CHAPTER

15

# Homeostasis

*Animation 15 : Homeostasis*
*Source & Credit: Wikispaces*

## CONCEPTS IN HOMEOSTASIS

Each organism of a species has assumed, in evolutionary history, a specific set up of internal environment at various levels of organization suitable to its surroundings i.e., external environment. External environment and its components fluctuate continuously, however, the organism resists and manages these changes by making adjustments to keep its own internal fluctuations within a narrow range thus protecting internal environment from the harms of the external fluctuations. The protection of internal environment from the harms of fluctuations in external environment is termed as **homeostasis**. The homeostasis keeps the internal fluctuations in a narrow range with various control systems compared to wider external fluctuations.

Most susceptible components of internal environment that may be affected by fluctuations in external environments are water, solutes and temperature. Also the mechanism an organism has adapted to eliminate harmful nitrogenous wastes depends upon the availability of water. The mechanism of regulation, generally between organism and its environment, of solute and the gain and loss of water is **osmoregulation**. The mechanism which eliminates nitrogenous waste is referred as **excretion**, whereas maintenance of internal temperature within a tolerable range is designated as **thermoregulation**.

Homeostasis is the central requirement in the maintenance of an organism, which compels the adaptations in the constant changing conditions and contribute in evolutionary process.

Likewise the control systems among intracellular and extracellular internal environment of an organism also at cell level keep fluctuating in narrow range in intracellular, within cell membrane, compared to in extracellular (vascular and other interstitial fluids) environment. Here, in addition to solute and water various essential metabolites, hormones etc. are kept in a required range.

Homeostasis does not mean to keep a fixed internal environment as changes maintained within a specific range are necessary for normal body functions. For example, water availability may fluctuate tremendously for the organisms in the external environment from abundant supply to almost dry conditions, however, the quantity of water in the body i.e. internal environment may vary in response to abundant supply and dry condition, but in a narrow range. The control systems would not let the body flooded with water in abundant supply and also not to dehydrate in dry conditions. Furthermore, adaptation to lower level of range in dry conditions and to higher level of range in abundant supply of water is good for the organism to feel normal within internal fluctuations forced by drastic external fluctuations.

The control systems have been acquired for the variety of homeostatic regulations. These living control systems work exactly on the mechanism of physical control system. It has three components: receptor, control centre and an effector. In a physical control system e.g. temperature control system, there is a sensor (thermometer) that monitors temperature change from a set point and signals to control centre to take action by switching on heater or cooling units in response to drop or rise in the temperature compared to set point. Similar to it in living system there is set point in temperature regulated (endothermic) animals. The receptors (sensor) detect temperature change, e.g. of increase and signal to control centre for action of cooling systems and the vice versa. Detection of change and signalling for effector's response to control system is a feedback mechanism. In these processes there is an inverse effector's response to the change in external environment as there is generally cooling effector's response to warmth sensing in external environment, thus are termed as negative feedback (Fig. 15.1).

*Animation 15.1 : Homeostasis*
*Source & Credit: Dynamic Science*

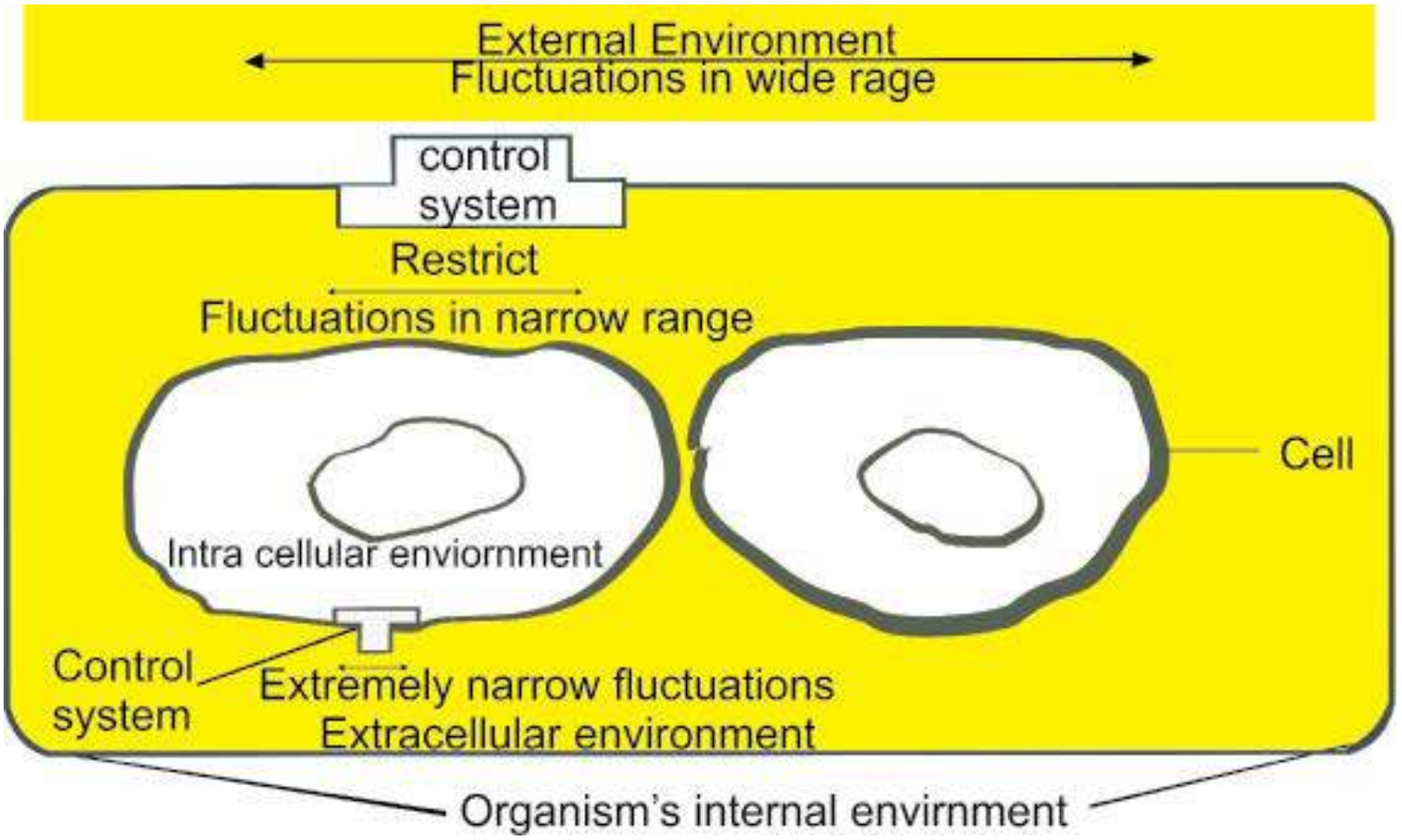



*Fig.15.1. Homeostasis: Controlling systems lower fluctuations in internal environments*

# OSMOREGULATION

## Water relatio. s of cell

Water is the solvent of the solutes in the cell. Each cell has been adapted to a defined quantity of water in relation to salts in it to perform its functions. Homeostatic mechanisms generally maintain this concentration.

## Bala. ce of water a. d solutes i. the body

Cells consistently encounter changing extracellular environment. It may be of diluted solution compared to the cell concentration, thus designated as **hypotonic** environment. The more concentrated external environment is termed as **hypertonic** and that resembles to internal solution is the **isotonic**.

The hypotonic environment osmotically causes entry of water into the cell and renders the cell solutions diluted. The cell

also becomes turgid. Thus it may be harmed (Fig. 15.2a). The hypertonic environment, on the other hand; renders cell solutions concentrated and shrinks the cell due to loss of water (Fig. 15.2c). To prevent these situations cells osmoregulate themselves to keep water and salts balance in plants and animals.

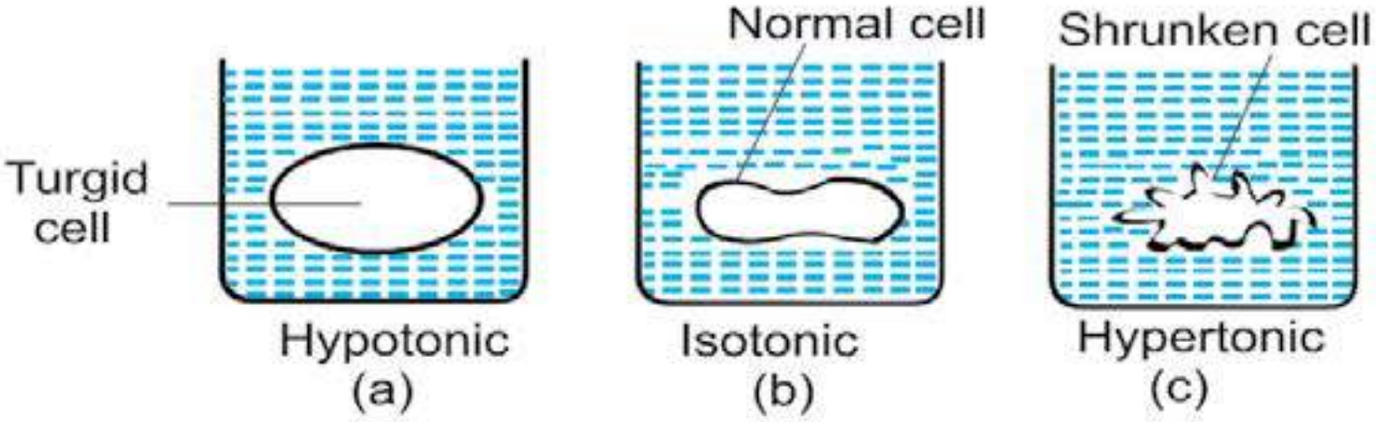



*Fig. 15.2 Response of the cell to various external environments i.e. different concentrations of solution without any regulation with control system at cell membrane, cell remains in normal state despite .differences in its internal to external environments.*

*Animation 15.2: Osmoregulation*
*Source and Credit: Andrew Biology*

## Osmoregulatio. i. Pla. ts

Plants are distributed in different habitats of aquatic, moderate and severely dry terrestrial nature, thus termed as hydrophytes, mesophytes and xerophytes, respectively.

**Hydrophytes** have the adaptations to remove the flooding of its cells in fresh water. In this type the surface area of leaves is very large to transpire water excessively. Extensive stomata are present on the upper surface facing the atmosphere to promote loss of water (Fig. 15.3a).

**Mesophytes** have moderate water availability. In sufficient supply of water stomata are kept open to promote loss of excess water, however, in restricted supply stomata close to prevent the loss e.g. Brassica, rose, mango etc.

**Xerophytes** have the adaptations for reduced rate of transpiration. Many xerophytes possess small, thick leaves to limit water loss by reducing surface area proportional to the volume. Their cuticle is thick, waxy and leathery. Stomata are on lower surface of leaves and located in depression. Some as cacti, during the driest season, shed their leaves to restrict transpiration completely, thus stems are the photosynthetic organs. In rainy season, stem stores water for use in dry conditions (Fig. 15.3b).

*Animation 15.3: Osmoregulation in plants*
*Source and Credit: Ameoba Sisters*

*Fig. 15.3a. A hydrophytic plant*

*Fig.15.3b. A xerophytic plant*

## Osmoregulation in Animals

Animal cells require more critical balance of water and solutes in the body as they cannot survive a net water gain or loss. Water continuously leaves and enters the cells; however, the quantity of the water and the solutes is kept in balance. There are two approaches in maintaining this balance.

1. Animal body fluids are kept isotonic to the external environment even for marine saltwater environment. These animals thus do not require actively to adjust their internal osmotic state, so are known as **osmoconformers**.

2. The animals whose body fluid concentrations differ noticeably the outside environment actively regulate to discharge excess water in hypotonic and excrete salts in hypertonic conditions therefore, are called as **osmoregulators**. Animals inhabiting different environments have distinct adaptations to regulate osmotic balance, e.g. marine, fresh water and terrestrial environments.

## Osmoregulation in Different Environments

**Marine:** Most marine invertebrates are osmoconformers. Among the vertebrates hagfishes are isotonic with the surrounding sea's water. Most cartilaginous fishes maintain lower, internal salt concentration than that of seawater. Their kidneys for osmoregulation excrete salts through gills and also possess salt excreting organs such as rectal glands. These employ active transport mechanism to remove salt against osmotic gradient. Some fishes have relatively low salts in body fluids but have rendered these hypertonic to that of seawater by retaining urea in adequate concentration. Because urea in high concentration is damaging so these fishes retain another chemical trimethylamine oxide(TMAO) for protection against urea. Bony fishes, the descendents of fresh water ancestors but later became marine constantly lose water from their hypotonic body fluids to hypertonic environments. These fishes have adapted themselves to drink large amount of seas water and excrete concentrated urine resulting in maximum salt excretion and minimum water loss (Fig. 15.4a).

Osmoregulation has enabled the animals and plants to distribute themselves in wide range of habitats.

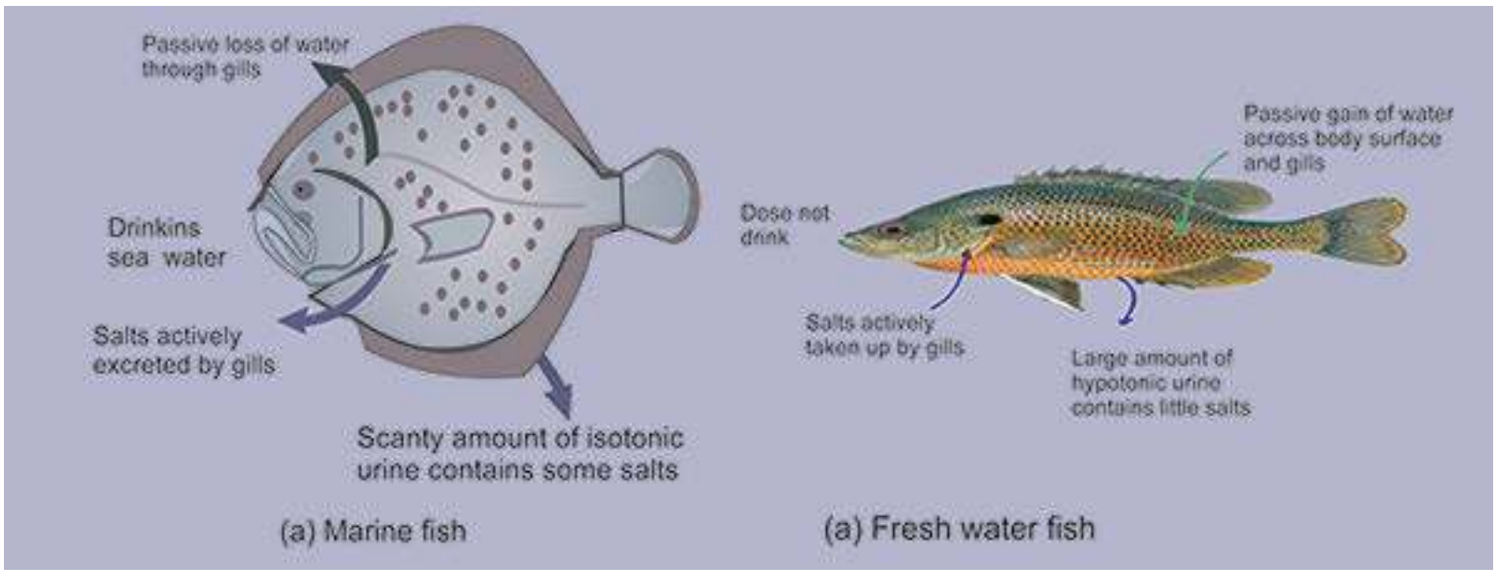



*Fig.15.4. Osmoregulation in: (a) Marine fish (b) Fresh water fish*

**Fresh Water:** Fresh water animals are constantly facing the osmotic flooding of body fluids and loss of salts. Fresh water protozoa, Amoeba and Paramecium pump out excess water by structures **contractile vacuoles**. Many fresh water animals including fishes remove excess water by producing large volumes of very dilute urine. The loss of salts is compensated by preference of salt containing food and by active uptake of salts by gills and skin (Fig. 15.4b).

**Terrestrial:** The evaporative loss of water leading to dehydration is the major problem for terrestrial life. Arthropods and vertebrates have successfully adapted to terrestrial mode of life. Terrestrial animals are covered by body surface, which prevents loss of water as the waxy exoskeletons of insects and multi-layered dead, keratinized skin cells of most terrestrial vertebrates. Drinking and eating moist foods compensate the loss of water. These animals also have metabolic and behavioral adaptations. Some desert mammals e.g. kangaroo rat survives without drinking water by feeding on seeds of desert plants containing more carbohydrates, which produce water of metabolism. Terrestrial animals produce concentrate urine in their kidneys that reabsorb most filtered water in the process of excretion. Terrestrial animals can tolerate dehydration and it differs in various animals. This characteristic is known as **anhydrobiosis**.

## EXCRETION

Among the assimilated nutrients in animals, carbohydrates and lipids are metabolized to $CO_2$ and $H_20$. Proteins and nucleoproteins metabolism produces waste nitrogen in various forms in different animals. The waste nitrogen proves toxic if it is concentrated in the cell, therefore, it must be removed from the body. The elimination of wasteful metabolites, mainly of the nitrogenous nature is called excretion.

In contrast, the mechanism of excretion in plants is different. Plants in their autotrophic mode of life produce oxygen and in metabolism produce $C0_2$ and $H_20$ as the excretory products. Plants also produce several organic and inorganic compounds which are stored for various purposes and are also removed when necessary.

Plant cells have large vacuoles; these can be used for either storage of useful compounds, or the storage of waste substances. These may accumulate at the concentrations that lead to crystal formation in the vacuoles. Plants produce certain wastes of inorganic and organic nature, which are stored in certain organs.

The leaves are the prominent organs for this purpose. These leaves are destined to fall off, as is the case of autumn leaves in plants or die off as happens in the leaves and stalk of certain bulbs e.g. bluebell, leaving the bulb underground. This is the reason gardener find rotted autumn leaves a good source of minerals. The falling of yellow leaves in autumn is th
seasonal time for the plants to get rid of the accumulated wastes and because of the reason leaves are said to be **excretophore**. According to an explanation the change in color in these leaves is not due to removal of chlorophyll as the microscopic examination of autumn leaves shows that leaves are loaded with pigmented compounds prior to falling off and many toxic materials like heavy metals increase sharply as the yellowing proceeds.

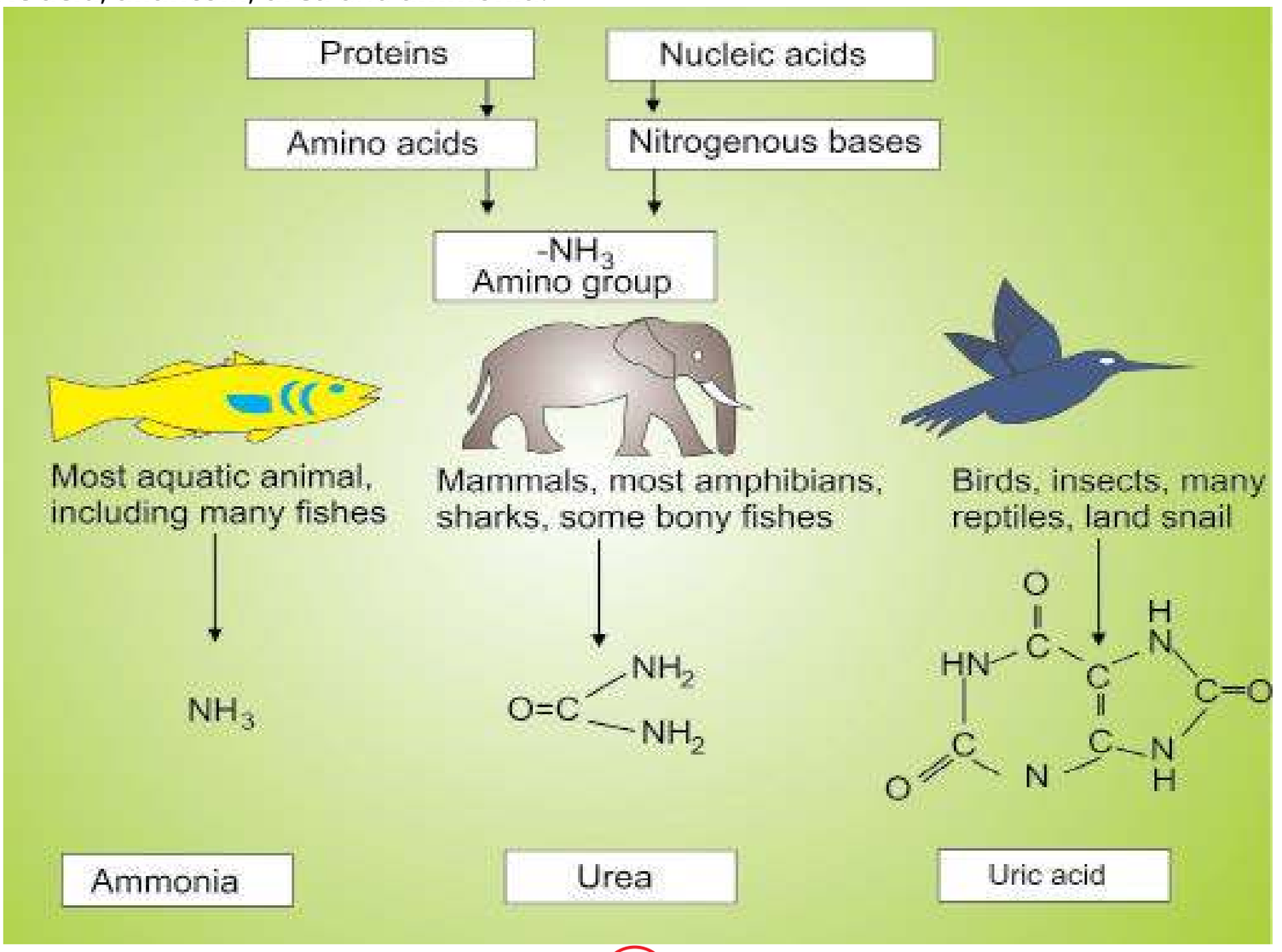
Some trees deposit strange chemicals in their branches and trunks, especially in old xylem which is no longer used for water transport. This takes place in **ebony** which produces very black wood in the center.These are considered to be, waste materials by plant physiologists.

Some plants will actively secrete waste compounds into the soil, occasionally using them as chemical weapons against other competing plants e.g conifers.

*Animation 15.4: Osmoregulation in plants*
*Source and Credit: Living BIo.net*

Keeping in view the definition of excretion, as discussed earlier, that it is the elimination of waste metabolites several products may be included in the list of excretory products. Water due to its removal in hypo osmotic environment is labelled as an excretory product in these specific conditions. Similarly, salts removed by animals in hypertonic environment are the excretory products for these animals.

Otherwise, overwhelmingly, nitrogenous waste metabolites constitute the excretory products. Primarily, in the catabolism of animo acids the amino group (---$NH_2$) is released **(deamination)** or transferred to another molecule for removal or reuse. Amino group not reused for recycling of amino acids is essentially dissolved in water and excreted to avoid toxic rise in the plasma. Elevated levels of these wastes can cause convulsions, coma and eventually death. Mostly excess nitrogen is excreted by animals as **ammonia, urea or uric acid** (Fig. 15.5). Lower quantities of nitrogen are excreted in the form of other compounds such as **creatinine, creatine** or **trimethylamine oxide** and in very small quantities as amino acids, purines and pyrimidines. Metabolism of purine and pyrimidine bases produces significant amount of nitrogenous wastes of **hypoxanthine**, **xanthine**, **uric acid**, **allantoin**, **urea** and **ammonia**.



## Nature of Excretory Products i. Relatio. to Habitats

Ammonia is very toxic and dissolves quickly in body fluids. Thus, it must be kept in low concentration in the body. To maintain its low concentration below that of body requires large volume of water also to eliminate it in urine as it is produced. This is possible in an hypotonic environment. Therefore, ammonia kept as the excretory product of the animals inhabiting hypotonic (e.g. fresh water) environment. About 500 ml water is needed to excrete lg of ammonia nitrogen.

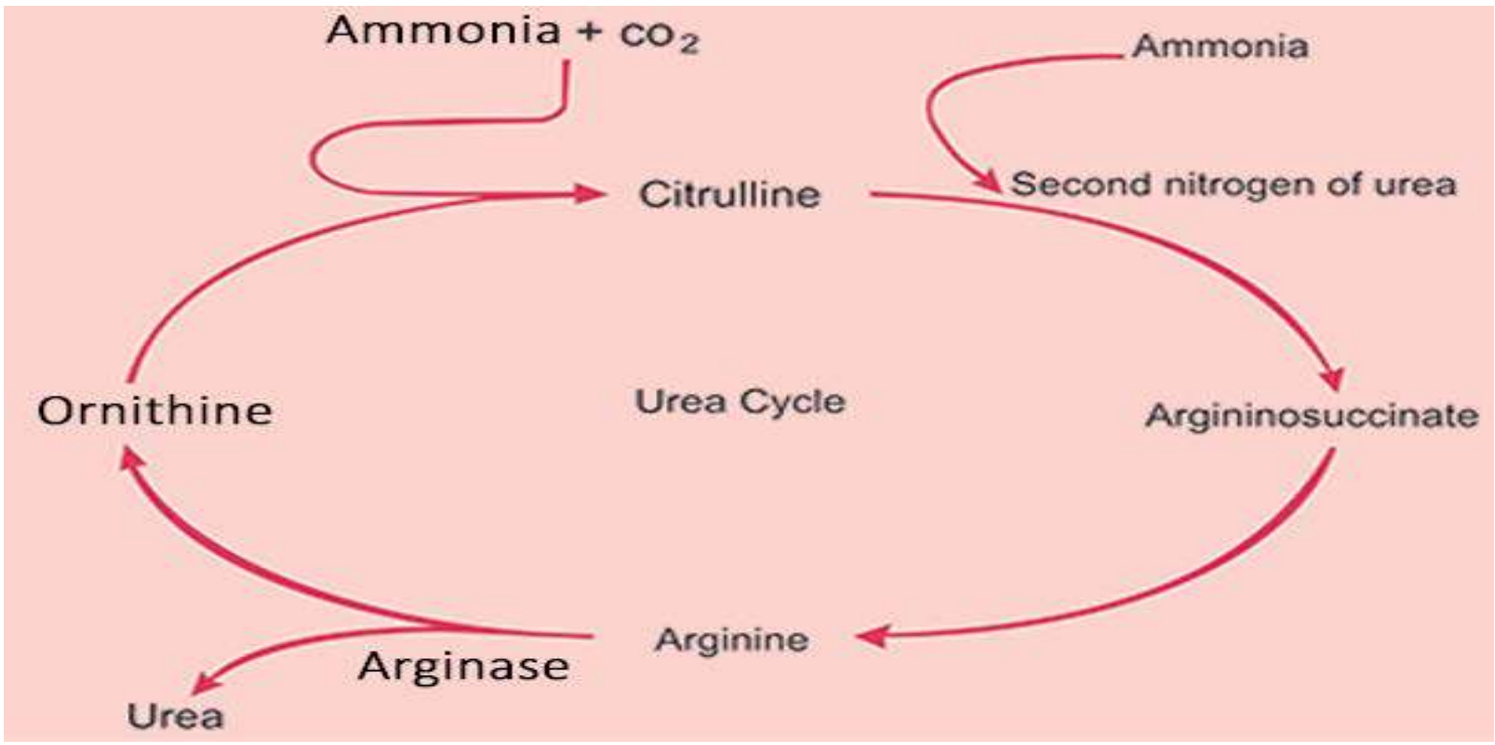



*Fig 15.6: Metabolic pathways in urea cycle*

In restricted supply of water, ammonia cannot be kept as excretory product, the other alternative is to change it into less toxic substance such as urea. Urea requires only 50 ml of water for its lg of nitrogen removal. Here excretory nitrogen is metabolically converted into urea by urea cycle (Fig. 15.6) in the animals inhabiting environment with restricted supply of water e.g. terrestrial mammals.

Aimals inhabiting environment with acute shortage of water supply require an excretory product which can be excreted with minimum amount of water. Only 1ml water is required to eliminate lg of nitrogen in the form of uric acid. Therefore the reptiles and birds that inhabit arid environment, excrete uric acid as excretory product. Animals excreting ammonia, urea .and uric acid are called as **ammonotelic, ureotelic** and **uricotelic** respectively. Ureotely and uricotely are evolutionary adaptations of nitrogenous waste in their habitats. Animals have adapted not only the chemical nature of excretory products but also the various adaptations have been obtained to provide diversity in excretory structures. The main representative models are described below:

## EXCRETION IN REPRESENTATIVE ANIMALS

### Excretio. i. Hydra

Hydra, a cnidarian, does not have specialized excretory structures. In it waste products simply diffuse into the isosmotic surroundings.

### Excretio. i. Pla. aria

Planaria the animals of the group of flatworms have simple tubular excretory system called **protonephridium**. A protonephridium is a network of closed tubules without internal openings. Tubular system is spread throughout the body and branches are capped by a cellular setup termed as **flame cell**. Each flame cell has a tuft of cilia, whose beating propels interstitial fluid into the tubular system (The beating of cilia looks like a flickering flame, therefore these cells are termed flame cells). The tubular system is drained into excretory ducts, which open to the exterior through several nephridiopores (Fig. 15.7).

Fresh water flatworms excrete very dilute urine. The parasitic flatworms, which are isotonic to the host environment mainly function in disposing nitrogenous wastes.

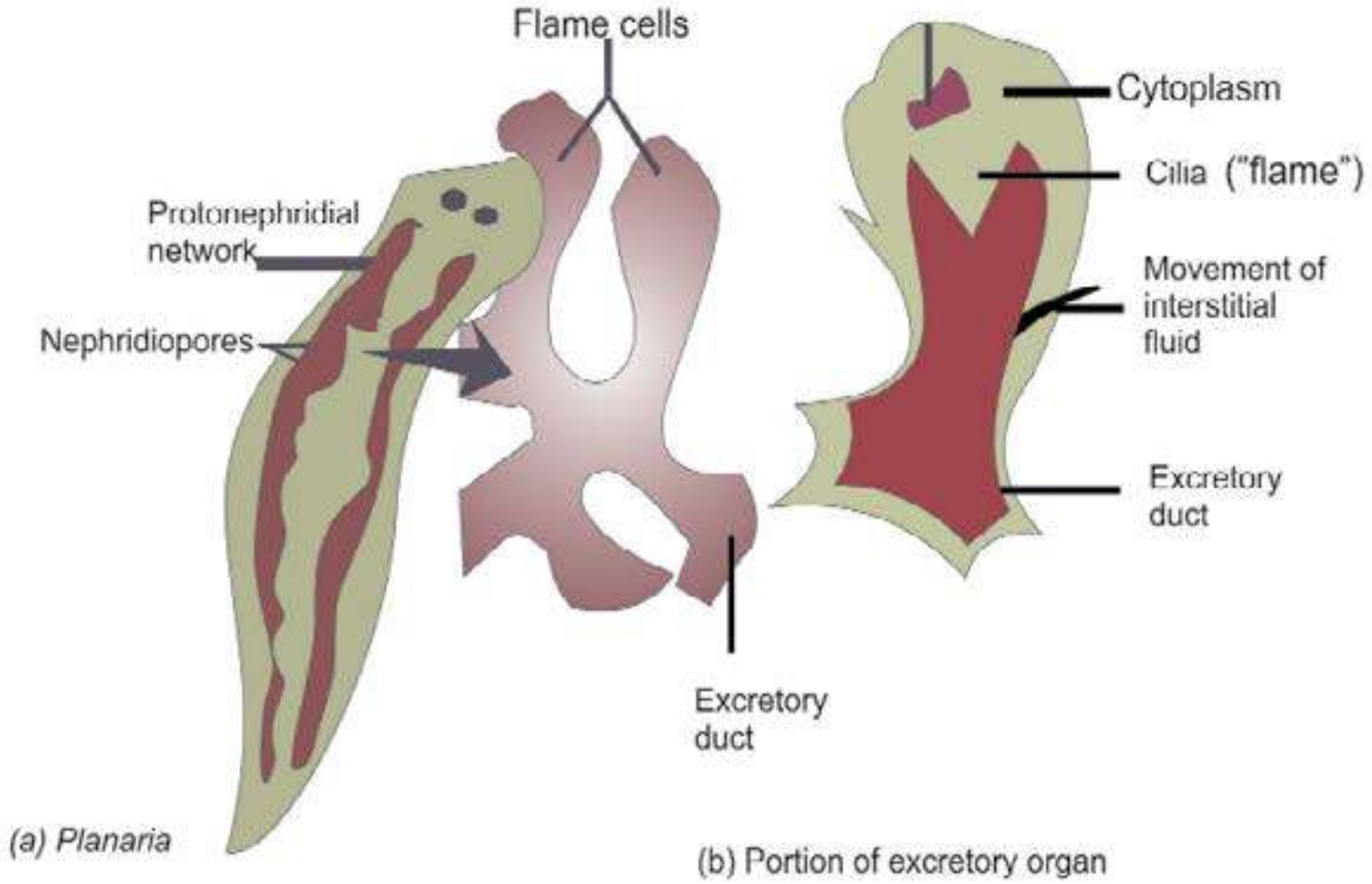



*Fig.15.7. Excretory system in Planaria*

## Excretio. i. Earthworm

Earthworm is an ideal example of another type of tubular excretory system called as **metanephridium.** Each segment of earthworm has a pair of metanephridia. This system has an internal ciliated opening the **nephrostome** immersed in coelomic fluid and enveloped by a network of capillaries. Nephrostome collects coelomic fluid. As fluid moves along the tubule, epithelium reabsorbs salt from the lumen and sends to blood vessels surrounding the nephridium. The left over appears as urine containing nitrogenous waste (Fig. 15.8).

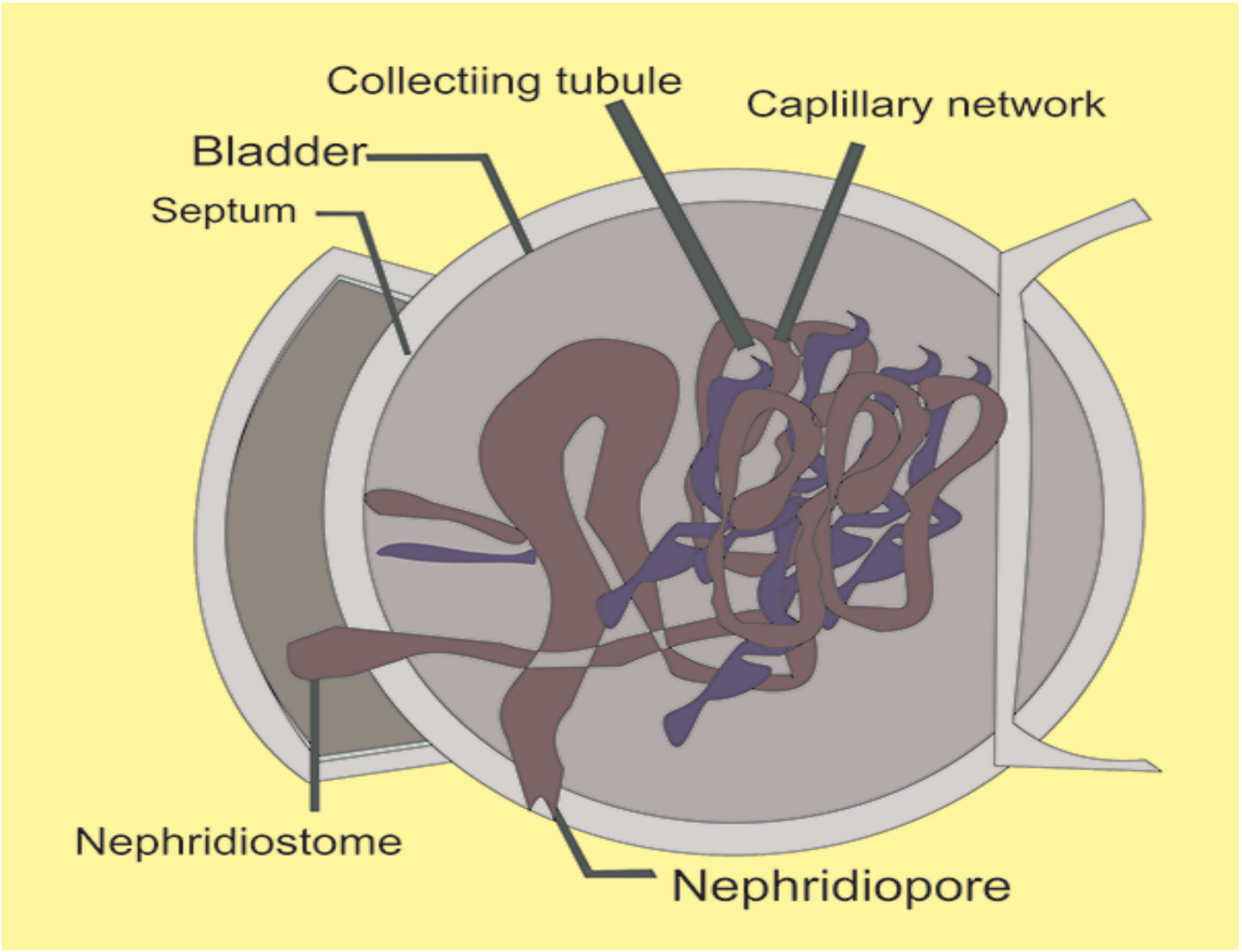



*fig: 15.8 : Excretory system in earthworm*

## Excretio. i. Cockroach

Terrestrial arthropods particularly in the insects, the excretory structures are adapted to collect excretory products from hemolymph in sinuses through suspended tubular structures called **Malpighian tubules**. These Malpighian tubules remove nitrogenous waste from the hemolymph. These are the only excretory structures in animal kingdom that are associated with digestive tract. The epithelial lining of the tubules transports solutes including salts and nitrogenous waste from haemolymph into tubules lumen. Fluid then passes to hind gut into the rectum. Rectum reabsorbs most of the salts and water, thus nitrogenous wastes are excreted as solid excreta, in the form of uric acid crystals along the feces.

This kind of adaptation in excretion is the success of these animals on land with acute shortage of water (Fig. 15.9)

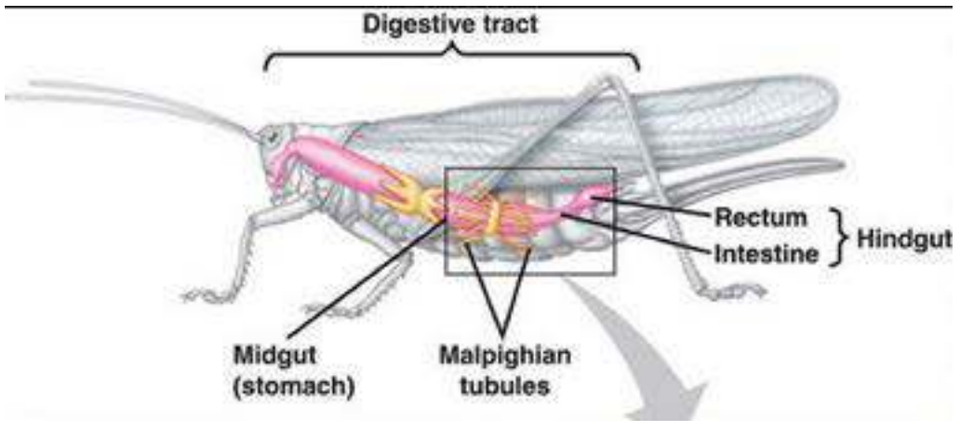



*Fig. 15.9 Excretory system in insect*

Insects are the only group of animals, which eliminate excretory waste with feces, in all other animals, there is no structural and functional relationship between nutritive and excretory system.

## EXCRETION IN VERTEBRATES

The ancestors of vertebrates, the invertebrate chordates have segmentally arranged excretory structures throughout the body like the metanephridia in earthworm. This character is well represented in the primitive vertebrate hagfishes which have kidneys with segmentally arranged tubules. However, the contrasting developments proceeded in evolution in other vertebrates with the appearance of kidneys. Kidneys contain numerous tubules, not arranged segmentally, closely associated with dense network of capillaries. The basic functional structure in the kidneys is **nephron**.

## Excretio. i. Huma.

**Normal Mechanisms :** Considering the chemical basis of life and its sustainability on metabolic pathways, the generation of wastes is primarily done at metabolic level and these are called **metabolic wastes**.

These include urea, produced from the metabolism of amino acids; creatinine, produced from muscle creatine; uric acid, from nucleic acids; bilirubin, end products of haemoglobin breakdown and metabolites of various hormones.
Metabolic wastes also include the toxins produced within the body and ingested into the body such as pesticides, drugs and food additives. The presence of wastes in the body causes serious hazards, thus are eliminated by excretory system.

## Excretory Orga. s:

Liver and kidneys are the primary structure for eliminating waste products.
Liver is the central station of metabolism and consequently the body's central metabolic clearing house. Due to this characteristic, liver functions are pivotal to homeostasis and involve interaction with most of body's organs systems. Liver supports the excretory role of the kidney by detoxifying many chemical poisons and produce ammonia, urea and uric acids from the nitrogen of amino acids. Removal of salts with water by the sweat glands and of sebum by sebaceous glands seems to be excretory in nature. The removal of water and salts from sweat glands is for the purpose of thermoregulation and of sebum on the skin is for protection against microorganism. Therefore in context of definition of excretion, skin may not be considered as an excretory organ. Among the various nitrogenous wastes described earlier, urea is the principal excretory product and liver form it from the waste nitrogen. The metabolic pathways involved in the production of urea are termed as **urea cycle**. Two ammonia and one carbon dioxide molecules are shunted into the cycle to generate one molecule of urea. One ammonia molecule combines with carbon dioxide and already available precursor from previous cycle **ornithine** to form **citrulline**, subsequently another ammonia combines to form **arginine**. The arginine is split by **arginase** to form urea and the precursor ornithine for next cycle (Fig. 15.6).

**Table 15.1. Major homeostatic functions of the liver**

| Functions | Major effects on homeostasis |
|---|---|
| **Synthesis:** Nitrogenous wastes: **$NH_3$**, urea, uric acid | Supports kidney in waste disposal |
| Plasma proteins: like a) prothrombin, fibrinogen b) albumin etc. | a) Blood clotting b) maintain osmotic balance of blood |
| Bile | Emulsifies fats in small intestine |
| Lipids, cholesterol, lipoproteins | Regulate blood chemistry, store energy and help to maintain cell membranes |
| **Storage:** Iron | Oxygenation of tissues as constituent of haemoglobin |
| Glycogen | Energy reserves |
| **Conversion:** Excess glucose in blood to glycogen, lactic, acid to glycogen and stored glycogen to glucose | Energy storage and use |
| **Recyclings:** Contents of old red blood cells (e.g., iron and other constitution of haemoglobin) | Oxygenation of tissue |
| **Detoxification:** Many harmful chemicals (e.g., food additives, pesticides, drugs etc) | Assist kidney in toxin disposal |

Liver is not only involved in the synthesis of nitrogenous wastes to assist kidney in their disposal, but also has numerous crucial functions of homeostasis importance. These functions belong to synthesis, storage, conversion, recycling and detoxification categories (Table 15.1).

Urea is detoxified form of ammonia in urea cycle, which can be retained in the body in greater amounts than ammonia and can be eliminated with 1/10 quantity of water as compared to ammonia.

## Uri. ary System

A pair of kidneys consists of millions of functional units, nephrons. The nephrons have extensive blood supply via the renal arteries, which leave each kidney via the renal vein. The function of kidney and blood in clearing wastes is very evident from the fact that weight of kidneys accounts for less than 1% of the total body weight while receive 20% of blood supplied with each cardiac beat. Following filtration of blood and further processing through tubular system urine is collected in a central cavity of the kidney, **pelvis.** Urine leaves the kidney through a duct **ureter**. The ureters of both the kidneys drain into **urinary bladder** through ureteral orifice. Urine leaves the body, during urination, from the bladder through a tube called the **urethra**, which empties near the vagina in females or through the penis in males. Sphincter muscles near the junction of the urethra and the bladder control the urine in bladder (Fig. 15.10).

*Animation 15.4: Urinary System*
*Source and Credit: Renal Pathology*

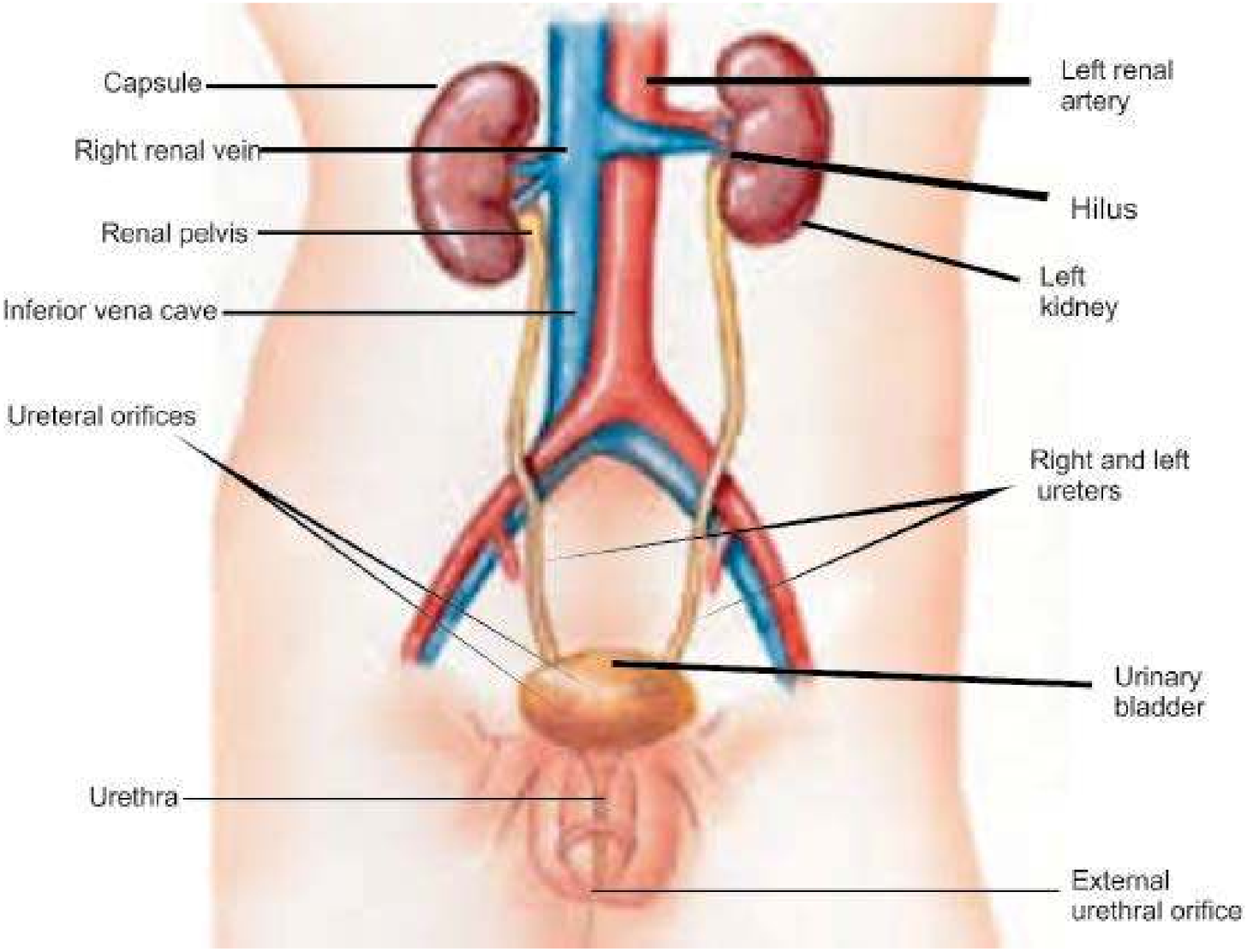



*Fig. 15.10. Human urinary system*

**Nephron:** The functional units, nephrons, in human kidneys are arranged along two distinct regions, an outer **cortex** and an inner **medulla**. The nephrons arranged along the cortex are called as **cortical**, however, those arranged along the border of cortex and medulla with their tubular system looping deep in inner medulla are **juxtamedullary** nephrons These juxtamedullary nephrons are specifically instrumental in the production of concentrated urine (Fig. 15.11).

In each nephron inner end forms a cup-shaped swelling, called **Bowman's capsule** and it is around a ball of capillaries called **glomerulus**. Glomerulus circulates blood through capsule as it arrives through **afferent arteriole** and leaves the capsule by **efferent arteriole**. The blood vessel subdivides again into another network of capillaries, the **peritubular capillaries**. Bowman capsule continues as extensively convoluted **proximal tubule**, **loop of Henle** and the **distal tubule**, which empties into collecting tubules. The **collecting tubules** open into pelvis. The filtrate from glomerulus passes through these structures and is processed ultimately for urine formation. The peritubular capillaries intermingle with proximal and distal tubules of the nephron. In juxtamedullary nephrons additional capillaries extend down to from a loop of vessels, **vasa recta**.

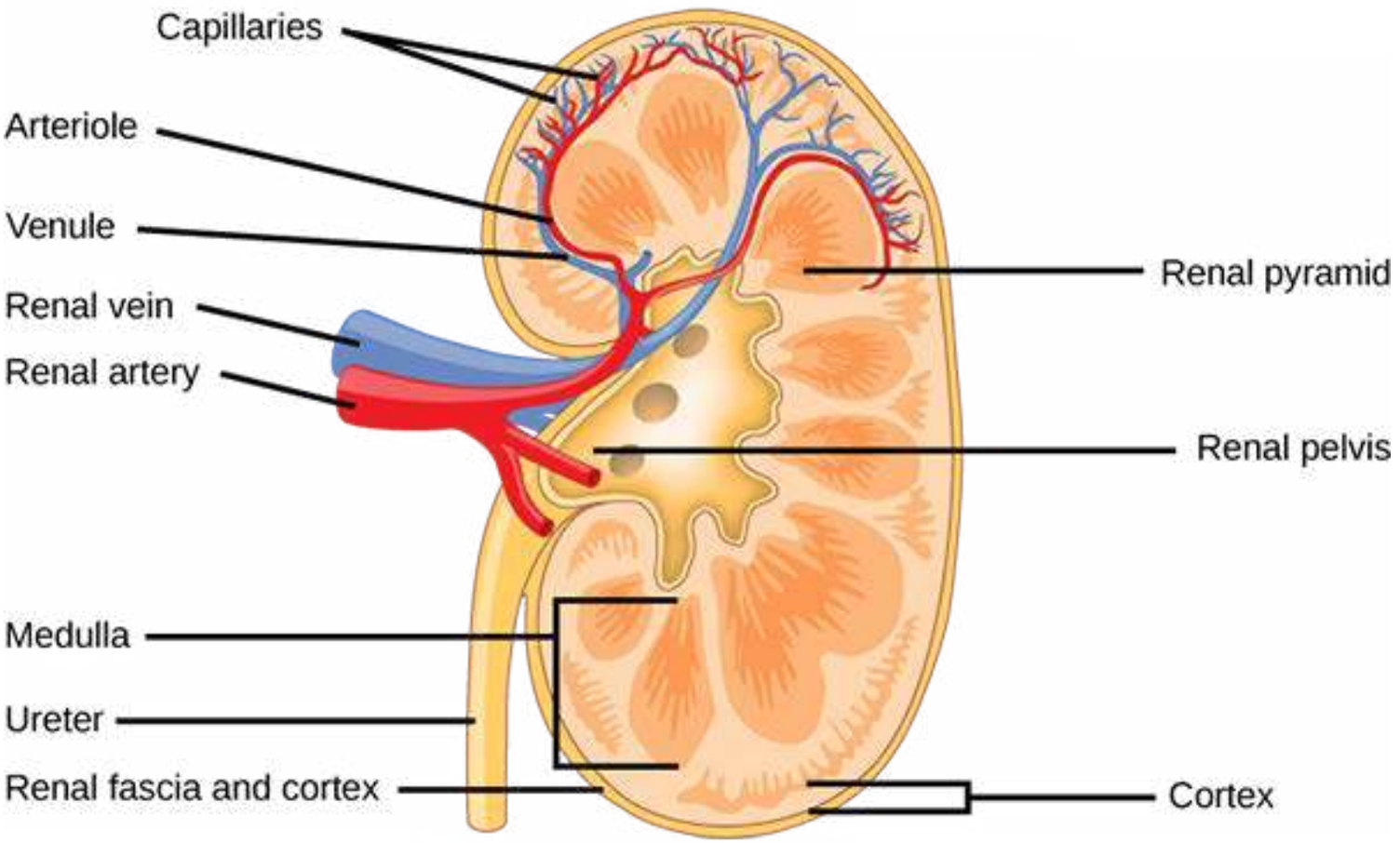



*Fig. 15.11. The structure of a kidney*

**Filtration:** Blood passing through glomerulus is filtered into Bowman's capsule. It is specifically filtered here, unlike at the other parts of the vessels, because glomerulus walls are porous, and the fraction of the blood pressure reaching here provides the **filtration pressure**. The filtrate appearing in Bowmans capsule is called as **glomerular filtrate**, which contains numerous useful substances such as glucose, amino acids, salts etc in aqueous solution.

**Reabsorption:** All the useful constituents of the glomerular filterate are reabsorbed in proximal tubules and when filtrate leaves proximal tubules, it mostly contains nitrogenous wastes.

**Secretion:** The tubular epithelium also secretes substances into the lumen, this secretion is very selective and is mainly of hydrogen ions to balance pH value of the filtrate passing through the tubule.

## Co. ce. tratio. of Excretory Products

In restricted supply of water, the conservation of water is the principal function of the body. This is done by concentration of the filtrate by counter current and hormonal mechanisms. In the sufficient or excess supply of water, reabsorption of water from the filtrate is reduced, specifically due to inhibition of release of antidiuretic hormone in the presence of hyposomotic body fluids.
The reduction in reabsorption causes large volumes of diluted urine. Mammalian kidney including human is adapted to conserve water by over 99.5% reabsorption of glomerular filtrate.

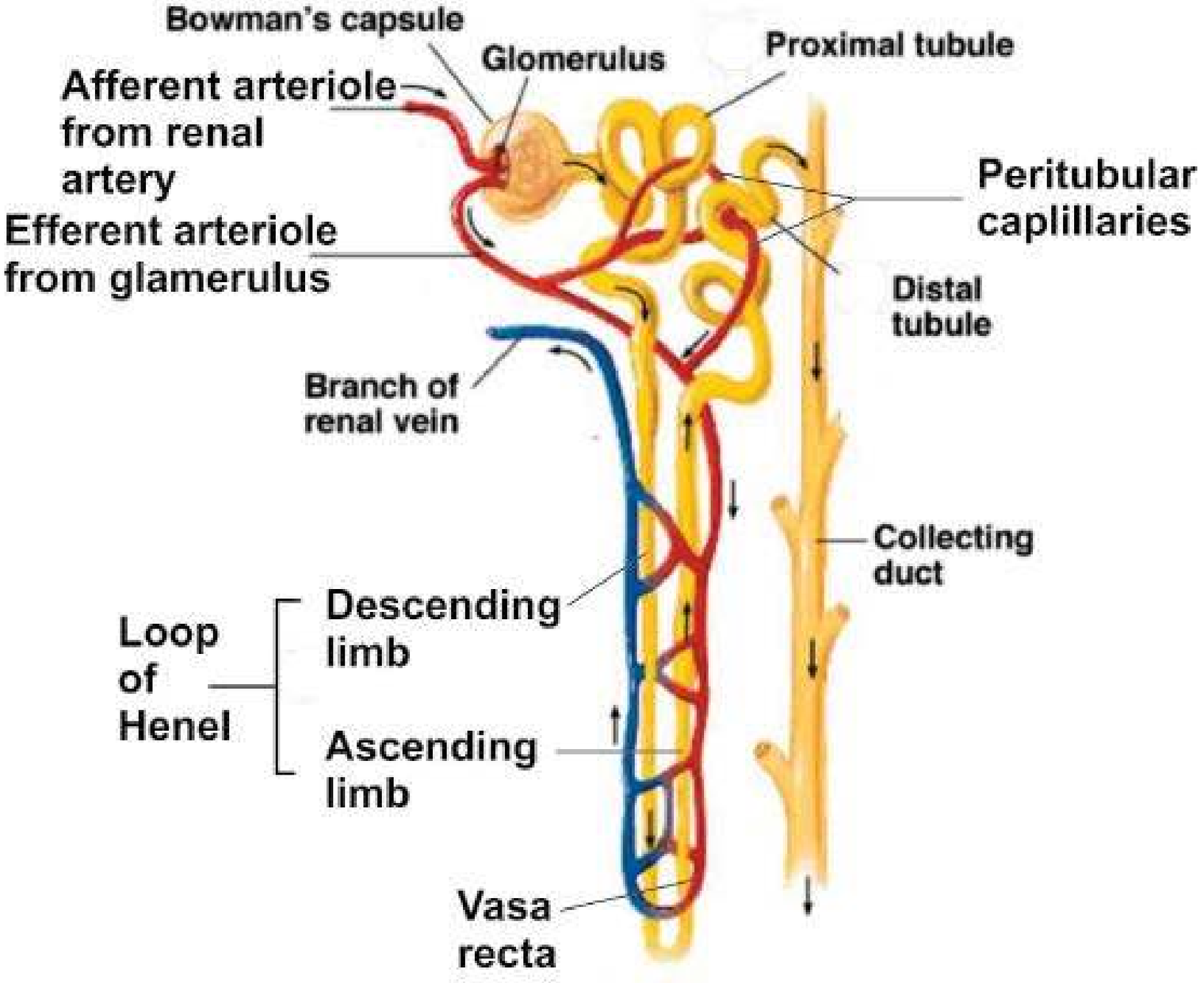



*Fig:15.12. a nephron with vascular supply*

The interstitial fluid of the kidney is gradually concentrated from cortical to medullary part, thus inner medulla is highly concentrated with the presence of urea and through a mechanism of **counter-current multiplier**. This mechanism causes gradual osmotic outflow of water from the filtrate back to kidney as it passes downward in the descending loop of Henle. Furthermore, ascending loop of Henle does not allow outflow of water from its filtrate, instead actively transport Na ions into kidney interstitium to sustain its high concentration.

**Hormones:** The active uptake of sodium in the ascending limb or thick loop of Henle is promoted by the action of **aldosterone**, the hormone secreted from **adrenal cortex**. The other site in the nephron, where reabsorption of water takes place is collecting tubules. **ADH** released from **posterior pituitary lobe** acts to actively transport water from filtrate in Distal tubules and collecting tubules back to kidney.

Gradually increasing osmotic concentration from cortex to inner medulla is a main factor for the production of hypertonic (concentrated) urine in mammals including human.

## Kid. ey as Osmoregulatory Orga.

The production of varied concentrations of urine depending on the availability of water exhibits clearly that kidney functions as an osmoregulatory organ along its excretory role of nitrogenous wastes.

*Animation 15.5: Kidney As Osmoregulatory Organ*
*Source and Credit: Blobs*

# Kid. ey Problems a. d Cures

Unusual situations may arise in the function of kidney by factors originating within kidney or outside. These cause serious kidney diseases.

**Kidney Stones:** Stony materials are found in the kidney and these cause urinary obstruction and are generally complicated by infections. These stones have specified chemical nature. These are formed in metabolic disease, **hypercalcemia** i.e. high level of circulating calcium in blood because of other diseases. **Hyperoxaluria** i.e. higher blood level of oxalates is other contributing factor in the formation of calcium oxalate stones. Oxalates are present in green vegetables and tomatoes therefore may be the source of hyperoxaluria. The incidence of calcium oxalate type stones are 70% of all the kidney stones. The incidence of other types of stones of calcium phosphate and of uric acid is 15% and 10% respectively. These salts are precipitated out during urine formation and accumulate later to form stone (Fig. 15.13).

*Animation 15.6: Kidney Problems*

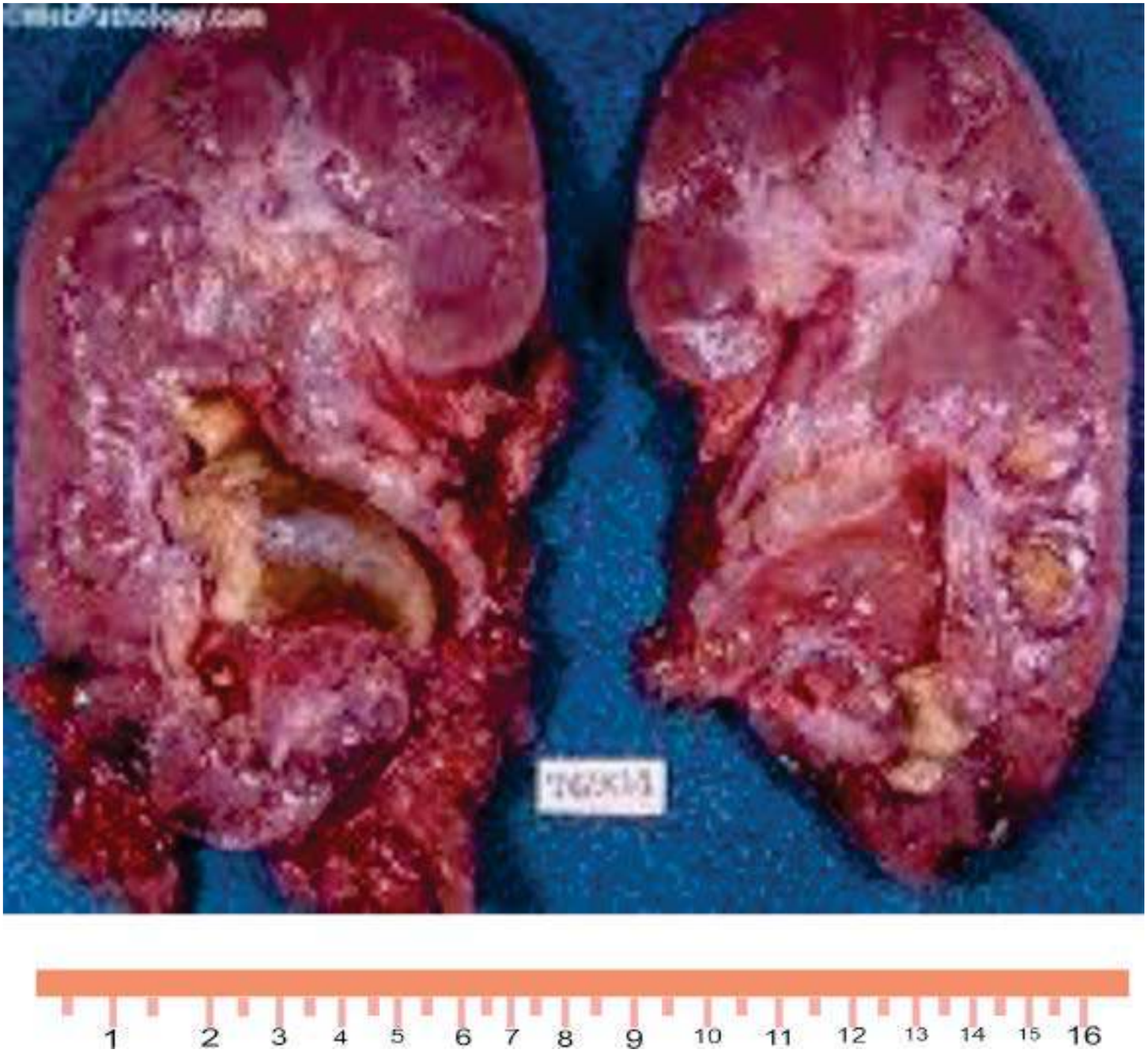



*Fig. 15.13. The kidney stones: Stone of phosphates are formed and trapped in the pelvis area*

**Lithotripsy:** The kidney stones have been removed by kidney surgery. Presently lithotripsy is used for non-surgical removal of kidney stone. It is the technique used to break up stones that form in the kidney, ureter or gall bladder. There are several ways to do it, although the most common is extracorporeal shock wave lithotripsy. High concentrations of X-ray or ultrasound are directed from a machine outside the body to the stone inside. The shock waves break the stone in tiny pieces or into sand, which are passed out of the body in urine.

**Renal Failure:** Various factors of pathological and chemical nature may progressively destroy the nephron, particularly its glomerular part. This results in increase in the plasma level of urea and other nitrogenous wastes. The rise in urea causes complications of increase in blood pressure and anemia etc.

**Dialysis :** In chronic renal failure, the function of the kidney is completely lost and is unable to remove nitrogenous waste. To remove nitrogenous waste, particularly the urea, the blood of the patient is treated through dialysis. It cleans the blood either by passing it through an artificial kidney or by filtering it within the abdomen. The wastes and excess water are removed during the treatment as is done by the healthy kidneys.

There are two types of dialysis: **hemodialysis** and **peritoneal dialysis.**
Hemodialysis means 'cleaning the blood'. In this procedure blood is circulated through a machine which contains a **dialyzer** also called an artificial kidney. Dialyzer has two spaces separated by thin membrane. Blood passes from one side of the membrane and dialysis fluid on the other. The wastes and excess water pass from the blood through the membrane into the dialysis fluid.

Peritoneal dialysis work on the same principle except that abdomen has a **peritoneal cavity**, lined by a thin epithelium called **peritoneum**. Peritoneal cavity is filled with dialysis fluid that enters the body through a catheter. Excess water and wastes pass through the peritoneum into the dialysis fluid. This process is repeated several times a day. Dialyzer is a kidney machine that works on the same principle as in a kidney for removal of nitrogenous wastes and excess water from the blood. It is used after kidney failure and dialysis is done again and again until a matching donor's kidney is transplanted.

**Kidney Transplant:** Dialysis may be used as a temporary measure. In high degree renal failure also called as **uremia** or **end-stage renal disease**, the dialysis can not be done hence thus the surgical transplantation of a matching donor kidney is the only option left for as the permanent treatment.

# THERMOREGULATION

Control systems operate in organisms to cope with environmental stresses including temperature extremes.

## Adaptations in Plants to Low and High Temperature

**High Temperature :** High temperature denatures the enzymes and damages the metabolism, therefore, it harms or kills the plants. Plants use evaporative cooling to manage with high temperature. Hot and dry weather, however, causes water deficiency resulting in closing of stomata, thus plants suffer in such conditions. Most plants have adapted to survive in heat stress as the plants of temperate regions face the stress of 40°C and above temperature. The cells of these plants synthesize large quantities of special proteins called **heat-shock proteins**. These proteins embrace enzymes and other proteins thus help to prevent denaturation.

**Low Temperature :** In low temperature the fluidity of the cell membrane is altered, because lipids of the membrane become locked into crystalline structures, which affects the transport of the solutes. The structure of the membrane proteins is also affected. Plants respond to cold stress by increasing proportion of unsaturated fatty acids, which help membrane to maintain structure at low temperature by preventing crystal formation. This adaptation requires time because of this reason rapid chilling of plants is more stressful than gradual drop in air temperature.
Freezing temperature causes ice crystal formation. The confinement of ice formation around cell wall does not affect as badly and plants survive, however, formation of ice crystals within protoplasm perforates membranes and organelles hence killing the cells. The plants native to cold region such as oaks, maples, roses and other plants have adapted to bring changes in solutes composition of the cells, which causes cytosol to super cool without ice formation, although ice crystals may form in the cell walls.

## MECHANISMS IN ANIMALS

### Body Heat, Heat Gain and Loss

Temperature of an animal depends upon the rate of change of body heat which in turn depends on rate of heat production through metabolic processes and the rate of external heat gain and rate of heat loss. This transfer of heat between an animal and its environment is done in numerous ways. Principally, infrared thermal radiation and direct and reflected sunlight transfer heat into the animal; whereas radiation and evaporation transfer heat out to the environment.

## Temperature Classification of Animals

Animals deal with variation in the thermal characteristics of their environment. There are animals in which body temperature tends to fluctuate more or less with ambient temperature where air or water temperatures are changed, these are **poikilotherms**, all invertebrates, fish, amphibians and reptiles are considered in this category. The other exposed to changing air or water temperature maintain their body temperature are the **homeotherms** and include birds and mammals. Several difficulties arise with this terminology with studies. It is observed that deep sea fishes maintain their body temperature due to the constant natural surroundings and lizards regulate their body temperature; and in contrast numerous birds and mammals vary their body temperature.
Therefore, a more widely applicable temperature classification scheme is based on the source of heat production. According to this animals that generate their own body heat through heat production as by-product during metabolism are **endotherms** include flying insects, some fishes, birds and mammals. **Ectotherm** is the other type, which produce metabolic heat at low level and that is also exchanged quickly with the environment, however, absorb heat from their surroundings. Most invertebrates, fish, amphibians and reptiles are in this category. A third category, **heterotherms** is of those animals who are capable of varying degrees of endothermic heat production but generally do not regulate their body temperature within a narrow range e.g. bats, humming bird etc.

## Regulatio. of Heat Excha. ge betwee. A. imals a. d E. viro. me. t

Animals use different mechanism for such regulation and these are of structural, physiological and behavioral nature.

**Structural Adaptations:** These may be long term changes in sub dermal fatty layer insulation and **pelage**. The presence of **sweat glands** and lungs modified for **panting**.

**Behavioral Adaptations:** These include moving of the animal to an environment where heat exchange between these is minimal e.g. ground squirrels move to burrows in midday heat and lizards bask in sun to gain heat. Animals also control the amount of surface area available for heat exchange by adjusting their postures.

# THERMOREGULATION IN MAMMALS (HUMAN)

## Regulatory Strategies

Mammals including human maintain their high body temperature within a narrow range of about 36-38 °C because of their endothermic characteristics. The origin of endothermy in birds and mammals have provided the opportunity to keep high metabolic rate and availability of energy round the clock, thus has acquired greater ability to adaptations and has assisted in much of their wider diversity and distribution in diversified regions of the earth.

These regulate the rate of metabolic heat production, balancing it with the rate at which they gain or lose heat from the surroundings. The rate of heat production is increased by increased muscle contraction by movements or shivering so called as **shivering thermogenesis**. Also hormones trigger the heat production as do thyroid hormones and are termed as **non-shivering** thermogenesis. Some mammals possess brown fat, which is specialized for rapid heat production. In overproduction of heat it is dissipated through exposed surfaces by increasing blood flow or the evaporative cooling. In mammals, it is observed that skin has been adapted as the organ of thermoregulation. (Fig. 15.14)

**In Cold Temperature :** Mammals have various mechanisms that regulate heat exchange with their environment. Vasodilation and vasoconstriction effect heat exchange and may contribute to regional temperature differences with in an animal. On a cool day a human's temperature may be several degrees lower in the arms and legs than in the trunk, where the most vital glands are situated. Most land mammals respond to cold by raising their furs thereby trapping the thicker layer of still air and it acts as good insulator between animal skin and the surroundings. Human mostly rely on a layer of fat just insulating beneath the skin as insulating material against heat loss. Similarly marine mammals such as whales and seals inhabit much colder water than their body temperature, have a very thick layer of insulating fat called as blubber just under the skin.

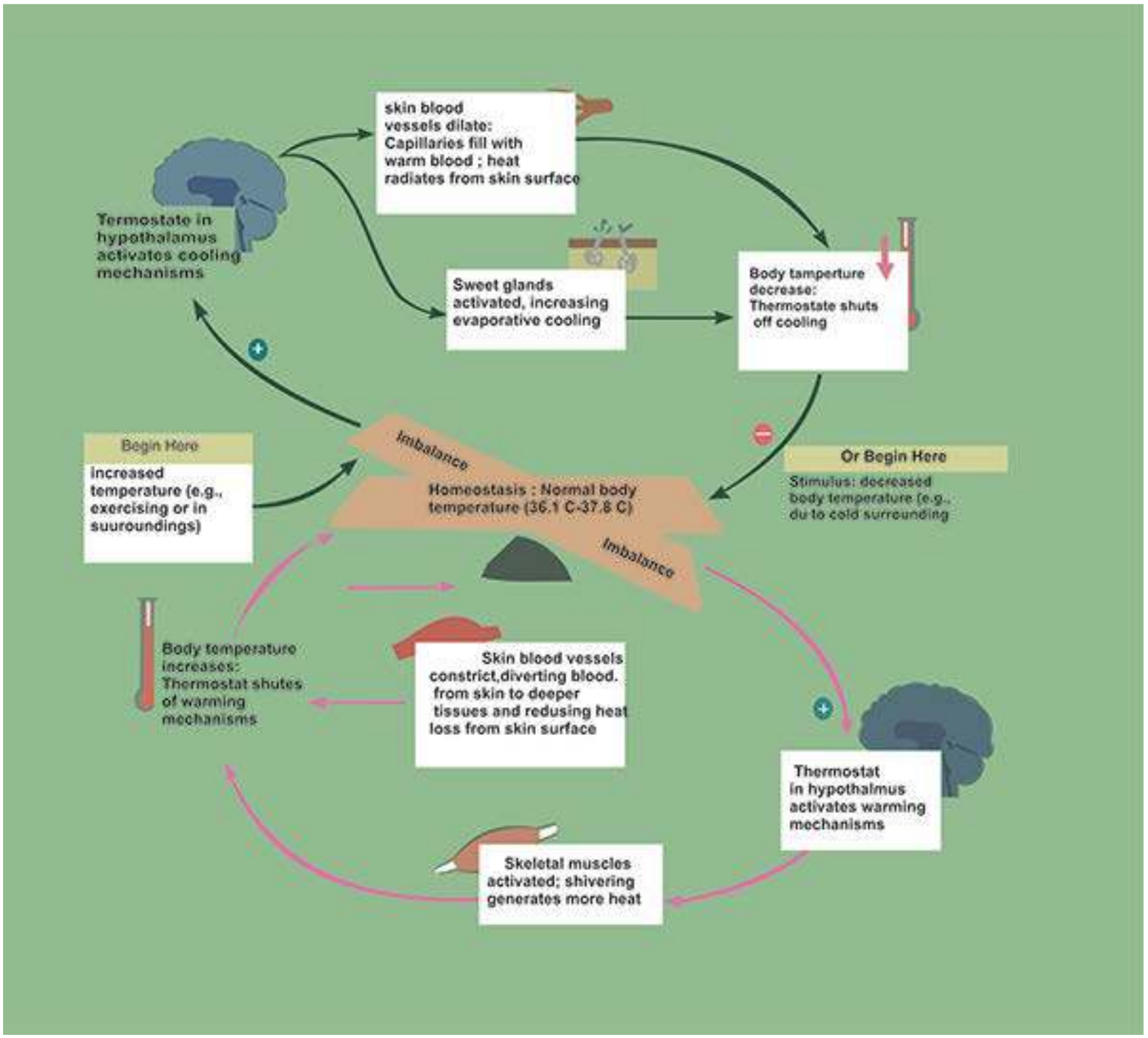



*Fig. 15.14 The thermostat function of the hypothalamus and feed back control mechanisms in human thermoregulation.*

**In Warm Temperature :** Marine mammals dispose off their excess heat into warm seas by large number of blood vessels in the outer layer of the skin. This dissipates the heat from the skin surface. In terrestrial mammals, in contrast is the mechanism of evaporative cooling. The sweat gland activity and the evaporative cooling is the one of the major temperature reducing strategies. Panting, the evaporative cooling in the respiratory tract, is'the other mechanism as represented in the dogs. Bats etc use saliva and urine for evaporative cooling.

## Thermostat Fu. ctio. a. d Feedback Co. trols i. Huma.

The body temperature regulation in humans is based on complex homeostatic systems facilitated by feedback mechanisms. The homeostatic thermostat is present in the hypothalamus, a brain part. It responds to the changes in the temperature above and below a set point which is 37°C.

In case of increase in temperature above the set point, certain warm temperature sensitive thermoreceptors in skin, hypothalamus and other parts of nervous systems send the signals to the system that increase the blood flow to the skin and also cause sweat gland activation and the sweat is evaporated for the cooling.

In cold temperature, the cold receptors send the impulses to hypothalamus to inhibit heat loss mechanisms and activate the heat conservation mechanisms. This includes constriction of superficial blood vessels and stimulating shivering and non shivering mechanisms.

## Temperature i. fever (Pyrexia)

In bacterial and viral infections mainly, leukocytes increase in number. These pathogens and the blood cells produce chemicals called as pyrogens. Pyrogens displace the set point of hypothalamus above the normal point of 37° C. Fever or high temperature helps in stimulating .the protective mechanisms against the pathogens

# Exercise

## Q.2. Fill in the blank.

(i) _____is the ability of an organism to regulate its fluid contents.
(ii) The detoxification of ammonia to _____ requires the precursor of ornithine.
(iii) In kidney nephron is closely associated with network of_____ .
(iv) In insects salt and water reabsorption takes places in the_____.
(v) The antidiuretic hormone act on_____ to promote reabsorption of water in vertebrate nephron.
(vi) The nephrons arranged along the border of cortex and medulla, with tubular system looping deep in the inner medulla, are called _____ . nephrons.
(vii) The non surgical procedure of removing kidney stone is termed as_____ .
(viii) _____ is the homeostatic thermostat in human.

## Q.3. Short questions

(i) Differentiate between osmoconformers and osmoregulators.

(ii) Define anhydrobiosis with an example.

(iii) Why does filtration takes place only at glomeruli part of nephron and nowhere else?

(vi) Mention two metabolic altered states that generally (70%) cause kidney stone formation.

(v) What is a renal failure?

(vi) Account one each main adaptation in plants to high and low temperatures.

## Q.4. Extensive questions

(i) Discuss nature of excretory products in animal to various habitats, specifically in association of water availability.

(ii) Account the excretory system in earthworm.

(iii) Highlight the role of liver as an excretory organ.

(vi) Draw a labeled diagram of a vertebrate nephron with all blood supply. State the function of each part.

(v) Describe thermoregulatory strategies in mammals including human in cold temperature.

(vi) Discuss excretion in plants.

(vii) Discuss some kidney problems with their cures.

CHAPTER

16

# Support And Movements

*Animation 16 : Support and movement*
*Source & Credit: Wikispaces*

# CONCEPT AND NEED

Animals and plants show a variety of physical and biochemical activities. The main difference between plants and animals is in their locomotion; animals show movement while plants do not.

Both plants and animals need support against gravity. The collenchymatous cells in plants give support to the baby plants and sclerenchymatous cells to the adult plants. In animals muscles, cartilage and bones provide support. They enable them to move towards food, away from danger and for shelter.

# SUPPORT IN PLANTS

You are familiar with the parts of plant like stem, root, leaves etc. One of the most important functions of the stem is to give support and acts as a supply line between root and aerial parts of the plant. In the stem, the function of support is shared among several types of cells (Fig 16.1).

## a) Pare. chyma cells:

The tissues which provide support to the plant are parencyhma. parenchyma cells of epidermis, cortex and pith take in water by osmosis. Thus an internal hydrostatic pressure called turgor pressure, keeps them rigid and resistant to bending. If they loose turgidity, herbaceous stem wilts. The turgor pressure is extremely important to maintain the turgidity in plants.

The collenchyma cell in cortex and highly lignified schlerencyma cells in xylem tissues,give support to the plants. In most terrestrial plants, the major mechanical stress is imposed by wind, so that stem must be able to resist bending. The vascular bundles containing the xylem are tough and inextensible to perform the same function as steel rods in reinforced concrete. This arrangement as a ring within the stem provides very effective resistance to wind stress, and weight bearing ability.

In the stem of some plants, for example, sunflower, the vascular bundles are strengthened by additional sclerenchyma fibers, which form bundle cap.

The loss of water due to ex-osmosis from plant cells causes plant or its parts to wilt. How plant cell maintains turgor pressure is an important phenomenon.

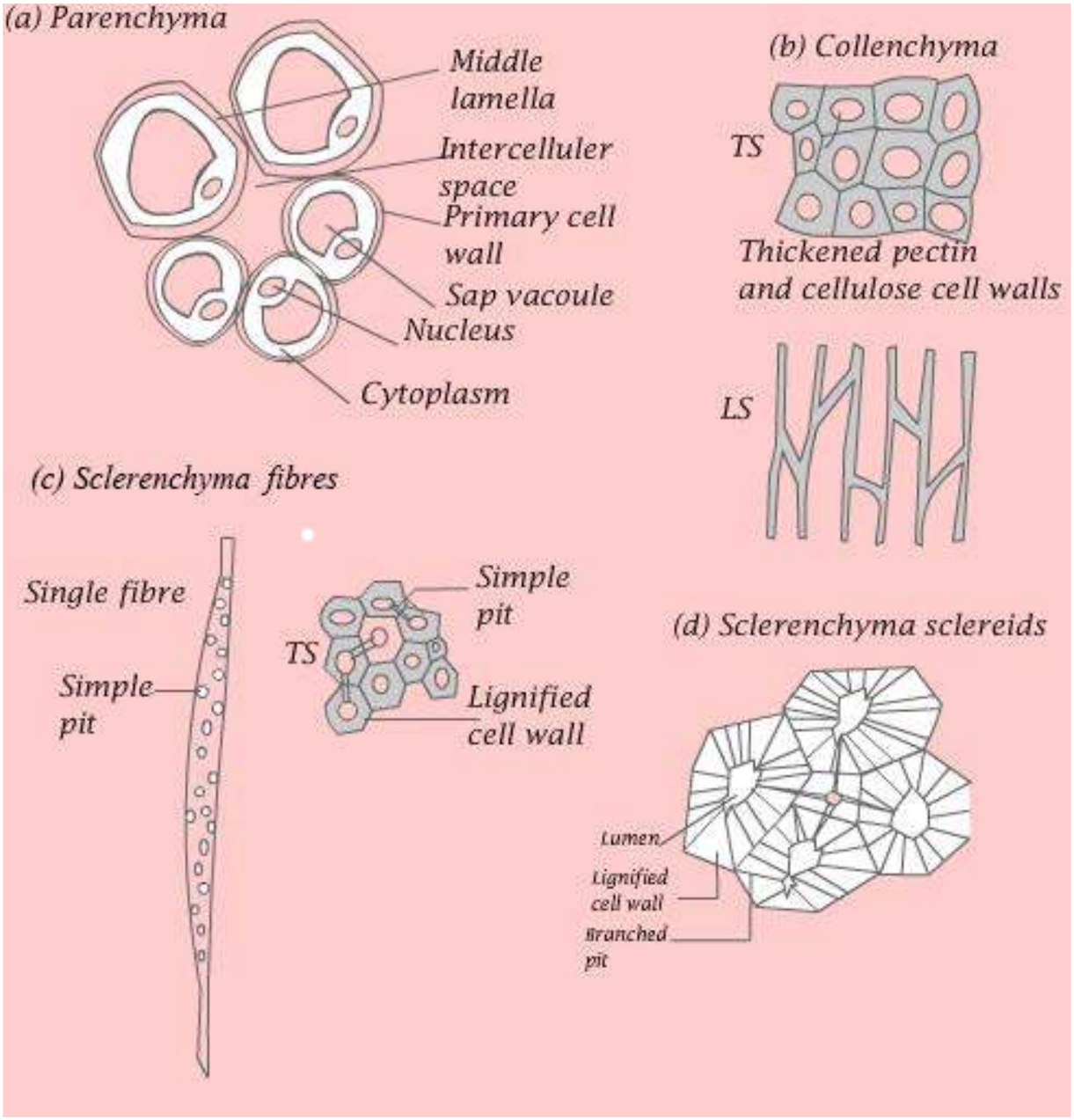



*Fig. 16.1 Specialized plants cells*

Turgor pressure is generated by high osmotic pressure of the cell vacuole. The membrane that bounds vacuole, is called tonoplast which contains a number of active transport systems that pump ions into the vacuole or vacuolar compartments despite the higher concentration than that of the extracellular fluid. Because of the higher ionic concentration, water enters the vacuole and hence provides turgidity, mechanical support, to soft tissues of plant. The tissues which provide support to the plants are:

## (b) Sclerenchyma Cells

They have thick secondary cell walls usually impregnated with lignin, an organic substance that makes the walls tough and hard. Most of the sclerenchyma cells are non-living. Their primary function is to provide support to the plant parts.
There are three types of sclerenchymatous cells.
**(i) Fibers (Tracheids):** These are long and cylindrical and they may exist as solid bundles in xylem or as bundle caps.

**(ii) Sclereides:** These are shorter than fibers and are found in seed coats and nut shells and provide protection.

**(iii) Vessels (Tracheae):** Long tubular structures, join end to end to form long water conducting pipe in xylem.

## (c) Collenchyma Cells

Collenchyma cells have protoplasts and usually lack secondary walls. They have angular thickening in their primary walls. They are usually grouped in strands or cylinders. Collenchyma cells provide support to young herbaceous parts of the plant. Young stems, for instance, often have a cylinder of collenchyma just below their surface. Collenchyma cells are elastic, elongate with the growth of stems and leaves.

## Significance of Secondary Growth

Stem and root often begin to thicken after their apical meristem has produced embryonic or primary tissue. An increase in plant girth due to vascular cambium and cork cambium is called secondary growth. The result of secondary growth is most evident in woody perennial plants like trees, shrubs and vine. Secondary growth occurs due to cell division in : (i) Vascular cambium (ii) Cork cambium.

**Vascular cambium** first appears as a cylinder of actively dividing cells between primary xylem and primary phloem. Vascular cambium gives rise to two new tissues, one is the **secondary xylem** next to the inner surface of the vascular cambium, the other is the **secondary phloem** appearing outer to the vascular cambium.

The secondary xylem causes most of the increase in stem thickness. Over the years a woody stem gets thicker and thicker as its vascular cambium produces layer upon layer of secondary xylem. These layers are visible as rings. Since one growth ring is formed in one year, a count of the rings at the base of trunk indicates the age of a tree at the time it was cut.

In most trees, the conduction of water and dissolved substances by secondary xylem become limited to the outer or younger portion of that tissue. As trees grow older only few annual growth rings are active in conduction at one time. The active portion is called **sap wood**. The inactive non-conducting wood is called **heartwood.**

In most species, the heartwood accumulates a variety of chemicals such as resins, oils, gums and tannins. These provide a resistance to decay and insect attack, for example, in red cedar and conifers.

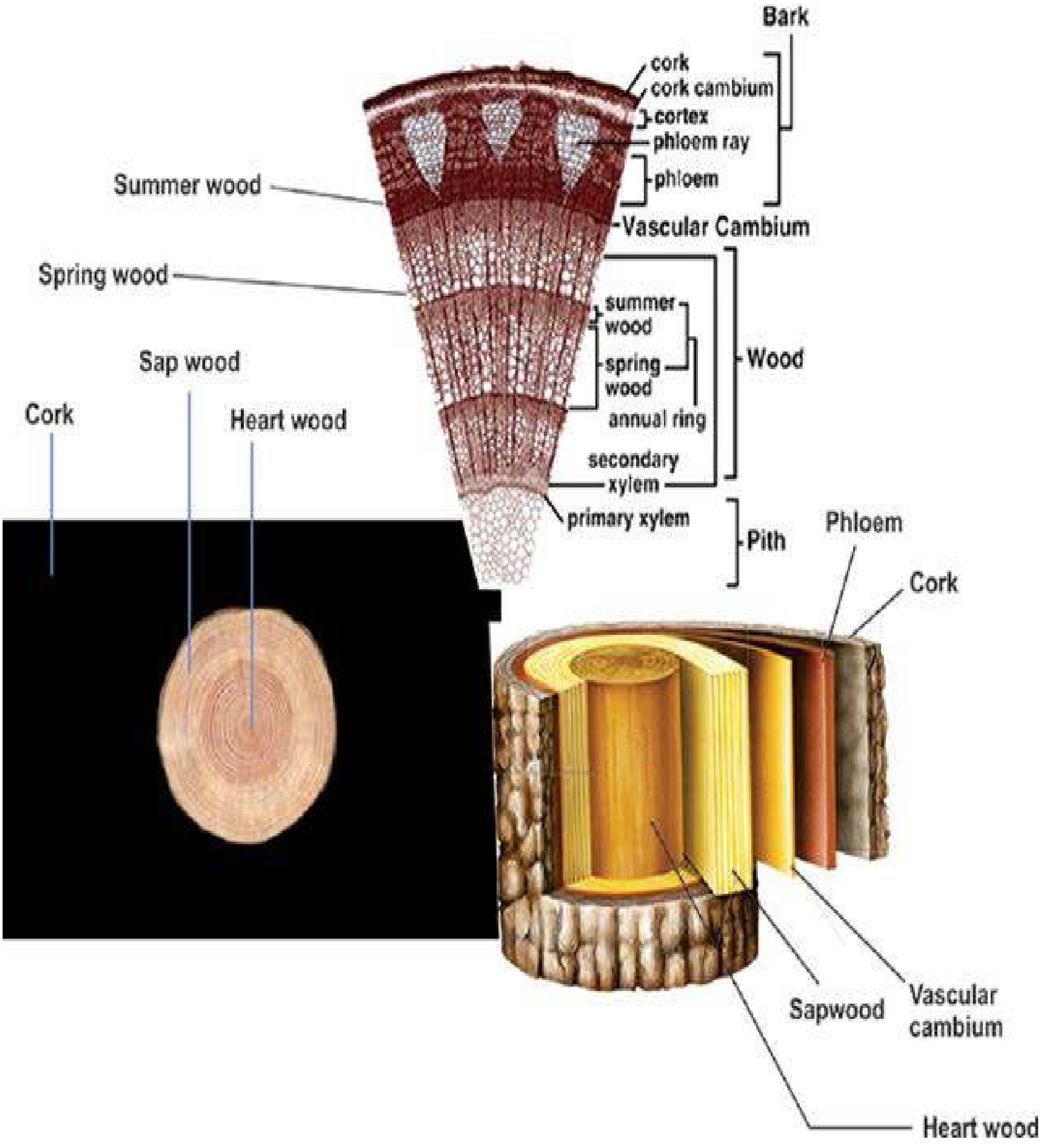



*Fig. 16.2 Dicot woody stem*

Another important function of the cambium is to form **callus** or wood tissue on or over the wound, soft parenchymatous tissues are rapidly formed on or below the damaged surface of stems and roots. Callus also unites the branches during budding and grafting.

The wood from different species of trees differs greatly in their suitability for specific uses. Density, hardness, flexibility, shock resistance, compression strength and texture determine quality and commercial use. The commercial cork is also made from the bark of trees such as Quercus suber.

## MOVEMENTS IN PLANTS

Organisms respond to the external as well as internal stimuli. Animals move in response to external stimuli; similarly plants also show movements. Animals change their location in response to stimulus. Plants are fixed therefore, they change their growth pattern.

### Types of Movements

There are two types of movements:

1. Autonomic movements
2. Paratonic movements.

Autonomic movements are spontaneous movements due to internal causes whereas paratonic movements are due to external causes.

**1. Autonomic movements :** Autonomic movements are of three types:

**(i)** Tactic movements **(ii)** Turgor movements **(iii)** Growth movements.

**(i) Tactic Movements :** These are the movements of an entire cell or organism i.e. locomotion due to internal stimulus. The tactic movement may be positive if it is towards the stimulus or negative if it is away from the stimulus. Tactic movements are the movements of locomotion; they are further classified on the basis of the nature of the stimulus, (a) **Phototactic movement:** It is a movement in response to stimulus of light. The movement may be towards the source of light (positive) or away from the source of light (negative). The best example of positive tactic movement is the passive movement of chloroplast due to cyclosis. This movement helps the chloroplast to absorb maximum light for $C0_2$ fixation. The light intensity and direction both affect the intra cellular distribution of chloroplasts. (b) **Chemotactic movement :** The movement in response to stimulus of chemicals is called chemotactic movement. The movements shown by sperms of liver-worts, mosses, ferns towards archegonia in response to stimulus of nucleic acid released by the ovum is one such example.

**(ii) Turgor Movements :** Turgor movement is due to differential changes in turgor and size of cells as a result of gain or loss of water. Rapid movements of leaflets in "touch-me-not" plant and sleep movements of the plants fall under this category of movements, (a) **Sleep movements**: Bean plants and some members of legume family lower their leaves in the evening and raise them in the morning. These are known as sleep movements. These sleeping movements are due to daily changes in turgor pressure in the pulvinus. The place of attachment of leaf with the shoot, pulvinus, is swollen portion of the petiole composed of parenchymatous cells with relatively large inter cellular spaces and central strand of vascular tissues.

When turgor pressure on the lower side of pulvinus increases the leaves rise and become horizontal. When turgor pressure decreases on the lower side of pulvinus, the leaves lower and go to "sleeping" position, (b) **Rapid movement of leaflets :** When the compound leaf of sensitive plant Mimosa is touched, the leaflets fold together. This response takes a second or two resulting from rapid loss of turgor by the cells in pulvinus at the base of each leaflet. The investigation has shown that potassium ($K^+$) ions move first, which causes water to leave the cell by exosmosis. It takes about ten minutes to regain the turgor and restore the internal turgidity of leaf

.

**(iii) Growth Movements :** Growth movements are due to unequal growth on two sides of plant organs like stem, root, tendrils, buds etc. There are three types of growth movements, (a) **Epinasty** : It is shown by leaves, petals etc. The upper surface of leaf in bud condition shows more growth as compared with the lower surface. This leads to opening of buds, (b) **Hyponasty:** If growth in the lower surface of the leaf in bud condition is more than that of the upper surface then the bud will remain closed, (c) **Nutation :** The growing tip of young stem moves in a zig-zag fashion due to alternate changes in growth on opposite sides of the apex. This mode of growth is called nutation.

**2. Paratonic Movements :** These movements are due to external causes. These are of following types.

**(a) Tropic Movements :** The word tropic is derived from Greek word 'Tropos' meaning 'turn'. It is the movement in curvature of whole organ towards or away from stimuli such as light, gravity, and touch. Following are common tropic movements: (i) **Phototropism :** It is the movement of part of plant, in response to stimulus of light and is caused by the differential growth of part of a plant like stem or root, (ii) **Thigmotropism :** It is the movement in response to stimulus of touch, for example climbing vines. When they come in contact with some solid object, the growth on the opposite side of contact increases and the tendril coils around the support, (iii) **Chemotropism** : The movement in response to some chemicals is called chemotropism. The hyphae of fungi are chemotropic. (iv) **Hydrotropism** : The movement of plant parts in response to stimulus of water is called hydrotropism. The growth of roots toward water is due to positive hydrotropism and growth of shoot away from water is negatively hydrotropic. (v) **Geotropism :** It is the response to gravity. Roots display positive geotropism and shoots negative geotropism.

**(b) Nastic Movements :** These are the non-directional movements of parts of plant in response to external stimuli. These are of two types: (i) **Nyctinasty :** The nyctinastic movements are shown by the organs in response to external stimuli leading to differential growth. These are due to turgor and growth changes. It may be of two types: (a) **Photonasty :** The principal stimulus is the photoperiod. The flowers open and close due to light intensity. (b) **Thermonasty** : It is due to temperature. The flowers of tulip close at night because of rapid growth in the lower side by upward and inward bending of the petals.

(ii) **Haptonastic** movements occur in response to contact. Examples include the action of the Venus fly trap.

## Role of Plant Growth Substances In Plant Movement

Plants do not move from one place to other like animals. However, their organs show movements, which are controlled by hormones. Auxins play major role in phototropism. It is believed that unequal distribution of auxin indole acetic acid (I A A) in the coleoptiles stumps, produces unequal cell enlargement, causing a bend in the organ towards source of light.

Auxins are also responsible for positive gravitropism of roots and negative geotropism of stems. Auxins inhibit the growth of root cells. The cells of the upper surface, therefore elongate and the root curves downward. Auxins on the other hand, stimulate the growth of the stem cells. The cells of the lower surface, elongate and stem curves upward. Nastic movements are due to some balance or ratio between growth inhibitors (abscisins) and growth stimulators (gibberellins). However, it has been observed that epinasty is due to auxins and hyponasty due to gibberellins.

## SUPPORT AND MOVEMENTS IN ANIMALS

The skeleton is tough and rigid framework of the body of animals which provides protection, shape and support to the body organs. It is composed of inorganic or organic substances or both. In protozoa it is secreted by a single cell, whereas in multicellular animals it is composed of specialized cells. There are three main types of skeleton in animals, hydrostatic skeleton, exoskeleton and endoskeleton.

# 1. Hydrostatic Skeleton

In animals that lack a hard skeleton, a fluid filled gastrovascular cavity or coelom can act as hydrostatic skeleton. Hydrostatic skeleton provides support and resistance to the contraction of muscles so that motility results. It is found in cnidarians, annelids and other soft-bodied invertebrates.

The sea anemone has hydrostatic skeleton. Its cavity is filled with sea water to extend its body and tentacles. The sea anemone closes its mouth and constricts its muscle fibers that are arranged in circles around its body. The contraction of these circular muscles puts pressure on the liquid in body cavity and that pressure forces the body to maintain upright stature.

In earthworm, the hydrostatic skeleton consists of fluid-filled compartments separated by septa. Contraction of circular muscle causes compartments to elongate and contraction of longitudinal muscle causes a compartment to shorten. Alternating waves of elongation and contraction move the earthworm through the soil, aided by paired setae in each segment.

# 2. Exoskeleton

An exoskeleton is hardened outer covering to which internal muscles are attached. The exoskeleton is inert and non-living. It is secreted by the ectoderm in animal cells. It is composed of two layers. The epicuticle is the outer most layer. Because it is made up of waxy lipoprotein, it is impermeable to water and serves as a barrier to microorganisms in insects. The bulk of exoskeleton is below the epicuticle and is called the procuticle.Procuticle consists of an outerlayer exocuticle and inner layer of endocuticle. The procuticle is composed of chitin, tough, leathery, polysaccharide and several kinds of protein. It is further hardened by sclerotization and sometimes by impregnation with calcium carbonate.

The simplest example of an exoskeleton is the shell of mollusca, which generally consists of just one or two pieces. Some marine bivalvia and snail have shell composed of crystals of calcium carbonate. The shell of land snail generally lacks the hard minerals and are much lighter. Molluscan shell can grow as the animal grows and growth rings are apparent on the shell. The soft parts of the molluscan body have a hydrostatic skeleton as well.

The most complex exoskeleton is found among the arthropods. The arthropods have made a variety of adaptations to allow them to live and grow within their exoskeleton. The invagination of exoskeleton forms firm ridges and bars for muscle attachment. Another modification of exoskeleton is the formation of joints. The exoskeleton are thin, soft and flexible at joints, consequently joint move very easily. Other modifications of exoskeleton include sensory receptors called sensilla that are in the form of bristles, and lenses and the modification of the exoskeleton that permits gaseous exchange.

The exoskeleton in arthropoda protects the animals against their enemies and rough environment. It also protects them from drying.

However, it has one disadvantage and that is animals cannot grow larger. The animal, therefore, needs to shed its exoskeleton periodically and replace it with one of the larger size. This process is known as “ecdysis or moulting.”

Ecdysis is divided into four stages:

1. Enzymes, secreted from hypodermal glands, begin digesting the old endocuticle. This digestion separates hypodermis and the exoskeleton.
2. The old exoskeleton is split and pores are formed.
3. The digestion of endocuticle is followed by secretion of new procuticle and epicuticle.
4. Finally, the new exoskeleton is hardened by deposition of calcium carbonate. During the hardening process, the arthropod is vulnerable to predators and remains hidden. All these changes are controlled by the nervous system and the hormone **ecdysone.**

## Some major functions of the skeletal system are as follows:

**(i) Support and shape :** Bones support soft tissues and serve as attachment sites for most muscles and provide shape to the body.
**(ii) Protection:** Bones protect critical internal organs, such as brain, spinal cord, heart and lungs.
**(iii) Movement:** Skeletal muscles attached to the bones help in moving the body.
**(iv) Mineral homeostasis:** Bones serve as store for calcium, phosphorus, sodium and potassium. Through negative feedback mechanisms, bones can release or take up minerals to maintain homeostasis.
**(v) Blood cell production:** Red and white blood cells are produced in bone marrow, a connective tissue found within certain bones.

## 3. Endoskeleton

The endoskeleton is primarily made up of two types of tissues, bones and cartilage. Both bones and cartilage are types of rigid connective tissue. Both consists of living cells embedded in the matrix of protein called collagen.

**Bone :** It is the most rigid form of connective tissue. The collagen fibers of bone are hardened by deposit of calcium phosphate. Bones supporting your arms and legs consist of an outer shell of compact bone, with spongy bone in the interior. Compact bone is dense and strong and provides an attachment site for a muscle. Spongy bone is light, rich in blood vessels, and highly porous. The cavities of spongy bone contain bone marrow where blood cells are formed. There are three types of cells associated with bone:
Bone-forming cell (osteoblast ), mature bone cell (osteocyte ), and bone dissolving cells (osteoclast ).

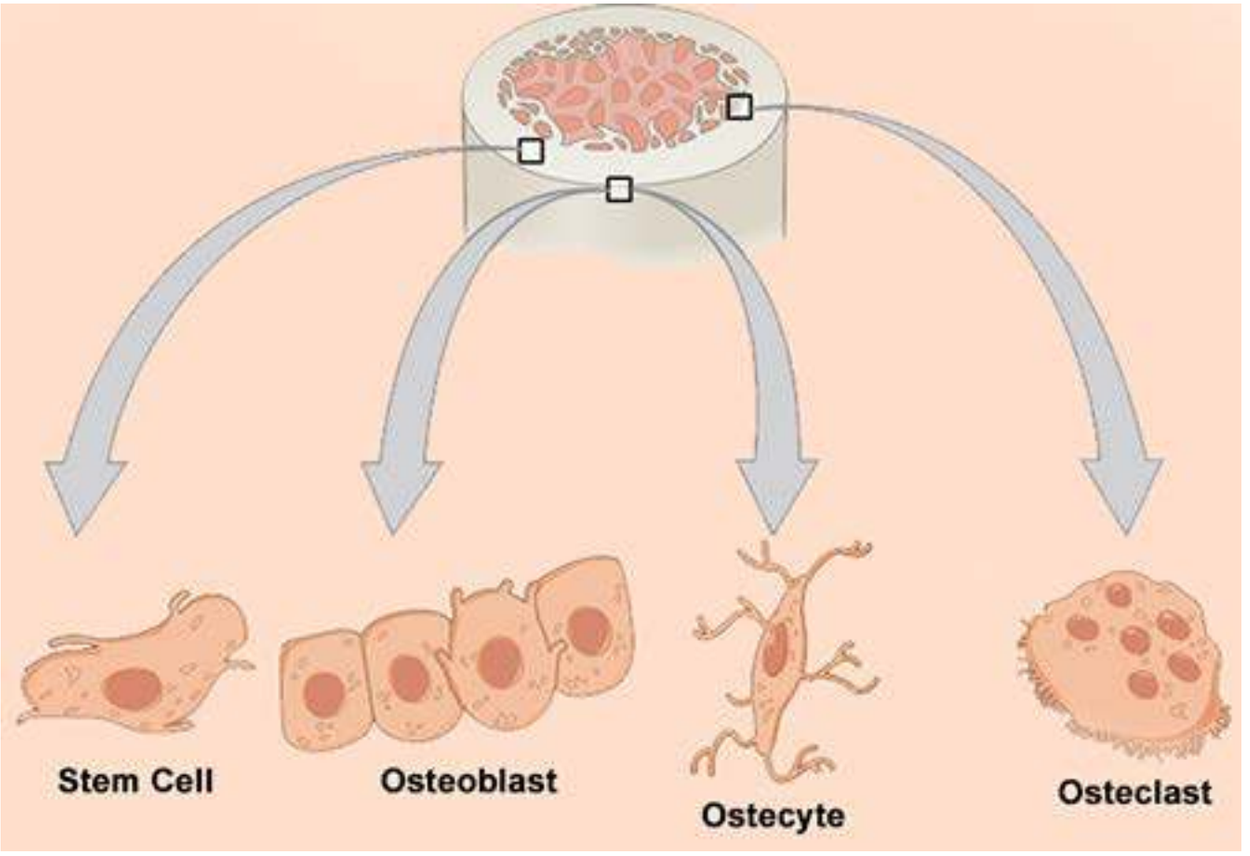



*Fig. 16.3 Cells of bone*

Early in development, when bone is replacing cartilage, the osteoclasts invade and dissolve the cartilage. Then osteoblasts replace it with bone. As bones grow, the matrix of bone is hardened and the osteoblasts are gradually entrapped within it.

