using standard symbols.

Pelvis: The hollow cavity formed by the two hipbones.

Peripheral nervous system: The division of the nervous system that connects the central nervous system to other parts of the body. Components of the nervous system that transmit messages to the central nervous system.

Pineal gland: A small gland located between the cerebral hemispheres of the brain that secretes melatonin.

Pioneer community: The initial community of colonizing species.

Placenta: An organ produced from interlocking maternal and embryonic tissue in placental mammals; supplies nutrients to the embryo and fetus and removes wastes.

Plasmids: Self-replicating, circular DNA molecules found in bacterial cells; often used as vectors in recombinant DNA technology. Small circles of double-stranded DNA found in some bacteria. Plasmids can carry from four to 20 genes. Plasmids are a commonly used vector in recombinant DNA studies.

Pleiotropic: A term describing a genotype with multiple phenotypic effects. For example: sickle-cell anemia produces a multitude of consequences in those it affects, such as heart disease, jidney problem, etc.

Polygenic inheritance: Occurs when a trait is controlled by several gene pairs; usually results in continuous variation.

Polymerase chain reaction (PCR): A method of amplifying or copying DNA fragments that is faster than cloning. The fragments are combined with DNA polymerase, nucleotides, and other components to form a mixture in which the DNA is cyclically amplified.

Polynucleotides: Long chains of nucleotides formed by chemical links between the sugar and phosphate groups.

Pons: The region that, with the medulla oblongata, makes up the hindbrain, which controls heart rate, constriction and dilation of blood vessels, respiration, and digestion.

Positive feedback control: Occurs when information produced by the feedback increases and accelerates the response.

Principle of segregation: Mendel's Þrst law; holds that each pair of factors of heredity separate during gamete formation so that each gamete receives one member of a pair.

Prions: Infectious agents composed only of one or more protein molecules without any accompanying genetic information.

Purine: One of the groups of nitrogenous bases that are part of a nucleotide. Purines are adenine and guanine, and are double-ring structures.

Pyrimidine: One of the groups of nitrogenous bases that are part of a nucleotide. Pyrimidines are single ringed, and consist of the bases thymine (in DNA), uracil (replacing thymine in RNA),

Recombinant DNA molecules: New combinations of DNA fragments formed by cutting DNA segments from two sources with restriction enzyme and then joining the fragments together with DNA ligase. Interspecies transfer of genes usually through a vector such as a virus or plasmid.

Recombinant DNA technology: A series of techniques in which DNA fragments are linked to self-replicating forms of DNA to create recombinant DNA molecules. These molecules in turn are replicated in a host cell to create clones of the inserted segments.

Recombination: A way in which meiosis produces new combinations of genetic information. During synapsis, chromatids may exchange parts with other chromatids, leading to a physical exchange of chromosome parts; thus, genes from both parents may be combined on the same chromosome, creating a new combination.

Reflex: A response to a stimulus that occurs without conscious effort; one of the simplest forms of behavior.

Reflex arc: Pathway of neurons, effector(s) and sensory receptors that participate in a reflex.

Renin: An enzyme secreted by the kidneys that converts angiotensinogen into angiotensin II.

Replication: Process by which DNA is duplicated prior to cell division.

Resting potential: The difference in electrical charge across the plasma membrane of a neuron.

Restriction fragment length polymorphism (RFLP): A heritable difference in DNA fragment length and fragment number; passed from generation to generation in a codominant way.

Rheumatoid arthritis: A crippling form of arthritis that begins with inþammation and thickening of the synovial membrane, followed by bone degeneration and disÞgurement.

RNA transcript: Term applied to RNA transcribed in the nucleus.

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Sarcomeres: The functional units of skeletal muscle; consist of Þlaments of myosin and actin.

Saturated fat: A fat with single covalent bonds between the carbons of its fatty acids.

Schwann cells: Specialized glial cells that form the myelin sheath that coats many axons. Cells surrounding the axons of some neurons, thus forming the myelin sheath.

Secretin: A hormone produced in the duodenum that stimulates alkaline secretions by the pancreas and inhibits gastric emptying.

Selective breeding: The selection of individuals with desirable traits for use in breeding. Over many generations, the practice leads to the development of strains with the desired characteristics.

Sex linkage: The condition in which the inheritance of a sex chromosome is coupled with that of a given gene; e.g., red-green color blindness and hemophilia in humans. Traits located on the X-chromosome.

Skeletal muscle: Muscle that is generally attached to the skeleton and causes body parts to move; consists of muscle fibers. Voluntary muscle cells that have a striated appearance. These muscles control skeletal movements and are normally under conscious control.

Sliding filament model: Model of muscular contraction in which the actin filaments in the sarcomere slide past the myosin filaments, shortening the sarcomere and therefore the muscle.

Smooth muscle: Muscle that lacks striations; found around circulatory system vessels and in the walls of such organs as the stomach, intestines, and bladder. Involuntary, not striated cells that control autonomic functions such as digestion and artery contraction.