Cartilage : It is much softer than bone. It is a form of connective tissue. It covers ends of the bone at the joint, and also supports the flexible portion of nose and external ears. The living cells of cartilage are called chondrocytes. These cells secrete flexible, elastic, non-living matrix collagen that surrounds the chondrocytes. No blood vessels penetrate into this cartilage. There are three main types of cartilage.

**(i) Hyaline Cartilage :** It is the most abundant type in human body. It is found at the movable joints.

**(ii) Elastic Cartilage:** It has matrix containing bundles of collagens fibers. It forms external pinnae of ears and the epiglottis.

**(iii) FibroCartilage:**

## HUMAN SKELETON

Human skeleton can be divided into two parts, axial skeleton and appendicular skeleton.

## 1) Axial Skeleton

The axial skeleton includes the skull, the vertebrae, ribs and the sternum.

**Skull:** It is made up of cranium and facial bones. The cranium consists of 8 bones (Fig 16.4), 4 unpaired and 2 paired which protect the brain. Parietal and temporal are paired bones, whereas frontal, occipital, sphenoid and ethmoid are unpaired bones. Besides that there are 14 facial bones of which 6 are paired and 2 unpaired. The paired facial bones are maxilla, zygomatic, nasal, lacrimal, palatine and inferior concha. The unpaired facial bones are mandible and vomer.

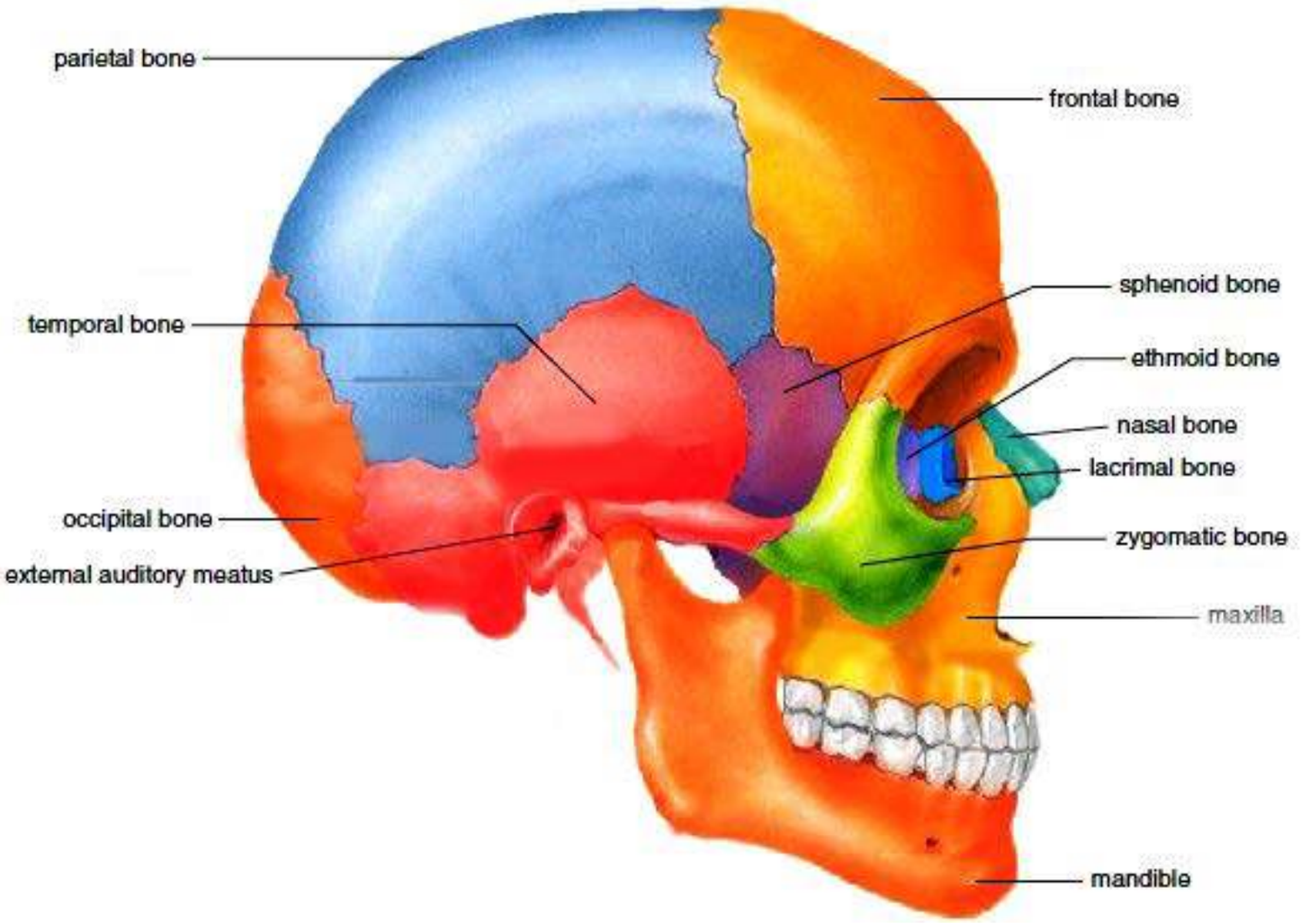



*Fig. 16.4 Human skull*

**Vertebral Column :** Vertebral column extends from the skull to the pelvis to form backbone, which protects the spinal cord (Fig 16.5). Normally the vertebral column has 4 curvatures, which provide more strength than does the straight column. The vertebral column consists of 33 vertebrae. The vertebrae are named according to their location in the body, viz, cervical, thoracic, lumbar and pelvic.

The **cervical** vertebrae include seven vertebrae which lie in the neck region. The first two cervical vertebrae are atlas vertebra and axis vertebra. There are twelve **thoracic** vertebrae located in the thoracic region, five in **lumbar** region and nine in **pelvic** region which form two sets, sacrum and coccyx. Sacrum is formed by the fusion of anterior five vertebrae, whereas coccyx is formed by the fusion of four posterior vertebrae.

**Rib cage :** It is composed of twelve pairs of ribs that articulate with the thoracic vertebrae. Ten of them connect anteriorly with sternum, either directly or through the costal arch. The lower two pairs of ribs are called “floating ribs” because they do not attach to the sternum. The rib cage provides support to a semi-vaccum chamber called the “chest cavity”.

## 2) Appendicular Skeleton

The appendicular skeleton consists of pectoral girdle and appendages (fore limbs), and pelvic girdle and appendages (hind limbs). (Fig 16.5)

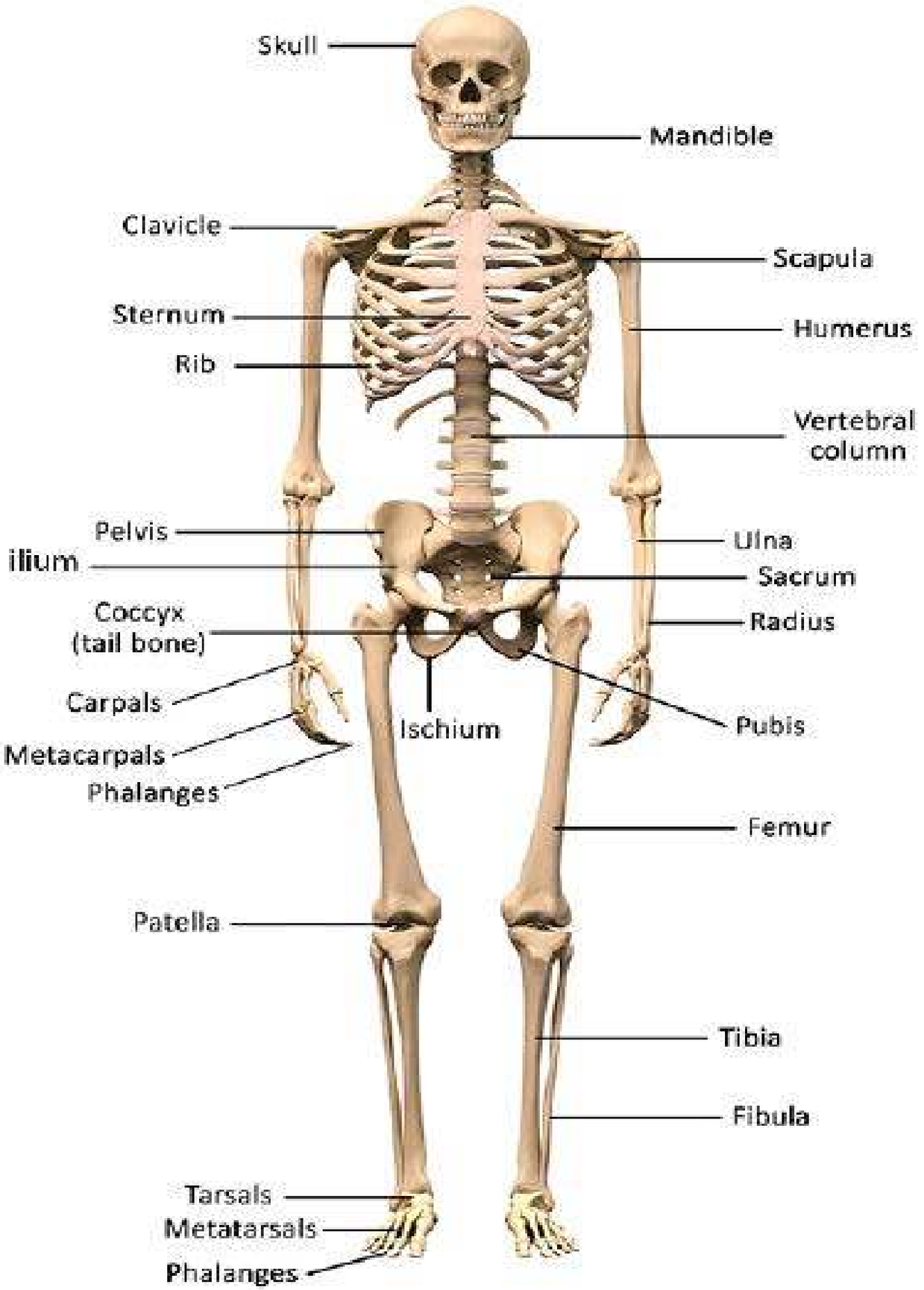



*Fig. 16.5 Human skeleton*

**Pectoral Girdle and Fore Limb :** Pectoral girdle comprises scapula, suprascapula, and clavicle. The clavicle connects scapula with sternum.

The fore limb consists of humerus, radius and ulna, 8 carpals, 5 metacarpals and 14 phalanges.

Humerus forms ball and socket joint with scapula, while at distal end humerus forms hinge joint with radius and ulna. The radius and the ulna at their distal end form multistage joint with eight wrist bones called carpals. Five metacarpals form the framework of palm of the hand. Five rows of the phalanges are attached to the metacarpals. They support the fingers.

**Pelvic Girdle and Hind Limb :** Pelvic girdle attaches the hind limb to the vertebral column (Fig 16.5). It consists of two coxal bones. Each is formed by the fusion of three bones ilium, ischium and pubis. The pelvic girdle supports the pelvic region.

The hind-limb consists of 1 femur, 2 tibia and fibula, 7 tarsals 5 meta-tarsals and 14 phalanges. Femur is the proximal bone which forms a hip joint with the hipbone, it is a ball and socket joint. At the distal end, the femur forms knee joint with the proximal end of two parallel bones called tibia and fibula. The distal end of the tibia and fibula forms a joint with seven tarsals, which are also distally attached to five metatarsal bones of ankle. Five rows of the fourteen phalanges of the toes are attached to metatarsals (Fig 16.5).

## Joints

Joints occur where bones meet. They not only hold our skeleton together, but also give it the mobility.

Joints are classified on the basis of the amount of movement allowed by them, into three categories:

**(i)** Immovable joints **(ii)** Slightly movable joints **(iii)** Freely movable joints

The freely movable joints are of two types viz. hinge joint and ball and socket joint (Fig. 16.6)

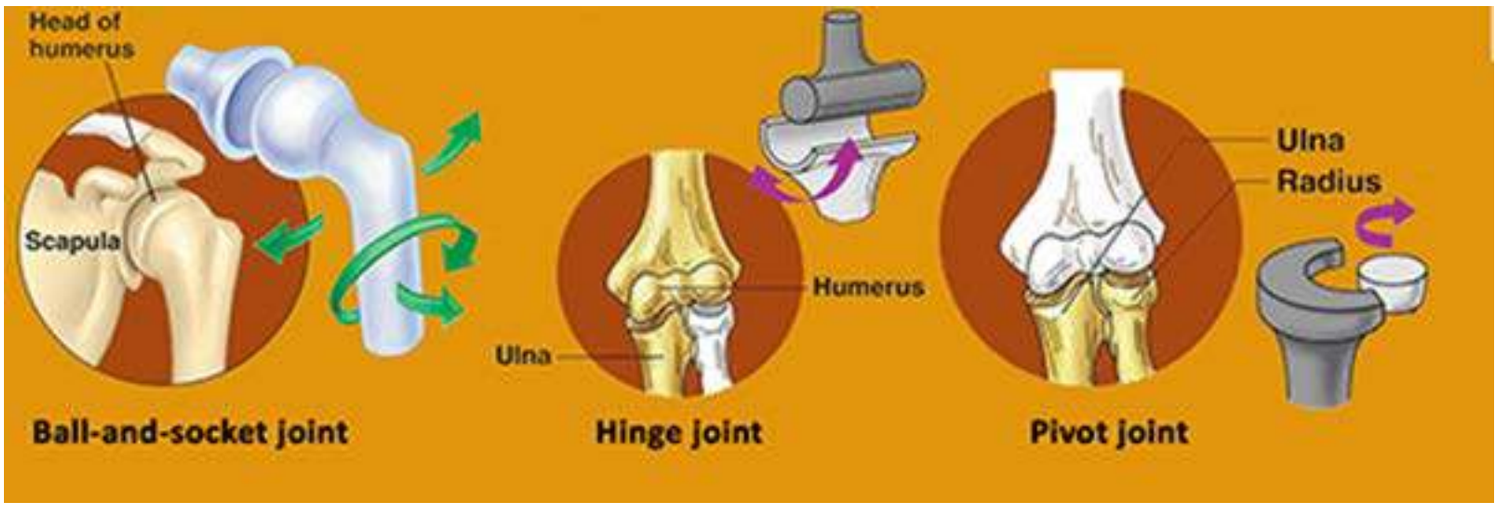



*Fig 16.6 Three kinds of joints*

Joints are also classified on the basis of structure:

**1. Fibrous Joints:** These joints are held together by short collagen fibers embedded in connective tissue. Such joints are present in the skull, and they fix teeth into the jaw.

**2. Cartilaginous Joints:** These joints allow little or no movement. Hyaline cartilage forms joint between growing bone. The bones held together by fibrous cartilage are found between vertebrae at the point where coxal bones meet in front of the pelvis.

**3. Synovial Joints:** These joints contain a cavity filled with fluid and are adapted to reduce friction between the moving joints. The joint is surrounded by a layer of connective tissue called "fibrous capsule" and their inner layer the synovial membrane. Some parts of capsule may be modified to form distinct ligament, holding the bones together.

Based on structure and movements allowed, the synovial joints can be classified further into major categories.

**(i) Hinge Joint :** The joint that allows the movements in two directions. These are at elbow and knee. At these joints, pair of muscles are arranged in the same plane as that of joints. One end of each muscle, the origin is fixed to the immovable bone on one side of joint and the other end of muscles, the insertion is attached to the far side of the joint.

**(ii) Ball and Socket Joint:** The joint that allows the movement in several directions. Such joints have at least two pairs of muscles present perpendicular to each other. They provide maximum flexibility. Hip joint and shoulder joint are the examples of ball and socket joints.

## DEFORMITIES OF SKELETON

Human skeleton supports an upright body. Sometimes our skeletal system becomes weak and results in deformations. The causes of the deformations are variable e.g.

### 1. Genetic Causes

Cleft palate, a condition in which palatine processes of maxilla and palatine bone fail to fuse. The persistent opening between the oral and nasal cavity interferes with sucking. It can lead to inhalation of food into the lungs causing aspiration pneumonia. **Microcephaly**, the small sized skull is caused by some genetic defect. **Arthritis** covers over 100 different types of inflammatory or degenerative diseases that damage the joints. **Osteoarthritis** is the most common chronic arthritis, which is a degenerative joint disease also caused by genetic defect.

### 2. Hormonal Causes

Osteoporosis is a group of diseases in which bone resorption out paces bone deposit. In this case bone mass is reduced and chemical composition of the matrix remains normal. Osteoporosis mostly occurs in aged women, which is related to decreased estrogen level. Other factors which may contribute include, insufficient exercise, diet poor in calcium and protein, smoking, etc. Estrogen replacement therapy (ERT) offers the best protection against osteoporotic bone fractures.

## 3. Nutritional Causes

Osteomalacia (soft bones) includes a number of disorders in which the bones receive inadequate minerals. In this disease, calcium salts are not deposited and hence ones soften and weaken. Weight bearing bones of legs and pelvis bend and deform. The main symptom is the pain when weight is put on affected bones.

**Rickets** is another disease in children with bowed legs and deformed pelvis. It is caused by deficiency of calcium in diet or vitamin 'D' deficiency. It is treated by vitamin 'D' fortified milk and exposing skin to sunlight.

## Disc - Slip

Each intervertebral disc is a cushion - like pad composed of an inner semi fluid **nucleus pulposus** which acts as rubber ball to give a disc its elasticity and compressibility and a strong outer ring of fibrocartilage, the **annulus fibrosus.** The annulus fibrosus holds together successive vertebrae.

The discs act as shock absorber during walking, jumping, running and to lesser extent bend laterally. Severe or sudden physical trauma to spines for example from bending forward while lifting a heavy object may result in **herniation** of one or more discs. The herniated disc (commonly known slipped disc) usually involves rupture of annulus fibrosus followed by protrusion of the spongy nucleus pulposus. If protrusion presses on spinal cord or on spinal nerves exiting from spinalcord, generate severe pain or even destruction of these netvous structure. Disc slip is treated with bed rest, traction and painkiller. If this fails disc may be removed surgically.

## Spondylosis

It is the disease, which causes immobility and fusion of vertebral joint.

## Sciatica

It is characterized by stabbing pain radiating over the course of sciatic nerve. It results due to injury of proximal sciatic nerve, which might follow a fall, a herniated disc or improper administration of an injection into the buttock. This may result in a number of lower limb impairment depending on the precise nerve root injured. When sciatic nerve is completely transected, the legs become nearly useless. They cannot be flexed and all foot-ankle movement is lost. Recovery from sciatic injury is usually slow and incomplete.

## Arthritis

Arthritis is inflammatory or degenerative disease that damages joints. It results in pain, stiffness, swelling of the joint. Acute forms of arthritis usually result from bacterial invasion and are treated with antibiotics. The membrane, lining the joint thickens, fluid production is decreased, which consequently leads to increased friction. Chronic arthritis includes osteoarthritis, rheumatoid arthritis, and gouty arthritis.

## REPAIR OF BROKEN BONES

Despite remarkable strength, the bones may break. During youth, most fractures result from trauma that may twist or break the bones such as sports injuries, automobile accidents, falls etc. In old age, bones become thin and weak and hence fractures occur more frequently.

A fracture is treated by reduction which follows realignment of the broken bone ends. There are two types of reduction: closed and open reduction. In closed reduction the bone ends are coaxed back to their normal position by physician's hand. In open reduction surgery is performed and the bone ends are secured together with pins or wires. After broken bone is reduced, it is immobilized by a cast (or by traction) to allow the healing process to begin. Healing time is 8-12 weeks, but it is much longer for large weight — bearing bones and for bones of elderly people (because of their poorer blood circulation).

The repair process of a simple fracture takes place in four phases:
**1. Hematoma Formation :** When a bone breaks, the blood vessels in the bone itself, and perhaps in surrounding are torn resulting in hemorrhage. As a result, a hematoma, a mass of clotted blood, forms at the fracture site. Soon after, bone cell deprived of food begin to die and the tissue at the fracture site becomes swollen and hence painful.

**2. Soft Callus Formation** : Next "soft callus" begins to form in 3-4 weeks. Capillaries grow into the hematoma and clear up the debris. Fibroblasts and osteoblasts migrate into the fracture site and begin to construct bone.

**3. Bony Callus Formation :** Osteoblasts and osteoclasts continue to migrate inward, multiply rapidly and gradually convert the soft callus into bony callus. Bone formation begins 3-4 weeks after injury and continues until a firm bony union is formed within 2-3 months later.

**4. Remodeling :** After several months bony callus is remodeled by removing the excess material on the outside of the bone. Final structure of remodeled area resembles that of the original unbroken bone because it responds to the same set of mechanical stimuli.

## MUSCLES

Many multicellular animals have evolved specialized cells for movement. These cells contain numerous filaments of special protein actin and myosin. The vertebrate possess three kinds of muscle cells, Smooth muscles, skeletal muscles and cardiac muscles (Fig 16.7)

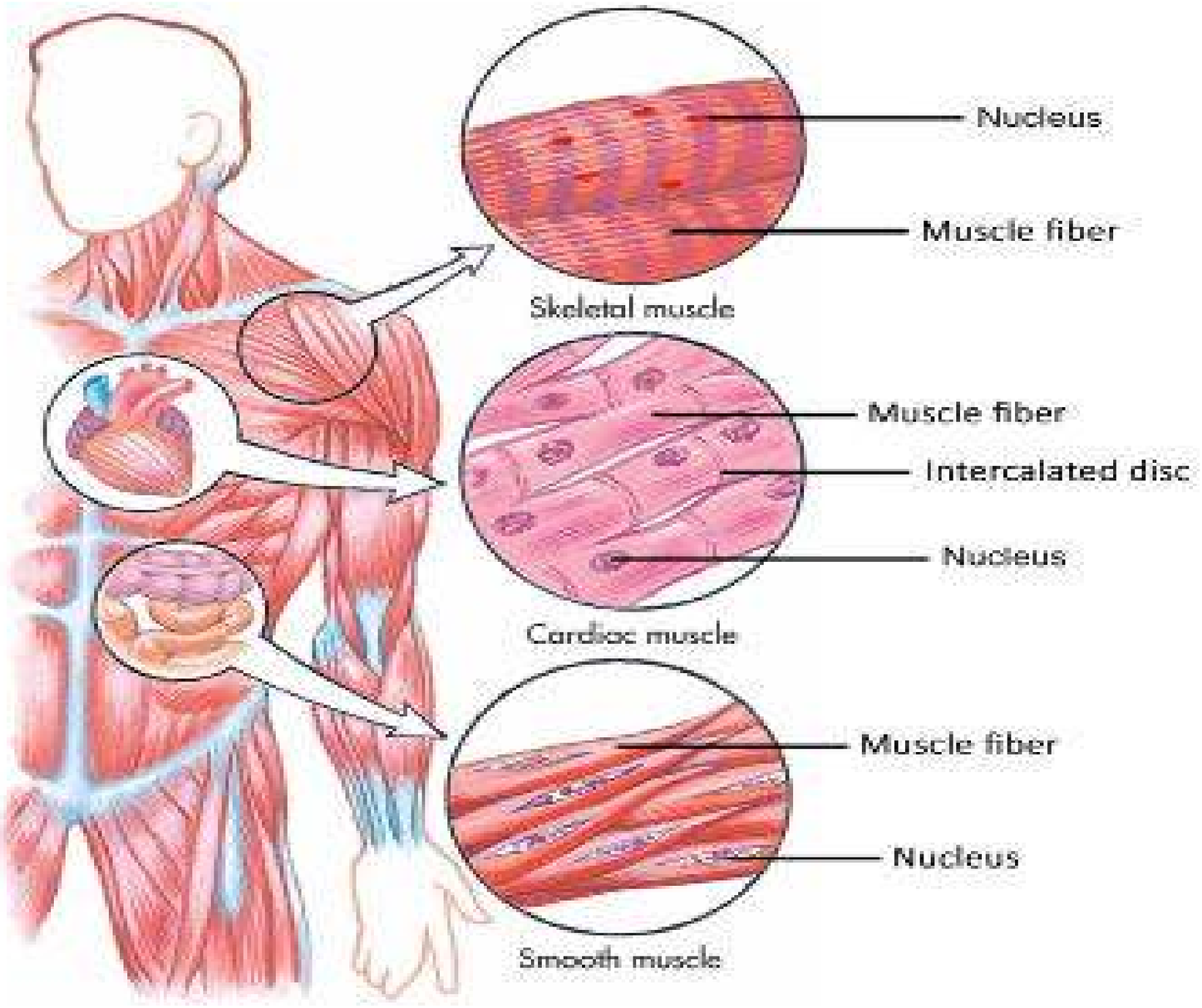



*Fig. 16.7 Location, characteristics, and functions of the three muscle types.*

| Property | Smooth | Cardiac | Skeletal |
|---|---|---|---|
| Muscle appearance | Unstriped | Irregular stripes | Regular stripes |
| Cell shape | Spindle | Branched | Spindle or cylindrical |
| Number of nuclei | One per cell | Many per cell | Many per cell |
| Speed of contraction | Slow | Intermediate | Slow to rapid |
| Contraction caused by | Spontaneous, stretch, nervous system, hormones | Spontaneous | Nervous system |
| Function | Controls movement of substances through hollow organs | Pumps blood | Moves the skeleton |
| Voluntary control | Usually no | Usually no | Yes |

## 1. Smooth Muscles

Smooth muscles were the earliest form of muscle to evolve and it is found throughout animal kingdom. Smooth muscles are long and spindle shape with each containing a single nucleus. It has no striations. It is not under the voluntary control. We describe smooth muscle tissue most precisely as visceral, non-striated and involuntary. These muscles are found in the blood vessels, digestive tract and many other organs.

## 2. Cardiac Muscles

These are muscles of the heart. They constitute most of the mass of the heart walls. Heart muscle is composed of chains of single cell, each with its own nucleus. The chain of cells are organized into fibres that are branched and interconnected. Key words for this muscle type are cardiac, striated and involuntary

## 3. Skeletal Muscles

The muscles that are attached to the skeleton and are associated with the movement of bones are called skeletal muscles. The skeletal muscles are consciously controlled and therefore, are called voluntary muscles. Skeletal muscles are also called striped or striated muscles because they show alternate light and dark bands, e.g., triceps and biceps. Generally, each end of the entire muscle is attached to bone by a bundle of collagen, non-elastic fibres, known as **tendons**.

**Skeletal Muscle Fibre :** Each muscle consists of muscle bundles, which are further composed of muscle fibres or cells. Each muscle fibre is a long cylindrical cell with multiple oval nuclei arranged just beneath its sarcolemma. Skeletal muscle fibres are huge cells. Their diameter is 10 - 100 μm. Sarcoplasm of the muscle fibre is similar to the cytoplasm of other cells but it contains usually large amount of stored glycogen and unique oxygen bonding protein myoglobin, a red pigment that stores oxygen.

When viewed in high magnification, each muscle fibre is seen to contain a large number of myofibrils 1-2 μm in diameter that run in parallel fashion and extend entire length of the cell. Bundles of these fibrils are enclosed by the muscle cell membrane or sarcolemma. The myofibrils consist of smaller contractile units called sarcomere. In each sarcomere a series of dark and light band are evident along the length of each myofibril. Each dark band is called **A band**, because it is anisotropic, i.e it can polarize visible light. The light band called **I band** is isotropic or non-polarizing. It gives the cell as a whole its striped appearance. Each **A band** has a lighter stripe in its mid section called H - zone (H stands for “hele” mean bright). The H-zone is bisected by dark line called M - line. The I bands have mid line called Z - line (Z for zwishen means between).

A sarcomere is the region of a myofibril between two successive Z - lines and is the smallest contractile unit of muscle fibre. The myofibrils contain myofilaments.

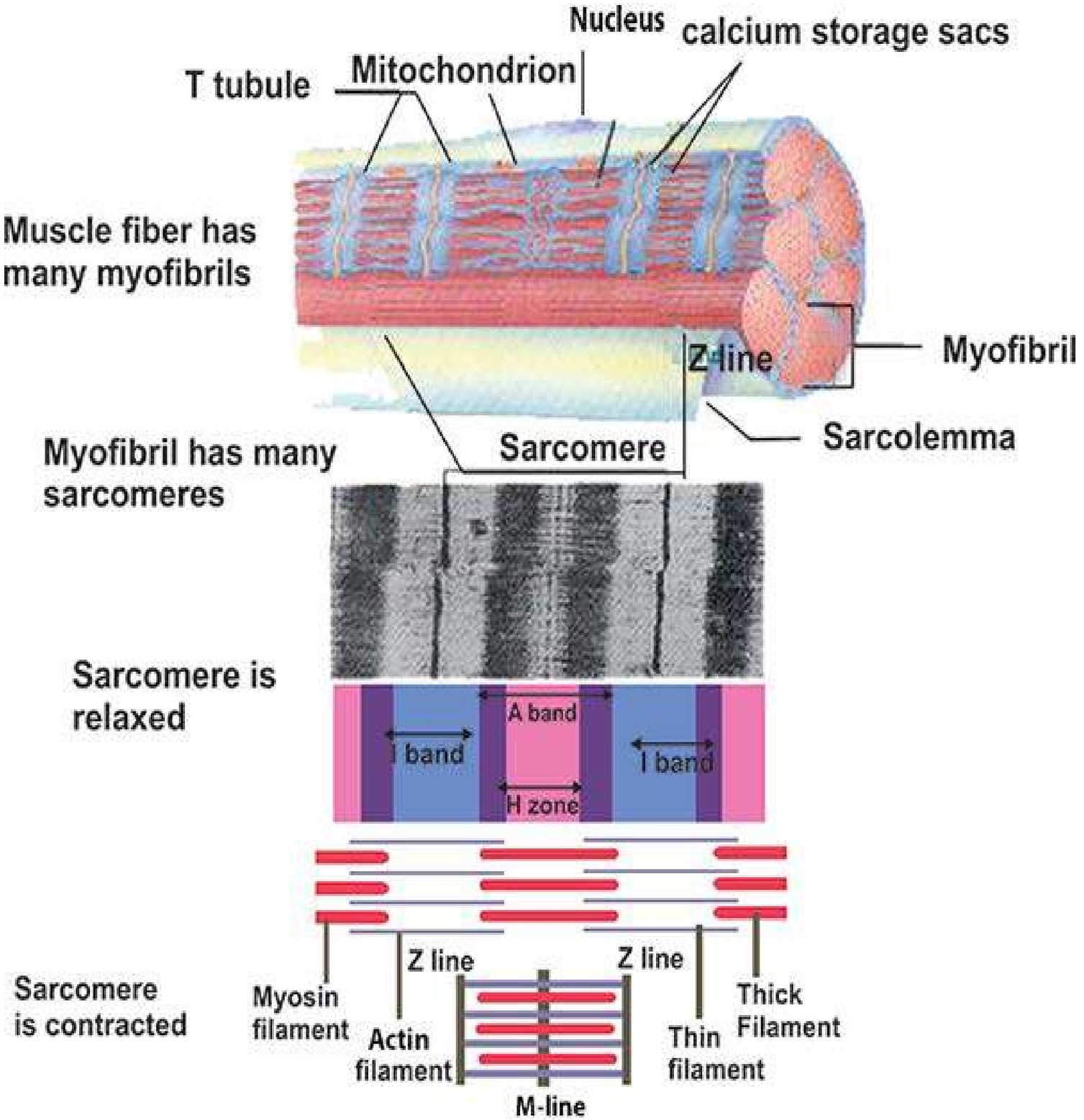



*Fig. 16.8 Ultrastructure of skeletal muscle fiber*

**Infrastructure of Myofilament :** Myofilament is made up of thick and thin filaments. The central thick filaments extend the entire length of the A-band. The thin filaments extend across the I-band and partly into A band.

The thick filament which is about 16 nm in diameter is composed of myosin. Each myosin molecule has a tail terminating in two globular heads. Myosin tail consists of two long polypeptide chains coiled together. The heads are sometimes called **cross bridges** because they link the thick and the thin myofilaments together during contraction (Fig. 16.8).

Thin filaments are 7 - 8 nm thick and are composed chiefly of actin molecule. The actin molecules are arranged in two chain which twist around each other like a twisted double strand of pearls. Twisting around the actin chains are two strands of another protein, **tropomyosin.** The other major protein in thin filament is troponin. It is actually three polypeptide complex, one binds to actin, another binds to tropomyosin while third binds calcium ions. Each myosin filament is surrounded by six actin filaments on each end.

## Sliding Filament Model

When muscle fibre contracts, the thin and thick filaments undergo shifting. The I-band reduces in length and Z-line gets closer.

Huxley and A. F. Huxley and their colleagues suggested a hypothesis in 1954 to explain all events in muscle contraction, this is called “Sliding filament model” of muscle contraction. According to this theory, the thin filaments slide past the thick one so that actin and myosin filaments overlap to greater degree. Thus the Z-line is brought close together, I-band shortens, the H zone disappears. In this process of contraction, the cross bridges of thick filament become attached to binding sites on the actin filament. The cross bridges then contract to pull the actin filament towards the center of the sarcomere.

### How the bridges are controlled

When the muscle is at rest, the tropomyosin is disposed in such a way that it covers the sites on the actin chain where the head of myosin becomes attached. When the muscle is required to contract, calcium ions bind with the troponin molecule and cause them to move slightly. This has the effect of displacing the tropomyosin and exposing the binding sites for the myosin head. Once the myosin head has become attached to the actin filament, ATP is hydrolysed and the bridge goes to its cycle. This ATP is provided by the large number of mitochondria present in each muscle cell.

From the above account it is revealed that ATP is needed to break the link between the myosin and the actin. After death, the amount of ATP in the body falls. Under these circumstances the bridges can not be broken and so they remain firmly bound. This results in the body becoming stiff, a condition known as rigor mortis.

## Controlling the Actin - Myosin Interaction By $Ca^{++}$ ions

Muscle contraction is initiated by nerve impulse arriving at the neuromuscular junction. All the fibres innervated by a single motor neuron are a “motor unit” and contract simultaneously in response to the action potential fired by the motor neurons. The sarcolemma of muscle fibre 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 thousands of T - tubules of each muscle cell are collectively called T-system. It extends and encircles the myofibril at the level of Z-line or A and I - junction. The T-tubule and the terminal portion of the adjacent envelope of sarcoplasmic reticulum 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 (SR). The calcium gates of the SR open releasing calcium into the cytosol, thus binding calcium ion to troponin molecules of the thin filament. The binding sites are exposed and cross bridges with myosin can form, and contraction occurs.

**All or None Response :** The contraction of each muscle fibre is based on “all or none” principle i.e. all of its fibrils participate in contraction. The degree of contraction depends upon the number of muscle fibers that participate in contraction.

Sarcoplasmic Reticulum (S.R) is continuous system of sarco-tubules extending throughout the sarcoplasm around each myofibril. It is like endoplasmic reticulum but devoid of ribosomes and exhibits a highly specialized repeating pattern.

## Energy For Muscle Contraction

Energy for muscle contraction comes from the ATP. Supply of ATP is. maintained by the aerobic breakdown of glucose in muscle cell, which comes from stored glycogen in the cell. When more energy is required due to high metabolism, it is provided by another energy storing substance called creatine phosphate. Sometime during oxygen deficiency or very high metabolic activity such as (prolonged or strenuous muscular activity), ATP requirement is met by anaerobic breakdown of glucose into Lactic acid. Lactic acid accumulation causes muscle fatigue. At rest, 1/5 of the lactic acid is broken aerobically and its energy is used to change the remaining 4/5 lactic acid into glucose.

### Effect of Exercise on Muscle

The amount of work a muscle does is reflected in changes in the muscle itself. When muscles are used actively, they increase in size or strength and become more efficient and fatigue resistant. Aerobic exercises such as swimming, jogging , and fast walking result in several changes in skeletal muscles. Capillaries surrounding the muscle fibres, as well as mitochondria within them increase in number and fibre synthesizes more myoglobin. These changes result in more efficient muscle metabolism and resitance to fatigue. Complete immobilization of muscle leads to muscle weakness and severe atrophy.

## Muscle Fatigue

Muscle fatigue is a state of physiological inability to contract. Muscle fatigue results from relative deficit of ATP. When no ATP is available, contractures or states of continuous contraction result because the cross bridges are unable to detach. Excess accumulation of lactic acid and ionic imbalance also contribute to muscle fatigue. Lactic acid, which causes muscle pH to drop (and the muscle to ache) causes extreme fatigue by breaking glucose.

## Tetany

Tetany is the disease caused by low calcium in the blood. It increases the excitability of neurons and results in loss of sensations. Muscle twitches and convulsion occur. If untreated the system progresses to spasm of larynx, respiratory paralysis and ultimately death occurs.

## Cramp

It is also known as tetanic contraction of the entire muscle: It lasts for just a few seconds to several hours, causing the muscles to become taut and painful. It is most common in thigh and hip muscles, it usually occurs at night or after exercise. It reflects low blood sugar level, electrolyte depletion, dehydration irritability of spinal cord and neurons.

# ARRANGEMENT OF SKELETAL MUSCLES FOR MOVEMENT OF SKELETON

Skeletal muscle has three parts: **origin** is the end of muscle which remains fixed when muscle contracts, **insertion** is the end of the muscle that moves the bone, and **belly** is thick part between origin and insertion, which contracts.

**Connective tissue** binds other tissues and helps to maintain body form by holding the various organs together. Connective tissue fibrils have two specialized kinds. **Ligaments** attach bone to bone and are slightly elastic. **Tendons** attach muscles to bones and are non-elastic.

**Tetanus:** The term tetanus is used for an acute infectious disease caused by anaerobic bacterium *Clostridium tetani* resulting in persistant painful spasms of some skeletal muscles. Typically begins gradually with stiffness of jaws and neck muscles and progresses to fixed rigidity of jaws (lock jaw) and spasms of trunk and limb muscles, usually fatal due to respiratory failure. Though rare in developed countries, the tetanus is the major killer in developing countries where the mortality rate is 40 percent.

## Movement of Bones

The majority of muscle tissue in your body is skeletal muscle. The skeletal muscles produce movements by pulling on tendons, cords of connective tissues that anchor muscle to the bones. The tendons then pull on bones. Most muscles pass across a joint and are attached to the bones that form joints. When such a muscle contracts, it draws one bone towards or away from the bone with which it articulates.

There are 650 muscles in human body, most of which occur in pairs. At joint, these muscles work against each other by contraction. This relationship is called **antagonism.**

Levered movement. Rigid external or internal skeletons are attached to muscles, which move parts of the skeleton at movable joints. Each bony “lever” is moved by an antagonistic muscle pair. One muscle reverses the action of the other, so that the lever can return to its original position.

The best example is the movement of elbow joint by biceps and triceps. The biceps bends the arm at the elbow joint, and triceps straightens it. The biceps brachii muscle arises by the two heads from scapula and is inserted into the medial surface of the radius bone. The other two muscles lie below the biceps brachi. The two muscles are brachialis and brachioradialis. The brachialis is inserted in the ulna, while brachioradialis is inserted in the radius. When these muscles contract they lift radius and ulna and bend the arm at the elbow. When triceps contracts it straightens arm at elbow. In the antagonistic pairs one muscle reverses the effect of the other and they do not contract simultaneously.

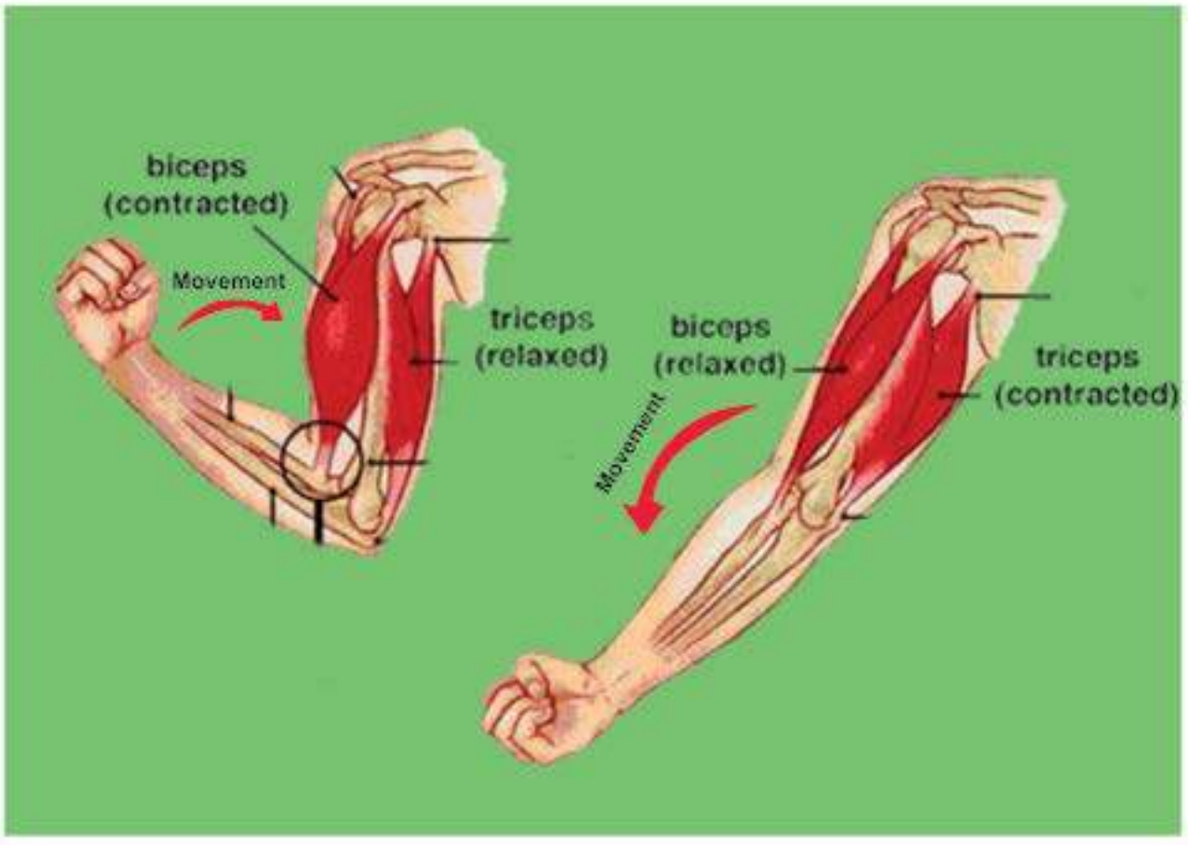



*Fig: 16.9 Working of hinge joint at elbow*

# LOCOMOTION IN PROCTOCTISTA AND INVERTEBRATES

There is an immense variety of organisms with different modes of locomotion.

## Locomotion In Euglena

Euglena moves with the help of flagellum. As the flagellum is whipped backwards, the organism moves forward. However, when the flagellum moves forward Euglena does not move backward. Locomotary flagellum is at the anterior end of the body and pulls the organism forward. Waves of activity are generated by the flagellum itself, and they pass in a spiral fashion from its base to its tip. They increase amplitude and velocity. The activity note of the flagellum causes the body of Euglena to rotate forward about its axis. Euglena is able to change its direction by the active contractile myonemes which run along the length of its body. When they contract the shape of the body as well as its direction changes. First the body becomes short and wider at the anterior end then in the middle and later at the posterior end. This characteristic movement is called Euglenoid movement.

## Locomotion in Paramecium

Paramecium moves with the help of cilia. This is called ciliary movement. All the cilia do not move simultaneously, a bunch of cilia moves in a progressive wave-like manner at a time. The wave starts at the anterior end and progresses backward.

Cilia are short, fine thread-like extensions of the cell membrane. The length of cilia ranges from many microns to many hundred microns and the diameter varies from 0.1 to 0.5. μ.

A cilium consists of nine peripheral double fibrils, giving the appearance of 8-shaped figure and two central smaller fibrils. All these fibrils run longitudinally through the cilium. These are covered with the extensions of the membrane.

The exact mechanism of movement of cilia is not known. However in 1955 Bradford suggested that movement of cilia is due to the simultaneous contraction or sliding of double fibrils in two groups one after the other.

1. Five out of nine (5/9) double fibrils contract or slide simultaneously with the result that cilium bend or shorten. It is called **effective stroke.**
2. The four out of nine(4/9) double fibrils contract and cilium becomes, straight. It is called **recovery stroke.**

As a result of bending and recovery strokes the Paramecium swims against water the energy for the movement of cilia is provided from the ATP. The enzyme present in the cilia breaks up ATP to release energy.

The action of the cilia is coordinated and all the cilia beat together in a sequence to propel the animal in one direction.

## Locomotion in Amoeba

In Amoeba movement takes place by means of pseudopodia. The pseudopodia are finger-like projections thrown in the direction of flow of the cytoplasm consequently, the body moves in that direction (Fig 16.10). The exact mechanism of formation of pseudopodia is still debatable.

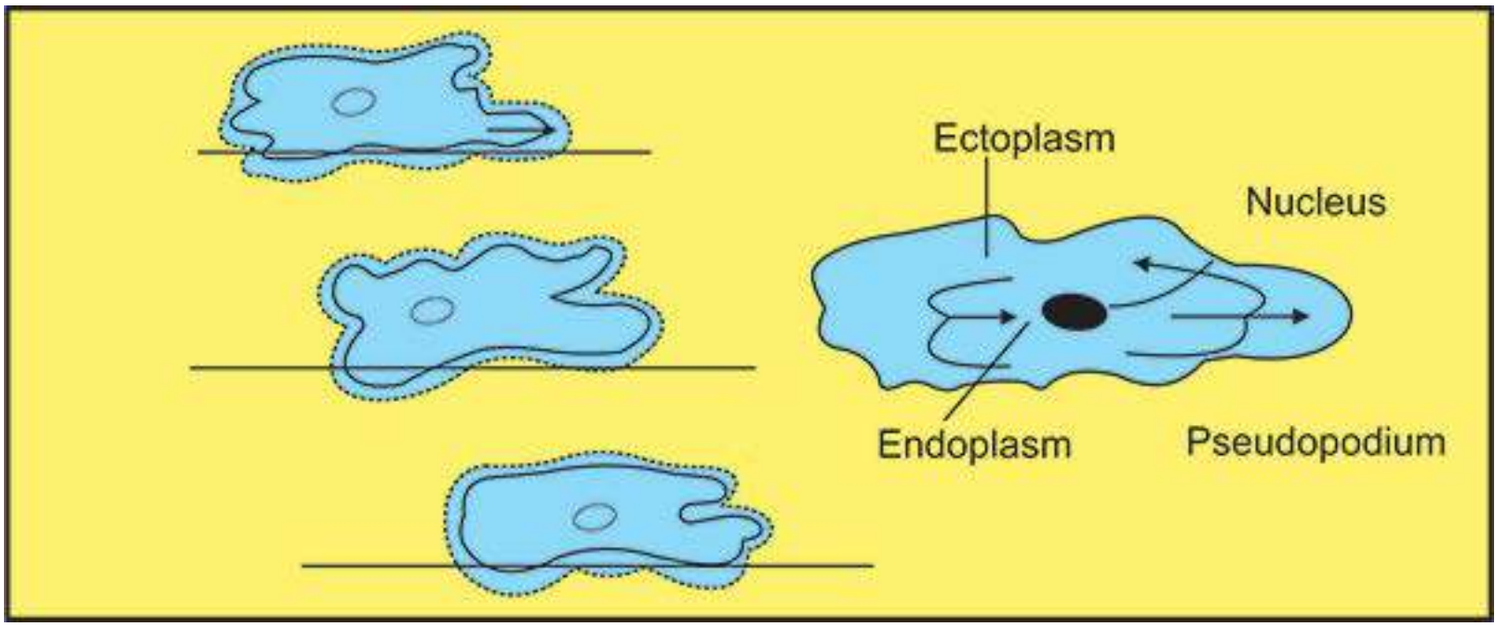



*Fig: 16.10: Amoeba showing amoeboid movement*

## Locomotion in Jelly Fish

Jellyfish has an umbrella - like body called bell. First of all water enters in the bell then the bell contracts, the water is forced out like a jet and the animal moves forward (Fig 16.11). This movement is known as **jet propulsion.**

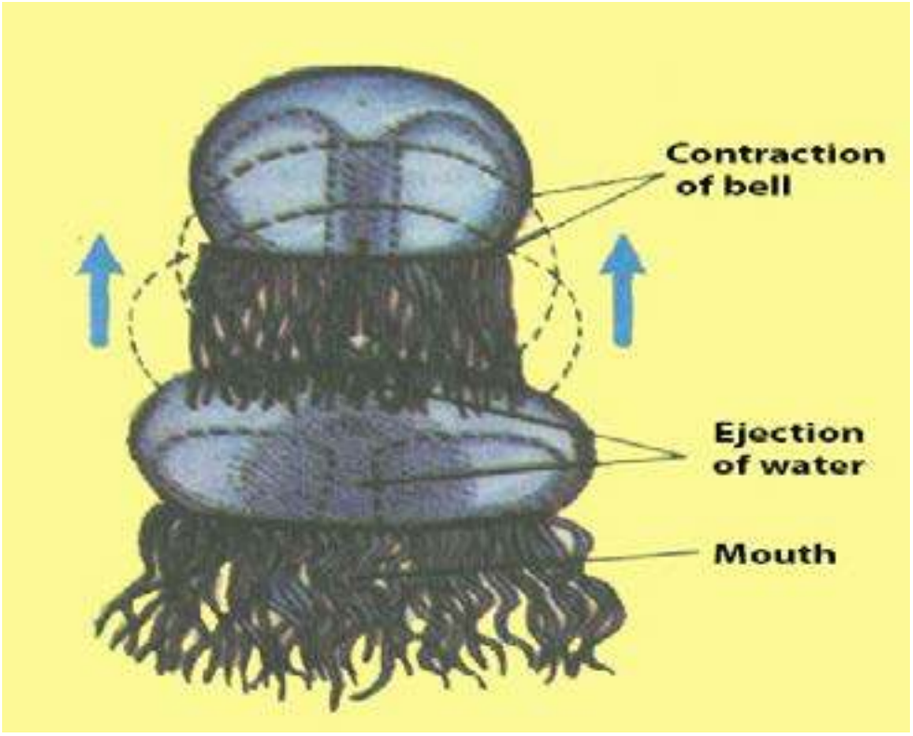



*Fig. 16.11 Jelly fish showing movement by Jet propulsion*

# Locomotion in Earthworm

Earthworm shows accordion like movement, in which setae and muscles both are involved (Fig 16.12). First of all earthworm becomes long and thin. The setae present on the lower side of anterior end come out, anchor and hold this end firmly. The longitudinal muscles now contract and circular muscles relax and body shortens thus pulling this portion forward. Then the setae of the posterior end come out and fix the animal on the ground. Now circular muscles contract, longitudinal muscles relax and body becomes thin and long. In this way, earthworm moves from one place to the other.

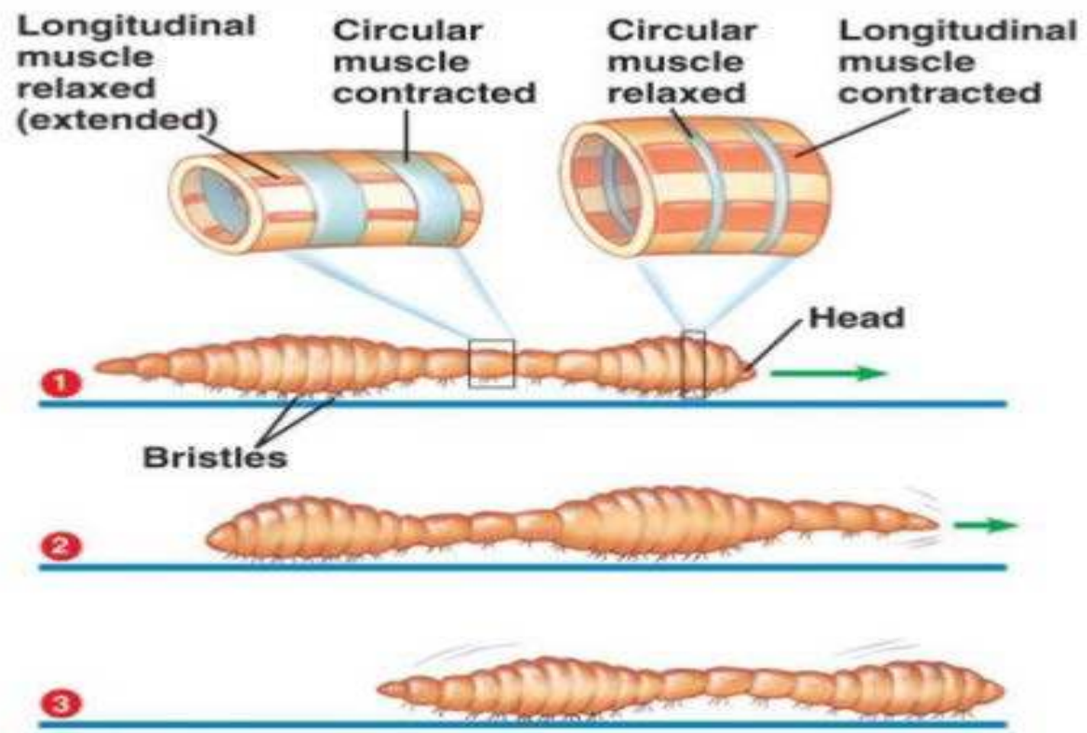



*Fig: 16.12 An earthworm crawling, by peristalsis*

## Locomotion in Cockroach

The mode of locomotion in cockroach is swift walking but it also takes to flight by its wings. In walking, the legs are used on one side, the foreleg pulls the body forward and the hind leg pushes it in the same direction. The middle leg of the opposite side acts as a prop. In the mean time, the remaining three legs begin to move together and the process is repeated.

Out of the two pairs, the posterior pair of wings brings about the flight. These beat in air in such a manner that they support the body weight and drive it through the air.

## Locomotion in Snail

Snails and mussels are mollusks, which crawl or move very slowly by “foot”.

## Locomotion in Star Fish

Starfish moves with the help of tube feet. The tube feet are present on both sides of radial canal that extends upto the tip of arm. The tube feet extend when water is pumped into them, then they fix themselves by suction cup to some object. Later on they shorten and pull the body in this direction. In this way, the starfish moves in any direction. Arms of the starfish also help in swimming.

# LOCOMOTION AND SKELETON IN VERTEBRATES

In vertebrates, skeletal muscles and skeleton help in locomotion.

### Swimming in Fishes

Swimming in water presents very different problems from walking on land like man or flying in air like birds. The body of most fishes is streamlined, being tapered at both ends. This means that water flows readily over the body surface and friction is reduced to a minimum. Apart from the fins no other structures project from the body of fish and its seems that faster the fish, the more perfect is the stream lined. The dermal denticles of cartilaginous fish and the scales of bony fish are kept moist by slimy exudation from mucus or oil glands and this also considerably reduces friction between fish and water. Other adaptations proceed by fish for moving efficiently through the water are the fins. The dorsal and ventral, unpaired fins help to stablize the fish, the paired pectoral and pelvic fins are used for steering and balancing the animals, and caudal or tail fin, in coordination with paired fins provide forward movement of fish through water. Buoyancy in the water is maintained by a specialized structure in bony fish called swim bladder.

### Locomotion In Amphibian

The general build of body is essentially fish - like in amphibians. Such forms have two means of locomotion. They wriggle along their belly on the ground with the help of segmentally arranged muscles as.they “swim on land”, with legs hardly touching the ground when moving deliberately. On the other hand, a few raise up their body on the legs which then propel them along as movable levers.

In the anurans, the entire skeleton and muscular system has become specialized for the peculiar swimming and jumping methods of locomotion; by means of extensor thrusts of both kind of limbs, acting together.

Frogs and toads also walk and hop on land due to its strong hind limbs.

## Locomotion In Reptiles

The life style of reptiles reveals striking adaptations for locomotion. They move better than amphibians due to the evolution of skeleton. The reptiles use method of walking and running. The general form of the reptilian skeleton is based on one inherited from ancient amphibians. The skeleton is highly ossified to provide greater support.

Reptiles have cervical vertebrae. The first two cervical vertebrae (atlas and axis) provide greater freedom of movement for head. The axis is modified for rotational movement. The ribs of reptiles may be highly modified. The ribs of snakes have muscular connections to large belly scales to aid locomotion. Many prehistoric reptiles were bipedal meaning that they walked on hind limbs. They had a narrow pelvis and heavy out stretched tail for balance. Bipedal locomotion freed the front appendages, which became adapted for prey capture or flight in some animals.

## Locomotion in Air

The skeleton of a bird is modified for flight. The most obvious adaptations are the bones with large air spaces which make them lighter.

The fore limbs evolved into wings with very strong pectoral muscles which pull the wings up and down. The sternum is modified to form keel. The keel is needed for the attachment of muscles.

The body is covered with feathers which give the wing a large surface area to keep the birds in air. They also keep their bodies warm, so that they can produce enough energy to fly.

The body is streamlined to cut clearly through the air. The feathers lie smoothly against its body, so that the air can easily flow over them. A bird can fly either passively by gliding or actively by flapping its wings.

**Passive flight;** When birds glide, the wings act as aerofoils. An aerofoils is any smooth surface which moves through the air at an angle,to the airstream. The air flows over the wing in such a way that the bird is given lift; the amount of lift depends on the angle at which the wing is held relative to the airstream.

**Active flight:** When little or no support can be gained from upward air currents, the same effect can be achieved by flapping the wings. As the birds moves through the air, the air flows more quickly over the curved upper surface than over the lower surface. This reduces the air pressure on the top of the wing, compared with air pressure below the wing. There is, therefore, a net upward pressure on the wing which gives lift to the bird.

## Locomotion in Mammals

The most efficient way of supporting the body is seen in mammals. The limbs of the mammals have undergone further modifications to produce the following modes of locomotion.

**1. Plantigrade :** In this mode of locomotion the mammals walk on their soles with palm, wrist, and digits all resting more or less on ground, such as monkeys, apes, man and bear etc.

**2. Digitigrade :** Some mammals tend to walk on their digits only. They run faster than plantigrade animals. In these mammals, first digit usually reduces or completely lost as in rabbit, rodents etc.

**3. Unguligrade :** These mammals walk on the tips of toes modified into hoof as deer, goat. It is the most swift type of locomotion.

# Evloutionary changes in the arrangement of bones and related mode of locomotion in major groups of vertebrates

All vertebrates have a common body plan and have skeleton formed of the same basic parts, but there are many differences. Some of these can be related to changes in habitat for example, support and locomotion in sea requires adaptations which differ from those needed on land or in air. Most fishes are propelled forward by means of muscle contraction which pass along the body from anterior to posterior producing a characteristic S-band locomotion. Alternate contractions on both side produce lashing movements which drive the fish forward through the water. This type of motion is seen in cartilaginous fish like dog fish and sharks.

Most land vertebrates are tetrapods. In four footed amphibians and reptiles, the legs emerged from the sides of the body and the S-wriggle is retained as a part of the body. Girdles and limbs of tetrapods show clear cut homologies in fundamental structure.

The tetrapod pelvic girdle is united firmly to the sacral region of the vertebral column. It is composed on each side of three cartilaginous bones ilium, ischium, pubis. A depression, the acetabulum usually located at the point of junction of three bones, furnishes the articular surface for the femur. The limbs of tetrapods are fundamentally similar, fore and hind-limbs are also alike.

The tetrapod limb is primitively pentadactyle. Reduction and fusion accounts for many variations from the primitive condition that are encountered. For example in the case of mammalian locomotion the legs project beneath the body providing more effective support. In running mammal, stride length and power are increased by arching the spine first upward with the limbs fully extended, in this way the force produced by the back muscle is transmitted to ground.

Flight has evolved in three types of vertebrates namely in pterodactyls, birds and bats. It involves far more muscular effort than swimming and walking or running.

To generate sufficient lift to remain air-borne a flying organism must have wings with a large surface area in contact with the air and must beat its wings powerfully. The skeleton of birds is highly modified for flight. Among the more obvious adaptations are the enlargements of the pectoral girdle and the development of sternum to form a massive keel for the attachment of flight muscles. The supra-coracoid muscles provide power for tlhe upward stroke. The lifting action is possible because the tendon of the supra- coracoid muscles passes through an opening the formen triosseum formed between the scapula coracoid and clavicle bones and is attached to the upper surface of the humerus. The number of bones is reduced as compared to those in the limbs of other vertebrates and many bones are fused together to increase strength.

The shape of the wings greatly influences the speed and the type of flight which can be achieved. For example long narrow wings like those of gulls and other sea birds are ideal for gliding into wind. While short broad wings like those of many garden birds are effective for slow flapping flight. Bats have a quite different arrangement of wing bones but show a parallel range of adaptation for flight.

## Exercise

### Q.1 Fill in the blanks:

(i) Each muscle is enclosed by a membrane known as _____.

(ii) Osteoporois in caused by the decrease in the level of _____.

(iii) The “molting” is controlled by a hormone _____.

(iv) _____ is stored in the muscle cell as reserve food.

(V) Collenchymatous cells lack _____ in their primary wall.

(vi) There are _____ vertebrae in the neck region of mammals.

(vii) The most abundant proteins in the muscle are _____.

(viii) _____ connect a muscle to a bone.

(ix) Thick muscle filament is composed of _____.

### Q.2 Write whether the statement is true or false and write the correct statement if false.

(i) The shoulder joint is a hinge joint.

(ii) Tendons connect bones together at joints.

(iii) Arthritis often accompanies aging.

(iv) Calcium provides energy to the muscle contraction.

(v) Most of the sclerenchymatous cells are non-living.

(vi) Visceral muscle are striated, involuntary and smooth.

## Q.4 Short questions?

(i) What is the cause of cramps?

(ii) What is the difference between tetanus and muscle tetany?

(iii) What is a ligament?

(iv) What is “nutation”?

(v) How many ribs do not attach with the sternum?

(vi) How is rickets produced?

(vii) What is the cause of tetanus?

(viii) How is muscle fatigue produced?

(ix) Distinguish between the following.

(a) Axial skeleton and appendicular skeleton.
(b) Phototactic and chemotactic stimulus.
(c) Osteocytes and osteoblast.
(d) Brachialis and brachioradialis.
(e) Origin and insertion of muscles.
(f) Bone and cartilage.
(g) Troponin and tropomyosin.

## Q.5. Extensive questions.

(i) What are the disadvantages of exoskeleton?
(ii) What is the sliding filament model? What does it explain?
(iii) Describe a hinge joint and explain how it is moved by antagonistic muscle.
(iv) Define joints. How are they classified? Explain.
(v) Explain appendicular skeleton with the help of a diagram.
(vi) Draw and label the human skull.
(vii) Write the major evolutionary adaptation in the lines of tetrapod. .
(viii) Define secondary growth. Explain.
(ix) What are the main differences between exoskeleton and endoskeleton.
(x) List the functions of skeleton.
(xi) Explain the role of osteoclasts in remodeling of bone and describe the structure of compact bone.
(xii) List the main parts of axial skeleton.
(xiii) Distinguish between fibrous, cartilaginous and synovial joints.
(xiv) Discuss methods of locomotion in fish, land vertebrates and birds.

CHAPTER

17

# Coordination And Control

*Animation 17 : Neuron*
*Source & Credit: Wikispaces*

# INTRODUCTION

All organisms show certain common characteristics - one of them is to respond to stimuli. These stimuli may be internal or external, at molecular, sub-cellular, cellular or organism level - to which the organisms respond. The activities of different body parts in response to these stimuli must be coordinated. The coordination makes possible the integration of functions essential to organismic behaviour.

Coordination is must for any organism to survive. In the unicellular organisms coordination exists between various cellular processes, and they respond to changes in their environments such as temperature, light intensity, concentration of various chemicals and even to electric current.

In multi-cellular organisms, although there is a division of labour among cells yet every cell can respond to changes in its immediate vicinity. It must be noted that even the most highly developed organisms, e.g.'we humans are unable to detect and respond to many changes or stimuli in our environment. We are unaware and not able to respond to presence of bacteria on the surface of our body, because our sensory cells do not detect their presence - but some of our internal body cells do respond and produce chemicals or phagocytose them to destroy them. We are unable to see different radiations except for visible spectrum of light, but our body cells do respond to some of them.

*Animation 17.1: Coordination and Control*

# COORDINATION IN PLANTS
# CONTROL THROUGH HORMONES

Plants, as compared to animals, are far from being passive, and are complex dynamic organisms that grow, change, react (to external/internal stimuli, and show response. It is no exaggeration to say that plants behave - but their behaviour is fundamentally different from that of animals. The difference is due to two ways of life - sessile on one hand and motile on the other. Much of the behaviour of plants depends on variations in growth rates, or changes in the turgidity of cells, when they show movement. The most obvious difference is in the slow speed of response shown by plants.

Animals have evolved tissues like muscles, specialized for production of rapid movements. Plants and animals employ different ways to respond and have evolved control systems accordingly. In plants the control is solely by the plant hormones while in animals much more variety of hormones and the nervous control, make them respond with greater speed to specific stimuli.
Hormonal control in plants is relatively a slow process. Even after hormone is synthesized, there is a delay between the release, its arrival at the target cells, and its action in the body. So, response to stimulus that induced the secretion of hormone is usually not immediate. Keeping in view the slowness of the mechanisms of plant movement, the delay involved in hormonal control is insignificant. All the activities of plants from growth to fruit production and ripening, are under the control of plant hormones.
Plants therefore, respond to the stimuli by:
1. Regulating their growth and development in appropriate ways.
2. Controlling their body functions through plant hormones or growth hormones.

## PLANT MOVEMENTS

You have studied these in the previous chapter. Many plants do not show locomotion (movement of the whole organism). However, movements of plant organs are possible and are modified according to the nature and intensity of external stimuli. There are two kinds of plant movements, autonomic movements and paratonic movements.

# RESPONSES TO ENVIRONMENTAL STRESSES IN PLANTS

All plants need water, light, carbon dioxide and a variety of nutrients from their environment for optimal development and growth. The absence or short supply of any of these factors in environment may exert environmental stresses on plants affecting their health and survival. If plants are grown without light, they become extremely long and fail to form chlorophyll. They are said to be **etiolated**.

Many plants take on a yellowish hue when they fail to form sufficient chlorophyll. This condition known as **chlorosis** is usually arises from short supplies, of mineral nutrients in the soil.

# DEFENSE AGAINST PATHOGENS IN PLANTS

Diseases of plants may arise from infections by viruses, bacteria, fungi or lichens in most cases. You have already studied different diseases caused by the above mentioned pathogens in class XI. Plants may also show developmental abnormalities. If plants are wounded, they often develop masses of amorphous material with very poor differentiation known as **calluses**. Plant tumors and even plant cancers may arise and spread through the plant as an amorphous invasion of surrounding well differentiated tissues. **Galls** are growths on a plant that are induced by parasites and have usually highly organized growth e.g. The tumors induced by bacteria. They are usually less differentiated than other types of galls.

*Animation 17.2: Defense against pathogens in platns*

# BIOLOGICAL CLOCKS AND CIRCADIAN RHYTHMS

In living things, the behavior activities occur at regular intervals which are called **biorhythms** or **biological rhythms**. Biorhythms may occur showing periodicity of about 24-hours. These are called circadian (Latin circa =about, dies =day) which means about one day, so they are also called diurnal rhythms.

If the biorhythms are of about 365 days, these rhythms in activity are called **circannual.**

The organisms come across environmental changes that are cyclical in nature such as days, tides, and seasons etc. Many organisms maintain internal rhythm or clock, to predict the onset of the periodic changes and to keep them prepared for these changes.

Biorhythms may be the result of the following:

1. There may be direct response to various changes in the external (exogenous) stimuli.
2. There may be an internal (endogenous) rhythm that progresses the organism's behaviour in synchronicity w ith the exogenous temporal period, particularly a 24 hour or a 365 day period.
3. The synchronization mechanism may be a combination of 1 and 2.

The rhythms are in one's genes but the environment influences the rhythms to some extent. Thus timing of behavior results from a combination of effects of rhythmical internal processes and timed events of the environment.

Basic period of the clock is innate. Ervin Bunning of the University of Tubingen, Germany has shown that exposure of fruit fly *Drosophila* to constant conditions for 15 consecutive generations fails to eliminate the essentially 24 hr. rhythm of this insect.

## PLANT GROWTH REGULATORY SUBSTANCES

Some of the special substances produced by the plants which influence the growth and plant responses to various stimuli are given below.

**(a ) Auxins :** These are indole acetie acid (IAA) or its varients.

- In stem, promote cell enlargement in region behind apex. Promote cell division in cambium.
- In root, promote growth at very low concentrations. Inhibit growth at higher concentrations, e.g. geotropism. Promote growth of roots from cuttings and calluses.
- Promote bud initiation in shoots but sometimes antagonistic to cytokinins and is inhibitory.
- Promote apical dominance and fruit growth. They can sometimes induce parthenocarpy.
- Cause delay in leaf senescence (aging) in a few species.
- Inhibit abscission.

**Commercial applications:** Discovery of IAA led to the synthesis of wide range of compounds by chemists. The synthetic auxins are economical than IAA to produce and often more active because plants generally do not have necessary enzymes to break them down.

| **Synthetic auxins** | |
|---|---|
| NAA (Naphthalene acetic acid)<br>Indole propionic acid | Stimulates fruiting - help natural fruit set. Sometimes causes fruit setting in absence of pollination (parthenocarpy) |
| 2,4 D (2,4 Dichloro phenoxy acetic acid) | Selective weed killer Kills broad leaved species (dicots). Used in cereal crops and lawns to eliminate weeds.<br>Inhibits sprouting of potatoes.<br>Prevents premature fruit drop (retards abscission) |

**(b) Gibberellin:** These are produced commercially from fungal cultures.

- Promote cell enlargement in the presence of auxins. Also promote cell division in apical meristem and cambium.
- Promote 'bolting' of some rosette plants.
- Promote bud initiation in shoots of chrysanthemum callus.
- Promote leaf growth and fruit growth. May induce parthenocarpy.
- In apical dominance, enhance action of auxins.
- Break bud and seed dormancy.
- Sometimes may substitute for red light. Therefore, promote flowering in longday plants, while inhibit in short-day plants.
- Cause delay in leaf senescence in a few species.

**Commercial applications:** Some of their commercial applications are as under.

1. GA promote fruit setting e.g. in tangerines and pears and are used for growing seedless grapes (parthenocarpy) and also increase the berry size.
2. $GA_3$ is used in the brewing industry to stimulate a-amylase production in barley and this promotes malting.
3. To delay ripening and improve storage life of bananas and grape fruits.

**(c) Cytokinins:**

- Promote stem growth by cell division in apical meristem and cambium.
- Inhibit primary root growth.
- Promote lateral root growth.
- Promote bud initiation and leaf growth.
- Promote fruit growth but can rarely induce parthenocarpy.
- Promote lateral bud growth, also break bud dormancy.
- Cause delay in leaf senescence.
- Promote stomatal opening.

**Commercial application:** Cytokinins delay aging of fresh leaf crops, such as cabbage and lettuce (delay of senescence) as well as keeping flowers fresh. They can also be used to break dormancy of some seeds.

### (d) Abscisic acid :

- Inhibits stem and root growth notably during physiological stress, e.g. drought, and waterlogging.
- Promotes bud and seed dormancy.
- Promotes flowering in short day plants, and inhibits in long day plants (antagonistic to gibberellins).
- Sometimes promotes leaf senescence.
- Promotes abscission.
- Promotes closing of stomata under conditions of water stress (wilting).

**Commercial application:** Abscisic acid can be sprayed on tree crops to regulate fruit drop at the end of the season. This removes the need for picking over a large time-span.

### (e) Ethene:

- Inhibits stem growth, notably during physiological stress.
- Inhibits root growth.
- Breaks dormancy of bud.
- Promotes flowering in pineapple.
- Promotes fruit ripening.

**Commercial application:** Ethene induces flowering in pineapple. Stimulates ripening of tomatoes and citrus fruit. The commercial compound ethephon breaks down to release ethene in plants and is applied to rubber plant to stimulate the flow of latex.

## CO-ORDINATION IN ANIMALS

It is brought about in higher animals by nervous co-ordination and chemical co-ordination.

# NERVOUS CO-ORDINATION

This type of co-ordination involves specialised cells or neurons linked together directly or via the central nervous system, to form network that connects the cell or organs which receive stimuli (receptors) and those which carry out actions or responses (effectors). The neuron has the capacity to generate and conduct impulses which travel across the synapse and pass from the receptors to the effectors, brings about nervous coordination. The elements of nervous system which help in co-ordination are:

1. Receptors. 2. Neurons 3. Effectors.

## 1. Receptors

The neuron fibres and cell bodies can be excited by small electric shocks, mechanical, chemical, light and temperature stimuli. Receptors detect changes in the external and internal environment of the animal. The receptor may be a cell, or neuron ending or a receptor organ. Receptors are classified as follows :

**(a) Chemoreceptors:** These are for smell taste and for blood $CO_2$ oxygen, glucose, amino acids and fatty acid (e.g. receptors in the hypothalamus)

**(b) Mechanoreceptors:** These detect stimuli of touch pressure, hearing and equilibrium (eg. Free nerve endings + expanded lip endings + stray endings) !

(**c) Photoreceptors** (electromagnetic receptors), these respond to stimuli of light for example in eyes, rods and cones.

**(d) Thermoreceptors:** These are free nerve endings. These show response to cold and warmth.

**(e) Nociceptors:** (Undifferentiated endings) which produce the sensation of pain.

Each type of the principal type of sensation that we can experience pain, touch, sight, sound and so forth are called modalities of sensation. Yet despite the fact that we experience these different modalities of sensation; nerve fibres transmit only impulses. How is it that different nerve fibres transmit different modalities of sensation? The answer to this question is:

There are many receptors which respond to the mechanical conditions of the internal organs. Examples are the receptors of the stomach wall which may be concerned with arousal of 'hunger'; stretch receptors in the carotid and aortic arteries of tetrapods have important roles in the regulation of blood pressure; endings with similar properties are found in the branchial vessels of fishes.

1. Each nerve tract terminates at a specific point in the CNS; and the type of sensation is determined by the point in the nervous system to which the fibre leads. So touch stimulus is carried by nerve impulse in the 'touch' area of the brain. Similarly fibres from the eyes (retina) terminate in the visual cortex of the brain.
2. Moreover, each receptor organ is specialised to receive a particular type of stimulus and this is carried to the particular area of the brain.

*Animation17.5: Neuroanim*
*Source and Credit:pia-magazine*

# Working of Sensory Receptors with Special Reference to Skin

In the skin there are at least 3 different types of sensory endings involved in touch stimulus reception. In skin, the receptors are concerned with atleast five different senses: touch, pressure, heat, cold and pain.

1. Situated at the base of hairs, hair end organs receive touch stimulus.
2. Meissner's corpuscles (encapsulated endings) which lie in papillae which extend into the ridges of the fingertips. The corpuscle consists of spiral and much twisted endings, each of which ends in a knob. These are touch receptors.
3. Pacinian corpuscles - situated quite deep in the body. These are also encapsulated neuron endings and receive deep pressure stimulus. Those located in the limbs probably form a basis for vibration sense.

The intensity of stimulus received would either be transmitted in the form of repeated impulses or by more fibres carrying the impulse to the CNS.

The relative abundance of various types of receptors differs greatly e.g. pain receptors are nearly 27 times more abundant than cold receptors. The cold receptors are nearly 10 times more abundant than heat or temperature receptors. The receptors are not distributed evenly over the entire surface of the body e.g. touch receptors are much more numerous in the finger tips than in the skin of the back, as might be expected in view of the normal functions of those two parts of the body.

The detection of vibrations of the ground by terrestrial vertebrates is probably achieved by receptors in the joints.

The stimulus received by the receptors in the skin which are the endings of sensory neurons is passed to the motor neurons via inter or associative neurons which are present in the brain and via spinal cord impulse is sent by the motor neurons to the effectors, which are muscles and glands (Fig. 17.1).

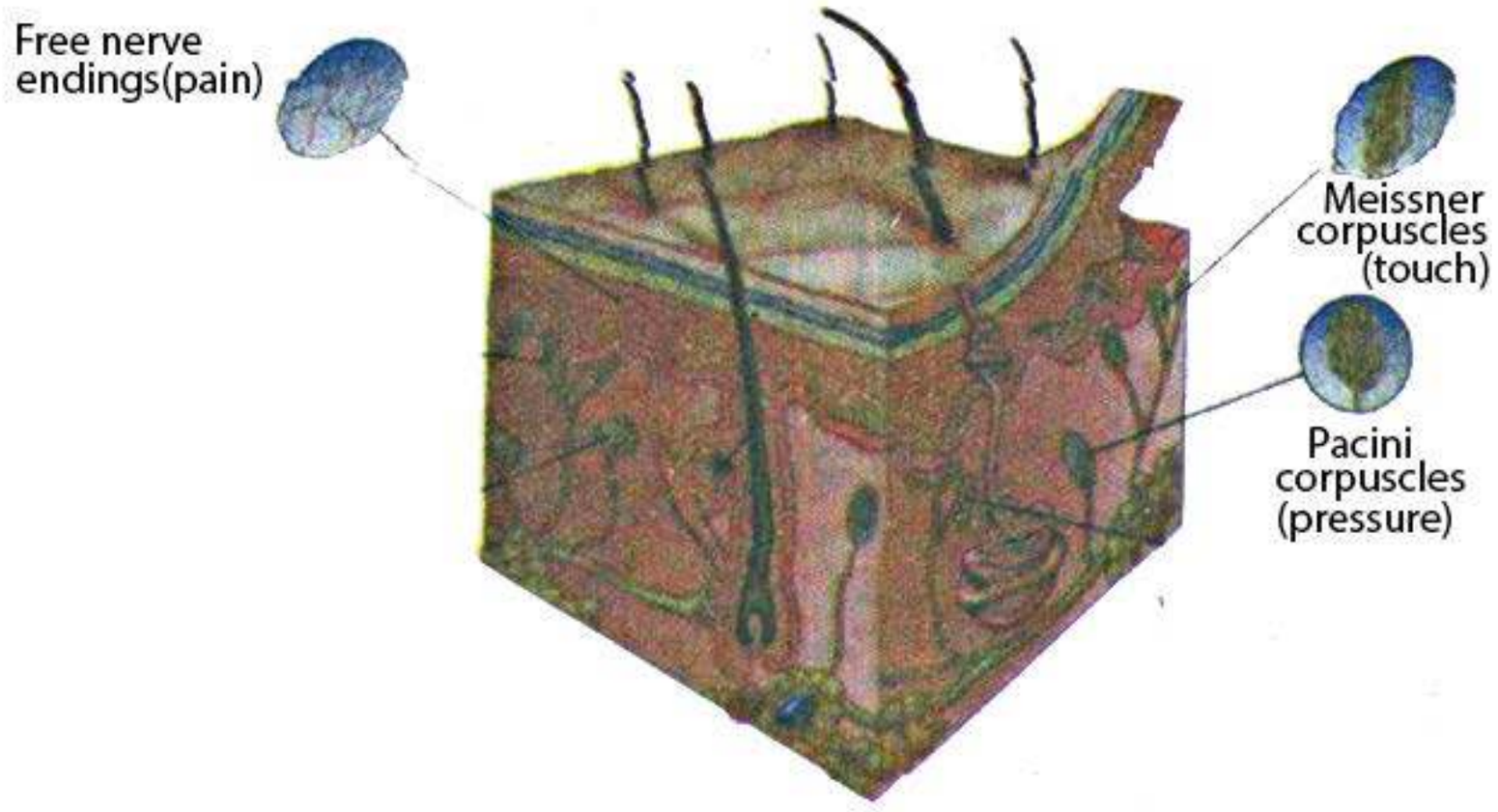



*Fig. 17.1 Sensory receptors of the skin.*

The sensations of touch, pressure, heat, cold, and pain are detected by modified sensory neurons having naked nerve endings (touch and pain receptors) or specialized cellular corpuscles (pressure, hot and cold receptors).

## 2. Neurons

The chief structural and functional units of the nervous system are neurons, but there are other cells, in higher animals, and in humans called **neuroglia**, which make up as much as half of the nervous system. Neuroglia play a vital role in the nutrition of neurons and their protection by myelin sheath. There are three functional types of neurons-the sensory, associative (intermediate/ relay) and motor neurons, in mammals (Fig. 17.2)

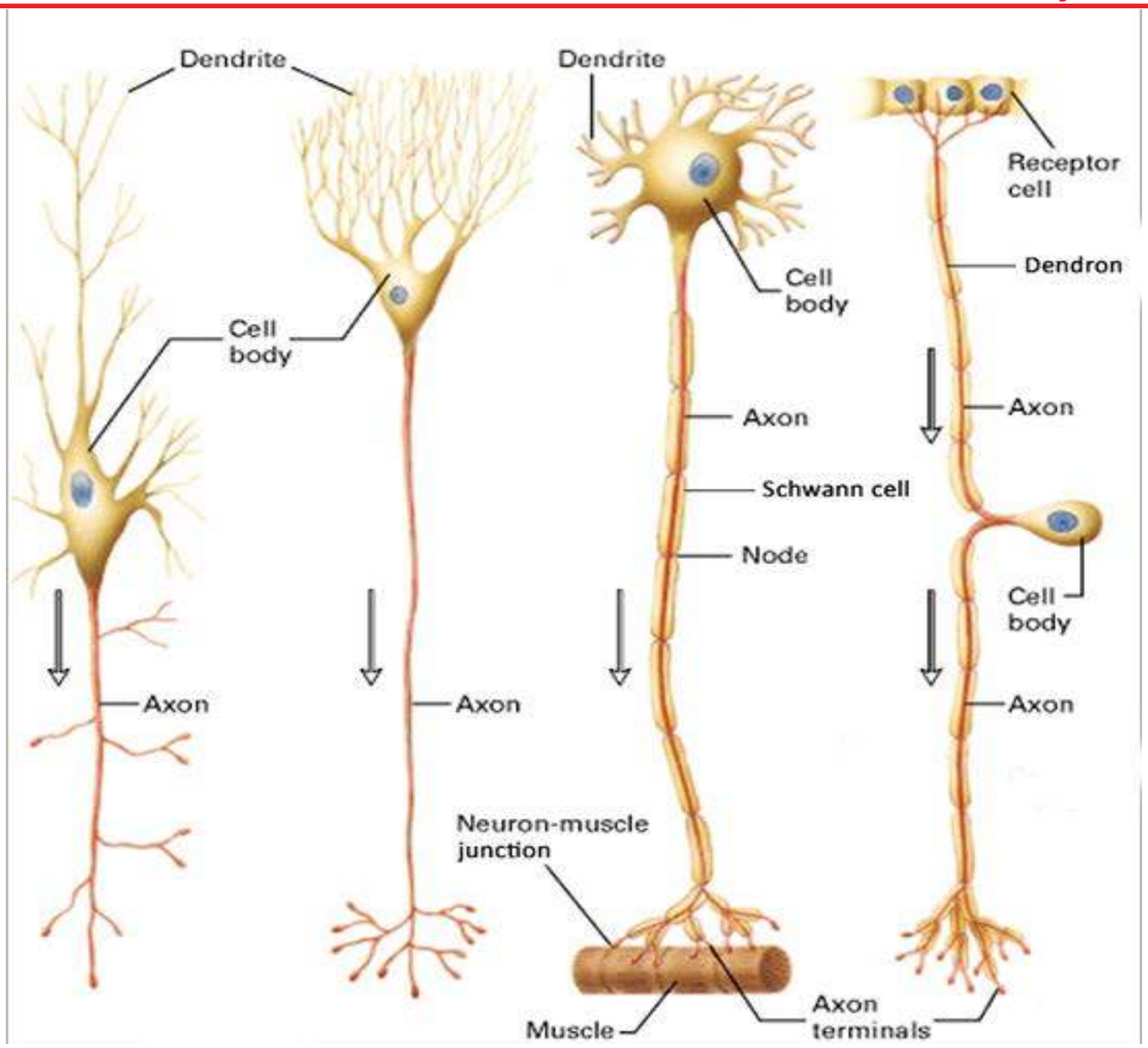



*Fig 17.2 Avariety of neuron types in human, beings.*

(a) The dendrites unlike the axon, often give a spiny look. (b)The dendrites of certain brain cells branch profusely, giving cell a treelike appearance, (c) Motor neurons have long axons that run from the C. nervous system to the effector (muscle); these axons are frequently,"but not always myelinated. Note the presence of many granules ip the cell body and dendrites and their absence from the axon.(d) Many sensory neurons have only one fiber, which branches a short distance from the cell body, one branch (peripheral) running between the receptor site and the dorsal-root ganglion in which the cell body is located, and the other branch (central) running from the ganglion into the spinal cord or brain. Except for its terminal portions, the entire fiber is structurally and functionally of the axon type, even 'though the peripheral branch c mducts impulses toward the cell body. A sensory neuron of this type thus has no true dendrites a though the peripheral branch is often called a dendron because of the direction in which it conducts impulses.

The neuron has protoplasmic processes arising from its cell body containing nucleus and various organelle embedded in the cytoplasm. There are two main types of cytoplasmic processes or fibres. The one which carry impulse towards cell body is called **dendron**, if it is a single fibre but if smaller fibres _they are called **dendrites** (singular: dendrite). The processes conducting impulses away from cell body are termed axons. These may be more than a meter long in some neurons. **Nissl's granules** which are groups of ribosomes associated with rough E.R, and Golgi apparatus are present in the cell body. Microtubules, neurofibrils, rough endoplasmic recticulum and mitochondria are present throughout the axoplasm (cytoplasm of axon) of the neuron.

The cell body or soma is the main nutritional part of the cell and is concerned with the biosynthesis of materials necessary for the growth and maintenance of the neuron. If the cell body of the neuron remains intact, it can regenerate axonal and dendrite fibres; but neurons once mature, do not divide any further.

## 3. Effectors

These are the structures which respond when they are stimulated by impulse coming via motor neuron. The principal effectors are glands, which respond by secreting; and muscles which respond by contracting. Flow of information through the nervous system is explained with the help of a reflex arc.

## Reflex Arc

Flow of impulse through the nervous system involving receptors, neurons, and effectors will be clear if we study an example of a reflex arc.

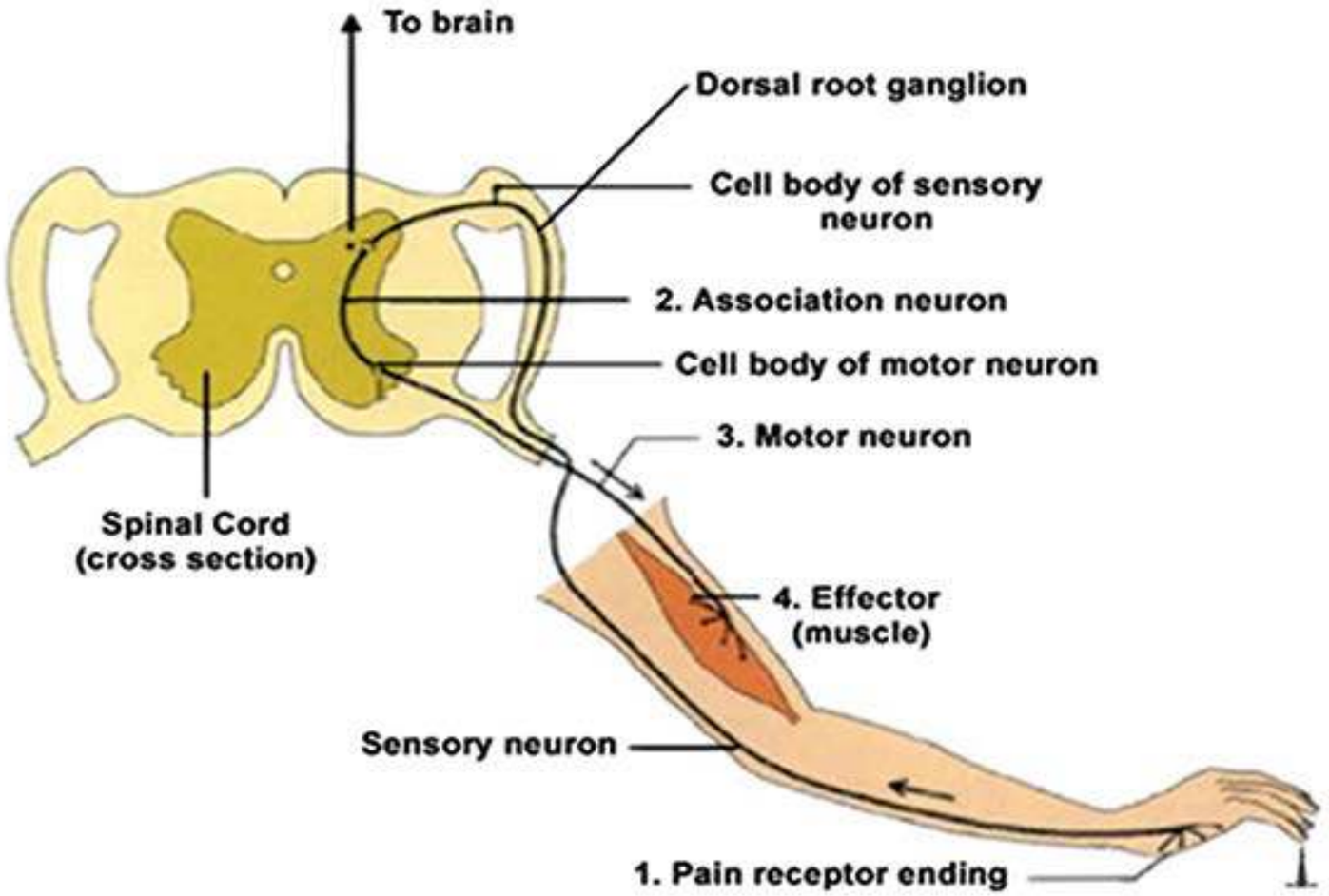



*Fig. 17.3 The pain-withdrawal reflex*

This simple reflex circuit includes each of the four elements of a neural pathway. (1) The sensory neuron has pain-sensitive endings in the skin and a long fiber leading to the spinal cord. That neuron stimulates (2) an association neuron in the spinal cord, which in turn stimulates (3) a motor neuron, also in the cord. The axon of the motor neuron carries action potentials to (4) muscles, causing them to contract and withdraw the body part from the damaging stimulus. The sensory neuron also makes a synapse on association neurons not involved in the reflex that carry signals to the brain, informing it of the danger.

Reflex arc is the path way of passage of impulse during a reflex action. Reflex action is a type of involuntary action. (Fig. 17.3). The direction of stimulus is from receptors to sensory neuron to associative (association / relay) neuron and then through motor neuron to the effectors.

*Animation17.7: Reflex rotuline*
*Source and Credit: Corpshumain*

# Nerve Impulse

Nerve impulse is a wave of electrochemical changes, which travels along the length of the neuron involving chemical reactions and movement of ions across the cellmembrane. Electrical potential is a measure of the capacity to do electrical work. It represents a type of stored energy which is-manifested during separation of charges across a barrier. In the case of neuron, the charges are positive and negative ions, and the charge separating barrier is the plasma membrane. The electrical potential that exists across a cell membrane is known as **membrane potential**. A typical neuron at rest is more positive electrically outside than inside the cell membrane. This net difference in charge between the inner and the outer surface of a non-conducting neuron is called the **resting membrane potential.** The major factors which are involved in resting membrane potential are:

**1. Sodium and potassium ions:** Of the many kinds of ions present in the nerve cells and the surrounding fluid, sodium ($Na^+$) and potassium ($K^+$) ions are the most important. Sodium ions are tenfold higher in concentration outside than inside the membrane surface, whereas potassium ions are twenty times more concentrated inside than outside. All the neurons have very active sodium and potassium pumps located in their cell membranes. Driven by the splitting of ATP, these pumps transport $Na^+$ out and $K^+$ into the cell, both against their respective concentration gradients. For every two $K^+$ that are actively transported inward, three $Na^+$ are pumped out. So inside becomes more negative than the outside ofthe cell membrane o f neurons. (Fig. 17.4)

**2. Negative organic ions:** The large negative organic ions (such as proteins, organic acids etc) are much more inside the membrane than outside, where they are only in negligible concentration. This makes the inside of neuron membrane more negative.

**3. Leakage of K+ ions from neurons:** The cell membrane is virtually impermeable to all ions except K+. Since the membrane is slightly permeable to K+, some of it leaks out of the cell. The loss of this positive ion from the neuron by diffusion accounts for more negative'charges inside than outside the cell membrane of neuron.

**4. No conduction of nerve impulse**

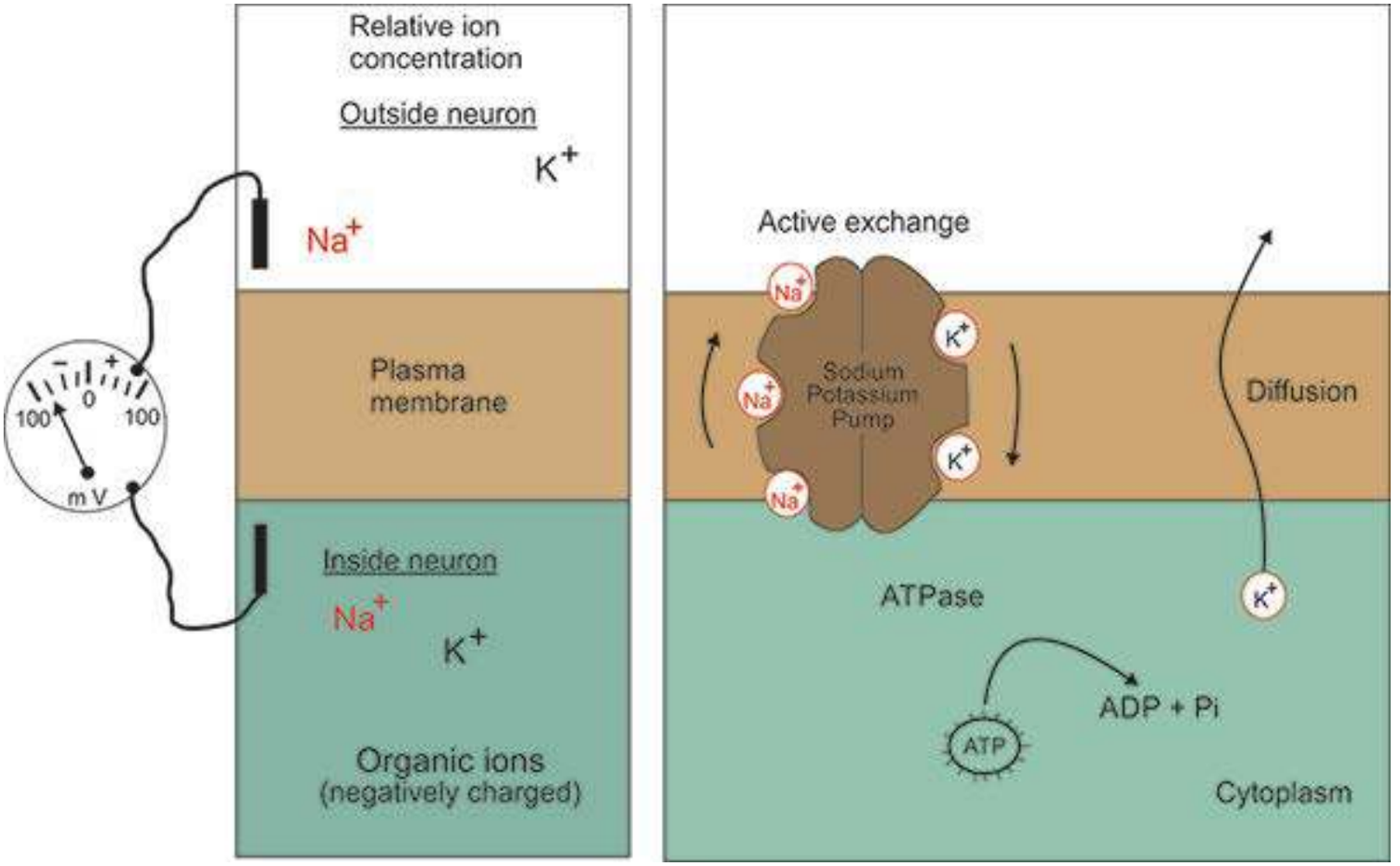



*Fig. 17.4 Resting potential*

(a) In the unstimulated state, a neuron has a membrane potential of approximately - 70mV. The relative concentrations of the principal ions inside and outside the neuron are indicated by the sizes of the chemical'"symbols (Na+ = sodium ion, K+ = potassium ion), (b) Two of the major processes that contribute to the negative resting potential are the active exchange of Na+ for K+, .and the outward diffusion of K+. The sodium - potassium pump actively transports Na+ out and K+ into the cell, and is powered by the splitting of ATP by an associated enzyme, ATPase.

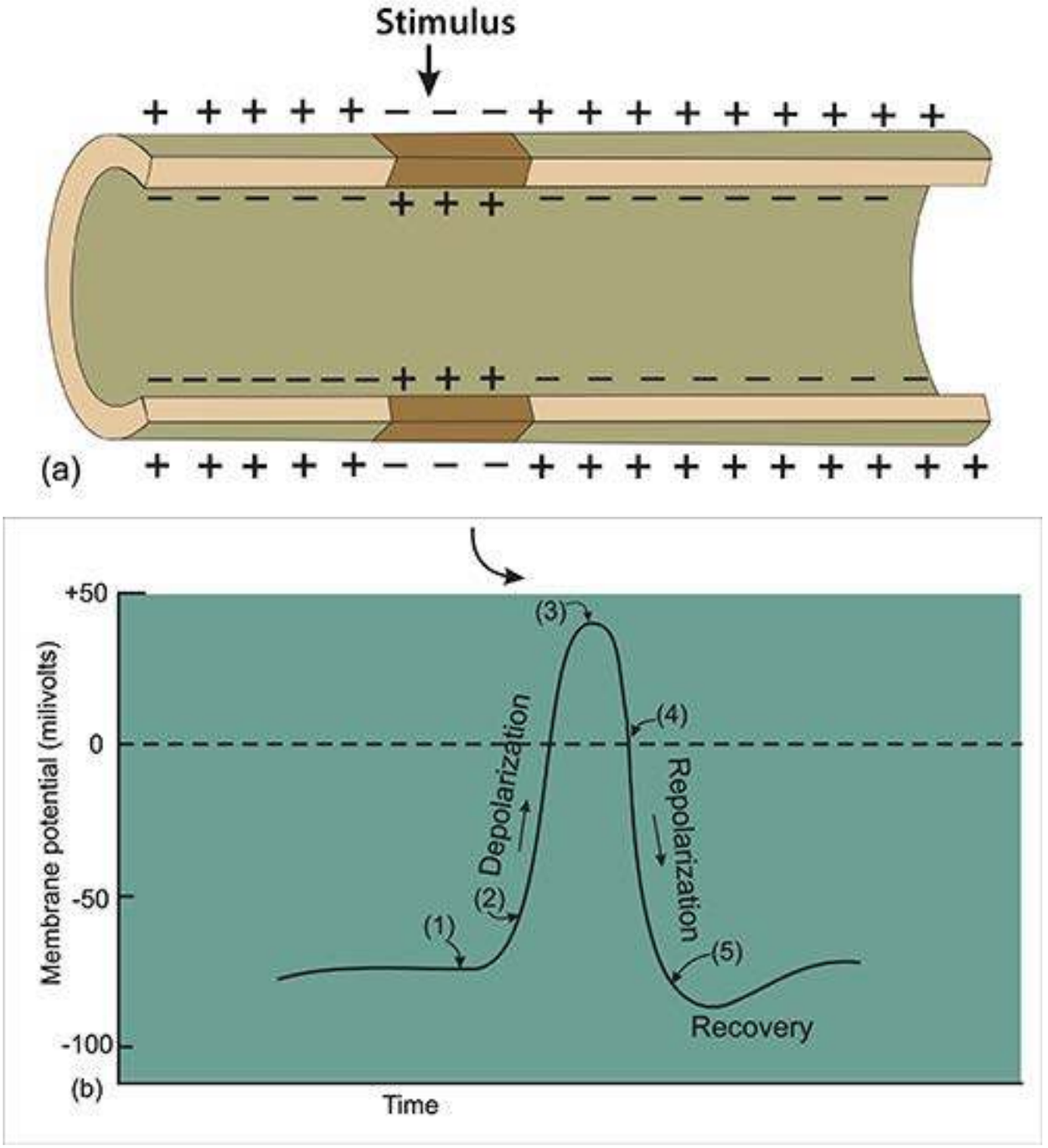
**Initiation of nerve impulse:** Under normal conditions a nerve impulse is initiated by an appropriate stimulus (called threshold stimulus) applied at one end of the neuron and it results in a remarkable localized change in the resting mefmbrane potential.

*Animation17.8: Diporepol*
*Source and Credit: cybercuba*

It disappears for a brief instant and is replaced by a new potential called **action** or **active membrane** potential which is in the form of impulse. During this state, the inner membrane surface becomes more positive than the outside. This change is so brief (for perhaps a millisecond) that only a portion of the neuron is in the active membrane potential state.
The major factors involved in changing the resting membrane potential to active membrane potential are: (Fig 17.5)

**1. $Na^+$ and $K^+$ ions movement:** The passage of nerve impulse is associated with increase in permeability of $Na^+$ ions moving inwards upsetting the potential momentarily, making the inside more positive than outside. Neurophysiologists believe that the increased permeability is due to the opening of specific pores in the membrane, termed “sodium gates”. When these gates open, sodium ions rush into the neuron by diffusion. Some $K^+$ moves out.

**2. Charges are reversed:** The inner side of the cell membrane has excess of positive ions (thus positive charges) at its internal surface, and the outer surface becomes more negative.




*17.5 Active or action potential*

(a) When a neuron is stimulated, the cell membrane at the point of stimulation undergoes a momentary reversal in charge (dark color) called an action potential. Perhaps for a millisecond, the inside of the membrane becomes positive relative to the outside, (b) Sequence of membrane potential changes associated with an action potential: (1) resting potential (polarized state); (2) sodium gates open and Na+ diffuses into the cell, causing a depolarization of the membrane; (3) ; sodium gates close and potassium gates open; (4) K+ diffuses out, causing a repolarization of the membrane; (5) sodium - potassium pump restores original ion gradients and resting potential (recovery). Steps (2) - (5) take a mere 2- - 3 milliseconds.

**3. Passage of nerve impulse:** During active membrane potential, the neuron conducts the impulse in the form of nerve impulse.

**4. Membrane potential:** Active membrane potential of +0.05 volts (+50mv) exists.
These changes occur along the length of neuron till the impulse reaches synapse. Soon after passage of the impulse, the resting membrane potential is restored by the movement of a small number of ions especially K+ moving out. This neuron now is ready to conduct another impulse.

It may be added that in myelinated neurons the impulse jumps from node to node (node of Ranvier). This is called **saltatory impulse.**

The normal speed of nerve impulse in humans is 100 meters per second but maximum speed recorded is 120 meters per second.

## Synapse

Consecutive neurons are so arranged that the axon endings of one neuron are connected to the dendrites of the next neuron. There is no cytoplasmic connection between the two neurons and microscopic gaps are left between them. Each of these contact points is known as **synapse.**

A single neuron may form synapses with many incoming fibres of different neurons.

A nerve impulse is passed from one neuron to the other through the synapse, but a single impulse does not necessarily get across the synapse. It may take two or three impulses arriving in rapid succession or perhaps simultaneously from two or more fibres to start an impulse in the next neuron.

The action potential cannot jump from one neuron to the next in line; rather the message is transmitted across synapse in the form of chemical messenger called neurotransmitter.

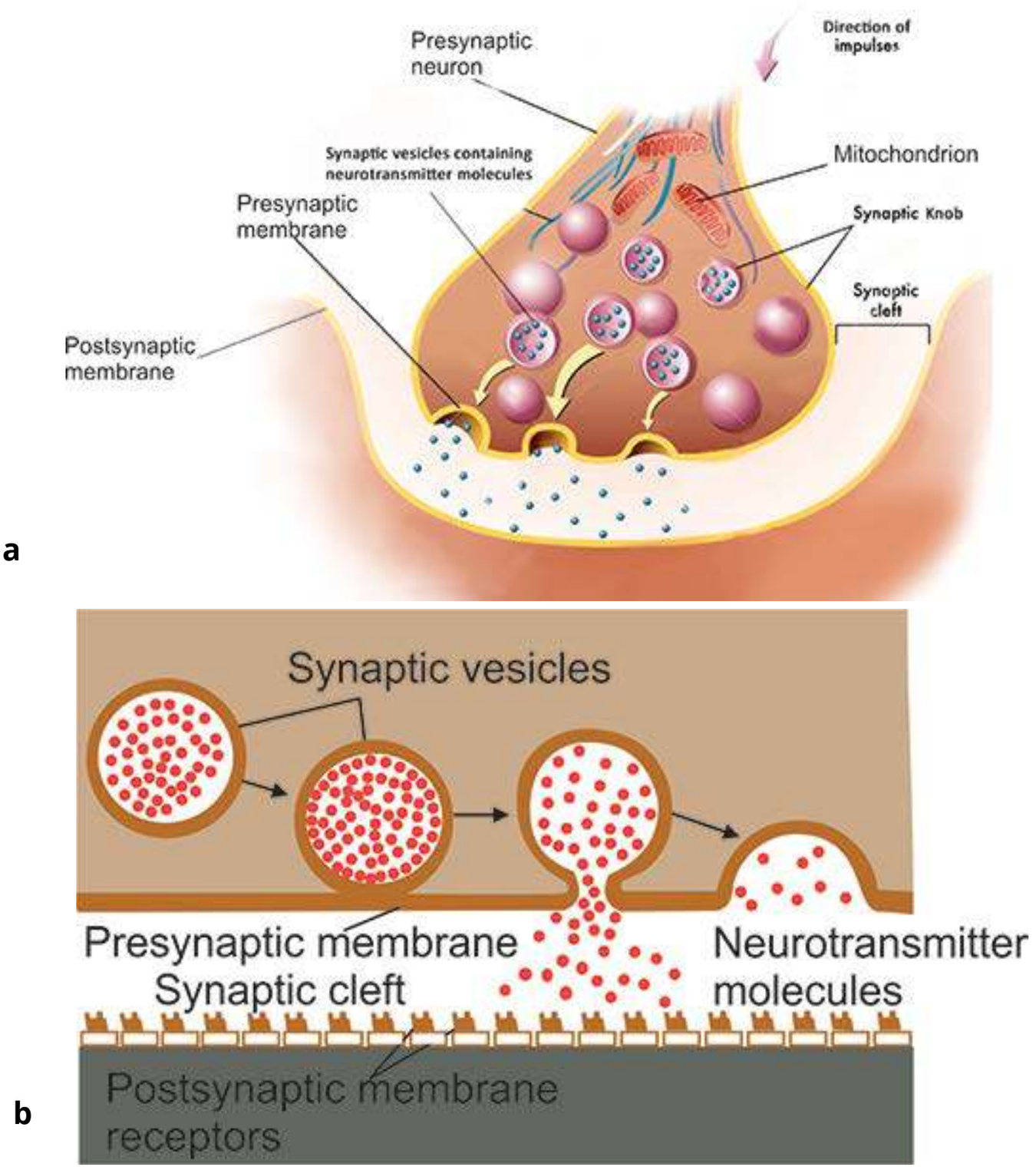



*Fig 17.6 Communication across a synapse*

When an impulse reaches a synaptic knob, synaptic vesicles within fuse with the presynaptic membrane, causing the release of neurotransmitter molecules into the synaptic cleft. The neurotransmitter molecules bind to the receptors, on the postsynaptic membrane, triggering an action potential in the postsynaptic neuron, by causing changes in its permeability to certain ions. (Fig. 17.6)

Neurotransmitters are chemicals which are released at the axon ending of the neurons, at synapse. Many different types of neurotransmitters are known. These are: acetylcholine, adrenaline, nor-epinephrine, serotonin and dopamine.
Acetylcholine is the main transmitter for synapses that lie outside the central nervous system. Others are mostly involved in synaptic transmission within the brain and spinal cord.

## Evolution of Nervous System

There are two designs of nervous system in the animal kingdom.

1. A diffused nervous system, such as that of Cnidarians (Hydra, jelly fish and their relatives)
2. A centralized nervous system, found to varying degrees in more complex organisms, from platyhelminthes to chordates including humans.

To understand the organization of the above mentioned types of nervous system, we would study them in *Hydra*, *Planaria* and humans. Nervous system design is highly co-related with the animal's life style. The first main type of nervous system is a diffused nervous system. Hydra shows this type of nervous system (Fig. 17.7a).

*Hydra,* a cnidarian, is a small animal which is sedentary in its life style and prey and other dangers are equally likely to come from any direction. Its nervous system consists of a network of neurons, which is present between the ectoderm and endoderm. There is no head in this animal and so there is no centralized nervous system i.e. no brain and nerve cords etc. However, a cluster cell of bodies of neuron's forming ganglia can be seen here and there. It has been observed that neurons are so arranged in the network that it is not possible to distinguish them in connected functional types of neurons as in higher animals i.e. there are no sensory, associative (inter/relay) neurons, or motor neurons, there are no specialized sense, organs in this animal. It has been observed and studied that when an appropriate stimulus is given, *Hydra* responds - and almost the whole body of the animal responds as a unit. The tentacles are more responsive and react to the stimulus instantaneously (Fig. 17.7a).

The second type of nervous system is present in Planaria (Fig. 17.7b) and humans. It is centralized nervous system. The nervous system of *Planaria* is better developed as compared with that of *Hydra* because in *Planaria*:

(i) There is beginning of a centralized nervous system. In the anterior brain region of the body of *planaria,*
there is a bilobed mass composed of two ganglia. This acts as a "brairr "or a centralized collection of neurons. This receives and sends impulses from and to different parts of the body. There is no such concentration of neurons or a coordinating centre in *Hydra* - only a network of neurons is present.

(ii) There is differentiation of neurons into sensory associative and motor neurons. In *Planaria*, associative neurons are present in the brain and longitudinal nerves. Sensory neurons carry impulse to 'brain' or nerves and motor neurons carry impulse from central nervous system to different parts of the body. In *Hydra* there is no differentiation of neurons.

(iii) In *Planaria* at the anterior region, sense organs in the form of eyes and chemoreceptors are present. There are no specialized sensory organs in *Hydra*.

(iv) The receptor cells sensitive to pressure and touch-are present in *Planaria*. There are no specialized sensory cells in *Hydra*, but some nerve cells are moo, sensitive, to a particular stimulus - chemical or mechanical, than others.

(v) There are definite nerves, the longitudinal and lateral in Planaria. There are no nerves in *Hydra.*
(vi) In **Planaria** in addition to a superficial nerve net just below epidermis, there is a deeper plexus embed 7.7a).

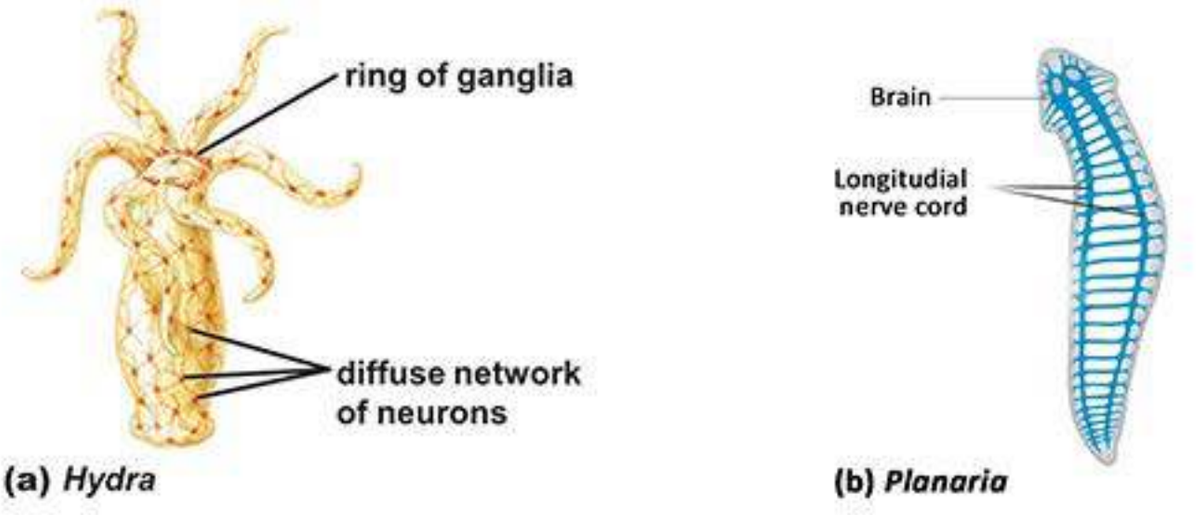
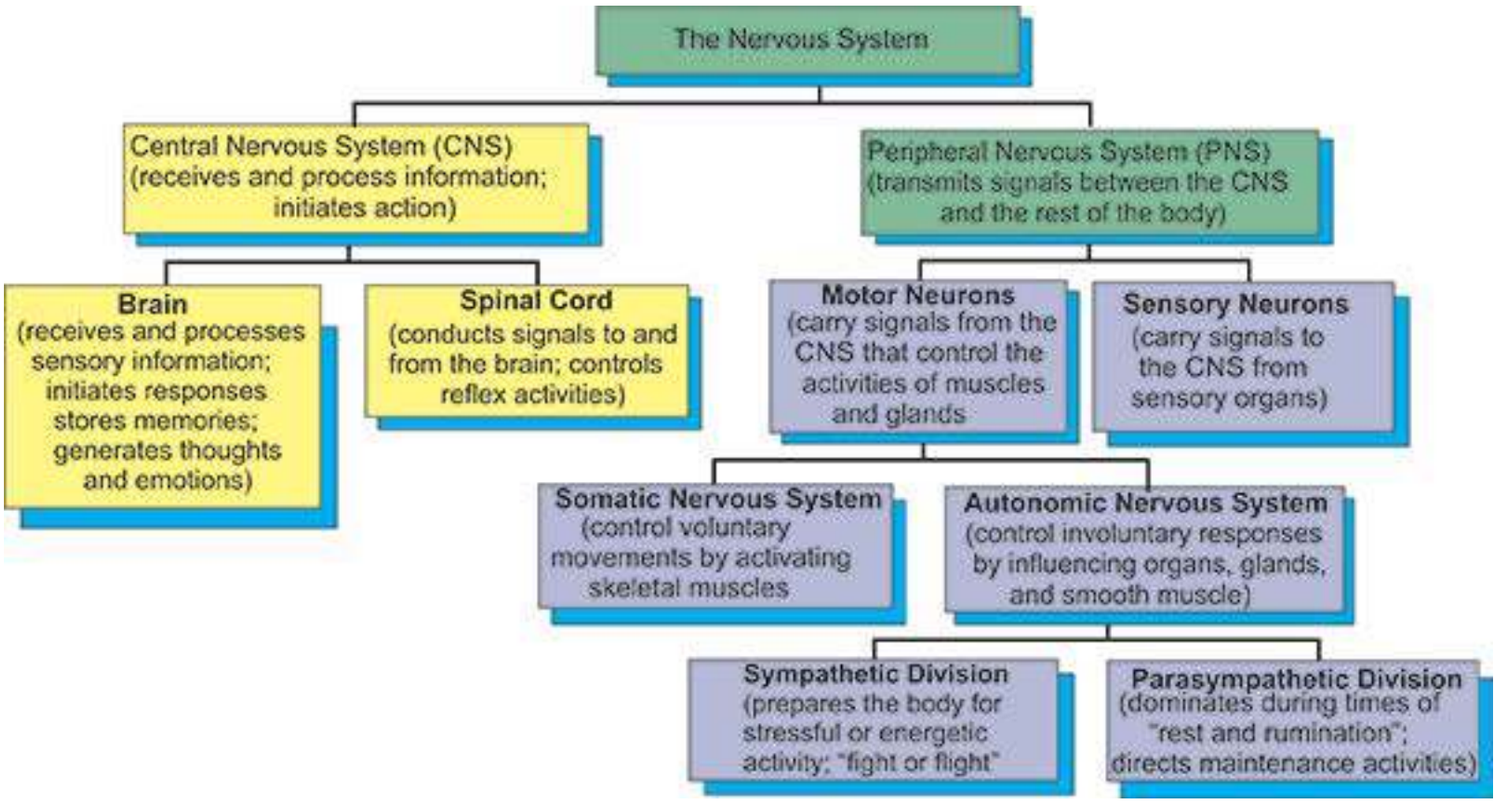



*Fig. 17.7 Nervous systems in Hydra and Planaria.*




*17.8 Classification of the human nervous system*

## HUMAN NERVOUS SYSTEM

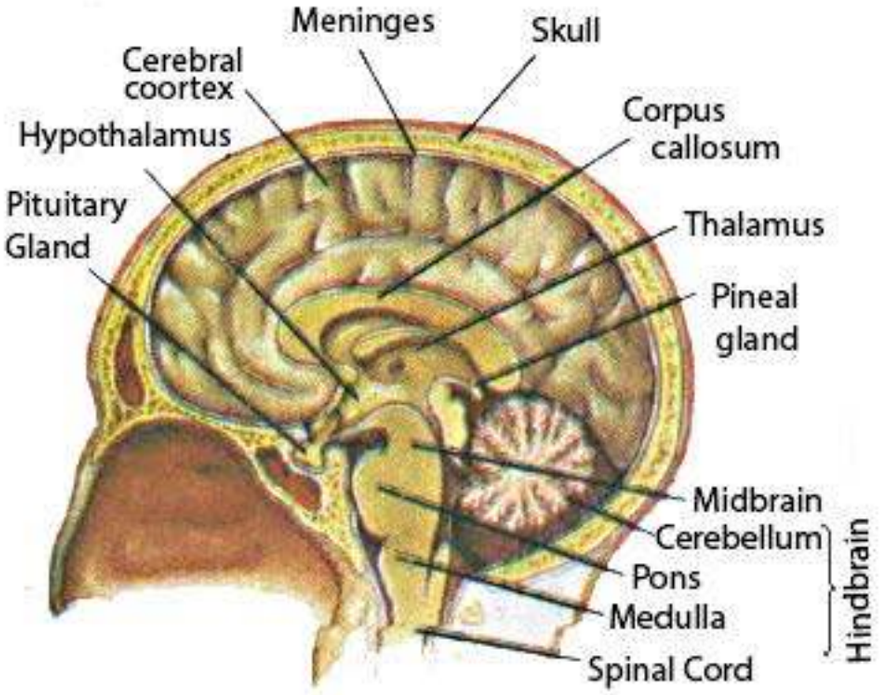
Human nervous system is a type of centralized nervous system. Its classification in different subdivisions and different functions performed by these subdivisions are given in Fig 17.8.

# Central Nervous System (CNS)

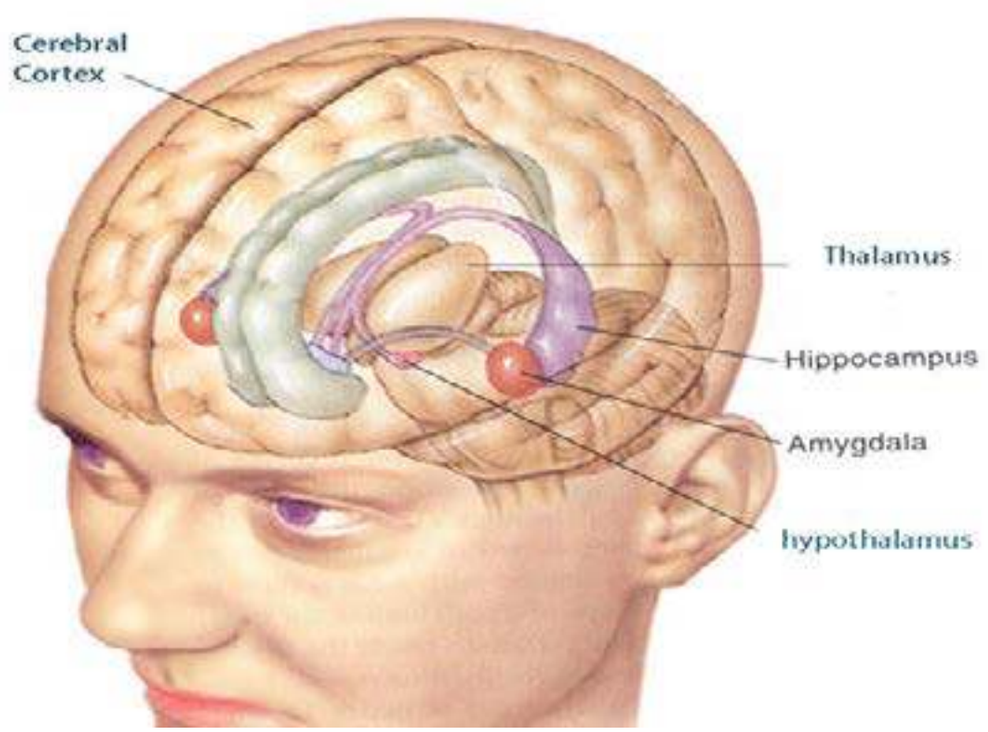
The CNS consists of brain (Fig. 17.9) and spinal cord, which are both protected in three ways. Cranium, which is a part of skull, protects the brain and neural arches, of vertebrae of vertebral column protect the spinal cord. The brain and spinal cord are also protected by triple layers of meninges. The cerebrospinal fluid (CSF), similar in composition to blood plasma, bathes the neurons of brain and spinal cord and it cushions against the bumps and jolts. Both brain and spinal cord are hollow. The spinal cord has central canal and brain has many cavities (ventricles) filled by CSF, which is also present between the meninges.

**Brain:** The brain can be divided into forebrain, midbrain and hindbrain. Forebrain is further divided into three functional parts, the thalamus, the limbic system (Fig. 17.10) and the cerebrum. Thalamus carries sensory information to the limbic system and cerebrum. The information includes sensory input from auditory and visual pathways, from the skin and from within the body.

The limbic system is located in an arc between the thalamus and cerebrum. Limbic system works together to produce our most basic and primitive emotions, drives, and behaviours, including fear, rage, tranquillity, hunger, thirst, pleasure and sexual responses. Portion of limbic system is also important in the formation of memories. The limbic system consists of hypothalamus, the amygdala, and hippocampus, as well as nearby regions of cerebrum. The hypothalamus through its hormone production and neural connections acts as a major co-ordinating centre controlling body temperature, hunger, the menstrual cycle, water balance, the sleep-wake cycle etc.
n the amygdala, clusters of neurons produce sensation of pleasure, punishment or sexual arousal when stimulated. It is also involved in the feelings of fear and rage.




*17.9 The human brain*
A section through the midline of the human brain reveals some of its major structures.




17.10 The limbic system and thalamus
The limbic system extends through several brain regions. It seems to be the center of most unconscious emotional behaviors, such as love, hatred, hunger, sexual responses, and fear. The thalamus is a crucial relay center among the senses, the limbic system, and the cerebral cortex.

I

Hippocampus plays an important role in the formation of long term memory, and thus is required for learning. Cerebrum is the largest part of the brain and is divided into two halves, called cerebral hemispheres. These halves communicate with each other by means of a large band of axons, called corpus callosum.

Tens of billions of neurons are packed into this part. The outer region, the cerebral cortex, forms folds called convolutions, which greatly increase its surface area. This part receives sensory information, processes it, stores some in memory for future use, directs voluntary movements, and is responsible for the poorly understood process that we call thinking.

The cerebral cortex contains primary sensory areas where signals originating in sensory organs such as eyes and ears are received and converted into subjective impressions, such as light and sound. Nearby association areas interpret this information. This area is also involved in speech and also receives and interprets sensations of touch from all parts of the body. This area is also a centre for sending impulses to voluntary muscles, controlling movements. This is also involved in intelligence, reasoning and judgement.

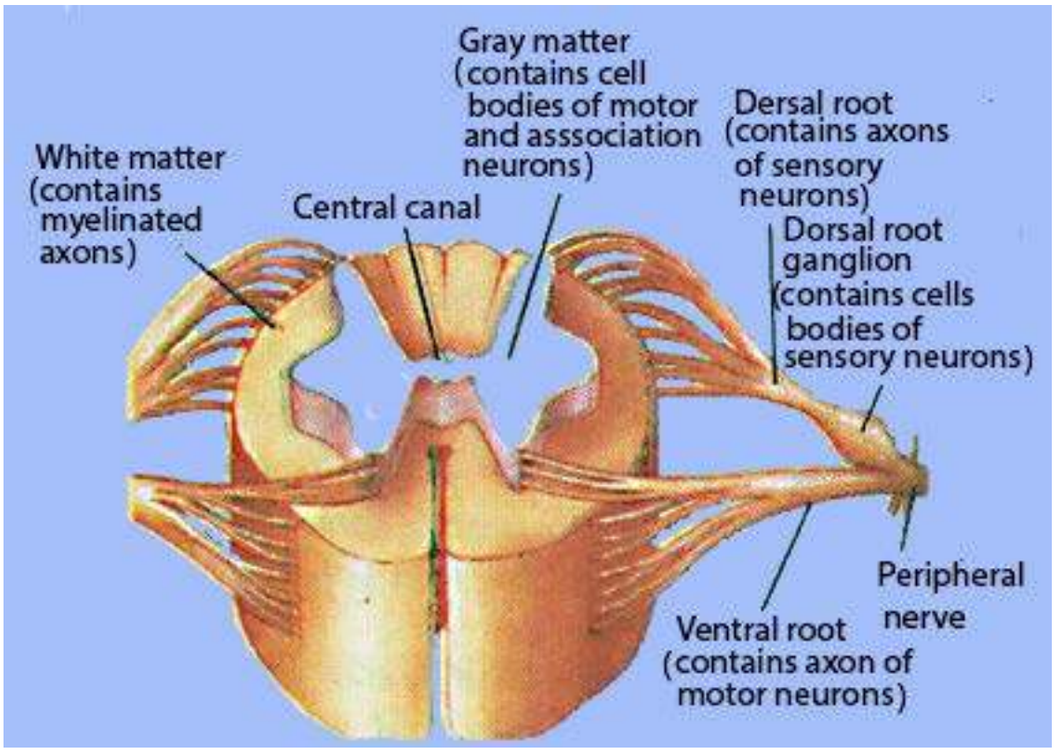
The left cerebral hemisphere controls the right side of the body, and right cerebral hemisphere controls the left side of the body. **Midbrain** is reduced in humans, and it contains auditory relay centre and centre that controls reflex movements of eyes. Midbrain contains reticular formation, which is a relay centre connecting hindbrain with the forebrain. Reticular formation is very important in screening the input information, before they reach higher brain centres. **Hindbrain** includes the medulla, pons and cerebellum. Medulla controls several automatic functions, such as breathing, Heart rate, blood pressure and swallowing. Certain neurons in pons, located above the medulla, appear to influence transitions between sleep and wakefulness, and the rate and pattern of breathing. The cerebellum is important in co-ordinating movements of the body. The cerebellum guides, smooth and accurate motions and maintains body position. The cerebellum is also involved in the learning and memory storage for behaviours. It is best developed in bird , which is engaged in the complex activity of flight.

**Spinal Cord:** Medulla oblongata narrows down into an oval shaped hollow cylinder, the spinal cord, running through the vertebral column. It is made up of a very large number of neurons, the cell-fibres and bodies of which are arranged in a definite pattern. In cross section, the spinal cord shows an inner butterfly shaped grey matter, containing a central canal and the outer portion composed of white matter. Gray matter, as in other parts of nervous system consists of cell bodies and non-myelinated nerve fibres or tracts. White matter is made up of myelinated nerve fibres or tracts.

The spinal cord is the centre for great many reflexes and it serves as a pathway for conduction of impulses to and from different parts of the body and brain (Fig 17.11).

## Peripheral Nervous System (PNS)

It comprises of sensory neurons and motor neurons, which may form ganglia and the nerves. Ganglia are the concentrations of cell bodies of neurons. The nerves are the bundles of axons or dendrites, bounded by connective tissue. They may be sensory motor or mixed nerves depending upon the direction of impulse they conduct. In humans, there are 12 pairs of nerves, which arise from the brain, or lead to the brain. These nerves are called **cerebral** or **cranial nerves**. Some of these nerves are sensory, some motor, and some are mixed. From the spinal cord 31 pairs of spinal nerves arise or lead to spinal cord. All these nerves are mixed having fibres of both sensory and motor neurons.




*17.11 The Spinal cord*

Motor neurons form somatic nervous system, which controls voluntary movements, which are under the conscious control of the body, involving skeletal muscles. Motor neurons also form autonomic nervous system, which controls involuntary responses by influencing organs, glands and smooth muscles. The autonomic nervous system is further divided into sympathetic nervous system and para sympathetic nervous system (Fig 17.9).

## Autonomic Nervous System

The motor neurons of autonomic nervous system are divided into the sympathetic and para sympathetic system. Both of these systems function automatically, innervate all internal organs, utilize two neurons and one ganglion for each impulse.

**Sympathetic system :** Most ganglion fibres of the sympathetic system arise from the middle protion of the spinal cord and almost terminate in ganglia that lie near the cord. This system is important during emergency situations and is associated with "fight or flight." This system accelerates the heart beat, dilates the pupil and inhibits the digestion of food etc.

**Parasympathetic system :** A few cranial nerves including the vagus nerve together with the nerves from the bottom portion of spinal cord, form the parasympathetic nervous system. It promotes all the internal responses which are associated with the relaxed state i.e. contraction 6f the pupils, promotes digestion of food, retards heart beat etc.

## Nervous Disorders

Following are some of the common disorders of nervous system in humans:

**1. Parkinson's disease :** It is a nervous disorder, characterized by involuntary tremors, diminished motor power and rigidity. The mental faculties are not affected. The disease is believed to be caused by cell death in a brain area that produces dopamine. Onset of disease is usually in 50's and 60's. The disease is slowly progressive; the patient may live for many years. The disease may result by head trauma. Effective drugs are available such as L- dopa. A naturally occuring protein called glial cell-line derived: neurotrophic factor (GDNF) has been shown to boost uptake'ofdopamine, when delivered to lab. rats and monkeys. GDNF may be used in near future for humans in the treatment of this disease.

**2. Epilepsy:** It is one of the convulsive disorders of nerves which are characterized by abrupt transient symptoms of motor, sensory, psychic or autonomic nature, frequently associated with changes in consciousness. These changes are believed to be secondary to sudden transient alterations in brain function associated with excessive rapid electric discharges in the gray matter. The onset of epilepsy is usually before age 30. Later age onset suggests organic disease. In some patients, emotional disturbances play a significant "trigger" role. Electroencephalography is the most important test in the study of epilepsy. Anticonvulsant drugs are used. Alcohol aggravates epilepsy, so persons suffering from epilepsy should avoid alcohol.

**3. Alzheimer's disease:** Alzheimer's disease was first described by Alois Alzheimer in 1907. It is characterized by the decline in brain function. Its symptoms are similar to those diseases that cause dementia (memory loss). There is a genetic predisposition to the disease in some people, so it tends to run in families. There is also evidence that high levels of aluminium may contribute to the onset of this disease. There is also decline in brain function with age.

## Effect of Drugs on Coordination

**Action of Nicotine:** Nicotine affects post synaptic membrane in CNS and PNS. It mimics the action of acetylcholine on nicotine receptors, so it is stimulant of nerve impulse. It increases the heart beat rate, blood pressure and digestive tract mobility. Nicotine may induce vomiting and diarrhoea and even may cause water retention relation by kidneys.

## CHEMICAL COORDINATION

In animals, it involves endocrine system which comprises endocrine glands in various parts of the body, which secrete hormones. The endocrine or ductless glands are, with a few exceptions, discrete groups of cells, which make specific chemical compounds called hormones (Greek hormone is exciting, setting in motion). Endocrine system consists of some 20 endocrine glands/tissues lying in different parts of the body.

# Hormones

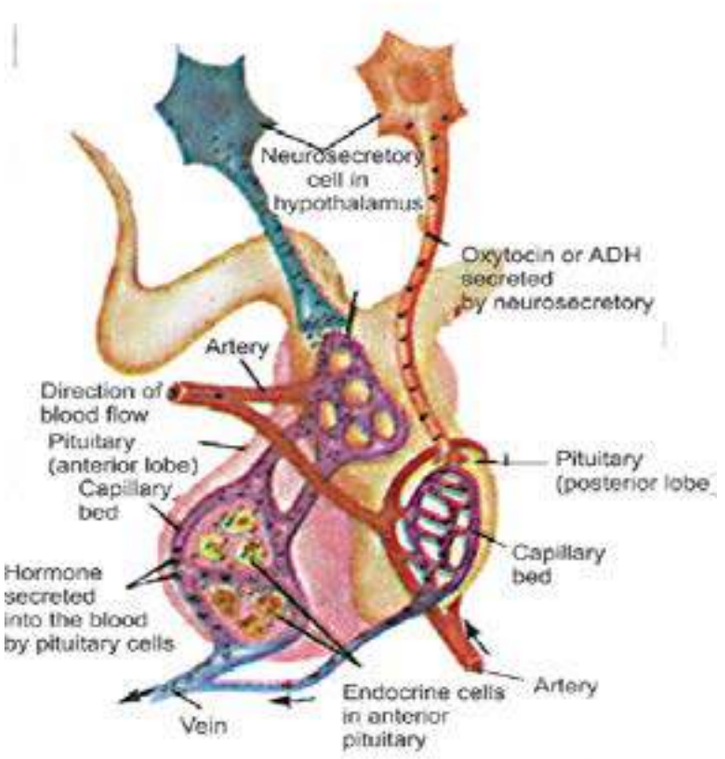
Hormones are organic compounds of varying structural complexity (see below). They are poured directly and are transported to blood to respective target tissues. The hormones affect the target cells. They do not initiate new biochemical reactions but produce their effects by regulating enzymatic and other chemical reactions, already present. They may either stimulate or inhibit a function. Hormones may also control some long term changes, such as rate of growth, rate of metabolic activity and sexual maturity.

Chemically hormones may be of following four types:
(i) Proteins (e.g. insulin and glucagon .) (ii) Amino acids & derivatives (e.g. Thyroxine, epinephrine and norepinephrine) (iii) Polypeptides (e.g. vasopressin or anti-diuretic hormone and oxytocin), and (iv) Steroids (e.g. oestrogens, testosterone and cortisone.)

# ENDOCRINE GLANDS OF MAMMALS

## Hypothalamus

It is a part of the forebrain. It is here that many of the sensory stimuli of nervous system are converted into hormonal responses. It is believed that oxytocin and antidiuretic hormone (ADH) are produced in hypothalamus and travel down the nerves to the posterior lobe of pituitary to be stored. They are released from their storage after receiving nerve impulses from the hypothalamus. (Fig 17.13)




*17.13 The Hypothalamus - Pituitary Connection.*

Neurosecretory cells in the hypothalamus produce and secrete a variety of hormones. One of the nerve clusters synthesizes oxytocin and vasopressin, then stores them in nerve endings located in the posterior pituitary. Upon proper stimulation from the brain, oxytocin and vasopressin are released into the blood supply of the posterior pituitary. Other nerve clusters in the hypothalamus produce and secrete a battery of releasing and inhibiting hormones, which are carried by the blood to the anterior pituitary. There, they regulate the secretion of various tropic hormones, growth hormone, and prolactin manufactu red by the anterior pituitary cells.

# The Pituitary Gland

In man, the pituitary gland or hypophysis cerebri is an ovoid structure about 0.5 gm in the adult and is connected to brain through a short stalk (the infundibulum). It has three lobes viz, anterior, median and posterior. The anterior lobe is often referred to as the master gland, because in addition to producing primary hormones it produces the tropic hormones which control the secretion of homones in many of the other endocrine glands (Fig. 17.13).

**Anterior lobe:** Anterior lobe of pituitary secretes the following hormones:

**1. Somatotrophin hormone (STH) :** Somatotrophin releasing factor (SRF) is secreted from hypothalamus throughout the life. When growth has mostly ceased after adolescence, the hormone continues to promote protein synthesis throughout the body. If produced in excess during early life, leads to gigantism or if later in life causes the abnormal development of hands, feet, jaws, etc. (known as acromegaly). If there is undersecretion, dwarfism results, as well as other symptoms associated with lack of thyroid and adrenal hormone.

**2. Thyroid stimulating hormone (TSH) :** Release of thyrotroph in releasing factor from the hypothalamus is controlled by the levels of nuyoxine in the blood. In the presence of low levels of thyroxine, there is increasing production of TSH and vice versa (Fig 17.16). It is secreted throughout life but particularly reaches high levels during the periods of rapid growth and development. It acts directly on the cells of the thyroid gland, increasing both their numbers and their secretory activity (Fig. 17.15).

**3. Adrenocorticotrophic hormone (ACTH) (Corticotrophic hormone):** Release of corticotrophin releasing factor from the hypothalamus is controlled by steroid levels in the blood and by direct nervous stimulation of the hypothalamus as a result of stress e.g. cold, heat, pain, fright, infections. Excess and deficiency results ui disturbance of normal adrenal functions.

**4. Gonadotrophic hormones (GH) :** These are follicle stimulating hormone (FSH), luteinising hormone (LH also called interstitial cell stimulating hormone ICSH, in the male), prolactin (sometimes inappropriately called luteotrophic hormone, LTH).

FSH and LH/1CSH share a common hypothalamic releasing factor. Prolactin is continuously produced from the pituitary and is inhibited by prolactin inhibiting factor (PIH) from the hypothalamus. Prolactin stimulates milk production and acts with LH as described below. FSH in females stimulates follicle development and secretion of oestrogens from the ovaries; in males it stimulates development of the germinal epithelium of the testis and sperm production. LH works with FSH to stimulate oestrogen secretion and rupture of mature follicles to release egg or ovum. It also causes the lutenisation (lit. “turning yellow’) of the latter and acts synergistically with prolactin to maintain the corpus luteum (and hence the progesterone it secretes). ICSH in the male stimulates the interstitial cells of the testis to secrete testosterone.

**Median lobe :** Median lobe secretes the following hormone :

**Melanophore stimulating hormone (MSH) :** Its inhibition of secretion is controlled by hypothalamus. External light governs its secretion. More secretion in pregnancy stimulates melanocytes in skin to produce brown pigment, melanin, which darkens the skin. Excess MSH is secreted in Addison's disease. One of the symptoms of which is darkening of the skin.

**Posterior lobe:** Posterior lobe of the pituitary gland secretes the following hormones:
**1. Antidiuretic hormone (ADH) or Vasopressin:** Its secretion iscaused by decrease in blood pressure, blood volume, and osmotic pressure of the blood which is detected by osmoreceptors in hypothalamus. External' sensory stimuli also influence hypothalamic neurosecretory cells. Increased levels cause increased water reabsorption in distal parts of nephron. A lack of this hormone produce diabetes insipidus, characterized by production of large quantities o f dilute urine and great thirst.

**2. Oxytocin :** Its release is stimulated by distension of cervix, decrease in progesterone level in blood, and neural stimuli during parturition and suckling. Primary action is on smooth muscle, particularly in the uterus during childbirth, and also causes milk ejection from mammary glands.

## Thyroid gland

In mammals it consists of two lobes situated below the larynx (Fig. 17.15). It produces thyroxine (or tetraiodo-thyonine: T4), tri-iodothyronine or T3 (which has a structure similar to thyroxine with 3 iodine atoms rather than 4) and calcitonin hormone. The thyroid is active continuously but produces higher levels of secretions during periods of rapid growth and sexual maturation and in stress situations such as cold and hunger.

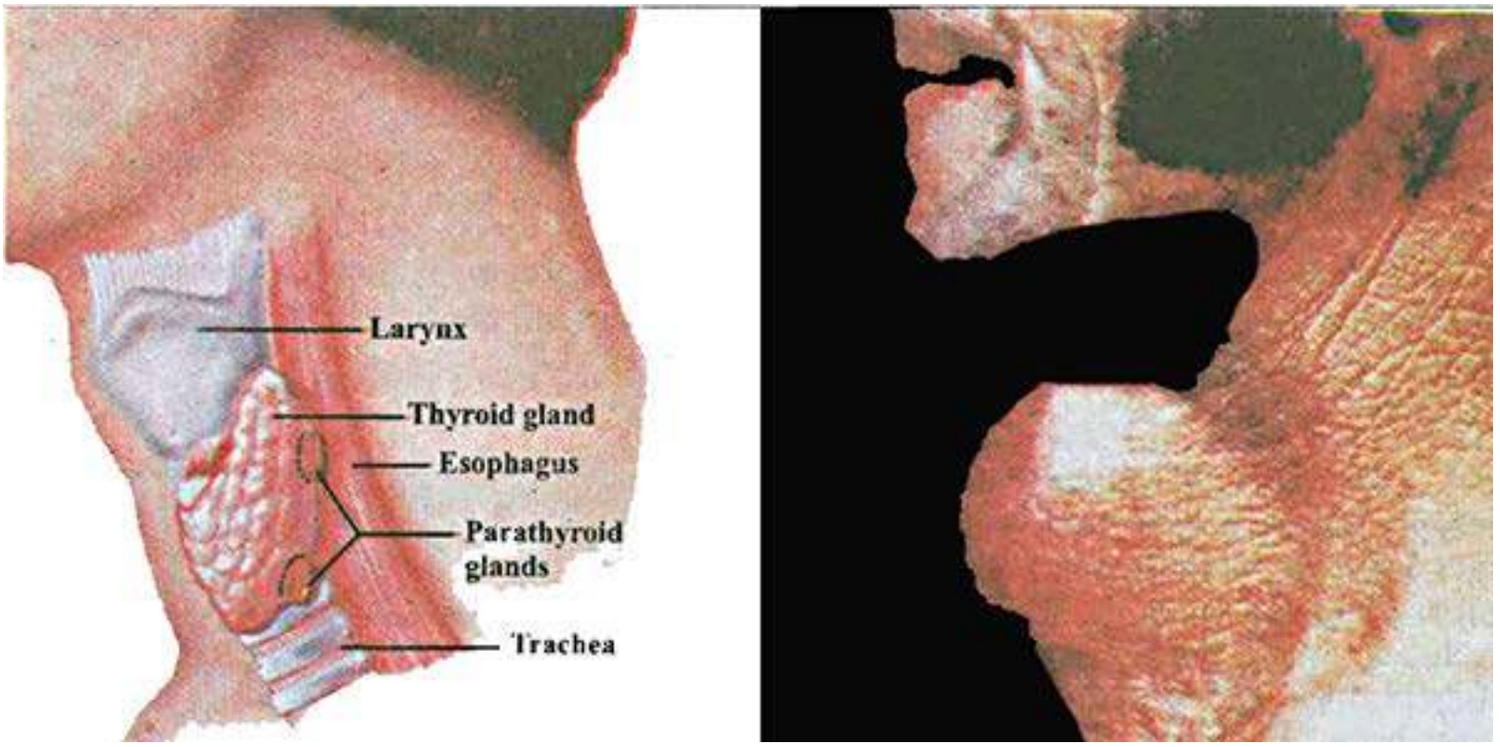
Thyroxine and tri-iodothyronine, the two hormones act in essentially the same way. They act on the basal metabolic rate by stimulating the breakdown of glucose and release of heat and generation of ATP. They also act in conjunction with somatotropin in bringing about growth, and act directly on brain cells causing them to differentiate. In amphibians, they bring about the process of metamorphosis. If secretion of thyroid is deficient,, tadpole larva of frog does not metamorphose to develop into frog, but instead grow to a large sized tadpole.

Excess thyroxine produces a condition called Graves' disease, with exophthalmic goiter and increase in the basal metabolic rate. This can lead to cardiac failure if prolonged. The cause of Graves' disease is the production of an abnormal body protein which continuously stimulates the thyroid to excessive secretion.

If congenitally deficient, the lack of thyroxine causes cretinism, where the individual fails to develop normally. They are small, have coarse scanty hair, thick yellowish scaly skin and are mentally retarded. They also fail to develop sexually. Deficiency later in life, perhaps due to iodine shortage in diet, produces swelling of the neck (goiter) and may lead to deposition of excess fat as a result of which'weight is increased. The condition is known as myxoedema, and it is characterized by puffiness of hands and skin.

All bodily and mental processes are retarded. High $Ca^{+}$ ion concentration in the blood causes stimulation of the synthesis and release of calcitonin; low levels of $Ca^{++}$ ions suppress its manufacture. Excess or deficiency leads to disturbance of calcium metabolism with its associated effects on nerve, skeleton, muscle, blood etc. Calcitonin is antogonistic to parathormone hormone.

Table salt with iodine is recommended so that there is no deficiency of iodine and thus of thyroxine in the body.




*17.15 The thyroid and parathyroid glands*

(a) The thyroid and parathyroid glands are Iocatevl Mow the Uirynx in the neck',
(b) Individuals with iodine-deficient diets may have goiter, a condition in which the thyroid becomes greatly enlarged.

## Parathyroids

In man the glands are found embedded in the posterior part of the lateral lobes of the thyroid. These produce a hormone called parathormone. Low levels of blood $Ca^{++}$ ions stimulate the parathyroid directly to increase parathormone production whereas high evels of $Ca^{++}$ ions suppress its release. Under-activity causes a drop in blood $Ca^{++}$ ions which in turn leads to muscular tetany. Over-activity would lead to a progressive demineralization of the bones similar to rickets, as well as to the formation of massive kidney stones. Both conditions may be fatal.

## Islets of Langerhans (Pancreas)

This is under control of the pituitary trophic hormones STH and ACTH and also responds directly to the level of blood glucose. The islets contain large number of p cells associated with insulin production. The smaller number of a cells secrete glucagon. In general, insulin depresses blood glucose levels, in a variety of ways which include increasing glycogen synthesis and increasing cell utilization of glucose. It also stimulates conversion of glucose into lipid and protein, which in turn reduce glucose levels.

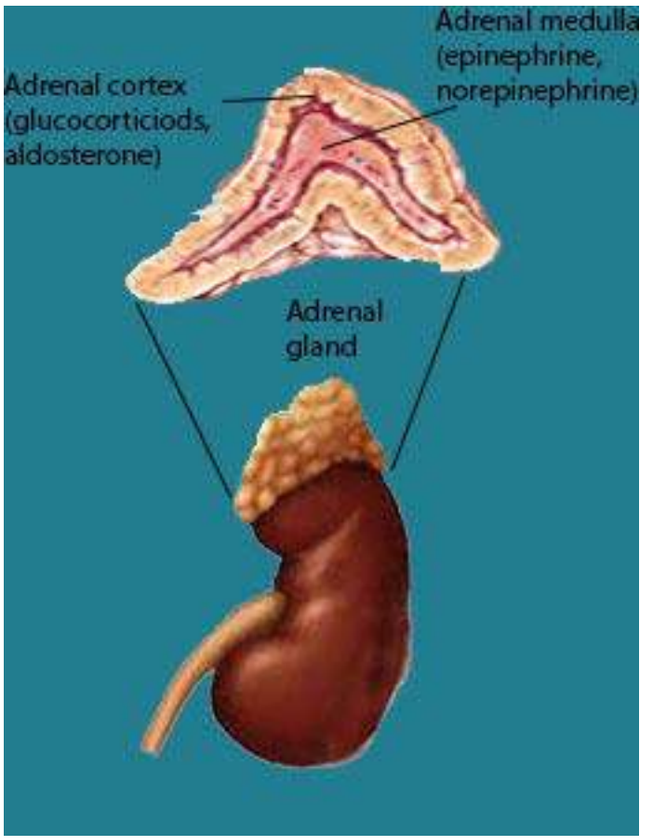
Insulin inhibits the hydrolysis of glycogen in the liver and the muscles. Failure to produce insulin leads to a condition called **diabetes mellitus**. The symptoms of this are high level of blood sugar, sugar in the urine, a disturbance of the body's osmotic equilibrium and derangement of the nervous system. Toxic metabolites from fat (which need 'glucose energy' for their oxidation) also accumulate and are only lost from the kidney with valuable metal cations. The body becomes dehydrated. If excess insulin is produced the utilization of sugar is too great and its level falls in the blood (hypoglycaemia) which upsets nerve and muscle functioning.

Glucagon is essentially antagonistic to insulin and causes an increase in blood glucose level s. It does this mainly by promoting breakdown of glycogen to glucose in the liver and muscles. It also increases the rate of breakdown of fats.

Glucagon abnormalities seem rare as endocrine disorders. Tumors on the $\alpha$ cells will cause excess glucagon secretions and consequently high blood glucose levels. This in turn damages the $\alpha$ cells with the results described above.

## Adrenals

A pair of adrenal gland is present, one on top of each kidney. Its outer layer in called adrenal cortex and inner is adrenal medulla. The medulla produces the hormones adrenaline (epinephrine) and noradrenaline (norepinephrine) The adrenal cortex secretes cortico-steroids such as cortisol, corticosterone, aldosterone, and androgenic hormones. (Fig. 17.16)




*17.16 The adrenal gland*

**Adrenaline and noradrenaline hormones:** Both adrenaline and noradrenaline are secreted in stress situations. Essentially adrenaline dilates blood vessels in certain parts of the body such as the skeletal muscles and increases the heart's output. Noradrenaline constricts blood vessels but again only in certain areas, such as the gut, so the effects of the two hormones are synergistic in raising blood pressure. Adrenaline and noradrenaline promote the release of glucose from liver glycogen and reinforce the effects of the sympathetic system. Rarely found, but in excess, these hormones lead to abnormally high blood pressures. In rats whose adrenal medulla has been removed surgically, the ability to withstand any stress situation - such as cold - is markedly diminished.

**Cortical hormones:** The adrenal cortex is active at all times but especially so following shock or stress situations and infections. Cortisol is the glucocorticoid, and brings about an increase in blood glucose level mainly by its production fronr protein and by antagonizing the action of insulin.

Corticosterone is both a glucocorticoid and a mineralocorticoid; it increases blood glucose levels and regulates mineral ion balance. Aldosterone is the principal mineralo-corticoid and conserves the level of Na+ ions in the body by preventing their loss from the kidney tubules.

The destruction of the adrenal cortex, such as occurs in Addison's disease, will lead to general metabolic disturbance, in particular weakness of muscle action and loss of salts. Stress situations, such as cold, which would normally be overcome, lead to collapse and death. The reverse of this is found in Cushing's disease where too much cortical hormone is produced. Symptoms are an excessive protein breakdown resulting muscular and bone weakness. The high blood sugar disturbs the metabolism as in diabetes. Androgens cause development of the secondary male characteristics. Very small amounts of androgens are secreted in both male and female by adrenal glands. A tumor on the inner part of the adrenal cortex in a female can cause excess of androgens to be produced and thus the development of certain male characteristics. Such cases are very rare.

## Gut

Many parts of the gut function as endocrine tissue. The important hormones produced are:

**1. Gastrin:** Gastrin is the hormone produced by mucosa of the pyloric region of the stomach. It stimulates the secretion of gastric juice. It is produced under the influence of protein food in the stomach after it is partially digested.

**2. Secretin:** It is produced from the duodenum when acid food touches its lining. It affects the pancreas to produce and release pancreatic juice and also affects the rate of bile production in the liver.

## Gonads

## (a) Ovary

**1. Oestrogen :** Oestrogen is secreted by ripening follicles (and, in many species, by interstitial cells of the ovary) whose development has been initiated by FSH from the pituitary. Oestrogens bring about the development of the secondary sexual characters in the female, cause thickening of the uterine wall and, at a point during the oestrous or menstrual cycle, exert a positive feedback which results in a sharp rise in LH output by the pituitary. They also aid in healing and repair of uterine wall after menstruation. Under the influence of oestrogen, some of the cells of uterine wall become glandular and start secreting proteinaceous secretions which are taken up by the embryo during its early stages of development. Deficiency of the sex hormones, for one reason or another, leads
in the young of failure to mature sexually and sterility in the adult.

**2. Progesterone :** Produced by the ruptured follicle in response to LH from the pituitary. Progesterone inhibits further FSH secretion from the pituitary, thus preventing any more follicles from ripening. It also affects the uterus, causing further thickening and vascularization of its wall, and other areas of the female body, preparing it for maintaining the state of pregnancy. It suppresses ovulation. That is why it is a major constituent of birth control pill.

## (b) Testes

The testes consist of many coiled seminiferous tubules where the spermatozoa develop and, between the tubules, regions of interstitial cells produce gonadal hormones called testosterone and 17 β-hydroxytestosterone.

After the initiation of development, the sex organs in the foetus produce them, and their level rises fairly consistently until puberty. After puberty the supply of LH (ICSH), and therefore, the level of testosterone, remains constant. In the foetus, it initiates the development of the sex organs. At puberty it brings about development of the male secondary characteristics and promotes the sex drive. The castrated male fails to develop secondary sexual characteristics and his body tends more towards the form of the immature female.

## Feedback Mechanism

It is a type of interaction in which a controlling mechanism is itself controlled by the products of reactions it is controlling.

For proper body functions, two opposing systems are needed, if there are accelerators, there must be inhibitors. If one hormone in the body promotes or stimulates a reaction, another hormone would be checking the same. In the body, interaction is mainly maintained due to feedback mechanism. In this way, concentration of secretions is itself controlled because certain information is passed to the source or in other words is fed back so that the output of the secretion is adjusted accordingly, depending on the activity of the body. The interaction between the. pituitary and other endocrine glands, over which it exerts control, is an example of feedback mechanism and this mechanism is very common in living systems. Feedback in thyroid gland function is described. (Steps correspond to the fig. 17.17).

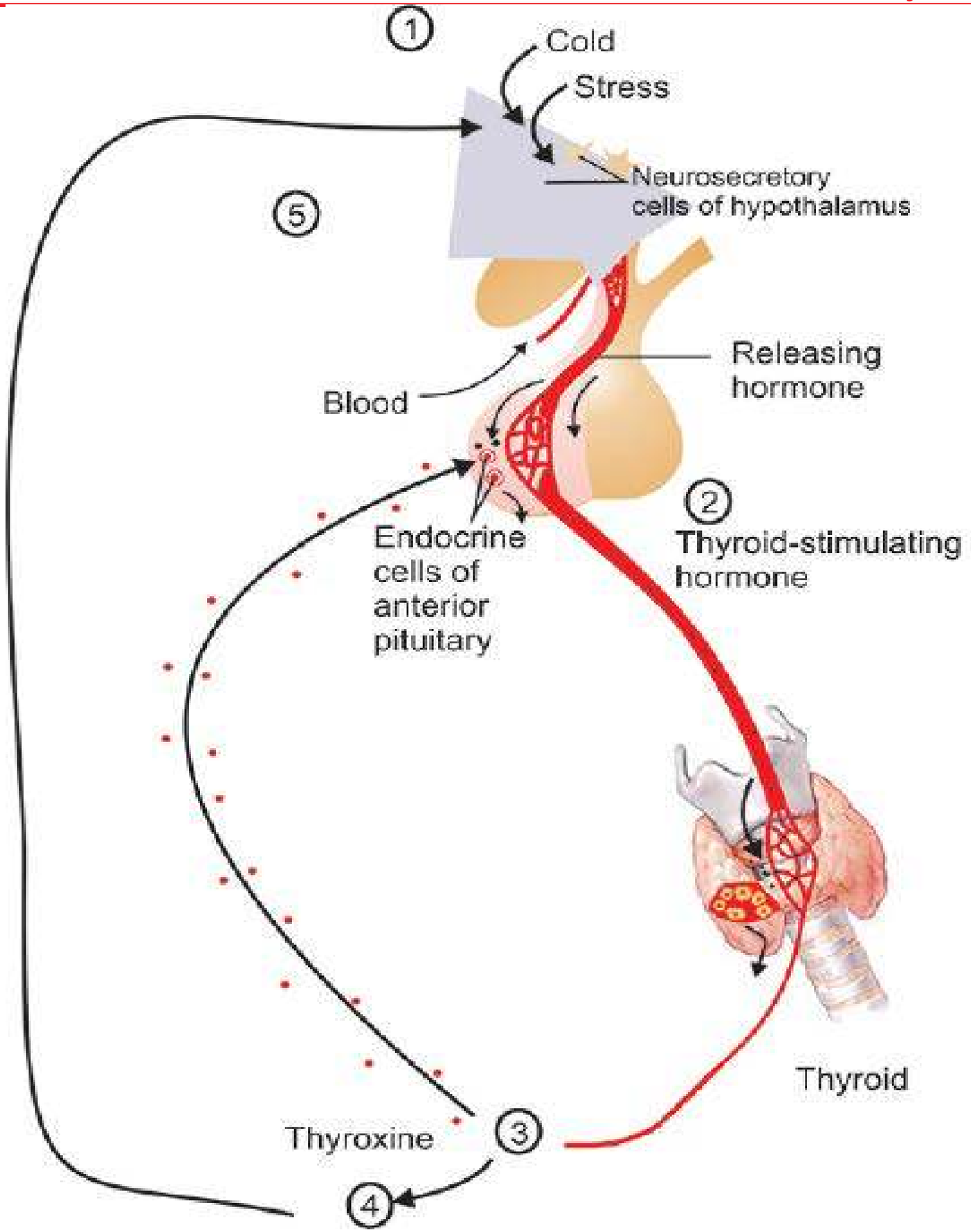



*Fig. 17.17 Negative feedback in thyroid gland function*

1. Low body temperature or stress stimulates neurosecretory cells of the hypothalamus, whose releasing hormones trigger the release of 2.Thyroid-stimulating hormone (TSH) in the anterior pituitary. 3. The TSH then stimulates the thyroid gland to release thyroxine. 4. Thyroxine causes an increase in the metabolic activity of most body cells, generating ATP energy and heat. 5. Both raised the body temperature and higher thyroxine levels in the blood inhibit the releasing-hormone cells and the TSH-producing cells.

**Comparison of Nervous Coordination and Chemical Coordination**

**Similarities:**

1. Both hormone producing cells and nerve cells (neurons) synthesize chemical “messenger”.
2. Both release the messenger chemicals in extra cellular spaces of the body.
3. Both help in co-ordination of the body.
4. Both function in response to specific stimuli either from within the body or from the external environment.
5. Both are homeostatic in function.

## Differences:

| Nervous Coordination | Chemical Coordination |
|---|---|
| 1. Neurons (sensory, associative and motor), are the basic units of structure and function. In addition neuroglial cells are also present, which provide nutrition and protection to neurons. | 1. Hormone producing cells and neuro secretory cells (such as those found in the hypothalamus), release hormones and are units of structure and function. |
| 2. Chemicals produced by neuron endings act where they are produced i.e. very close to the cells they influence, commonly from less than a micrometer away For example, acetylcholine produced by nerve endings at synapse, excites the next neuron. | 2. Chemicals produced (the hormones or neuro hormone) are poured into and are transported by blood. These hormones affect the target cells, which are far away from where the hormones are produced. ADH is produced from posterior lobe of pituitary giand; but affects the target cells present in the nephron and collecting tubule of kidney, to control re-absorption of water. |
| 3. in this system the neurons release its neurotransmitter into one or a small group of specific cells. | 3. The blood borne hormones bathe millions of cells indiscriminately and only a few respond to these hormones. |
| 4 This has immediate effect or show response to a stimulus instantly. | 4. There may have immediate effects (e.g. insulin), but mostly hormones have prolonged or delayed effects for example growth hormone. |
| 5. This control is affected through the electrical signals that travel within the cell itself and it releases its neuro transmitters only where it reaches its target | 5. This control involves only chemical stimulation and the target cells are far away from them: |
| 6, This shows faster or rapid effect. The speed of impulse in most cases is 100 meters/second; but maximum speed of nerve impulse recorded in the human beings is 120 meters/second. | 6. it is not very rapid; but shows slow but prolonged effects. |
| 7. The chemicals involved in this system (the neurotransmitters or neuro hormones) are short lived i.e. broken down shortly after .heir release. Thus the effects of messengers sent by neurons tend to be of much shorter duration. | 7. The hormones are the chemicals, which remain active for much longer duration within the blood; and thus have much longer duration for their actions. |

# BEHAVIOUR

Behaviour is divided into two main types, innate behaviour and learned behaviour.

## Innate Behaviour

It is a collection of responses that are predetermined by the inheritance of specific nerve or cytoplasmic pathways in multicellular or unicellular (acellular) organisms. As a result of the built in pathways,a given stimulus would produce invariably the same response. All plant behaviour is innate.

These behaviour patterns have been developed and been refined over many generations (selected) and their primary adaptive significance lies in their survival value to the species.

Another feature is the economy it places on nerve pathways within multicellular organisms since it does not demand on the higher centre of the nervous system.

Types of innate behaviour:

### 1. Orientation

**(i) Kineses:** It is a behaviour in which an organism changes the speed of random movements which help them to survive in the environment e.g. this type of behaviour enables pilibugs to reach the moist area which is required for their life.

**(ii) Taxes:** In contrast to kineses a taxis (plural: taxes) is a directed movement either towards (positive taxis ) or away from (negative taxis) a stimulus.

### 2. Reflexes and instincts

These are extremely complex behaviours and include biological rhythms, territorial behaviour, courtship, mating, aggression, altruism, social hierarchies and social, organizations.

# Instincts & Learning

Darwin (1859) was the first to propose an objective definition of instincts in terms of animal behaviour. He treated instincts as complex reflexes made up of units compatible with the mechanisms of inheritance, and thus a product of natural selection, that had evolved together with the other aspects of life. Thus instinctive behaviour is a part of one's inherited structure by which the individual responses to a particular stimulus. This response is similar in members of a species. All animals inherit certain responses which equip them to live having abilities like walking, moving running and eating etc.

The early ethologists (Uexkull 1934, Lorenz 1935) thought that animals sometimes respond instinctively to specific though often complex stimuli. Such stimuli came to be called "sign stimuli". A sign stimulus is a part of stimulus configuration and may be relatively simple part. For example a male three-spined stickle back fish has a characteristic red belly when in breeding condition. This is a 'sign stimulus' that elicits aggression in other territorial males.

Instincts equip an animal with specific response to a particular stimulus, thus enabling it to adapt to its environment. Learning on the other hand, depends on the experiences in one's own life but for this to occur, depends upon the development and evolution of the nervous system of that animal. So the higher animals have higher level of learning. Lower animals because of poorly developed systems to responds to a particular stimulus learn very slowly, and even in some cases do not have the ability to modify or change their instinctive behaviour. The selective responses to stimuli suggested that there must be some built-in mechanism by which sign stimuli were recognized. This mechanism came to be called the innate releasing mechanism (IRM). The important aspect of this concept is that the mechanism is envisaged as being innate, that is, both the recognition of the sign stimulus and the resulting response to it are inborn and characteristic of the species.

Instinct can equip an animal with series of responses. This is important for animals with short life spans and with little or no parental care. For example, a female digger wasp (*Ammophila adriaansei*) prepares a nest, catches caterpillars, kills them by sting, puts them in nest, lays eggs on them and then closes the nest. After doing all this, she dies. The larvae after emerging from the eggs, start feeding on caterpillars killed by their mother before death and grow to digger wasps. All this is completed within few weeks and is done by instincts of digger wasp, which may be responding to perception of a caterpillar (the possible sign stimulus) in different ways.

| Instinctive behaviour | Learning behaviour |
|---|---|
| • This is the type of behaviour that depends on the heredity material which the animal inherits. The animal may be born with the right responses built in the nervous system as part of its inherited structure. | • This type of behaviour depends on the environmental influence, but the ability to modify the behaviour depends on the heredity material. |
| • Experience has no obvious influence on this type of behaviour. | • Experience has an obvious influence on this type of behaviour. |
| • This type of behaviour depends on the selection operating during the history of species, so that it helps in the adaptability of the organism in the environment. | • This type of behaviour depends on the selection operating during the history of the individual (during one's life-time) so as to help the organism in its adaptability in the given environment. |
| • Instinct can equip an animal with a series of responses. This is advantageous for animals with short life spans, and with little or no parental care. | • Learning can equip an animal with a set of adaptive responses to its environment. This is advantageous for those animals -which have long life spans and have parental care, so that they can modify the behaviour by previous experiences. |
| • This type of behaviour evolves slowly in the species. | • This type of behaviour evolves during the life cycle of the individual but the ability of learning depends on the genetic basis of the individual. |
| For example:<br>(i) Honey bees inherit the ability to form wing muscles and wings for flight. They inherit the tendency to fly towards flowers to seek nectar and pollen.<br><br>(ii) Behaviour of digger wasp is instinctive; but it does learn certain things during its brief life, such as locality of each of its nests, where it has to return after hunting. | For example:<br>(i) Conditioned reflex type I, in case of dogs where dogs learn to salivate on ringing of bell alone.<br><br>(ii) Trial and error learning in case of cat, when it learns to press, the lever to open the door of the cage.<br><br>(iii) Crawling snail on a sheet of glass, learns that tapping has no harmful effect and ceases to respond after few early responses. |

# Learning Behaviour (Modification through experience)

Thorpe defined learning as that process which manifests itself by adaptive changes in individual behaviour as a result of experience.

Thorpe classified learning behaviour into six types:
(1) Imprinting
(2) Habituation
(3) Conditioning or conditioned reflex type i.
(4) Operent conditioning or conditioned reflex type ii.
(5) Latent learning
(6) Insight learning.

**1. Imprinting :** Imprinting is a form of learning which is best known in birds such as geese, ducks, and chickens, which are all precocial birds. Shortly after hatching, ducklings and other young birds have a tendency to follow moving objects in their surroundings. They show a brief sensitive period during which the shape of form of objects can be 'imprinted', with the result that the young birds will follow them. Normally, of course, the first moving object encountered is the mother bird, and it is obviously adaptive for the young birds to learn her appearance and to follow her. However, if its parents are absent, a young bird may imprint on other species of birds, human beings, or inanimate objects.

**2. Habituation :** Habituation is the simplest form of learning and involves modification of behaviour through a diminution of response to repeated stimuli. A loss of receptivity to repetitious stimuli can be useful in preventing a drain of energy and attention for trivial purposes. For examples:

(i) A snail crawling on a sheet of glass retracts into its shell when glass is tapped. After a pause, it emerges and continues moving. A second tap causes retraction again but it emerges more quickly. Ultimately, tapping has no effect and snail ceases to respond.

(ii) Rodents respond to alarm calls by others in their group, if these calls are continued and no danger is confirmed, further calls may be ignored.

**3. Conditioning or conditioned reflex type I:** Conditioning or conditioned reflex type I involves the pairing of an irrelevant stimulus with a natural primary stimulus that elicifs an automatic response.

Pavlov conditioned the dogs to secrete saliva on ringing of the bell, which is not normal stimulus for secretion of saliva. In his experiments, he would ring the bell just before giving food to the dogs, so the dogs became conditioned to secondary stimulus or conditioned stimulus (ringing of bell) and started secreting saliva in response to it as if it were the natural stimulus. This type of learning broadens the ability of an organism to react appropriately to environmental changes, since the conditioning process removes dependence on one kind of reflex symbol for action.

**4. Operent conditioning or conditioned reflex type II:** Operent conditioning or conditioned reflex type II (also called trial and error learning) is a more complex type of learning than habituation. This type of learning has been demonstrated and studied by Thorndike and B.F. Skinner, a Harvard psychologist. Under natural conditions, the achievement of a particular goal is the reward that directs random activities into a behavioural pattern. Trial and error repetitions, step by step, lead to final achievement. Experiments on rats and cats were performed to run a maze to either get or find food, or to depress a lever and come out of the cage. In this case first experience is accidental and then it is rewarded, animal learns with latter experience.

**5. Latent learning:** Thorpe defined latent learning as the association of indifferent stimuli or situations without patent reward.
Suppose we put a rat in a maze as it wanders about and accidentally gets food. Did he learn anything before getting the food in the first experience? If we put the rat in the same maze again, it may directly reach the food. That means when the rat was wandering, it did learn something without even the incentive of any reward.

**6. Insight learning:** Kohler performed many experiments on chimpanzees, and showed that they have higher form of learning called insight learning. Insight learning is an extreme case of behavioural modification involving the application of insight or reasoning to a novel situation. If an animal can direct its behaviour to solve a problem for which it has no previous experience then reasoning is involved. Reasoning in humans appears to involve a recasting of an external situation in the imagination and a manipulation of the concepts to produce a solution that can be applied to situations. However, such insight or reason may be found in other primates. This is the highest form of learning. For example: A chimpanzee is placed in a cage in which a choice piece fruit hangs from the ceiling. This chimpanzee cannot reach the fruit, but the keeper has placed some boxes of different sizes in the cage. After a short period of head scratching, the chimpanzee moves the largest box and piles other smaller boxes over it, and climbs up to reach the fruits.

## Exercise

### Q.1 .Fill in the blanks

(i) Neurotransmitter molecules bind to the receptors on the _____ membrane at synapse.
(ii) Excess of _____ hormone is secreted in Addison's disease.
(iii) Operent learning has been demonstrated and studied by _____ and _____.
(iv) _____ are plant hormones which delay the life of fresh leaf crops.
(v) All membranes of neurons have very active_____and _____pumps.

### Q.2 Write whether the statement is true or false and write the correct statement and pumps.

(i) Impulses travel much more rapidly along myelinated neurons.
(ii) All glial tissue consist of glial cells.
(iii) Saltatory conduction is carried out by those nerve fibres that have nodes of Ranvier.
(iv) The myelin sheath of neuron is particularly good conductor of electric impulse.
(v) The resting membrane potential is maintained largely by the sodium pump.
(vi) Hormones initiate new biochemical reactions in the body.

### Q.4. Short questions

(i) Define cir-cadian rhythm.

(ii) What is the difference between CNS and PNS?

(iii) What are the functions of parathyroid gland?

(iv) Define the term hormone.

(v) What are the commercial applications of auxins?

(vi) List different types of tropisms.

(vii) Write a note on Alzheimer's disease.

## Q.5. Extensive questions.

(i) Describe different types of learning behaviour.

(ii) Describe in detail the role of adrenal glands.

(iii) Define nerve impulse. Explain the mechanism involved by labelled diagrams.

(iv) How is the nervous system of Planaria better developed than that of *Hydra*?

(v) Describe the structure and functions of the different parts of human brain.

(vi) Writea note on pituitary gland.

CHAPTER

18

# Reproduction

*Animation.18: reproduction*
*Source & Credit: wikispaces*

Every species of organisms can reproduce new individuals of that species. In organisms, methods of reproduction are varied and some are quite complex. It is very important to the survival of a species or a population. Reproduction is the mechanism that- produces new generations and maintains a species-population.

Reproduction is of two types, asexual reproduction and sexual reproduction. Asexual reproduction requires only a single parental organism which gives rise to offspring by mitotic cell division, during which the total chromosomes content of the cell is exactly replicated and passed on to daugher cells, so that the offspring are genetically identical to the parent. Methods of asexual reproduction are fission, sporulation, budding, vegetative propagation, artificial propagation, parthenogenesis and apomixis etc.

Sexual reproduction usually involves two parents. A fertilized egg is produced through the union of meiotically produced specialized sex cells (egg and sperm) from each parent. Meiosis or reduction division gives rise to gametes (gametogenesis) in which not only the chromosome number is halved (haploid) but reshuffling of genes leads to recombination of genes. This not only maintains the chromosome number in a species but also produces genetic variations, an important factor in the survival and adaptation of a species or a population (Fig. 18.1).

In plants, if there isalternationof generations namely a diploid sporophyte and a haploid gametophyte, meiosis occurs during spore formation (sporogenesis).

In asexual reproduction, although increase in number of genetically alike individuals from a parent is very rapid but this is not an adaptive method and may at some stage jeopardize the survival of a species. Man has favoured this type of reproduction for his own needs, commonly in plants but now tissue culture technique in plants and cloning in animals are being adopted for producing organisms of valuable characteristics, without a change in their genetic make up. Cloning has been practised successfully but its disadvantages like rapid aging and low resistance to environmental stress and diseases are still the limitations for commercial ventures. Also it is still not being accepted socially and morally in general.

# REPRODUCTION IN PLANTS

In plants both sexual and asexual reproduction are foun. In asexual reproduction layering, grafting, budding etc. are the artificial modes.

In sexual reproduction, plants have **diplohaplontic life cycle** with alternating diploid sporophyte and haploid gametophyte generations. If the two generations are vegetatively similar, such alternation of generations is referred to as isomorphic, and if they are dissimilar it is called heteromorphic.

Evolution of pollen tube is an important step in land adaptation by the spermatophytes. Pollen tube acts as vehicle for male gametes for their safe transport to female gamete in ovule in hostile land environment. Evolution of pollen tube is parallel to the evolution of seed and is a tool of success for seed plants.

Seed plants are predominatly present all around us due to their better sexual reproduction, modification of flower and infloresence for pollination, involving gamete transfer by pollen tubes,food storage for developing embryo, protection by seed coats and dispersal with the help of fruit formation (angiosperms). Seeds are capable of enduring unfavourable conditions in dormant form (seed dormancy) and as soon as, conditions become favourable for establishing the seedling, it germinates.

*Animation 181:Reproduction*
*Source & Credit: Ameoba Sisters*

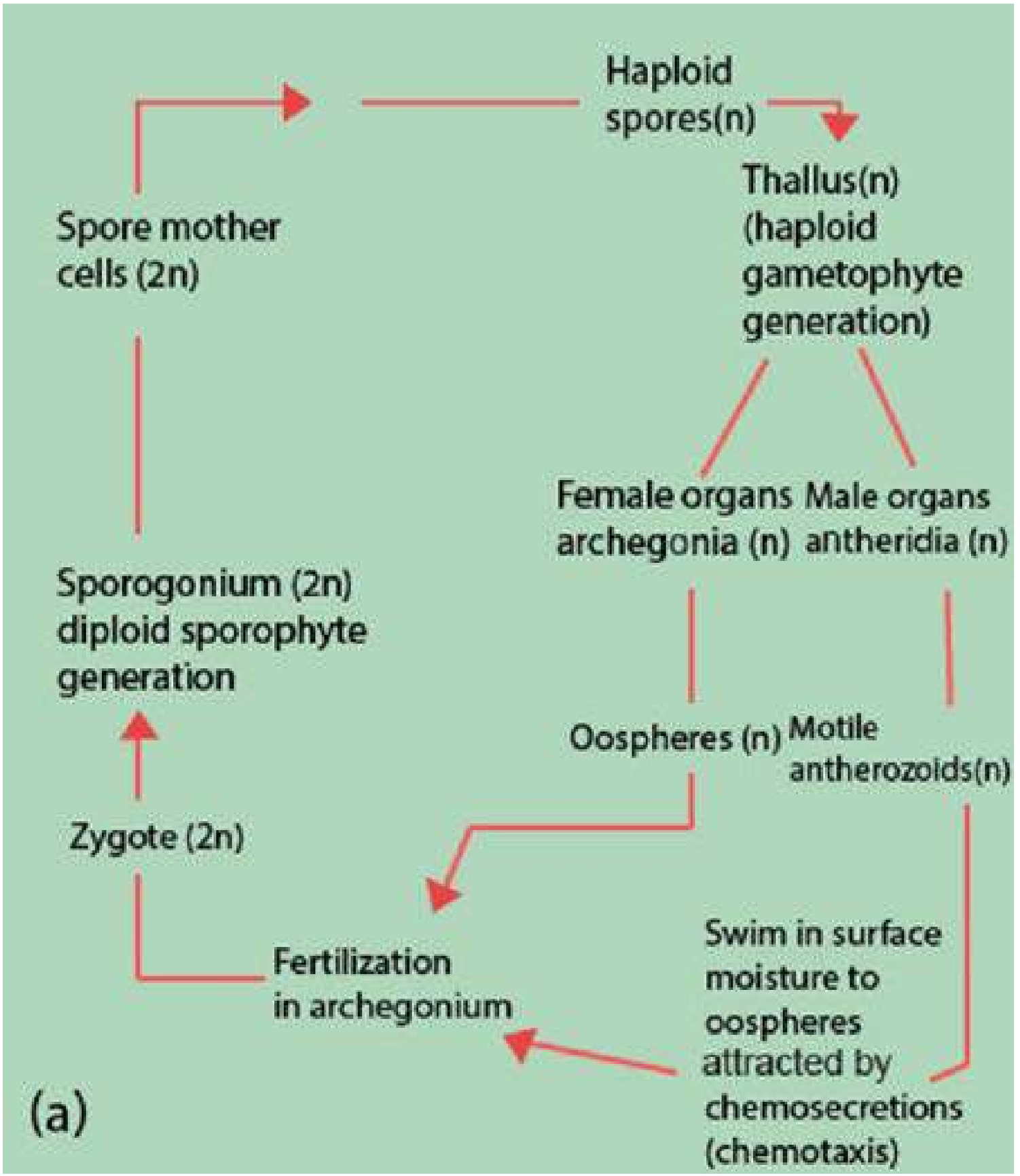



*Fig. 18.1 (a) Bryophyte life cycle. Note that the sporophyte is completely dependent upon the gametophyte.*

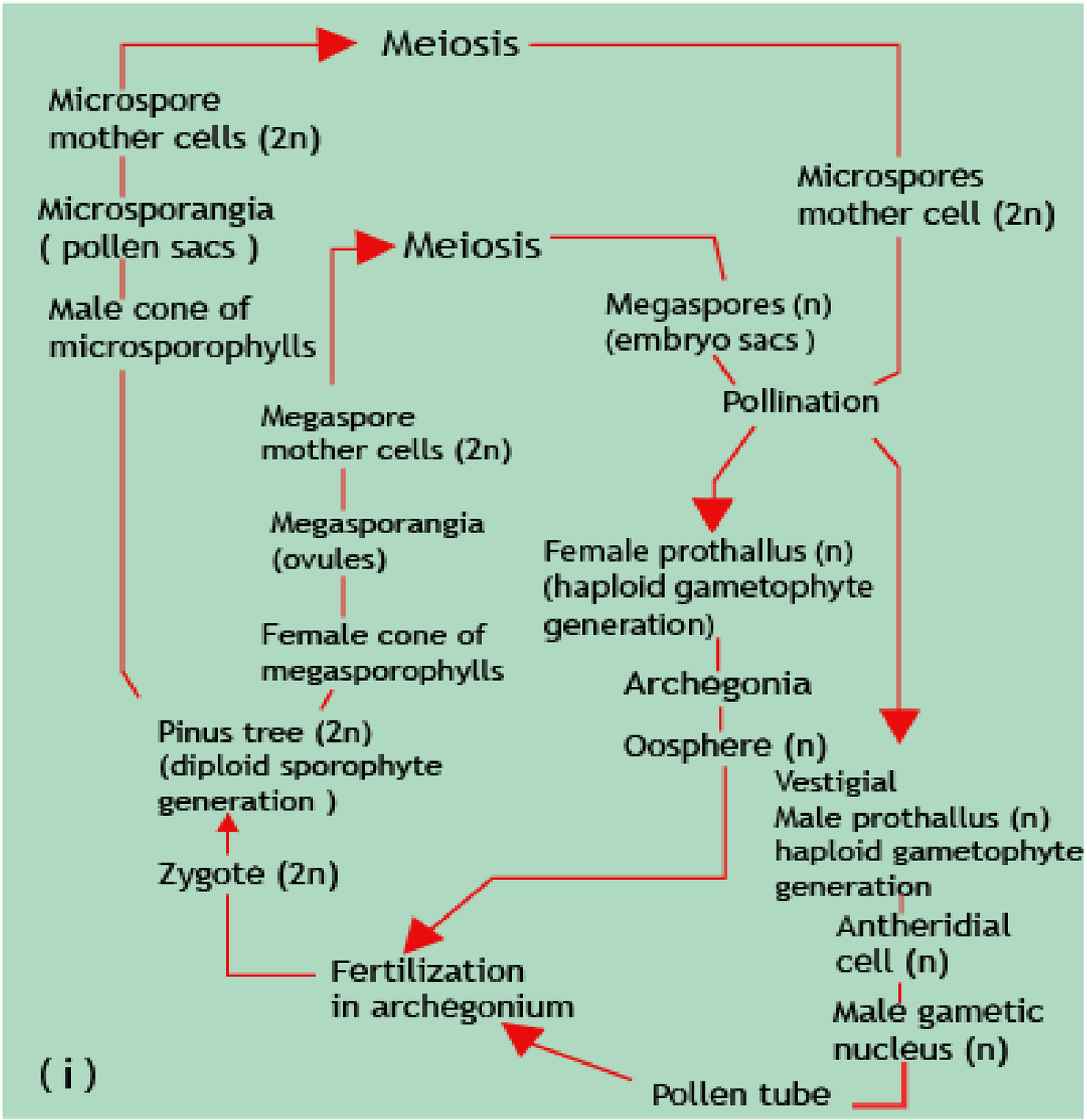
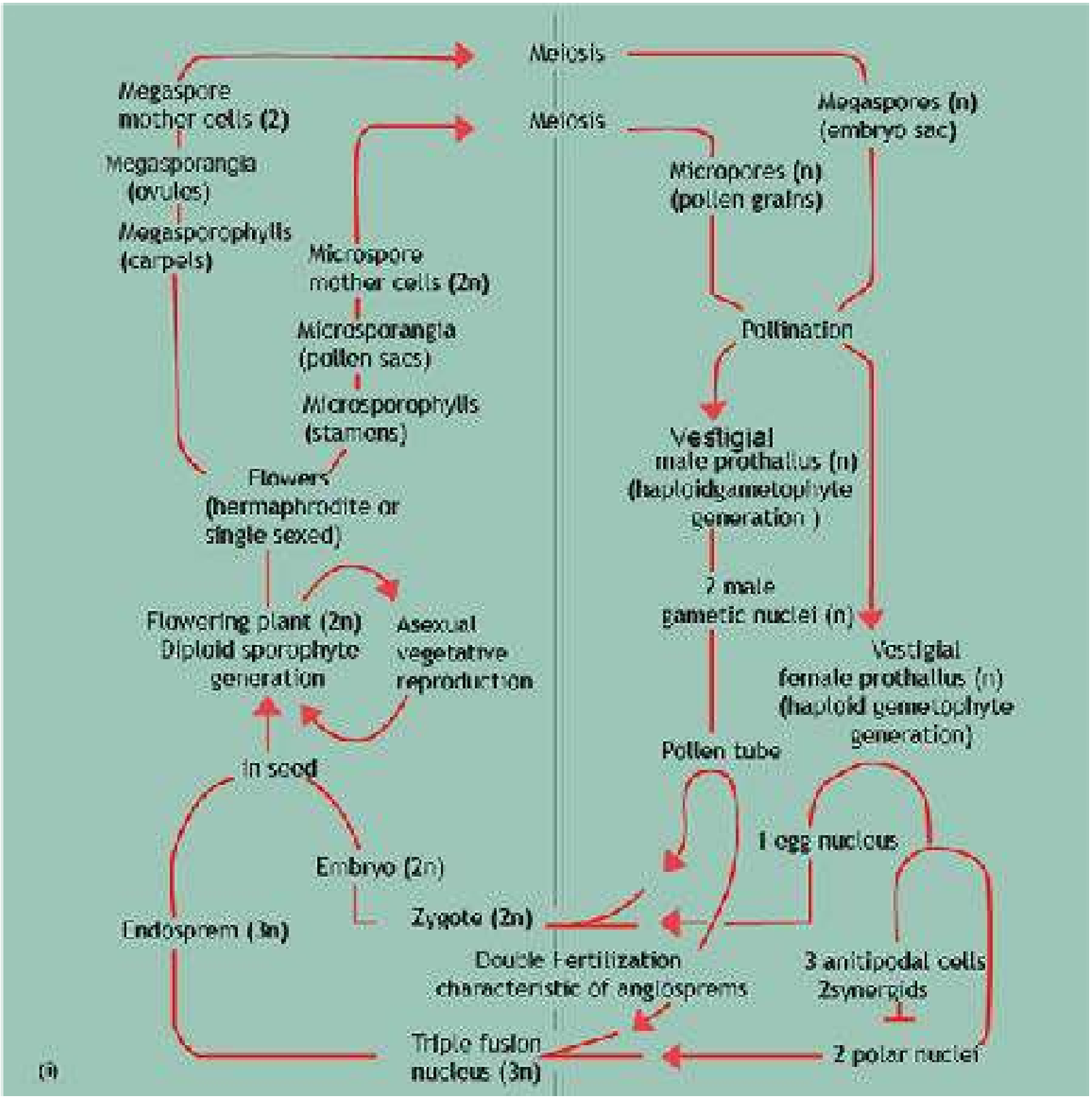



*Fig. 18.1 (b) Spermatophyte life cycles (i) Gymnosperm life cycle, Pinus sylvestris (Class Pinatae). (ii) Angiosperm life cycle.*




*18.1 (ii) Angiosperm life cycle*

## Parthenocarpy

In some cases, fruit development proceeds without fertilization and thus no seed formation takes place e.g. banana, pineapples and some varieties of oranges and grapes. Such development is called parthenocarpy. It is due to hormonal imbalance; usually high auxin levels occur in these ovaries. Parthenocarpy is sometime artificially induced for commercial purposes, by adding auxins in tomato, peppers etc.

## Seed Dormancy

It is the special condition of rest, which enables an embryo to survive long periods of unfavourable environmental conditions, such as water scarcity or low temperature. During this period of rest the embryo ceases or limits its growth. This is of great survival importance to the plant in that it prevents the dormant seed from germinating in response to conditions such as a warm spell in winter. Germination or resumption of normal growth by a dormant embryo requires certain, very precise combinations of environmental cues, to avoid any accidental stimulus which may prove fatal later on.

## Fruit set and Fruit ripening

Germinating pollen grain is not only an important structure for safe transfer of gametes and insurance for fertilization but also a rich source of auxins as well as commonly stimulating the tissues of the style and ovary to produce more auxin. This auxin is necessary for ‘fruit set’, i.e. retention of the ovary, which becomes the fruit after fertilization. Without it abscission of flowers normally occurs, leading to low fruit yields. After fertilization, the ovary and the ripe seeds continue to produce auxins which stimulate fruit development. Developing seeds are not only a rich source of auxins and gibberellins, but also of cytokinins.

These growth substances are mainly associated with development of the embryo and accumulation of food reserves in the seed and some times in the pericarp (fruit wall).

Fruit ripening is often accompanied by a burst of respiratory activity called the climacteric. This is associated with ethane production, which helps in ripening of the fruit.

## Photoperiodism

Apart from photosynthesis and phototropic responses, another very important way in which light exerts its influence on living organisms is through variations in day length called photoperiod. In plants, photoperiod and temperature affect flowering, fruit and seed production, bud and seed dormancy, leaf fall and germination.

Photoperiod affects flowering, when shoot meristems start producing floral buds instead of leaves and lateral buds.

Effect of photoperiodism was first studied in 1920 by Garner and Allard. They studied that tobacco plant flowers only after exposure to a series of short days. Tobacco plant naturally flowers under same conditions, in autumn, but flowering could be induced by conditions artificially to short days exposing. With further studies they were able to classify flowering plants into long-day plants, which require long days for flowering and day-neutral plants flower without being influenced by photoperiod.

Later on, further studies indicated that it is really the length of the dark period which is critical. Thus short-day plants are really long-night plants. If they are grown in short days, but the long night is interrupted by a short light period, flowering is prevented. Long-day plants will flower in short days if the long night period is interrupted (Table 18.1)

*Animation 181:Photoperiodism*
*Source & Credit: Leaving BIo*

*Table 18.1 (a) Classification of plants according to photoperiodic requirements for flowering*

| Short-day plants (SDPs | Long-day plants (LDPs) | Day-neutaral plants (DNPs) |
|---|---|---|
| Flowering induced by dark periods longer than a critical length, e.g. cocklebur 8.5 h; tobacco 10-11h. (Under natural conditions equivalent to days shorter than a critical length, e.g. cocklebur 15.5 h; tobacco 13- 14h) e.g. cocklebur (Xanthium), chrysanthemum, soyabean, tobacco, strawberry | Flowering induced by dark periods shorter than a critical length, e.g. henbane 13h. (Under natural conditions equivalent to days longer than a critical length, e.g. henbane 11 h). e.g. henbane (Hyoscyamus niger), snapdragon, cabbage, spring wheat, spring barley. | Flowering indepenedent of photoperiod. e.g. cucumber, tomato, garden pea, maize, cotton. |

*Table 18.1 (b) Some phytochrome-controlled responses in plants.*

| General process effected | Red light promotes |
|---|---|
| Photoperiodism | Stimulates flowering in long-day plants. Inhibits flowering in short-day plants. See flowering. |

Further experimentation also revealed that quantity of light is also influenced by the quality of light. Cocklebur, a short day plant, will not flower if its long night is interrupted but experiments revealed that red light was effective in preventing flowering and far-red light reversed the effect of red light. It was also demonstrated that the last light treatment always determines the response. This response to light intensity and quality led to the discovery of blue pigment that is red light sensitive protein, the phytochromes.

Phytochrome exists in two forms i.e. P 660 and P 730. P 660 a quiscent form absorbs red light at a wave length of 660 nm and is converted to active P 730, P 730 absorbs far red light at 730 nm and is converted to P 660. In nature, the P 660 to P 730 conversion takes place in day light and P 730 to P 660 conversion occurs in the dark. Thus during the day a plant has P 730 phytochromes while during the night it contains more phytochromes in the form of P 660. The presence of either form provides the plants with a means of detecting whether it is in a light or dark environment. The rate at which P 730 is converted to P 660 provides the plant with a "clock" for measuring the duration of darkness.

It has been found that red light inhibits flowering the short day plants but promotes flowering in long day plants, under conditions during which flowering normally takes place. This observation led to hypothesize that the P730-P660 interconversion might be the lant time - regulator for flowering. According to this hhypothesis, p 730, converted from P 660 by the absorption of red light, would inhibit flowering in short day plants but promote flowering in long day plants. Because P 730 accumulates in the day and diminishes at night, short day plants coud flower only if the night were long enough, during which a great amount of P730 would not be completely inactivated, so that enough P 730 would remain at the end of night to promote flowering. But now it is generally agreed that the time measuring phenomenon of flowering is not totally controlled by the interconversion of P 660 to P 730. Other factors, like presence or absence of light and length of dark, or light period also play an important role in flowering. Phytochromes seems to be responsible for the detection of either light or darkness. The biological clock once stimulated causes production of florigen hormone in leaves, which travels through phloem to the floral buds, initiating flowering.

## Vernalisation

Biennials and perennial plants are stimulated to flowering by exposure to low temperature. This is called **vernalisation**. The low temperature stimulus is received by the shoot apex of a mature stem or embryo of the seed but not by the leaves as in photoperiodism.

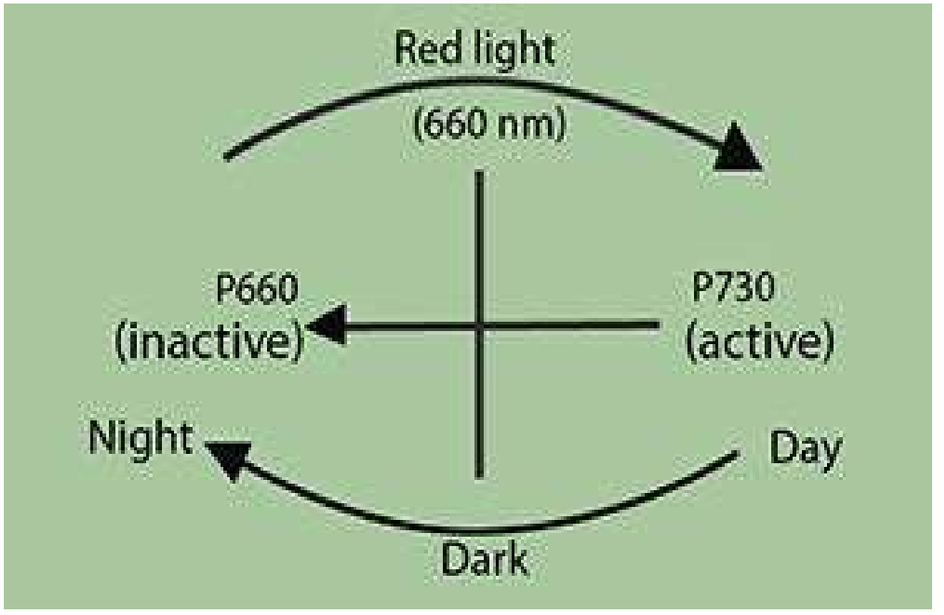
For some plants, vernalisation is an absolute requirement or in some cases it simply assists in inducing flowering. The duration of low temperature (chilling) treatment required varies from four days to three months.

Temperature around 4°C is found to be very effective. It stimulates the production of “vernalin” hormone which induces vernalisation, it is now believed that vemalin is nothing special but actually is gibberellin.

Photoperiodism and vernalisation serve to synchronise the reproductive behaviour of plants with their environment, ensuring reproduction at favourable times of year. They also ensure that members of the same species flower at the same time, encouraging cross pollination for genetic variability.

## REPRODUCTION IN ANIMALS

Animals like plants also reproduce both asexually as well as sexually. But asexual reproduction is less common in animals as compared to plants. Binary fission, multiple fission (animal like protoctists) budding (Hydra) parthenogenesis, tissue culturing, cloning and identical twins are the common asexual methods of reproduction.




In honeybee males are haploid and produce sperms by mitosis.

## Asexual Reproduction

Parthenogenesis is defined as the development of an egg without fertilization, ants, bees and wasps are good examples. In the honeybees, males (or drones) develop from unfertilized eggs. The queen bee, though carrying male gametes from male, has the ability to lay eggs that have not been fertilized. The sperms she receives from a drone bee are stored in a pouch closed off by a valve. The eggs may be fertilized or may not be fertilized from the stored sperms. The haploid egg develop into haploid offspring, it is called haploid parthenogensis.

In some cases e.g. in aphids, diploid parthenogenesis may occur, in which the egg- producing cells of the female, undergo a modified form of meiosis involving total non-disjuction of the chromosomes, they retain the diploid number of chromosome. Egg (diploid) develops into young females. Parthenogenesis has the advantage of accelerating the normal reproductive rate.

## TISSUE CULTURING AND CLONING

In tissue culturing technique in plants, cambium tissue excised from plants can be stimulated by the addition of nutrients, cytokinins, and IAA (indole acetic acid). These cells show continuous growth and differentiate into a new plant, genetically identical to their parents.

Tissue culture is now widely used for the rapid propagation of desired varieties or for varieties difficult to propagate by cuttings. Similar techniques have been developed for the tissue culture of animal cells.

In flowering plants, one form of parthenogenesis is called apomixis. In this a diploid cell of the ovule, either from the nucellus or megaspore, develops into a functional embryo in the absence of a male gamete. The rest of the ovule develops into the seed and the ovary into the fruit.

Organisms produced from a single cell by subculturing (cloning) are called clones. In animals and especially among vertebrates, a nucleus from the somatic cell is removed and introduced into an egg cell, whose own nucleus has been destroyed by ultra violet radiation. The egg with transplanted diploid somatic cell nucleus develops into an organism, genetically identical to the parent who has contributed the nucleus.

The cloning of desirable animals such as prize bulls, race horses etc. might be as useful as cloning of useful varieties of plants.

However, the application of the technique to humans would be open to serious moral questions. Theoretically any number of genetically identical copies of the same man or woman might be made. The use of cloned cells allows the quantitative study of the action of hormones, drugs and antibodies to be made on cells. Such a technique is a useful substitute for investigating the effect of drugs, cosmetics and pharmaceutical products on animal cells without exposing laboratory animals to these chemicals.

Cloning has the advantage that all the offspring behave similarly, but if an environmental hazard develop (like an out break of a disease), non resistant strains are present to lessen the impact. Also the degree to which environment influences clone development is not fully known and any cloned cell would have to go through all the phases of development once again including embryo, fetus, baby and child hood (in case of human beings).

## IDENTICAL TWINS

In higher vertebrates including man, zygote after fertilization undergoes cleavage (cell division by mitosis). When embryo is at two celled stage, the two blastomeres, instead of remaining together, may separate and behave as two independent zygotes, each giving rise to a new individual. Both the organisms are products of mitosis, thus they have identical genetic make up and are called identical twins. They are produced mitotically (asexually).

In some cases, more than one egg is produced by the female and all these eggs are independently fertilized forming two or more zygote. These zygotes develop into new offsprings, but with different genetic combinations. Such a twins or triplets are called fraternal twins or triplets. They are produced sexually.

# SEXUAL REPRODUCTION

It is thought that asexual method of reproduction is a primitive form of reproduction than the sexual reproduction. At a later stage, a mechanism have evolved leading to production and union of gametes. Meiosis and genetic recombination played a major role in the development of more complex forms of life and types of gametes, from identical gametes (isogametes) to the heterogametic stage of motile male gametes (sperms or antherozoid) and non-motile female gametes eggs (ova). Sexual reproduction has advantage over asexual reproduction which is elaborated in the following table 18.2.

**Table 18.2**

| Asexual reproduction | Sexual reproduction (omitting bacteria) |
|---|---|
| One parent only. | Usually two parents. |
| No gametes are produced. | Gametes are produced. These are haploid and nuclei of two gametes fuse (fertilization) to form a diploid zygote. |
| Meiosis absent. | Meiosis is present at some stage in life cycle to prevent chromosome doubling in every generation. |
| Offsprings identical to parent. | Offsprings are not identical to parents. They show genetic variation as a result of genetic recombination |
| Commonly occurs in plants, less differentiated animals and micro-organisms Absent in more differentiated animals. | Occurs in the majority of plant and animal species. |
| Often results in rapid production of large number of offsprings. | Less rapid increase in number. |

Both in animals and plants, evolution of sexual reproduction also lead to the differentiation of sexes (male or female). Organisms are either having one sex (unisexual) or both the sexes (hermaphrodite or bisexual). Advance mode of sexual reproduction has unisexuality in animals but in plants bisexuality in general is retained. Despite the bisexuality (tape worm, earthworm etc.), cross fertilization is ensured for maintaining the advantage of genetic recombination.

Fertilization is the process which leads to the union of gametes. Fertilization may occur outside the body (external fertilization) or inside the body of the female (internal fertilization).

External fertilization occurs in aquatic environment where male gametes can swim towards the female-gametes in water medium. Development is also external due to the constant / stable conditions of water (frog, fish etc.)

In terrestrial conditions, fertilization is internal. Sperms are lodged in the female body where fertilization occurs. This may lead to external development as in reptiles and birds. They lay shelled eggs to protect the developing embryo from harsh terrestrial conditions. Such animals are called oviparous.

In mammals, internal fertilization leads to internal development and development of embryo is accomplished inside the female body, which gives birth to young one - such animals are called **viviparous**.

In some mammals like duckbill platypus and spiny ant-eater internal fertilization leads to internal development of young one in a shelled egg and when development is completed, shelled egg is laid which hatches to offspring This is called ovoviviparous condition.

Viviparous and ovoviviparous animals provide more protection to their young one during development. Nourishment is provided either through stored food in the egg or through placenta by the mother.

# REPRODUCTION IN MAN

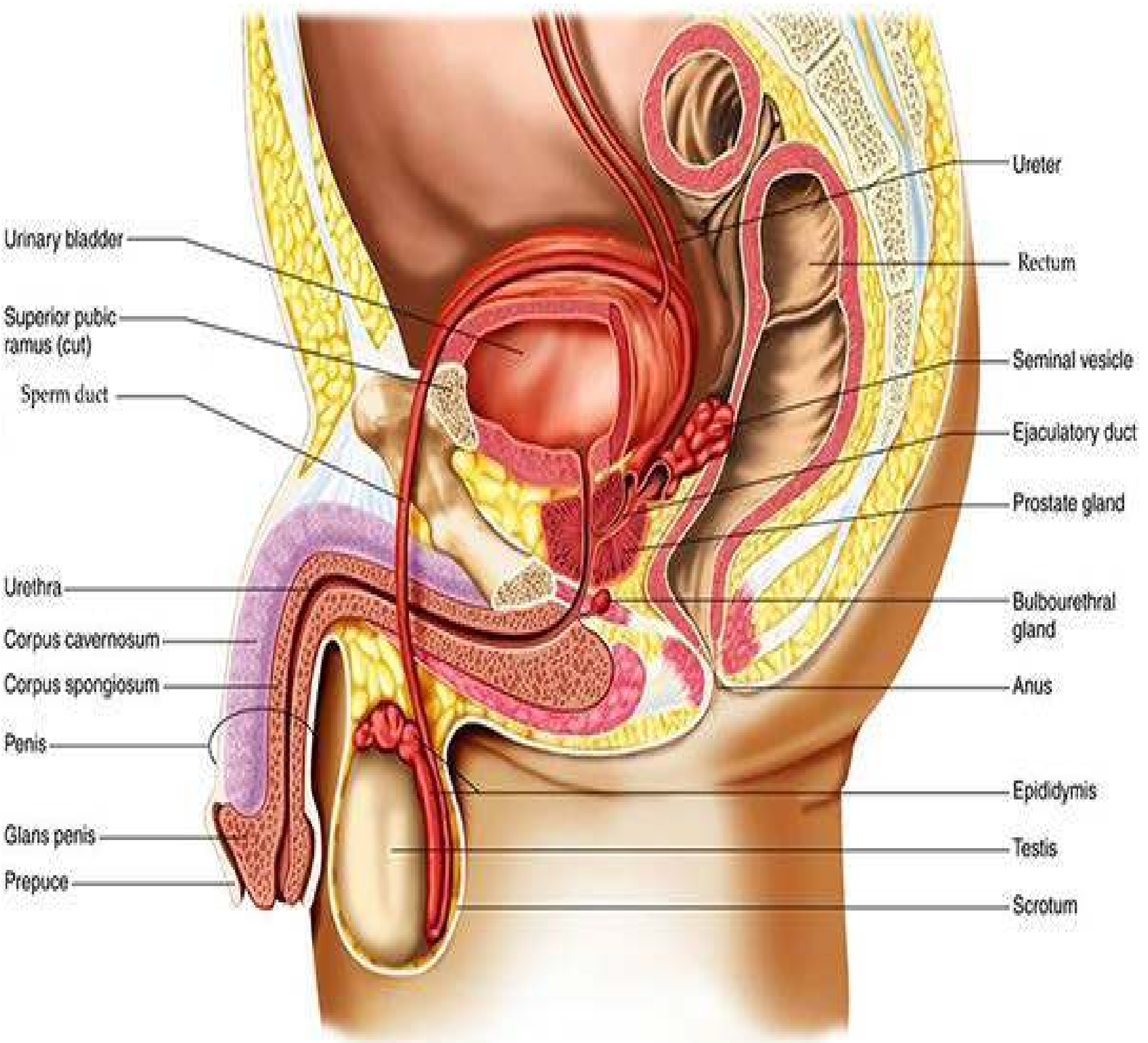
Male and female have separate reproductive systems.

## (a) Male Reproductive System

Male reproductive system consists of external genitalia which consist of a pair of testes which lie outside the body, in the sac-like scrotum and male copulatory organ which is used to transfer the sperms into the female reproductive tract. Each testis consists of a highly complex duct system called seminiferous tubules, in which repeated division by the cells of the germinal epithelium produce spermatogonia. These increase in size and differentiate into primary spermatocytes which undergo meiotic division to form secondary spermatocytes and spermatids. Eventually, the spermatids differentiate into mature sperms. Fluid secreted by sertoli cells provides liquid medium, protection and nourishment to sperms while they are in tl e tubules.

(Fig. 18.2 a,b, Fig. 18.3). The sperms are then transferred to the main duct of the male reproductive tract, the vas deferens, which forms highly convoluted epididymis. The sperms then pass through the urinogenital duct and ‘are discharged out.

*Animation 181:Sexual reproduction in plants*
*Source & Credit: Leaving BIo*


Ureter
Urinary bladder
Rectum
Superior pubic ramus (cut)
Seminal vesicle
Sperm duct
Ejaculatory duct
Prostate gland
Urethra
Bulbourethral gland
Corpus cavernosum
Corpus spongiosum
Anus
Penis
Epididymis
Glans penis
Testis
Prepuce
Scrotum

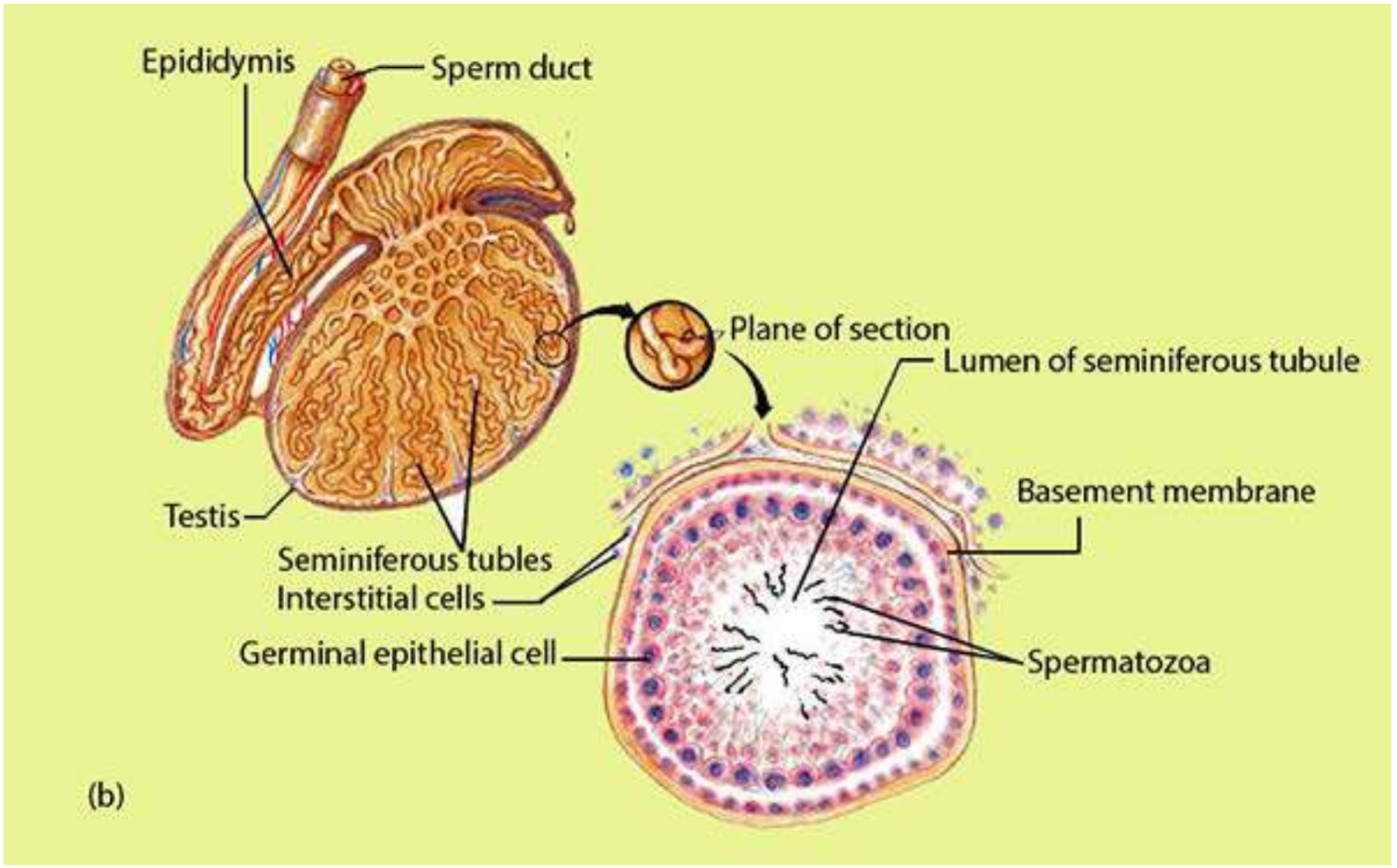



*Fig. 18.2 The human male reproductive system*
*The male reproductive system consists of two testes that produce sperms, ducts that carry the sperms, and various glands.*

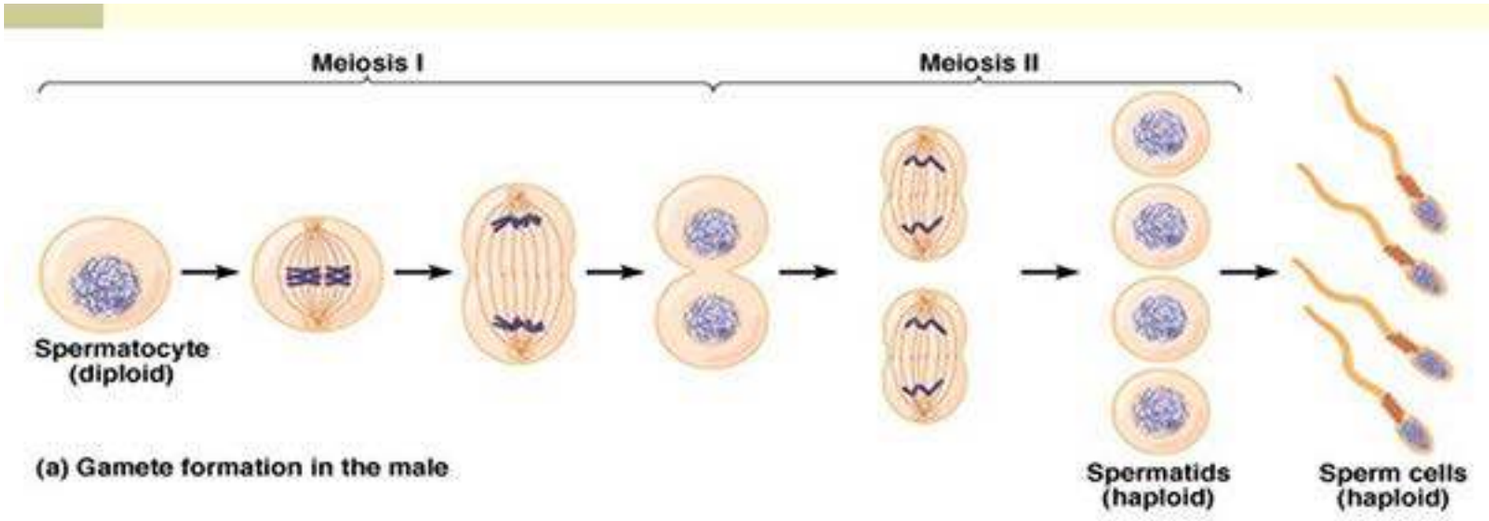


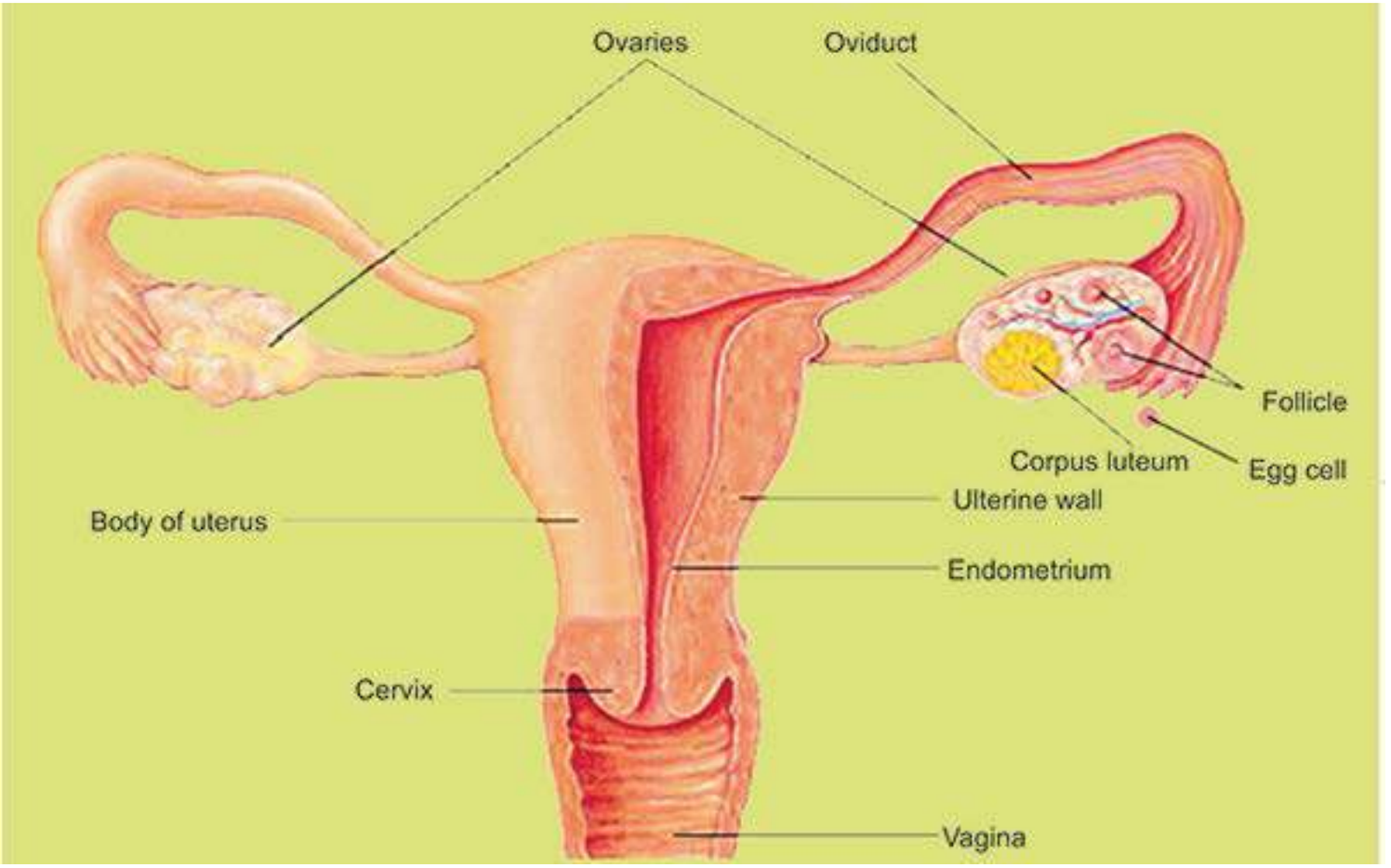

*Fig. 18.3 Gamete formation*

Between the seminiferous tubules are interstitial cells which secrete testesterone. This hormone is essential for the successful production of sperms and also controls the development of male secondary sexual characteristics during puberty.