Social behavior: Behavior that takes place in a social context and results from the interaction between and among individuals.

Sodium-potassium pump: The mechanism that uses ATP energy to reset the sodium and potassium ions after transmission of a nerve impulse.

Somatic nervous system: The portion of the peripheral nervous system consisting of the motor neuron pathways that innervate skeletal muscles.

Somatostatin: Pancreatic hormone that controls the rate of nutrient absorption into the bloodstream.

Start codon: The codon (AUG) on a messenger RNA molecule where protein synthesis begins.

Stem cells: Cells in bone marrow that produce lymphocytes by mitotic division.

Sternum: The breastbone.

Steroids: Compounds with a skeleton of four rings of carbon to which various side groups are attached; one of the three main classes of hormones. sticky ends Term applied to DNA sequences cut with restriction enzymes where the cuts will bond with each other or with another sequence cut with the same enzyme.

Stop codon: The codon on a messenger RNA molecule where protein synthesis stops.

Synapse: The junction between an axon and an adjacent neuron.

Synapsis: The alignment of chromosomes during meiosis I so that each chromosome is beside its homologue.

Synaptic cleft: The space between the end of a neuron and an adjacent cell. synaptic vesicles Vesicles at the synapse end of an axon that contain the

Target cell: A cell that a particular hormone effects by its direct action (either passing through the membrane or binding to a surface receptor).

Tarsals: The bones that make up the ankle joint.

Taxis: The behavior when an animal turns and moves toward or away from an external stimulus (pl.: taxes).

Template strand: The strand of DNA that is transcribed to make RNA.

Temporal lobe: The lobe of the cerebral cortex that is responsible for processing auditory signals.

Tendons: Bundles of connective tissue that link muscle to bone. Fibrous connective tissue that connects muscle to bone.

Termination: The end of translation; occurs when the ribosome reaches the stop codon on the messenger RNA molecule and the polypeptide, the messenger RNA, and the transfer RNA molecule are released from the ribosome.

Termination codon: One of three three-base sequences that initiate termination of the protein synthesis process. See stop codon.

Testosterone: Male sex hormone that stimulates sperm formation, promotes the development of the male duct system in the fetus, and is responsible for secondary sex characteristics such as facial hair growth.

Tetrad: The four chromatids in each cluster during synapsis; formed by the two sister chromatids in each of the two homologous chromosomes.

Transcription: The synthesis of RNA from a DNA template. The making of RNA from one strand of the DNA molecule.

Transfer RNAs (tRNAs): Small, single-stranded RNA molecules that bind to amino acids and deliver them to the proper codon on messenger RNA. The trucks of protein synthesis that carry the specified amino acid to the ribosome. Abbreviated tRNA.

Translation: The synthesis of protein on a template of messenger RNA; consists of three steps: initiation, elongation, and termination. Making of a polypeptide sequence by translating the genetic code of an mRNA molecule associated with a ribosome.

Translocation: 1) The movement of a segment from one chromosome to another without altering the number of chromosomes. 2) the movement of þuids through the phloem from one part of a plant to another, with the direction of movement depending on the pressure gradients between source and sink regions.

Tropic hormone: Hormonè made by one gland that causes another gland to secrete a hormone.

Tropism: The movement of plant parts toward or away from a stimulus in the plant's environment. Plant movement in response to an environmental stimulus.

True-breeding: Occurs when self-fertilization gives rise to the same traits in all offspring, generation after generation. Now interpreted as equivalent to homozygous.

Umbilical cord: The structure that connects the placenta and the embryo; contains the umbilical arteries and the umbilical vein.

Uracil: The pyrimidine that replaces thymine in RNA molecules and nucleotides.

Ureter: A muscular tube that transports urine by peristaltic contractions from the kidney to the bladder.

Urethra: A narrow tube that transports urine from the bladder to the outside of the body. In males, it also conducts sperm and semen to the outside.

Urine: Fluid containing various wastes that is produced in the kidney and excreted from the bladder.

Vasectomy: A contraceptive procedure in men in which the vas deferens is cut and the cut ends are sealed to prevent the transportation of sperm. Surgical separation of the vas deferens so that sperm, while still produced, do not leave the body.

Vasopressin: See antidiuretic hormone.

Vectors: Self-replicating DNA molecules that can be joined with DNA fragments to form recombinant DNA molecules.

Vestigial structures: Nonfunctional remains of organs that were functional in ancestral species and may still be functional in related species; e.g., the dewclaws of dogs.

X-chromosome: One of the sex chromosomes.

Z lines: Dense areas in myofibrils that mark the beginning of the sarcomeres. The actin filaments of the sarcomeres are anchored in the Z lines.

Useful Websites for Biology Students

- www.biology
- web.ukonline.co.uk/webwise/spinneret
- www.biology.about.com
- www.ase.org.uk
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