## (b) Female Reproductive System

The female reproductive system consists of ovaries, oviducts, uterus and the external genitalia (18.4).

A pair of ovaries lies within the body cavity of the female. Germ cells in the ovary produce many oogonia which divide mitotically to form primary oocytes. These are enclosed in groups of follicle cells. The primary oocyte divides meiotically into the haploid secondary oocyte and first polar body. Second meiotic division in the oocyte proceeds as far as metaphase but is not completed until the oocyte is fertilized by the sperm. In human only one ovum is usually discharged from the ovary at one time, this phenomenon is called ovulation.



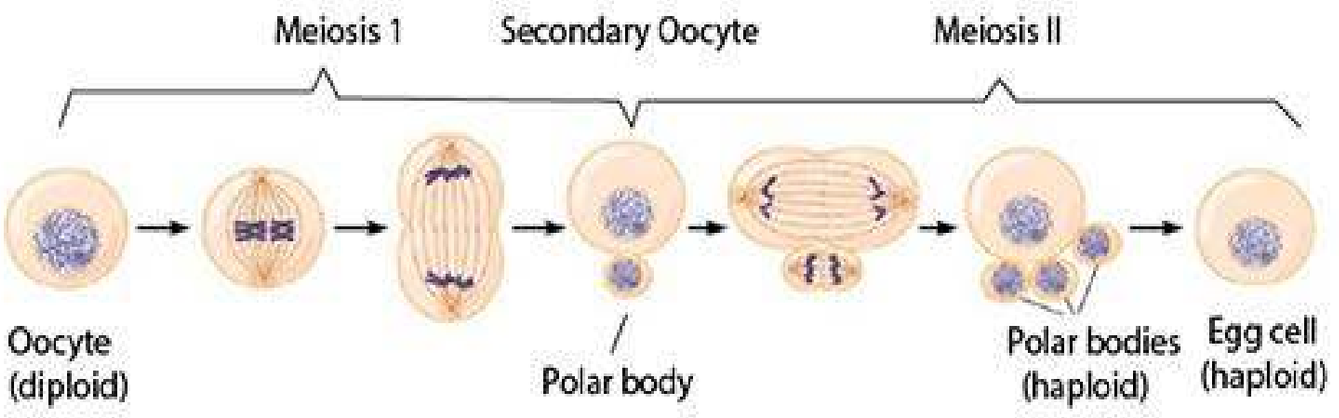



*Fig.18.4 (a)The human female reproductive system (b) Gamete formation*

The ovum is then transferred to the oviduct generally called fallopian tube Or uterine tube. The uterine tube opens into the uterus. The fertilization of the ovum takes place in the proximal part of the oviduct. The fertilized ovum (zygote) enters the uterus where it is implanted (conceived) and undergoes further development. A placenta is established between the uterine and foetal tissues for the exchange of oxygen,carbondioxide, waste, nutrients and other materials. Uterus opens into the vagina through cervix. Urethra and vagina have independent openings to the exterior.

**Female Reproductive cycle:** In females the production of egg is a cyclic activity as compared to males, where gamete production and release is a continuous process beginning at puberty and lasting throughout life.

In human females, the periodic reproductive cycle is completed in approximately 28 days and involves changes in the structure and function of the whole reproductive system. It is called the menstrual cycle and can be divided into four phases. The events of the menstrual cycle involve the ovaries (ovarian cycle) and the uterus (uterine cycle) and these are regulated by pituitary **gonadotropins.**

Primary steps in female reproductive cycles are:

1. The pituitary gland on the onset of puberty, releases follicle stimulating hormone (FSH) which stimulates the development of several primary follicles. Only one of these follicles continues to grow with its primary oocytes while the rest break down by a degenerative process known as follicle atresia.

2. The ovary, under the stimulus of FSH, also produces estrogen hormone.-This, on one hand, stimulates the endometrium (internal living of the uterus wall) and vascularizes it, and on the other hand, inhibits the secretion of FSH from pituitary gland.

3. Decrease of FSH and increase of estrogen, causes the pituitary gland to secrete luteinizing hormone (LH) which induces ovulation - the release of ovum from the follicle.

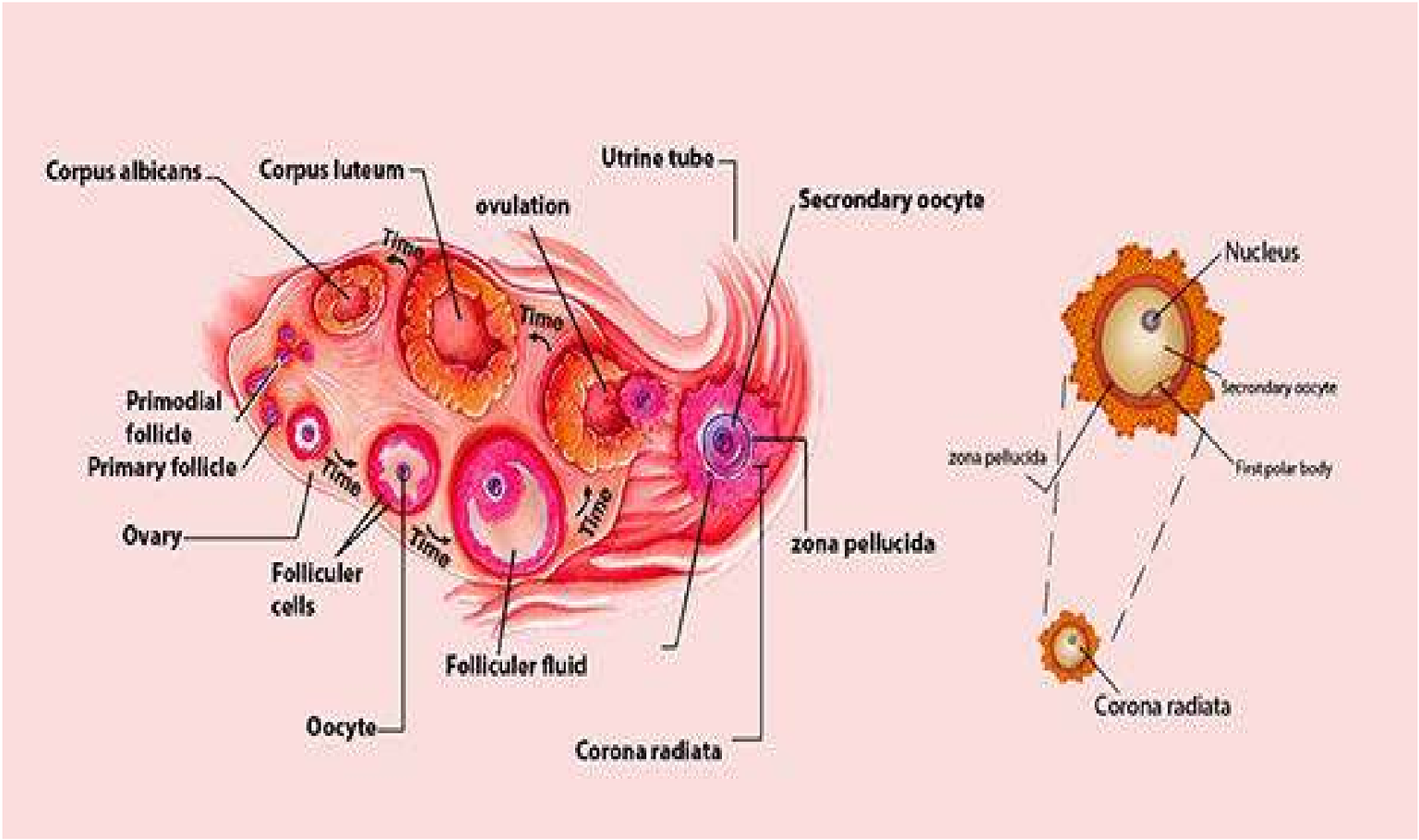
4. The follicle cells, after release of the egg. are modified to form a special structure called corpus luteum. This yellowish glandular structure starts" secreting hormone called progesterone. This hormone develops the endometrium and make it receptive for the implantation of the zygote (placenta formation).

5. If fertilization does not occur, the corpus luteum starts degenerating. The progesterone secretion diminishes and its supporting effect on the spongy endometrium is reduced, which suffers a breakdown. This causes the discharge of blood and cell debris known as menstruation. This stage usually lasts for 3 - 7 days (Fig 18.5)

Oestrous cycle is a reproductive cycle found in all female mammals except human being. In this cycle, the estrogen production prepares the uterus for conception partly and also follicle develops ova. At this stage, female needs a physical stimulus of mating for ovulation. She exhibits the desire for mating or is said to be on "heat"

The cycle is thus completed and the uterus is ready to enter into the next cycle. The human menstrual cycle generally repeats every 28 days although there is considerable variation in different individuals or even within the same individual at different times of her age. The end or complete stop of the menstrual cycle is called menupause, after which the female stops producing the ova.

Malnourishment and emotional stresses effect the female reproductive cycle, which may be disturbed. The cycle is not completed in its normal 28 days.



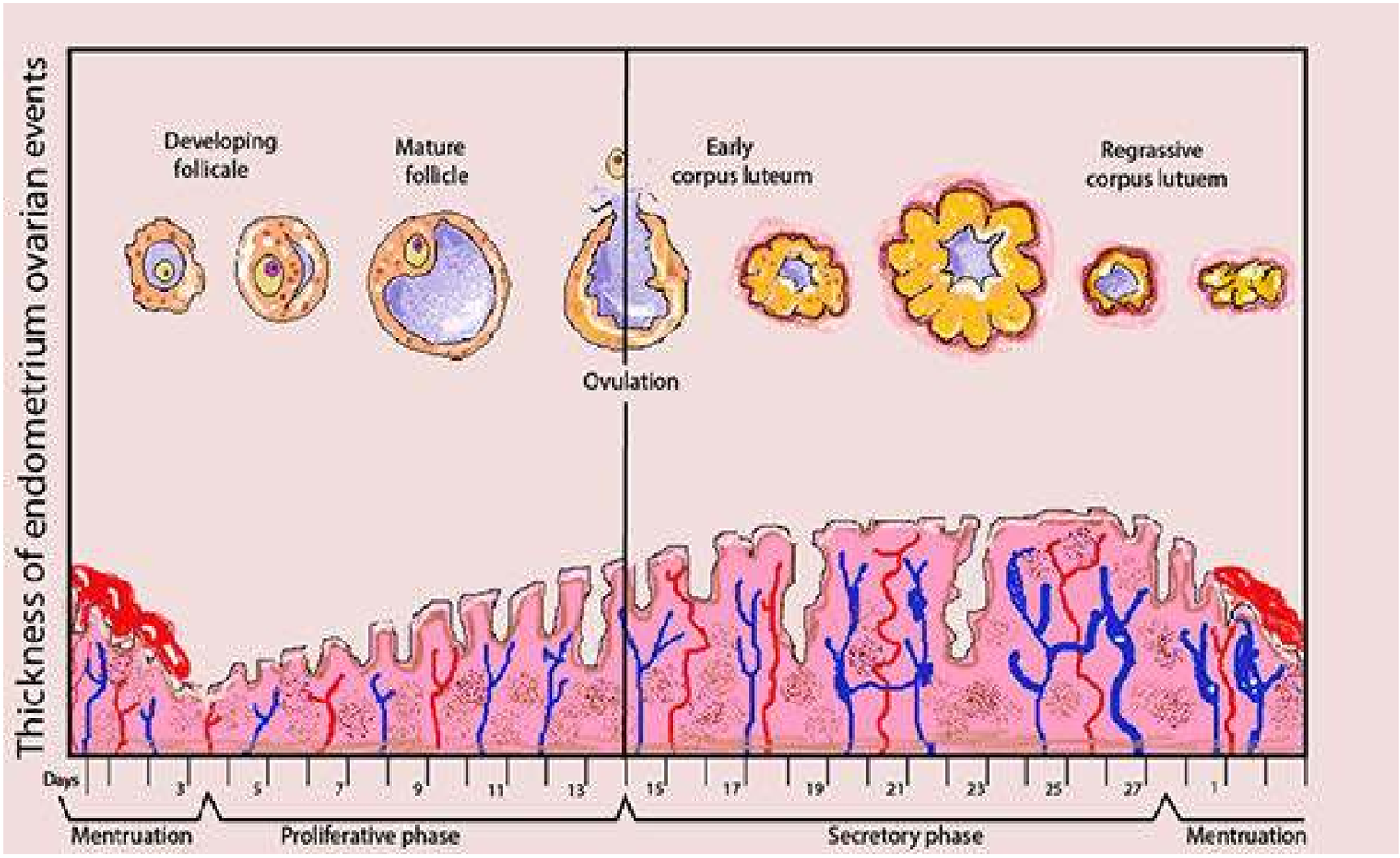



Fig. 18.5 The ovarian and uterine cycles in human female

The release of a secondary oocyte (ovulation) is timed to coincide with the thickening of the lining of the uterus. The uterine cycle in humans involves the preparation of the uterine wall to receive the embryo if fertilization occurs. Knowing how these two cycles compare, it is possible to determine when pregnancy is most likely to occur.

**Birth:** The total gestation period (pregnancy) is usually about 280 days.

Once the placenta is established, it starts secreting the progesterone hormone which maintains the pregnancy. Any disturbance in its secretion may lead to premature birth or miscarriage. Human embryo remains enclosed in amniotic sac filled with anmiotic fluid which is protective and shock absorpitive.

During this period, pituitary gland produces luteotropic hormone (LTH). Placenta also secretes human placental lactogen. Both these hormones stimulate mammary development in preparation for lactation.

From beginning of the 3rd month of pregnancy, the human embryo is referred to as the fetus. Most of the major organs are formed by the 12th week of pregnancy and the remainder of the gestation period is taken up by growth.

It was thought that hormonal activities within the mother i.e. decrease in progesterone level onset the birth. But recent evidence suggest that there is a high degree of fetal involvement in the timing of birth. The initial stage of birth is the result of the stimuli from the fetal pituitary. The ACTH released from fetal pituitary stimulates the fetal adrenal gland to release corticosteroids, which cross the placental barrier and enter the maternal blood circulation causing a decrease in progesterone production. The reduction of progesterone level, stimulates the pituitary gland to produce oxytocin hormone. This induces labour pains, i.e. contraction of the uterus wall. The release of oxytocin occurs in “waves” during labour and provides the force to expel the fetus from the uterus.

The cervix dilates and the uterine contractions spread down over the uterus and are strongest from top to bottom. Thus, pushing the baby downward leading to the delivery of the baby. The umblical cord is ligated and baby is released from the mother.

Within 10-45 minutes after birth, the uterus contracts and separate the placenta from the wall of the uterus and placenta then passes out through the vagina. This is called after birth. Bleeding, throughout this period, is controlled by the contraction of smooth muscle fibers which completely surround all uterine blood vessels supplying the placenta. Average loss of blood is about 350 $cm^3$.

## TEST TUBE BABIES

Recent biotechnical advantages has led to many improvements in human life. One of the important aspect is the test tube babies.

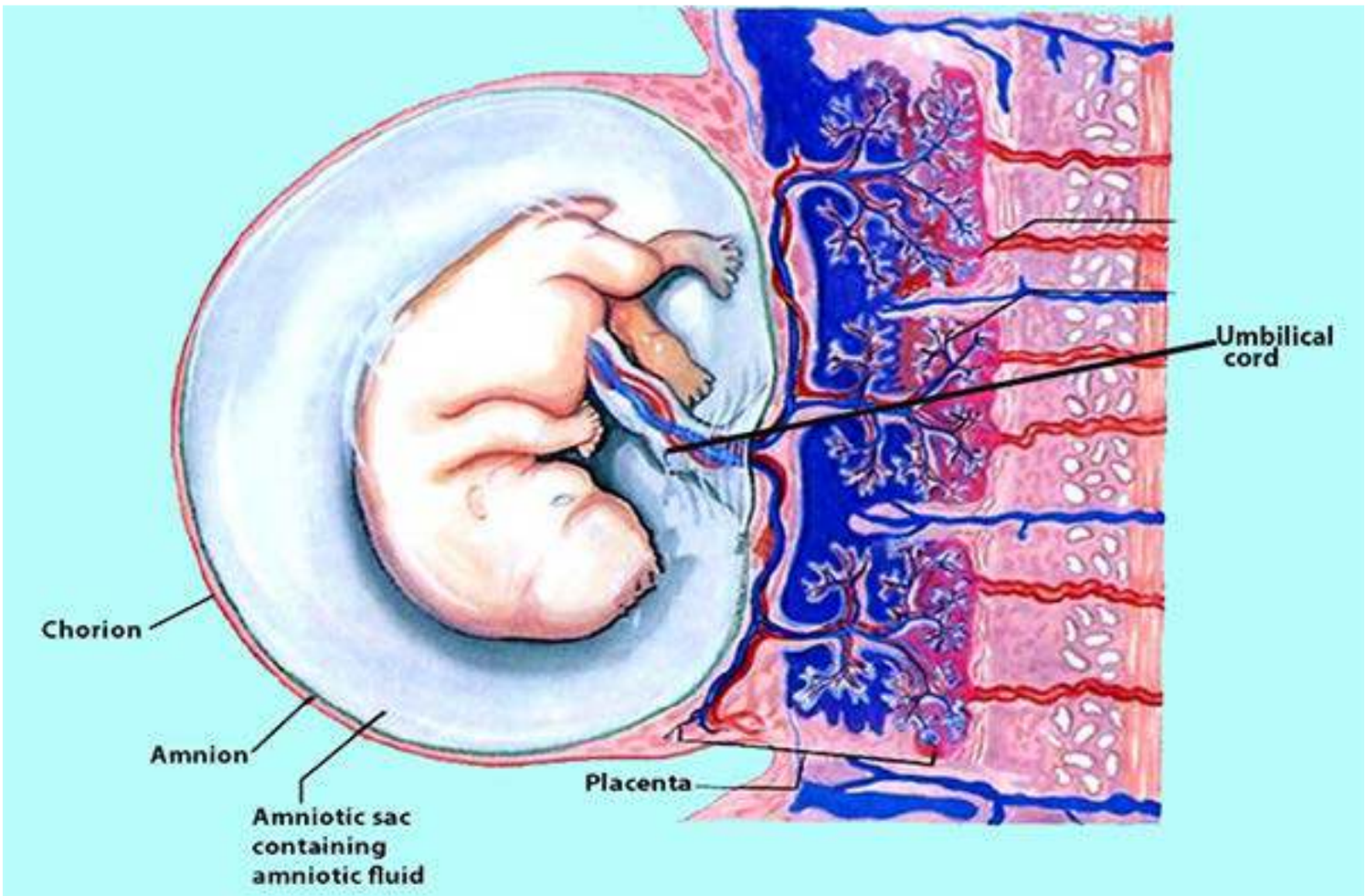



Fig. . 18.6 Placental structure

The embryonic blood vessels that supply the developing child with nutrients and remove the metabolic wastes are separated from the blood vessels of the mother. Because of this separation, the placenta can selectively filter many types of incoming materials and microorganisms.

Parents which are unable to enjoy the normal process of fertilization and birth of their offspring due to some physiological and physical abnormalities in any of the two parents are being benefited with this method.

Parental sperm and ovum is fertilized in vitro - outside the female body and then the zygote is implanted back into the mother uterus, placenta establishes and remaining development takes place in the body of the mother leading to normal birth.

# SEXUALLY TRANSMITTED DISEASES (STD)

Unhealthy attitudes and low moral values sometimes lead to serious complication. The carrier may transmit this disease to their healthy partners.

## (I) Gonorrhoa

It is caused by a gram positive bacterium *Neisseria gonorrhoeae*, mainly affecting the mucous membrane of urinogenital tract. New born infants may acquire serious eye infections if they pass through the infected birth canal. It is highly contagious through sexual contacts.

## (ii) Syphilis

It is caused by a spirochaete, *Treponema pallidum*. It damages the reproductive organs, eyes bones joints, central nervous system, heart and skin. Sexual contact is the major source of its dissimination.

## (iii) Genital Herpes

It is caused by a herpes simplex type 2 virus, most frequently transmitted by sexual contact causing infection of the genitalia. It produces genital soreness and ulcers in the infected areas. In infected pregnant woman, virus can be transmitted to infant during birth, causing damage to eyes and CNS of the infant.

## AIDS (Acquired Immune Deficiency Syndrome)

You are already familiar with this dangerous disease. Sexual contact is one of the major sources of its spread.

**Control :** The above dreadful sexual diseases can be controlled and prevented by avoiding sexual contacts with carrier or diseased person and adopting the hygienic conditions. The treatment involves medication for a long period except AIDS at present.

## Exercise

### 1. Fill in the blanks.

1. Asexual reproduction requires only a single _____organism
2. Sexual reproduction usually involves _____ parents.
3. Phytochromes are the special_____ sensitive pigments
4. External fertilization occurs in_____ environment.
5. _____ and _____animals provide more protection to their young one during development
6. A placenta is established between the uterine and_____ tissues for the exchange of oxygen.
7. The reduction of progesterone level, stimulates the_____gland to produce oxytocin hormone.

### Q.2 Write whether the statement is true or false and write the correct statement if false.

1. Asexual reproduction involves mitotic cell division.
2. Asexually produced offspring are genetically identical to their parents.
3. Sexual reproduction involves single parent.
4. Sexually produced offspring are identical to their parent.

### Q.4. Short questions

1. What changes occur in ovulation and menstruation during pregnancy?
2. What is the difference between oogenesis and spermatogenesis in humans?
3. How is a seed formed?
4. What is the importance of seed in the life cycle of a plant.

## Q3. Extensive questions.

1. What structures are associated with the human female reproductive system? What are their functions?
2. What are the functions of placenta during pregnancy?
3. Describe human menstrual cycle.
4. Write notes on the following:
   - (a) Parthenogenesis
   - (b) Herpes Genitalia
   - (c) Asexual reproduction
   - (d) Seedless fruits

CHAPTER

19

# GROWTH AND DEVELOPMENT

*Animation 19: Homeostasis*
*Source & Credit: Wikispaces*

In the course of its life cycle an organism changes from a fertilized egg into an adult. As development proceeds, all sorts of the changes take place. The most obvious change is growth. The progressive changes which are undergone before an organism acquires its adult form constitute embryonic development. Growth is the permanent and irreversible increase in size that occurs as an organism mature.

## GROWTH AND DEVELOPMENT IN PLANTS

In plants growth and development involve cell division, elongation and differentiation of cells into tissues and then organs. Growth is an irreversible increase in size and development is a programmed series of stages from a simpler to more complex form. As development proceeds, cellular differentiation of structure and function takes place.

A plant has a growth pattern called **open growth**. Throughout life, the plant adds new organs such as branches, leaves and roots, enlarging from the tips of roots and shoot but the rate of growth is not uniform throughout the plant body. At the beginning, the growth is slow, but gradually it becomes rapid, attains a maximum, then gradually slows down. In vascular plants, growth occurs through the activity of meristems. Meristems are young tissues or group of cells that retain the potential to divide. In lower plants, the entire plant body is capable of growing, but in higher plants, the entire plant body is not capable of growing but growth is limited to certain regions known as growing points.These growing points consist of groups of cells which are capable of division, these growing points are called meristems. These meristematic cells are located at the stem and root and they are of the following types.

### (i) Apical Meristems

The apical meristems are found at the tips of roots and shoot and are primarily concerned with the extension of plant body. These are perpetual growth zones found at the apices of roots and stems. They are responsible for increase in the number of cells at the tips of roots and stem, so they play important role in primary growth (Fig 19.1).

*Animation 19.1: Apical Meristems*
*Source & Credit: Animated Abstarct*

## (ii) Intercalary Meristems

These are the parts of apical meristem which get separated from apex by permanent tissues. They are situated at the bases of internodes in many plants. They play important role in the production of leaves and flowers. These are of temporary nature.

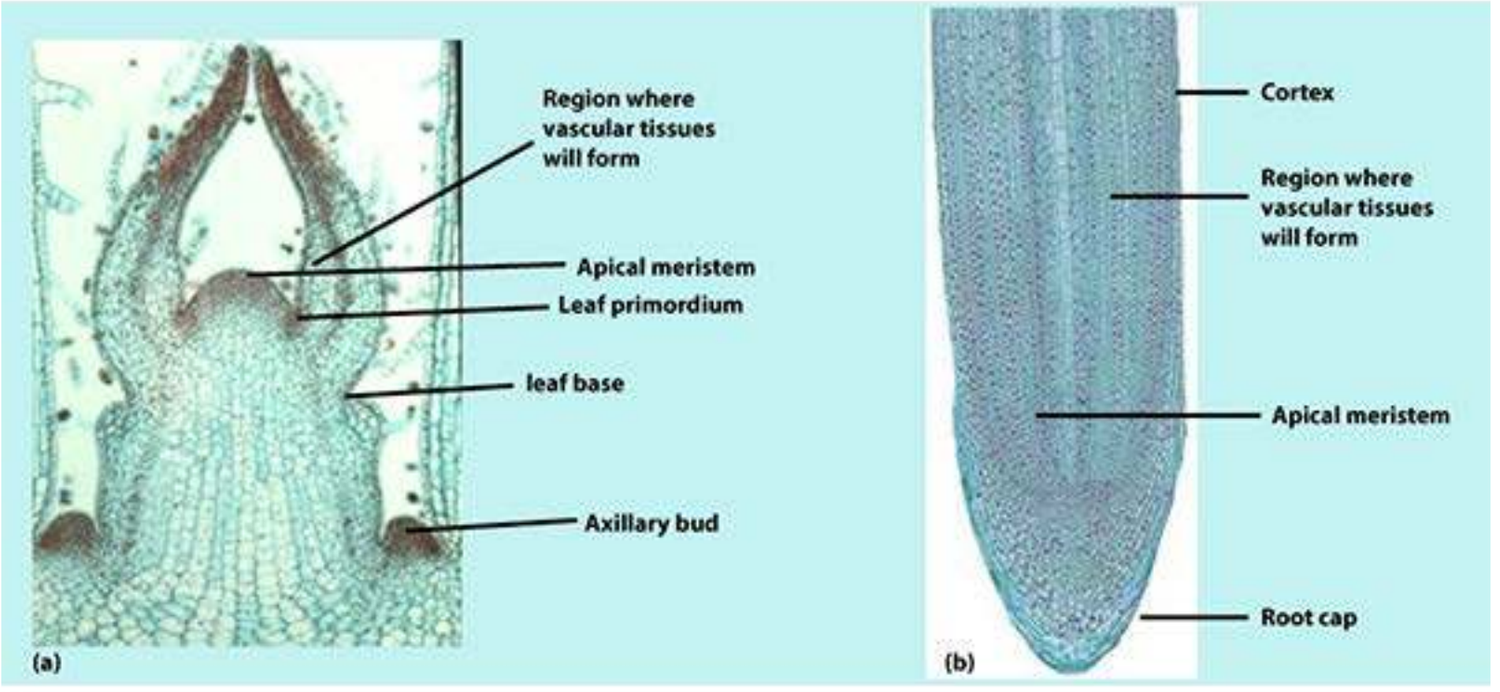



*Fig. 19.1 Photomicrographs of the apex of a shoot (a) and a root (b).*

## (iii) Lateral Meristems

Lateral meristems are cylinders of dividing cells. They are present in dicots and gymnosperms. Vascular and cork cambium are the examples of lateral meristem. They play an important role in the increase in diameter of stem and root and in secondary growth are determinate i.e. they grow to certain size and then stop e.g. leaves, flowers and fruits; while others are indeterminate i.e. they- grow by meristems that continually replenish themselves, remaining youthful e.g. vegetative root and stem.

## Types of Growth:

**(i) Primary Growth :** Primary' tissue is added by the apical meristem

**(ii) Secondary Growth :** Secondary tissue is added by the intercalary or vascular cambium leading to increase in thickness.

**Phases of Growth :** Growth of multicellular plant is divided into four phases, cell division, elongation, maturation and differentiation.

During **cell division**, the number of cells increase by mitosis. It occurs at the tip of root and shoot where cells are small, have spherical nuclei lying in the center of cytoplasm, which is non-vacuolated. As a result of cell division, each daughter cell proceeds to enlarge. Synthesis of cytoplasm and cell wall material also takes place in this zone.
A little distance from apex of root and shoot lies the **zone of elongation** and is only of few millimeters in length. During elongation the cell volume increases upto 150 fold due to uptake of water. Plasticity of the cell wall increases and wall pressure is reduced. Synthesis of new cytoplasm and cell wall material proceeds on.

During **maturation**, the final size of a given type of a cell is attained.The cells which develop into pith, cortex and certain other tissues do not elongate further along the axis, while other cells like fibers and tracheids elongate lengthwise more than in other direction.

When the cell enlargement ceases, the process of **differentiation** starts. During this growth phase the walls of cells become thicker, the walls of many kinds of cells and tissues become pitted; thickening appear on the walls of xylem vessels, cells of various tissues differ in spatial dimensions and many new structural features develop. (Fig 19.2**)**

## Conditions of Growth

The growth rate is influenced by number of factors both external and internal. External factors are temperature, light, oxygen, carbon dioxide, water, nutrition etc. while internal factors are hormones, vitamins etc.

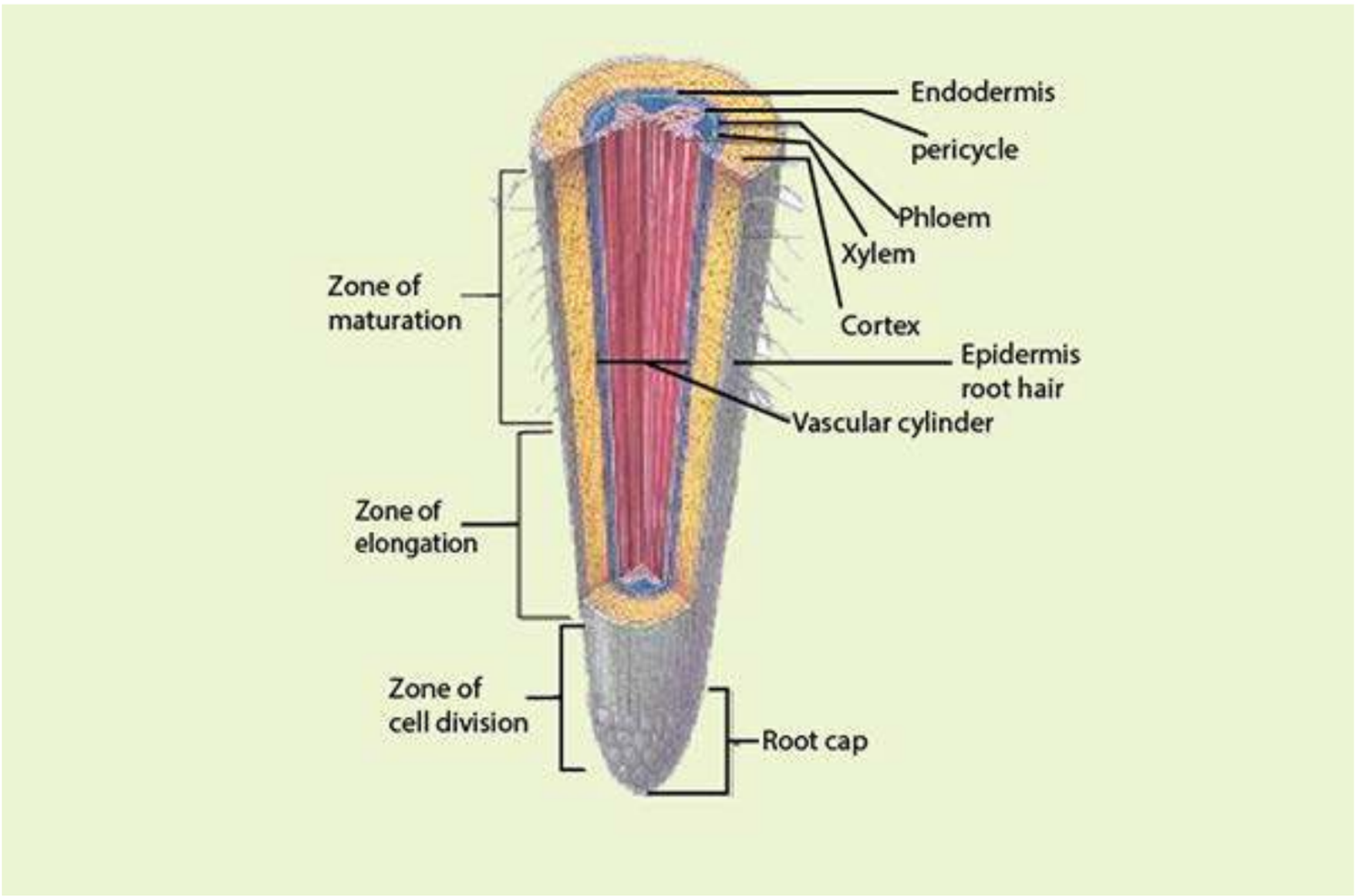



*Fig. 19.2 The root tip is divided into four zones.*

## (A) Externa! factors

**(i) Temperature :** Temperature influences the rate of growth within a certain range (0-35°C). Normally rate of growth increases with rise of temperature and decreases with decrease in temperature. For maximum growth, the optimum temperature is 25-30°C and it is least at 5-10°C. But at a very high temperature (35-40°C), the rate of growth stops and the plant may die.

**(ii) Light :** Light plays very important role in the growth of plants. By light, we mean the fractions of light, which is absorbed by plant during photosynthesis. Generally, light influences growth in three ways; intensity, quality and duration.

The increase in intensity of light increases the number of cell divisions. The red light favours elongation of cells and blue light enhances cell division but retards cell enlargement. Similarly, ultraviolet rays also retard cell elongation. Duration of light affects the growth of vegetative and reproductive structures. It also plays a role in inducing or suppressing flowering. The phenomenon is termed as **photoperiodism**.

**(iii) Oxygen** : For successful growth, regular supply of oxygen is necessary. Without oxygen, no metabolic activity is possible and no growth takes place. A very high supply of oxygen however, inhibits growth.

**(iv) Carbon Dioxide :** We know carbon dioxide is essential for carrying out normal process of photosynthesis but a very high concentration of it can retard growth.

**(v) Water :** By absorbing water, the cells elongate. The plant growth ceases in the absence of water.

**(vi) Nutrition :** Nutrients supply energy to growing plants. With the increase in nutrition, growth increases, whereas decrease in nutrition causes retardation of growth.

### (B) Internal Factors

(i) Hormones : Plant hormones also influence growth e.g. Indole-3-acetic acid / (IAA) causes elongation of cells.

**(ii) Vitamins** : Vitamins are orgasmic compounds synthesized within the plant bodies in the presence of light. If the plants are grown in dark, the vitamin deficiencies are induced and growth of plant body ceases.

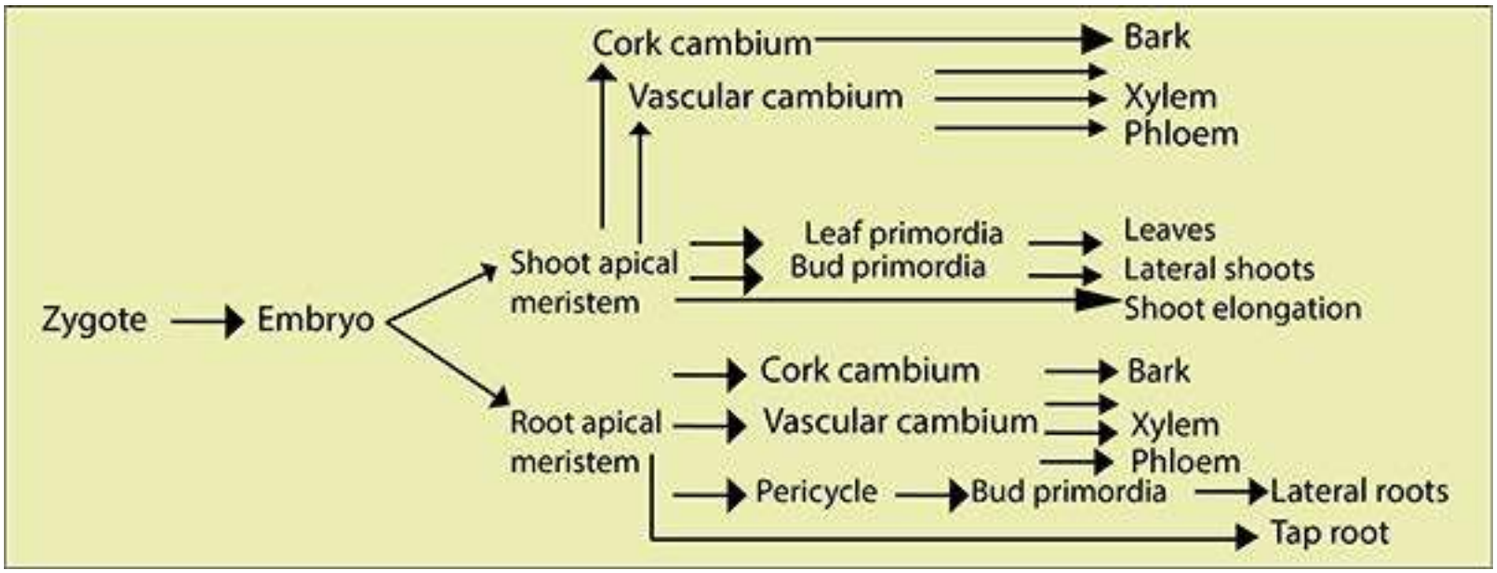



*Fig. 19.3Graphic representation of growth and differentiation in plants*

## Differentiation

As you have studied, once a seed has germinated, the plant's further development depends on the activities of the meristematic tissues, and we know that shoot and root apical meristems give rise to all cells of the adult plant. Differentiation is the formation of specialized tissues, which can be considered to occur in plant in five stages (Fig 19.3).

**Stage 1** Represents the formation of embryo.

**Stage 2** Within the embryo, shoot and root apical meristems are recognized.

**Stage 3** Cambium is recognized, it is responsible for secondary growth.

**Stage 4** There is production of leaf primordial (these are the cells committed to become leaves, shoot or roots). Root primordia develop from the root cambium, called pericycle. Leaf and shoot primordia develop directly from apical meristematic cells.

**Stage 5** Fully differentiated tissues and structure are formed including xylem, phloem, leaves, shoots and roots.

## Growth Correlations

The development of a plant is usually correlated with its growth and different organs growing at different rates in different directions and the development of different parts takes place. Such reciprocal relationship is known as **correlation**.

One of the most important correlative effect in plants is **apical dominance**. In many plants, only apical bud grows while growth is suppressed in lower axillary buds. In an experiment, when apical bud was removed, the growth in the lower buds was inhibited. So active shoot apex controls the development of lateral buds. Thus, the auxin of the terminal bud is responsible for inhibiting the growth of lateral buds by a phenomenon known as apical dominance (Fig 19.4). Later Thimann and Skoog in 1934 performed experiments and showed that **apical dominance** was caused by auxin diffusing from the apical bud which inhibited the growth of lateral shoots is called **inhibitory effect**. The removal of apex releases the lateral buds from apical dominance. It is called **compensatory effect.**

Research has also indicated that not only auxin causes apical dominance, cytokinins also play important role in apical dominance and in many cases if cytokinins are applied directly on the inhibited bud, it allows lateral buds to be released from apical dominance. It is also seen that those plants that have dense growth of lateral branches, have very little apical dominance. As far as practical application of apical dominance is concerned, it plays an important role in tap root development, and the inhibition of sprouting of lateral buds (eyes) in potato tuber by applying synthetic auxin. In the later case, the sprouting of eyes is prevented and storing period is increased from one to three years (Fig. 19.4).

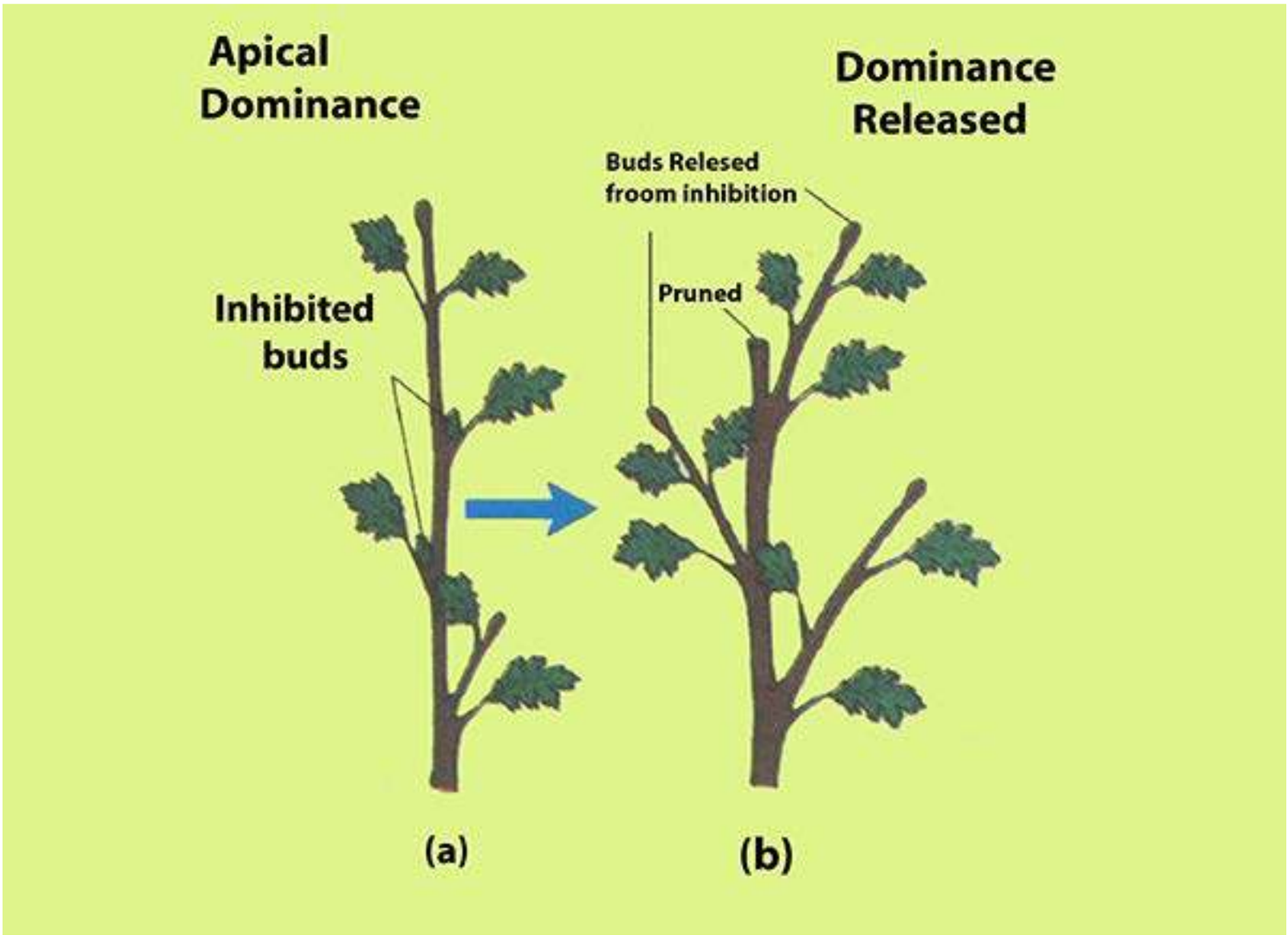
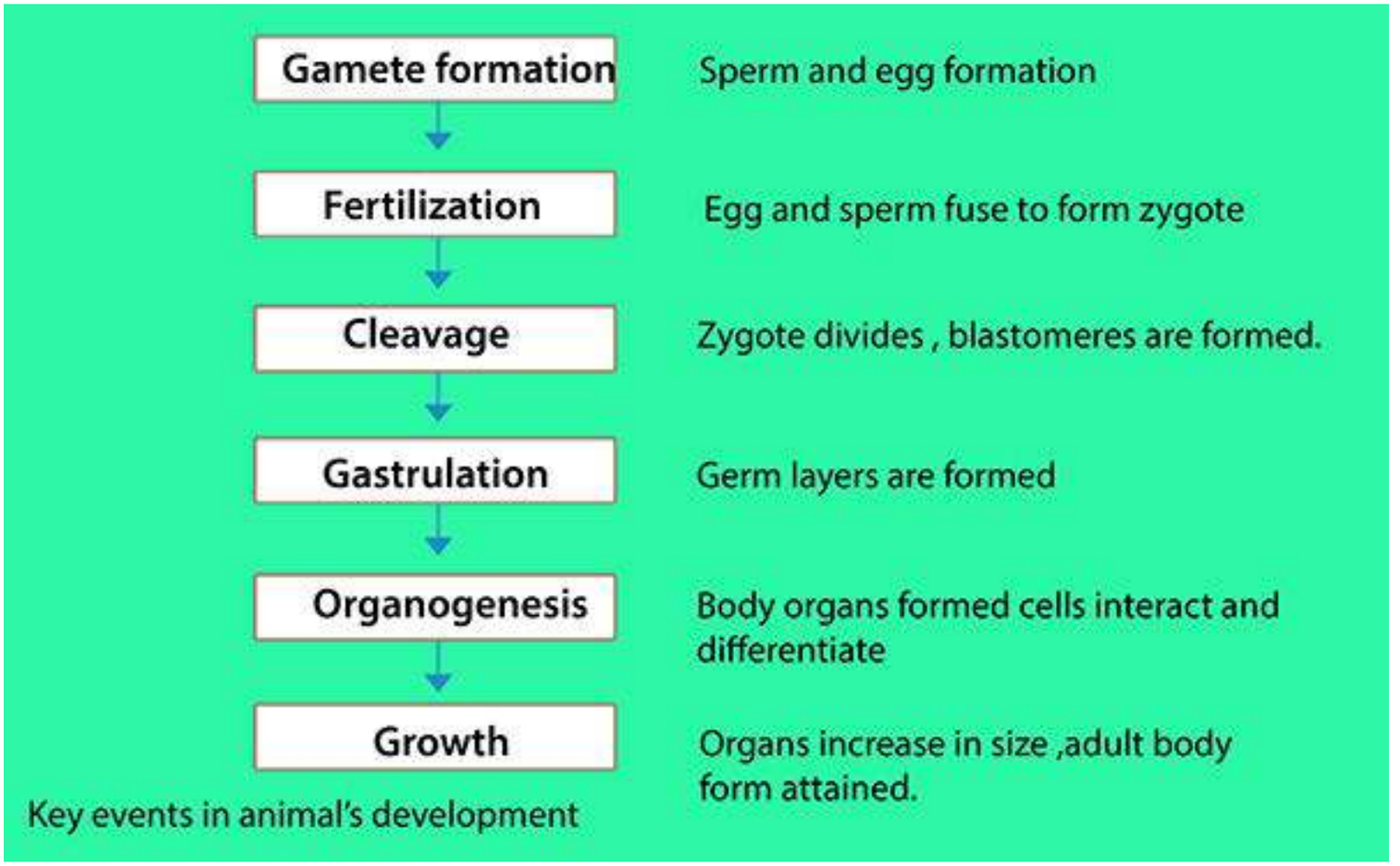



*Fig. 19.4 Apical Dominance : The Influence of Auxin*

## GROWTH AND DEVELOPMENT IN ANIMALS

Embryology is the study of growth and differentiation undergone by an organism in the course of its development from a single fertilized egg into a highly complex and an independent living being like his parents.

Development is an ordered sequence of irreversible steps, with each step setting up the necessary conditions for the next step. Since all animals are somehow related through the process of evolution, there are some similarities in their various forms of development. Here, we will see a broad outline of the early stages of development. This can be described in terms of several stages, depicted below:



Key events in animal's development

## Development of Chick

The development of chick has been taken as a basic scheme of development. It will provide basis for understanding the early differentiation of the organ systems and the fundamental process of body formation, which is common to all vertebrates.

**Fertilization and Incubation :** The chick egg (called the yolk) is surrounded by various accessory coverings secreted by the female reproductive tract.

Fertilization is internal and normally takes place just as ovum is entering the oviduct. The shell is secreted as the egg passes through the shell gland (the uterus).

When an egg has been laid, the development ceases unless the temperature of egg is kept nearly up to the body temperature of the mother. In incubating eggs artificially, the incubators are usually regulated at temperature between 36-38°C. At this temperature, the chick completes development and is hatched on the twenty first day.

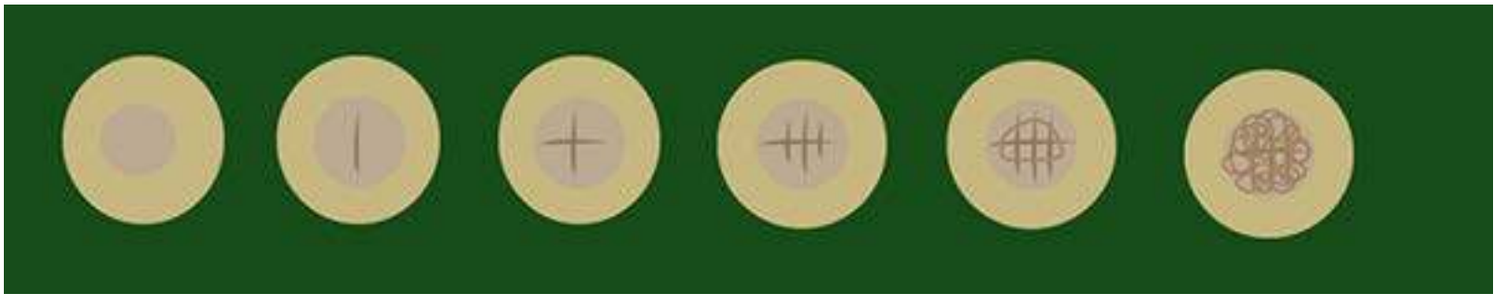


*Fig. 19.5 Cleavage stages in chick*

*Animation 19.2: Development in Chick*
*Source & Credit: Backyard Chicken*

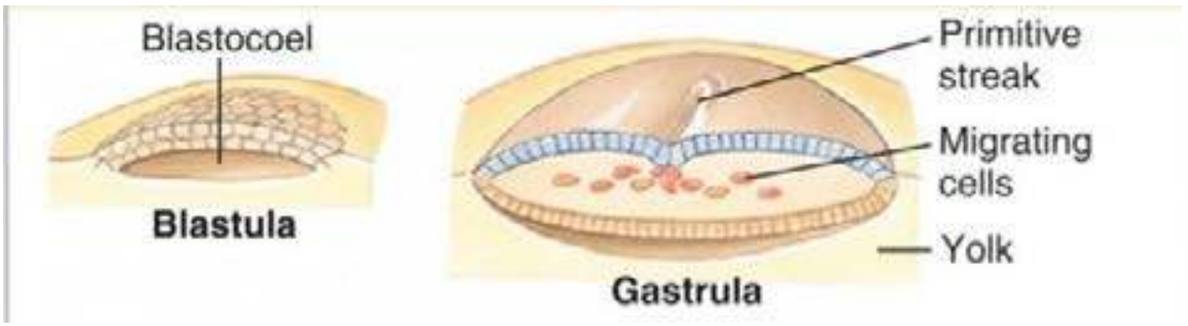
### Cleavage :

Immediately after fertilization, the egg undergoes a series of mitotic divisions, called cleavage. In bird's egg the process of cell division is confined to the small disc of protoplasm lying on the surface of the yolk at the. animal pole. This type of cleavage is referred as discoidal cleavage. The cleavage furrows start in the clear cytoplasmic region (Fig 19.5). The first two cleavage planes are vertical while the third runs horizontally parallel to the surface and thus cuts underneath the cytoplasm and separates it from the yolk. The successive cleavages become irregular and number of cells increase.

**Morulla :** Cleavage results in the formation of a rounded closely packed mass of blastomeres. This is morula, it consists of a disc shaped mass of cells two or more layers in thickness (blastoderm) lying close to the yolk. In the center of the blastoderm, the cells are smaller and completely defined while those at the periphery, are flattened, and larger.

### Blastulla :

The morula stage is short-lived and soon changes into blastula and is characterized by the presence of a segmentation cavity or blastocoele. The discoidal cap of cells above the blastocoele is called **blastoderm**. The marginal area of the blastoderm in which the cells remain undetached from the yolk and closely adherent to it is called the zone of junction (Fig 19.6).




*19.6: Blastuia and gastrula stages in embryo of chick*

**Gastrulation :** It is characterized by the movement and rearrangement of cells in the embryo. During gastrulation, the blastoderm splits into two layers: an upper layer of cells called **epiblast**, and a lower layer of cells called **hypoblast**. The epiblast is mainly presumptive ectoderm and mesoderm (Fig 19.7). The hypoblast is mainly presumptive endoderm because hypoblast cells grow outward over the surface of the yolk, then downward around it to form the endodermal lining of a yolk sac. At this stage, the central cells of blastoderm can be separated from the yolk, under these central cells a pool of fluid develops, raising them off the yolk and giving the area a translucent appearance - the **area pellucida**, while the peripheral part of the blastoderm where the cells lie unseparated from the yolk is termed as area opaca, the white area that transmits light. The upper layer of the blastoderm consists of the presumptive mesoderm and ectoderm.

## Notochord and Mesoderm Formation

In the chick, the mesodermal cells do not invaginate as in amphibians, but migrate medially and caudally from both sides and create a mid line thickening called primitive streak (which grows rapidly in length as more and more presumptive mesodermal cells continue to aggregate in the middle. All this results in the change of shape of blastoderm, (it changes from circular to pear shaped).

*Animation 19.2: Mesoderm Formation*
*Source & Credit: UNSW Embryology*

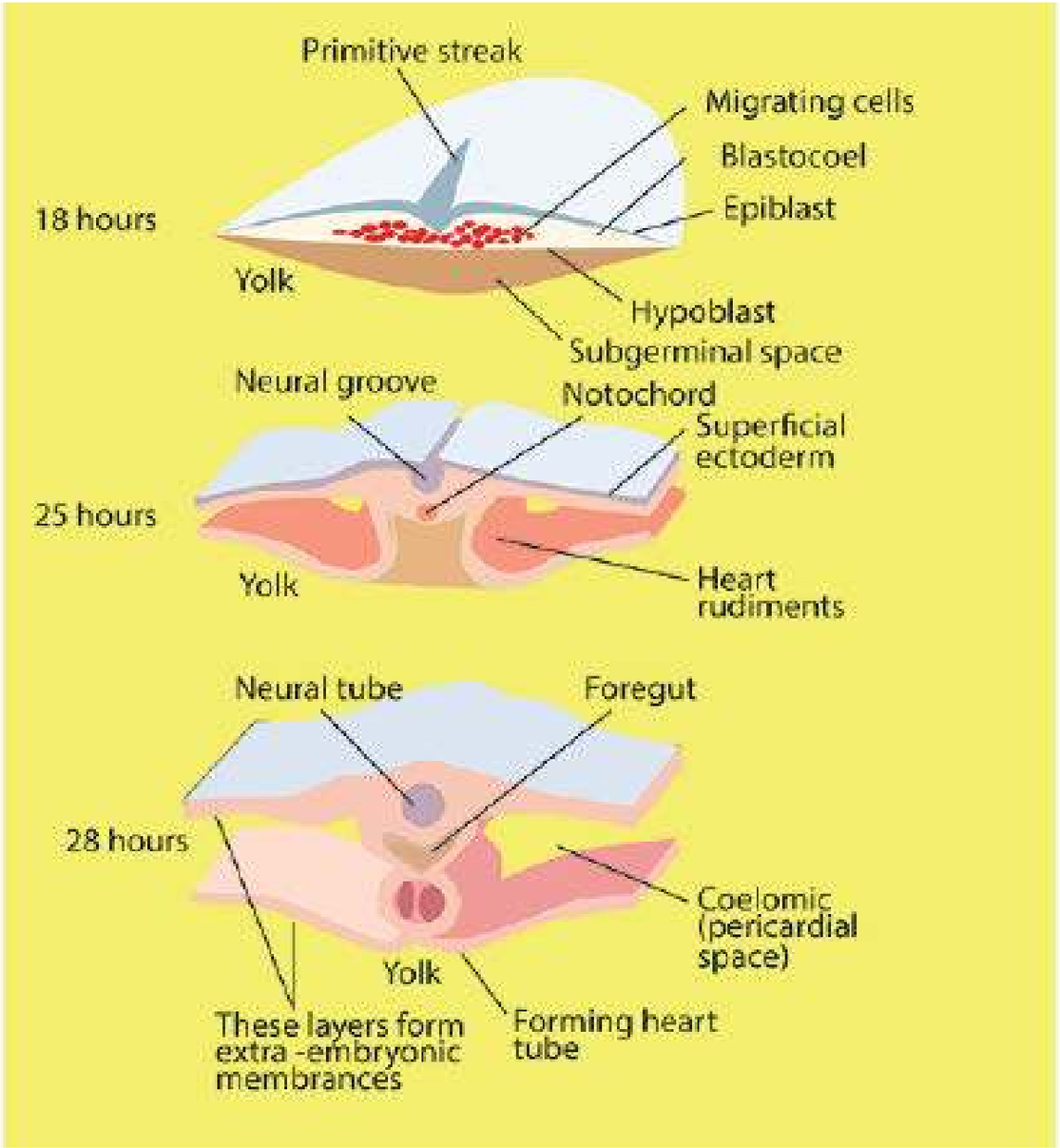



*Fig. 19.7 Gastrulation in the chick*

The anterior end of the primitive streak is occupied by an aggregation-the . primitive node or notochordal cells while rest of cells are mesodermal cells. Thus primitive streak represents the dorsal and both lateral lips of blastopore.

The continuous migration of cells takes place between epiblast and hypoblast and results in the formation of groove along the whole length of primitive streak. This is named as primitive groove, marked on either side by thickened margins, the primitive ridges.

At the cephalic end of primitive streak, closely packed cells form a local thickening known as Hensen's node. The Hensen's node however, mark the site of a somewhat special type of invagination.

Shortly, after the primitive streak has been formed and the endoderm was well established, cells begin to push in from the region of Hensen's node to form the rod like notochord in the midline beneath the ectoderm. In chick embryo of about 18 hours, notochord is one of the few prominent structural features. In sections of embryo incubated from 18-20 hours, it is seen that ectoderm has spread and become organized into a coherent layer of cells merging peripherally with the yolk and the marginal area where the expanding germ layers merge with the under lying yolk is known as germ wall and the cavity between the yolk and the endoderm which has been called gastrocoele is now termed as primitive gut.

From Hensen's node, dorsal mesoderm is formed and is organized into somites. The lateral plate mesoderm is splitted into two sheet like layers viz somatic mesoderm and splanchnic mesoderm, with a space between them. The cavity formed between somatic and splanchnic mesoderm is coelom. Somites are seen in 25-26 hours embryo, these are compact cell masses lying immediately lateral to neural folds.

**Neurulation :**

On the dorsal surface of gastrula, over the notochord, presumptive neural ectoderm is present in the form of a band. As gastrula elongates, the band thickens to form a neural plate. In chicks of 18 hours, neural plate was seen as a flat, thickened area of ectoderm. In embryos of 21-22 hours, a longitudinal folding has occurred, establishing the neural groove in the mid dorsal line, on either side of neural folds. In 24 hours embryos, the folding of neural plate is clearly visible. The embryo is now termed as neurula. The anterior end of the neural groove is widest and forms the future brain and rest of portion is future spinal cord. In the meantime, the neural plate sinks and the neural folds grow toward one another and meet in the middorsal line, fuse and convert the neural groove into neural tube. At each end of neural tube, a small opening called anterior and posterior neuro-pores are also seen, which close later on. With the formation of neural tube, there is formation of central nervous system and the cavity enclosed is known as neurocoel. This whole process is named as **neurulation.**

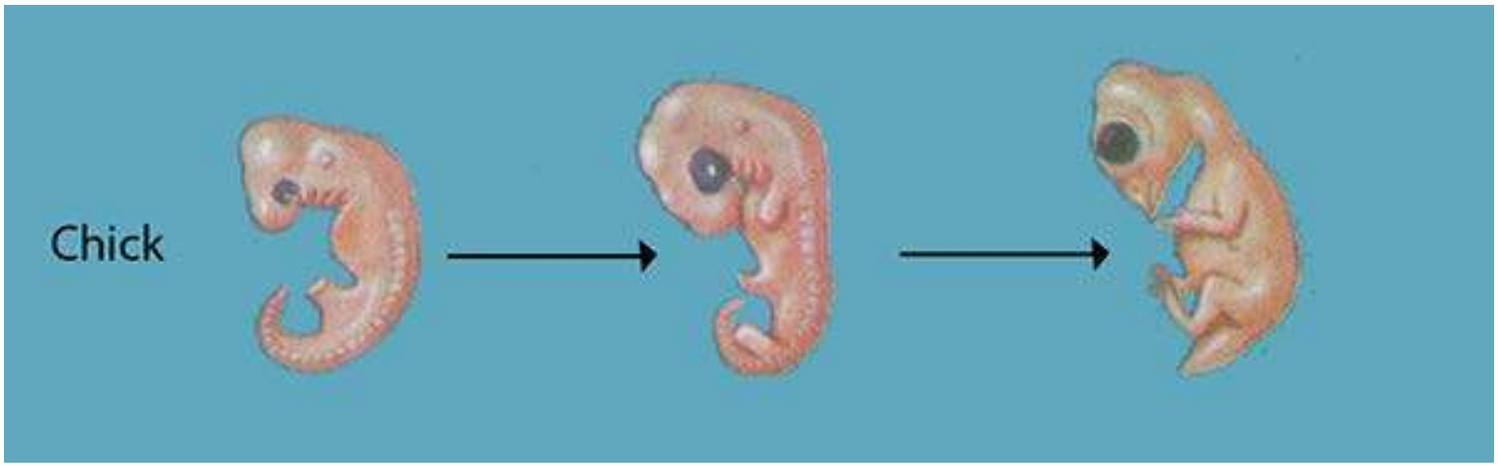



*Fig:19.8 Early chick embryos*

## Mechanisms of Development

We know that from a single celled zygote, multicellular individual is formed and zygote contains complete information in the form of genome which has come in the form of chromosomes from the eggs and sperms. During cleavage, zygote divides into many cells. Each cell has full set of chromosomes and gets complete instructions from the parents. During differentiation however some genes remain active, while others switch off. The importance of nucleus and cytoplasm during development is revealed from the following experiments.

1.In 1892, Hans Dietrisch, took sea urchin egg at two-cell stage, shook it apart and separated it into two cell. Later on, it was seen that both half embryos developed into normal larvae. Dietrisch concluded that both these cells .

2. contained all the genetic information of the original zygote.

Another experiment was performed by Spemann. He took salamander zygote, and with the help of minute ligature of human hair divided the zygote into two equal halves. The nucleus was present in one half, but the other half had no nucleus. When the developmental process continued, it was seen that cleavage was completed in the half containing nucleus but the anucleate half was not seen dividing. Eventually, when nucleated side had reached a 16-cell stage, one of the cleavage nuclei crossed the narrow cytoplasmic bridge to the anucleate side. Immediately this side started dividing.

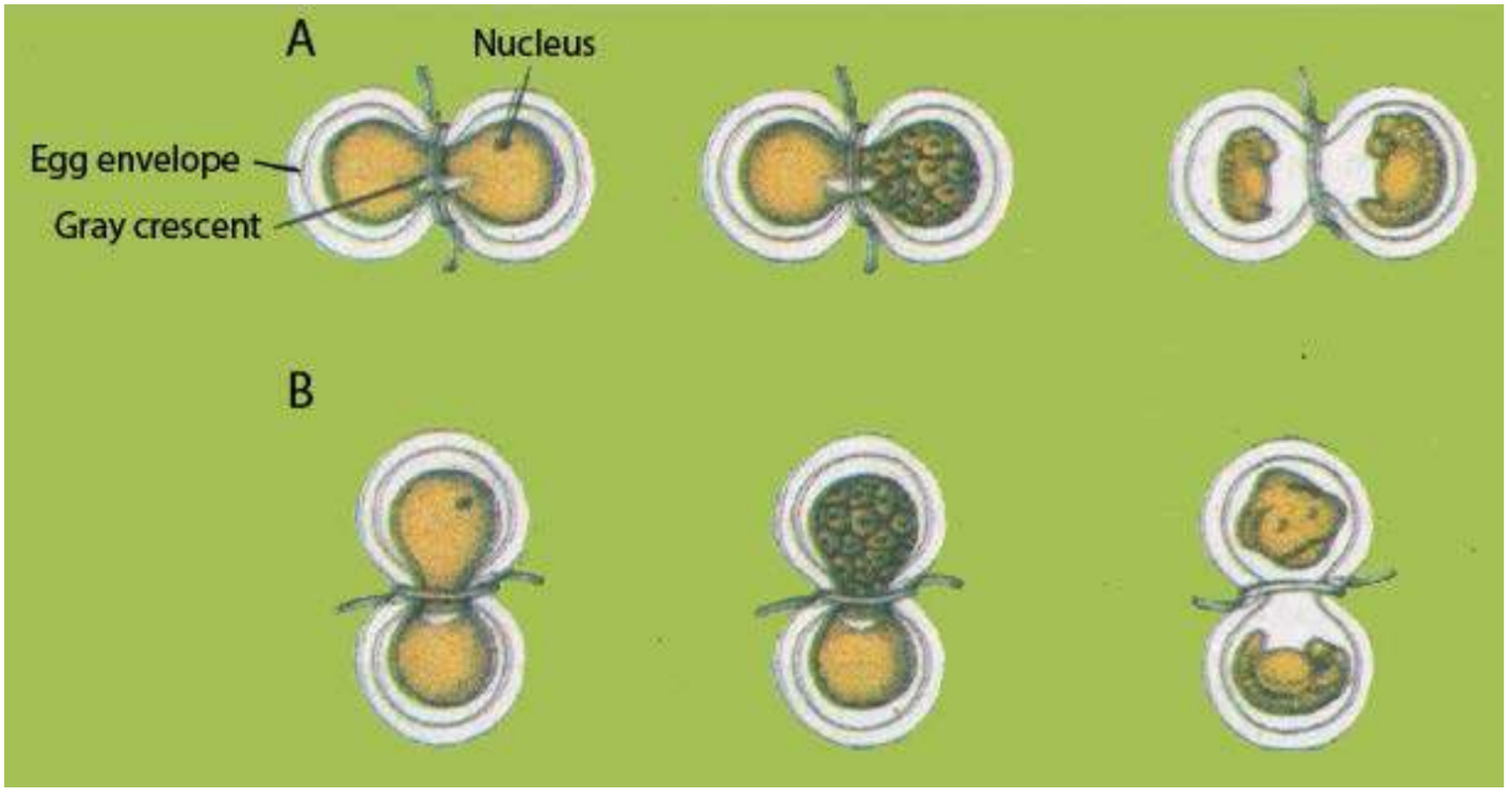



*Fig. 19.9 Spemann's delayed nucleation experiments. Two kinds of experiments were performed. A, Hair ligature was used to constrict an uncleaved fertilized newt egg. Both sides contained part of the gray crescent. The nucleated side alone cleaved until a descendant nucleus crossed over the cytoplasmic bridge. Then both sides completed cleavage and formed two complete embryos. B, Hair ligature was placed so that the nucleus and gray crescent were completely separated. The side lacking the gray crescent became an unorganized piece of belly tissue; the other side developed normally.*

**3.**Spemann also performed another experiment. He separated the two halves of embryo; both of them contained nuclei. Both these halves developed into complete embryos. He also observed that from a 16-cell embryo even, if a single cell is separated, it contains a complete set of genes and form a complete embryo. Through series of experiments, Spemann also observed that sometimes it may happen that the nucleated half can develop into abnormal ball of cells. Later studies revealed that development depends on the position of gray crescent. Gray crescent is the pigment free area that appears at the time of fertilization. So in the half lacking gray crescent, no further development can take place.

On the basis of above experiments, Spemann made two conclusions.

i) All cells contain the same nuclear information.

ii) In the gray crescent area, cytoplasm contains information essential for development.

Next question is, if all the cells contain same nuclear material, what causes the cells to differentiate. There are two ways by which cell undergo differentiation and become committed to particular determinative molecules.

1. During cleavage, cytoplasmic segregation of determinative takes place.
2. Induction or interaction with the neighboring cells takes place.

## Role of Cytoplasm in Development

It is known that different cytoplasmic components contain different morpho genetic determinants that are responsible for cell differentiation. These determinants are present in blastomeres. The fertilized egg of an ascidian contains cytoplasm of five different colours that is segregated into different blastomeres.

1. **Clear cytoplasm.** It produces larval epidermis.
2. **Yellow cytoplasm.** It gives rise to muscle cells.
3. **Gray vegetal cytoplasm.** It gives rise to gut.
4. **Grey equatorial cytoplasm.** It produces notochord and neural tube.

## Role of Nucleus in Development

Most gene controlled substances, which can easily be identified are found in the cytoplasm, and are probably produced in it. Through experiment, it is found that production of developmentally active substances by the nucleus itself, or its immediate neighborhood, is, however available in some cases. One of such example is in the multicellular alga, Acetabularia. It consists of rhizoid, which is attached to the ground, from which arises a long stalk with an umbrella shaped cap at its top. On the basis of structure and shape of the cap, two species of *Acetabularia* have been identified; *Acetabularia mediterranea*, which has regular shaped cap, and A. *crenulata*, which has irregular shaped cap.

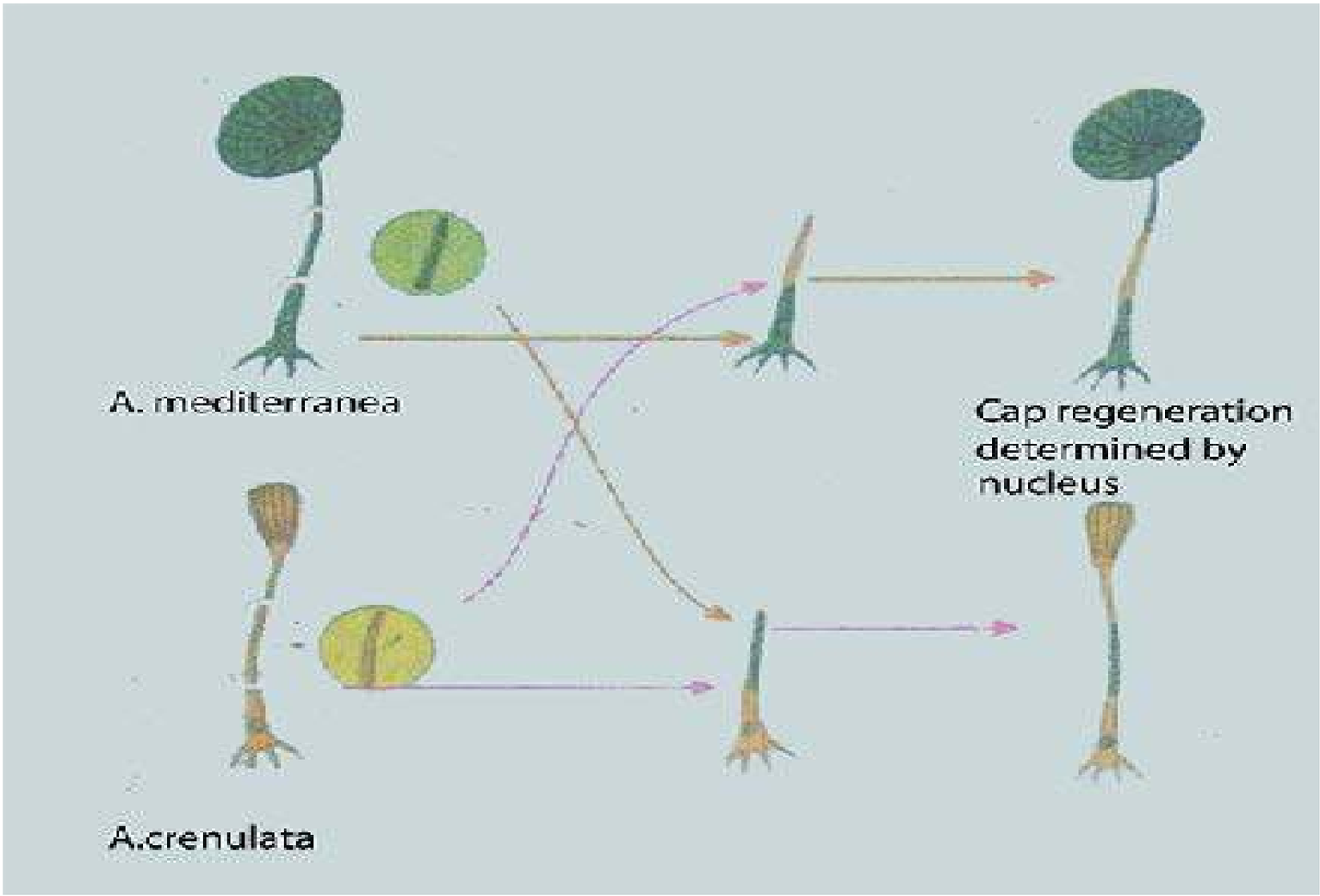



*Fig. 19.10 Nuclear control of cap structures in two species of Acetabularia.*

There is only a single nucleus, although they may attain the size of several centimeters or more. Haemmerling showed that if the cap is removed, a new one is regenerated. He cut off the nucleus containing rhizome from an alga of one species *(A. mediterranea)* and grafted a similar piece containing the nucleus of another species *(A. crenulata*). When the cap was now removed, it was seen that the new regenerated one had the characters of *A. crenulata*. So nucleus lying at the base of the alga and not the stalk to which the regenerate was attached determined the structure of cap. It means that irrespective of the fact to which species the cytoplasm belong, the genes were able to express according to the type of nucleus

From all these experiments , it was concluded that both gene and cytoplasm play important role in development . Nucleus contain all gene, which determine the characteristics of the individual, while cytoplasm plays the role of selection of genes.

## Concept of Differentiation:

A fertilized egg contains cytoplasmic components that are unequally distributed within the egg. These different cytoplasmic components are believed to have morphogenetic **determinants** that control the functioning of a specific cell type. This is now called differentiation.Zygote contains complete information for the development of an individual but it is difficult to see, how these cells differentiate.

In order to understand the concept of differentiation, Spemann performed a series of experiments on amphibian embryo.

He took out piece of ectoderm from frog's embryo and grew it in a separate dish. The embryo from which the piece of ectoderm was removed , was unable to form normal nervous system but has a defective nervous system. Similarly , the isolated piece did not develop any structure even though it was active and healthy . In another experiment , he separated the mesoderm underlying ectoderm and folded the flap of ectoderm to its original piece . The frog did not develop any nervous system. So it was proved that mesoderm had some effect on the ectoderm to simulate the ectoderm cells to form nervous system.

## Embryonic Induction

The capacity of some cells to evoke a specific development response in other is widespread phenomenon in development . Work on embryonic induction was reported by Hans Spemann and Hilde Mangold in 1924. They took two embryos of salamander at the gastrula stage and removed a piece of dorsal blastopore lip from one embryo , and transplanted it into a ventral or lateral position of another salamandar gastrula. It invaginated and developed a notochord and somites. It also induced the second embryo to form neural tube and a complete nervous system was formed where the dorsal balstopore lip was placed . The developing embryo had both the grafted tissue and induced lost time. Later on, it was seen that only cells from the dorsal lip of balstopore were capable of inducing a complete embryo . This area corresponds to the presumptive area of notochord, somites and prechordal plate. Spemann designated the dorsal lip area the **primary organizer** because it was the only tissue capable of inducing development of secondary embryo in the host . This was called **primary induction**

## AGING

Aging is an inevitable process and despite all the efforts to inhibit or stop it aging process goes on . It can be defined as negative physiological changes in our body . We identify the adult individual by the following signs of old age , all of them need not be present e.g. loss of hair pigment , development of small pigmented areas in the skin of face and arms , dryness and wrinkling of skin , loss of agility , increased weight due to fat poor vision and forgetfulness , general weakness and decreased body immunity.

Degeneration of organ and tissue may also take place e.g. in joints, arthritis arises from the degenration of cartilage , degeneration and disappearance of the elastic tissues in the tunica media of the blood vessel result in arteriosclerosis , blood clotting in the coronary arteries.

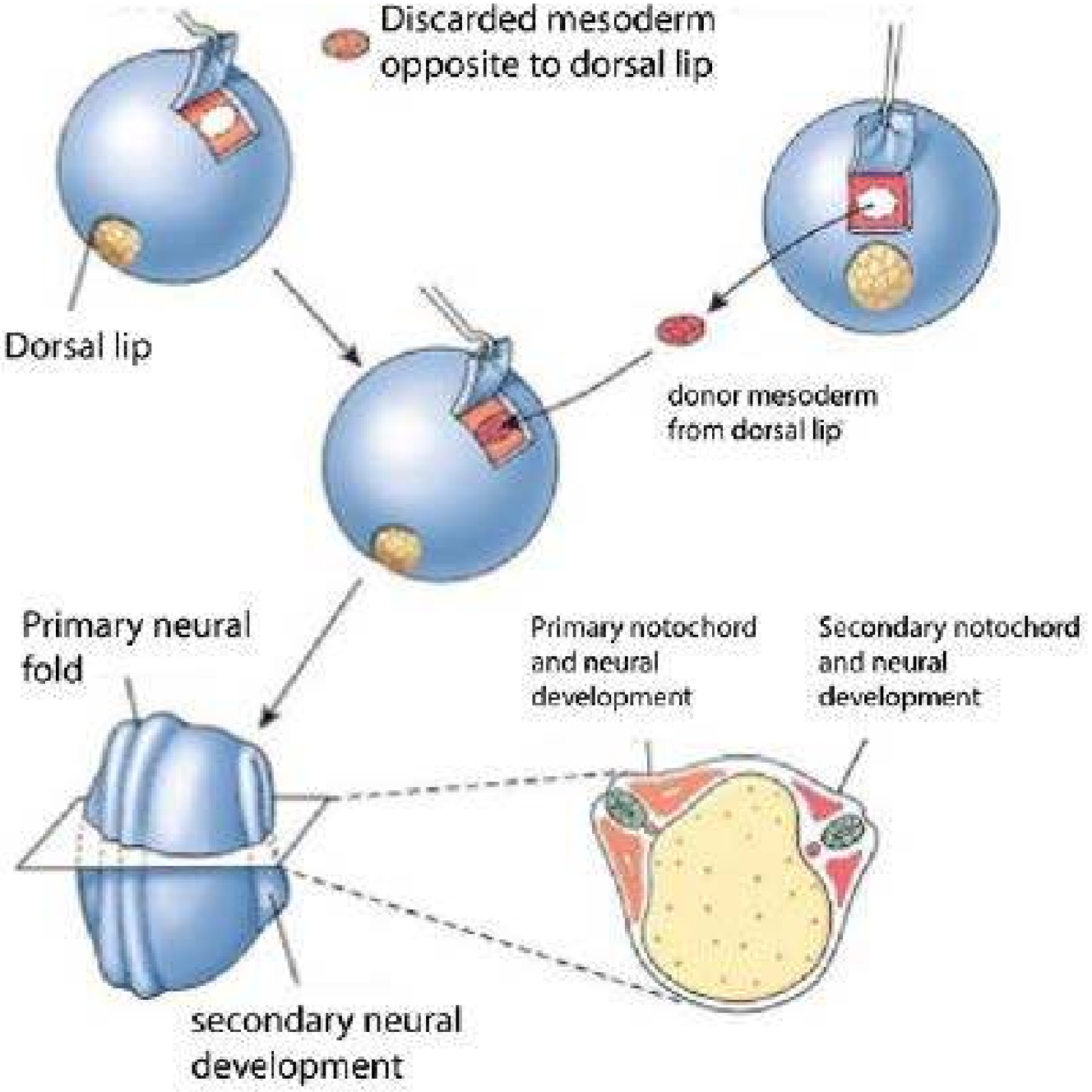



*Fig. 19.11 The spemann primary organizer experiment*

The exact process of aging is still unknown , but the following points are worth consideration.

1. The cells of tissues have only a finite number of mitotic division and hence the cells may have reached their finite number by the time tissue or organ is fully grown. For example in the case of nervous system, mental activity and memory deteriorate and there are fewer nerve cells in old age.

2. Changes in intracelluar substances take place during aging . For example, collagen acquires increased cross linkages in its protein molecules , while elastic tissues loss their elasticity with the passage of the time . There is also hardening and loss of resilience in dense connective tissues and cartilage.

**3.** Spontaneous mutation may result in loss of cells and degeneration of tssues . The process of aging can be slowed down by better nutrition and improved living conditions e.g. regular meals, regular exercise , adequate sleep , abstinence from smoking and maintaining ideal weigth can prolong life by an average of 11 years.

Today, there is a great interest in gerontology, the study of aging. The number of older individuals are expected to rise. In the next half century, the number of people over age 75 will rise from the present 8 million to 14.5 million ,and the number of over age 80 will rise from 5 million to 12 million. The human life span is judge to be maximum of 120-125 years. The present goal of gerontology is not necessarily to increase life span but to increase health span.

## REGENRATION

The ability to regain or recover the lost or injured part of the body is called **regeneration** .In sponges due to simple organization sponges possess greate power of regeneration . These not only replace the parts lost during injury , but any piece of the body is capabale of growing into a complete sponge. The process, is however , very slow and requires months or years for the complete development .

If lobster loses its pincer claw a new claw regenerates. If starfish breakes off portions of their arms into pieces till the central disc completely devoid of arms is left , the central disc in almost all cases and also the arms in some cases are capable of developing into separate individuals. If head of earthworm is removed, a new head regenerates. Limb regeneration has been studied mostly in salamanders of various ages. In these forms, the limbs are readily regenerated throughout life, more rapidly when the amphibian is young and small. Besides limb, other parts of the body also have considerable regeneration capacity e.g. tail in the larva of amphibians and in lizards. For example, lizard can easily discard its tail but tail can be regenerated by special features of its tail.

Healing of fracture and repair of a skin wound are some other examples of regeneration.

In plants, regeneration is the basis of plant propagation. Almost any part or even a very small fragments of a plant e.g. a piece of stem or leaf or even a single tissue cell may develop" into a full plant. A part of the stem with a few leaves may be taken from many kinds of plants and when planted in soil form a complete plant.

*Animation 19.3: Regenration*
*Source & Credit: Giphy*

In the process of regeneration, many of the various cell types which were present in the missing part of the body are replaced by the differentiation of cells e.g. in flatworms, and planaria the unspecialized cells, neoblasts, which are always present in the body of adult are mobilized and migrate to the site of amputation, where they differentiate into specialized cell types. But in other organisms like salamanders or newts some of the specialized tissue cell types in the stump of an amputated limb apparently dedifferentiate (become less specialized) and then proceed to differentiate into the same and probably different types of cells.

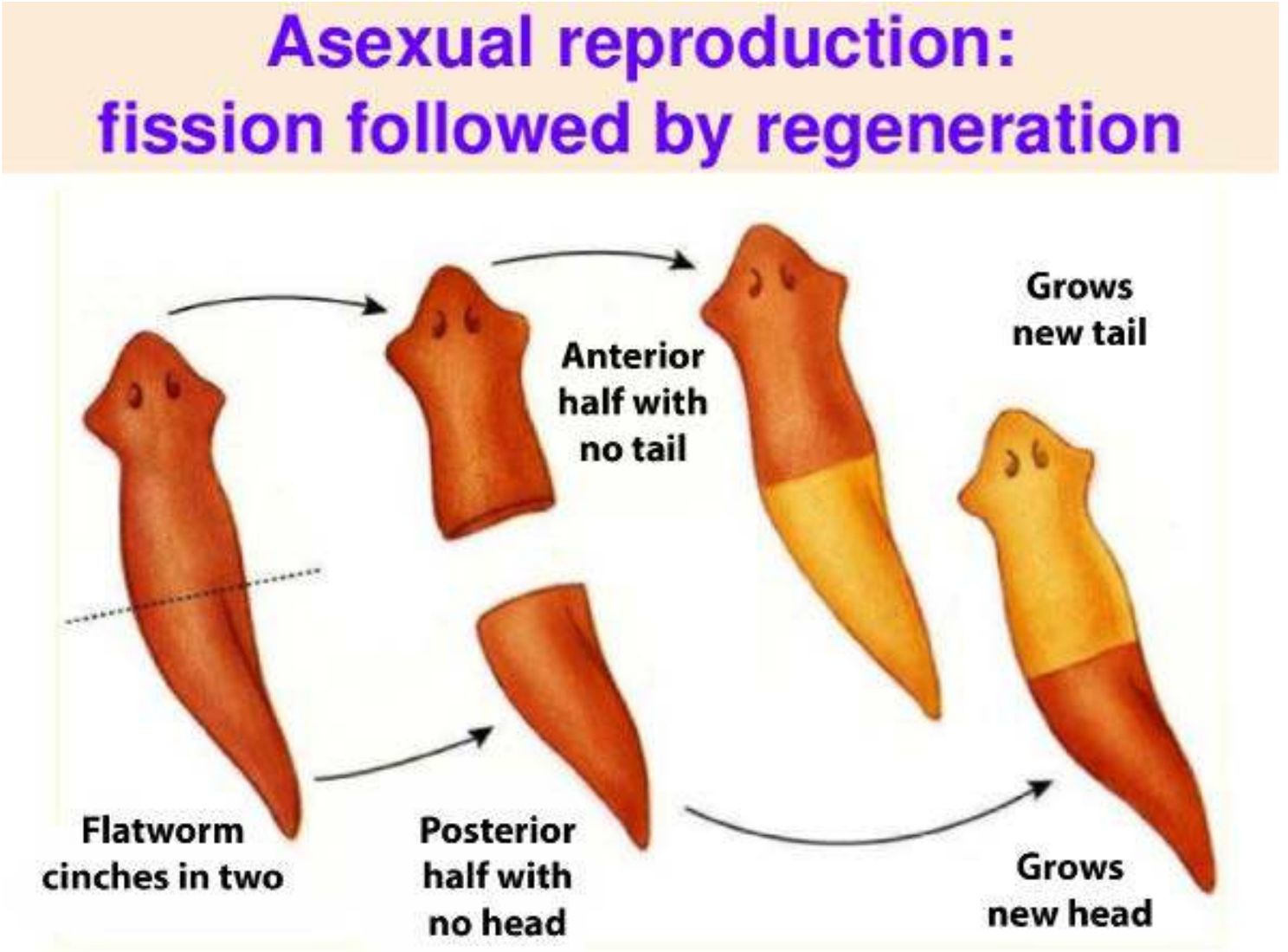



*Fig:19.12 Regeneration in (a) Start fish (b) Planaria*

## ABNORMAL DEVELOPMENT

Sometimes, under unfavourable conditions, some parts of the body show abnormal development. Teratology is the branch of biology, which deals with these abnormal developments and causes for such developments. Anything which interferes with the normal process of development is the factor causing abnormalities.

The normal process of development is disturbed by abnormalities inherited from parents, abnormalities due to chromosomes or genes, environmental factors or metabolic defects.

Abnormalities are inherited from parents through abnormal or defective gene(s). Abnormality of development is also related to the presence of defective gene on sex chromosomes e.g. in haemophilia only males suffer from this disease. It again, depends whether the gene is dominant or recessive, homozygous or heterozygous.

Chromosomal abnormalities result when one of the sex chromosomes (x or y) is missing or extra and these abnormalities lead to syndromes. Kline-felter's Syndrome (xxy) is an example of trisomy of the sex chromosome while Turner's Syndrome (xo) is the condition in which one of the sex chromosomes is missing. Another condition, xyy leads to tallness, aggressiveness, mental defect and antisocial behavior. These abnormalities arise during the formation of gametes, when these gametes unite to from zygote.

Environmental factors causing or contributing to abnormal development are grouped together as teratogens. Ionizing radiations (e.g. x. rays) are well known for their teratogenic action. Because, they often have their effect on the developing ovum or spermatozoan, causing damage or changes (mutations) in the genes. Nutritional deficiencies, absence of certain substances (e.g. vitamins and trace elements), toxins and drugs even ingested by mother, effect the differentiation of every tissue in the foetus. If such deficiency is high, a cell may cause death of foetus.

Metabolic defects lead to structural deviations from the normal. During organogenesis, when various body organs are formed, sometimes, one organ or its part is missing or it is repeated and it can result into abnormal organs or body parts and the individual born are malformed.

In microcephaly, the individuals are born with small skull. Individuals with cleft palate have their upper lip folded or the individual has harelip. In conditions of the fingers in hand or feet are more or less than five.

## EXERCISE

**Q1. FIll in the blanks.**

**(i)** The influence of notochordal cells on the ectodermal cells to become nervous system was called_____ .

(ii) _____is a condition in which individuals have small skull.

(iii) Growth is accompanied by two factors.

(a) by increase in _____(b) increase in_____.

(iv) _____are the regions where growth is initiated by the proliferation **of cells.**

**Q.2 Write whether the statement is true or false and write the correct statement if false.**

i). Primary growth leads to increase in length, while secondary growth leads to increase in width.

ii). The plants in which flowering is not at all effected by the day length are called day neutral plants.

iii). The somatic mesoderm soon splits in the middle to form two layers

(a) Outer parietal layer (b) Inner visceral layer

iv). In the clear cytoplasmic area, cytoplasm contains information essential for development.

v) The phase of cell movement and rearrangement is called cleavage.

**Q.4 Short questions.**

**(i)** What is organizer and inducer substance?

(ii) What is differentiation?

(iii) Define embryonic induction.

(iv) Differentiate between growth and development.

(v) What is meristem?

**Q.5 Extensive questions.**

**(i)** What is aging. How will you explain this process.

(ii) What is regeneration? Why it is so effective in some animals and missing in others?

(iii) Describe in detail the developmental processes of chick.

(iv) What is growth, discuss different phases and condition for growth?

(v) What is development, describe the principles of development in detail?

CHAPTER

20

# CHROMOSOMES AND DNA

*Animation 20:: Growth and development*
*Source & Credit: Wikipedia*

Chromosomes are thread like structures that appear inside the nucleus at the time of cell division. They were first observed by the German embryologist Walther Fleming in 1882, when he was examining the rapidly dividing cells of salamander larvae. Since their discovery, chromosomes have been found in the cells of all eukaryotes. Their number however varies from species to species. **Pencillium,** a fungus, has only one pair of chromosomes, while some ferns have more than 500 pairs. A mosquito has 6, honeybee 32, corn 20, sugarcane 80, frog 26 and a mouse has 40 chromosomes. Human cells have 46 chromosomes, consisting of 23 pairs (Fig 20.1). Each of these 46 chromosomes contains hundreds or thousands of genes that play important roles in determining how a person's body develops and functions. The possession of all these chromosomes is therefore, essential for survival. Missing of a part or whole of chromosome leads to serious consequences, and death occurs.

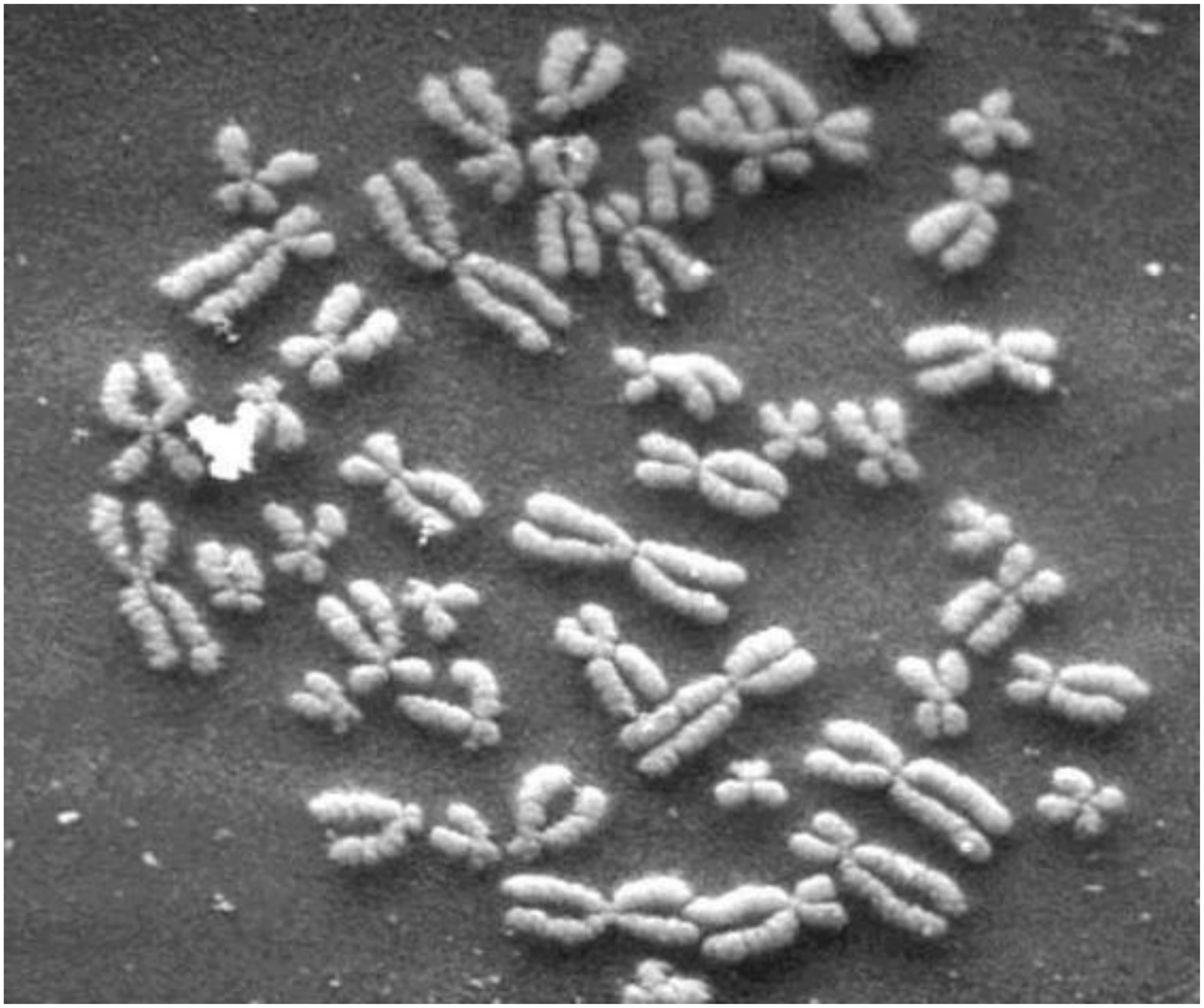


*Fig. 20.1 Human chromosomes*

## TYPES OF CHROMOSOMES

Typically, a chromosome is made of chromatids, centromere, (primary constriction), and a secondary constriction (Fig 20.2).

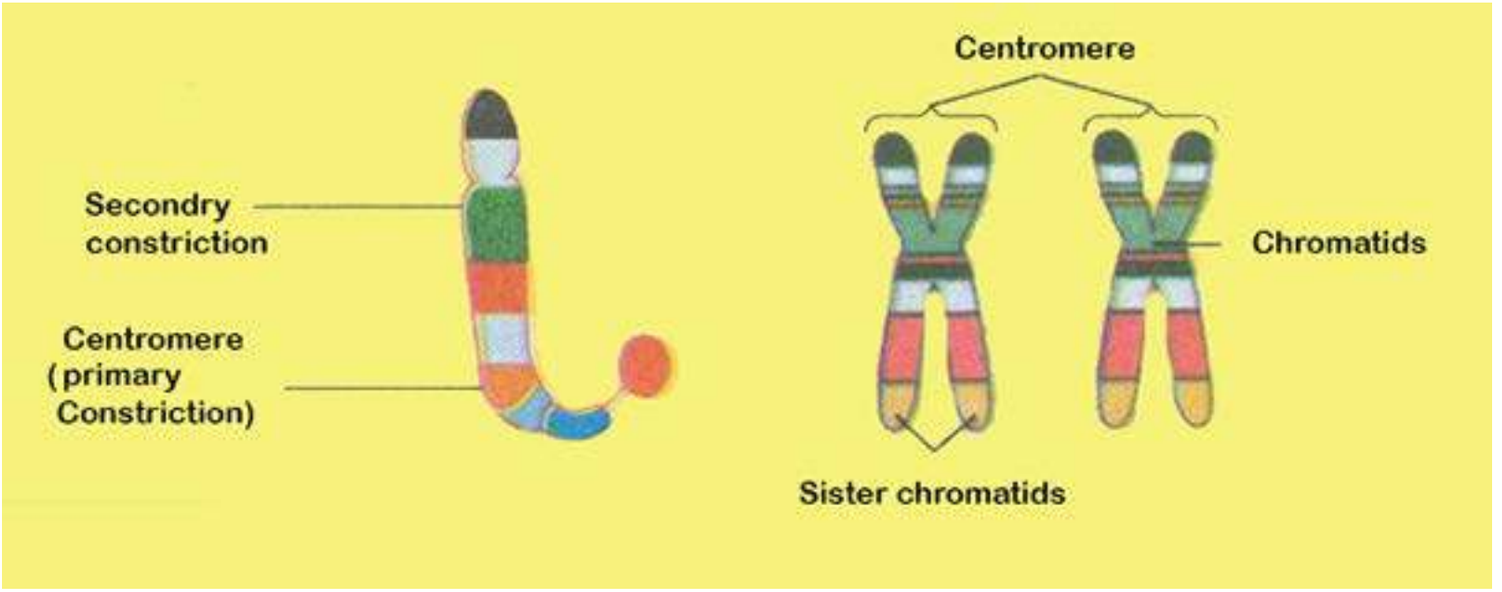



*Fig 20.2 Structure of chromosome*

Chromosomes may widely differ in appearance. They vary in size, staining properties, the location of centromere, relative length of two arms on either side of centromere, and the position of constricted regions along the arms. The particular array of chromosomes that an individual possesses is called its karyotype (Fig 20.3). Karyotypes show marked differences among species and sometimes even among individuals of the same species.

The chromosomes are called telocentric, acrocentric, sub metacentric and metacentric depending upon the location of centromere between the middle and tip of the chromosomes.

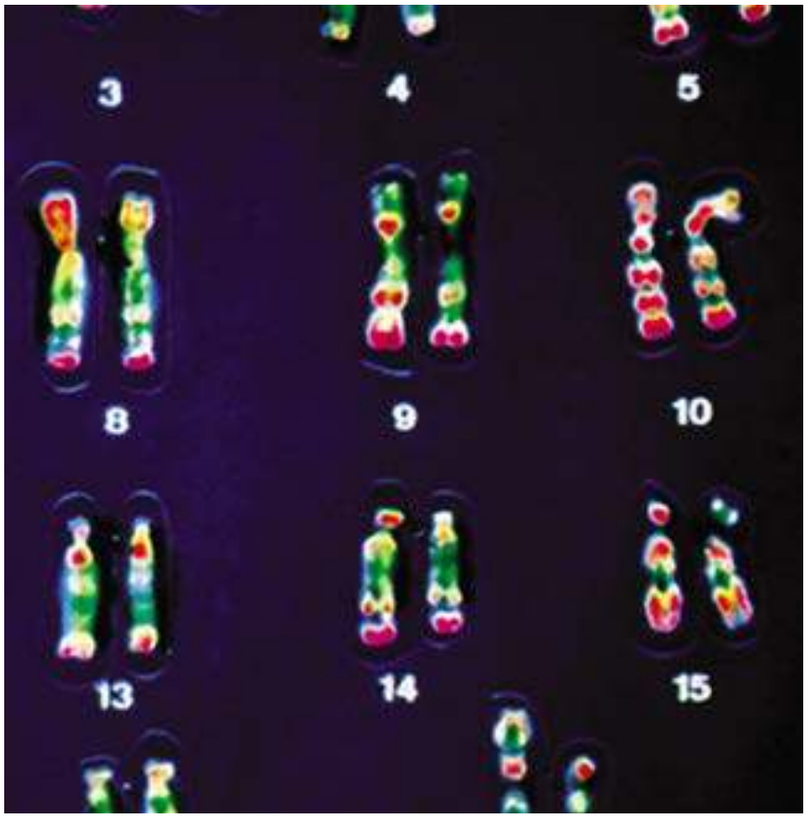



*Fig. 20.3 A human karyotype*

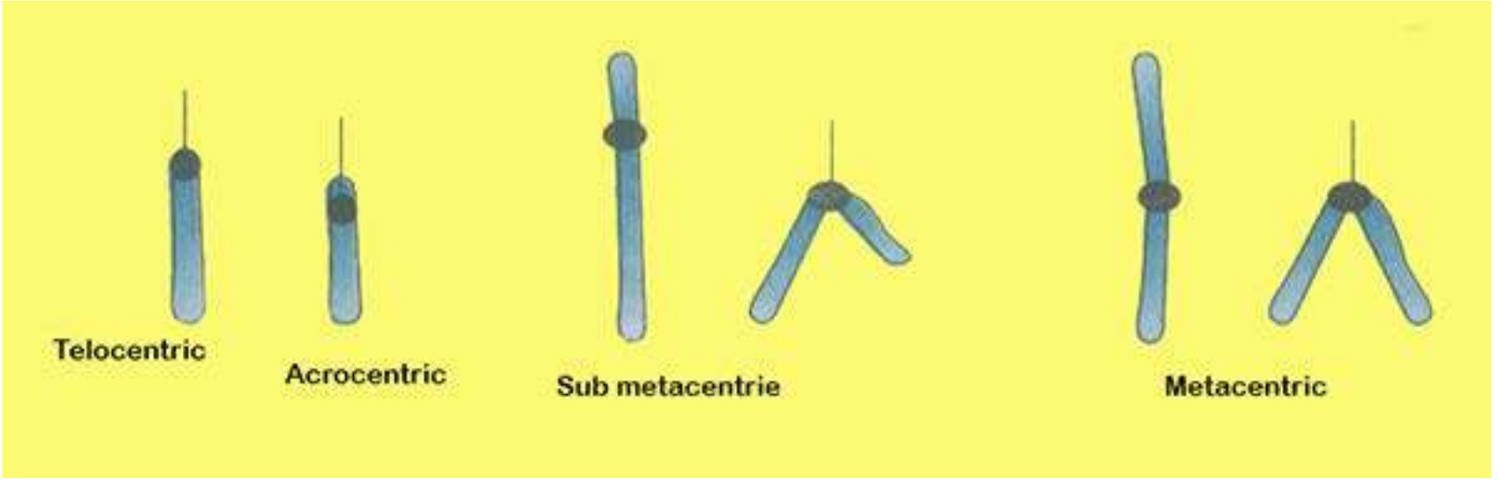



*Fig. 20.4 Shapes of chromosomes depends upon the location of centromere*

These chromosomes- acquire different shapes at the time of anaphase during cell division. The usual shapes are i, j and v.

## COMPOSITION OF CHROMOSOME

Chromosomes are composed of DNA and protein. Most are about 40% DNA and 60% protein. A significant amount of RNA is also associated with chromosomes, because these are the sites of RNA synthesis. The DNA of a chromosome is one very long, double stranded fiber that extends unbroken through the entire length of the chromosome. A typical human chromosome contains about 140 million (1.4 x 108) nucleotides in its DNA. The amount of information, one chromosome contains would fill about 280 printed books of 1000 pages each, if each nucleotide corresponds to a word and each page had about 500 words on it. Further more, if the strand of DNA from a single chromosome were laid out in a straight line, it would be about 5 centimeter long. Fitting such a strand into a small space of nucleus is nature's marvel - and that's only 1 of 46 chromosomes. In the cell, however, the DNA is coiled allowing it to fit into a much smaller space than would otherwise be possible.

How can this long DNA fibre coil so tightly? If we gently disrupt a eukaryotic nucleus and examine the DNA with an electron microscope, we find that it resembles a string of beads (Fig 20.5). Every 200 nucleotides, the DNA duplex is coiled around a core of eight histone proteins forming a complex known as a nucleosome. Unlike most proteins, which have an overall negative charge, histones are positively charged due to an abundance of the basic amino acids arginine and lysine. They are thus strongly attracted to the negatively charged phosphate groups of the DNA. The histone cores thus act as magnetic forms that promote and guide the coiling of the DNA. Further coiling occurs when the string of nucleosomes wraps up into higher order coils called supercoils.

Highly condensed portions of the chromatin are called **heterochromatin**. Some of these portions remain permanently condensed, so that their DNA is never expressed. The remainder of the chromosome called **euchromatin** is condensed only during cell division,

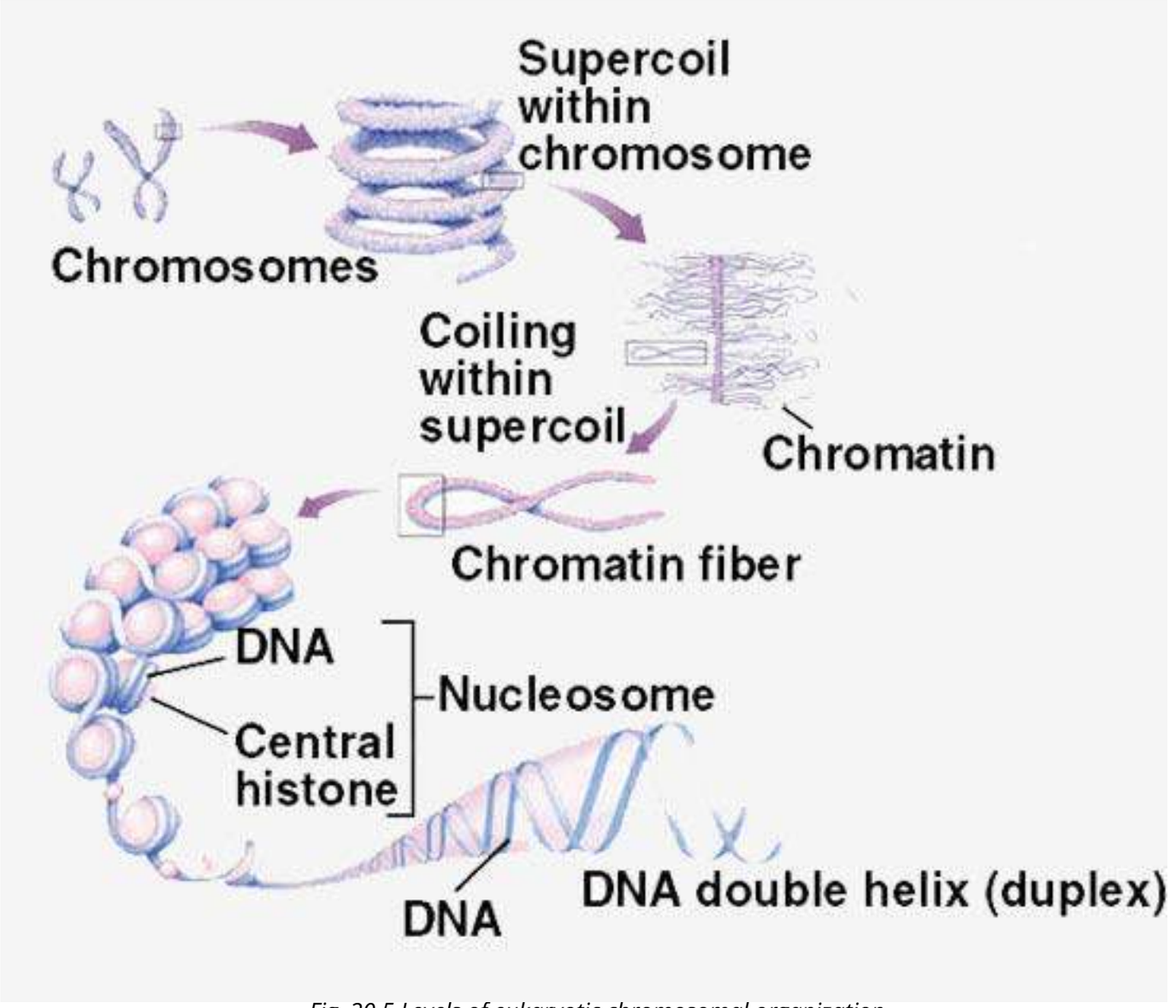



*Fig. 20.5 Levels of eukaryotic chromosomal organization*

when compact packaging facilitates the movement of the chromosomes. At all other times, euchromatin is present in an open configuration and its genes can be 125 expressed. The way, chromatin is packaged when the cell is not dividing is not well understood beyond the level of nucleosomes and is a topic of intensive research.

## THE CHROMOSOMAL THEORY OF INHERITANCE

A central role for chromosomes in heredity was first suggested in 1900 by the German geneticist Karl Correns, in one of the papers announcing the rediscovery of Mendel's work. Soon after, observations that similar chromosomes paired with one another during meiosis led directly to the chromosomal theory of inheritance, first formulated by the American Walter Sutton in 1902.

Several pieces of evidence supported Sutton's theory. One was that reproduction involves the initial union of only two cells, egg and sperm. If Mendel's model was correct, then these two gametes must make equal hereditary contributions. Sperm, however, contain little cytoplasm, suggesting that the hereditary material must reside within the nuclei of the gametes. Furthermore, while diploid individuals have two copies of each pair of homologous chromosomes, gametes have only one. This observation was consistent with Mendel's model, in which diploid individuals have two copies of each heritable gene and gametes have one. Finally, chromosomes segregate during meiosis, and each pair of homologue orients on the metaphase plate independently of every other pair.

There is however one problem with this theory. If Mendelian characters are determined by genes located on the chromosomes, and if the independent assortment of Mendelian traits reflects the independent assortment of chromosomes in meiosis, why does the number of characters that assort independently in a given kind of organism often greatly exceed the number of chromosome pairs the organism possesses? This has led many early researchers to have serious reservations about Sutton's theory.

In 1910 Thomas Hunt Morgan, studying the fruit fly, Drosphila melanogaster, detected a mutant male fly, one that differed strikingly from normal flies of the same species its eyes were white instead of red.

Morgan crossed mutant male to a normal female. All $F_1$ progeny had red eyes. He then crossed red eyed flies from $F_1$ generation with each other. Of the 4252 $F_2$ progeny Morgan examined, 782 (18%) had white eyes. Although the ratio of red eyes to white eyes in the $F_2$ progeny was greater than 3:1, the results of the cross nevertheless provided clear evidence that eye colour segregates.

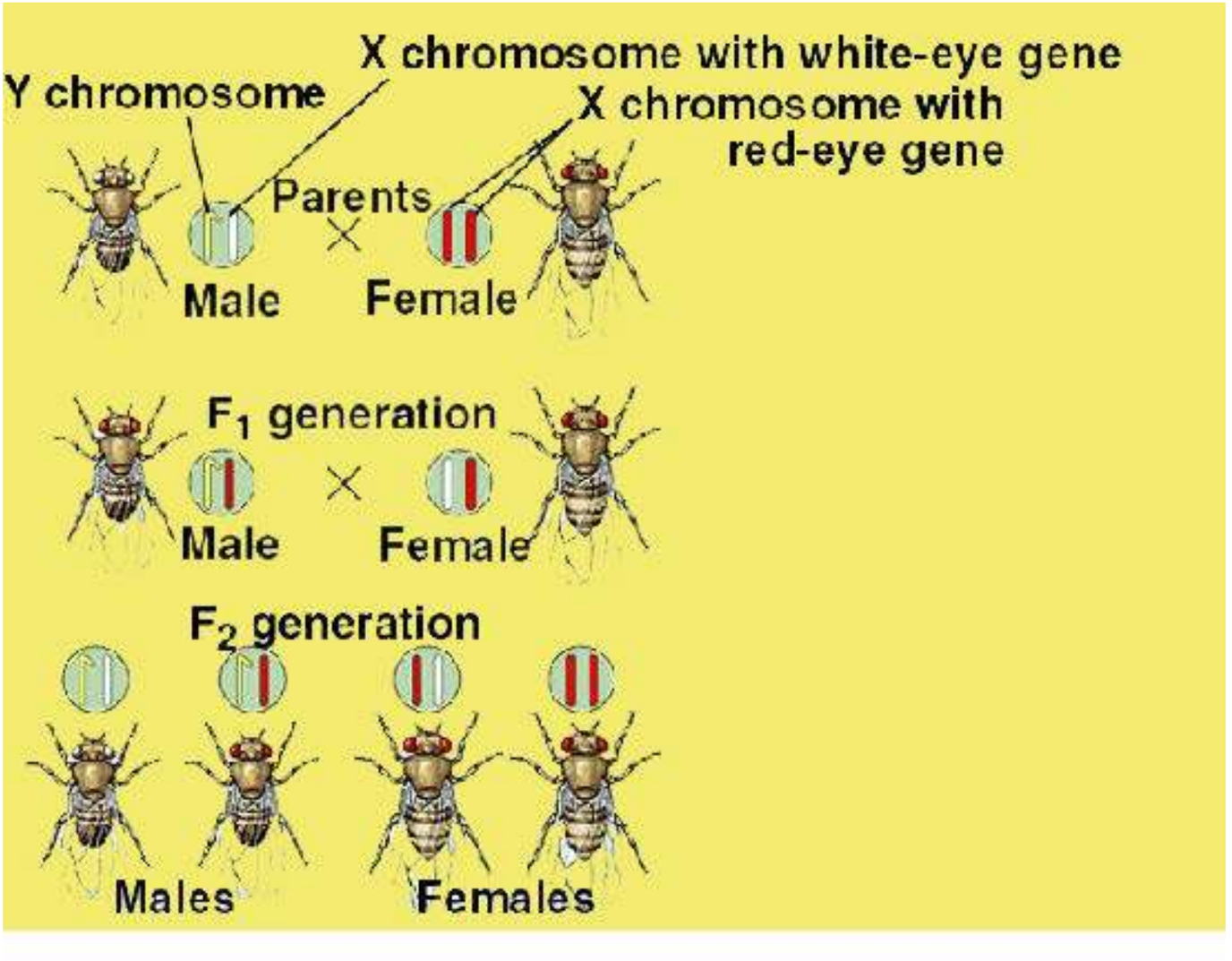



*Fig. 2Q.6 Morgan's experiment demonstrating the chromosomal basis of Sex linkage.*

However, there was something about the outcome that was strange and totally unpredicted by Mendel's theory - all of the white eyed $F_2$ flies were male!

How could this result be explained? Perhaps it was impossible for a white eyed female fly to exist; such individuals might not be viable for some unknown reason. To test this idea, Morgan test crossed the female $F_1$ progeny with the original white eyed male. He obtained both white-eyed and red-eyed males and females in a 1:1:1:1 ratio, just as Mendelian theory predicted. Hence a female could have white eyes. Why, then were there no white eyed females among the progeny of the original cross?

The solution to this puzzle involved sex. The gene causing the white eye trait in Drosophila resides only on the X chromosome. It is absent from the Y chromosome. A trait determined by a gene on the X chromosome is said to be sex linked. Knowing that the white eye trait is recessive to the red eye trait, the Morgan's result was a natural consequence of the Mendelian assortment of chromosomes (Fig 20.6).

Morgan's experiment was one of the most important in the history of genetics because it presented the first clear evidence that the genes determining Mendelian traits do indeed reside on the chromosomes, as Sutton had proposed. The chromosome theory of inheritance therefore, propounds that genes are located on chromosomes. The segregation of the white-eye trait has one-to-one correspondence with the segregation of the X chromosome, in other words, Mendelian traits such as eye colour in Drosophila assort independently because chromosomes do.

## DNA AS HEREDITARY MATERIAL

The first evidence of hereditary nature of DNA was provided by a British microbiologist Frederick Griffith who made some unexpected observations while experimenting with pathogenic bacteria. When he infected mice with a virulent strain of Streptococcus pneumoniae bacteria (then known as Pneumococcus), the mice died of blood poisoning. However, when he infected similar mice with a mutant strain of S. pneumoniae that lacked the virulent strains polysaccharide coat, the mice showed no ill effects. The coat was apparently necessary for virulence.

The normal pathogenic form of this bacterium is referred to as the S form because it forms smooth colonies on a culture dish. The mutant forms, which lacks an enzyme needed to manufacture the polysaccharide coat, is called the R form because it forms rough colonies.

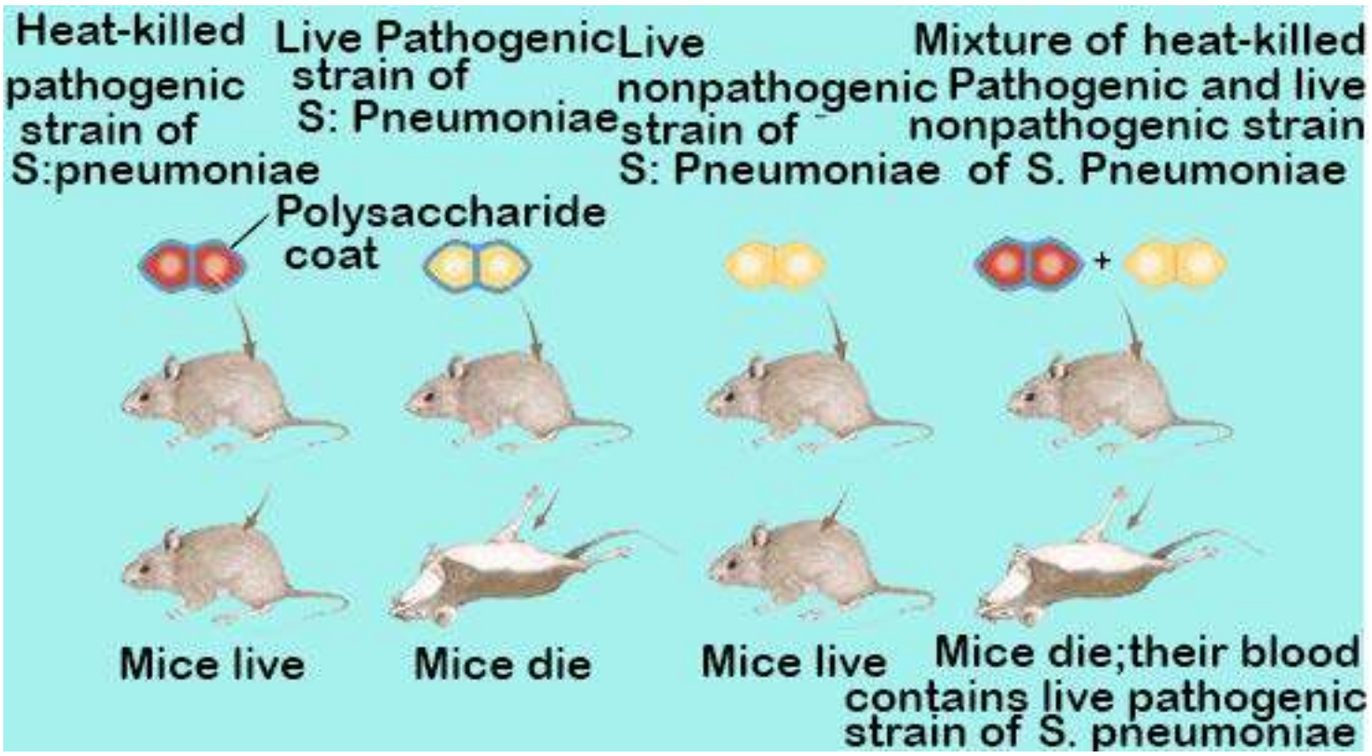



*Fig 20.7 Griffith's discovery of transformation*

To determine whether the polysaccharide coat itself had a toxic effect. Griffith injected dead bacteria of the virulent S strain into the mice; the mice remained perfectly healthy. As a control, he injected mice with a mixture containing dead S bacteria of the virulent strain and live coatless R bacteria, each of which by itself did not harm the mice (Fig 20.7). Unexpectedly, the mice developed the disease symptoms and many of them died. The blood of the dead mice was found to contain high levels of live, virulent streptococcus type S bacteria, which had surface proteins characteristic of the live (previously R) strain. Somehow, the information specifying the polysaccharide coat had passed from the dead, virulent S bacteria to the live, coatless R bacteria in the mixture, permanently transforming the coatless R bacteria into the virulent S variety. Transformation is the transfer of. genetic material from one cell to another and can alter the genetic make up of the recipient cell.

The agent responsible for transforming Streptococcus 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 Streptococcus and live R Streptococcus that Griffith had used. Then they removed as much of the protein as they could from their preparation, eventually achieving 99.98% purity. Despite removal of nearly all the protein, the transforming activity was not reduced. Moreover, the properties of transforming principle resembled those of DNA. The protein digesting enzymes or RNA digesting enzymes did not affect the principle's activity, but the DNA digesting enzyme DNase destroyed all the transforming activity.

Additional evidence supporting Avery's conclusion was provided in 1952 by Alfred Hershey and Martha Chase who experimented with bacteriophages T2. In some experiments they labelled viruses with radio isotope 32P, which was incorporated into the newly synthesized DNA of grooving phage. In other experiments, the viruses were grown on a medium containing 35S, an isotope of sulphur which is incorporated into the amino acids of newly synthesized protein coats.

After the labelled viruses were permitted to infect bacteria, the bacterial cells were agitated violently to remove the protein coats of the infecting viruses from the surfaces of the bacteria. This procedure removed nearly all of the 35S label from the bacteria. However the 32P label had transferred to the interior of the bacteria (Fig 20.8) and was found in viruses subsequently released from the infected bacteria. Hence, the hereditary information injected into the bacteria that specified the new generation of viruses was DNA and not protein.

*Animation 20.2: DNA*
*Source & Credit: Mr.Birnbaum's Biology*

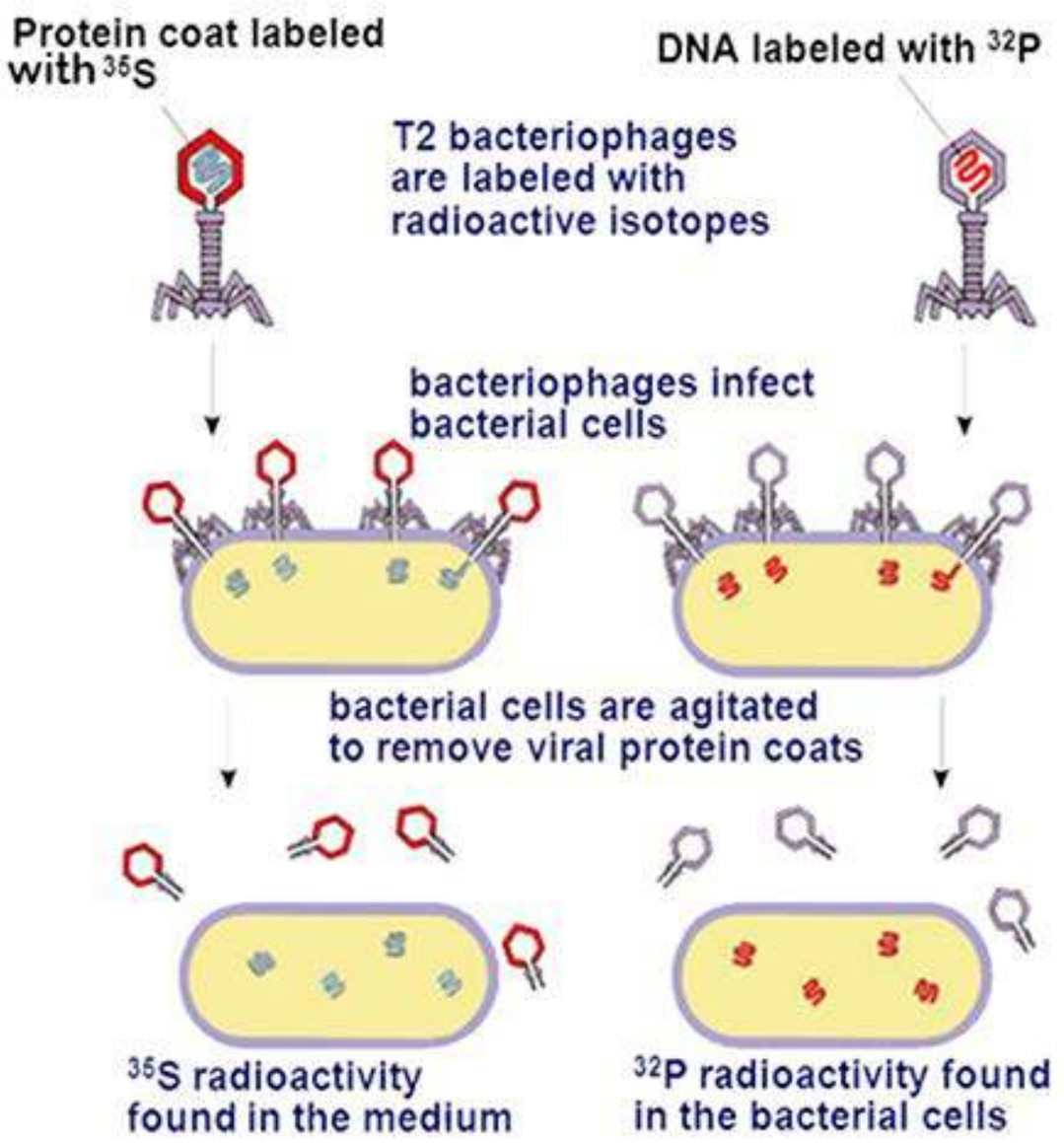



*Fig 20.8 the Hershey and chase experiment*

## Chemical Nature of DNA

A German Chemist, Friedrich Miescher, discovered DNA in 1869, only four years after Mendel's work was published. Miescher extracted a white substance from the nuclei of human cells and fish sperm. He called this substance "nuclein" because it seemed to be specifically associated with the nucleus.

Since nuclein was acidic, it came to be known as nucleic acid. For 50 years biologists did little research on the substance, because nothing was known of its function in cells. In 1920's, the basic structure of nucleic acids was determined by the biochemist P.A. Levene, who found that DNA contains three main components (Fig 20.9) : (1) phosphate (P04) groups, (2) five carbon sugars, and (3) nitrogen containing bases called purines (adenine, A, and guanine, G) and pyrimidines (thymine, T and cytosine, C, RNA contains uracil, U instead of T). Levene concluded that DNA and RNA molecules are made of repeating units called nucleotides. In a nucleotide nitrogen base is attached to carbon number 1 of a pentose sugar and phosphate group is attached to carbon number 5 of the sugar. In addition a free hydroxyl (-OH) group is attached to the 3' carbon atom (Fig 20.10). The 5 'phosphate and 3' hydroxyl groups allow DNA and RNA to form long chains of nucleotides, because these two groups can react chemically with each other. The reaction between the phosphate group of one nucleotide and the hydroxyl group of another is a dehydration synthesis, eliminating a water molecule and forming a covalent bond that links the two groups (Fig 20.11). The linkage is called a phosphodiester bond because the phosphate group is now linked to the two sugars by means of a pair of ester (P-O-C) bonds. The two unit polymer resulting from this reaction still has a free 5' phosphate group at one end and a free 3' hydroxyl group at the other, so that it can link to other nucleotides. In this way, many thousands of nucleotides can join together in long chains. Linear strands of DNA or RNA no matter how long, will almost always have a free 5' phosphate group at one end and a free 3'hydroxyl group at the other.

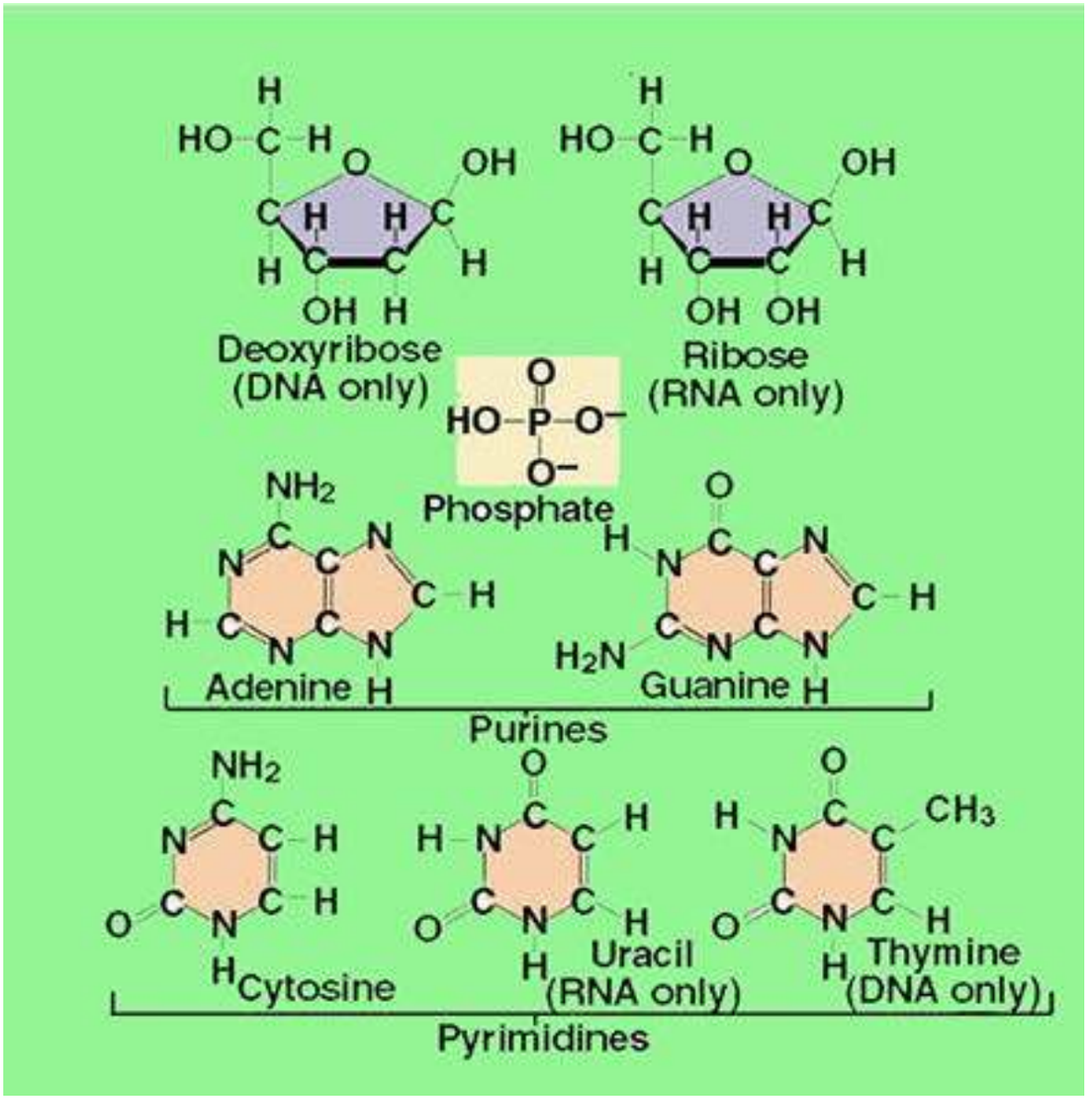



Fig 20.9 Nucleotide subunits of DNA and RNA

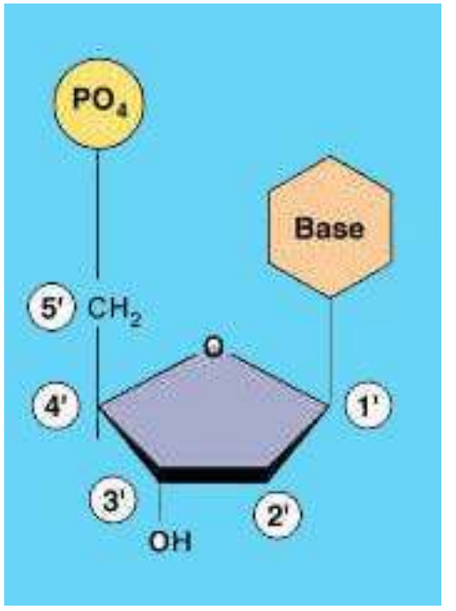



Fig 20.10 Numbering the carbon atoms in a ncleoties

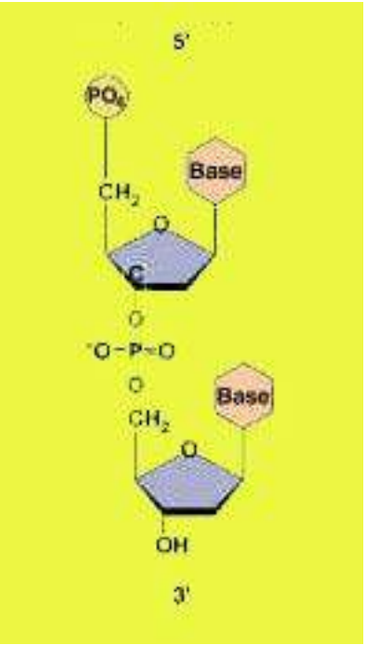



Fig 20.11 A phosphodiester bond.

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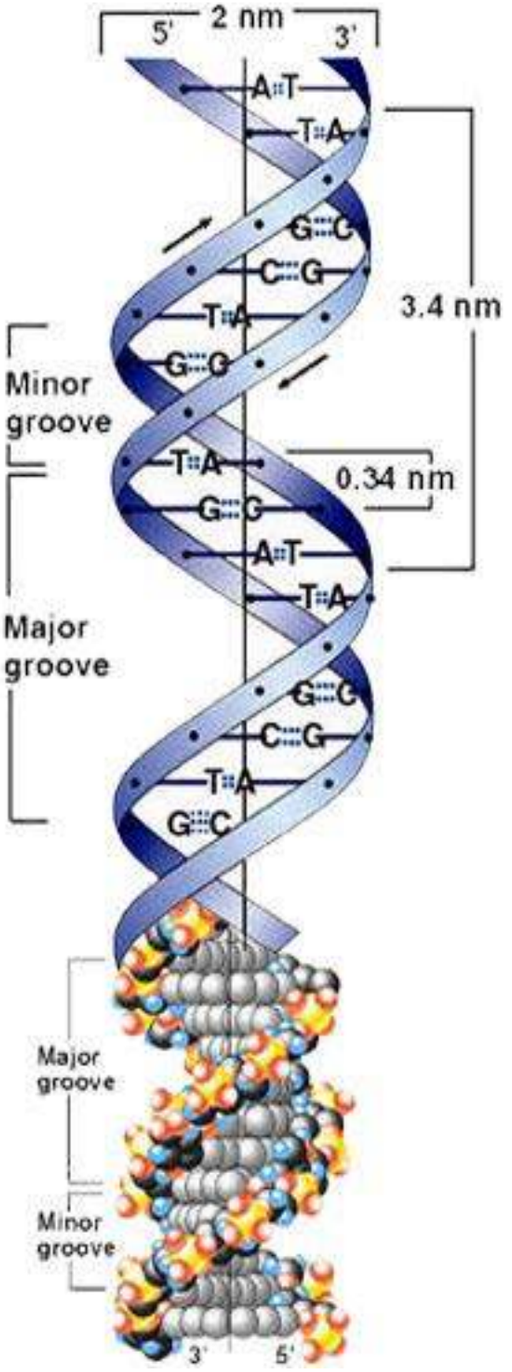
Erwin Chargaff later showed that the amount of adenine in DNA always equals the amount of thymine, and the amount of guanine always equals the amount of cytosine. It also implies that there is always equal proportion of purine (A+G) and pyrimidine (C+T).

The significance of the regularities pointed out by Chargaff became obvious when a British chemist Rosalind Franklin carried on an X-ray diffraction analysis of DNA.In this analysis, a molecule is bombarded with a beam of X- rays. When individual rays encounter atoms their path is bent or diffracted and the diffraction pattern is recorded on the photographic film. When carefully analyzed this pattern gives three dimensional structure of a molecule.

Rosalind Franklin prepared this X- ray diffraction pattern of DNA in the laboratory of British Biochemist Maurice Wilkins, who prepared DNA fibers. The diffraction pattern suggested that the DNA molecule had a shape of a helix with a diameter of 2 nm and a complete helical turn every 3.4 nm (Fig 20.12).

**Double Helical Structure of DNA (Watson and Crick's Model)**

Learning informally of Franklin's results, before they were published in 1953, James Watson and Francis Crick, two young researchers in University' of Cambridge, quickly worked out a likely structure of the DNA molecule (Fig 20.12) which we now know was substantially correct. They' proposed that molecule is a simple double helix, with the basis of two strands pointed inward toward each other. forming base-pairs. In their model, base pairs always consist of purines, which are large, pointing toward pyrimidines which are small, keeping the diameter of the molecule a constant 2 nm. Because hydrogen bonds exist between the bases in a base pair, the double helix is stabilized as a duplex DNA molecule composed of two antiparallel strands, one chain running 3' to 5' and the other 5' to 3'. The base pairs are planar (flat) and stack 0.34nm apart as a result of hyperphobic interactions contributing to the overall stability of the molecule (Fig. 20.3). In the double helix, adenine forms two hydrogen bonds with thymine, while guanine forms three hydrogen bonds with cytosine. Adenine will not form proper hydrogen bonds with cytosine.and guanine will not form hydrogen bonds with thymine. Consequently adenine and thymine will always occur in the same proportion in any DNA molecule, as well guanine and cytosine, because of this base pairing.


2 nm
5'
3'
A::T
T::A
G::C
C::G
T::A
G::C
3.4 nm
Minor
groove
T::A
0.34 nm
G::C
A::T
T::A
Major
groove
G::C
C::G
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G::C
Major
groove
Minor
groove
3'
5'

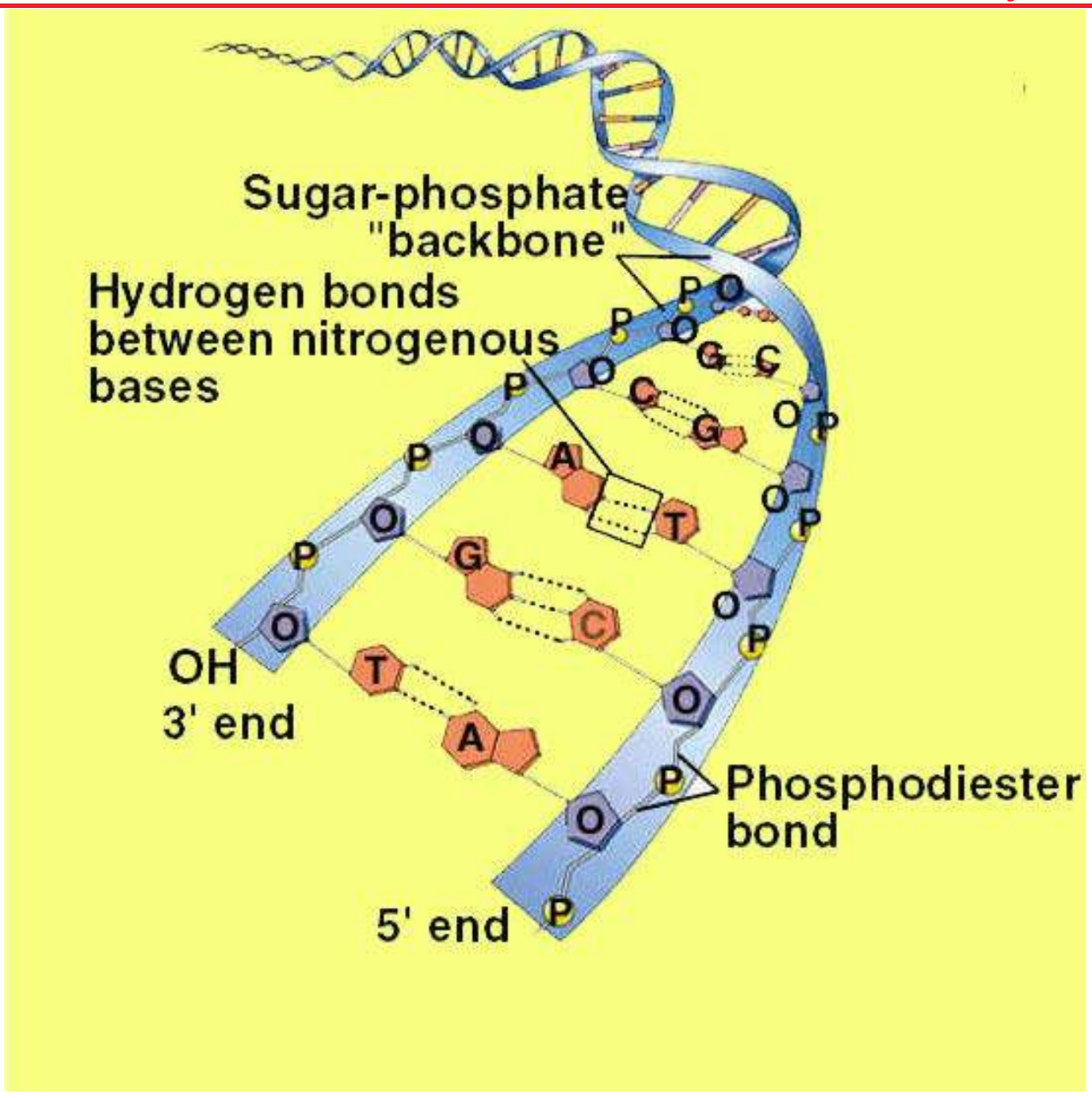



*Fig 20.13 DNA is a double helix*

## DNA Replication

The Watson - Crick model immediately suggested that the basis for copying the genetic information is complementarity. If one were to unzip the molecule, one would need only to assemble the appropriate complementary nucleotides on the exposed single strands to form two daughter complexes with the same sequences. This form of DNA replication is called **semi-conservative**, because while the sequence of the original duplex is conserved after one round of replication, the duplex itself is not. Instead, each strand of the duplex becomes part of another duplex. In semi-conservative replication, the two133 strands of the duplex separate out each acting as a model or mold, along which new nucleotides are arranged thus giving rise to two new duplexes. In this process by separation of two strands, primary structure has been conserved, whereas the secondary structure has been disrupted.

The other hypotheses of DNA replication were also proposed. The conservative model stated that the parental double helix would remain intact and generate DNA copies consisting of entirely new molecules. The dispersive model predicted that parental DNA would become completely dispersed and that each strand of all the daughter molecules would be a mixture of old and new DNA.

*Animation 20.3: DNA Replication*
*Source & Credit: weloveteaching*

## The Meselson - Stahl Experiment

The three hypothesis of DNA replication were evaluated by Mathew Meselson and Franklin Stahl of the California Institute of Technology in 1958. They grew bacteria in a medium containing heavy isotope of nitrogen, $^{15}N$, which became incorporated into the bases of the bacterial DNA. After several generations, the DNA of these bacteria was denser than that of bacteria grown in a medium containing the lighter isotope of nitrogen, $N^{14}$. Meselson and Stahl then transferred the bacteria from the $N^{15}$ medium to the $N^{14}$ medium and collected the DNA at various intervals.

They dissolved the DNA in cesium chloride and then spun it at a very high speed in an ultra-centrifuge. DNA strands of different densities got separated. The enormous centrifugal forces generated by the ultracentrifuge caused the cesium ions to migrate toward the bottom of the centrifuge tube, creating a gradient of CsCl, and thus of density. Each DNA floats or sinks in the gradient until it reaches the position where its density exactly matches the density of cesium there. Because $N^{15}$ strands are denser than $N^{14}$ strands, they migrate farther down the tubes to a denser region of the cesium chloride gradient.

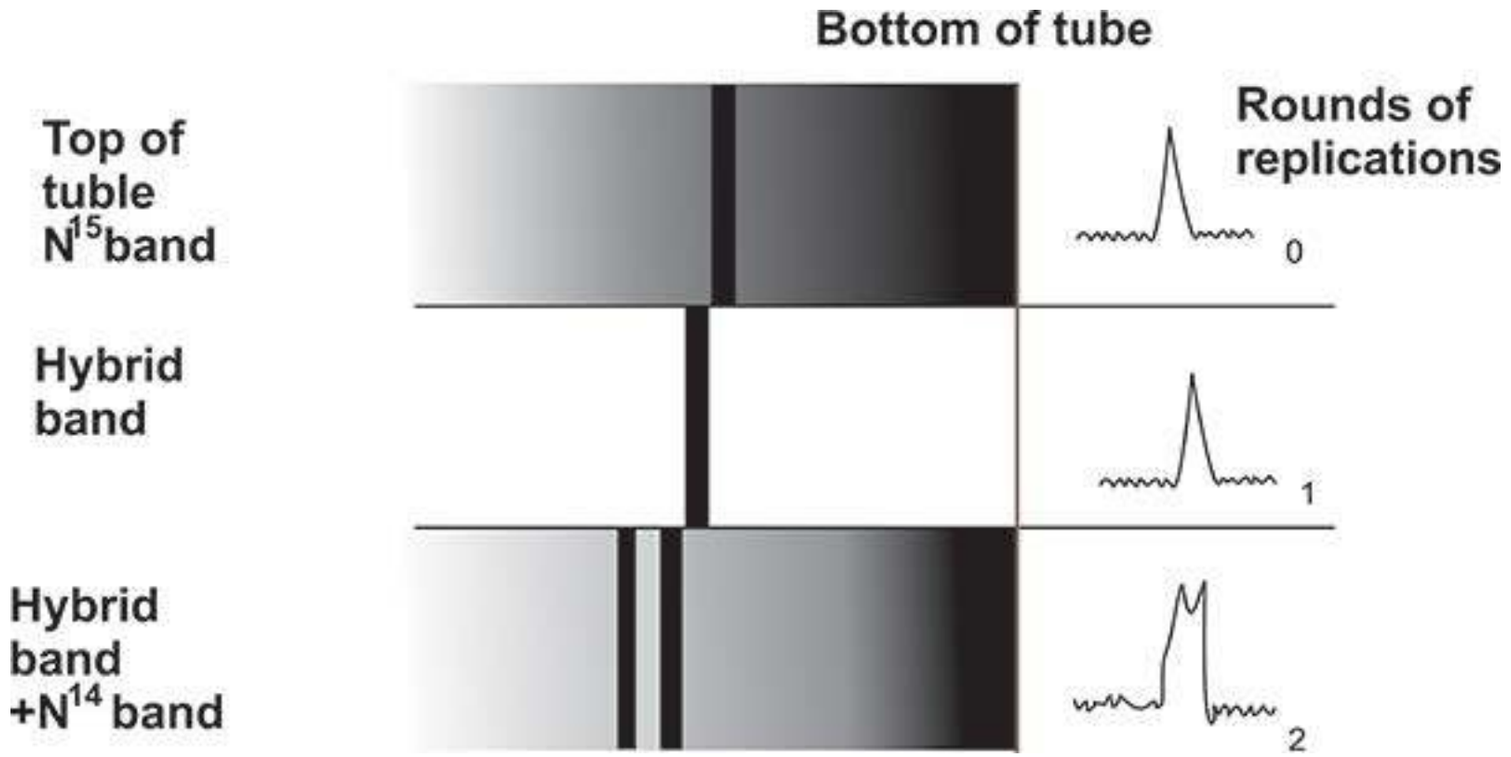


*Fig. 20.14 The key result of the Meselson and Stahl experiment. The bands on the left side of the figure sTiow N 1' DNA which is heavier and is present towards the bottom of the tube. The middle band is a hybrid DNA band of N1' and NM and hence lies above the Nlr band. This is after first round of replication. In the second round of replication, two bands are \isible one at the lex el of hybrid band and the other lighter band which is $N^{14}$ band.*

The DNA collected immediately after the transfer, was all dense. However, after the bacteria completed their first round of DNA replication in the $N^{14}$ medium, the density of their DNA had decreased to a value intermediate between $N^{14}$- DNA and $N^{15}$ - DNA. After the second round of replication, two density classes of DNA were observed one intermediate and one equal to that of $N^{14}$ - DNA (Fig 20.14).

Meselson and Stahl interpreted their results as follows: after the first round of replication, each daughter DNA duplex was a hybrid possessing one of the heavy strands of parent molecule and one light strand. When this hybrid duplex replicated, it contributed one heavy strand to form another hybrid duplex and one light strand to form a light duplex (Fig 20.15). Thus, this experiment clearly confirmed the prediction of the Watson-Crick model that DNA replicates in a semi-conservative manner.

*Animation 20.3: Meselson-Sathl Experiment*
*Source & Credit: weloveteaching*

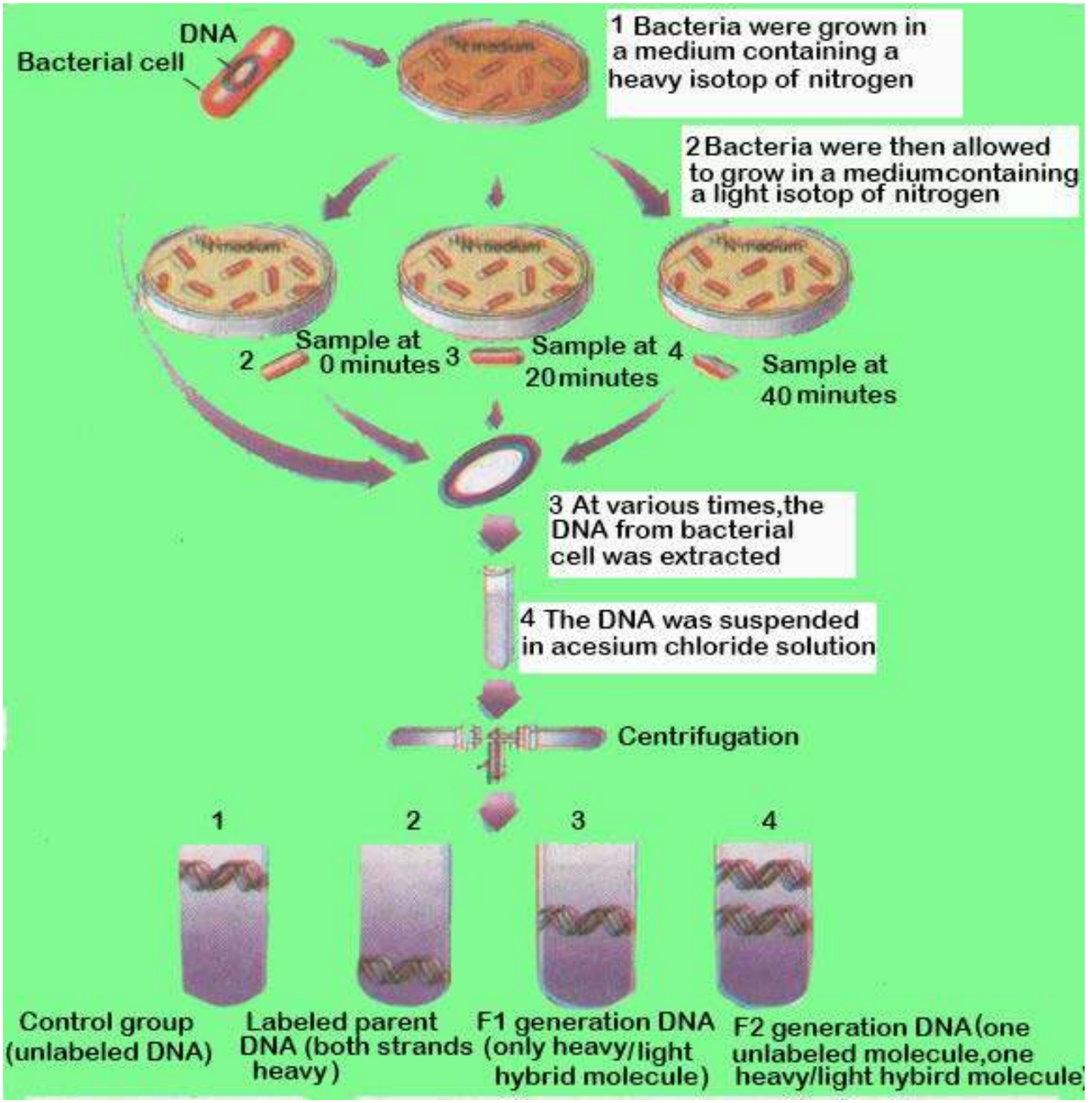



*Fig 20.15 The Meselson and stahl experiment : evidence demonstrting sei-conservative replication*

## The Replication Process

The DNA replication begins at one or more sites on the DNA molecule, where there is a specific sequence of nucleotides (Fig 20.16), The DNA polymerase III and other enzymes begin a complex process that catalyzes the addition of nucleotides to the growing complementary strands of DNA (Fig 20.17).

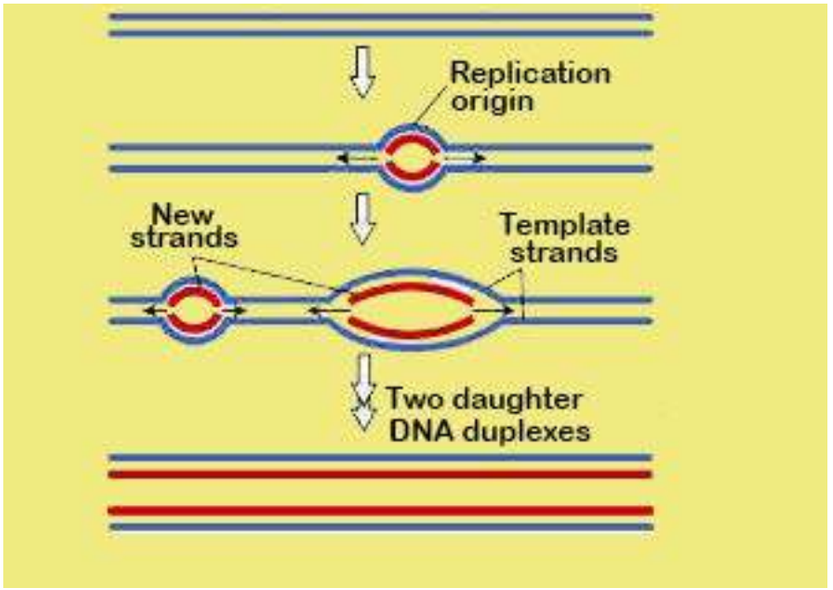



*FIg 20.16 Origins of replication*

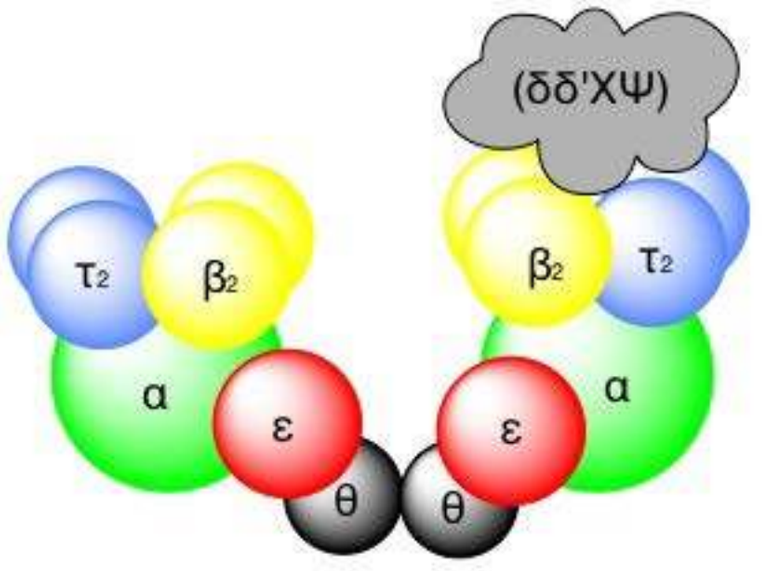



*Fig 20.18 Molecular structure of DNA polymerse III comle*

There are three DNA polymerases namely I, II and III in bacteria. DNA polymerase I is a relatively small enzyme that plays a supporting role in DNA replication. The true E.coli replicating enzymes is DNA polymerase III which is 10 times larger and far more complex in structure (Fig 20.18). The enzyme is a dimer and catalyzes replication of one DNA strand. Polymerase III progressively threads the DNA through the enzyme complex, moving at a rapid rate, some 1000 nucleotides / second. One of the features of the DNA polymerase III is that it can add nucleotides only to a chain of nucleotides that is already paired with the parent strands. Hence DNA polymerase cannot initiate synthesis on its own. Instead another enzyme, primase, constructs an RNA primer, a sequence of about 10 RNA nucleotides complementary to the parent DNA template. DNA polymerase IIIrecognizes the primer and adds DNA" nucleotides to it to construct the DNA strands. The RNA nucleotides in the primers are then replaced by DNA nucleotides.

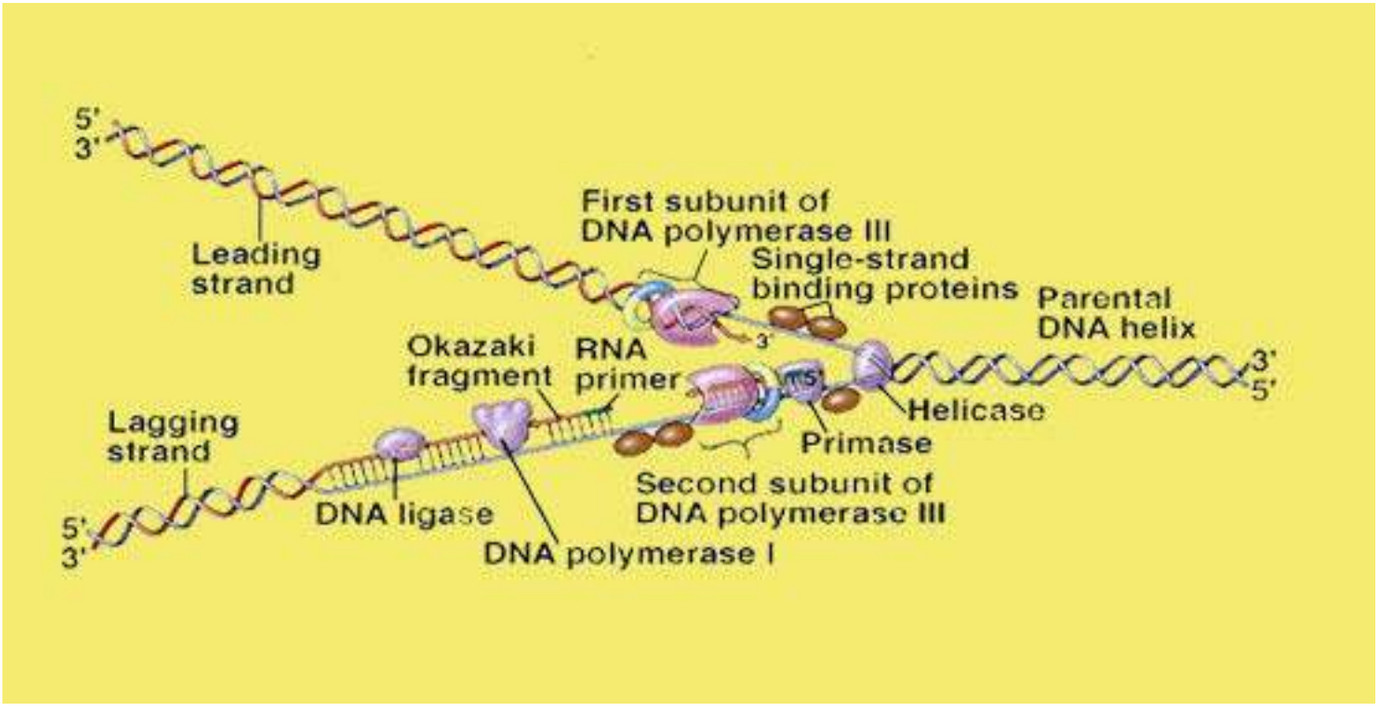



*Fig 20.19 A DNA replication fork*

Another feature of DNA polymerase III is that it can add nucleotides only to the 3' end of a DNA strand. This means that replication always proceeds 5' —» 3' direction on a growing DNA strand. Because the two parent strands of a DNA molecules are antiparallel, the new strands are oriented in opposite directions (Fig 20.19). Therefore, the new strands must be elongated by different mechanisms. Leading strand, which elongates toward the replication fork, is built up simply by adding nucleotides continuously to its growing 3' end. In contrast the lagging strand which elongates away from the replication fork, is synthesized discontinuously as a series of short segments that are later connected. These segments, called Okazaki fragments are about 100 - 200 nucleotides long in eukaryotes and 1000 - 2000 nucleotides long in prokaryotes. Each Okazaki fragment is synthesized by DNA polymerase III in 5' -> 3' direction, beginning at the replication fork and moving away from it. When the polymerase reaches the 5' end of the lagging strand, another enzyme, DNA ligase, attaches the fragment to the lagging strand. The DNA is further unwound, new RNA primers are constructed, and DNA polymerase III then jumps ahead 1000 - 2000 nucleotides (toward the replication fork) to begin constructing another Okazaki fragment.

## WHAT IS A GENE?

Archibald Garrod and William Bateson concluded in 1902 that certain diseases among their patients were more prevalent in particular families. By examining several generations of these families, Garrod found that some of the diseases behaved as if they were the product of simple recessive alleles. He concluded that these disorders were Mendelian traits and that they had resulted from changes in the hereditary information in an ancestor of the affected families.

Garrod investigated several of these disorders in detail. In alkaptonuria the patients produced urine that contained homogentisic acid. This substance oxidized rapidly when exposed to air, turning the urine black. In normal individuals, homogentisic acid is broken down into simpler substances. With considerable insight Garrod concluded that patients suffering from alkaptonuria lacked the enzyme necessary to catalyze this breakdown. He speculated that many other inherited diseases might also reflect enzyme deficiencies.

From Garrod's finding, it could be inferred that the information encoded within the DNA of chromosomes acts to specify particular enzymes. This point was not actually established, however, untill 1941, when a series of experiments by Stanford University geneticists George Beadle and Edward Tatum provided definitive evidence on this point. Beadle and Tatum deliberately set out to create Mendelian mutations in chromosomes and then studied the effect of these mutations on the organisms (Fig 20.20).

Beadle and Tatum exposed Neurospora spores to X-rays, expecting that DNA in some of these spores would experience damage in the regions encoding the ability to make compounds needed for normal growth (Fig 20.20). DNA changes of this kind are called mutations and the organisms that have undergone such changes are called mutants. Initially, they allowed the progeny of the irradiated spores to grow on a defined medium containing all of the nutrients necessary for growth, so that any growth deficient mutants resulting from the irradiation would be kept alive.

To determine whether any of the progeny of the irradiated spores had mutations causing metabolic deficiencies, Beadle and Tatum placed subcultures of individual fungal cells on a "minimal" medium that contained only sugar, ammonia, salts, a few vitamins and water. Cells that had lost the ability to make other compounds necessary for growth would not survive on such a medium. Using this approach, Beadle and Tatum succeeded in identifying and isolating many growth deficient mutants.

Next the researchers added various chemicals to the minimal medium in an attempt to find one that would enable a given mutant strain to grow. This procedure allowed them to pinpoint the nature of the biochemical deficiency that strain had. The addition of arginine, for example, permitted several mutant strains, dubbed arg mutants, to grow. When their chromosomal positions were located, the arg mutations were found to cluster in three areas.

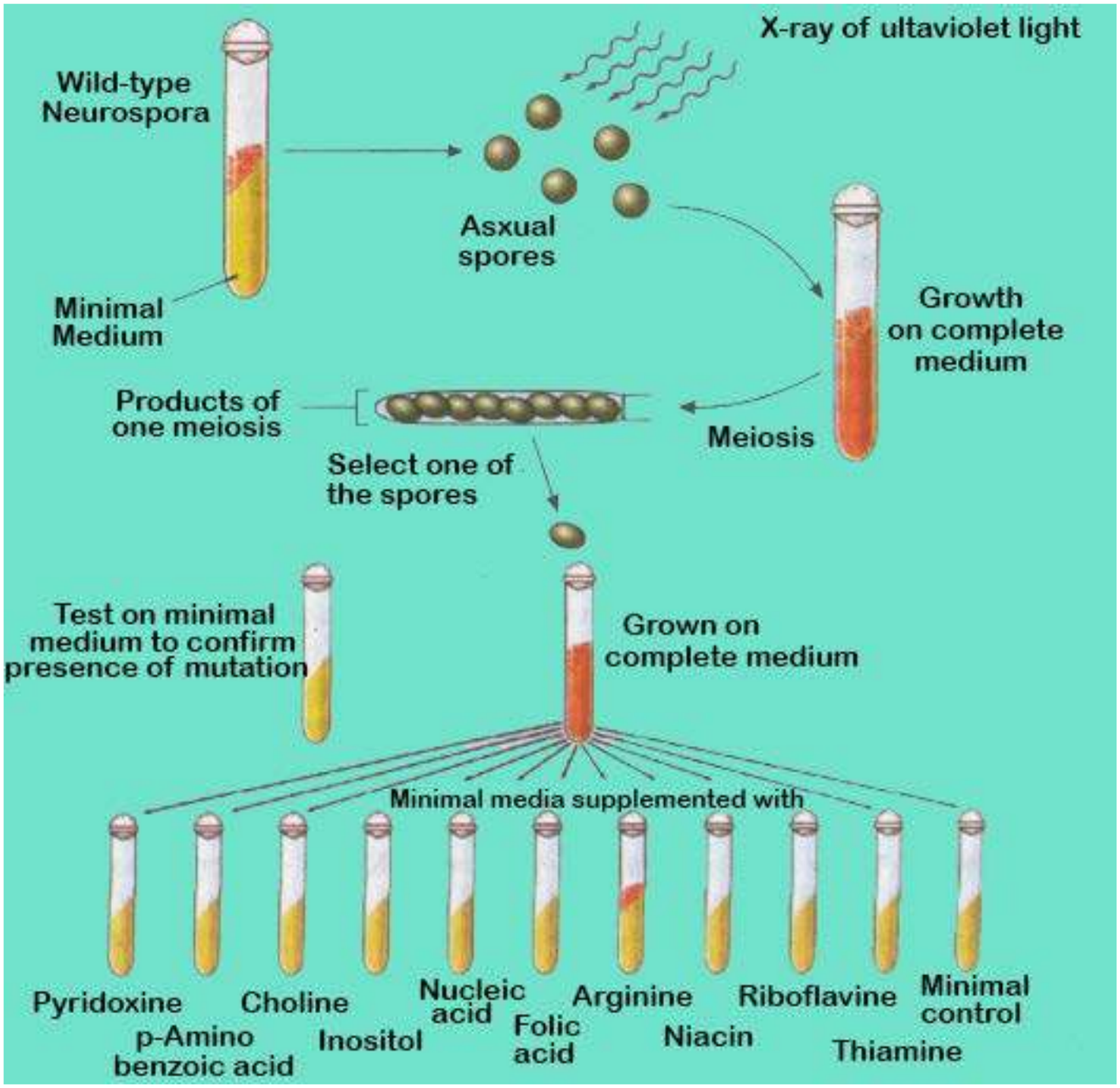



*Fig 20.20 Beadle and Tatum's procedure for isolating nutritional mutats in Neurospora*

## One - gene / one - polypeptide Hypothesis

For each enzyme in the arginine biosynthetic pathway, Beadle and Tatum were able to isolate a mutant strain with a defective form of that enzyme, and the mutation was always located at one of a few specific chromosomal sites. Most importantly, they found there was a different site for each enzyme. Thus, each of the mutant they examined had a defect in a single enzyme, caused by a mutation at a single site on one chromosome. Beadle and Tatum concluded that genes produce their effects by specifying the structure of enzymes and that each gene encodes the structure of one enzyme (Fig 20-21). They called this relationship one - gene / one - enzyme hypothesis. Because many enzymes contain multiple protein or polypeptide subunits, each encoded by a separate gene, the hypothesis is today more commonly referred to as “one gene / one- polypeptide”.

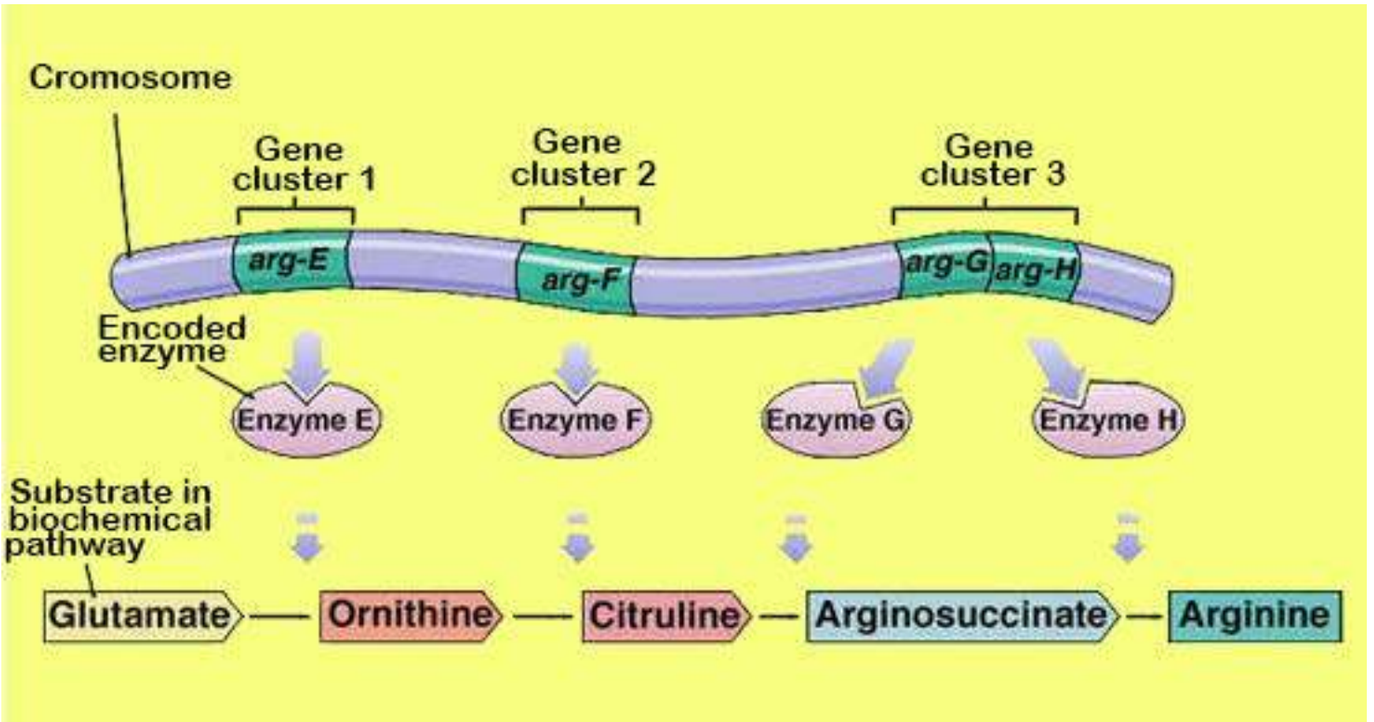



*Fig. 20.21 Evidence for the “one-gone/one-polypeptide” hypothesis.*

Enzymes are responsible for catalyzing the synthesis of all the parts of an organism. They are also responsible for the assembly of nucleic acids, proteins, carbohydrates and lipids. Therefore, by encoding the structure of enzymes and other proteins, DNA specifies the structure of the organism itself.

## How DNA encodes protein structure?

In 1953, an English biochemist Frederick Sanger, described the complete sequence of amino acids of insulin. Sanger's achievement was significant, as it was demonstrated for the first time that proteins consisted of definable sequences of amino acids. Soon it was revealed that all enzymes and other proteins are strings of amino acids arranged in a certain definite order.

Following Sanger's pioneering work, Vernon Ingram in 1956 discovered the molecular basis of sickle cell anemia, a protein defect inherited as a Mendelian disorder. By analyzing the structure of normal and sickle cell haemoglobin, Ingram, working at Cambridge University, showed that sickle cell anemia is caused by a change from glutamic acid to valine at a single position in the protein (Fig 20.22). The alleles of the gene encoding hemoglobin differed only in their specification of this one amino acid in the hemoglobin amino acid chain.

These experiments and other related ones have finally brought us to a clear understanding of the unit of heredity. The characteristics of sickle cell anemia and most other hereditary traits are defined by changes in protein structure brought about by an alteration in the sequence of amino acids that make up the protein. This sequence in turn is dictated by the order of nucleotides in a particular region of chromosome. For example, the critical change leading to sickle cell disease is a mutation that replaces a single thymine with an adenine at the position that codes for glutamic acid converting the position to valine. The sequence of nucleotides that determines the amino acid sequence of a protein is called a gene.

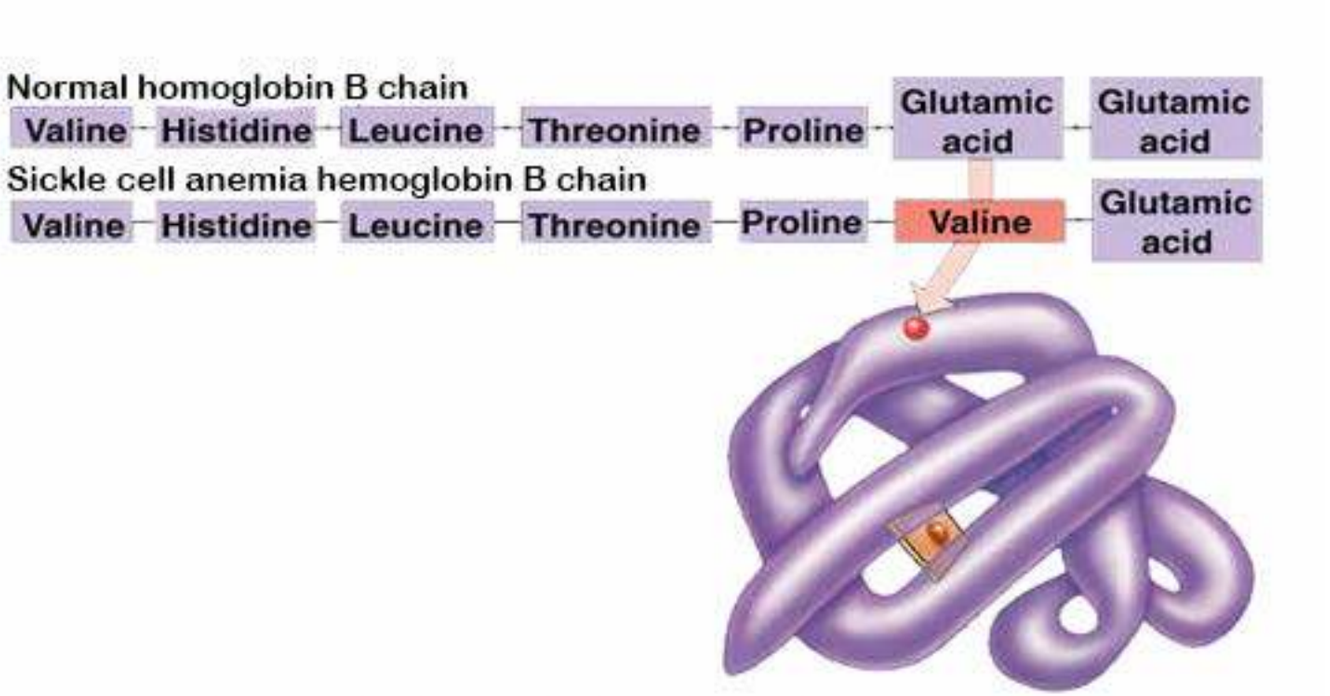



*Fig 20.22 The necular basic of a hereditary disease , sickle cell anemia*

## CELLS USE RNA TO MAKE PROTEIN

All organisms use the same basic mechanism of reading and expressing genes, which is often referred to as central dogma. The genetic information resides in DNA, which is also the main fountain head. The genetic information flows down into RNA, which is then converted into protein (Fig 20.23).

The first step of central dogma is the transfer of information from DNA to RNA, which occurs when an mRNA copy of the gene is produced. The process is called transcription. Transcription is initiated when the enzyme RNA polymerase binds to a particular binding' site called a prom oter located upstream of the gene. The enzyme then moves along the strand into the gene and mRNA is synthesized. At stop signal on the other end of gene, the enzyme disengages itself from the DNA and releases the newly assembled RNA chains. This chain is a complementary transcript of the gene from which it was copied.

The second step of the central dogma is the transfer of information from RNA to proteins, which occurs when the information contained in the mRNA is used to direct the synthesis of polypeptides by ribosomes. This process is called translation, because the nucleotide sequence of the mRNA is translated into an amino acid sequence in the polypeptide.

The two steps of central dogma taken together are also means of gene expression.

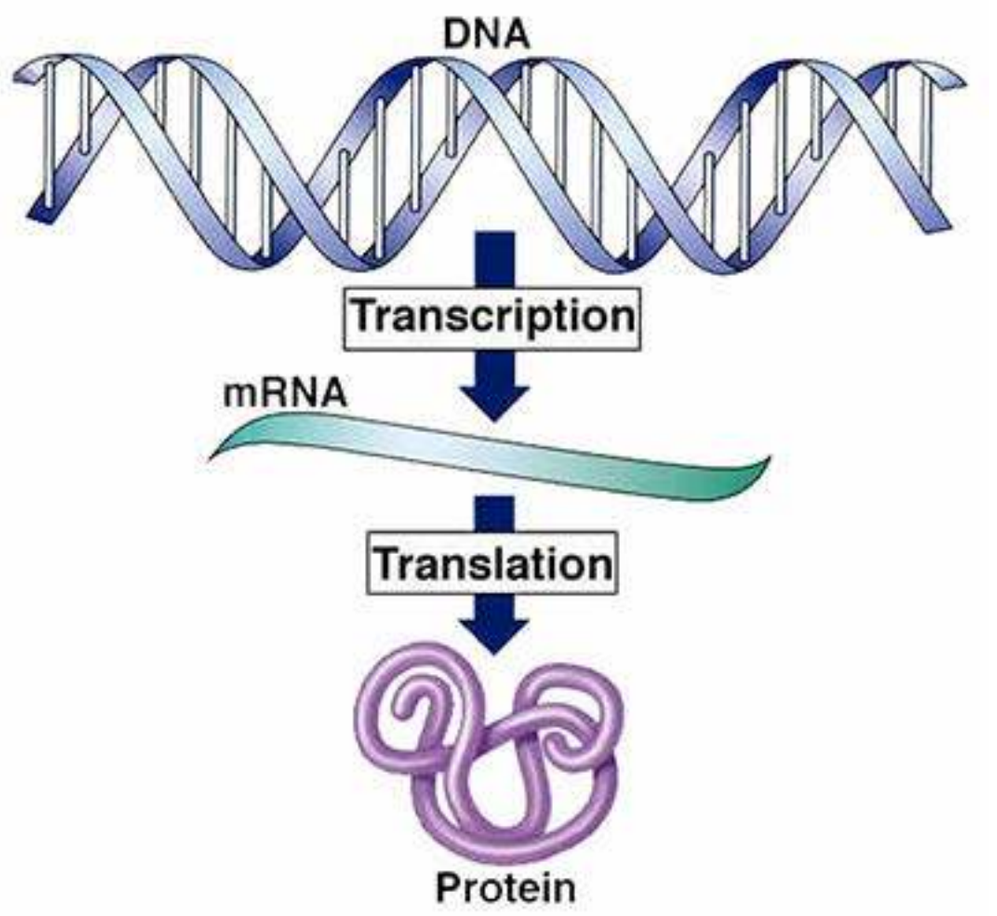



*Fig. 20.23 The central dogma of gene expression.*

## Three types of RNA

The class of RNA found in ribosome is called ribosomal RNA (rRNA). During translation, rRNA provides the site where polypeptides are assembled. In addition to rRNA, there are two other major classes of RNA in the cells : transfer RNA (tRNA) and messenger RNA (mRNA). Transfer RNA molecules transport the amino acids to the ribosomes for use in building the polypeptides and also position each amino acid at the correct place on the elongating polypeptide chain (Fig 20.24). Human cells contain about 45 different kinds of tRNA molecules. Messenger RNA are long strands of RNA that are transcribed from DNA and that travel to the ribosomes to direct precisely which amino acids are assembled into polypeptides.

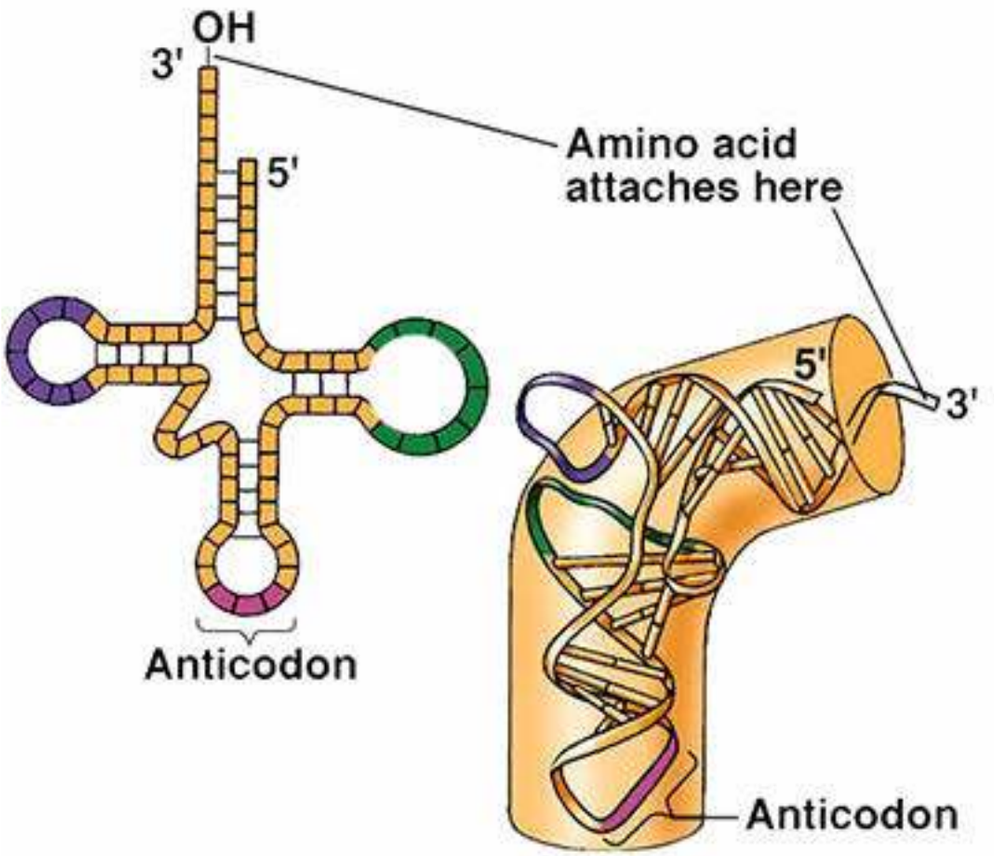



*Fig. 20.24 The structure of tRNA*
*(a) two-dimensional schematic*
*(b) three dimensional structure.*

## Transcription

This is the process in which an RNA copy of the DNA sequence encoding the gene is produced with the help of an enzyme, RNA polymerase. Only one of the two strands of DNA are transcribed. This strand is called template strand or the antisense strand. Thq opposite strand is called coding strand or the sense strand. The RNA polymerase enzymes synthesize RNA from 5' —» 3' direction. There is only one type of RN A polymerase in prokaryote which is responsible for the synthesis of all the three types of RNAs viz. rRNA, mRNA and tRNA. On the other hand there are three types of RNA polymerases in eukaryotes namely RNA polymerase I, which synthsize rRNA, RNA polymerase II, which synthesizes mRNA and RNA polymerase III which synthesizes tRNA.

Transcription starts at the RNA polymerase binding site called promoter on the DNA template strand. In prokaryotes within promoter there are two binding sites TTGACA also called -35 sequence and TAT A AT sequence also called -10 sequence, which have affinity for the RNA polymerase. In eukaryotes these sites are at -75 and -25 sites, respectively

The binding of RNA polymerase to the promoter is the first step in gene transcription. One of the subunits of RNA polymerase sigma factor, is responsible for correct initiation of transcription process. Once the transcription has started the sigma factor is released and the remaining part of the enzyme (core enzymes) moves over template; strand and completes the transcription of the gene. The DNA strands open up at the place where enzyme is attached to the templete strand forming transcription bubble. The transcription bubble moves down the DNA, leaving the growing strand protruding from the bubble (Fig 20.25). The stop sequences at the end of the gene terminate the synthesis of mRNA. The simplest stop signal is a series of GC base pairs followed by a series of AT base pairs. The RNA formed in this region forms a GC hairpin (Fig 20.27) followed by four or more U ribonucleotides. The hairpin causes RNA polymerase to stop synthesis.

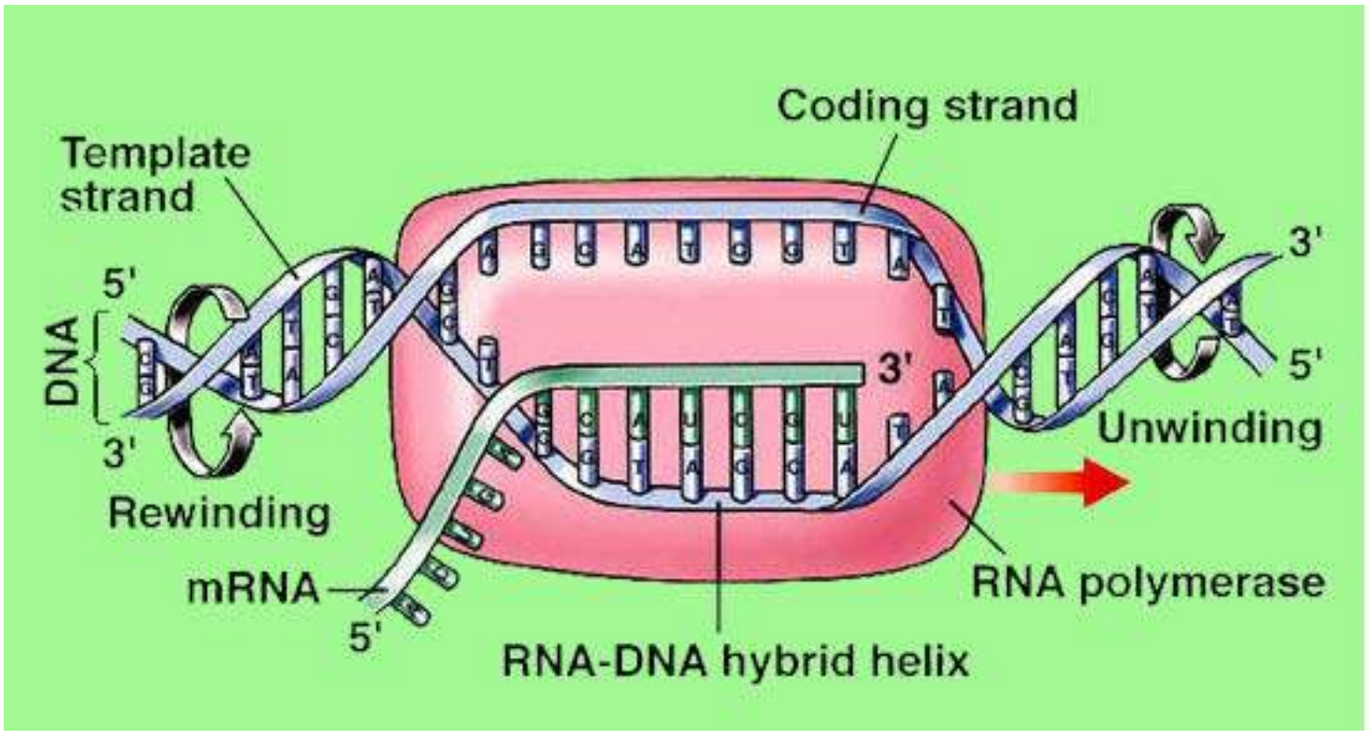



*Fig. 20.25 Model of a transcription bubble.*

In bacteria the newly synthesized mRNA is directly released into the pytoplasm, when it is converted into polypeptide chain. In eukaryotes however, it has to travel long distance from inside the nucleus to ribosomes outside in the cytoplasm. The eukaryotic mRNA is therefore modified in several ways to aid this journey. A cap and a tail is added so that the molecule may remain stable during long journey to ribosome. The cap is in the form of 7 methyl GTP, which is linked 5' to 5' with the first nucleotide, whereas tail is in the form of poly A tail linked to 3' end of the RNA. These caps and tails save the mRNA from variety of nucleases and phosphatases.

## GENETIC CODE

Genetic code is a combination of 3 nucleotides, which specify a particular amino acid. There are three nucleotides in .a codon, because a two nucleotide codon would not yield enough combinations to code for the 20 different amino acids that commonly occur in proteins. With four DNA nucleotides (G,C, T and A ) only 42 or 16, different pairs of nucleotides could be formed. However, these same nucleotides can be arranged in 43 or 64 different combinations of three, more than enough to code for the 20 amino acids. The genetic code is a triplet code and the reading occurs continuously without punctuation between the three nucleotide units.

After Crick's initial experiments, Marshall Nirenberg, Philip Leader and Har Gobind Khorana tested all the 64 codons by making artificial mRNAs and triplet codons and using them to synthesize a protein or aminoacyl-tRNA complexes in cell free systems. '

The full genetic code was determinal during m id 60s (Table 20.1). Out of 64 codons, three codons UAA, UAG and UGA do not code for any amino acid and hence are known as nonsense codons. These codons are usually present at the end of the gene and hence are also called stop codons. Every gene starts with initiation codon AUG, which encodes the amino acid methionine.

Table 20.1 The Genetic Code

| First letter | Second Letter U | | Second Letter C | | Second Letter A | | Second Letter G | | Third letter |
|---|---|---|---|---|---|---|---|---|---|
| U | UUU<br>UUC | phenylalanine | UCU<br>UCC | Serine | UAU<br>UAC | Tryosine | UGU<br>UGC | Cysteine | U<br>C |
| | UUA<br>UUG | Leucine | UCA<br>UCG | | UAA<br>UAG | Stop<br>Stop | UGA<br>UGG | Stop<br>Tryptophan | A<br>G |
| C | CUU<br>CUC | Leucine | CCU<br>CCC | Proline | CAU<br>CAC | Histidine | CGU<br>CGC | Arginine | U<br>C |
| | CUA<br>CUC | | CCA<br>CCG | | CAA<br>CAG | Glutamine | CGA<br>CGG | | A<br>G |
| A | AUU<br>AUC | Isoleucine | ACU<br>ACC | Treonine | AAU<br>AAC | Asparagine | AGU<br>AGC | Serine | U<br>C |
| | AUA<br>AUG | Methionine;<br>Start | ACA<br>ACG | | AAA<br>AAG | Lysine | AGA<br>AGG | Arginie | A<br>G |
| G | GUU<br>GUC | Valine | GCU<br>GCC | Alanine | GAU<br>GAC | Aspartate | GGU<br>GGC | Glycine | U<br>C |
| | GUA<br>GUG | | GCA<br>GCG | | GAA<br>GAG | Glutamate | GGA<br>GGG | | A<br>G |

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 UGA codon is normally a stop codon but, in mitochondria it reads as tryptophan. Likewise AUA was read as methionine instead of isoleucine and AG A and AGG for termination of protein synthesis is instead of arginine. Thus it appearsthatgenetic code is not quite universal.

## TRANSLATION

In prokaryotes, translation begins when the initial portion of an mRNA molecule binds to rRNA molecule in a ribosome. The mRNA lies on the ribosome in such a way that only one of its codons is exposed at the polypeptide site at any time.
A tRNA molecule possessing the complementary three nucleotide sequence or anticodon, binds to the exposed codon on the mRNA. As the ribosome moves along the messenger RNA, successive codons on the mRNA are exposed and the series of tRNA m olecules bind one after another to the exposed codons. Each of these tRNA m olecules carries an attached amino acid, w hich is added to the end of the grow ing polypeptide chain.

Particular tRNA molecules become attached to specific amino acids through the action of activating enzymes called aminoacyl-tRNA synthetase, one of which exists for each of the 20 common amino acids (Fig 20.26).

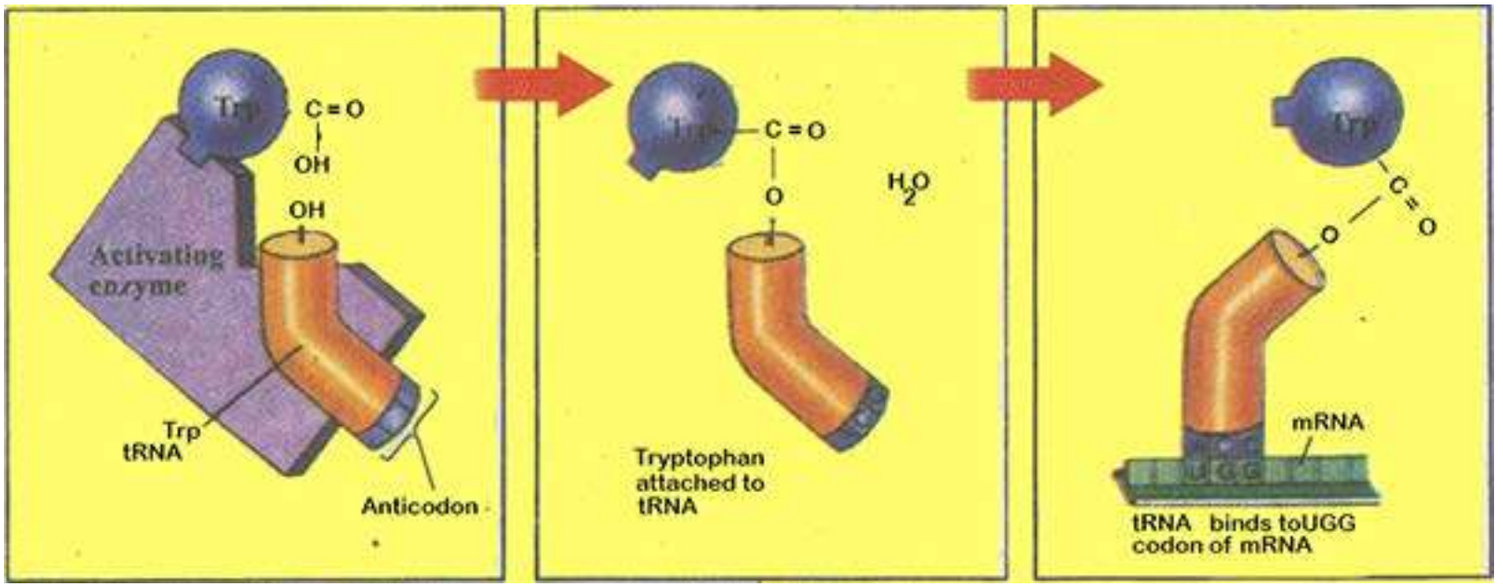



*Fig. 20.26 Activating enzymes "read" the genetic code.*

In prokaryotes, polypeptide synthesis begins with the formation of initiation complex (Fig. 20.27). First a tRNA molecule carrying a chemically modified methionine (called N-formyl methionine) binds to the small ribosomal subunit. Proteins called initiation factor position the tRNA on the ribosomal surface at the P site (peptidyl site) where peptide bonds will form. Nearby two other sites will form. A site (for aminoacyl site), where successive amino acid bearing tRNAs will bind and the E site (for exit site) where empty tRNAs will exit the ribosome (Fig 20.27). This initiation complex, guided by another initiation factor, binds to AUG on the mRNA.

After the initiation complex has formed, the large ribosome subunit binds tRNA molecule with the appropriate anticodon appears, proteins called elongation factors assist in binding it to the exposed mRNA codon at the A site. The two amino acids which now he adjacent to each other undergo a chemical reaction, catalyzed by the large ribosomal subunit, which releases the initial methionine from its tRNA and attaches it instead by a peptide bond to the second amino acid (Fig. 20.28).

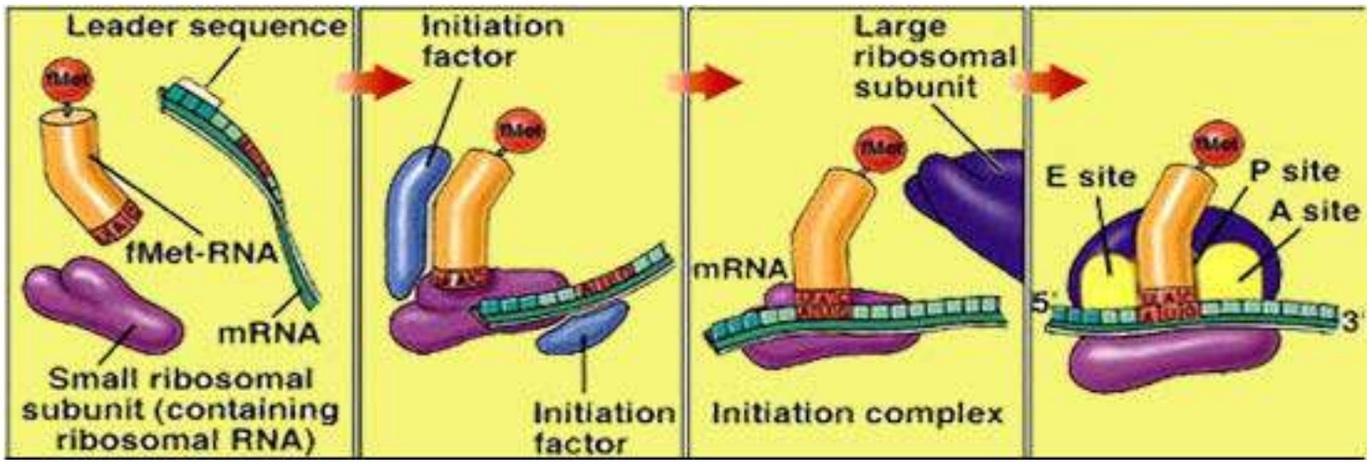



*Fig. 20.27 Formation of the initiation complex.*

The ribosome now moves (translocates) three more nucleotides along the mRNA molecule in the 5' —> 3' direction, guided by other elongation factors. This movement translocates the initial tRNA to the E site and ejects it from the ribosome, repositions the growing polypeptide chain (at this point containing two amino acids) to the P site, and exposes the next codon on the mRNA at the A site (Fig 20.28). When a tRNA molecule recognizing that codon appears, it binds to the codon at the A site, placing its amino acid adjacent to the growing chain. The chain then transfers to the new amino acid, and the entire process is repeated.

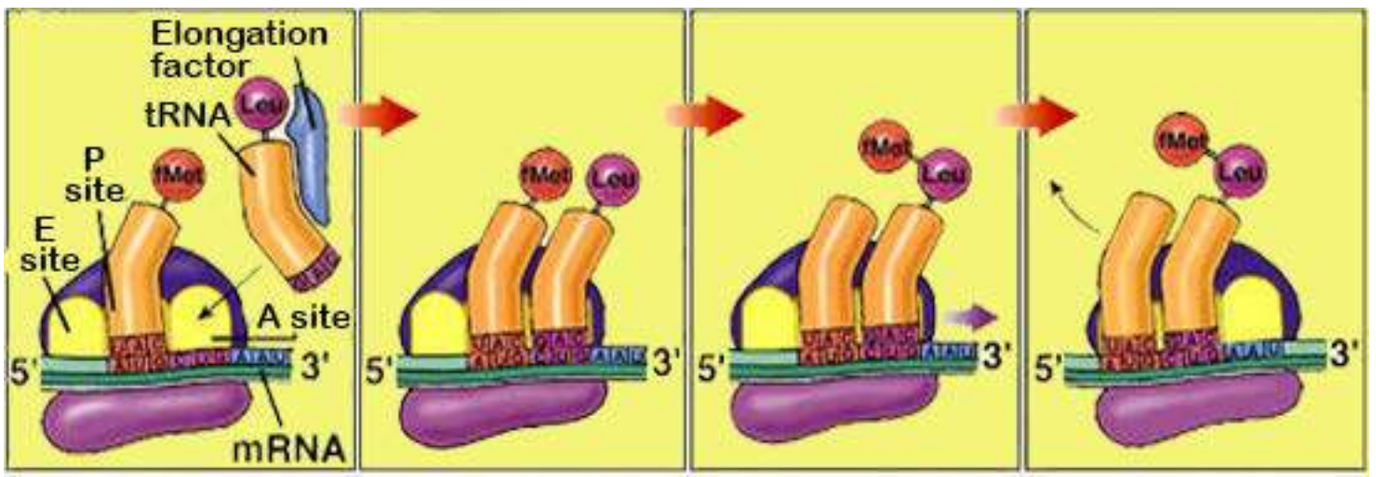



*Fig. 20.28 The translocation process.*

Elongation continues in this fashion until a chain-terminating non sense codon is exposed (for example UAA in Fig 20.29). Nonsense codons do not bind to tRNA, but they are recognized by release factors, proteins that release the newly made polypeptide from the ribosomes.

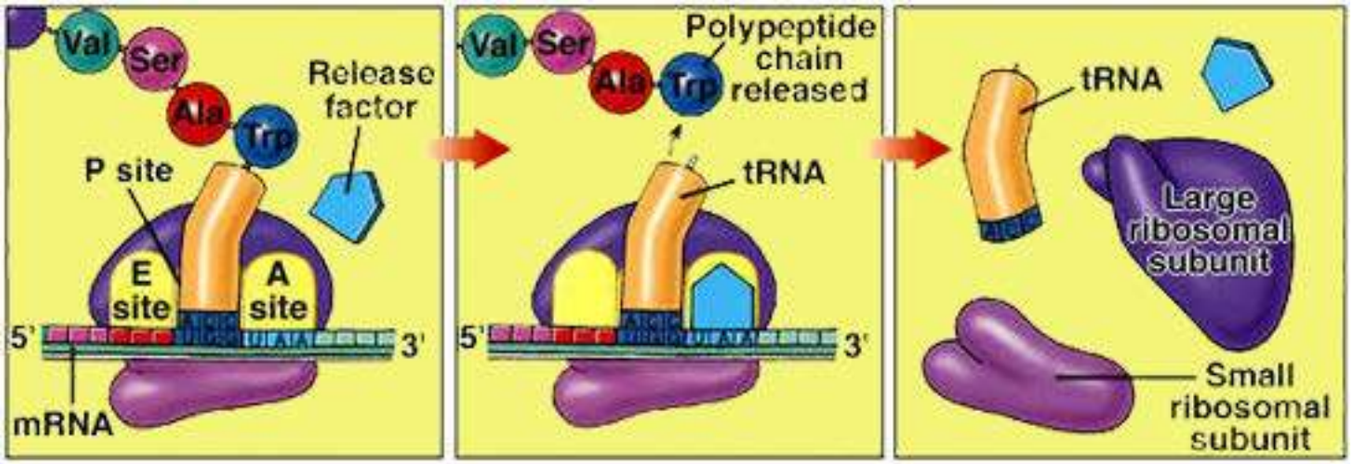



*Fig. 20.29 Termination of protein synthesis*

## MUTATIONS

The cells of eukaryotes contain an enormous amount of DNA. If the DNA in all of the cells of an adult human were lined up end to end, it would stretch nearly 100 billion kilometers - 60 times the distance from Earth to Jupiter.

Changes in the DNA occur either due to mistake in replication or damage to the genetic message causing mutations. The mutations in somatic cells do not pass on to offspring and so have little evolutionary consequence than germ line changes. The mutation in germ line cell is passed to subsequent generations thus providing the raw material from which natural selection produces evolutionary change.

Mutations can broadly be classified as (i) chromosomal aberration and (ii) point mutation. Chromosomal aberrations are mega changes which involve presence of an extra chromosome or loss of a chromosome from the diploid number of chromosomes, or changes like deletions, insertions, inversions etc in the parts of the chromosome, Such chromosomal aberrations lead to syndromes like Down's syndrome, Klinefelter's syndrome etc.

Point mutations are mutational changes which affect the message itself, producing alterations in the sequence of DNA nucleotide (Table 20.2). If alterations involve only one or a few base pairs in the coding sequence they are called point mutations. While some point mutations occur due to spontaneous pairing errors that occur during DNA replication, others result from damage to the DNA caused by mutagens, usually radiations or chemicals. The latter class of mutations is of particular practical importance because modem industrial societies often release many chemical mutagens into the environment. Sickle cell anemia and phenylketonuria are well known examples of point mutation, both of which have been discussed in previous page. In sickle ceil anemia a point mutation leads to the change of amino acid glutamic acid into valine at position 6 from N terminal end in hemoglobin P chain. This consequently alters the tertiary structure of the hemoglobin molecule, reducing its ability to carry oxygen.

In phenylketonuria, phenylalanine is not degraded because of defective enzyme phenylalanine hydroxylase. Phenylalanine consequently accumulates in the cells leading to mental retardation, as the brain fails to develop in infancy. This disorder is because of the point mutation.

## EXERCISE

### Q.1 Fill in the blanks.

1. Particular tRNA molecules become attached to specific amino acids through the action of activating enzymes called_____.
2. _____ _____is the transfer of genetic material from one cell to another and can alter the genetic make up of the recipient cell.
3. In a bacteria, a subunit of RNA polymerase called_____ recognizes-10 sequence in the promoter and binds RNA polymerase there.
4. A typical human chromosome contain about nucleotides in its DNA.
5. Miescher extracted a white substance from the nuclei of human cells and fish sperm and called this substance_____ .

### Q.2 Write whether the statement is true or false and write the correct statement if it is false.

1. The strand of DNA that is not transcribed is called the coding strand.
2. TA TAAT sequence called - 35 sequence is part of promoter, where transcription actually starts.
3. Rosalind Franklin carried out an x-ray diffraction analysis of DNA.
4. The base pairs in DNA helix are planar and stack 34 nm apart as a result of hydrophobic interactions.

### Q.4 Short Questions

1. What are the three major classes of RNA?
2. What is the function of RNA polymerase in transcription?
3. How did Crick and his colleagues determine how many nucleotides are used to specify each amino acid?
4. What is anticodon?

## Q.5 Extensive Questions

1. How did Hershey and Chase determine which components of bacterial viruses contain the hereditary information?
2. ‘ What is the three dimensional shape of DNA? How does three dimensional shape of DNA fit with Chargaff s observations on the proportions of purines and pyrimidines in DNA?
3. How did Meselson and Stahl show that DNA replication is semi conservative?
4. What is the basis for the requirement that the leading and lagging strands be replicated by different mechanisms?
5. What hypothesis did Beadle and Tatum test in their experiments on Neurospora ?

CHAPTER

# 21 Cell Cycle

*Animation 21 : Cell cycle*
*Source & Credit: Wikispaces*

## INTRODUCTION

The cell undergoes a sequence of changes, which involves period of growth, replication of DNA, followed by cell division. This sequence of changes is called cell cycle.

It comprises two phases viz., interphase which is the period of non-apparent division and the period of division also known as mitotic phase. Each phase is further subdivided into different sub-phases.

## INTERPHASE

The period of life cycle of cell (cell cycle) between two consecutive divisions is termed as the interphase or misleadingly called resting phase. It is the period of great biochemical activity and can further be divided into $G_1$-phase, S-phase and $G_2$-phase.

$G_1$ (Gap 1) is the period of extensive metabolic activity, in which cell normally grows in size, specific enzymes, are synthesized and DNA base units are accumulated for the DNA synthesis. Post-mitotic cell can exit the cell cycle during $G_1$ entering a phase called $G_0$, and remain for days, weeks, or in some cases (e.g., nerve cells and cells of the eye lens) even the life time of the organism without proliferating further. Following the $G_1$ is the S-phase (synthesis phase) during which the DNA is synthesized and (chromosome are replicated) which initiates $G_2$ phase (pre-mitotic phase), thus preparing the cell for division e.g., energy storage for chromosome movements, mitosis specific proteins, RNA and microtubule subunits (for spindle fibers) synthesize. Cells then proceed to next phase which is the period of division). At each stage, there are specific check points, which determine the fate of new phase according to cell's internal make up. Length of each phase is variable. In the case of human cell, average cell cycle is about 24 hours, mitosis takes 30 minutes, $G_1$ 9 hours, the S-phase 10 hours, and $G_2$ 4.5 hours whereas full cycle in yeast cells is only 90 minutes.

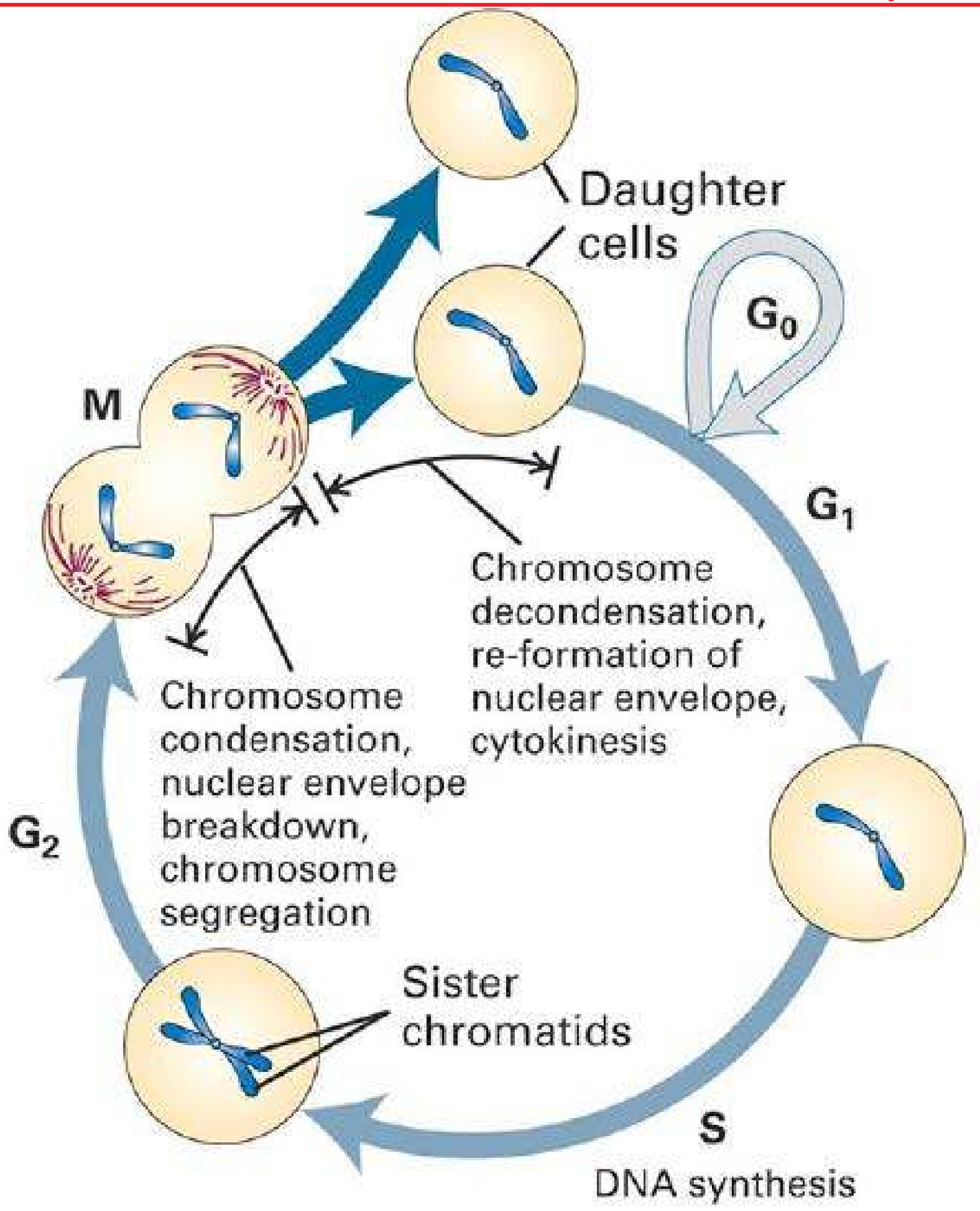



*Fig. 21.1 The fate of a single parental chromosome throughout the eukaryotic cell cycle.*

# MITOSIS

It is the type of cell division, which ensures the same number of chromosomes in the daughter cells as that in the parent cells. In spite of slight differences, major steps of mitosis are similar in plants as well as in animals. However, to avoid the confusion our statement will base on the animal cell. It can take place in haploid as well as in diploid cells in nearly all parts of the body if and when required.

Mitosis is a continuous process, but conventionally it may be divided into two phases, i.e., karyokinesis, which involves the division of nucleus and cytokinesis that refers to the division of the whole cell (Fig.21.2).

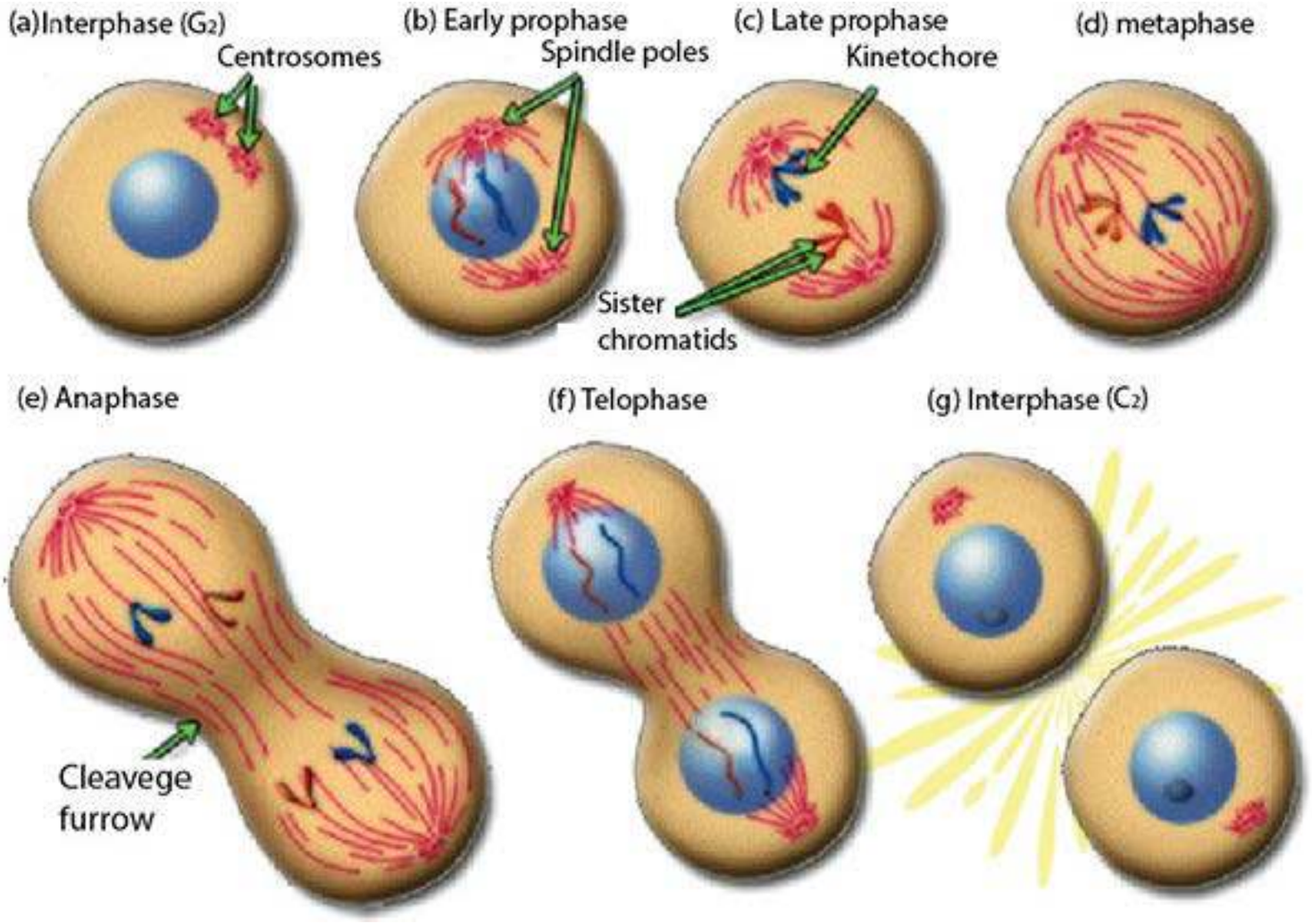



*Fig 21.2 The stages of mitosis and cytokinesis in an animal cell.*

## Karyokinesis

At the beginning of the process in an animal cell, the partition of the centriole takes place, which have been duplicated during interphase but present in the same centrosome. Early in the mitosis the two pair of centrioles separate and migrate to opposite sides of the nucleus, establishing the bipolarity of the dividing cells.

Three sets of microtubules (fibers) originate from each pair of centrioles. One set the astral microtubules, radiate outward and form aster, other two sets of microtubules compose the spindle. The kinetochore microtubules attach to chromosomes at kinetochores and polar microtubules do not interact the chromosomes but instead interdigitate with polar microtubules from the opposite pole. These microtubules are composed of a protein tubulin and traces of RNA.

This specialized microtubule structure including aster and spindle is called mitotic apparatus. This is larger than the nucleus, and is designed to attach and capture chromosomes, aligning them and finally separating them so that equal distribution of chromosomes is ensured.

Karyokinesis can further be divided into prophase, metaphase, anaphase and telophase for thorough understanding, though it is a continuous process.

## Prophase

During interphase (non-dividing phase) of the cell cycle the chromosomes are not visible even with electron microscope, but using histologic stains for DNA, a network

of very fine threads can be visualized. This network is called as chromatin.
The chromatin material gets condensed by folding and the chromosomes appear as thin threads (0.25μm - 50μm in length) at the beginning of prophase.
Chromosomes become more and more thick ultimately each chromosome is visible having two sister chromatids, attached at centromere. Towards the end of prophase, nuclear envelope disappears and nuclear material is released in the cytoplasm, nucleoli disappear. Mitotic apparatus is organized (as described above). Cytoplasm becomes more viscous.

### Metaphase

Each metaphase chromosome is a duplicated structure which consists of two sister chromatids, attached at a point called centromere or primary constriction. The centromere has special area, the kinetochore, with specific base arrangement and special proteins where kinetochore fibers of mitotic apparatus attach.
The kinetochore fibers of spindle attach to the kinetochore region (specialized area in centromere) of chromosome, and align them at the equator of the spindle forming equatorial plate or metaphase plate. Each kinetochore gets two fibers one from each pole.

### Anaphase

It is the most critical phase of the mitosis, which ensures equal distribution of chromatids in the daughter cells. The kinetochore fibers of spindle contract towards their respective poles, at the same time polar microtubules elongates exert force and sister chromatids are separated from centromere. As a result, half sister chromatids travel towards each pole.

### Telophase

Reaching of the chromosomes at opposite poles terminates anaphase and start telophase. The chromosomes decondense due to unfolding, ultimately disappear as chromatin. Mitotic apparatus disorganizes nuclear membrane and nucleoli reorganize, resulting two nuclei at two poles of the cell.

### Cytokinesis

During late telophase the astral microtubules send signals to the equatorial region of the cell, where actin and myosin are activated which form contractile ring, followed by cleavage furrow, which deepens towards the center of the cell, dividing the parent cell into two daughter cells.

Mitotic events in plant cells are generally similar to the events observed in animal cells but there are some major differences. Most higher plants lack visible centrioles, instead they have its analogous region from which the spindle microtubules radiate. Moreover, shape of the plant cell does not change greatly compared with an animal cell- because it is surrounded by a rigid cell wall. At cytokinesis, in place of contractile ring a membrane structure, phragmoplast is formed from vesicle which originate from Golgi complex. These vesicles originate actually during metaphase, line up in the center of the dividing cell, where they fuse to form phragmoplast at the end of telophase. The membrane of vesicles becomes the plasma membrane of daughter cells. These vesicles also contain materials for future cell wall such as precursors of cellulose and pectin (Fig.21.3).

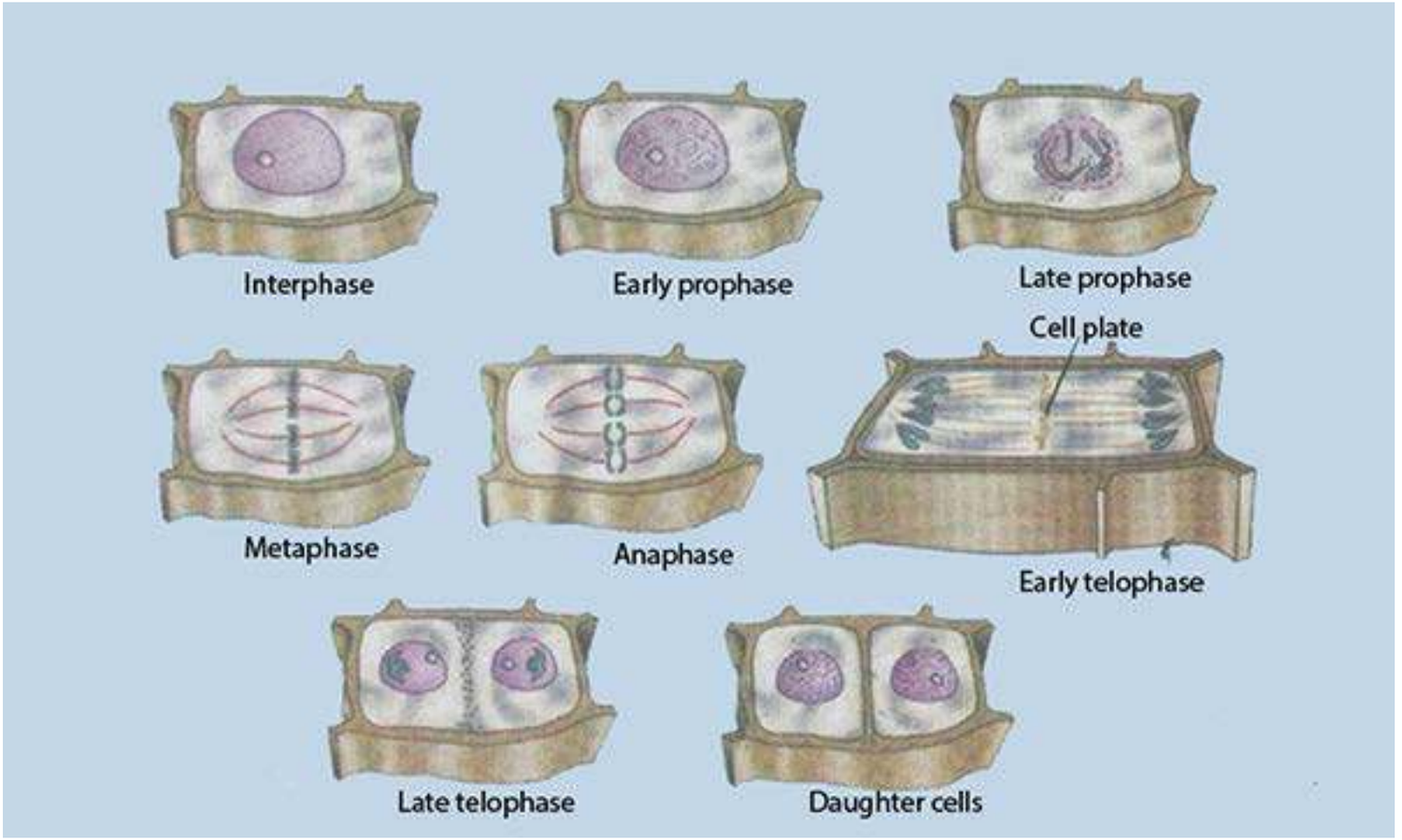


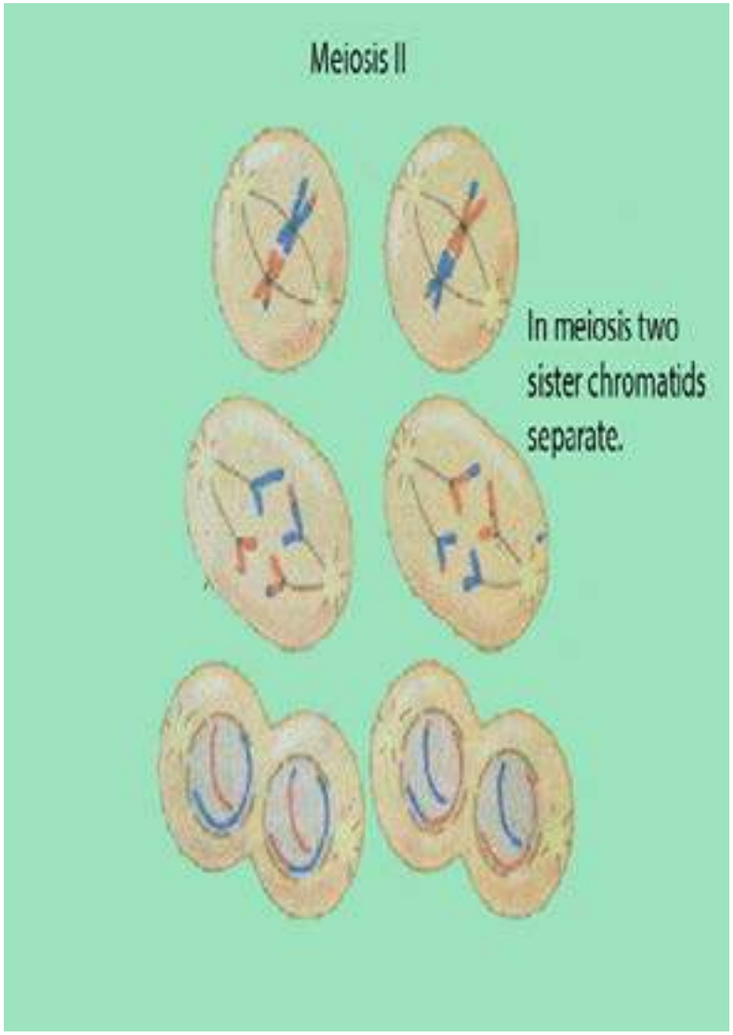

*Fig 21.3 Mitosis in a higher plant cell*

### Importance of mitosis

In mitosis the hereditary material is equally distributed in the daughter cell. As there is no crossing over or recombination, the genetic information remains unchanged generation after generation, thus continuity of similar information is ensured from parent to daughter cell. Some organisms, both plants and animals, undergo asexual reproduction. Regeneration, healing of wounds and replacement of older cells all are the gifts of mitosis. Development and growth of multicellular organisms depends upon orderly, controlled mitosis. Tissue culture and cloning seek help through mitosis. For all this an organism requires managed, controlled and properly organized process of mitosis, which otherwise may result malfunction, unwanted tumors and lethal diseases like cancer.

## Cancer (uncontrolled cell division)

The multiplication of cells is so carefully regulated and responsive to specific needs of the body, that process of cell death and birth are balanced to produce a steady state. Sometime the control, that regulates the cell multiplication, breaks down. A cell in which this occurs, begins to grow and divide in unregulated fashion without body's need for further cells of its type. When such cells produce new cells which continue to proliferate in incontrolled fashion, an unwanted clone of cells, called tumor is formed, which can expand indefinitely. Tumors arise frequently, especially in older animals and humans, and are of two basic types. Some tumors are of small size and localized (not transferred to other parts) called benign. The cells in this type usually behave like the normal cells and have little deleterious effects,, only due to either its interference with normal cells or its hormone-like secretions.



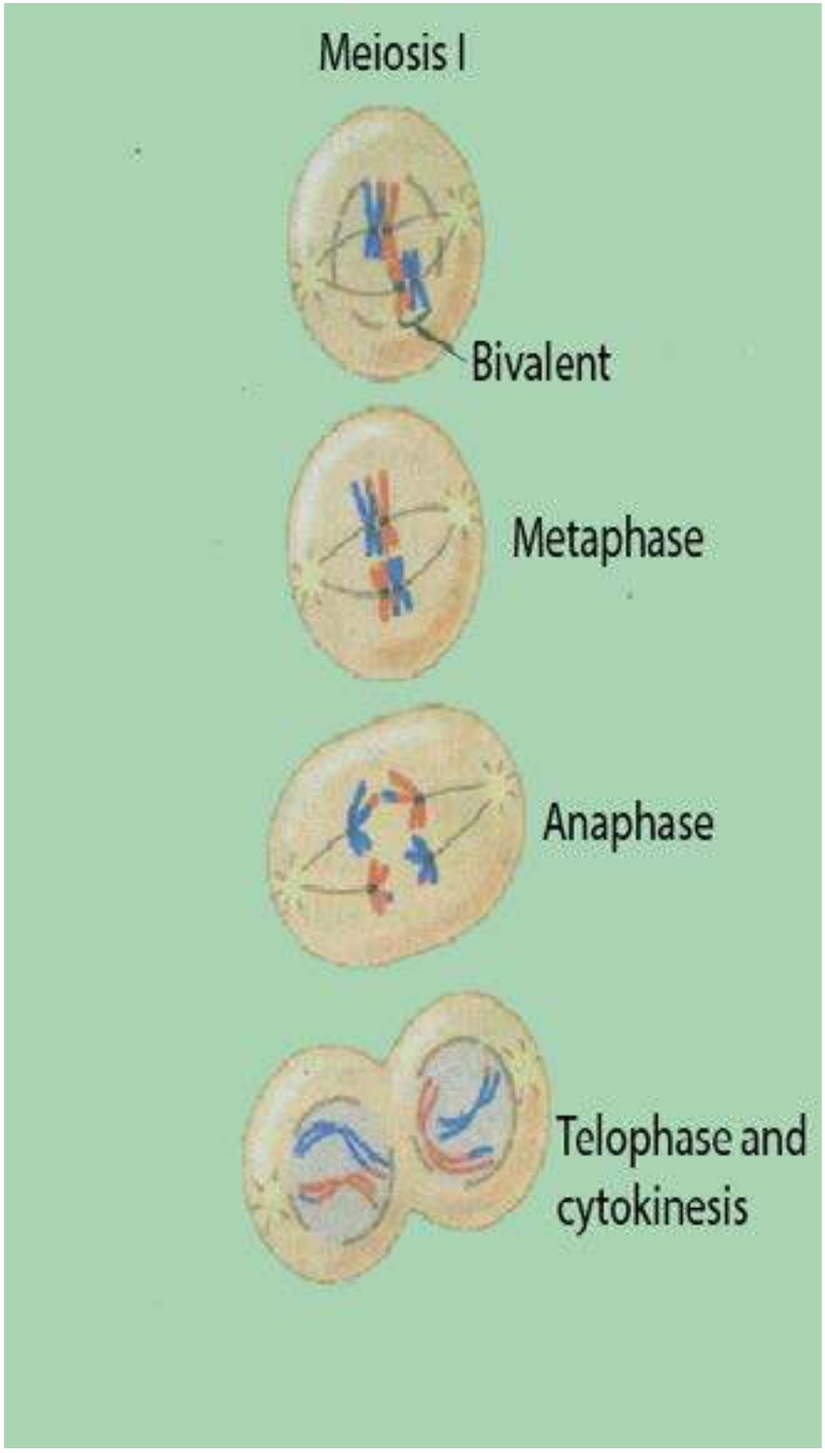




*Fig: 21.4 result of meiosis,four haploid cells, each with half as many chromosomes as the original cells.*

In contrast, the cells composing a malignant tumor or cancer, divide more rapidly, mostly invade surrounding tissues, get into the body's circulatory system, and set up areas of proliferation, away from their site of original appearance. This spread of: tumor cells and establishment of secondary areas of growth is called as metastasis.

Cancer cells can be distinguished from normal cells because they are less differentiated than normal cells, exhibit the characteristics of rapidly growing cells, i.e is, high nucleus to cytoplasm ratio, prominent nucleoli and many mitosis.

The presence of invading cells in otherwise normal tissue is an indication of malignancy. Cancer is caused mainly by mutations in somatic cells. Secondly, the cancer results from the accumulation of as few as three to as many as twenty mutations, in genes that regulate cell divisidn. These mutations bring two basic changes in the cancer cells. First, the metastatic cells break their contact with other cells and overcome the restrictions on cell movement provided by basal lamina and other barriers, ultimately metastatic cells can invade other parts of the body. Secondly, they proliferate, unlimitedly, without considering the checks or programmes of the body.

## MEIOSIS

Meiosis is the special type of cell division in which the number of chromosomes in daughter cells is reduced to half, as compared to the parent cell. In animals at the time of gamete formation, while in plants when spores are produced. Each diploid cell after meiosis produces four haploid cells, because it involves two consecutive divisions after single replication of DNA. Two divisions, are meiosis I and meiosis II. The first meiotic division is the reduction division, whereas second meiotic division is just like the mitosis. Both divisions can further be divided into substages like prophase 1, metaphase 1, anaphase 1, telophase 1 and same names are used for meiosis II also (Fig.21.4).

### Prophase I

This is very prolonged phase, and differs from the prophase of mitosis, because in this chromosomes behave as homologous pairs. Each diploid cell has two chromosomes of each type, one member from each parent, because of fusion of male and female gametes. Each chromosome has two chromatids, because chromosomes have been replicated during interphase. The interphase of meiosis lacks G2 stage. These similar but not necessarily identical chromosomes are called as homologous chromosomes. Prophase 1 further consists of the followings stages.

### Leptote. e:

The chromosomes become visible, shorten and thick. The size of the nucleus increases and homologous chromosomes start getting closer to each other.

**Zygotene:** First essential phenomenon of meiosis i.e., pairing of homologous chromosomes called synapsis starts. This pairing is highly specific and exactly pointed, but with no definite starting point(s). Each paired but not fused, complex structure is called bivalent or tetrad.

**Pachytene:** The pairing of homologous chromosomes is completed. Chromosomes become more and more thick. Each bivalent has four chromatids, which wrap around each other. Non-sister chromatids of homologous chromosomes exchange their segments due to chiasmata formation, during the process called crossing over. In this way reshuffling of genetic material occurs which produces recombinations. Pachytene may lasts for days, weeks or even years, whereas leptotene and zygotene can last only for few hours.

**Diplotene:** The paired chromosomes repel each other and begin to separate. Separation however, is not complete, because homologous chromosomes remain united by their point of interchange (chiasmata). Each bivalent has at least one such point, the chromatids otherwise are separated (Fig. 21.5).

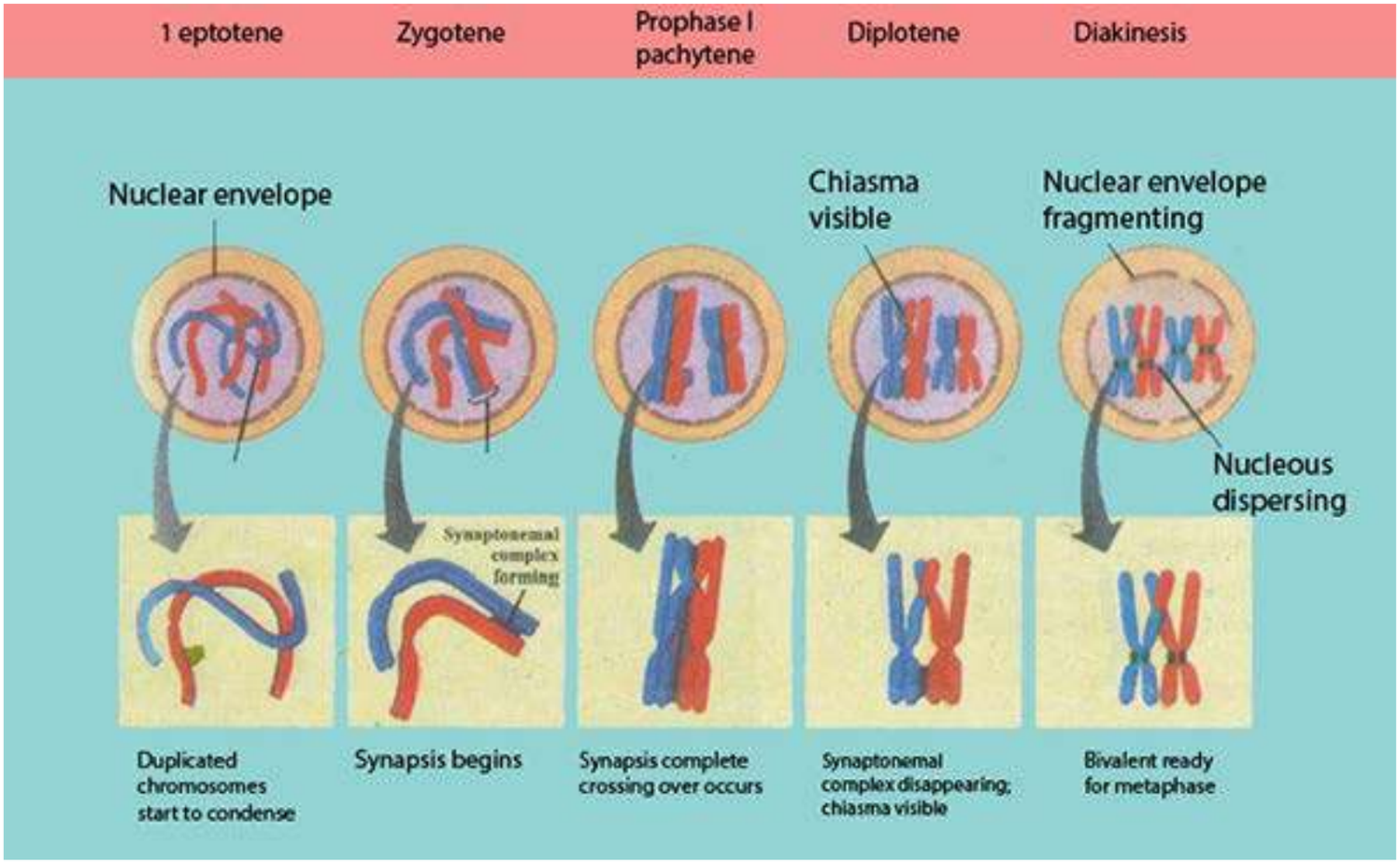



*Fig. 21.5 Chiasmata formation*

**Diakinesis:** During this phase the condensation of chromosomes reaches to its maximum. At the same time separation of the homologous chromosomes (started during diplotene) is completed, but still they are united at one point, more often at ends. Nucleoli disappear.

### Metaphase I

Nuclear membrane disorganizes at the beginning of this phase. Spindle fibers originate and the kinetochore fibers attach to the kinetochore of homologous chromosome from each pole and arrange bivalents at the equator. The sister chromatids of individual chromosome in bivalent behave as a unit.

### Anaphase I

The kinetochore fibers contract and the spindle or pole fibers elongate, which pull the individual chromosome (each having two chromatids) towards their respective poles. It may be noted here that in contrast to anaphase of mitosis, sister chromatids are not separated. This is actually reduction phase because each pole receives half of the total number of chromosomes.

### Telophase I

Nuclear membrane reorganizes around each set of chromosomes at two poles, nucleoli reappear thus two nuclei each with half number of chromosomes are formed, later on cytoplasm divides thus terminating the first meiotic division. It is also to be noted that chromosomes may decondense during this stage.

### Meiosis II

After telophase I two daughter cells experience small interphase, but in contrast to interphase of mitosis there is no replication of chromosomes.

Prophase II, metaphase II, anaphase II and telophase II are just like the respective phases of mitosis during which the chromosomes, condense, mitotic apparatus forms, chromosomes arrange at the equator, individual/sister chromatids move apart, and ultimately four nuclei at the respective poles of two daughter cells (formed after meiosis I) are formed. Cytokinesis takes place and four haploid cells, with half of the number of chromosomes (chromatids) are formed.

### Importance of Meiosis

Crossing over and random assortment of chromosomes are two significant happenings of meiosis. During crossing over, parental chromosomes exchange segments with each other which results in a large number of recombinations. At the same time during anaphase the separation of homologous chromosomes is random, which gives very wide range of variety of gametes. Both these phenomena cause variations and modifications in the genome. These variations are not only the bases of evolution, but also make every individual specific, particular and unique in his characteristics. Even the progeny of very same parents, i.e., brothers and sisters are not identical to each other.

Meiosis usually takes place at the time of sexual cell (gamete) formation, spore formation in plants, thus having the number of chromosomes in each, which is restored after fertilization and maintains chromosome number constant generation after generation. Had meiosis not been the process, the chromosome number may have been doubled after every generation. Can you imagine the consequences?

## MEIOTIC ERRORS (NON-DISJUNCTION)

Meiosis is an orderly occurring phenomenon, which ensures every phase with appropriate finish, but some times, at any point the result may be unexpected, causing abnormalities.One of such abnormalities is chromosome non-disjunction, in which chromosomes fail to segregate during anaphase and telophase and do not finish with equal distribution of chromosome among all the daughter nuclei. This results either increase or decrease in the number of chromosomes, causing serious physical, social and mental disorders. This non-disjunction may be in autosome or in sex chromosome. Some examples of each type may be discussed below in some detail.

### Down's Syndrome (Mongolism)

It is one of the consequences of autosomal non-disjunction in man, during which 21st pair of chromosome fails to segregate, resulting in gamete with 24 chromosome. When this gamete, fertilizes normal gamete the new individual will have 47 (2n + 1) chromosomes. Non-disjunction appears to occur in the ova and is related to the age of mother. The chances of teenage mother having Down's syndrome child is one in many thousands, forty years old mother, one in hundred chances and by forty-five the risk-is three times greater. The affected individuals have flat, broad face, squint eyes with the skin fold in the inner corner, and protruding tongue, mental retardation, and defective development of central nervous system.

Autosomal non-disjunction may occur in other than 21st chromosome which usually results in abortion, or death in very early age.

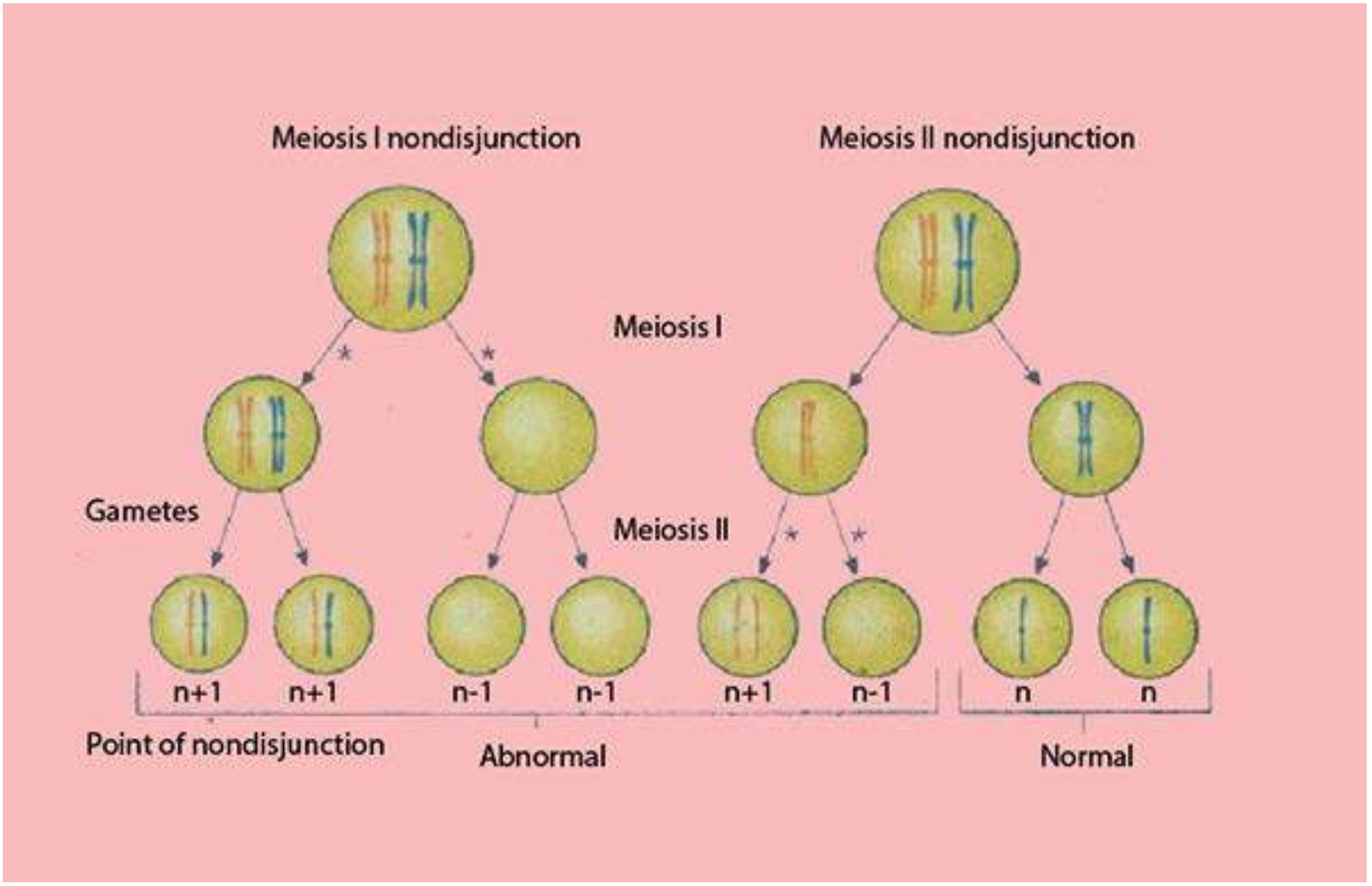
### Klinefelter's Syndrome

These individuals have additional sex chromosome e.g., 47 chromosomes (44 .autosome + XXY). They are phenotypically male but have frequently enlarged breasts, 'tendency to tallness, obesity, small testes with no sperms at ejaculation and under developed secondary sex characters.

Males with 48 chromosomes (44 autosomes + XXXY), with 49 chromosomes (44 autosomes + XXXXY) and with 47 chromosomes (44 autosomes + XYY) are also observed (Fig. 21.6).

### Turner's Syndrome

These affected individuals have one missing X chromosome with only 45 •chromosomes (44 autosomes + X). Individuals with this condition often do not survive pregnancy and are aborted. Those who survive have female appearance with short stature, webbed neck, without ovaries and complete absence of germ cells.




| Syndrome | Sex | Chromosomes | Frequency | |
|---|---|---|---|---|
| | | | Abortions | Births |
| Down | M or F | Trisomy 21 | 1/40 | 1/700 |
| Patau | M or F | Trisomy 13 | 1/33 | 1/15,000 |
| Edward | M or F | Trisomy 18 | 1/200 | 1/6,000 |
| Turner | F | XO | 1/18 | 1/6,000 |
| Metafemale | F | XXX or (XXXX) | 0 | 1/1,500 |
| Klinefelter | M | XXY or (XXXY) | 0 | 1/1,500 |
| Jacobs | M | XYY | ? | 1/1,000 |

*Fig. 21.6 Non-disjunction of autosomes (a) Non disjunction occurring during meiosis I and meiosis II, gametes (asterisks mark points of non-disjunction), (b) Frequency of syndromes*

## Necrosis and Apoptosis

Cells in an organism depend upon various extracellular and intracellular signals for its regulated, controlled activities like cell division, pattern formation, differentiation, morphogenesis and motility. Each cell is predestined to its fate i.e., what responsibility it has to take and in which way. Even the death of the cell is programmed.

Programmed cell death helps in proper control of multicellular development, which may lead to deletion of entire structure (e.g., the tail of developing human embryos) or part of structure (e.g., tissue between developing digits). Cell death even controls the number of neurons, because most of the neurons in the human body die during development.

Cell death in multicellular organisms is controlled by two fundamentally different ways, i.e., either the cell commits suicide in the absence of survival signals (trophic factors) or cells are murdered by killing signals from other cells.

Internal programme of events and sequence of morphological changes by which cell commits suicide is collectively called as apoptosis (Greek word that means dropping off or falling off).

During this process the dying cells shrink and condense ultimately split up, thus releasing small membrane bounded apoptotic bodies, which are generally phagocytosed by other cells (Fig.21.7). Intracellular constituents are not released freely in extracellular atmosphere which otherwise might have deleterious effects. In contrast to suicide, the cell death due to tissue damage is called necrosis, during which the Fig21.7 typical cell swells and bursts, releasing the intracellular contents, which can damage neighbouring cells and cause inflammation.

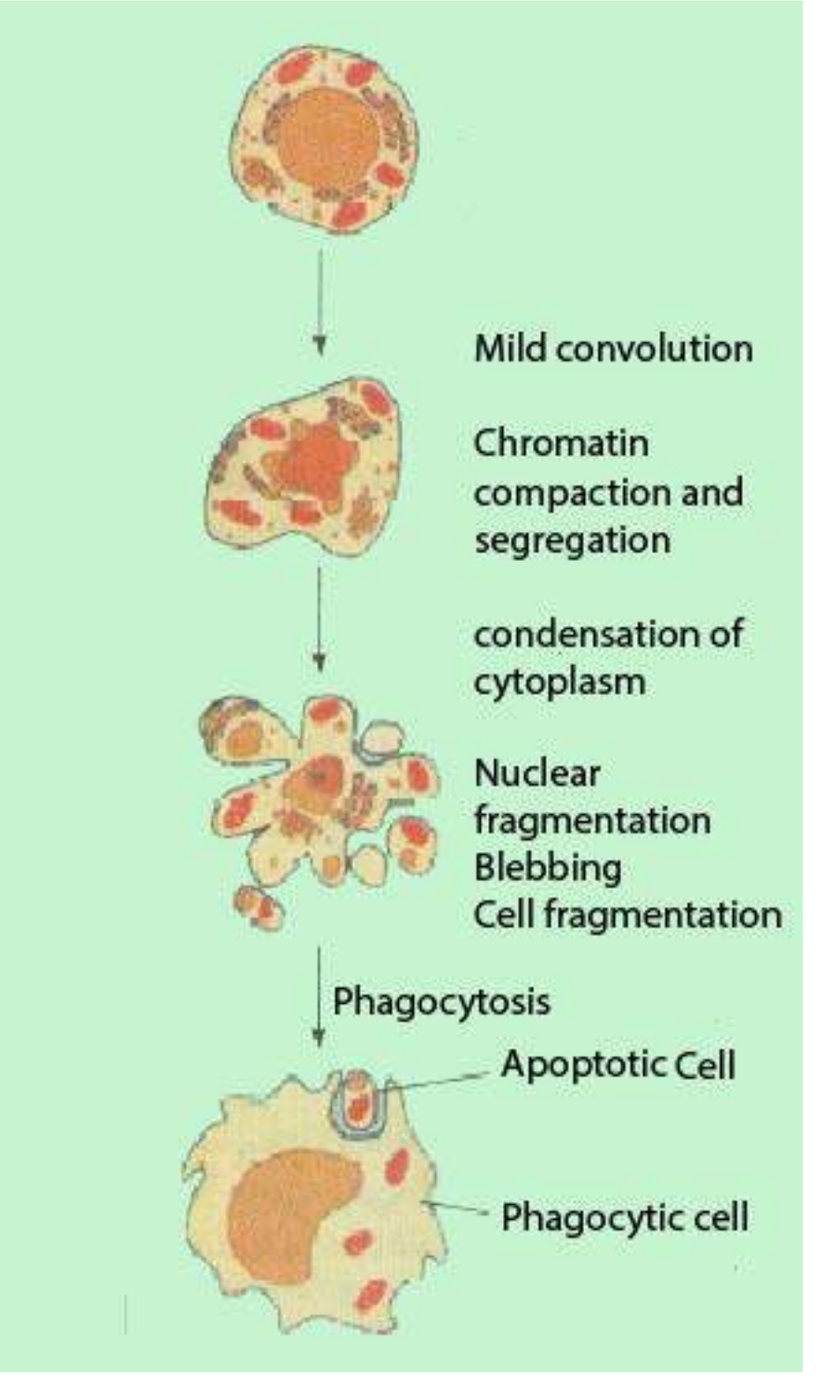



*Fig: 21.7 Ultrastructural features of cell death by apoptosis*

## EXERCISE

**Q.1 Fill in the blanks.**

1. Mongolism is also known as_____ .
2. During_____ homologous chromosomes get close to each other.
3. _____phase precedes G2 phase.
4. Polar microtubules during anaphase.
5. Mitotic apparatus is formed during_____ off cell division.
6. The chromosome number (44+1) denotes_____Syndrome.
7. Intracellular contents are released during the type of cell death called ---------.

**Q.3 Write true / false against each statement, fif It is false, rewrite tfhettmie statement**

1. Meiosis occurs in haploid cells only.
2. Cell cycle is comprised of two phases i.e. karyokinesis and cytokinesis.
3. A point where non-sister chromatids cross each other is called kinetochore.
4. $G_0$ stands for no gap,
5. Full life cycle of yeast cells require 90 seconds to be completed.
6. Crossing over takes place during metaphase I.

7. Autosomal non disjunction may occur in chromosomes other than 21st chromosome,
8. Benign tumors are always non localized,
9. Cancer is caused mainly by mutations in germ cells.
10. Genetic informations remain unchanged during mitosis.
11. Homologous chromosomes are necessarily identical.
12. The cells are kept alive due to trophic factors.
13. Cytokinesis involves the division of cytochromes.
14. Phragmoplast is a type of fragmentation.

## Q.4. Short questions

**1.** Differentiate between necrosis and apoptosis.
2. What are the functions of mitotic apparatus?
3. How can you identify the cancer cells?
4. Give importance and significance of meiosis.
5. Define chromosomal non disjunction.
6. What are symptoms of turner's syndrome?
7. Define cell cycle. Highlight its importance and significance.
8. Is interphase a resting phase? Why?
9. In what respect does mitosis in plant cells differ from that in animal cells?

## Q3. Extensive questions.

1. How does cytokinesis occur in animals cells? In which way does it differ from that in plant cell?
2. Why and how do the chromosomes get separated during anaphase of mitosis?
3. What is the role of centriole in an animal cell? How is this function carried out in plant cell?
4. In what respect can cell death be regarded beneficial?
5. Compare mitosis with meiosis and describe their importance.
6. Define disjunction and discuss its effect.
7. Describe meiosis and explain its significance.

CHAPTER

22

# VARIATION AND GENETICS

*Animation 22:: Variation and Genetics*
*Source & Credit: Wikispaces*

## GENES, ALLELES AND GENE POOL

Hereditary characteristics pass from parents to offspring through genes in their gametes. Gene is the basic unit of biological information. In fact DNA stores all sorts of biological information coded in the sequence of its bases in a linear order, and genes are actually parts of DNA comprising its base sequences. The position of a gene on the chromosome is called its locus.

Genes are responsible for producing startling inherited resemblences as well as distinctive variations among generations. When these pass in the form of intact parental combination between generations, inherited similarities are conserved; but when these shuffle, mutate or juggle with each other, variations emerge. Genes form pairs on pairs of homologous chromosomes. One member of a gene pair is located on one homologue, and the other member on the other homologue. Partners of a gene pair are called alleles. Each allele of a gene pair occupies the same gene locus on its respective homologue. Both alleles on one locus may be identical, or different from each other. (Fig. 22.1).

*Animation 22: Gene Pool*
*Source & Credit: GIF SOUP*

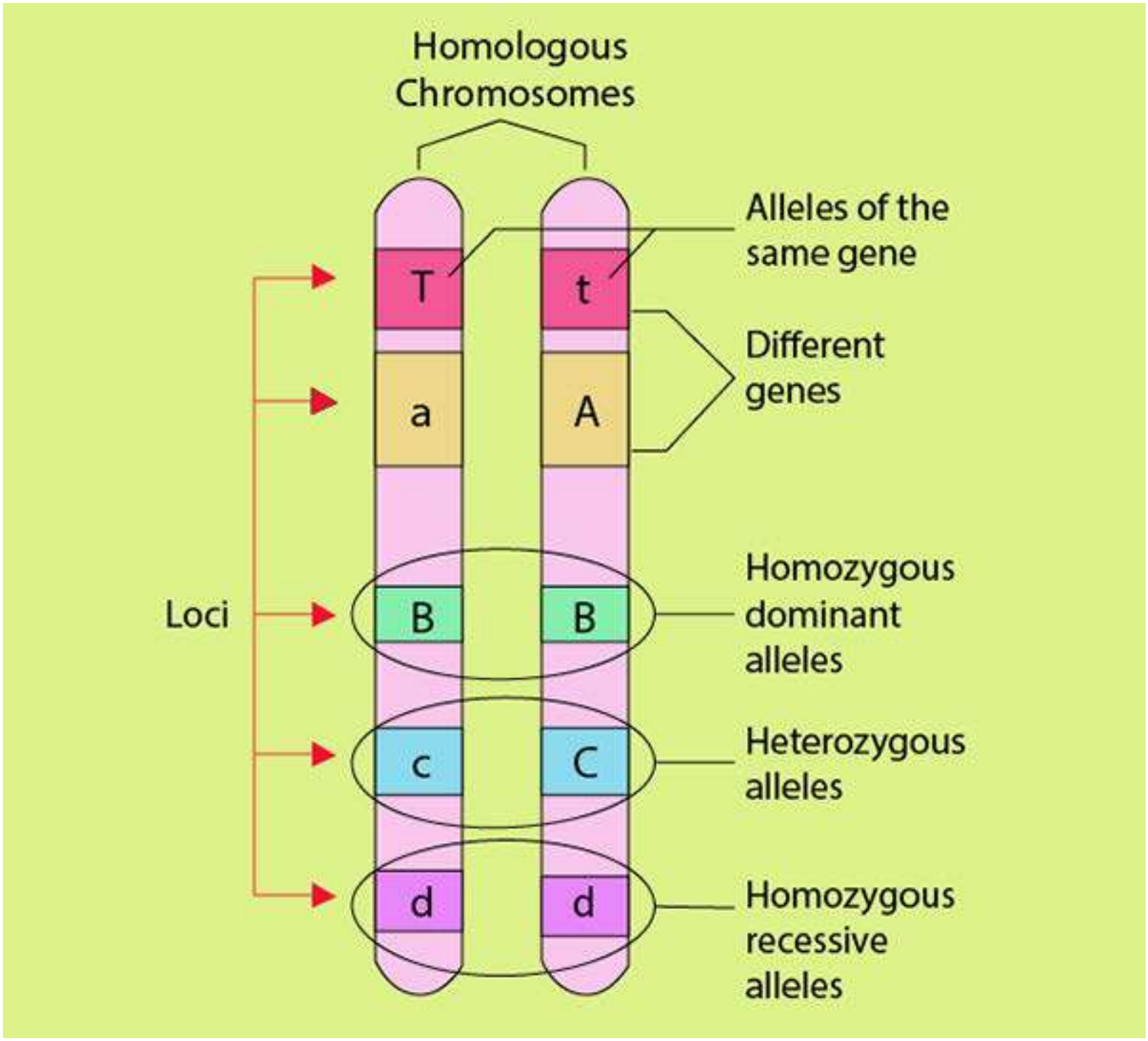



*Fig 22.1 Allelic pairs on a homologous pair of chromosomes*

Phenotype is the form of appearance of a trait. Genotype is the genetic complement i.e., the genes in an individual for a particular trait. A flower may be red or white in colour. Flower colour is a trait and red and white are its two phenotypes. Each form of expression is determined-by a different allele of the colour gene. Allele “R” is the determiner for redness, while “r” is the determiner for whiteness.

## GENE POOL

Any group of interbreeding organisms of the same species that exist together in both time and space is called a population. All the genes/alleles found in a breeding population at a given time are collectively called the gene pool. It is the total genetic information encoded in the total genes in a breeding population existing at a given time.

If we imagine population not as a group of individuals, but as a group of individually segregating and randomly assorting alleles, we can understand the concept of “beanbag genetics”. The alleles are like beans in a beanbag. The entire beanbag full of beans is the gene pool of the population. In the beanbag approach we can imagine the entire gene pool comprising all the alleles for all the different traits at once, or we can just focus on some subset, such as all the alleles for a single trait.

Jumping genes do not settle peacefully on their loci, they keep on hopping on different loci on the same chromosome or other chromosomes.

For convenience, we can focus on the gene pool for a single particular trait. A sample population of 100 diploid plants, some of which bear red flowers, others bearing white flowers has a sum total of 200 of all the different alleles (R or r) for flower colour trait as its gene pool.

## MENDEL'S LAWS OF INHERITANCE

Gregor Johann Mendel (1822 - 1884) laid the foundation of classical genetics by formulating two laws of heredity; law of segregation and law of independent assortment. He was a priest. He performed series of breeding experiments on garden pea, Pisum sativum in his monastery garden for eleven years (1854 — 1865). Pisum sativum was easy to cultivate and it grew well in his garden. Its flowers were hermaphrodite. It was normally self-fertilizing, but could also be cross-fertilized. As the time gap between generations was short, Mendel could raise many generations of pea within a short time. Pea had many sharply distinct traits. Each trait had two clear cut alternative forms or varieties; e.g., seed shape had a round or wrinkled phenotype, plant height was either tall or short, seed colour could be yellow or green. Mendel called them contrasting pair of a trait. He focussed on seven such pairs (Fig. 22.2).

He first established true-breeding lines or varieties for each trait. A true - breeding variety upon self - fertilization always produced offspring identical to the parents, e.g., a true breeding "round" seed plant produced only "round" seeds. Similarly, a true breeding "wrinkled" seed plant produced only "wrinkled" seeds.

After establishing 14 pure - breeding lines of seven characters, he cross-fertilized plants that differed in one character only. The offspring of such a cross were called monohybrids. He cross-fertilized a true breeding round-seeded male plant with a true breeding wrinkled-seeded female plant (Fig. 22.3).

*Animation 22.2:Mendel's Law of Inheritance*
*Source & Credit: Ms.Anderson Biology Class*

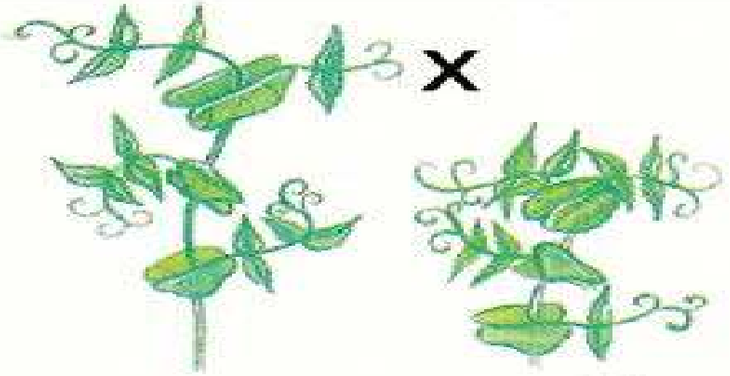
| Trait | Dominant vs. recessive |
|---|---|
| Flower color |  Purple × White |
| Seed color |  Yellow × Green |
| Seed shape |  Round × Wrinkled |
| Pod color |  Green × Yellow |
| Pod shape |  Round × Constricted |
| Flower position |  At leaf junction Axial × At tips of branches Top |
| Plant height |  (6-7feet)Tall × Short (inche 9-18) |

*Fig 22.2 Seven traits of garden pea studied by Mendel.*

He called it first parental generation (Pi). Their offspring were called Fi or first filial generation. All Fi offspring were round like one of the parents. Wrinkled phenotype did not appear at all. Round dominated wrinkled. Its dominance was complete because no offspring intermediate between parents was found. He called the trait that appeared in F, as dominant; while the trait, which was masked, as recessive.

Then Mendel allowed self-fertilization among F| monohybrids to raise F2 progeny. As a result of monohybrid cross 3A of F2 were round and lA wrinkled.

Mendel got similar results and the same 3:1 ratio in offspring of monohybrid crosses for all the seven contrasting pairs of traits.
Mendel proceeded a step ahead. He self- fertilized F2 plants to raise F3. He noted that 1/3 of F2 round produced only round, while 2/3 of F2 round produced both round and wrinkled in . 3:1 ratio; but F1 wrinkled produced only wrinkled.

He concluded that 1/3 of F2 rounds were true-breeding like Pi round, and 2/3 of F2 rounds were monohybrids like Fj round.

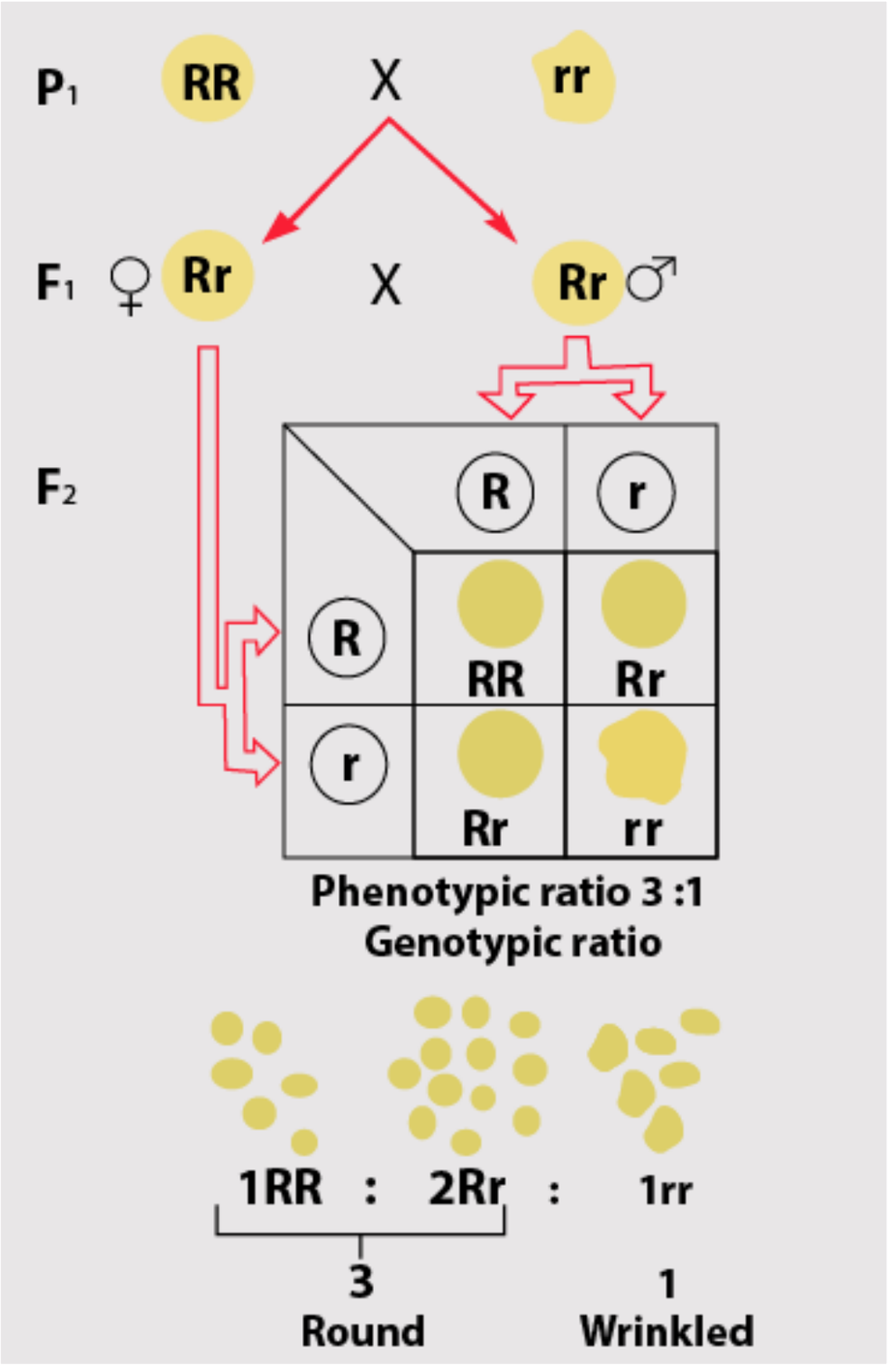



*Fig 22.3 Mendel'scross to study single trait inheritance in pea.*

## Mendel's Interpretations

Mendel proposed that each contrasting form of a trait, e.g., roundness or wrinkledness of seed was determined by particulate hereditary factors, which he called 'elementen'. These factors carrying hereditary information were transmitted from parents to offspring through gametes. Each pea plant had a pair of these factors, one derived from male parent and the other from female parent. Both of these factors together controlled expression of a trait. He designated dominant factor with a capital letter and recessive factor with a small letter; e.g., R for roundness factor and r for wrinkledness factor. Johannsen renamed them as 'genes'.

The true - breeding round seed plant of P| generation carried 'RR' alleles while the true - breeding wrinkled seed plant of Pi carried 'it' alleles. When both the alleles of a gene pair in an organism are same, the organism is homozygous for that gene pair. An individual with a homozygous genotype is a homozygote.

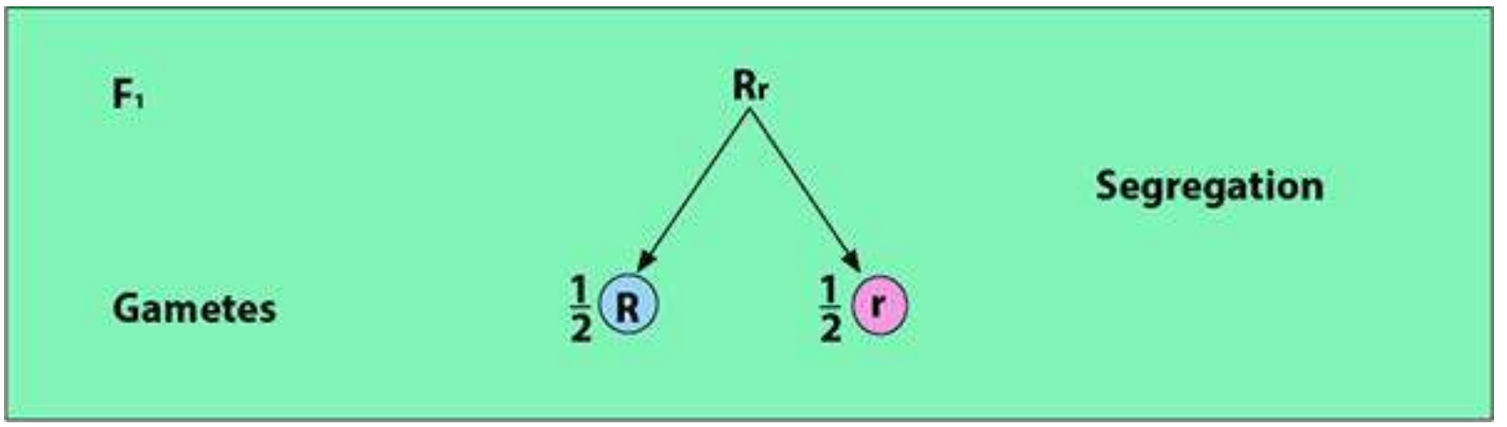



*Fig 22.4 Segregation of alleles during gamete formation*

Mendel inferred that the factors of a pair (alleles) separated from each other during gamete formation so that each gamete got only one factor (allele) for each trait. So half the gametes got one allele, and the other half carried the other allele. Fertilization was random. When male gamete carrying factor (R) fertilized female gamete with factor (r), the complete set of the two factors (Rr) for the trait was restored in zygote.

The zygote developed into Fj offspring that was heterozygous 'Rr', because the two alleles of its gene pair were different from each other. An individual with a heterozygous genotype is a heterozygote. Fi offspring (Rr) was a monohybrid for seed shape; it was round in phenotype but heterozygous in genotype. Its alleles also segregated during gamete formation (Fig. 22.4).

Punnett square indicates that lA of F2 progeny would have been 'RR' (homozygous round), lA + lA = Yi Rr (heterozygous round), and lA rr (wrinkled).
Mendel actually observed 3 ; 1 phenotypic ratio in F2. His phenotypic data of F3 can also be explained on the basis of 1 : 2 : 1 genotypic ratio of F2. Mendel compared the results of all the seven separately studied characters, and found them strikingly similar to formulate law of segregation.

**Law of Segregation** : According to law of segregation, the two coexisting alleles for each trait in an individual segregate (separate) from each other at meiosis, so that each gamete receives only one of the two alleles. Alleles unite again at random fertilization of gametes when zygote is formed.

## Test Cross

Mendel devised a cross called test cross, which is used to test the genotype of an individual showing a dominant phenotype. It is a mating in which an individual showing a dominant phenotype is crossed with an individual showing its recessive phenotype. This cross finds out the homozygous or heterozygous nature of the genotype (Fig. 22.5).

*Animation 22: Test Cross*
*Source & Credit: Pinterest*

| Case 1 | Case 2 |
|---|---|
| If the seed is homozygous round(RR) it will grow into a pea plant that forms all gametes with only `R` allele.Wrinkled seed plant is always homozygous recessive.it will form all gametes with `r` allele.Fertilization will result in 100% round seed progeny. | If the seed is heterozygous round (Rr), it will grow into a plant that forms half the gametes, with 'R`and half with `r` allele. Wrinkled seed plant will form only `r` type of gametes. Fertilization will result into 50% round and 50% wrinkled seed progeny. Even a single wrinkled seed in the progeny is a convincing proof for Heterozygous nature of the round parent. |

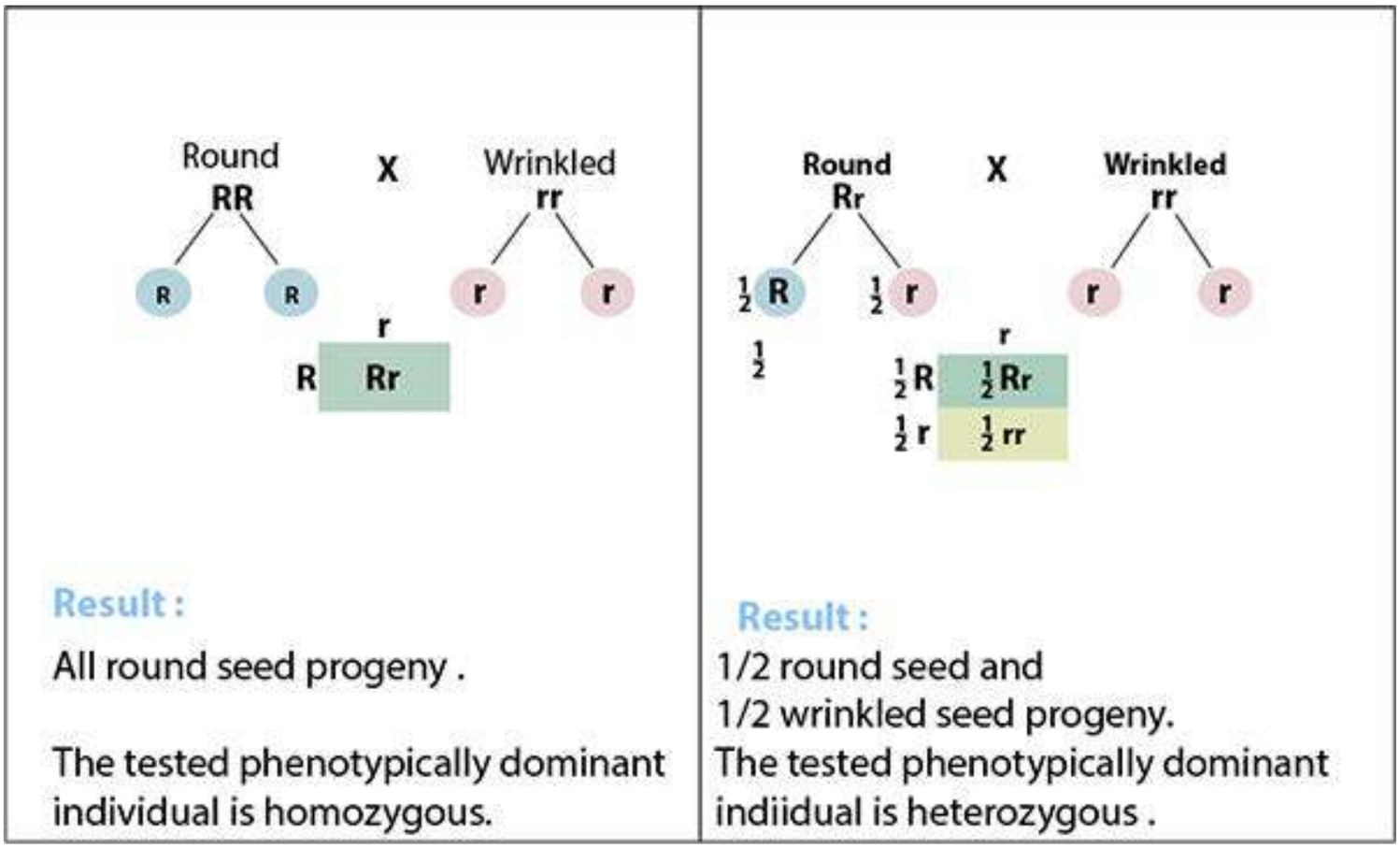



*Fig 22.5 Test cross of a round seed*

# Dihybrid and Dihybrid Cross

After thoroughly studying each trait separately , Mendel decided to study the inheritance of two simultaneously , e.g., seed shape and seed colour. Seed shape could be round or wrinkled. Similarly , seed colour could be yellow or green. He crossed true breeding round and yellow seed plants with true breeding wrinkled and green seed plants . All $F_1$ **dihybrid** were round and yellow seeded due to dominance. Then he made a **dihybrid cross** by allowing self-fertilization among F1 dihybrids. The results was quite surprising. Seeds produced as F2 progeny were ot only in the two **parental combination** i.e., round yellow and wrinkled green, but also in two **new phenotypic combination** i.e., round green and wrinkled yellow. A clear cut 9:3:3:1 phenotypic ratio was found in F2. Appearance of these new recombinant phenotypes of F2 indicated that some sort of shuffling of alleles had occurred during gemete formation. Mendel inferred the mechanism of this shuffling as **independent assortment of alleles** into gametes. He concluded that the alleles for seed shape and colour were not bound to remain in parental combination forever, i.e., 'R' with 'Y' and 'r' with 'y' ;rather these were free to assort independently . R could go with Y or y in any gamete with equal change.

*Animation 22: Dihyrid Cross*
*Source & Credit: GIF SOUP*

Similarly, r could go with y or Y in any gamete with equal probability. Four types of gametes, i.e., RY, Ry, rY and ry were formed in equal number in a perfect ratio of 1:1 : 1:1. When these gametes randomly fertilized each other, a 9:3:3:1 phenotypic ratio was produced among F2 progeny (Fig 22.6).

Mendel formulated Law of Independent Assortment : “When two contrasting pairs of traits are followed in the same cross, their alleles assort independently into gametes.” Alleles of one pair inherit independently of alleles of the other pair. The distribution of alleles of one trait into gametes has no influence on the distribution of alleles of the other trait. Thus the chance for a plant to be round or wrinkled is independent of its chance of being yellow or green.

**Probability** is the chance of an event to occur. Inheritance of seed shape is an independent event. In F2 offspring of a monohybrid cross the independent chance for a seed to be round is 3/4 , or it to be wrinkled is 1/4. Inheritance of seed colour is another separate event. The independent chance in F2 of a monohybrid cross for a seed to he vellow is 3/4 or it to be green is 1/4. When two independent events are occunng simultaneously like m Dihybrid cross, the ratio of each joint phenotypic combination can be obtained by multiplying the probabilities of individual phenotypes. It is called

**product rule.**
The joint probability that both of the independent events will occur simultaneously, is equal to the product of individual probabilities of each event.

*Animation 22: Product Rule*
*Source & Credit:*

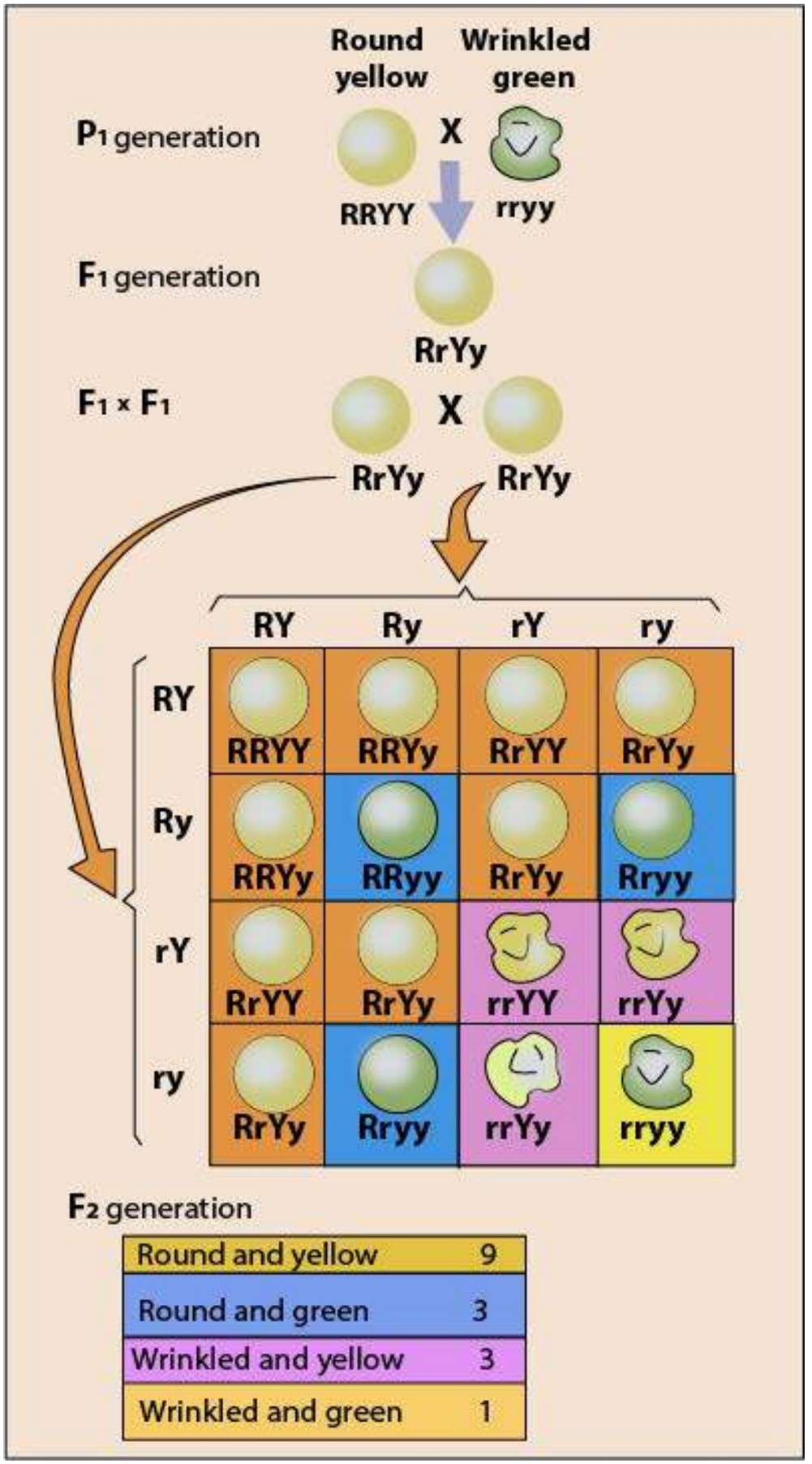



*Fig 22.6 Dihybrid cross produces parental as well as recominant types.*

| Event No. 1 | Event No. 2 | Both events at a time |
|---|---|---|
| **Seed shape** | **Seed colour** | **Seed shape and colour** |
| Independent probability to be: | Independent probability to be: | Joint probability to be: |
| Round =<br>Round =<br>Wrinkled =<br>Wrinkled = | yellow =<br>green =<br>yellow =<br>green = | Round yellow =9/16<br>Round green = x = 3/16<br>Wrinkled yellow = x = 3/16<br>Wrinkled green = |

Genes are located at specific loci on chromosomes. Independent assortment of genes depends upon independent assortment of their chromosomes. All the genes present on a homologous pair of chromosomes are linked to each other in the form of a linkage group. These cannot assort independently. Those traits assort independently whose alleles are riding non homologous chromosomes. Pea has seven homologous pairs of chromosomes. Mendel knew nothing about chromosomes. The traits he studied were confined to only four chromosomes. He reported independent assortment of those traits whose genes were either on different homologous chromosomes, or were so far away from each other on the same chromosome that they appeared to assort independently due to crossing over.

Mendel presented his findings to Brunn Society for the study of Natural Science in 1865. His work was published in the proceedings of the society in 1866. That laid the foundation of classical genetics. His work lay neglected for 34 years. In 1900, 16 years after his death, three botanists; Correns, De Varies and Tschermach independently rediscovered and acknowledged his work.

**Activity:** Normal individuals have melanin pigment in their skin, hair and eyes. Albinos totally lack pigment in their bodies. Albinism is a recessive trait in humans. Two normal parents have an albino child. What is the probability that their next child will also be an albino?

## DOMINANCE RELATIONS

Dominance is a physiological effect of an allele over its partner allele on the same gene locus. There are four types of dominance relations among alleles, each indicating a different style of their functional effect upon each other.

1.Complete dominance 2.Incomplete dominance
3.Cociominance 4. Over dominance

### Complete Dominance

When one allele (R) is completely dominant over the other (r), presence of the recessive allele is functionally hidden, so the heterozygote (Rr) has the same round phenotype as (RR) homozygote.

The contrasting pairs of alleles for all the seven characters chosen by Mendel showed complete dominance. After Mendel, further breeding experiments were carried out on different plants and animals. Many novel phenotypes and phenotypic rat tios were observed that could not be explained on the basis of complete dominance.

### Incomplete Dominance

In 1899 Carl Correns was working on a flowering plant named 4 O'clock. When he crossed a true breeding fed flowered plant with a true breeding white flowered 4 O'clock, all the F] hybrids had pink flowers. This new phenotype had a shade intermediate between those of the parents due to an intermediate amount of pigment in petals. When Correns self-fertilized Fi pink, the F2 showed all three phenotypes of flowers'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.

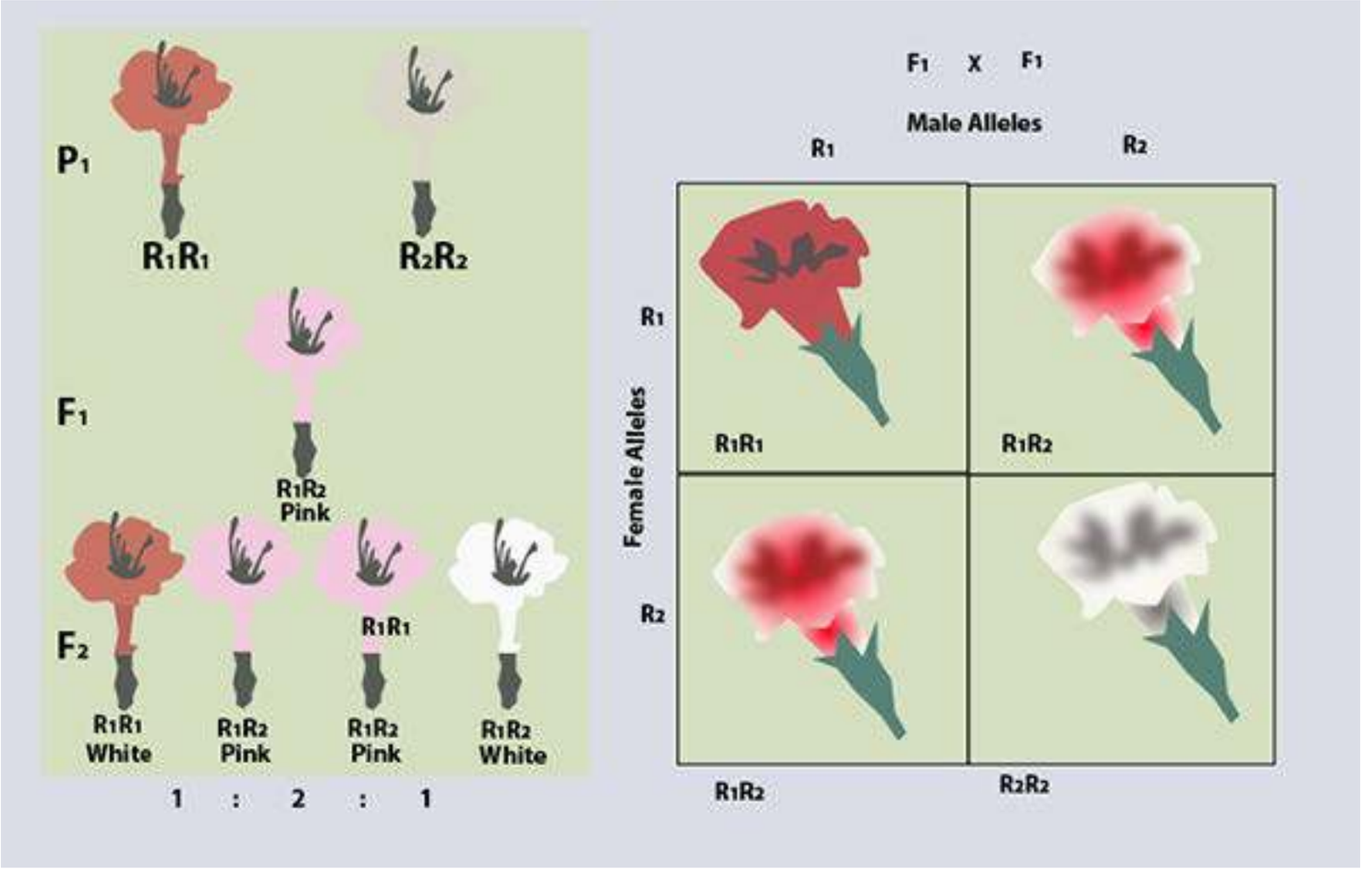



*Fig 22.7 Incomplete dominance in 4 O' clock*

When the phenotype of the heterozygote is intermediate between phenotypes of the two homozygotes, it is called **incomplete or partial dominance.**

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. Allele for red is designated as R|, and the allele for white as R2 (Fig. 22.7).

Punnett square indicates that the phenotypic ratio is the same as the genotypic ratio. There is absolutely no need of a test cross. Do these results make Mendel's principles invalid? The flower colour does show blending at phenotypic level in Fi, which is quite contrary to what Mendel observed. But the re-appearance of red and white flowers in F2 confirms that blending does not occur at genetic level.

## Codominance

The phenotype of heterozygote is distinct in quality from those of the two homozygotes. It is not an intermediate quantitative expression like incomplete dominance. Each allele of the gene pair is associated with a different substance, e.g.,

$$\text{Allele } A_1 \xrightarrow{\text{Produces}} \text{Substance X}$$
$$\text{Allele } A_2 \xrightarrow{\text{Produces}} \text{Substance Y}$$

Codominance occurs when both the alleless express independently in heterozygote; (A|A2) and form their respective products X and Y. The codominant heterozygote would have both substances at the same time.

Different alleles of a gene that are both expressed in a heterozygous condition are called **codominant.**

## MN BLOOD TYPE OR BLOOD GROUP SYSTEM

Human blood groups can be of many types, e.g. ABO, MN, MNSs, Rh ete. Landsteiner and Levine discovered MN blood types in man on the basis of specific antigens present on RBC. These RBC antigens induce production of their specific antibodies. There are three general phenotypes; M,N and MN. M phenotype has antigen M which is produced by gene LM. N phenotype has antigen N that is produced by its allele LN. MN phenotype has both M and N antigens, simultaneously produced by their alleles LM and LN

| Phenotvoe | Genotype | Antieens on RBC |
|---|---|---|
| M | $I^M I^M$ | M |
| N | $I^N I^N$ | N |
| MN | $I^M I^N$ | M and N |

If a man of M blood group marries a woman of N blood group, all their children will have MN blood group (Fig. 22.8)

*Animation 22: Blood Group System*
*Source & Credit: waynesword.palomar*

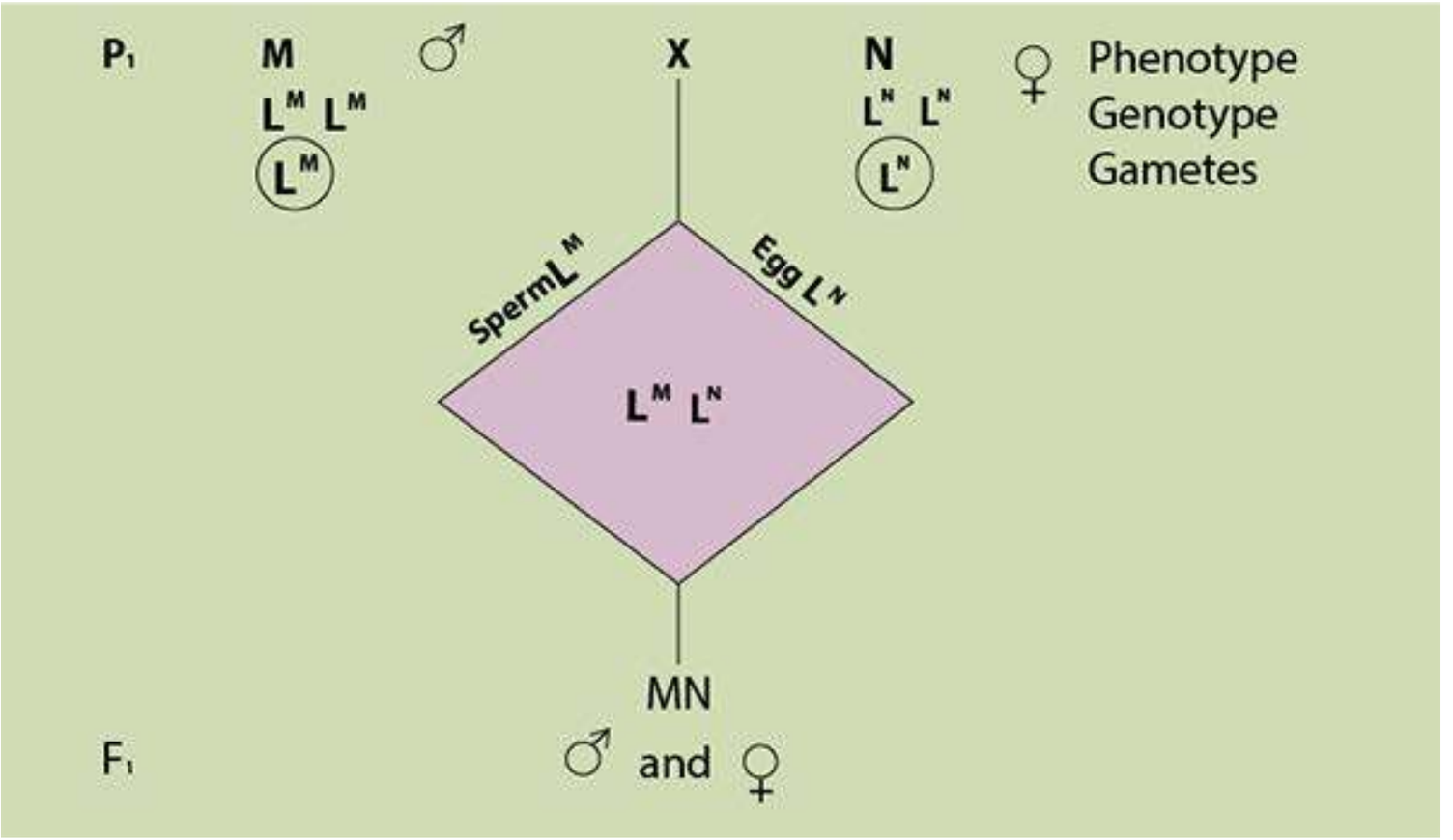



*Fig 22.8 Codominance in MN Blood group alleles.*

## Over Dominance

This dominance relation is fascinating because the over dominant heterozygote exceeds in quantity the phenotypic expression of both the homozygotes. In fruit fly Drosophila the heterozygote (w+ / w) has more quantity of fluorescent pigments in eyes than wild (w+ / w+) or white eye (w / w) homozygotes.

## MULTIPLE ALLELES

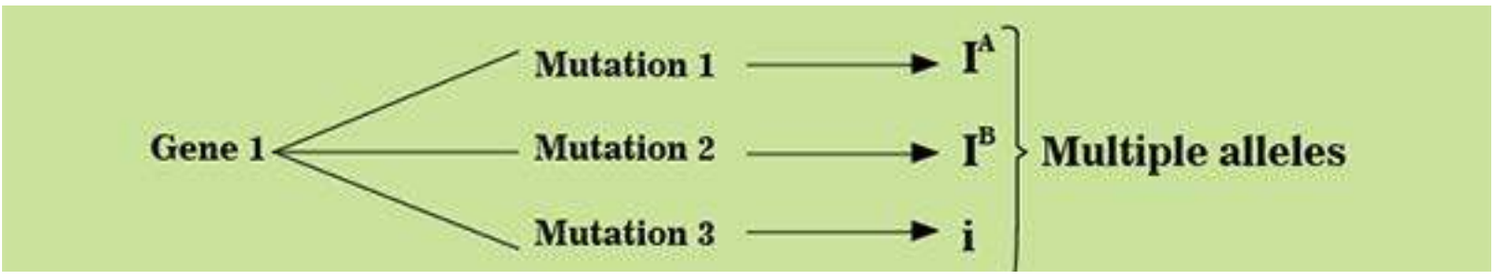
Gene mutations may produce many different alleles of a gene. Some genes may have as many as 300 alleles. All such altered alternative forms of a gene, whose number is more than two, are called multiple alleles. Any two of these multiple alleles can be present in the genome of a diploid organism, but a haploid organism or a gamete can have just one of them in its genome.

## ABO - The First Discovered Multiple Allelic Blood Group System in Man

ABO blood group system was discovered by Karl Landsteiner in 1901. ABO system has four different phenotypes which are distinct from each other on the basis of specfic antigens on the surface of RBC. A person having antigen A has blood group A; a person having antigen B has blood group B; a person having both the antigens A and B has blood group AB; but a person having neither antigen A nor B would have blood group O.

Bernstein explained the genetic basis of ABO system in 1925. This blood group system is encoded by a single polymorphic gene I on chromosome 9. It has three multiple alleles IA, IB, and i.

Allele IA specifies production of antigen A, and allele IB specifies production of antigen B, but allele i does not specify any antigen. Their dominance relations are interesting too. Alleles IA and IB are codominant to each other, because each expresses equally in IA IB heterozygote to produce AB phenotype. But allele i is recessive to both IA and IB. Therefore IA IA or IAi genotypes will produce phenotype A. Similarly IB IB or IBi produces phenotype B. The homozygous ii will produce phenotype O.



The blood group 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.

Anti-A and anti-B antibodies appear in plasma during the first few months after birth. They are naturally occuring in the absence of corresponding antigen. The blood serum of A phenotype contains anti-B antibodies. They will agglutinate7or clump any RBC which have B antigens on them. B phenotype contains anti-A antibodies in the serum and agglutinate any RBC with antigen A. Phenotype AB has neither anti-A nor anti-B antibodies in the serum. The serum of O blood type contains both anti-A and anti-B antibodies. The blood serum containing anti-bodies is called antiserum.

Any blood transfusion is ideally safe if it does not cause agglutination in the recipient. Agglutination leads to serious results because clumped cells cannot pass through fine capillaries. The blood samples of the donor and the recipient are cross matched for compatibility before giving transfusion. If incompatible blood is transfused, dangerous hemolytic reaction occurs. Either the antibodies of the recipient destroy the RBC of donor or the antibodies of the donor hemolyze the RBC of the recipient.

Blood group A can be transfused only into A and AB recipients because they do not have anti - A antibodies. Blood group B can be transfused only into B and AB recipients as they do not have anti - B antibodies. AB blood can be transfused only into AB recipients because they have neither anti - A, nor anti B antibodies. O blood has neither A nor B antigen, but it does have anti - A and anti-B antibodies. An O recipient can only be given tranfusion from a donor O. Phenotype O can also be used as donor for small transfusions to A, B and AB recipients because donor's antibodies are quickly absorbed by other tissues or greatly diluted in the recipient's blood stream. O blood group individuals are called universal donors. AB blood group individuals are called universal recipients because they can receive transfusions of blood from any of the four blood groups.

A and B antigens can also be present in saliva and other body fluids of some persons called secretors. Secretors have dominant secretor gene "Se" on chromosome 19.

Genetic analysis on the basis of blood groups helps in solving cases of disputed parentage. It can only be used to prove that an individual is not the parent of a particular child, e.g. a child of AB phenotype (IA IB) can not be the child of a parent of phenotype O (ii). Similarly a man of B phenotype cannot be father of a blood type A child, whose mother is of phenotype O. His father could either be A or AB phenotype.

Activity : Two new born babies get mixed up in the nursery of a hospital. Baby I is. type B and baby II is of type O. Determine their parentage from the phenotypes of these two couples. Mr. Haris is type A and Mrs. Haris is type AB. Mr. and Mrs. Bilal are both of type A.

## Rh Blood Group System

ABO blood type is further differentiated by a + or - sign. This positive or negative sign refers to the presence or absence of another blood group system antigen called Rh factor. Rh blood group system is defined on the basis of **Rh factor** present on the surface of RBC. This system is named Rh after Rhesus monkey, because its antigen was first discovered in it by Landsteiner in 1930s.

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.

Gene D has two alleles, D and d. D is completely dominant over d. Persons having genotype DD or Dd have Rh factor on their RBC and are Rh+. Persons with genotype dd do not have Rh factor and are Rh-. Unlike the naturally occuring anti - A and anti - B antibodies of ABO system, anti - Rh antibody production requires a stimulus by the human Rh antigen itself. An Rh- person does not produce anti - Rh antibodies unless he is exposed to Rh antigen. Rh+ donor is totally incompatible for Rh- recipient. If an Rh- person receives Rh antigen through wrong Rh+ blood transfusion, he will begin to produce anti - Rh antibodies against Rh antigens. Rh- blood, clear of any anti - Rh antibody from a donor who has never been exposed to Rh antigen can be transfused to Rh+ recipient.

Erythroblastosis foetalis : **Maternal-foetal Rh incompatibility** Maternal-foetal incompatibility results when an Rh- woman, married to an Rh+ man conceives a child who is Rh+. If the man's genotype is DD, all of their offspring (Dd) will be Rh+. If the man's genotype is Dd, half of their offspring with Dd genotype will be Rh+. If RBC of Rh+ foetus cross the placental barrier and enter into Rh- mother's blood stream, the mother's immune system reacts to the foetal Rh antigen stimulus by producing a large number of anti - Rh antibodies. When mother's anti - Rh antibodies seep through placenta into blood circulation of foetus, they start hemolysis (break down / bursting) of RBC of foetus. As this destruction continues, the foetus becomes anaemic. The anaemic foetus starts to release many -immature erythroblasts into his blood stream. That is why this hemolytic disease of the new bom is called erythroblastosis foetalis. This anaemia may lead to .abortion or still birth. Even if the pregnancy continues, the liver and spleen of the foetus swell as they rapidly produce RBC. The breakdown product of RBC called bilirubin also accumulates in the foetus. Bilirubin damages his brain cells and turns his skin and whites of the eye yellow. This condition is jaundice. So the baby if born alive, suffer from severe hemolytic anaemia and jaundice. Such baby's blood should be immediately replaced by Rh" blood free of anti - Rh antibodies. The first Rh incompatible pregnancy may not face much problems if very few of foetal antigens cross placenta into maternal circulation and the amount of maternal antibody production is not very high. But when placenta detaches at birth, a large number of foetal cells enter mother's blood stream and stimulate production of large amount of anti - Rh antibodies by the mother. These anti - Rh antibodies persist in mother's blood for a long time and are persistent risk for the next Rh+ foetus. Rh sensitization of Rh' mother is avoided by a simple therapy. She is given an injection of Rh antiserum during early pregnancy and immediately after birth. The Rh - antibodies in the Rh antiserum will destroy Rh+ RBC of the foetus before they stimulate production of maternal anti - Rh antibodies. The injected antiserum disappears before the next pregnancy

Sometimes a mild ABO incompatibility protects the baby against a more severe Rh incompatibility. If O' mother conceives A+ or B+ baby, any^ foetal A or B type RBC entering the mother's blood are quickly destroyed by her anti - A or anti - B antibodies, before she can form anti - Rh antibodies.

Activity: An Rh" woman is married to an Rh+ man whose father was also Rh". What is the probable risk of erythroblastosis foetalis in their babies?

## EPISTASIS

When an effect caused by a gene or gene pair at one locus interferes with or hides the effect caused by another gene or gene pair at another locus, such a phenomenon of gene interaction is called epistasis. 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.

### Bombay Phenotype

The expression of-ABO blood type antigens by IA or IB gene depends upon the presence of another gene H. ABO locus is on chromosome 9, while H locus is on chromosome 19. H gene changes a precursor substance into substance H. It produces an enzyme that inserts a sugar onto a precussor glycoprotein on the Surface of RBC. Only then antigen A or antigen B specified by IA or I gene could attach to this sugar of substance H. The recessive allele h cannot insert sugar molecule to glycoprotein. Therefore, hh individuals lack the site of attachment for antigen A pr antigen B. Thus A and B antigens cannot adhere to their RBC and fall away. Their RBC lack A and B antigens although they do not lack IA and IB genes. They are phenotypically like O, but are not genotypically O. Their phenotype is called Bombay phenotype (Fig. 22.9).

**Activity**: A student, of biology learns about ABO blood types. He knows that he'is type O, and his father is type A and mother is type AB. He wonders how his blood type could have arisen. Suggest how type A and AB parents could produce a child of blood type O.

## PLEIOTROPY

When a single gene affects two or more traits, the phenomenon is called pleiotropy. Such a gene with multiple phenotypic effect is called **pleiotropic.**

**Examples:**

1. White eye gene in Drosophila also affects the shape of sperm storing organs (spermathecae).
2. Genes that affect growth rate in humans also influence both weight and height.
3. In cats, the dominant allele W not only makes fur pure white but also causes deafness. In ww homozygous normal pigmented cats, melanocytes produce pigment of fur and also contribute to 'hair cells in inner ear that sense sound.

When a cat gets W allele, its melanocytes fail to develop properly. Melanocyte failure causes both phenotypes, i.e. white fur and deafness.

## CONTINUOUSLY VARYING TRAITS

Genotype interacts with environment to produce phenotype. Phenotypic expression of traits has two aspects:

(i) Qualitative
(ji) Quantitative

Qualitative differences are large and more obvious, but quantitiave variations are small and less striking. Some traits, like pea seed shape, show discontinuous qualitative variations with two sharply distinct phenotypes, round or 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 many traits like height, weight, intelligence and skin colour in humans, and grain colour in wheat exibit continuous quantitative variation over a range of many phenotypes.
endel focused on traits that showed only two qualitatively different phenotypes which could be determined by just two alternate alleles of a single gene. Darwin observed small continuous variations within individuals of a population. Such a range of phenotypic spectrum of a trait cannot be traced to a single gene with two alleles. Even a few multiple alleles of a single gene cannot make such a wide range of phenotypes.

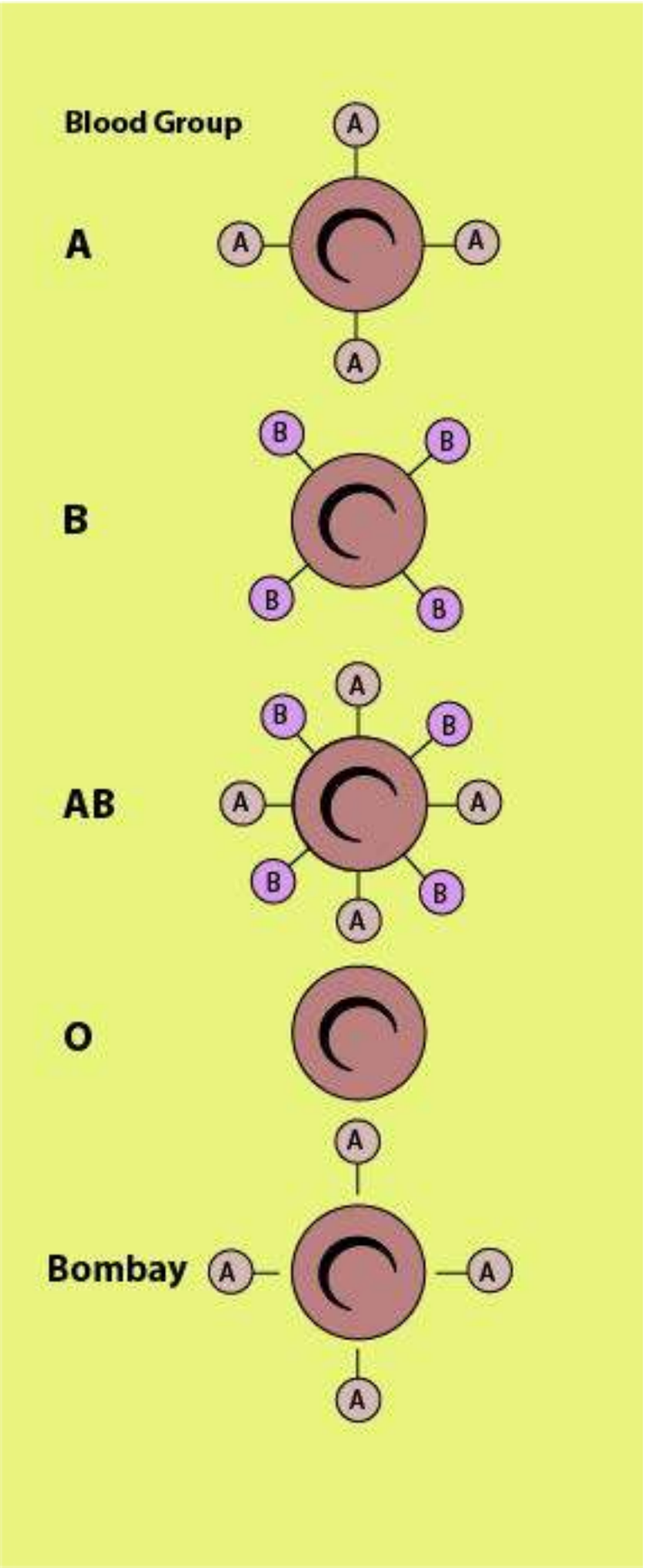



*Fig 22.9 Bombay phenotype results from epistasis*

MA 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 called **polygenic traits,** and their genes are **polygenes.** Each polygene has a small positive or negative effect on the character. Polygenes supplement each other and sum of positive and negative effects of all individual polygenes produce quantitative phenotypes of a continuously Varying trait.

Wheat grains vary in colour from white to dark red. This trait shows a continuous spectrum of colour variation. (Fig 22-10). Some grains are white, some are deep red but most grains have shades in between from light pink to moderately dark red. Nilsson - Ehle 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 Fi grains had light red colour, intermediate between two parental shades. It seemed as if it was a case of incomplete dominance. But when Fi.grains were grown to mature plants and crossed with each other, F2 grains had exactly seven shades of colour in the ratio of 1 dark red : 6 moderately dark red : 15 red : 20 light red : 15 pink : 6 light pink : 1 white (Fig. 22-11).

*Fig 22.10 Colour variation in wheat grains is a polygenic traits.*

Three different gene pairs, i.e. 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 code 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 no (zero) dose negative effect. If all the six alleles code for red pigment (AABBCC), the grain is dark red; when none of the six alleles encode 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 the colour phenotype of the grain is the sum of the individual effects of all the six alleles.Environmental factors like light, water and nutrients also influence the amount of grain colour. Environmental variations make the distribution of phenotypes more smooth and continuous.

Human skin colour is also a quantitative trait which is controlled by three to six gene pairs. The greater the number of pigment specifying genes, the darker the skin. A child can have darker or lighter skin than his parents.

Human height is a more complex polygenic trait. The perfectly continuous variation in range of human heights produces a smooth bell - shaped curve (Fig 22-12). A few people are very tall or very short, but most individuals fall in the average or mean value. This trait is controlled by many pairs of genes at different loci. Even multiple alleles may be possible at each locus. More the number of alleles for shortness, the shorter the height will be. Similarly greater the number of alleles for tallness, the taller

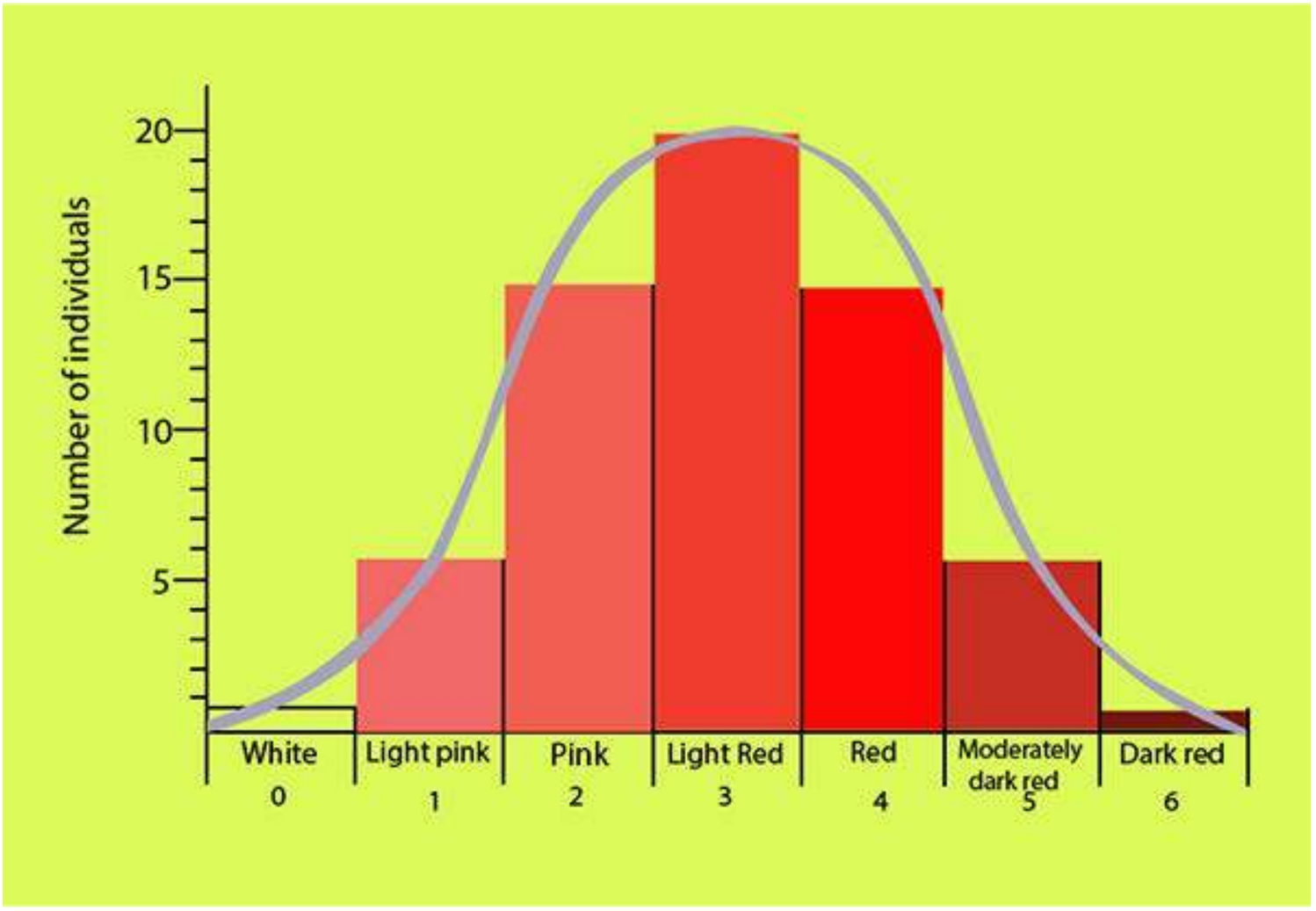



*Fig 22.11 Number of pigment - contributing alleles in F2*

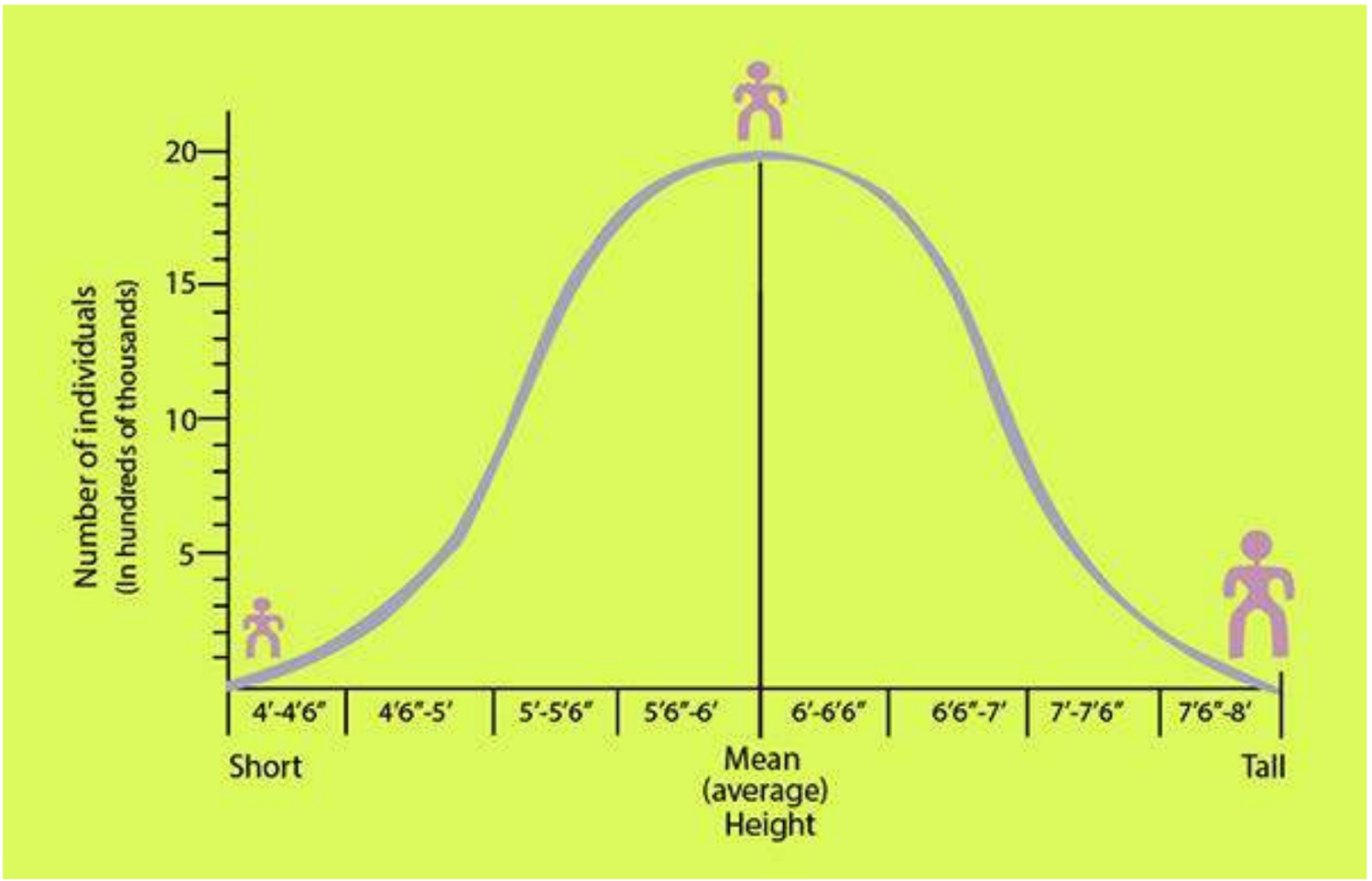
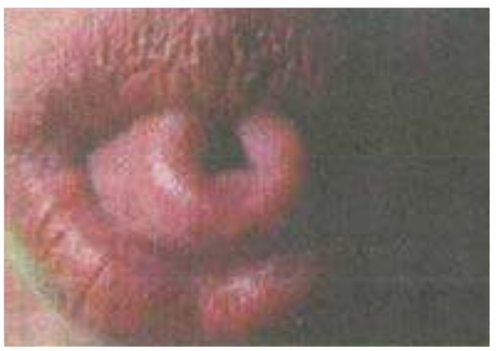



*Fig.22.12-Human hight is a continously varying trait*

the height will be. Environment also has a strong influence on height, intelligence and skin colour in humans. Constant exposure to sun darkens skin. Poor nutrition prevents achieving genetically determined height. Healthy and encouraging social environment promotes intellegence.

Activity : Study continuous variations in height and discontinuous variation in tongue rolling ability Of man and record your observations as histograms.

Frequency histograms illustrate variations. A frequency histogram is a simple graph. The horizontal or X axis indicates the range of different phenotypes of a trait within a population. The vertical or Y axis indicates the number of individuals or their percentage in the population.



Some people can roll their tongue into a distinct U shape when they extend it out of their mouth. They are called rollers (Fig 22.13). This ability is due to a single dominant gene. It is a discontinous variation inherited in simple Mendelian fashion. Its frequency diagram forms asymmetric distribution curve, with much greater frequency of phenotypes at one end than at the other.

Human height is a continuously varying trait. If we plot a frequency diagram of heights of humans in a large population, so many phenotypes are found with categories blending into one another. It forms a smooth bell shaped normal distribution curve. Measure the heights of a fairly large number of students in your college in cms, each to the nearest centimeter. Also note the ability of each student as roller or non roller. Record your observation in a table like this.

| Sr.NO | Name | Height in cm | Roller/ Non-Roler |
|---|---|---|---|
| | | | |

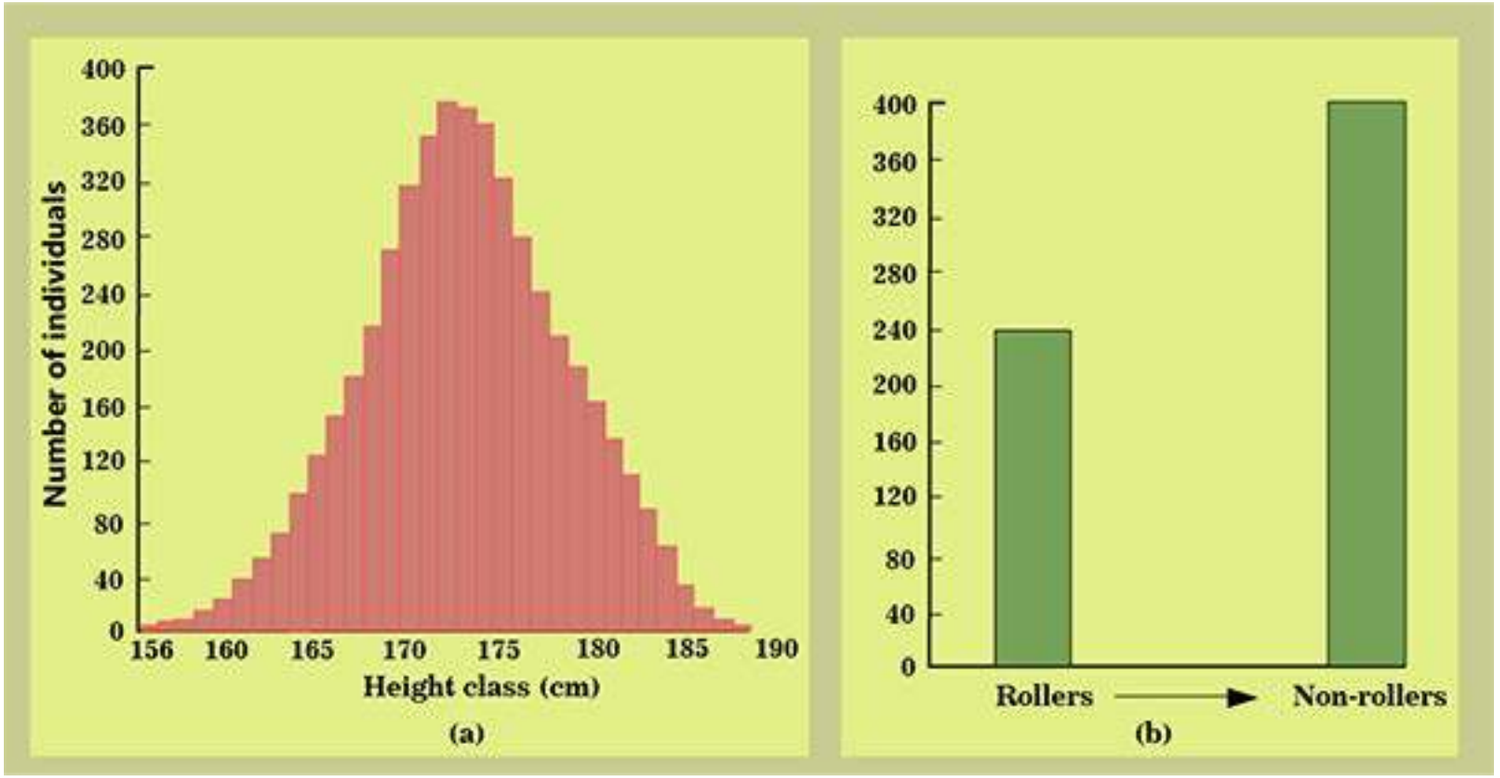



*Fig 22.14 Comparison of a continuous and a discontineous variation in human*

Representing each measurement class as a bar with its height proportional to the number of individuals in each class, plot the graph (Fig 22-14).

## GENE LINKAGE

Every organism possesses numerous characters controlled by thousands of genes, but the number of chromosomes is limited. .Therefore, each chromosome must carry many genes on it. All the genes located on the same chromosome are linked to each other. This phenomenon of staying together of all the genes of a chromosome is called linkage. Gene linkage is a physical relationship between genes. A chromosome carries its linked genes en bloc in the form of a **linkage group.** The number of linkage groups corresponds to the number of homologous pairs of chromosomes. Man has 23 linkage groups. Genes for colour blindness, haemophilia, gout etc form one linkage group on human X - chromosome. Similarly, gene for sickle cell anaemia, leukemia and albinism make another linkage group on human chromosome 11. Linked genes whose loci are close to each other do not obey Mendel's law of independent assortment, because these cannot assort independently during meiosis. Gene linkage also minimizes the chances of genetic recombination and variations among offspring.

*Animation 22: Gene Linkage*
*Source & Credit: Point Pleasant Beach High School*

## CROSSING OVER

Linked genes can be separated by crossing over. Closer the two gene loci, more strongly are their genes linked. The farther apart two genes lie, greater are chances of their separation through crossing over. Crossing over is an exchange of segments between non-sister chromatids of homologous chromosomes during meiosis.' Let us visualize crossing over by considering only one pair of homologous chromosome (Fig. 22-16). The homologous chromosomes pair up lengthwise, point to point and locus to locus. One homologue carries genes 'A' and 'B \ the other homologue has 'a' with 'b'. Chiasmata are formed at many places between non-sister chromatids of homologous chromosomes. Crossing over occurs at 4 strand stage between non-sister chromatids. It may take place at more than one place along a chromosome. Exchange of chromosome segments logically means exchange of DNA, i.e. genes or alleles. As alleles of non-sister chromatids are different, an exchange between their segments results in recombination of genes. Allele 'b' crosses over to homologue containing allele 'A'; and allele 'B' comes on the homologue of 'a'. Then homologous chromosomes separate by opening up chiasmata. The sister chromatids also separate from each other and each becomes an independent chromosome to move singly in each of the four haploid gametes. Four types of gametes are formed; two with parental combinations of linked genes, i.e. AB and ab, and two with recombination of genes, i.e. Ab and aB. If crossing over does not occur, only the two parental types of gametes are formed. Parental types of gametes produce parental types of offspring, while recombination gametes produce recombinant types of offspring.

*Animation 22: Crossing Over*
*Source & Credit: GIF SOUP*

$$\text{Recombination frequency} = \frac{\text{Recombination types}}{\text{Sum of all combinations}} \times 100$$

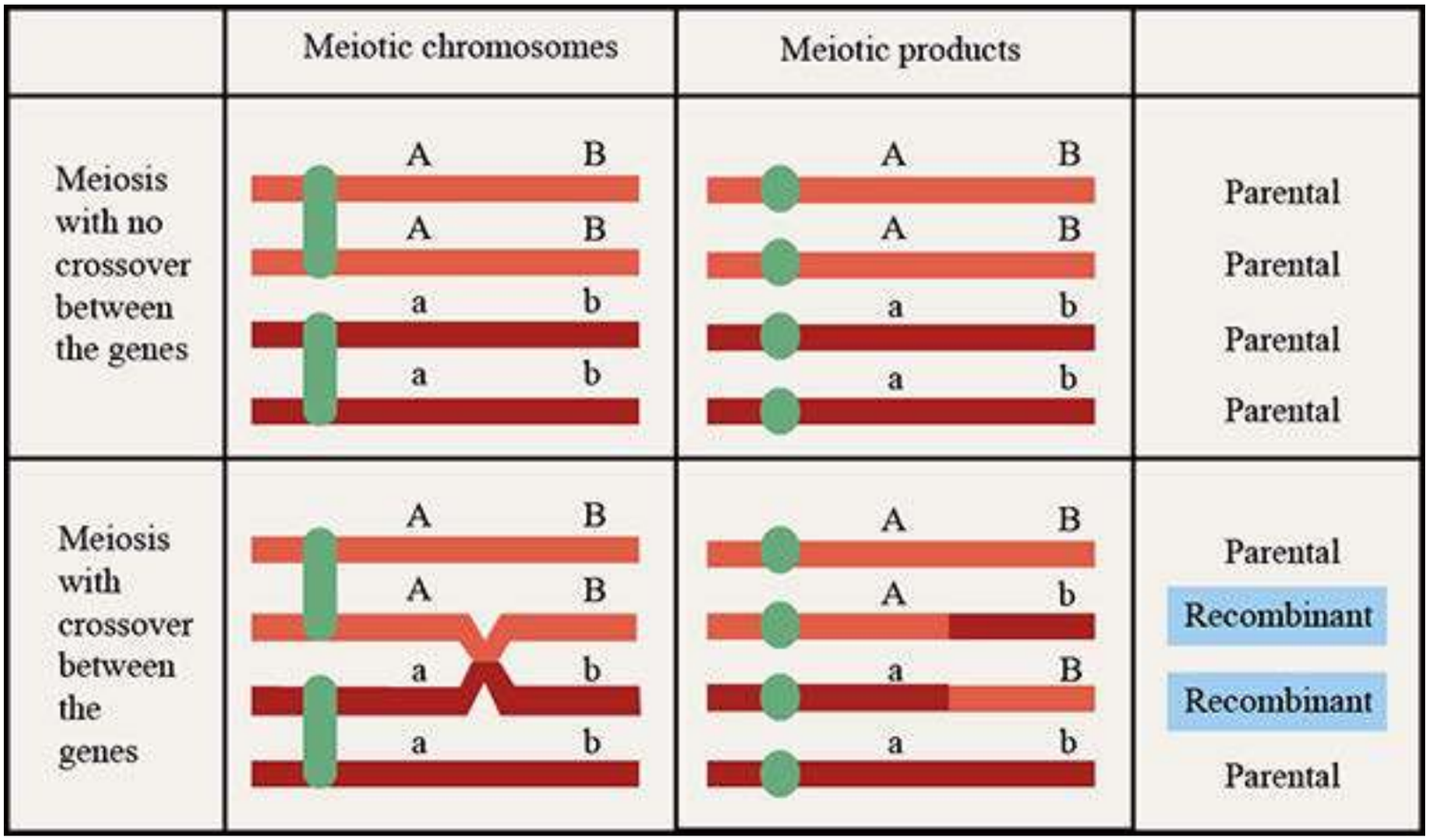



*Fig 22.16 Crossing over recombine genes.*

## Cross Over or Recombination Frequency

It is the proportion of recombinant types between two gene pairs as compared to the sum of all combinations.

The recombination frequencies between two linked genes can be calculated by backcrossing the heterozygote to a homozygous double recessive (Fig. 22-17).

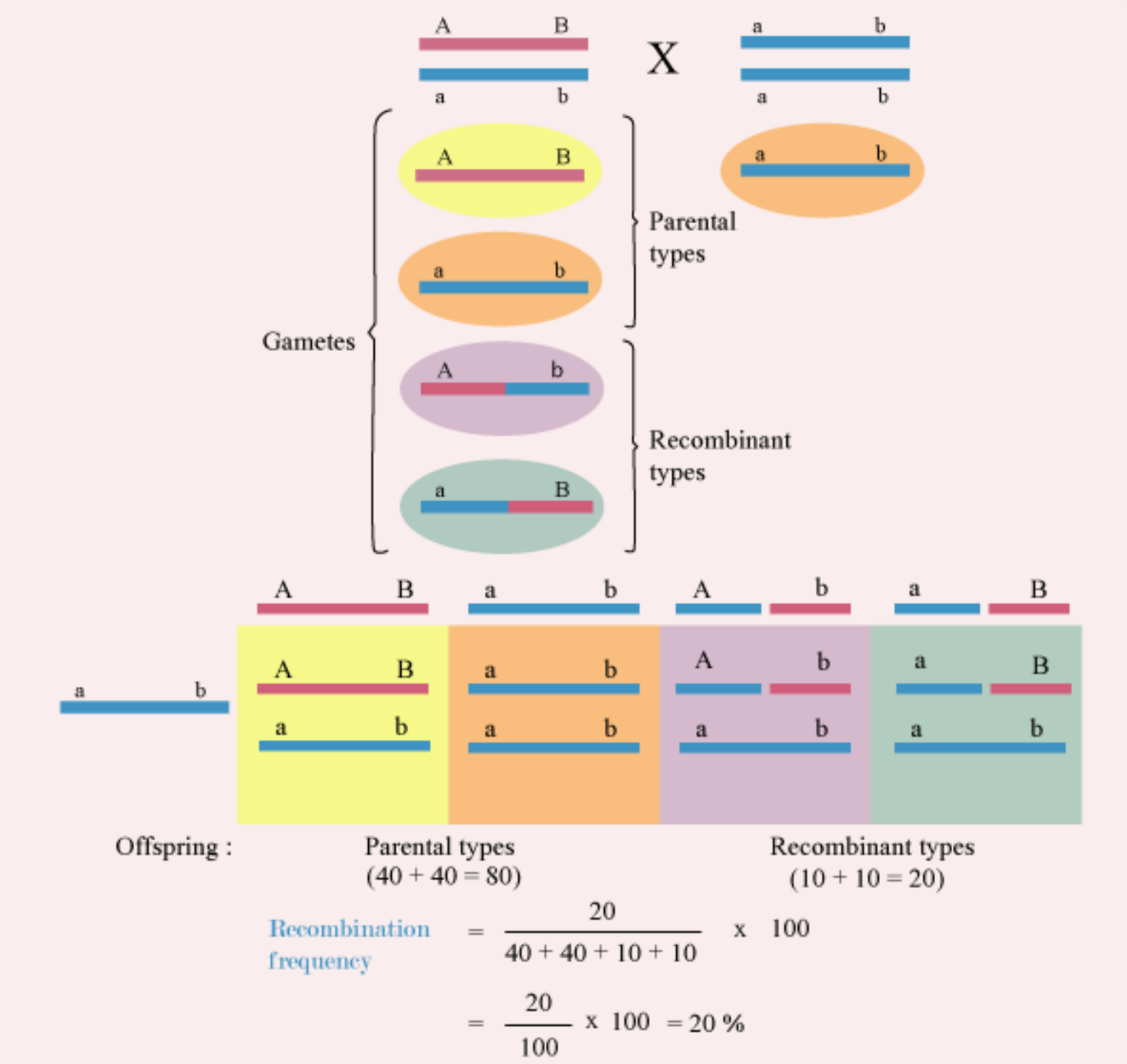
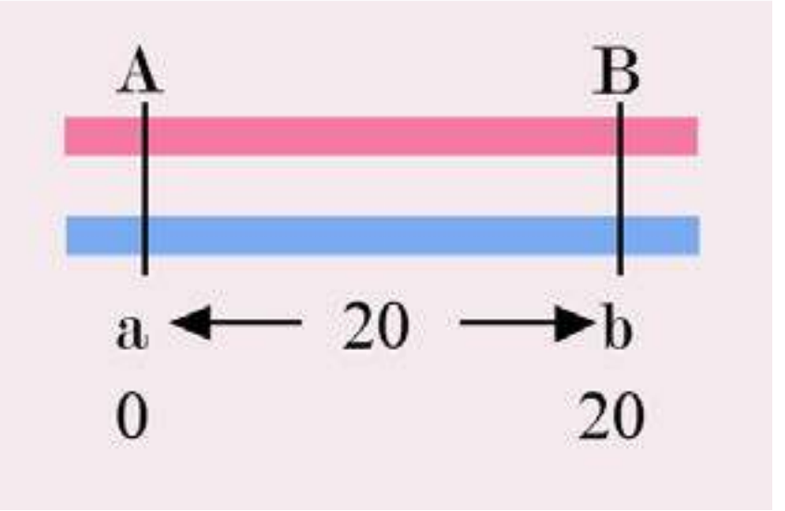



*Fig 22.17 Recombination frequency between two linked genes.*

The recombination frequency is directly proportional to the distance between the linked gene loci. Genes can be mapped on a chromosome on the basis of their recombination frequencies. If 1% of recombination frequency is equal to 1 unit map distance, the two linked genes A and B with a 20% recombination frequency must be 20 units apart.




Crossing over produces genetic variations among offspring. Genetic variations lead to tremendous variations in their traits. Variations provide raw material for evolution by letting them adapt successfully to the changing environment.

## SEX DETERMINATION

### Sex Chromosomes

The search for mechanism of inheritance of sex started after discovery of Mendel's wlork in 1900. A clear picture of the genetic basis of sex determination emerged after the discovery of sex chromosomes.

The fruit fly, Drosophila melanogaster has eight chromosomes in the form of four homologous pairs. T.H. Morgan (1911) noticed a peculiar difference in the chromosomes of male and female Drosophila (Fig 22-18). The chromosomes of the three homologous pairs were similar in both of the sexes, but the fourth pair was very different. The female had two similar rod shaped X-chromosomes in the fourth pair, while the male had one rod shaped X-chromosome but the other a morphologically different, J-shaped Y chromosome in the fourth heteromorphic pair. X and Y chromosomes are called sex-chromosomes because these have genes for determination of sex. Chromosomes of the other three pairs are autosomes. All chromosomes other than sex-chromosomes are called autosomes. Autosomes do not carry any sex determining gene.

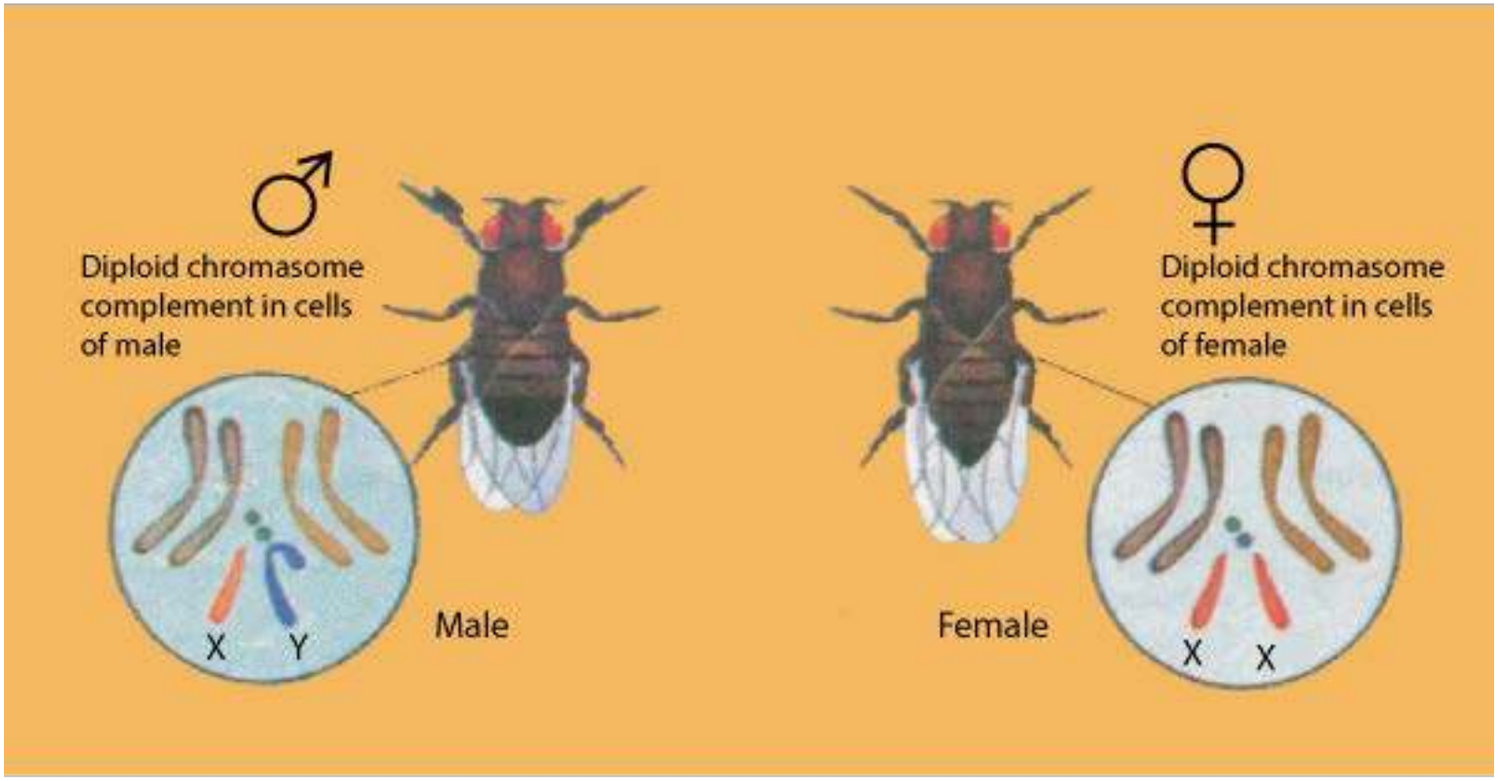



*Fig 22.18 Chromosomed of and Dorsophila melanogaster.*

Humans have 46 chromosomes in the form of 23 pairs. 22 pairs are of autosomes and one pair is of sex-chromosomes. Autosome pairs are common in both the sexes but the 23 rd sex chromosome, pair is very different in males and females (Fig. 22-19). A woman has two similar X chromosomes in her 23rd pair but a man has an X chromosome along with a much shorter Y chromosome in his 23rd pair. The 23rd pair in man is heteromorphic. She is XX but he is XY.

SRY is the male determining gene. It is located at the tip of short arm of Y-chromosome. Its name SRY stands for “Sex determining regions of Y.”

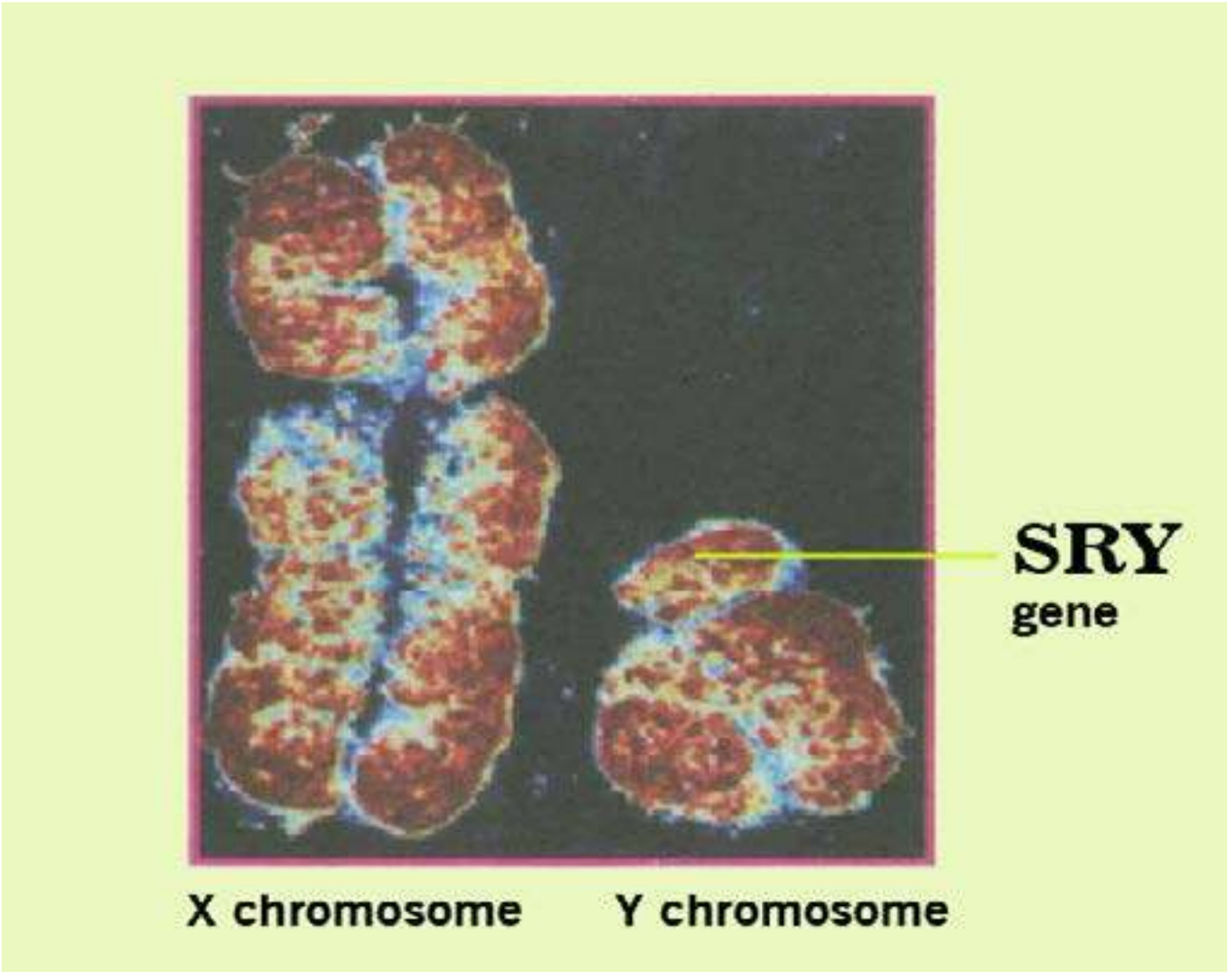



*Fig 22.19 Sex Chromosomes of a man*

In some grasshoppers males and females have different number of chromosomes. The female has 24 chromosomes in the form of 11 pairs of autosomes and a pair of X chromosomes. But the male grasshopper has 23 chromosomes. He has 11 pairs of autosomes and only one X chromosome. The other member for sex chromosome pair is entirely missing in male. Thus male is XO and female is XX.

## Patterns of Sex Determination

There is a wide variety of sex determining ‘ mechanisms but three patterns are more, pommon.

**1. XO - XX Type** This pattern of sex determination is found Tn 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 t\yp I types of sperms; half the sperms have X ‘ chromosome while the othher half are without any sex chromosome. A gamefe wtihout any sex chromosome is called nullo geamete.

Some species have compound sex chromosomes. They maintain many X or Y or both XY chromosomes of more than one kind that act together as a single sex- determining group. That is why the difference in number of chromosomes between male and female is very large. In the round worm Ascaris incurva, the female has 42 chromosomes in the form of 8 pairs of compound X along with 13 pairs of autosomes (16+26). Its male has 35 chromosomes comprising 8X plus one Y alongwith 13 pairs of auto some (8+1+26).

Female is XX, because it has two X -chromosomes. It is homogametic, 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-carrying sperm fertilizes the egg, an XX female offspring is produced. If the nubo
sperm fertilizes the egg, an XO male offspring is produced (Fig. 22-20). Sex ratio between male and female offspring is 1:1.

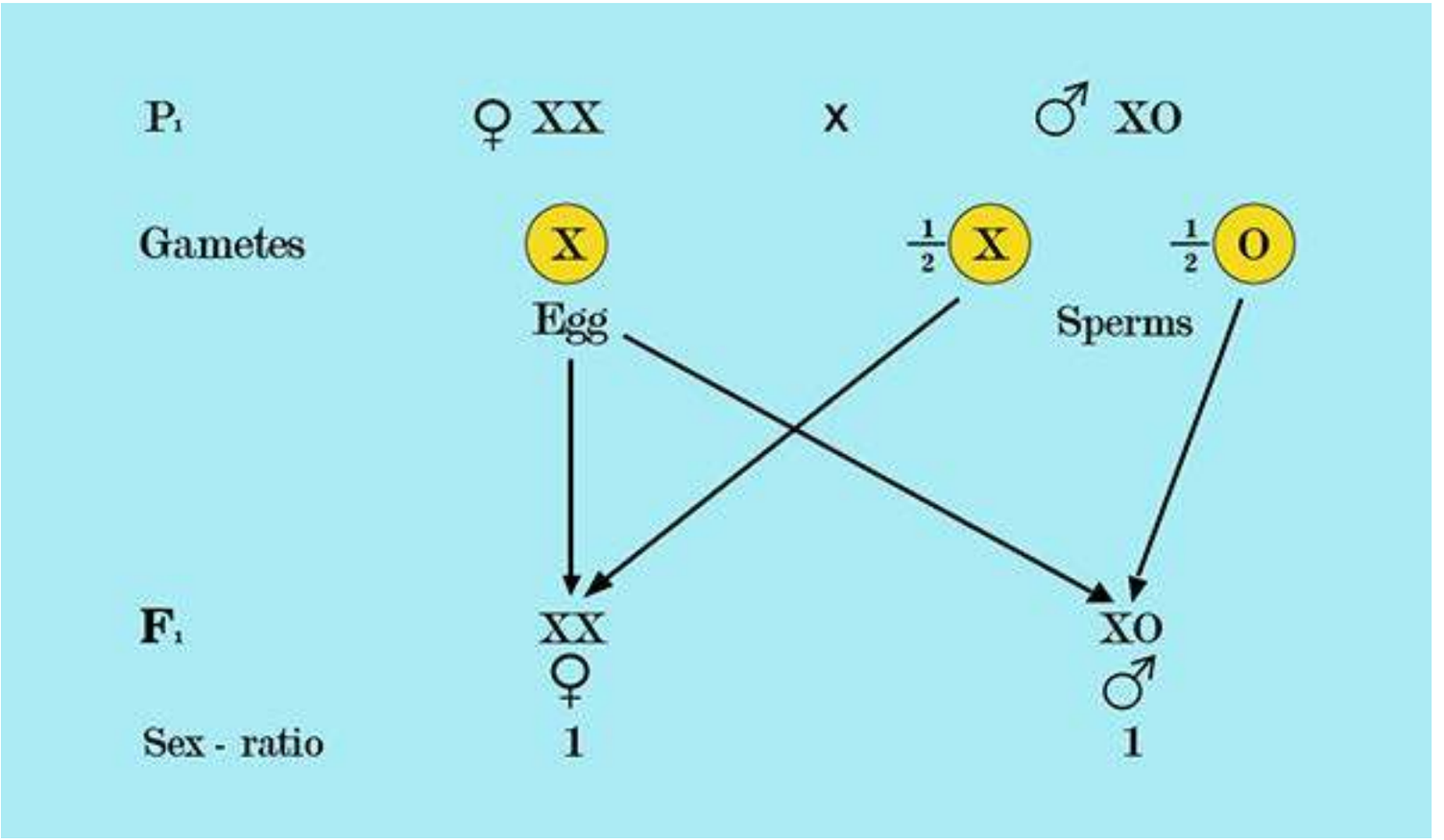



*Fig 22.20 Sex determination in grass hopper and Protenor bug.*

2. XY-XX Type : This pattern of sex determination is found in Drosophila, man 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. 22.21).

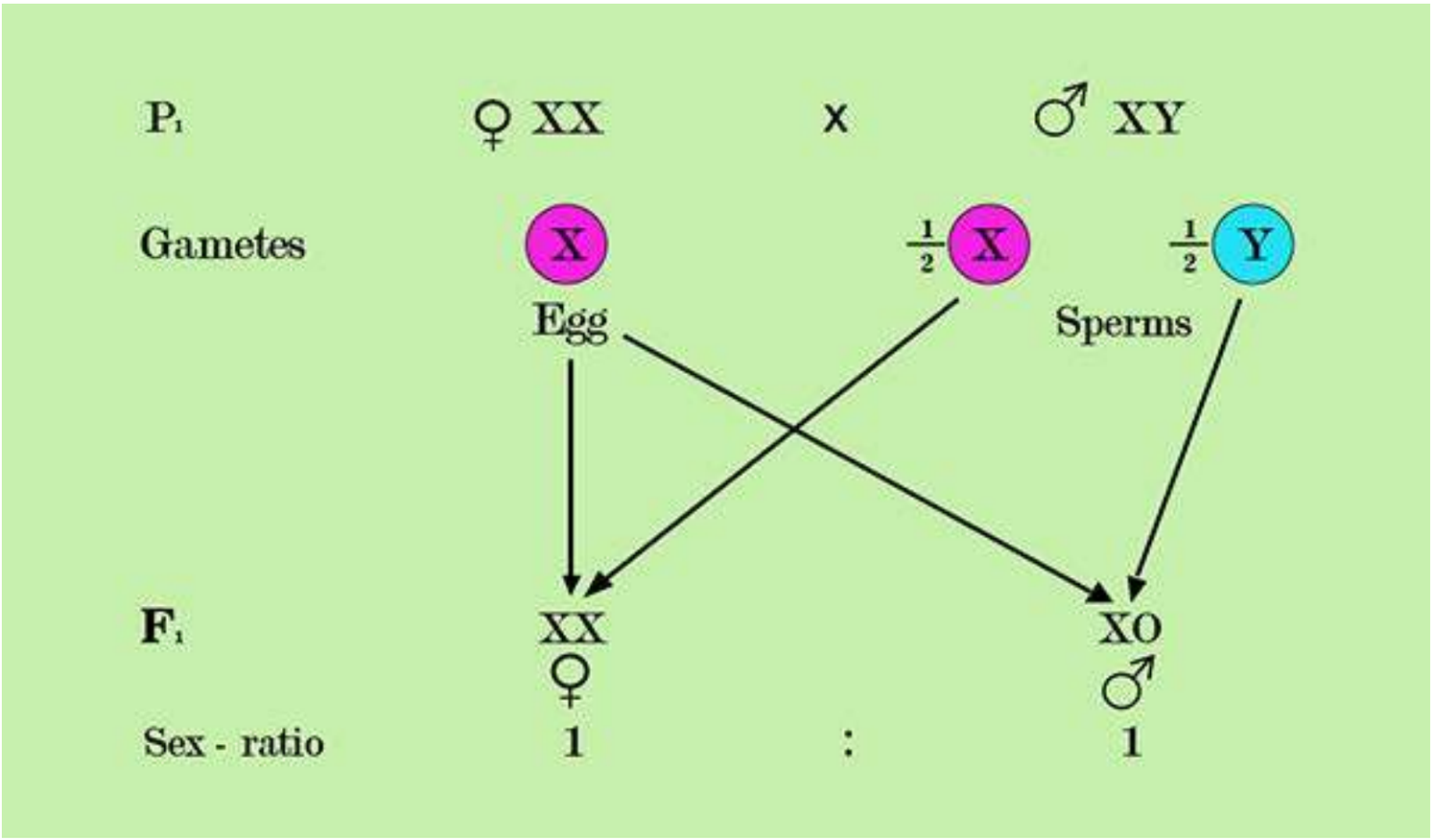



*Fig 22.21 Sex Determination in man and Drosp*

**3. ZZ - ZW 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 ZW but the male is homogametic ZZ. Female produces two kinds of eggs Z and W in equal proportions. All sperms are alike, each carrying a Z - chromosome. It is the kind of egg that determines the sex of offspring. When a Z - carrying egg is fertilized by the sperm, a male offspring is produced, but when a W - carrying egg is fertilized by the sperm a female offspring is produced. Sex ratio is 1:1 (Fig. 22.22).

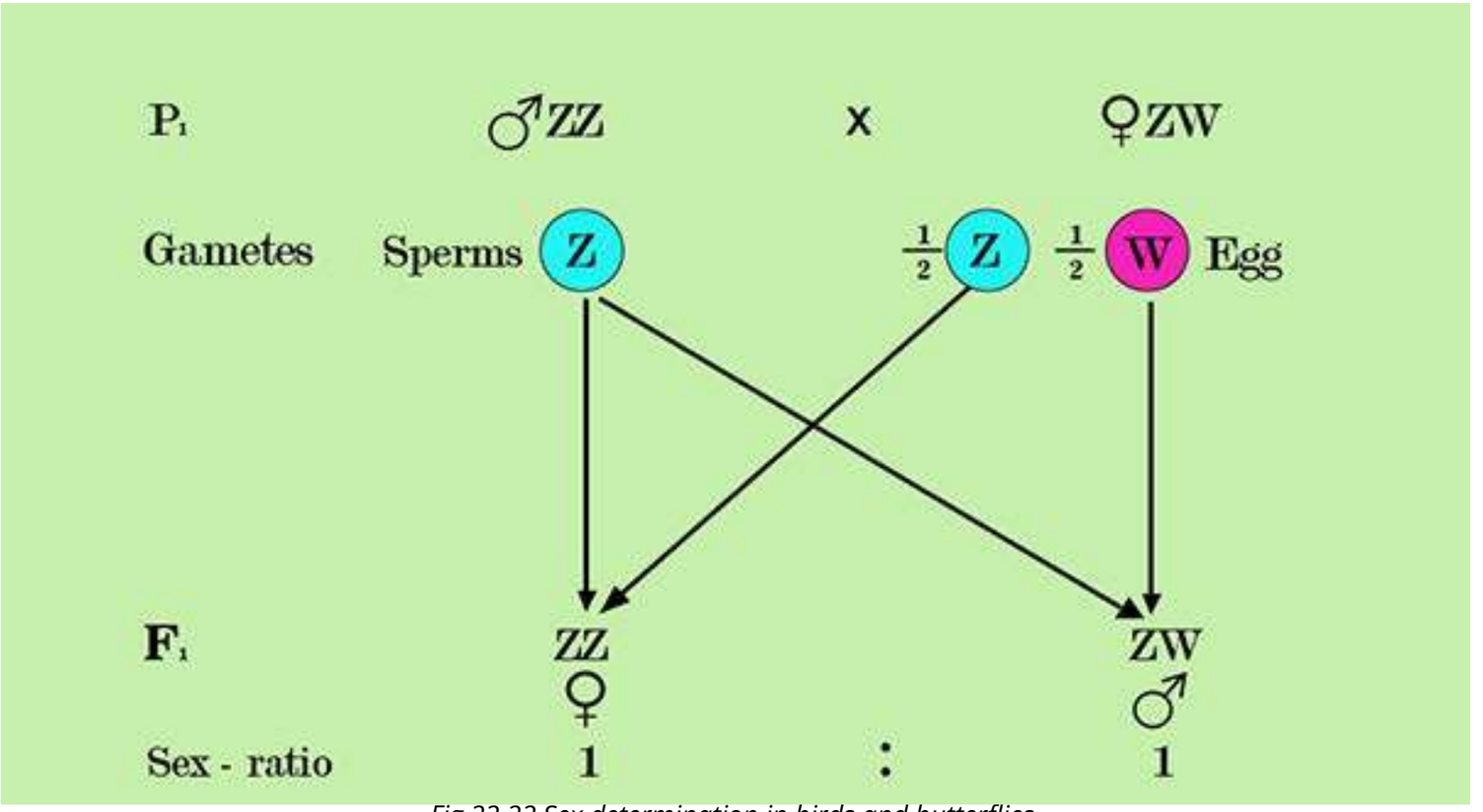



*Fig 22.22 Sex determination in birds and butterflies.*

## Comparison of chromosomal determination of sex between Drosophila and Humans

Although both Drosophila and humans follow the same XY - XX 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 disjunctional gametes in humans is a sterile male called Klinefelter's syndrome, but the same XXY set of chromosomes in *Drosophila* produces a fertile female (Fig. 22-23).

| Species | XX | XY | X0 | XXY |
|---|---|---|---|---|
| DROSOPHILA | ♀ | ♂ | ♂ | ♀ |
| Humans | ♀ | ♂ | ♀ | ♂ |

**Fig 22.23 Comparison of sex determination in man and** *Dorsophilia*

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 very 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.

## Sex Determination in Plants

Plants show a variety of sexual situations. Some species like Ginkgo are dioecious having plants of separate sexes. Male plants produce flowers with only stamens and female plants produce flowers with only carpels. Some dioecious plants have a difference of sex chromosomes between the sexes. These have an X - Y system. These plants typically exhibit an X - chromosome - autosome balance system for sex determination. Many other sex - determining mechanisms are also seen in dioecious plants. Correns (1907) discovered that pollens of certain plants were sex - determining. All eggs are of one type. Pollens of the two types are produced in equal number. One kind of pollen after fertilizing the egg produces male plant whereas the other kind of pollen after fertilization produces female plant (Fig. 22-24).

Many species of eukaryotic micro organisms like yeast do not have sex chromosome. These depend on genic system for determination of sex. In this system the sexes are specified by simple allelic differences at a small number of gene loci e.g., a and a are the two mating types (sexes) of yeast, controlled by MAT a and MAT a alleles respectively.

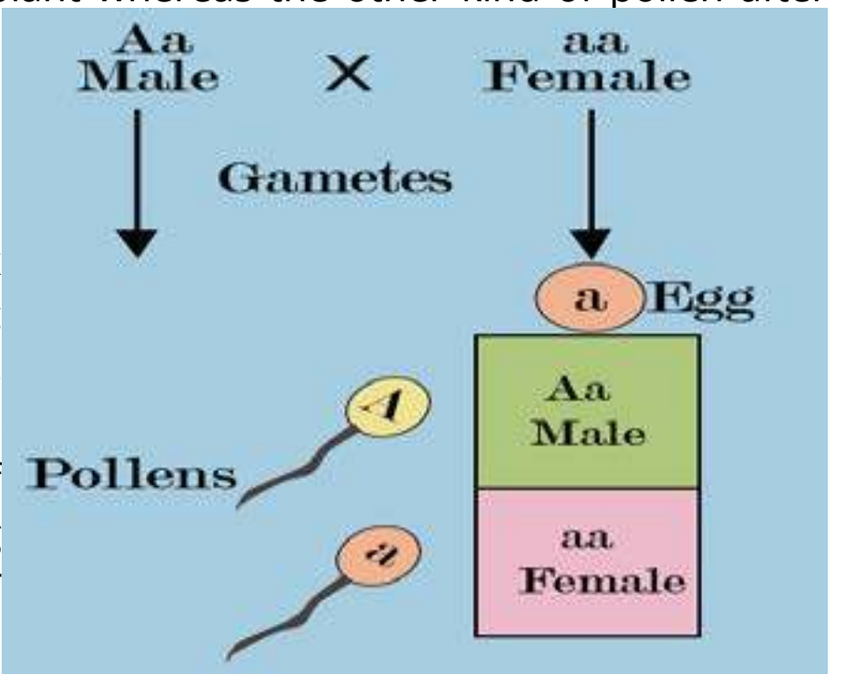



*Fig 22.24 Pollens determines Sex*

## SEX LINKAGE

### Sex Linkage in Drosophila

Thomas Hunt Morgan (1910) provided experimental evidence in support of chromosomal theory of heredity through discovery of sex linkage in fruitfly Drosophila.

Drosophila is a very useful organism for genetic studies for many reasons: *

1. The tiny fly is often seen hovering over rotten fruits. It can be easily collected and cultured on mashed banana and other fruits. It does not need large spacious cages. It lives happily in ordinary glass bottle of jams and marmalades. It eats yeast that grows on mashed banana.
2. Male and female Drosophila show sexual dimorphism i.e. these are morphologically distinct from each other. Male is smaller in size with black rounded abdomen. Female is larger with pointed abdomen. Male has sex combs on front legs.
3. Drosophila has a generation time of just two weeks. It lays a large number of eggs which hatch out into fertile offspring. Many generations can be raised in a relatively short time.
4. 4. Drosophila is perfectly suited for genetic studies. It shows fairly large number of distinct contrasting traits. Morgan and his colleagues studied pattern of inheritance of more than 85 traits of Drosophila. Its larvae are excellent material for dissection for chromosome study. It has only eight chromosomes in four homologous pairs that can be conveniently studied under a microscope. Its salivary gland cells have giant chromosomes in their nuclei. These giant chromosomes have characteristic banding patterns corresponding to genes.
5. 5. The entire genome of Drosophila has been successfully sequenced as part of human genome project.

Morgan raised cultures of Drosophila flies to study different traits, such as colour of the eye. Normal fruit flies, the wild type, have bright red eyes. One of his coworkers Calvin Bridges, observed an unusual white eye mutant male fly. (Fig. 22.25).

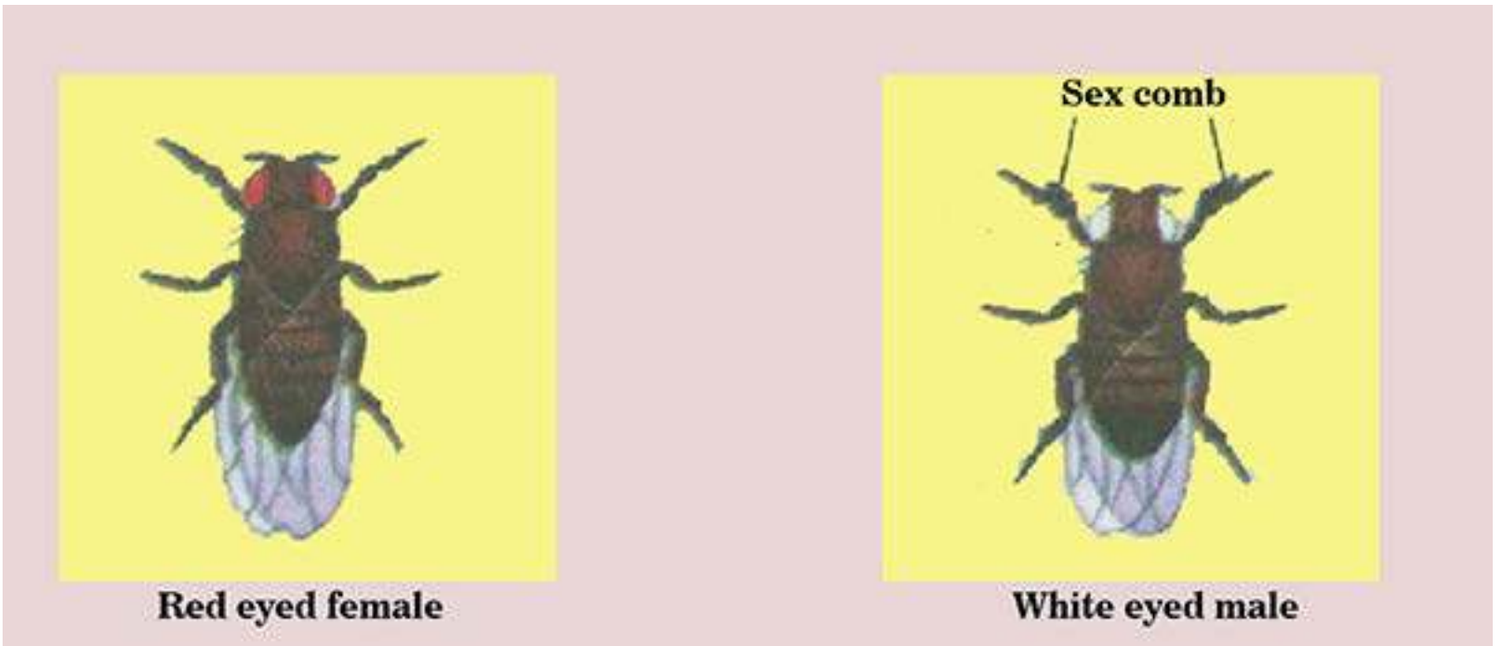



**Fig 22.25 Wild type red eyed female and mutant white eyed male** *Dorsophilia*

Morgan mated this white eyed male with a wild type red eyed female. All 1237 offspring of this cross had red eyes. Morgan concluded that red eye is a dominant trait (Fig 22-26a).

Morgan allowed males and females of F( generation to mate and produce F2 generation. He counted 2459 red-eyed females, 1,011 red-eyed males and 782 white eye males among F2 (Fig. 22.26b).

The proportion of 3470 red eyed to 782 white eyed flies did not perfectly fit into Mendelian 3 : 1 ratio. The number of recessive phenotype individuals was too small. There was another pecularity in this result. All the white-eyed flies were only males. There was no white eye female in F2 generation.

The inheritance of eye colour some how seemed to be related to the 'sex' of the offspring. Morgan proposed that:

(i) The gene for eye colour is located on X chromosome, (ii) the alleles for eye colour are present only on X chromosome. There is no corresponding allele for this trait on Y chromosome.

Thus even a single recessive allele on X chromosome can express itself in males because Y chromosome is empty for that gene. Males are hemizygous as they carry just one allele on their only X chromosome. Females have two X'chromosomes, each carrying an allele of the trait. Females can be homozygous or heterozygous.

Symbol "w" represents the recessive allele for white eye, and "w+" designates its wild type allele for red eye. The genotypes of the parents of Pi cross were: Xw+ Xw+ for red eye female, and Xw Y for the white eye male.

Morgan's hypothesis explained clearly why all the white eyed flies in F2 generation were only males.

**Step 3: Test cross :** Morgan wanted to test his hypothesis (Fig. 22-26c). He crossed the P| white eyed male (XWY) with one of its own daughters, the red eyed heterozygous female from F| generation. This test cross produced 129 red-eyed females, 132 red-eyed males, 88 white-eyed females and 86 white eyed males. White-eyed flies were less viable than red-eyed flies. Half the female offspring in fact had red eyes and half had white. Similarly half the males had red eyes and half had white.

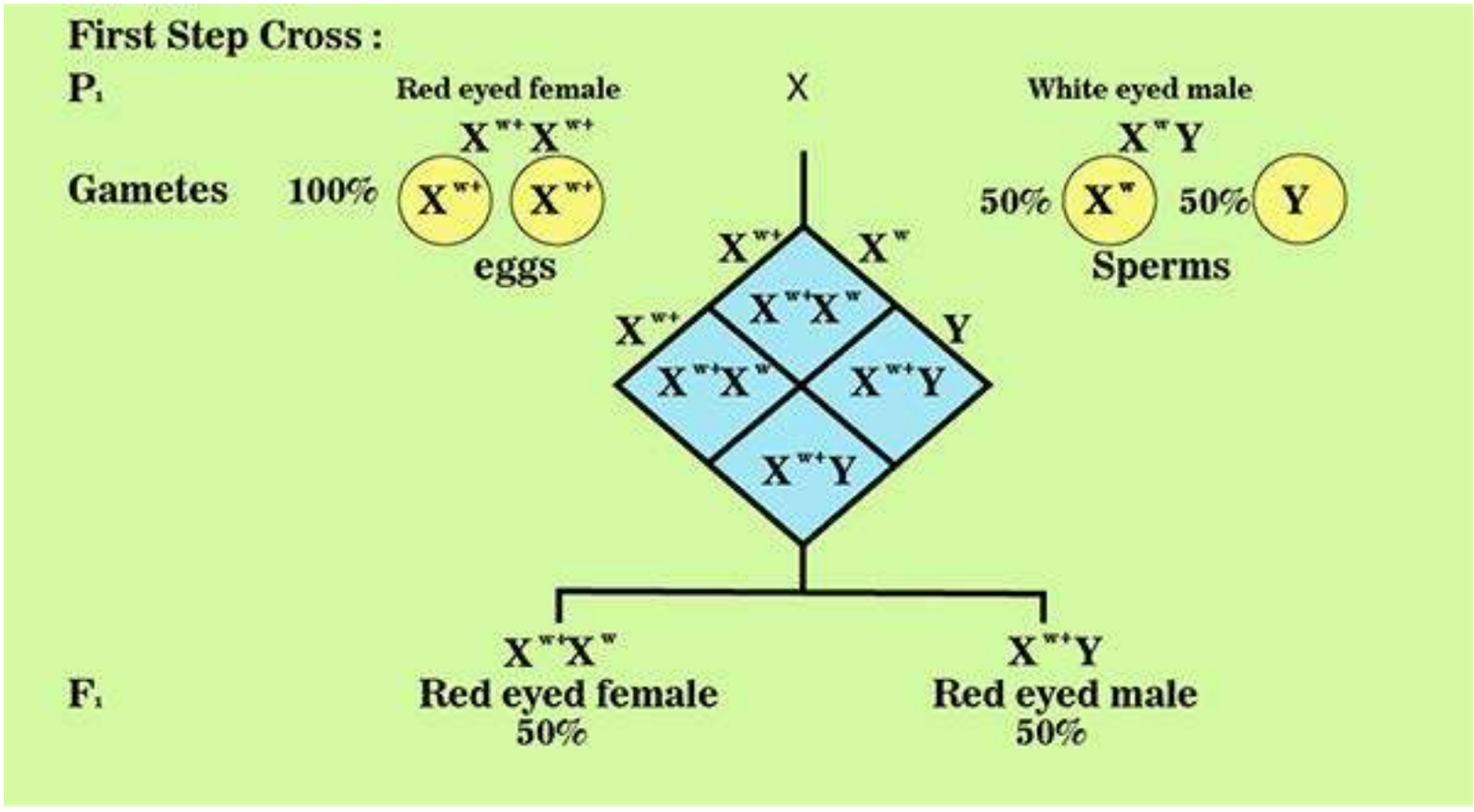



*Fig 22.16(a)*

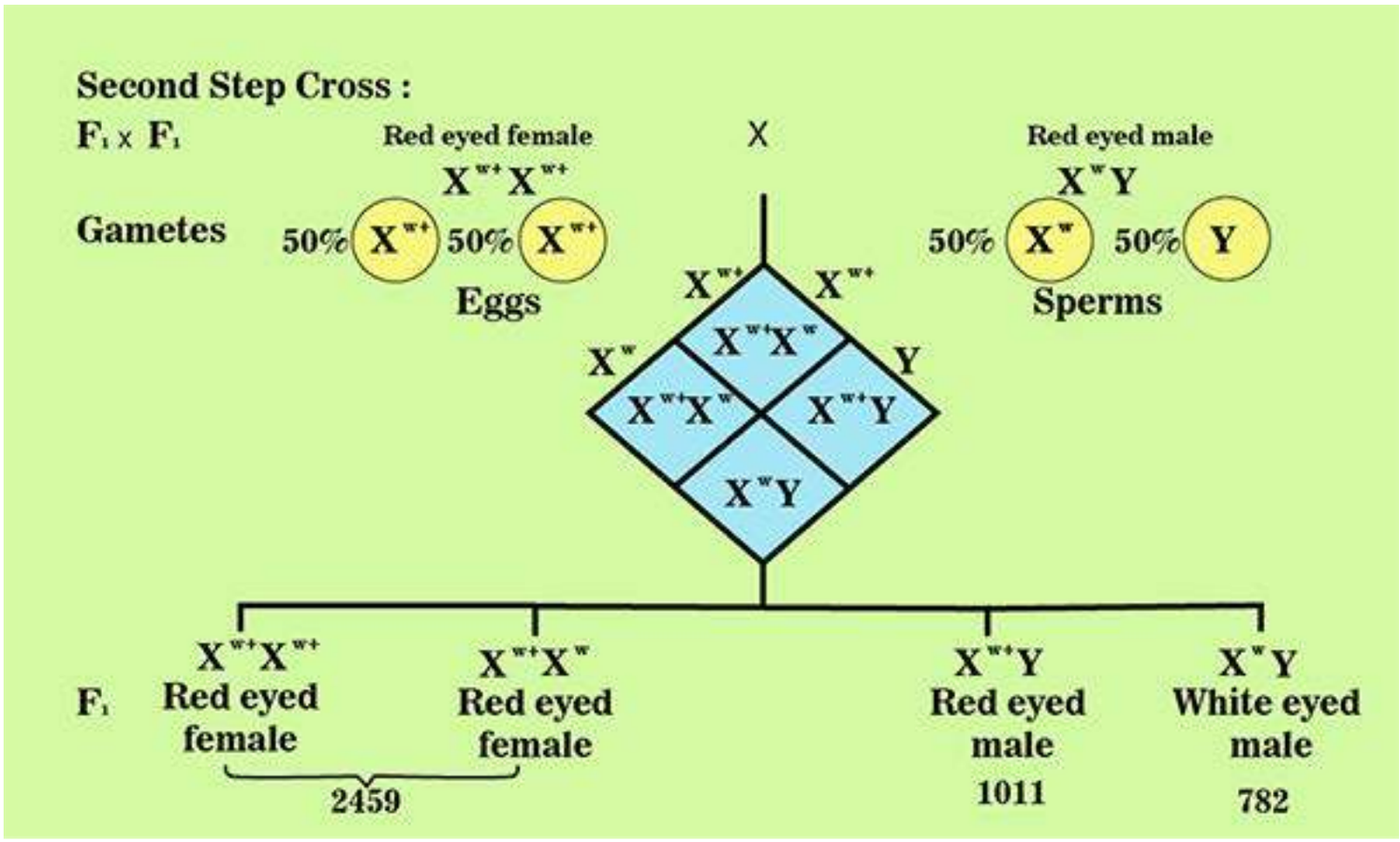



*Fig 22.26(b)*

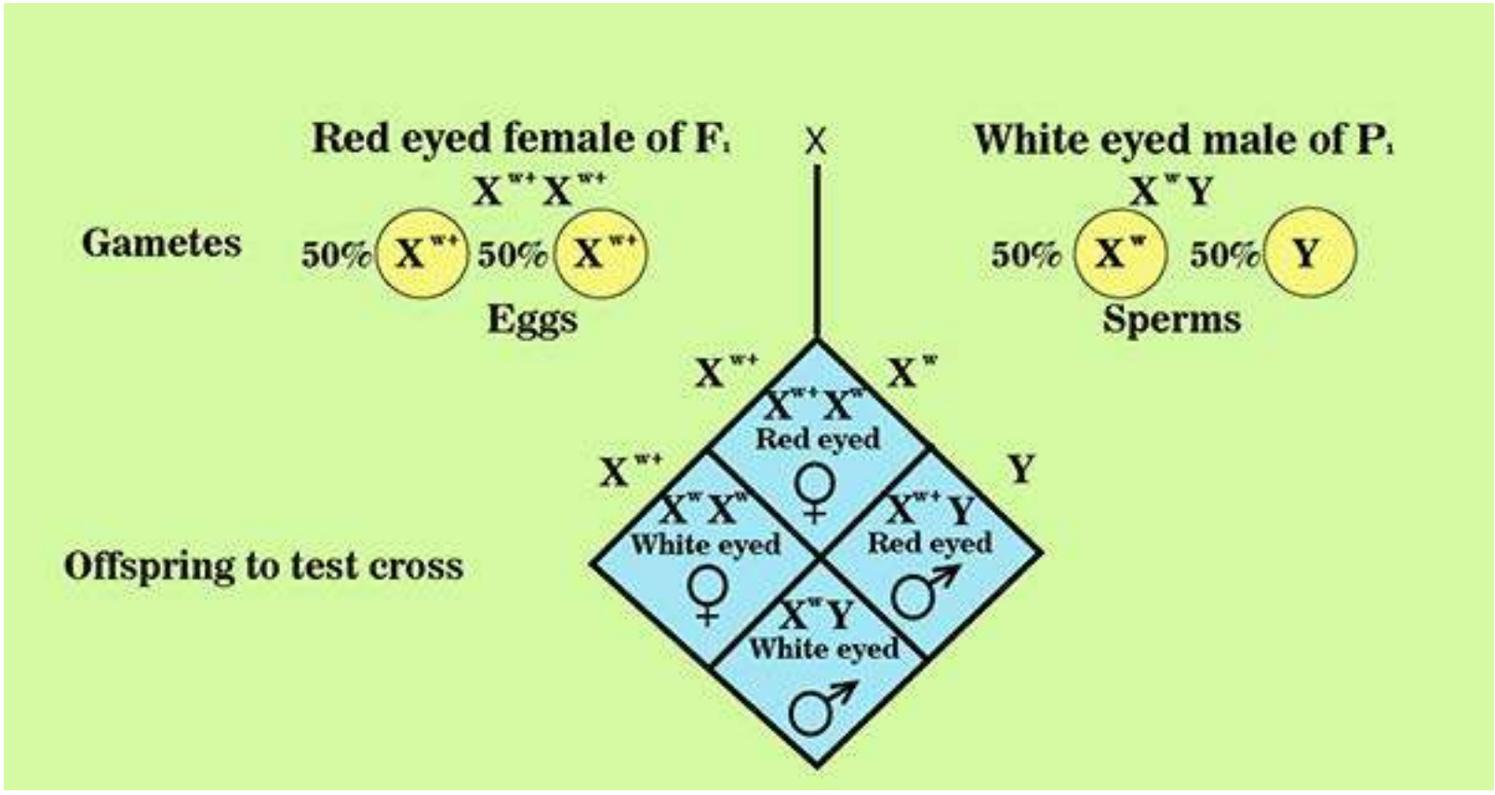



*Fig 22.26(c)*

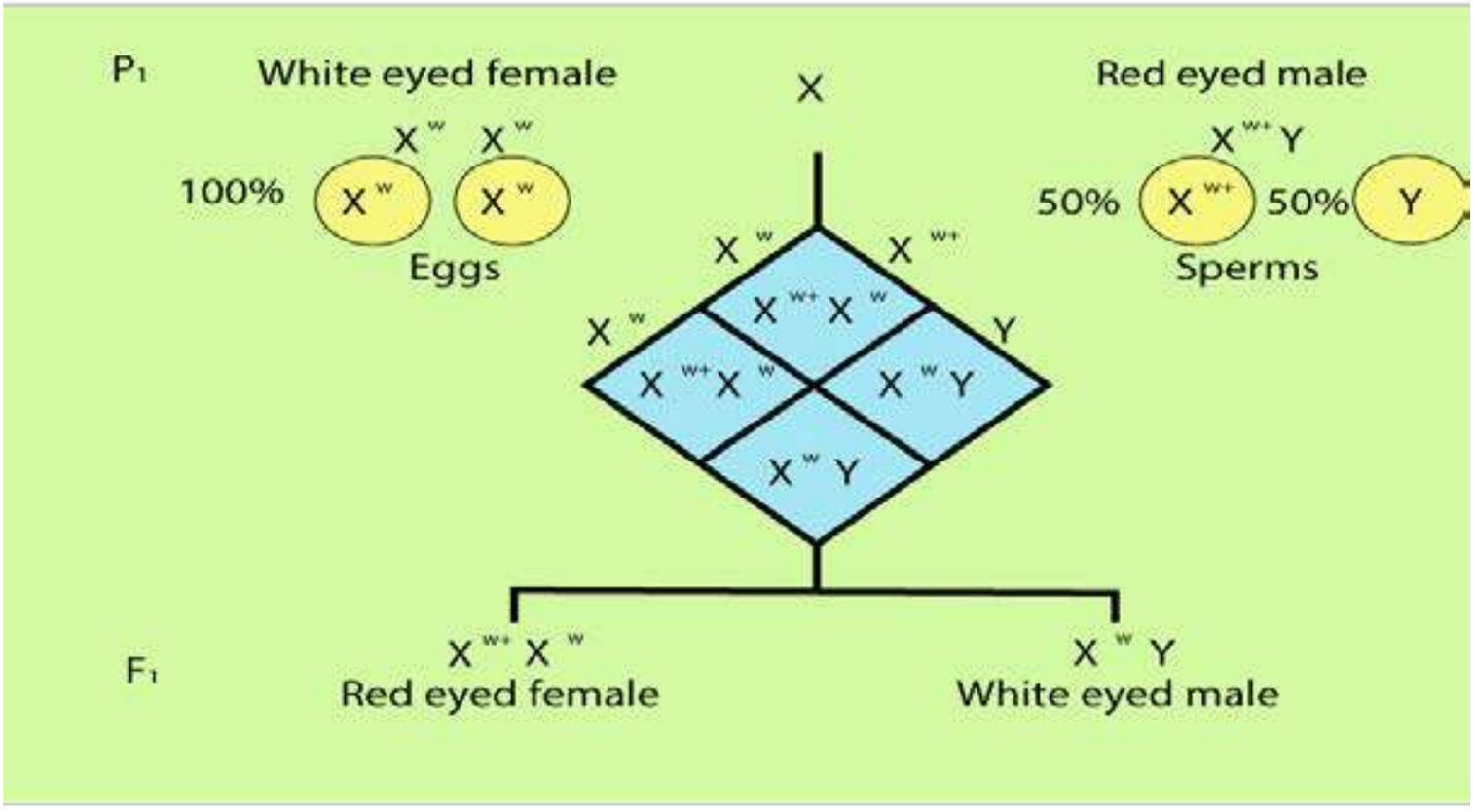



*Fig 22.26(d)*

**Step 4:** Reciprocal cross as a confirmatory test: Appearance of white eyed female provided an opportunity for a further confirmatory test. Morgan mated a white eyed female with a red-eyed male (Fig. 22.26d). All female offspring had red eyes, and all male offspring had white eyes. Then these Fi red eyed females and white eyed males were mated to produce F2. Half of the F2 females had red eyes, half had white. Similarly half of the F2 males had red eyes and half had white. This Fi x Fi cross was exactly like step 3 test cross.

A trait whose gene is present on X chromosome is called **X - linked trait.** X - linked traits are commonly referred as **sex-linked traits**. 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 an X chromosome from each parent, an X - linked trait passes in a crisscross fashion from maternal grandfather (Pi) through his daughter (Fi) to the grandson (F2). It never passes direct from father to son because a son inherits only Y chromosome from father.

Morgan's discovery of sex-linked inheritance was a great contribution to the understanding of genes and chromosome. In 1933, T. H. Morgan was awarded a Nobel Prize for his contributions to genetics.

Y chromosome is not completely inert. It does carry a few genes which have no counterpart on X chromosome. Such genes are called **Y-Linked genes** and their traits are called Y-linked traits e.g. SRY gene on Y chromosome of man determines maleness. Y - linked traits are found only in males. These traits directly pass through Y chromosome from father to son only. As females do not normally inherit Y chromosome, such traits can not pass to them. Some genes like bobbed gene in Drosophila are present on X and Y both. These are called **X - and - Y linked genes**. These are also called pseudoautosomal genes because their pattern of inheritance is like autosomal genes.

## 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 an X - linked recessive gene. Their patterns of inheritance are very different from each other.

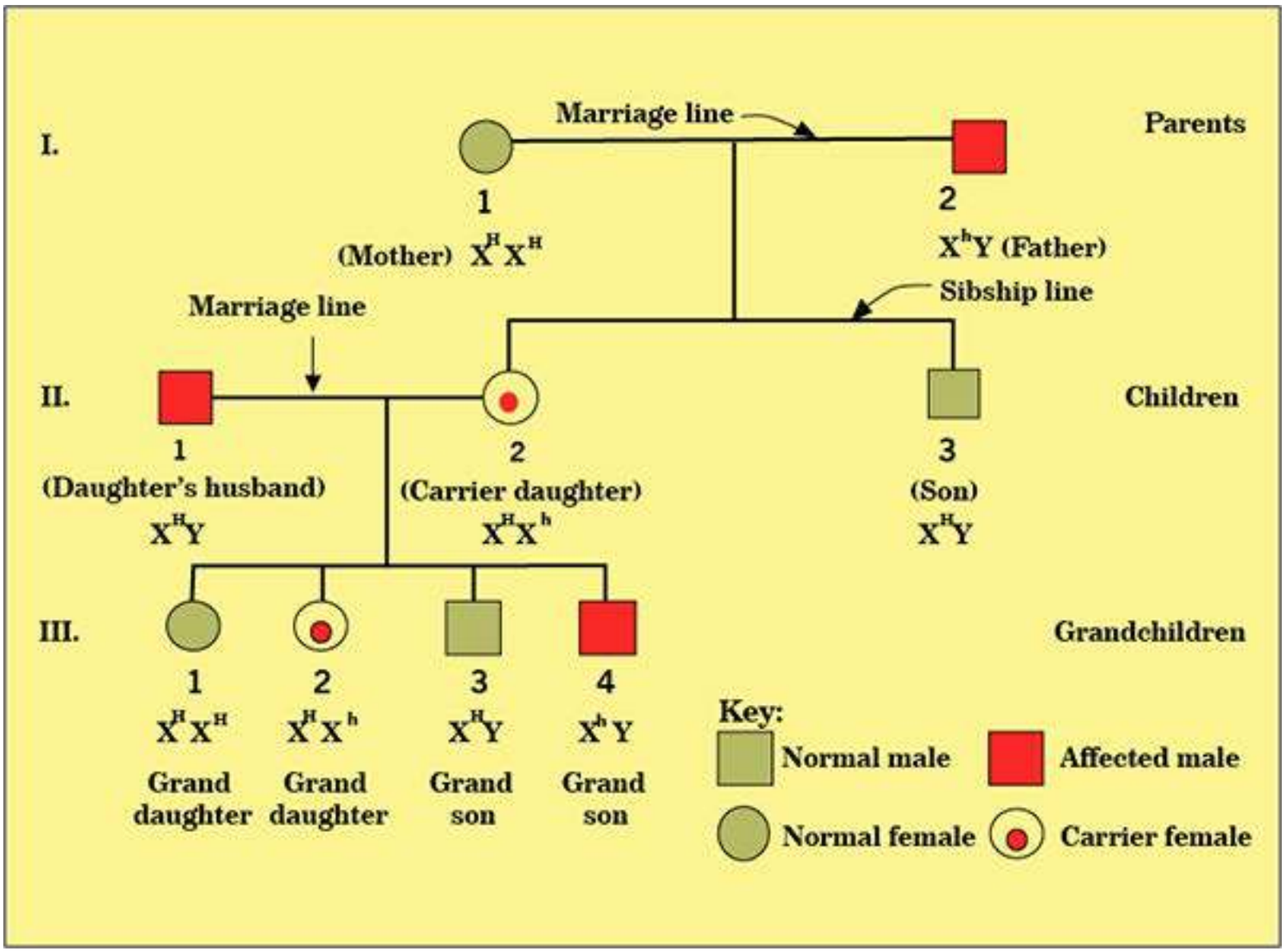



*Fig 22.27 Transmission of X-linked recessive traits(heamophilia) in humans.*

X - linked recessive inheritance: Experimental matings are not practically possible in humans. Mode of inheritance of human traits can be traced through pedigrees.

Genetics of Haemophilia: Haemophilia is a rare X — linked recessive trait. Haemophiliac's blood fails to clot properly after an injury, because it has either a reduction or malfunction or complete absence of blood clotting factors. It is a serious hereditary disease because a haemophiliac may bleed to death even from minor cuts. Haemophilia is of three types: A, B and C. Haemophilia A and B are non - allelic recessive sex - linked, but haemophilia C is an autosomal recessive trait. 80% haemophiliacs, suffer from haemophilia A due to abnormality of factor VIII, about 20% suffer from haemophilia B due to disturbance in factor IX, but less than 1% suffer from haemophilia C due to reduction in factor XI. Being X - linked recessives, haemophilia A and B affect men more than women, but haemophilia C affects both the sexes equally because it is autosomal. Chances for a man to be affected by haemophilia A and B are greater than a woman. A woman can suffer from haemophilia A or B only when she is homozygous for the recessive allele, but a man with just one recessive allele will display the trait. Haemophilia A and B zigzag from maternal grandfather through a carrier daughter to a grandson. It never passes direct from father to son. Gene for normal is H. Gene for haemophilia A is h. In generation I of this pedigree (Fig. 22.27) a man (I - 2) suffering from haemophilia A marries a normal woman (I - 1). He passes haemophilia gene to his daughter (II - 2) through his X chromosome. He cannot pass this gene to his son (II - 3) because the son receives only Y chromosome from him. His daughter (II - 2) also receives another X but with normal dominant allele from her mother (I - 1).

The daughter looks phenotypically normal, but she is heterozygous and a carrier for the recessive gene. When she marries a normal man (II - 1) she passes her father's trait to one of her two sons (HI - 4) who inherits grandfather's X from her. The single recessive allele for haemophilia expresses successfully in the hemizygous son because his Y chromosome does not carry its counterpart. The other son (III - 3) is normal as he

Many X - linked traits in man are also found X - linked in other mammals like mouse, rabbit, dog, sheep, horse, donkey, cattle, kangaroo and chimpanzee.Was the mammalian X chromosome conserved throughout mammalian evolution?

inherits grand mother's X with normal gene, One daughter (III - 1) with both normal X is normal, but the other daughter (III - 2) is carrier like her mother.

Activity: Cases of Haemophilia A are reported in Queen Victoria's family. Pedigree of Queen Victoria's family (Fig. 22.28) indicates that Queen Victoria was a carrier mother, because she gave birth to an affected son Prince Leopold. Prince Leopold passed on this recessive X - linked trait in typical zigzag fashion through his carrier daughter (III - 1) to his grandson Rupert (IV - 1). Assign genotype to each individual. Can you explain how Alexis (IV - 3) became haemophiliac?

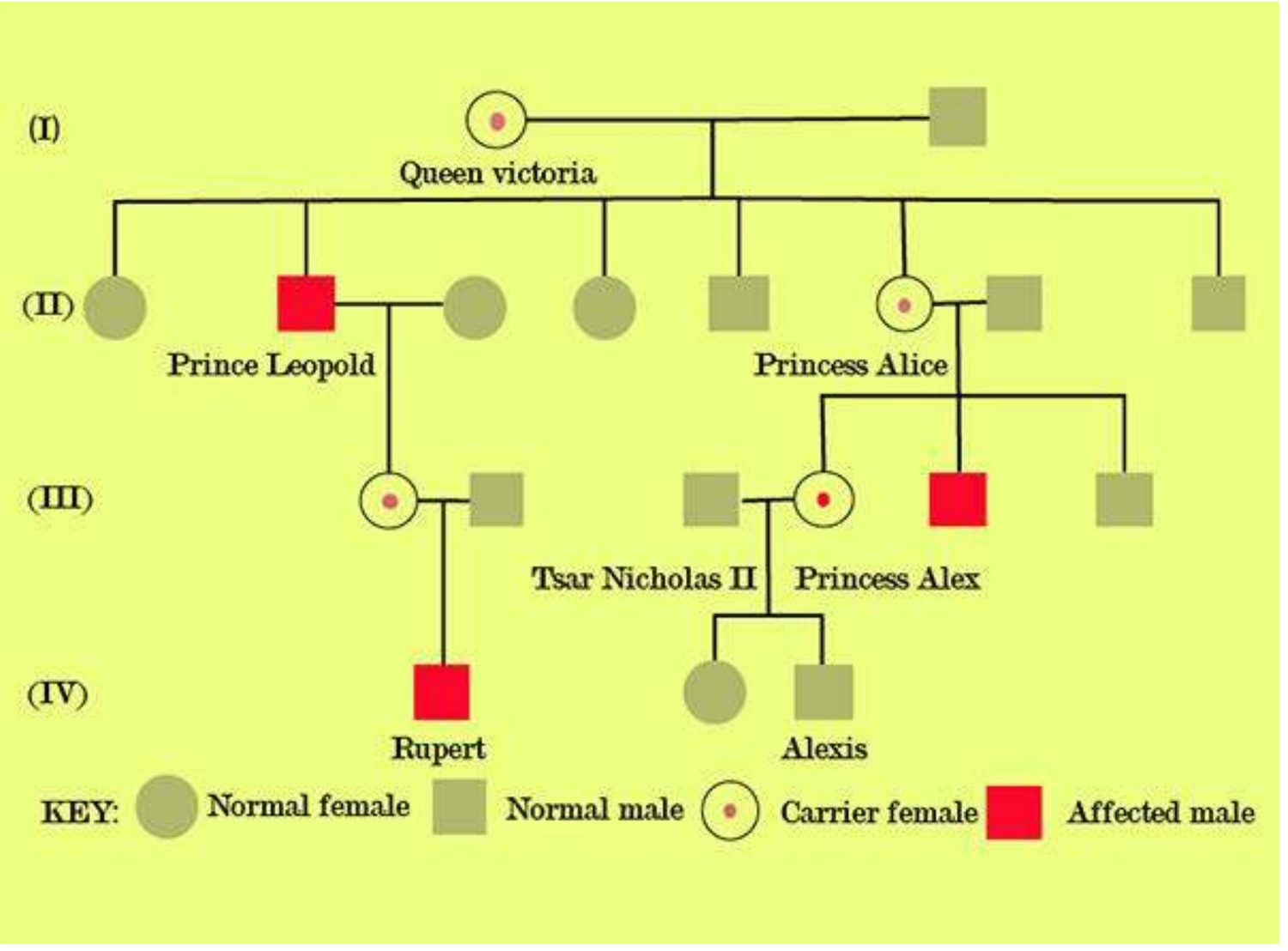



*Fig 22.28 Pedigree of Queen Victoris's family showing cases of Hemolhilia A.*

## :Genetics of colour-blindness

Normal trichromatic colour vision is based on three different kinds of cone cells in the retina, each sensitive to only one of the three primary colours, red, green or blue. Each type of cone cell has specific light absorbing proteins called opsins. The genes for red and green opsins are on X chromosome, while the gene for blue opsin is present on autosome 7. Mutations in opsin genes cause three types of colour-biindness. A **dichromat** can perceive two primary colours but is unable to perceive the one whose opsins are missing due to mutation. **Protanopia** is red blindness, deuteranopia is green blindness, while tritanopia is blue blindness. Some people can detect red and green but with altered perception of the relative shades of these colours. They have abnormal but still partially functional opsins. They are protanomalous and deuteranomalous for red and green weakness respectively. A **monochromat** can perceive one colour. Monochromacy is true colour-blindness. Blue cone monochromacy is an X - linked recessive trait in which both red and green cone cells are absent. That is why it is also called red - green colour-blindness. It is a common hereditary disease. Like any sex - linked recessive trait, it also zigzags from maternal grandfather through a carrier daughter to a grandson. It never passes direct from father to son. This type of colour-blindness is more common in men than women, because chances for a male to be affected by it are muh more than a female.

Testicular feminization syndrome is a rare X-linked recessive trait.Although the persons affected by this trait have a male set of XY chromosomes, yet tffn gene on their X chromosome develops them physically into females. They have breast, female genitalia, a blind Vagina but no uterus. Degenerated testis are also present in abdomen. Such individuals are happily married as females but are sterile. It is an androgen insensitivity syndrome. Male sex hormone testosterone has no effect on them.

Activity: A sex-linked recessive allele “c” produces red - blindness. Its normal dominant allele is “C”. A normal woman whose father was red-blind, marries a red-blind man. What proportion of their children can have normal colour vision?

X - linked dominant inheritance : Pattern of X - linked dominant inheritance is different from X - linked recessive. It is more common in females than males. All daughters of an affected father, but none of his sons are affected. Any heterozygous affected mother will pass the trait equally to half of her sons and half of her daughters (Fig. 22.29). Hypophosphatemic rickets is an X - linked dominant trait. It is a rare hereditary disease. It is different from common dietary rickets, which could be cured by taking vitamin D. It does not result from vitamin D deficiency but its cause is a genetic communication failure at molecular level. The genes encoding bone proteins never receive vitamin D's message to function.

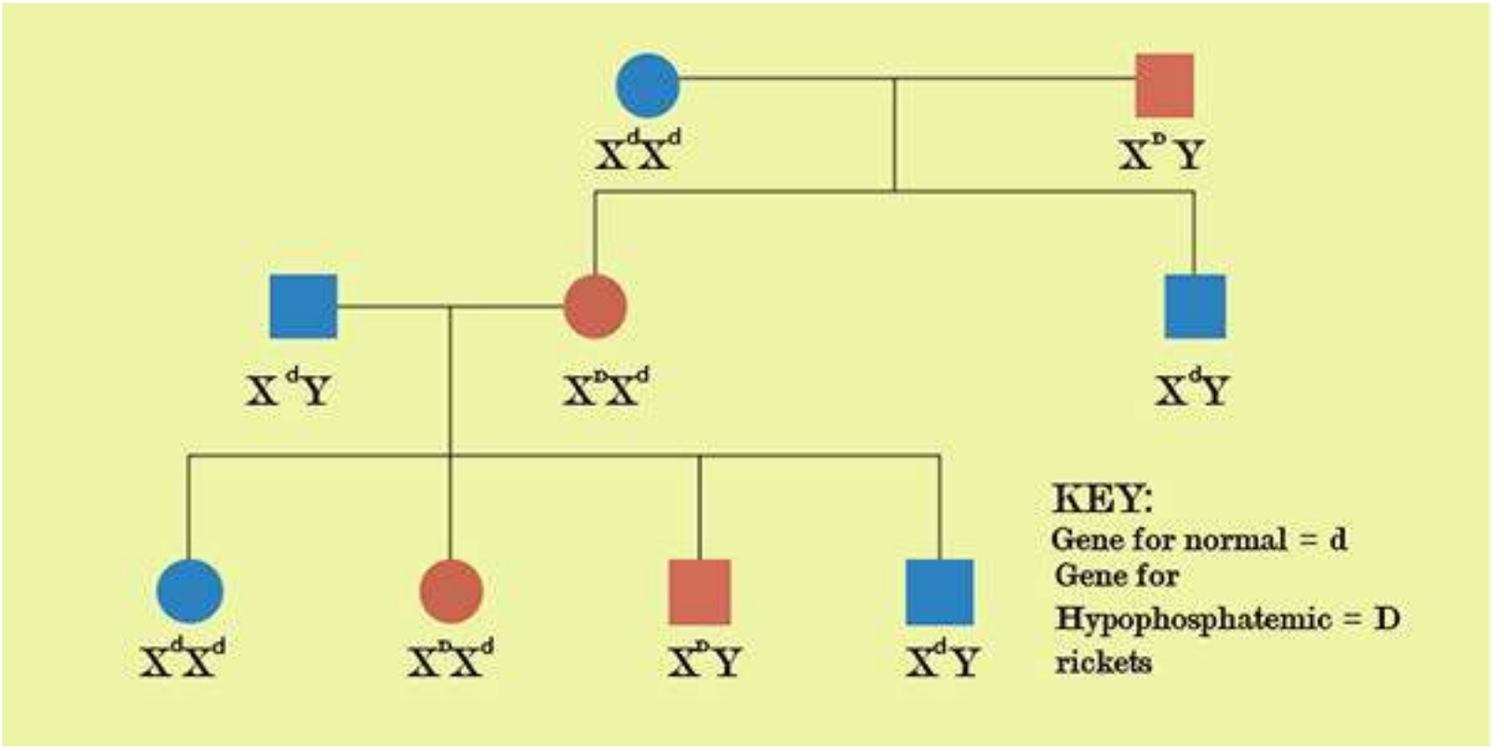



*Fig 22.29 Tranmission Of X-linked dominant traits in humanss.*

Y - Linked inheritance : Pattern of Y - linked inheritance is very peculiar. Maleness is a Y - linked trait. Y - linked trait passes through Y - chromosome from father to son only. Such traits cannot pass to daughters because they do not inherit Y - chromosome. All sons of an affected father are affected by a Y - linked trait (Fig. 22.30). SRY' gene on Y chromosome determines maleness in man. It is male sex switch which triggers developmental process towards maleness after 6 week pregnancy.

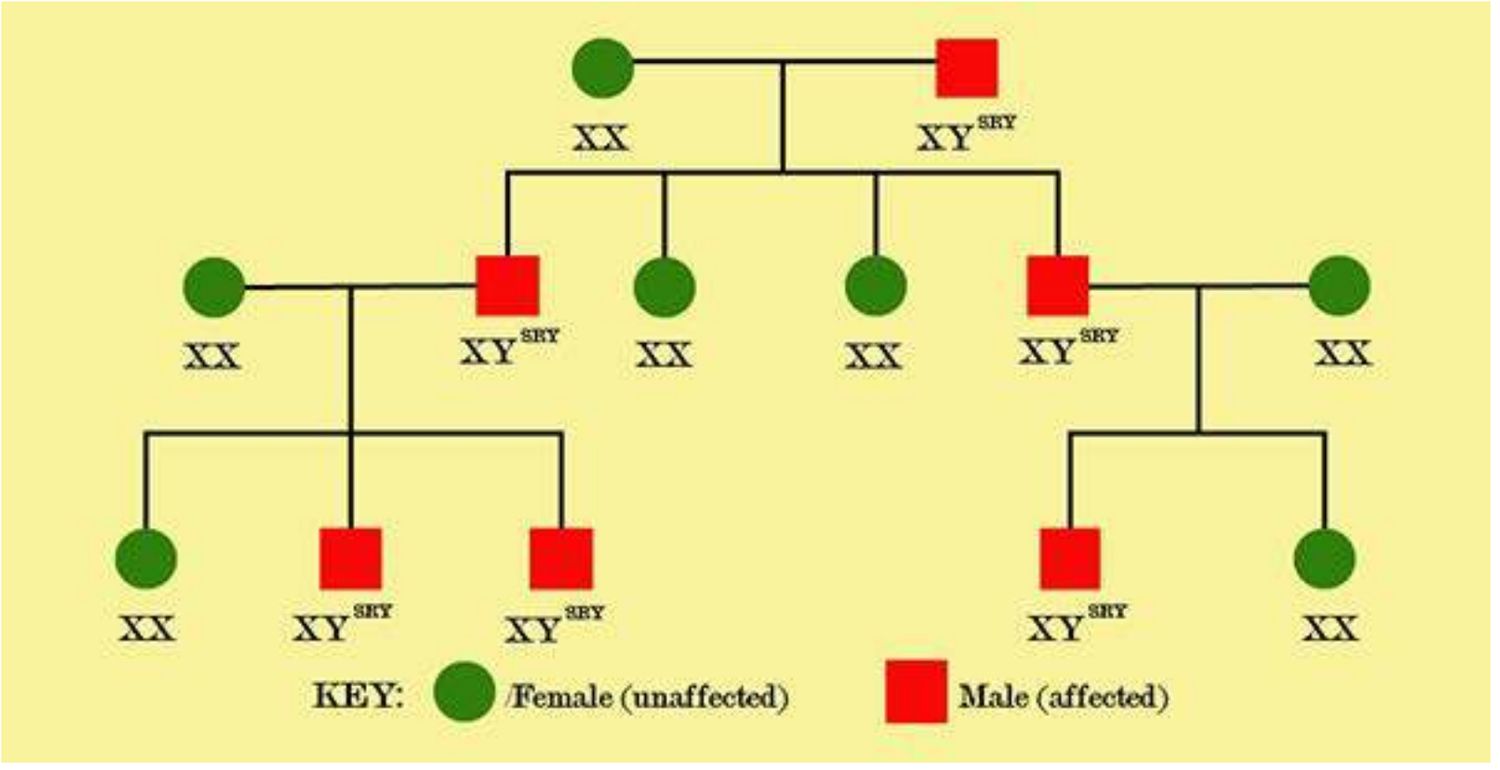



*Fig 22.30 Y-linked inheritance in man*

### Sex Limited Trait

A sex-limited trait is limited to only one sex due to anatomical differences. Such trait affects a structure or function of the body present in only males or only females. These trails may be controlled by sex-linked or autosomal genes. Genes for milk yield in dairy cattle affect only cows. Similarly beard growth in humans is limited to men. A woman does not grow a beard herself but she can pass the genes specifying heavy beard growth to her sons.

### Sex Influenced Trait

Sex influenced trait occurs in both males and females but it is more common in one sex. It is controlled by an allele that is expressed as dominant in one sex but recessive in the other. This difference in expression is due to hormonal difference between the sexes. Pattern 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.

Activity: A man is 45 years old and bald. His wife also has pattern baldness. What is the risk that their son will lose his hair?

## DIABETES MELLITUS AND ITS GENETIC BASIS

Diabetes mellitus is a hereditary disease. It is actually a heterogenous group of disorders which are characterized by elevated blood sugar level. Diabetics are unable to metabolise blood sugar in their body. They pass glucose in their urine. Diabetes is the leading cause of kidney failure, adult blindness, lower limb amputation and heart disease.

There are two major types of diabetes: Type I is IDDM or insulin dependent diabetes mellitus. Type II is NIDDM or non insulin dependent diabetes mellitus. Type I is also called Juvenile diabetes because it usually occurs in early age before 40. It arises due to deficiency of pancreatic hormone insulin that normally routes blood glucose to cells for use. Type I is an auto immune disorder. The immune system backfires and manufactures auto antibodies against body's own cells. Sometimes, specific viral infections activate auto immune response. T - cells of immune system attack pancreas and destroy insulin producing (5 - cells. As a result, pancreas does not produce insulin. Diabetics of type I must receive exogenous (from outside source) insulin to survive.

Progress is being made in understanding the genetic basis of this disease. The •insulin gene is located on short arm of chromosome 11. Polymorphism and genetic variations within this locus is responsible for diabetes type I susceptibility. But today, it is no more just a recessive single gene trait, rather it is a multifactorial (polygenic with environmental influence) inheritance associated with several alleles.

Diabetes mellitus type II is non insulin dependent. It accounts for 90% of all diabetic patients. These persons produce some endogenous insulin themselves, but their body cells gradually fail to respond to insulin and cannot take up glucose from blood. They develop a sort of insulin resistance. It occurs among people over the age of 40, and is more common among the obese. Obesity increases insulin resistance. As exercise reduces obesity it indirectly increases insulin sensitivity and improves glucose tolerance.

There, definitely exists a genetic component in the form of an underlying tendency to develop diabetes under certain environmental conditions. About 2% - 5% of type II diabetics get the disease early in life, before 25 years of age. It is called maturity onset diabetes of the young (MODY). MODY can be inherited as an autosomal dominant trait. About 50% of cases of MODY are caused by mutations in glucokinase gene. Glucokinase enzyme usually converts glucose to glucose - 6 - phosphate in pancreas. MODY can also be caused by mutations in any of the four other genes which encode transcription factors involved in pancreatic development and insulin regulation. But these four MODY genes do not play any significant role in adult - onset type II.

Blood pressure is also an example of multifactorial trait. There is a correlation between systolic and diastolic blood pressure of parents and their children. This correlation is partly due to genes common in them. Blood pressure is also influenced by environmental factors such as diet, stress and tension.

## Exercise

### Q1 Fill in the blanks.

1. _____is the basic unit of biological information.
2. A sudden change in the structure of a gene is called _____
3. _____is the chance of an event to occur.
4. A cross among monohybrids is a_____cross.
5. An individual with a homozygous genotype is called_____ .
6. Different alleles of a gene that are both expressed in a heterozygote are called_____
7. When a heterozygote exceeds the phenotypic expression of both the homozygotes the phenomenon is called_____ .
8. When a single gene affects two or more traits, the phenomenon is called_____
9. A gene with multiple phenotypic effect is called_____ .
10. The phenomenon of staying together of all the genes of a chromosome is called_____
11. _____ minimizes the chances of genetic recombination.
12. _____is an exchange of segments between non-sister chromatids of homologous chromosomes during meiosis.
13. All cliromosomes other than sex chromosomes are called_____.
14. _____is the maleness determining gene in man.
15. Type _____of diabetes mellitus is non insulin dependent.
16. Polygenic inheritance with environmental influence is called _____ inheritance.

### Q.2 Short questions.

1. In grasshopper, the male has XY and the female has XX types of sex chromosomes.
2. Pea is normally a self fertilizing plant.
3. Dihybrids are offspring of the parents who differ in one contrasting pair of trait.
4. X - linked traits pass direct from father to son.
5. A person suffering from Blue cone monochromacy can not see blue colour.
6. In birds and moths eggs determine sex.
7. A homozygote forms all gametes of the same type.
8. The allele for a sex limited trait is dominant in one sex but recessive in the other.

9. Pattern baldness is a sex influenced trait.
10. Carriers of haemophilia show no symptoms of the disease.

## Q.4 Short Questions.

1. **Differentiate between**:

| | |
|---|---|
| Phenotype and genotype | Gene and allele |
| Homozygous and heterozygous | Monohybrid and dihybrid |
| Autosome and sex chromosome | Dominance and epistasis |
| Allele and multiple allele | X-linked trait and Y-linked trait |
| Incomplete dominance and codominance | Sex limited and sex influenced trait |
| Continuous and discontinuous variations | Dominant trait and recessive trait |
| | Wild type and mutant |

2. What is a gene pool?
3. Was pea a lucky choice for Mendel? What would have happened if he had studied an eighth character?
4. What is a test cross? Why did Mendel devise this cross?
5. What would happen if alleles of a pair do not segregate at meiosis? How would it affect the purity of gamete?
6. If the alleles do not assort independently, which type of combination is missing in the progeny.
7. Why has each gamete equal chance of getting one or the other allele of a pair?
8. Does the dominant allele modify the determinative nature of its recessive partner?. What sort of relationship do they have?
9. Which type of traits can assort independently?
10. Why does the blood group phenotype of a person remain constant throughout life'?
11. What is a universal blood donor?
12. How can you protect the baby against Rh - incompatibility?
13. Which type of genes do not obey law of independent assortment?
14. How can linked genes be separated from each other ?
15. What is multifactorial inheritance?
16. What is MODY?
17. Can a child have more intelegence (IQ score) than his parents?

## Q.4 Extensive Questions

1. What is incomplete dominance? Explain it with an example.
2. Define Mendel's law of segregation. Explain it with an example.
3. Define Mendel's law of independent assortment. Explain it with an example.
4. Define probability. Derive 9:3:3:1 F2'ratio of independent assortment through product rule.
5. What is codominance? Explain the phenomenon of codominance with an example.
6. Define multiple alleles. Describe multiple allelic blood group system of man.
7. What is Rh factor? Describe the genetic basis of Rh - blood group system of man.
8. What is erythroblastosis foetalis? Discuss this adverse effect of Rh incompatibility? Also suggest a therapy to avoid Rh sensitization of an Rh" mother married to an Rh+ man.
9. Define epistasis. Explain epistatic gene interaction with an example.
10. What is a pleiotropic gene? Discuss pleiotropy with examples.
11. What are polygenes? Explain polygenic inheritance.
12. What is crossing over? Define recombination frequency and explain its significance.
13. What are sex-chromosomes? Discuss the chromosomal patterns of sex determination in organisms.
14. Compare chromosomal determination of sex between Drosophila and humans.
15. Define gene pool. Explain the concept of gene pool in a sample population.
16. What is sex linkage? Explain T. H. Morgan's study of sex - linkage in Drosophila.
17. Compare the pattern of inheritance of an X - linked dominant trait with an X - linked recessive trait in humans.
18. Explain diabetes mellitus and its genetic basis.
19. Discuss the genetics of colour-blindness or haemophilia.

CHAPTER

# 23 BIOTECHNOLOGY

*Animation 23 : Biotechnology*
*Source & Credit: Wikispaces*

Since Mendel's work was rediscovered in 1900, geneticists have made startling advances which have led to a new era of DNA technology. Modem techniques enable desired substance, for example insulin. Not very long ago, people with insulin dependent they receive human insulin, a product of biotechnology. Since the 1980s, biotechnology has produced drugs and vaccines to curb human illnesses.

Genetically, engineered bacteria have been used to clean up environmental pollutants, increase the fertility of the soil, and kill insect pests. Biotechnology also extends beyond multicellular organisms. It is now possible to alter the genotype and subsequently the phenotype of plants and animals. Indeed, gene therapy in humans, attempting to repair a faulty gene is already undergoing clinical trials. There are those who are opposed to manipulation of genes for any reason. Although, there have been no ill effects as yet, they fear the possibility of health and ecological repercussions in the future.

## Cloning of a gene

Produces many identical copies. Recombinant DNA technology is used when a very large quantity of a gene is required. The use of polymerase chain reaction (PCR) creates a lesser number of copies within a laboratory test tube.

## Recombinant DNA Technology

Recombinant DNA technology popularly known as genetic engineering aims at synthesizing recombinant DNA which contains DNA from two different sources. In order to produce recombinant DNA, the following are required:

1. Gene of interest, which is to be cloned.
2. Molecular scissors to cut out the gene of interest.
3. Molecular carrier or vector, on which gene of interest could be placed.
4. The gene of interest alongwith the vector is then introduced into an expression system, as a result of which a specific product is made.

## How to get a gene?

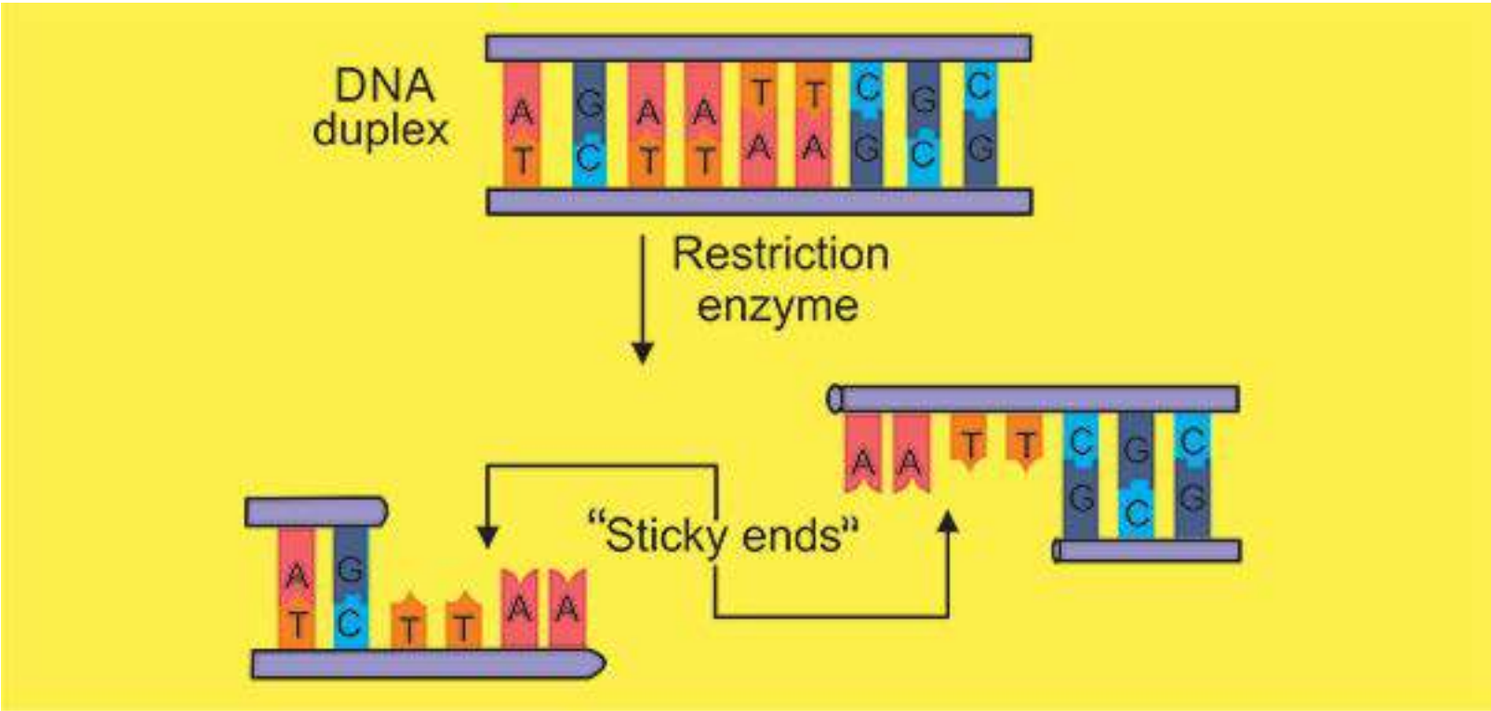
There are three possible ways to get the gene of interest.
(a) to isolate it from the chromosome
(b) to synthesize it chemically, and
(c) to make it from mRNA

Genes can be isolated from the chromosomes by cutting the chromosomes on the flanking sites of the gene using special enzymes known as restriction endonucleases. If, however, the genes are small, they can also be synthesized in the laboratory. Another very common method of getting the gene is to synthesize it in the laboratory from messenger RNA, using reverse transcriptase. This DNA molecule is called complementary DNA (cDNA).

## Molecular Scissors: Restriction Endonucleases

These are natural enzymes of bacteria, which they use for their own protection against viruses. The restriction enzyme cuts down the viral DNA, but does no harm to the bacterial chromosofhe. They are called restriction enzymes because they restrict the growth of viruses. In 1970, Hamilton O. Smith, at Johns Hopkins University, isolated the first restriction enzyme. Bacteria produce a variety of such restriction enzymes, which cut the DNA at very specific sites characterized by specific sequence of four or six nucleotides arranged symmetrically in the reverse order. Such sequences are known as palindromic sequences. So far more than 400 such enzymes have been isolated out of which about 20 are frequently used in recombinant DNA technology.

EcoRl, a commonly used restriction enzyme, cuts double-stranded DNA when it has this sequence of bases at the cleavage site (Fig. 23.1). Notice there is now a gap into which a piece of foreign DNA can be placed, if it ends in bases complementary to those exposed by the restriction enzyme. The single stranded but complementary ends of the two DNA molecules are called “sticky ends” because they can bind by complementary base pairing. They, therefore, facilitate the insertion of foreign DNA into vector DNA.




*Fig, 23.1 Restriction enzyme ECoRI, cuts this specific sequence of nucleotides in such a way that sticky ends are produced.*

## Molecular Carrier: Vector

To make recombinant DNA, one often begins by selecting a vector, the means by which recombinant DNA is introduced into a host cell. One common type of vector is a plasmid. Plasmids were discovered by investigators studying the sex life of the intestinal bacterium *Escherichia coli*.

Plasmids are natural extra-chromosomal circular DNA molecules which carry genes for antibiotic resistance and fertility etc. One of the plasmids discovered earlier pSC 101 has antibiotic resistance gene for tetracycline, whereas pBR 322 has antibiotic resistance genes for tetracycline as well as ampicillin. Inserting gene of interest in tetracycline resistant gene of plasmid pBR 322 would enable separating out colonies of bacteria in a medium containing ampicillin and vice versa.

## Recombinant DNA

For preparation of a recombinant DNA, the plasmid is cut with the same enzyme which was used for isolation of the gene of interest (Fig. 23.2). The gene of interest (insulin) is then joined with the sticky ends produced after cutting the plasmid with the help of another special enzyme knqwn as DNA ligase. This enzyme seals the foreign piece of DNA into the vector. Now the two different pieces of DNA have been joined together, which is now known as recombinant DNA or chimaeric DNA

*Animation 23.1: Recombinant DNA*
*Source & Credit:Pinterest*

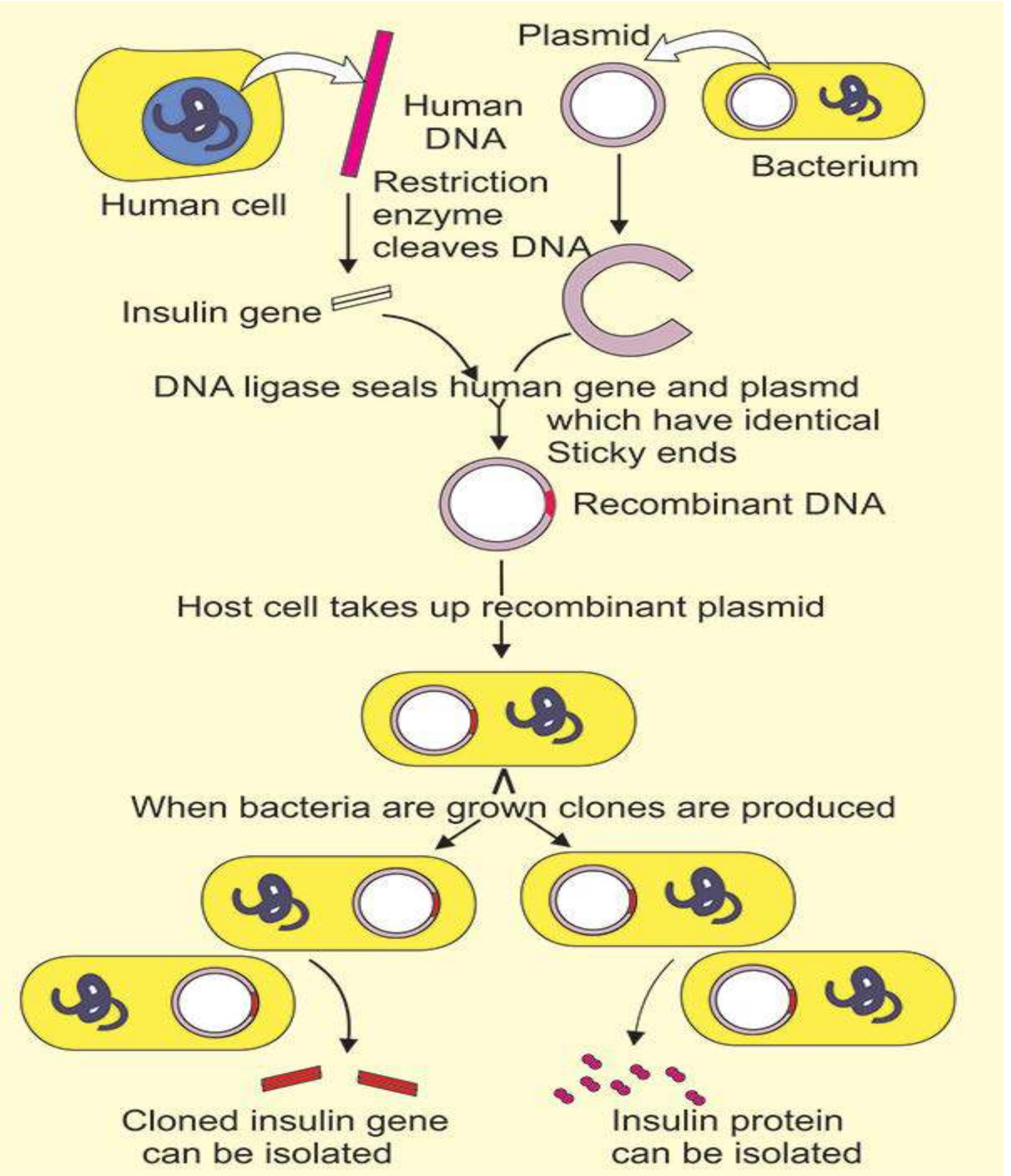



*Fig. 23.2 Cloning of a gene.*

## Expression of the Recombinant DNA

A clone can be a large number of molecules (i.e. cloned genes) or cells (i.e. cloned bacteria) or organisms that are identical to an original specimen. Fig. 23.3 compares the use of a plasmid and a virus to clone a gene. 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. From this bacterial clone, the cloned gene can be isolated for further analysis, or protein product can be separated (Fig 23.2). Besides plasmids, the DNA of bacterial viruses (for example, lambda phage) can also be used as a vector. After lambda phage attaches to a host bacterium, recombinant DNA is released from the virus and enters the bacterium. Here, it will direct the reproduction of many more viruses. Each virus in bacteriophage clone contains a copy of the gene being cloned (Fig. 23.3).

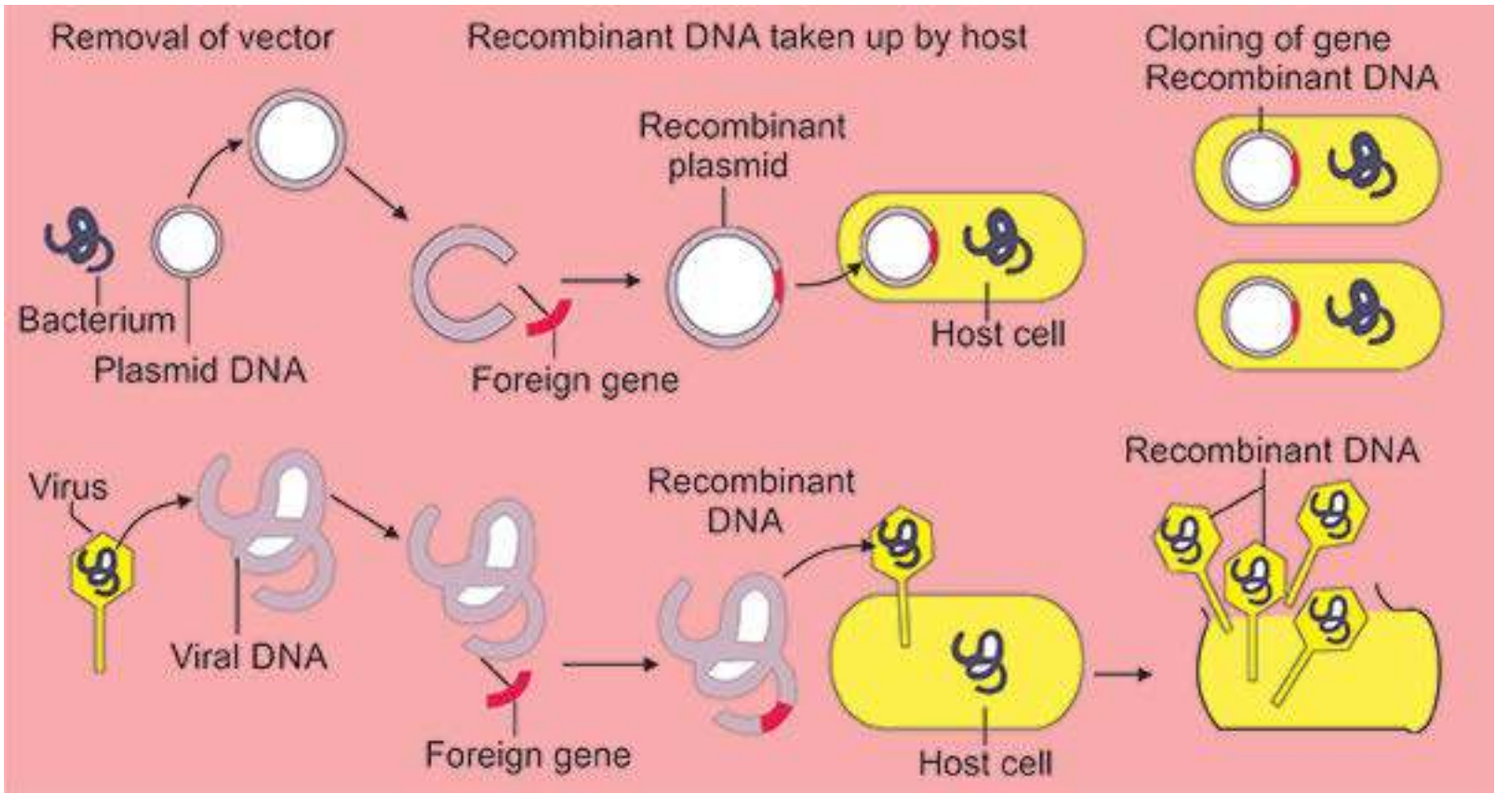



*Fig. 23.3 Plasmid DNA (upper part of figure) as well as viral DNA (lower part of the figure) can be used as vectors for cloning gene of interes*

## Genoiftic Library

A genome is a full set of genes of an individual. A genomic library is a collection of bacterial or bacteriophage clones, each clone containing a particular segment of DNA from the source cell. For making a genomic library, an organism's DNA is simply sliced up into pieces, and pieces are put into vectors (i.e. plasmids or viruses) that are taken up by host bacteria as shown in Fig. 23.3. The entire collection of bacterial or bacteriophage clones that result contains all the genes of that organism.

A particular probe can be used to search a genetic library for a certain gene. A probe is a single stranded nucleotide sequence that will hybridize (pair) with a certain piece of DNA. Location of the probe is possible because the probe is either radioactive or fluorescent. Bacterial cells, each carrying a particular DNA fragment, can be plated onto agar in a petri dish. After the probe hybridizes into the gene of interest, the genes can be isolated from the fragment (Fig 23.4). Now this particular fragment can be cloned further or even analyzed for its particular DNA sequence.

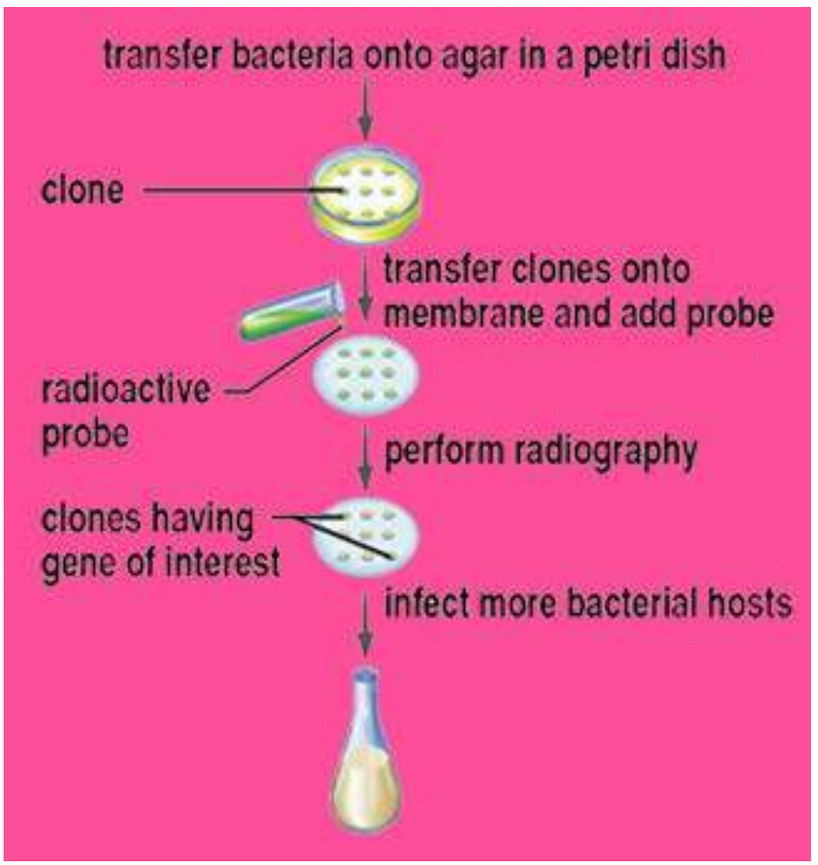



*Fig 23.4 Identification of a cloned gene*

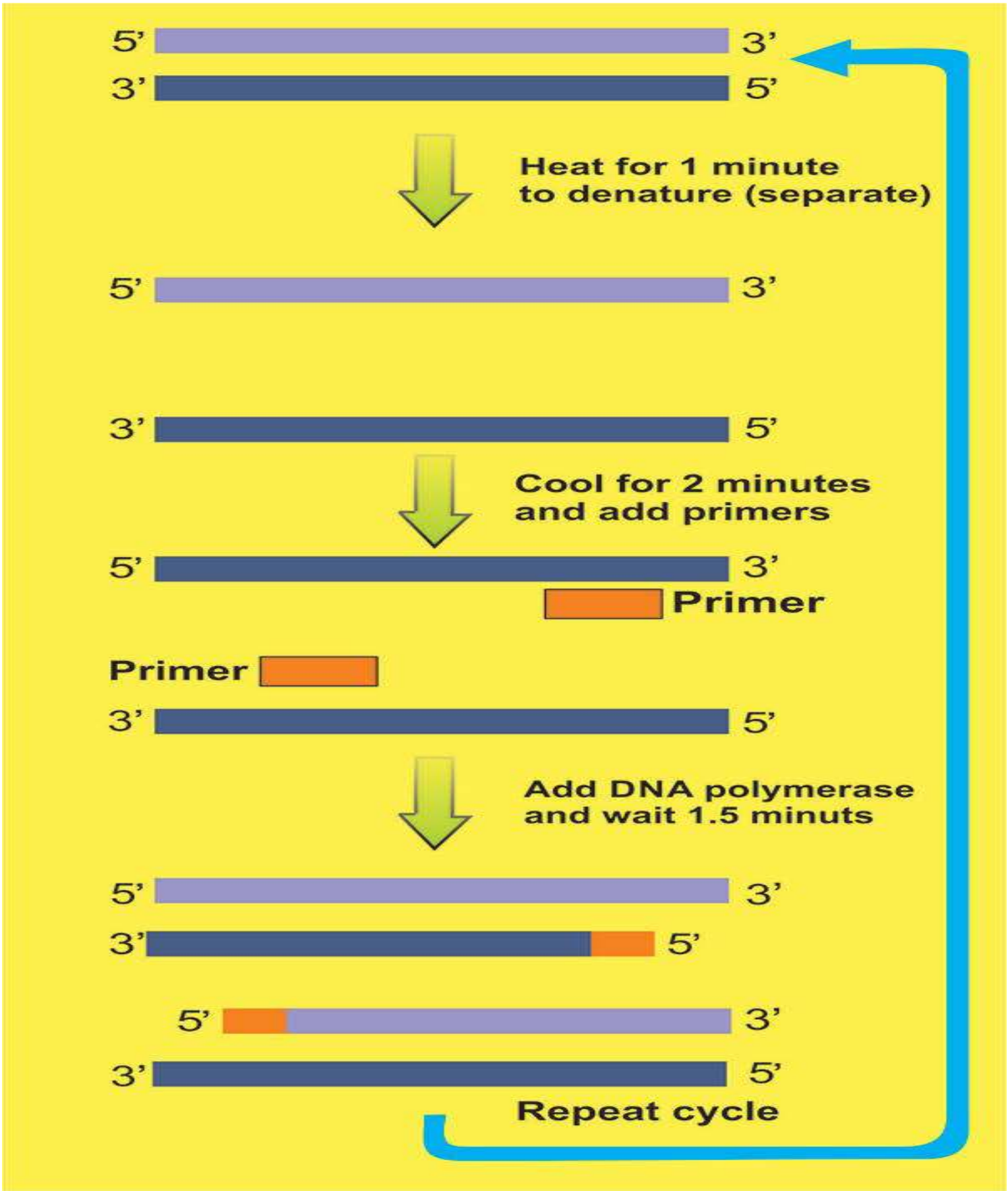



*Fig 23.5 Polymerase chain reaction (PCR)*

# The polymerase Chain Reaction

Kary B. Mullis developed the polymerase chain reaction (PCR) in 1983. Earlier methods of obtaining multiple copies of a specific sequence of DNA were time consuming and expensive. In contrast, PCR can create millions of copies of a single gene or any specific piece of DNA quickly in a test tube. PCR is very specific - the targeted DNA sequence can be less than one part in a million of the total DNA sample. .This means that a single gene or smaller piece of DNA, among all the human genes can be amplified (copied) using PCR.

PCR takes its name from DNA polymerase, the enzyme that carries out DNA replication in a cell. It is considered a chain reaction because DNA polymerase will carry out replication over and over again, until there are millions of copies of the desired DNA. PCR does not replace gene cloning, which is still used whenever a large quantity of gene or protein product is needed.

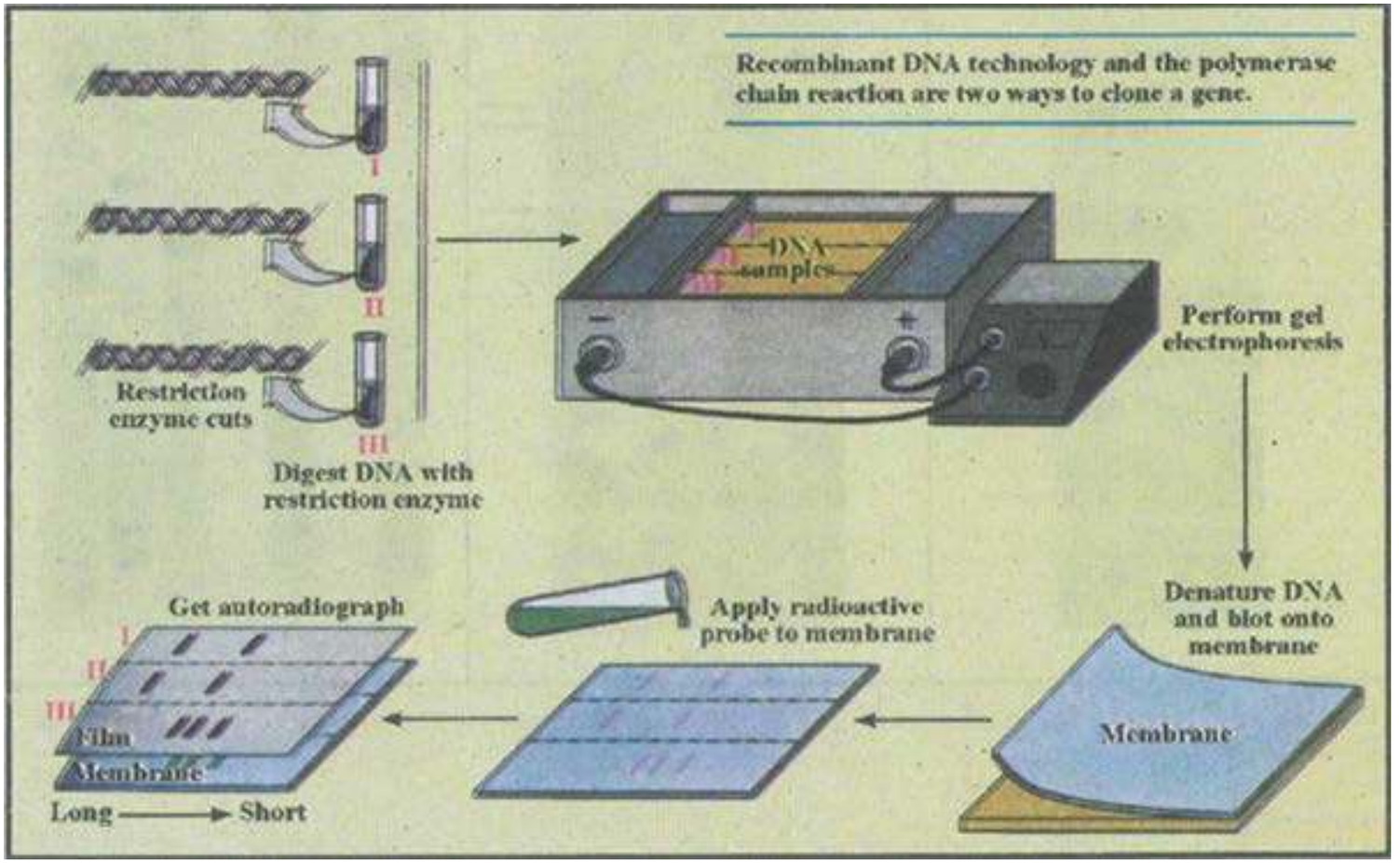
Before carrying out PCR, primers - sequences of about 20 bases that are complementary to the bases on either side of the "target DNA" - must be available. The primers are needed because DNA polymerase does not start the replication process; it only continues or extends the process. After the primers bind by complementary base pairing to the DNA strand, DNA polymerase copies the target DNA (Fig 23.5) .

DNA polymerase used is temperature - insensitive (thermostable) enzyme extracted from the bacterium *Thermus aquaticus*, which lives in hot springs. Commonly, this enzyme is also known as **Taq polymerase**. It can withstand high temperature, which is used to separate double stranded DNA, therefore, replication need not be interrupted by the need to add more enzyme. PCR is done these days in an automatic PCR machine or thermocycler, which is a routine piece of equipment in any laboratory.

*Animation 23.2 : PCR*
*Source & Credit: members.jcom*

## Analyzing DNA

The entire genome of an individual can be subjected to DNA finger printing, a process described in Fig. 23.6. The genome is treated with restriction enzymes, which results in a unique collection of different sized fragments. Therefore, restriction fragment length polymorphism (RFLPs) exists between individuals. During a process called gel electrophoresis, the fragments can be separated according to their lengths (molecular weight or size), and the result is a number of bands that are so close together that they appear as a smear. However, the use of probes for genetic markers produces a distinctive pattern that can be recorded on X-ray film.




*Fif 23.6 DNA fingerprinting. Three samples of DNA(I , II , IIi)were cut with a restriction enzyme and run on agarose gel. The gel pattren was then transferred to a membrane and DNA was denatured. The denatured DNA on the paper was hybridized with radioactive probe. Since the radioactive probes and complemetary arrangement of bases to the original DNA ,all DNA fragments were labelled , which appeared as black bands with autogradiagram.*

The DNA from a single sperm enough to identify a suspected rapist. Since DNA is inherited, its finger print resembles that of one's parents. DNA finger printing successfully identified the remains of a teenager who had been murdered eight years before because the skeletal DNA was similar to that of the parent's DNA.

In Fig. 23.7 are given some DNA finger prints. The figure 23.7 (a) shows comparison of child's finger print with that of his parents. The child has received DNA from both of his parents. Arrows indicate that some bands in him are like his father, some like his mother. Some bands are. however, unique to him, which do not match with any of the parents.

Fig. 23.7 (b) shows a case of disputed parenthood. Two persons $F_1$ and $F_2$ claim to be the father of child C, whose mother's finger print is given under M. The child has received DNA from both of his parents. Obviously $F_1$is not the real father.

The arrows on left side show common bands between mother and child while those on right show common bands between the father and the child.

Fig. 23.7(c) shows DNA finger prints which have been presented as forensic evidence. A criminal on a deserted place assaulted a woman. She scratched his face in her defence but he murdered her and ran away. Forensic scientist recovered murder's hair and skin cells from underneath her nails. They prepared DNA finger prints from blood of victim, from murderer's skin and hair, and from three suspects blood. Can you compare them for specific DNA sequence and tell who is in guilty and who is not? The suspect 1 has finger prints, which is similar to linger print from skin cells taken from underneath nails of the victim.Therefore suspect 1 is the culprit. The suspect 2 and 3 are not.

PCR amplification and analysis can be used (1) to diagnose viral infections, genetic disorders, and cancer (2) in forensic laboratories to identify criminals; and (3) to determine the evolutionary history' of human population. It has been possible to sequence DNA taken from a 76,000 years old mummified human braiti and from a 17 to 20 million years old plant fossil following PCR amplification.

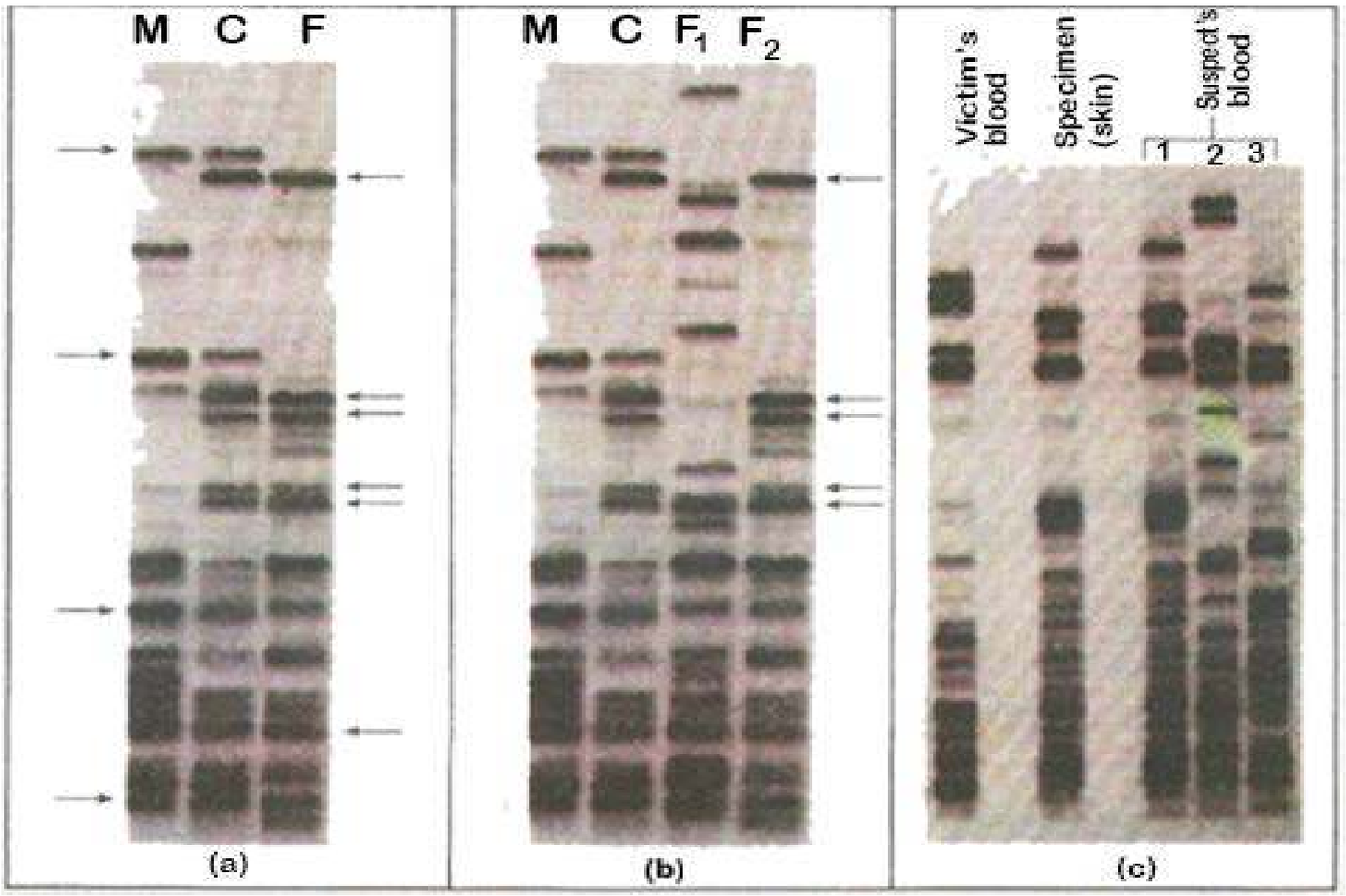



*Fig 23.7(a) Comparison of a child's DNA fingerprint (c) with his parent's DNA fringerpints (Mand F),* *(b) DNA fingerprints as evidence for paternity.* *(c) DNA Test - a powerful tool of forensic science.*

## Gene Sequencing

In the late 1970s, methods were developed that allowed the nucleotide sequence of any purified DNA fragement to be determined simply and quickly. The main principle of these methods is :

1. To generate pieces of DNA of different sizes all starting from the same point and ending at different points.
2. Separation of these different pieces of DNA on agarose gel.
3. Reading of sequence from the gel.

For generation of different sized DNA fragments, two methods arc generally used. One is Sanger's,method in which dideoxyribonucleoside triphosphates arc used to terminate DNA synthesis at different sites. The other method is known as Maxam-Giibcrt method in which DNA threads are chemically cut into pieces of different sizes

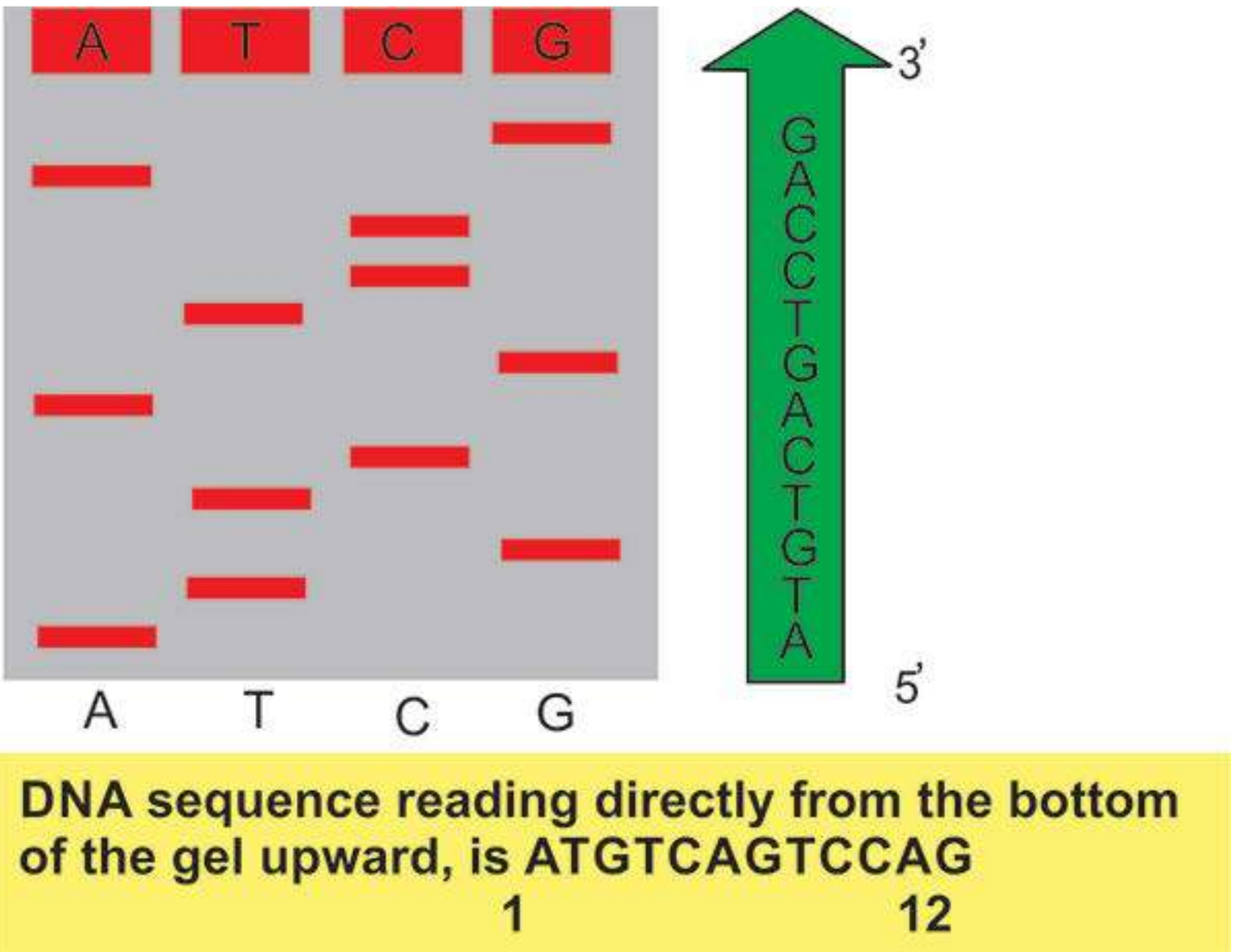



*Fig 23.8 The enzymatic or dideoxy method of sequencing DNA*

Fig 23.8 shows typical gel obtained after dideoxy method. The volume of DNA sequence information is now so large that powerful computers must be used to store and analyze it. DNA sequence is now completely automated, robotic devices mix the reagents and then load, run and read the order of the nucleotide bases from the gel. This is facilitated by using chain terminating nucleotides that are each labelled with a different colored fluorescent dye; in this case, all four synthesis reactions can be performed in the same tube, and the products can be separated in a single lane of a gel. A detector positioned near the bottom of the gel reads and records the color of fluorescent label on each band as it passes through a laser beam. A computer then reads and stores this nucleotide sequence.

Owing to the automation of DNA sequencing, the genomes of many organisms have been sequenced. These include plant chloroplasts and animal mitochondria, large number of bacteria, many of the yeasts, a nematode worm. *Drosophila*, the model plant *Arabidopsis*, the mouse and human. Researchers have also deduced the complete DNA sequence of a variety of human pathogens.

## THE HUMAN GENOME PROJECT

The human genome project is massive effort originally founded by the U.S. government and now increasingly by U.S. pharmaceutical companies to map the human chromosomes. Many non-profit and for profit biochemical laboratories around the world are now involved in the project which has two primary goals.

*Animation 23.3: Human Genome Project*
*Source & Credit: CRDD*

The first goal is to construct a genetic map of the human genome. The aim is to show the sequence of genes along the length of each type of chromosome, such as depicted for the X chromosome in Fig 23.9. When the DNA sequence of human chromosome no. 22, one of the smallest human chromosomes, was completed in 19.99, it became possible for the first time to see exactly how genes are arranged along an entire vertebrate chromosome. With the publication of the entire human genome in 2001, the genetic landscape of all human chromosomes suddenly came into sharp focus. The sheer quantity of information provided by the human genome project is unprecedented in biology. The human genome is 25 times larger than any other genome sequenced so far.

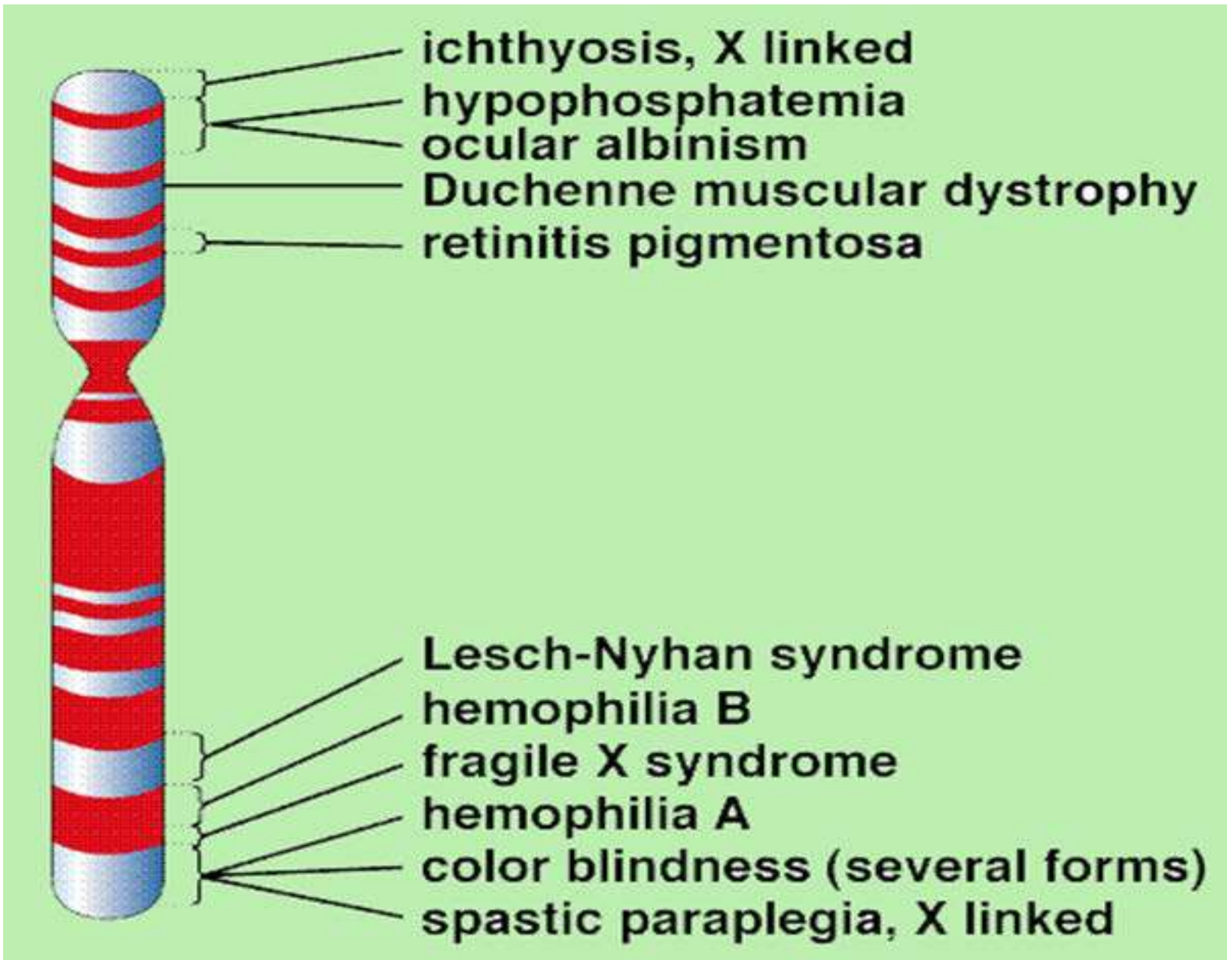



*Fig 23.9 Genetic map of X chromosome*

The map for each chromosome is presently incomplete, and in many instances scientists rely on the placement of RFLPs. These sites eventually allow scientist to pinpoint disease causing genes because a particular RFLP and a defective gene are often inherited together. For example it is known that persons with Huntington disease have a unique site where a restriction enzyme cuts DNA. The test for Huntington disease relies on this difference from the normal.

The second goal is to construct a base sequence map. There are three billion base pairs in the human genome and it is estimated it cohld take an encyclopaedia of 200 volumes, each with 1000 pages, to list all of these. Yet this goal has been reached and all the chromosomes have been sequenced.

## BIOTECHNOLOGY PRODUCTS

Today bacteria, plants and animals are genetically engineered to produce biotechnology products. Organisms that have a foreign gene inserted into them are called **transgenic organisms.**

### Transgenic Bacteria

Recombinant DNA technology is used to produce bacteria that reproduce in large vats called **bioreactors**. If the foreign gene is replicated and actively expressed, a large amount of protein product can be obtained. Biotechnology products produced by bacteria, such as insulin, human growth hormone, tissue plasminogen activator, haemophilia factor Vm, and hepatitis B vaccine are now in the market.

Transgenic bacteria have been produced to promote health of plants for example, bacteria that normally live on plants and encourage the formation of ice crystals have been changed from frost - plus to frost - minus bacteria. Also, a bacterium that normally colonizes the roots of com plants has now been endowed with genes (from another bacterium) that code for an insect toxin. The toxin protects the roots from insects. Bacteria can be selected for their ability to degrade a particular substance and then this ability can be enhanced by genetic engineering. For instance, naturally occurring bacteria may be engineered to do an even better job of cleaning up beaches after oil spills.

Industry has found that bacteria can be used as biofilters to prevent airborne chemical pollutants from being vented into the air. They can also remove sulfur from coal before it is burned and help to clean up toxic waste dumps. One such strain was given genes that allowed it to clean up levels of toxins that would have killed other strains. Further, these bacteria were given “suicide” genes that caused them to self-destruct when the job had been accomplished.

Organic chemicals are often synthesized by having catalysts act on precursor molecules or by using bacteria to carry out the synthesis. Today, it is possible to go one step further and to manipulate the genes that code for these enzymes. For instance, biochemists discovered a strain of bacteria that is specially good at producing phenylalanine; an organic chemical needed to make aspartame, the dipeptide sweetener better known as Nutrasweet. They isolated, altered and formed a vector for the appropriate genes so that various bacteria could be genetically engineered to produce pucnylaianine. Many major mining companies already use bacteria to obtain various metals. Genetic engineering may enhance the ability of bacteria to extract copper, uranium and gold from low grade sources. Some mining companies are testing genetically engineered organisms that have improved bioleaching capabilities.

*Animation 23.4: Transgenic Bectria*
*Source & Credit: 33rd Square*

# Transgenic Plants

Techniques have been developed to introduce foreign genes into immature plant embryos, or into plant cells that have had the cell wall removed and are called **protoplasts.** It is possible to treat protoplasts with an electric current while they are suspended in a liquid containing foreign DNA. The electric current makes tiny, selfscaling holes in the plasma membrane through which genetic material can enter. Then a protoplast will develop into a complete plant. Foreign genes transferred to cotton, com and potato strains have made these plants resistant to pests because their cells now produce an insect'toxin. Similarly, soybeans have been made resistant to a common herbicide. Some corn and cotton plants are both pest and herbicide resistant. In 1999 these transgenic crops were planted on more than 70 million acres worldwide and the acreage is expected to triple in about five years. Improvements still to come for are increased protein or starch content and modified oil or amino acid composition.

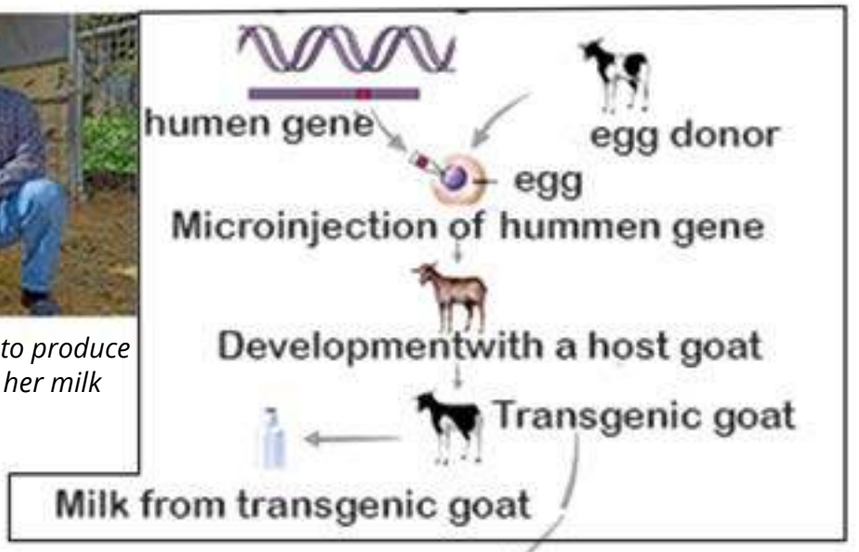
*Animation 23.5:Transgenic Plants*
*Source & Credit: Wikipedia*

Agribusiness companies also are in the process of developing transgenic versions of wheat and rice in addition to com. This is considered an absolute necessity if the 2020 global demand for rice, wheat and com is to be met. World grain harvests have continued to rise since the 1960s when special high-yield hybrid plants were developed during the so called green revolution. But the per capita production has now flattened out because of continued population growth. The hope is that genetic engineering will allow fanners to surpass the yield barrier. Perhaps, the stomata, the pore-like openings in the leaves, could be altered to boost carbon dioxide intake or cut down water loss.
Another possible goal is to increase the efficiency of the enzyme Rubisco which captures C02 in most plants. A team of Japanese scientists are attempting to introduce the C4 cycle into the rice. Plants that utilize the C4 cycle avoid the inefficiency of carboxylase by using a different means of capturing C02. Unlike the single gene transfers that have been done so far, these modifications would require a thorough re-engineering of plant cells. Single gene transfers will cause plants to produce various products. A weed called mouse-eared cress has been engineered to produce a biodegradable plastic (polyhydroxy-butyrate) in cell granules.
Plants are being engineered to produce human hormones, clotting factors, and antibodies in their seeds. One type of antibody made by com can deliver radio isotopes to tumor cells, and another made by soybeans can be used as treatment for genital herpes. Plant-made antibodies are inexpensive and there is little worry about contamination with pathogens that could infect people. Clinical trials have begun.

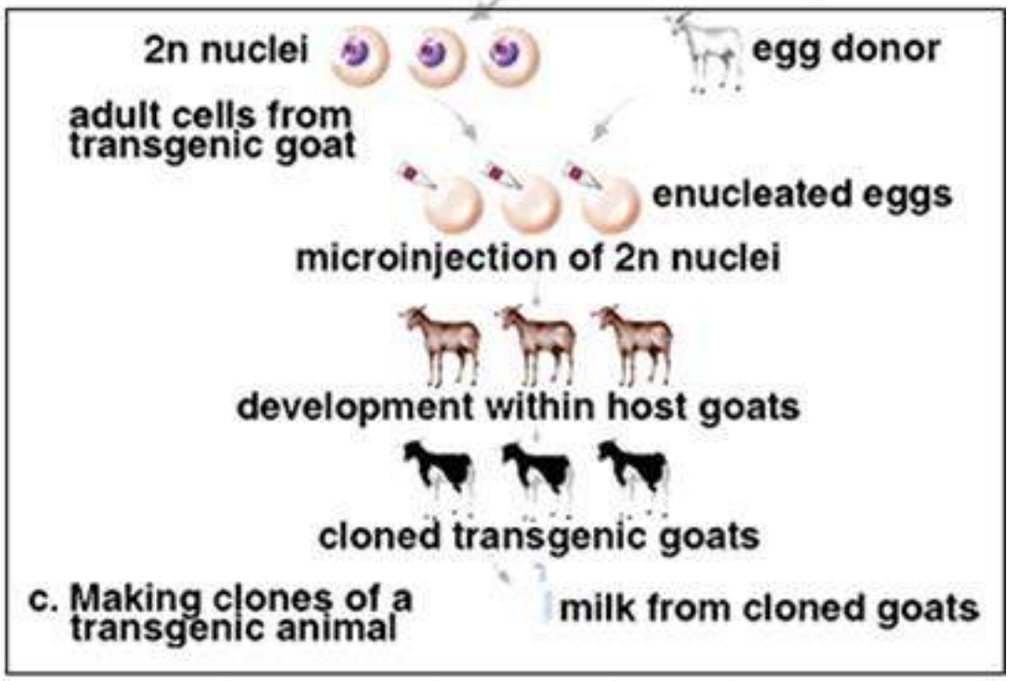
## Transgenic Animals

Techniques have been developed to insert genes into the eggs of animals. It is possible to micro eggs by hand, but another method uses vortex mixing. The eggs and silicon - carbide needles, and the needles make DNA can enter. When these eggs are fertilized, the resulting offspring are transgenic animals. Using this technique many types of animal eggs have taken up the gene for bovine growth hormone. The procedure has been used to produce larger fishes', cows, pigs, rabbits and sheep. Genetically engineered fishes are now being kept in ponds that offer no escape to the wild because there is much concern that they will upset or destroy natural ecosystems.

*(a) This goat is genetically engineered to produce antithrobin III , which is secreted in her milk*




*(b) The procedure to produce a transgenic animal.*




*(c) The procedure to clone a transgenic animal*

Gene pharming, the' use of transgenic farm animals to produce pharmaceuticals is being pursued by a number of firms. Genes that code for therapeutic, and diagnostic proteins are incorporated into the animal's DNA, and the proteins appear in the animal's milk. There are plans to produce drugs for the treatment of cystic fibrosis, cancer, blood diseases and other disorders. Antithrombin III, for preventing blood clot during surgery, is currently being produced by a herd of goats, and clinical trials have begun. Figure 23.10 out lines the procedure of producing transgenic mammals. DNA containing the gene of interest is injected into donor eggs. Following in vitro fertilization, the zygotes are placed in host females where they develop. After female offspring mature, the product is secreted in the milk. The scientists of United States Department

of Agriculture have been able to genetically engineer mice to produce human growth hormone in their urine instead of in milk. They expect to be able to use the same technique on larger animals. Urine is a preferable vehicle for a biotechnology product than milk because all animals in a herd urinate - only females produce milk; animals start to urinate at birth - females don't produce milk until maturity; and its easier to extract proteins from urine than from milk.

## Cloning of Transgenic Animals

Imagine that an animal has been genetically engineered to produce a biotechnology product. What would be the best possible method of getting identical copies of the animals? Asexual reproduction through cloning the animal would be the preferred procedure to use. Cloning is a form of asexual reproduction because it requires only the genes of that one animal. For many years it was believed that adult vertebrate animals could not be cloned. Although each cell contains a copy of all the genes certain genes are turned off in mature specialized cells. Different genes are expressed in muscle cells, which contract, compared to nerve cells, which conduct nerve impulses and to glandular cells, which secrete. Cloning of an adult vertebrate requires that all genes of an adult cells be turned on again if development is to proceed normally. It had long been thought this would be impossible. In 1997, scientists at the Roslin Institute in Scotland announced that they achieved this feat and had produced a cloned sheep called Dolly.

Since then calves and goats have been cloned. Figure 23.10 shows that after enucleated eggs have been injected with 2n nuclei of adult cells, they can be coaxed to begin development. The offspring have the genotype and phenotype of the adult that donated the nuclei; therefore, the adult has been cloned. In the procedure that produced cloned mice, the 2n nuclei were taken from cumulus cells.

Cumulus cells are those that cling to an egg after ovulation occurs. A specially prepared chemical bath was used to stimulate the eggs to divide and begin development. Now that scientists have a method to clone mammals, this procedure will undoubtedly be used routinely. In the United States, a presidential order prohibits the cloning of humans. But certain other countries are experimenting with the possibility.

# GENE THERAPY

Gene therapy is the insertion of genetic material into human cells for the treatment of a disorder. It includes procedures that give a patient healthy genes to make up for faulty genes and also includes the use of genes to treat various other human illnesses such as cancer and cardiovascular diseases.

*Animation 23.6: Gene Therapy*
*Source & Credit: Ethris*

There are two main methods used for gene therapy Ex-vivo and in vivo. Ex- vivo gene therapy is shown in Fig. 23.11. in which children in the severe combined immunodeficiency syndrome (SCID) is treated. These children lack an enzyme adenosine deaminase (ADA) that is involved in the maturation of T and B cells and, therefore, they are subjected to life threatening infections. Bone marrow stem cells are removed from the blood and infected with a retrovirus (RNA virus) that carries a normal gene for the enzyme then the cells are returned to the patient. Bone marrow stem cells are preferred for this procedure, because they divide to produce more cells with same genes. Patients who have undergone this procedure do have a significant improvement in their immune function that is associated with a sustained rise in the level of ADA enzyme activity in the blood

Among the many gene therapy trials, one is for the treatment of familial hypercholesterolemia a condition that develops when liver cells lack a receptor for removing cholesterol from the blood. The high levels of blood cholesterol make the patient subject to fatal heart attacks at a young age. In a newly developed procedure, a small portion of the liver is surgically excised and infected with a retrovirus containing a normal gene for the receptor. Several patients have experienced a lowering of serum cholesterol levels following this procedure.

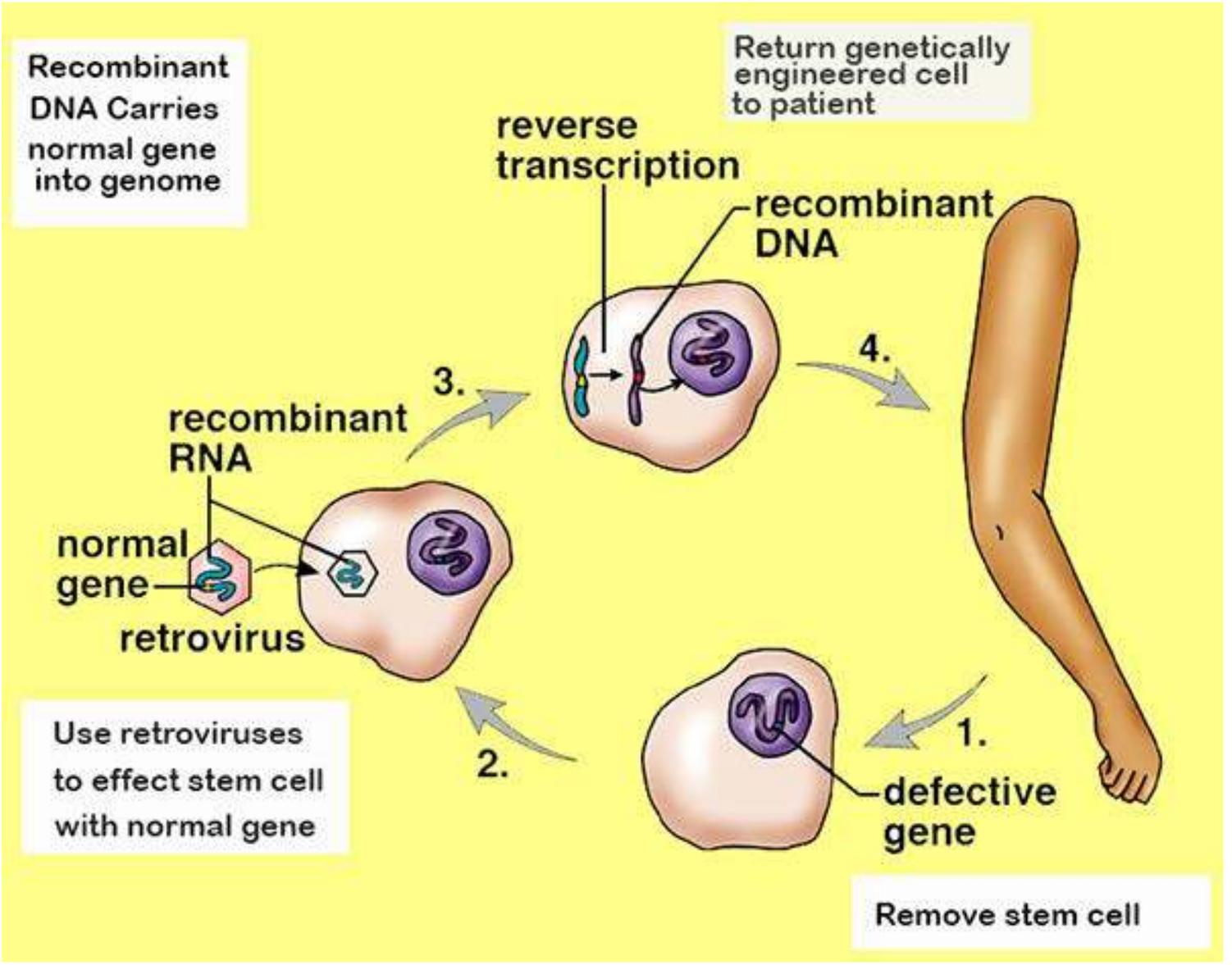



*Fig 23.11 Ex vivo gene therapy in human*

Cystic fibrosis patients lack a gene that codes for trans-membrane carrier of the chloride ion. Patients often die due to numerous infections of the respiratory tract. And 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 patient's nostrils. Due to limited gene transfer, this methodology has not as yet been successful.

Gene therapy is also being done to cancer patients, which makes them more tolerant of chemotherapy. In clinical trials researchers have given genes to cancer patient that either make healthy cells more tolerant of chemotherapy or make tumors more vulnerable to it. Once the bone marrow stem cells were protected it was possible to increase the level of chemotherapy to kill the cancer cells.

During coronary artery angioplasty, a balloon catheter is sometimes used to open up a closed artery. Unfortunately, the artery has a tendency to close up once again. But investigators have come up with a new procedure. The balloon is coated with a plasmid that contains a gene for vascular endothelial growth factor. The expression of the gene, which promotes the proliferation of blood vessels to bypass the obstructed area, has been observed in at least one patient.

Perhaps it will be possible to used in vivo therapy to cure hemophilia, diabetes. Parkinson disease, or AIDS. To treat hemophilia, patients could get regular doses of cells that contain normal clotting-factor genes or such cells could be placed in organoids, artificial organs that can be implanted in the abdominal cavity. To cure Parkinson's disease, dopamine-producing cells could be grafted directly into the brain.

## TISSUE CULTURE

Tissue culture is the growth of a tissue in an artificial liquid culture medium. German botanist Gottlieb Haberlandt said in 1902 that plant cells are totipotent - each cell has the full genetic potential of the organism - and, therefore, a single cell could become a complete plant. But it wasn't until 1958 that Cornell botanist F.C. Steward grew a complete carrot plant from a tiny piece of phloem. He provided the cells with sugars, minerals and vitamins, but he also added coconut milk. (Later it was discovered that coconut milk contains the plant hormone cytokinin). When the cultured cells began dividing, they produced a callus, an undifferentiated group of cells.

Then the callus differentiated into shoot and roots and developed into a complete plant.

Tissue culture techniques have by now led to micropropagation, a commercial method of producing thousands, even millions of identical seedlings in a limited amount of space. One favourite method to accomplish micro propagation is by meristem culture. If the correct proportions of auxins and cytokinin are added to a liquid medium, many new shoots will develop from a single shoot tip. When these are removed more shoots form. Since the shoots are genetically identical the adult plants that develop from them are called clonal plants, all having the same traits. Another advantage of meristem culture is that meristem, unlike other portions of a plant, is virus free, therefore the plants produced are also virus free (The presence of plant viruses weakens plants and makes them less productive).

Because plants are totipotent, it should be possible to grow an entire plant from a single cell. This, too has been done. Enzymes are used to digest the cell walls of a small piece of tissue, usually mesophyll tissue, from a leaf, and the result is naked cells without walls, called protoplasts. The protoplasts regenerate a new cell wall and begin to divide. These clumps of cells can be manipulated to produce somatic embiyos. Somatic embryos that are encapsulated in a protective hydrated gel (and sometimes called artificial seeds) can be shipped everywhere. It is possible to produce millions of somatic embryos at once in large tanks called bioreactors. This is done for certain vegetables like tomato, celery, asparagus and for ornamental plants like lilies, begonias and African violets. A mature plant develops from each somatic embryo. Plants generated from the somatic embryo vary somewhat because of mutations that arise; dunng the production process. These so called somaclonal variations are another way to produce new plants with desired traits.

Anther culture is a technique in which mature anthers are cultured in a medium containing vitamins and growth regulators. The haploid tube cells with in the pollen grains divide, producing proembryos consisting of as many as 20 to 40 cells. Finally the pollen grains rupture releasing haploid embryos. The experimenter can now generate a haploid plant, or chemical agent can be added that encourages chromosomal doubling. After chromosomal doubling the resulting plants are diploid but homozygous for all their alleles. Anther culture is a direct way to produce plants that express recessive alleles. If the recessive alleles govern desirable traits, the plants have these traits.

The culturing of plant tissues has led to a technique called cell suspension culture. Rapidly growing cultures are cut into small pieces and shaken in'a liquid nutrient medium so that single cells or small clumps of cells break off and form a suspension. These cells will produce the same chemicals as the entire plant. For example cell suspension cultures of Cinchona ledgeriana produce quinine and those of Digitalis lanata produce digitoxin. Scientists envision that it will be possible to maintain cell suspension cultures in bioreactors for the purpose of producing chemicals used in the production of drugs, cosmetics and agricultural chemicals. If so, it will no longer be necessary to farm plants for the purpose of acquiring the chemicals they produce.

## Genetic Engineering of Plants

Traditionally, hybridization, the crossing of different varieties of plants or even species, was used to produce plants with desirable traits. Hybridization, followed by vegetative propagation of the mature plants, generated a large number of identical plants with these traits. Today it is possible to directly alter the genes of organisms. Transgenic plants carry a foreign gene that has been introduced into their cells so that they have new and different traits.

Since a whole plant will grow from a protoplast, it is necessary only to place the foreign gene into a living- protoplast. A foreign gene isolated from any type of organism is placed in the tissue culture medium.

High-voltage electric pulses can then be used to create pores in the plasma membrane so that the DNA enters. In one of the first procedures carried out, a gene for the production of the firefly enzyme luciferase was inserted into tobacco protoplast and the adult plants glowed when sprayed with the substrate luciferin (Fig. 23.12).

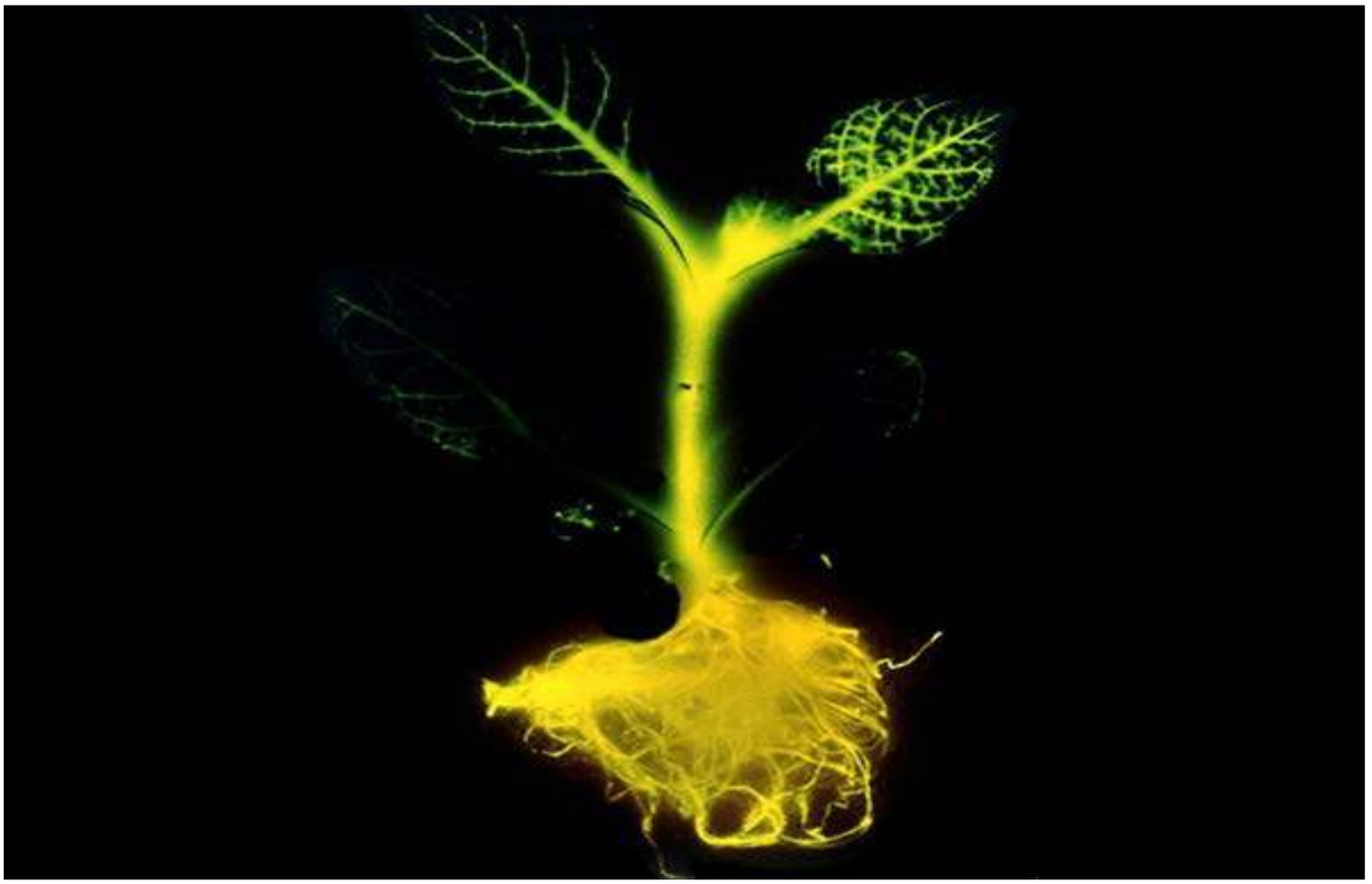


*Fig 23.12 Tabacoo plant containing Luciferase gene glows when sprayed with luciferin*

Unfortunately, the regeneration of cereal grains from protoplasts has been difficult. Com and wheat protoplasts produce infertile plants. As a result, other methods are used to introduce DNA into plant cells with intact cell wall. In one technique, foreign DNA is inserted into the plasmid of the bacterium *Agrobacterium,* which normally infects the plant cells. A plasmid can be used to produce' recombinant DNA. Recombinant DNA contains genes from different sources, namely those of plasmids and the foreign genes of interest. When the bacterium infects the plant the recombinant plasmid is introduced into the plant cells (Fig.23.12). In 1987, John C Sanford and Theodore M. Klein of Cornell University developed another method of introducing DNA into a plant tissue culture callus.

They constructed a device, called the particle gun, that bombards a callus with DNA coated microscopic metal particles. Then genetically altered somatic embryos develop into genetically adult plants. Many plants including com and wheat varieties have been genetically engineered by this method.

## Agricultural Plants with Improved Traits

Cotton, com, potato and soybean plants have been engineered to be resistant to either insect predation or herbicides that are judged to be environmentally safe. Some com and cotton plants have been produced that are both insect and herbicide resistant. In 1999, transgenic crops were planted on more that 70 million acres world wide and the acreage is expected to triple in about five years. If crops are resistant to a broad-spectrum herbicide and weeds are not then the herbicide can be used to kill the weeds. When herbicide resistant plants were planted weeds were easily controlled, less tillage was needed and soil erosion was minimized.

One aim of genetic engineering is to produce crops that have the improved agricultural or food quality traits such as those listed in the table below:

| **Improved Agricultural Traits** | |
|---|---|
| Herbicide resistant | Wheat, rice, sugar beets, canola |
| Salt tolerant | Cereals, rice, sugarcane |
| Drought tolerant | Cereals, rice, sugarcane |
| Cold tolerant | Cereals, rice, sugarcane |
| Improved yield | Cereals, rice, com, cotton |
| Modified wood pulp | Trees |

| **Improved Food Quality Traits** | |
|---|---|
| Fatty acid / oil content | Com, soybeans |
| Protein / starch content | Cereals, potatoes, soybeans, rice, com |
| Amino acid content | Com, soybean |
| Disease protected | Wheat, com, potatoes |

Production of salt tolerant plants had been a dream of genetic engineer. Recently salt - tolerant *Arabidopsis* has been produced. For this the scientists first identified a gene coding for a channel protein that transports Na+ along with H+ across a vacuole membrane. Isolating Na+ in a vacuole prevents it from interfering with plant metabolism. Then, the scientists cloned the gene and used it to genetically engineer plants that overproduce the channel protein. The modified plants thrived when watered with a salty solution. Irrigation, even into fresh water, inevitably leads to a salinization of soil that reduces crop yields. Today, crop production is limited by effects of salinization at about 50% of irrigated levels. The next step to solve this problem is to produce salt - tolerant crops. It is believed that the production not only of salt - but also drought and cold tolerant crops will reduce the need for added farm acreage by increasing agricultural yields that will provide enough food for a world population that is expected to nearly double by 2050.

Some progress has also been made to increase the food quality of crops. Soybeans have been developed that mainly produce the monounsaturated fatty acid, oleic acid, a change that may improve human health. These altered plants also produce vernolic acid and ricinoleic acid, derivatives of oleic acid that can be used as hardenes in paints and plastics. The necessary genes were derived from Vemonia and castor bean seeds and were transferred into the soybean genomes.

Genetic Engineering is also expected to increase productivity. To that end, stomata might be altered to boost carbon dioxide intake or cut down water loss. The efficiency of the enzyme RuBP carboxylase which captures C02 in plants could be improved. A team of Japanese scientists is working on introduc ing the C4 photosynthetic cycle into rice. Unlike C3 plants, C4 plants do well in hot dry weather. These modifications would require a more complete engineering of plant cells than the single gene transfers' that have been done so far.

## Production of Products

Single gene transfers have allowed plants to produce various products such as human hormones, clotting factors and antibodies. One type of antibody made by com can deliver radioisotopes to tumor cells and another made by soybeans can be used as treatment for genital herpes clinical triats have begun.

Recently, a group of scientists from Biosource Technologies located in Vacaville, California reported that they have been able to use the tobacco mosaic virus as a vector to introduce a human gene into adult tobacco plants in the field. Note that this technology by passes the need for tissue culture completely. Tens of grams of a-galactosidase, an enzyme that can be used to treat a human lysosome storage disease, were harvested per acre of tobacco plants. And it only took thirty days to get tobacco plants to produce antigens to treat non-Hodgkin's lymphoma after being sprayed with a genetically engineered vims.

## EXERCISE

**Q.1. Fill in the blanks.**

1. The use of polymerase chain reaction (PCR) creates a _____ of copies in a laboratory test tube.
2. _____free living organisms in the environment that have had a foreign gene inserted into them.
3. _____known sequences of DNA that are used to find complementary DNA strands; can be used diagnostically to determine the presence of particular gene.
4. _____production of many identical copies of a gene.
5. _____self duplicating ring of accessory DNA in the cytoplasm of bacteria.

## Q.3. Short questions.

1. How and why transgenic animals that secrete a product are often cloned?
2. Explain two primary goals of Human Genome Project. What are possible benefits of the project?
3. Explain and give examples of ex vivo and in vivo gene therapies in humans?

## Q.4. Extensive questions.

1. What is the methodology for producing recombinant DNA to be used in gene cloning?
2. What is a genomic library, how would you locate a gene^of.interest in the library?
3. What is the polymerase chain reaction (PCR), amfftow is it carried out to produce multiple copies of a DNA segment?
4. What is DNA finger printing, a process that utilizes the entire genome?
5. For what purpose have bacteria, plants and animals been genetically altered?-

CHAPTER

# 24

# Evolution

*Animation 24: Evolution*
*Source & Credit: Wikispaces*

Questions of origins of earth and life on it have been on the minds of humans since prehistoric times. Many of us are also concerned with questions of origin: How old is the planet earth? How long has life been on earth? How did life arise on earth? How did a certain animal species come into existence? Answers for these questions come from scientific inquiry. In this chapter we will study some aspects of organic evolution.
Evolution refers to the processes that have transformed life on earth from its earliest forms to the vast diversity that we observe today. Evolutionary change is based mainly on the interactions between populations of organisms and their environments. Whenever we say or hear the word evolution, name of Darwin comes in our mind immediately. In fact, he was the first person who argued from evidence that species were not specially created in their present forms, rather they had evolved from ancestral species. He also proposed a mechanism for evolution, which he termed Natural Selection.

## CONCEPT OF EVOLUTION VS SPECIAL CREATION

In a bid to explain the cause of diversity of life and interrelationship among living organisms, two schools of thought emerged in the earlier 19th century. Creationists believed in the Theory of Special Creation, whereas evolutionists believed in the Theory of Natural Selection. According to the theory of special creation, all living things came into existence in their present forms especially and specifically created by Nature. Among the scientists who believed in divine creation was Carolus Linnaeus (1707-1778).

*Animation 24.1: Evolution*
*Source & Credit: wifflegif*

| Scientist's Name | Life Span | Achievements |
|---|---|---|
| Linnaeus | 1707-1778 | Sought and found order in the diversity of life. He introduced binomial nomenclature for naming species. |
| Lamarck | 1744-1829 | Published his theory of evolution. |
| Malthus | 1766-1834 | Published Essay on the "Principle of Population". |
| Cuvier | 1769-1832 | Contributed much to the science of Palaeontology and explained Earth's history by catastrophism. |
| Lyell | 1797-1875 | Published Principles of Geology. |
| Darwin | 1809-1882 | 1. Voyage of the Beagle<br>2. Began his notebooks on the origin of species.<br>3. Wrote his essay on the origin of species. |
| Mendel | 1822-1884 | Published papers on inheritance. |
| Wallace | 1823-1913 | Sent his theory to Darwin. |

The idea that organisms might evolve through time, with one type of organism giving rise to another type of organism, is an ancient one, existing from the days of Aristotle. Aristotle recognized that organisms ranged from relatively simple to very complex structures. However, the present day concept of evolution is based on a known history (Table 24.1).

Let us now discuss some details of the work done by these scientists. As you know, Carolus Linnaeus in the eighteenth century classified organisms. He grouped similar species in the same genus and similar genera in one family. But as a natural theologian, he believed that species were permanent creations. A century later, the taxonomic system of Linnaeus became a focal point in Darwin's arguments for evolution.

## EVOLUTION FROM PROKARYOTES TO EUKARYOTES

One of the speculations trying to explain the origin of life is that it may have begun deep in the oceans, in underwater hot springs called hydrothermal vents. These vents could have supplied the energy and raw materials (for the origin and survival of early life forms. A group of bacteria, called archaeobactiria-that tolerate temperatures up to 120°C and seem to have undergone less evolutionary ihange than any other living species supports this vent hypothesis.

The nutrients produced in the primitive environment would have limited early life., If life were to continue, another source of nutrients was needed. Photosynthesis, probably freed living organisms from a dwindling supply of nutrients. The first photosynthetic organisms probably used hydrogen sulfide as a source of hydrogen for reducing carbon dioxide to sugars. Later, water served this same purpose, and oxygen liberated by photosynthetic reactions began to accumulate in the atmosphere. Earth and its atmosphere slowly began to change.

Ozone in the upper atmosphere began to filter ultraviolet radiation from the sun, the reducing atmosphere slowly became an oxidizing atmosphere, and at least some living organisms began to utilize oxygen. About 420 million years ago, enough protective ozone had built up to make life on land possible. Ironically, the change from a reducing atmosphere to an oxidizing atmosphere also meant that life could no longer arise abiotically .The first cells were most likely very simple prokaryotic forms. The prokaryotes may have arisen more than 3.5 billion years ago. Eukaryotes are thought to have first appeared about 1.5 billion years ago. The eukaryotic cell might have evolved when a large anaerobic (living without oxygen) amoeboid prokaryote ingested small aerobic (living with oxygen) bacteria and stabilized them instead of digesting them. This idea is known as the endosymbiont hypothesis (Fig.24.la) and was first proposed by Lynn Margulis. According to this hypothesis, the aerobic bacteria developed into mitochondria, which are the sites of aerobic respiration and most energy conversion in eukaryotic cells. The possession of these mitochondria like endosymbionts brought the advantage of aerobic respiration to the host.

Flagella (whiplike structures) may have arisen through the ingestion of prokaryotes similar to spiral-shaped bacteria called spirochetes. Ingestion of prokaryotes that resembled present-day cyanobacteria could have led to the endosymbiotic development of chloroplasts in plants.

Another hypothesis for the evolution of eukaryotic cells proposes that the prokaryotic cell membrane invaginated (folded inward) to enclose copies of its genetic material (Fig. 24.1b). This invagination resulted in the formation of several double membrane-bound entities (organelles) in a single cell. These entities could then have evolved into the eukaryotic mitochondrion, nucleus, chloroplast etc.

Whatever the exact mechanism for the evolution of the eukaryotic cell might be, the formation of the eukaryotic cell led to a dramatic increase in the complexity and diversity of life-forms on the earth. At first, these newly formed eukaryotic cells existed only by themselves. Later, however, some probably evolved into multicellular organisms in which various cells became specialized into tissues, which, in turn, formed organs for many different functions. These multicellular forms then adapted themselves to life in a great variety of environments.

*Animation 24.2: Evolution from Prokaryots to Euokaryot*
*Source & Credit: Ameoba Sisters*

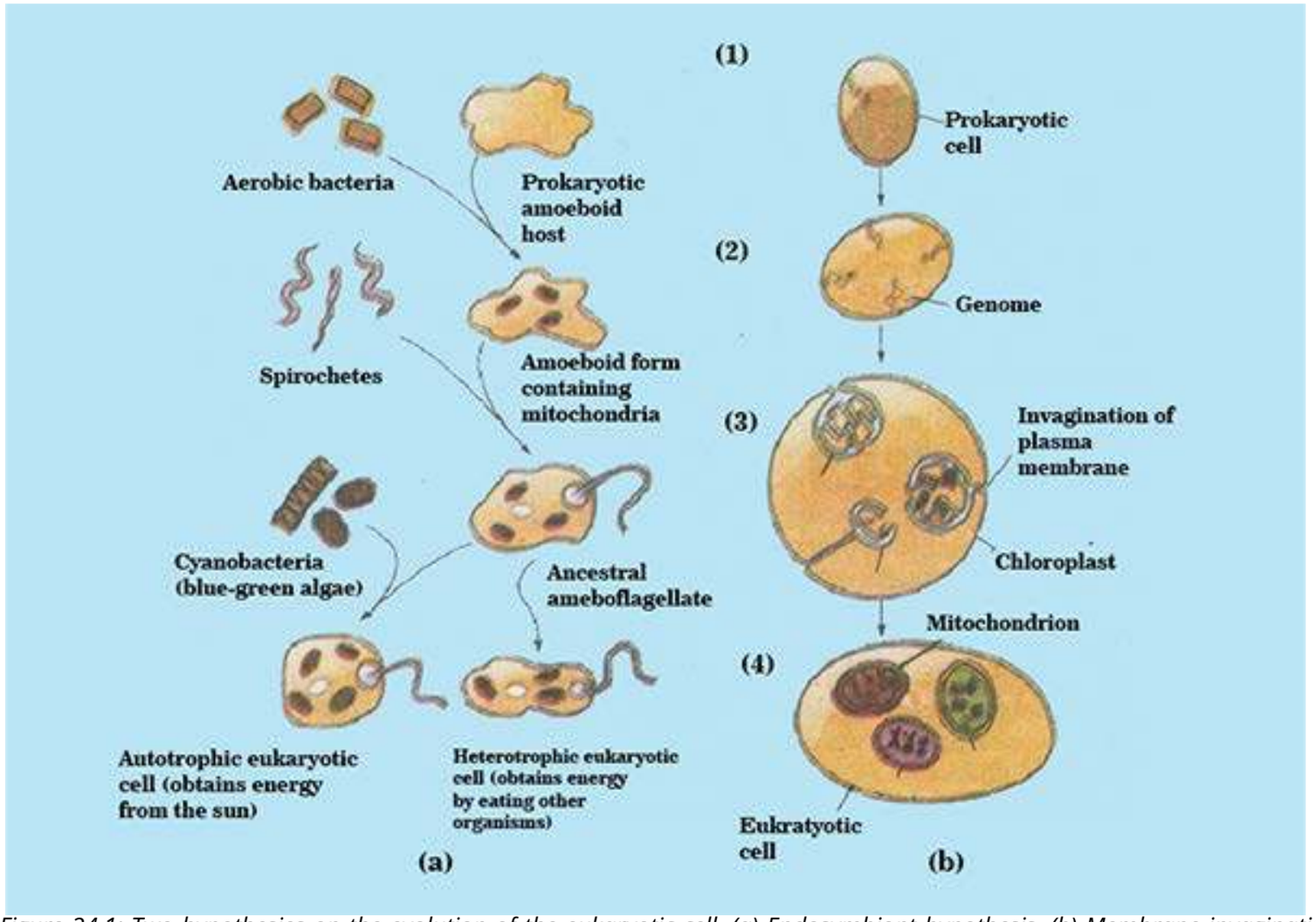



*Figure 24.1: Two hypothesies on the evolution of the eukaryotic cell. (a) Endosymbiont hypothesis, (b) Membrane invagination hypothesis. (1) A prokaryotic cell (2) Duplicates its genetic material (genome) (3) The plasma membrane then invaginates to form double membrane-bound organelles, and the individual genomes separate from each other (4) The nuclear genome eventually enlarges, while the other organelle genomes lose many of their genes, resulting in a eukaryotic cell.*

## INHERITANCE OF ACQUIRED CHARACTERISTICS

Toward the end of the eighteenth century, several naturalists suggested that life had evolved along with the evolution of earth. But only one of Darwin's predecessors developed a comprehensive model that attempted to explain how life evolves. Jean Baptiste Lamarck (1744-1829) published his theory of evolution in 1809, the year Darwin was bom. Lamarck was in-charge of invertebrate collection at the Natural History Museum in Paris. He presented a mechanism to explain how specific adaptations evolve. Lamarck argued that those parts of the body used extensively to cope with the environment become larger and stronger, while those that are not used deteriorate.

Among the examples Lamarck cited were the blacksmith developing a bigger bicep in the arm that works the hammer and giraffe stretching its neck to new lengths in pursuit of leaves to eat. The second idea Lamarck adopted, was called the inheritance of acquired characteristics. In this concept of heredity, the modifications an organism acquires during its lifetime can be passed along to its offspring'e.g. the long neck of the giraffe, Lamarck reasoned, evolved gradually as the cumulative product of a great many generations of ancestors stretching higher and higher. However, now we know that acquired characteristics cannot be inherited.

## Charles Darwin

Charles Darwin was born in Shrewsbury, in Western England, in 1809. He joined ' the expedition on Beagle to South American coastline. He observed and collected thousands of specimens of diverse fauna and flora of South America. He noticed that the fauna and flora of the different regions of the continent had a definite South American stamp, very distinct from the life forms of Europe. Furthermore, the South American fossils that Darwin found, though clearly different from modem species, were distinctly South American in their resemblance to the living plants and animals of that continent.

A particularly puzzling case of geographical distribution was the fauna of the Galapagos islands. Most of the animal species on the Galapagos live nowhere else in the world, although they resemble species living on the South American mainland. It was as though the islands were colonized by plants and animals that strayed from the South American mainland and then diversified on the different islands. Among the birds Darwin collected on the Galapagos were 13 types of finches that, although quite similar, seemed to be different species. Some were unique to individual islands, while other species were distributed on two or more islands that were close together.

After returning to Great Britain in 1836, Darwin perceived the origin of new species and adaptations as closely related processes. A new species would arise from an ancestral form by the gradual accumulation of adaptations to different environments, separated from original habitat by geographical barriers. Over many generations, the two populations could become dissimilar enough to be designated as separate species. This is apparently what happened to the ***Galapagos*** finches.

By the early 1840s, Darwin had worked out the major features of his theory of natural selection as the mechanism of evolution. In 1844, Darwin wrote a long essay on the origin of species and natural selection.

But before it could be published Alfred Wallace, a young naturalist working in the East Indies developed a theory of natural selection essentially identical to Darwin's. Wallace's paper, along with extracts from Darwin's unpublished 1844 essay, were presented to the Linnaean Society of London on July 1, 1858. Darwin quickly finished **The Origin of Species** and published it the next year. In this book Darwin developed two main points:

### 1. Descent with Modification :

Darwin believed in perceived unity in life, with all organisms related through descent from some common ancestor that lived in the remote past. In the Darwinian view, the history of life is like a tree, with multiple branching and rebranching from a common trunk all the way to the tips of the living twigs, symbolic of the current diversity of organisms. At each fork of the evolutionary tree is an ancestor common to all lines of evolution branching from that fork.

### 2. Natural Selection and Adaptation :

Darwin suggested that populations of individual species become better adapted to their local environments through natural selection. Darwin's theory of natural selection was based on the following observations.

1. Production of more individuals than the environment can support, leads to a struggle for existence among individuals of a population, with only a fraction of offspring surviving each generation.
2. Survival in the struggle for existence is not random,, but depends in part on the hereditary constitution of the surviving individuals. Those individuals whose inherited characteristics fit them best to their environment are likely to leave more offspring than the less fit individuals.
3. This unequal ability of individuals to survive and reproduce will lead to a gradual change in a population, with favourable characteristics accumulating over the generations thus leading to the evolution of a new species.

## Neo-Darwinism - The modern evolutionary synthesis

The **Origin of Species** convinced most biologists that species are **products of** evolution. An important turning point for evolutionary theory was the birth of population genetics, which emphasizes the extensive genetic variation within populations and recognizes the importance of quantitative characters. With progress in population genetics in the 1930s, Mendelism and Darwinism were reconciled, and the genetic basis of variation and natural selection was worked out. Thus, a comprehensive theory of evolution that became known as the **modern synthesis or Neo-Darwinism** was developed in the early 1940s. It is called a synthesis because it integrated discoveries and idea« from many different fields, including paleontology, taxonomy, biogeography, of course, population genetics.

## Evidences of Evolution

Evolution leaves observable signs. Darwin's theory of evolution was mainly based on the evidence from the geographical distribution of species and from the fossil record. However, there have been many evidences as biology progressed. New discoveries, continue to validate the evolutionary view of life. Let us discuss now some of the evidences.

Biogeography : It was the geographical distribution of species— biogeography— that first suggested the idea of evolution to Darwin. Islands have many species of plants and animals that are endemic but closely related to species of the nearest mainland or neighboring island. Consider armadillos, the armored mammals that live only in America. The evolutionary view of biogeography predicts that contemporary armadillos are modified descendants of earlier species that occupied these continents, and the fossil record confirms that such ancestors existed.

The Fossil Record : The succession of fossil forms is a strong evidence in favour of evolution. It provides a visual record in a complete series showing the evolution of an organism. For instance, evidence from biochemistry, molecular biology, and cell biology places prokaryotes as the ancestors of all life, and predicts that bacteria should precede all eukaryotic life in the fossil record. Indeed, the oldest known fossils are prokaryotes.

Another example is the chronological appearance of the different classes of vertebrate animals in the fossil record. Fossil fishes, the earliest vertebrates, with amphibians next, followed by reptiles, then mammals and birds. This sequence is consistent with the history of vertebrate descent. The evolution of horse provides an example of such a history.

Fossils are either the actual remains or - traces of organisms that lived in ancient geological times. The organism may be embedded in sand, resin or ice, or an impression or cast is made of the body parts, the tissue being replaced or petrified by silica or calcium carbonate minerals. Most fossils are found in sedimentary rocks.

Comparative Anatomy : Anatomical similarities between species grouped in the same taxonomic category bring another support to the theory of the Descent with modification. For example, the same skeletal elements make up the forelimbs of human, cats, whales, bats, and all other mammals, although these appendages have very different functions.

The basic similarity of these forelimbs is the consequence of mammals from a common ancestor. The amis, wings, flippers, and forelegs of different mammals are variations on a common anatomical theme that has been modified for divergent functions. Similarity in characteristics resulting from common ancestry is known as homology, and such anatomical signs of evolution are called homologous structures. Comparative anatomy supports that evolution is a remodeling process in which ancestral structures that functioned in one capacity become modified as they tale on new functions. The flower parts of a flowering plant are homologous. They are considered to have evolved from leaves, to form sepals, petals, stamens and carpels

Homologous organs are functionally different but structurally alike e.g. Fore limbs of man, bat, horse, whale etc. are example of divergent evolution. Analogous organs are functionally alike but structurally different e.g. wings of bat, birds and insects etc. are examples of convergent evolution.

The oldest homologous structures are vestigial organs, rudimentary structures of marginal, if any, use to the organism. Vestigial organs are historical remnants of structures that had important functions in ancestors but are no longer essential presently. For instance, the skeletons of whales and some snakes retain vestiges of the pelvis and leg bones of walking ancestors, (Fig. 24.2) vermiform appendix in carnivores, ear muscles in man etc.

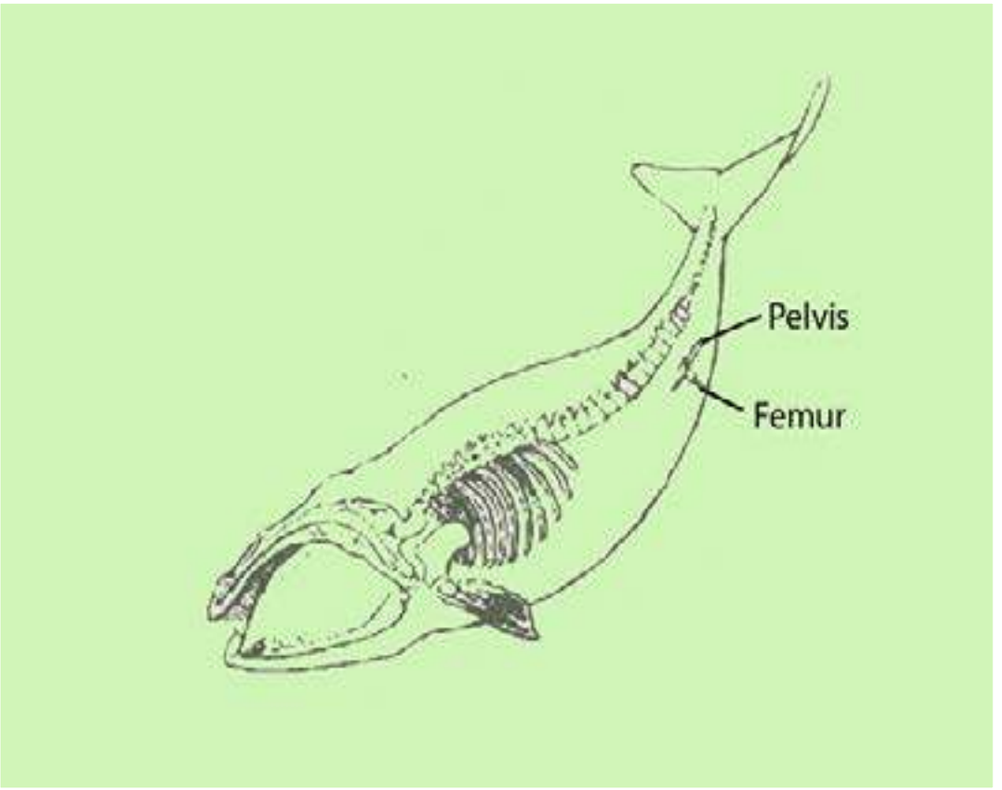
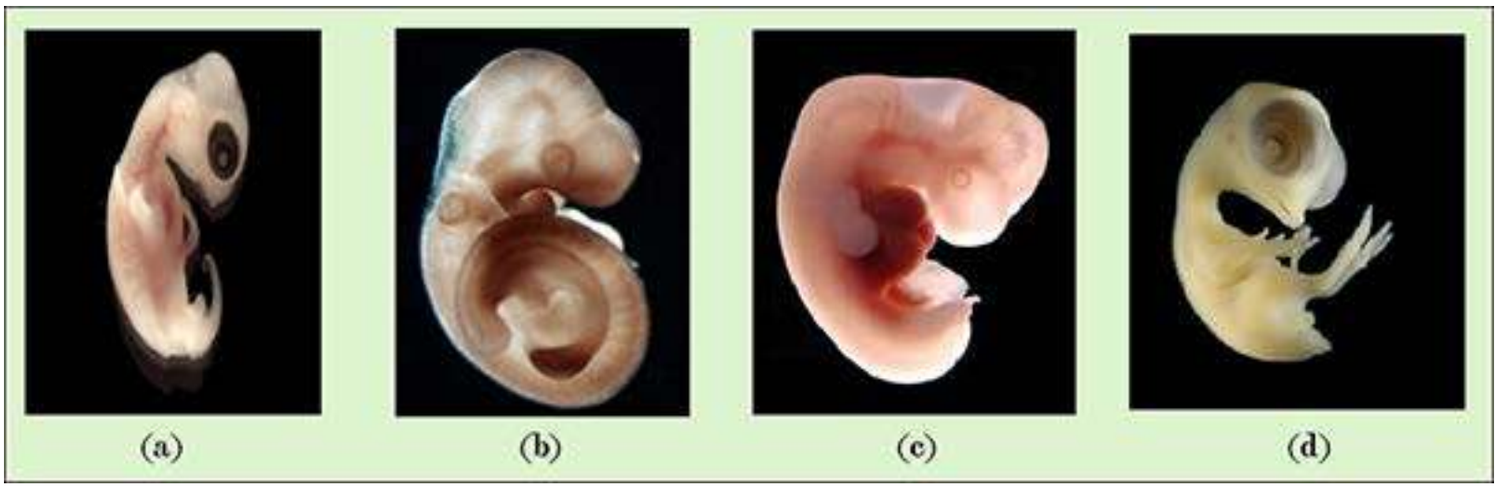



*Fig. 24.2: The whale retains pelvic and leg bones as useless vestiges*




*ig. 24.3 Homologies among vertebrates are clearly evident early in development, as the photos reveal. Embryo (a) turtle, (b) mouse, (c) human, (d) chick.*

Comparative Embryology : Closely related organisms go through similar stages in their embryonic development. For example, all vertebrate embryos go through a stage in which they have gill pouches on the sides of their throats. At embryonic stage of development, similarities between fishes, frogs, snakes, birds, humans, and all other vertebrates are much more apparent than differences (Fig.24.3). As development progresses, the various vertebrates diverge more and more, taking on the distinctive characteristics of their classes. In fish, for example, the gill pouches develop into gills; in terrestrial vertebrates, these-embryonic structures become modified for other functions, such as the eustachian tubes that connect the middle ear with the throat in humans.

Comparative embryology can often establish homology among structures, such as gill pouches, that become so altered in later development that their common origin would not be apparent by comparing their fully developed forms.

**Molecular Biology:** Evolutionary relationships among species are reflected in their DNA and proteins—in their genes and gene products. If two species have genes and proteins with sequences of monomers that match closely, the sequences must have been copied from a common ancestor. For example, a common genetic code brings evidence that all life is related. Molecular biology has thus provided strong evidence in support of evolution as the basis for the unity and diversity of life. Similarly, taxonomically remote organisms, such as humans and bacteria, have some proteins in common. For instance, cytochrome c, a respiratory protein is found in all aerobic species.

## NATURAL SELECTION AND ARTIFICIAL SELECTION

Natural selection occurs through an interaction between the environment and the variability inherent in any population. Darwin found evidence in artificial selection, the breeding of domesticated plants and animals. Humans have modified other species over many generation by selecting individuals with the desired traits as breeding stock. The plants and animals we grow for food bear little resemblance to their wild ancestors. From the changes achieved by artificial selection within a relativ ely short period of time, Darvviq postulated that natural selection operating over vast spans of time could account for the entire diversity of life. Population is a group of inter-breeding individuals belonging to a particular species and sharing a common geographic area.

Natural selection can amplify or diminish only those variations that are heritable. It is noteworthy to say that adaptations that an organism acquires by its own actions are not heritable. The specifics of natural selection are regional and timely; environmental factors vary from place to place and from time to time. An adaptation in one situation may be useless or even detrimental in other circumstances. An example of natural selection in action is the evolution of antibiotic resistance in bacteria.

## POPULATION, GENE POOL, ALLELE AND GENOTYPE FREQUENCIES

A population is a localized group of individuals belonging to the same species. For now, we will define a species as a group of populations that have the potential to interbreed in nature. Each species has a geographical range within which individuals are not spread out evenly, but are usually concentrated in several localized populations. A population may be isolated from others of the same species, exchanging genetic material only rarely. Such an isolation is particularly common for populations confined to widely separated islands, unconnected lakes, or mountain ranges separated by lowlands. Within a population individuals are concentrated in centers and are more likely to interbreed with members of the same population than with members of other populations. Therefore, individuals near a population center are, on average, more closely related to one another than to members of other populations.

The total aggregate of genes in a population at any one time is called the population's gene pool. It consists of all alleles at all gene loci in all individuals of the population. For a diploid species, each locus is represented twice in the genome of an individual, who may be either homozygous or heterozygous.

*Animation 24.3: Gene Pool*
*Source & Credit: S-Cool*

If all members of a population are homozygous for the same allele, that allele is said to be **fixed** in the gene pool. More often, there are two or more alleles for a gene, each having relative frequency (proportion) in the gene pool. Let us consider an example. Imagine a wildflower population with two varieties contrasting in flower color. An allele for pink flowers, which we will symbolize by A, is completely dominant over an allele for white flowers, symbolized by a. Suppose these are the only two alleles for this locus in the population. Our imaginary population has 500 plants. Twenty have white flowers because they are homozygous for the recessive allele; their genotype is aa. Of the 480 plants with pink flowers, 320 are homozygous (AA) and 160 are heterozygous (Aa). Since these are diploid organisms, there are a total of lOOOcopies of genes for flower color in the population. The dominant allele accounts for 800 of these genes (320x2 = 640 for AA plants, plus 160x1 = 160 for An individuals). Thus, the frequency of the A allele in the gene pool of this population is 80%, or 0.8. And since there are only two allelic forms of the gene, the a allele must have a frequency of 20%, or 0.2. Related to these allele frequencies are the frequencies of genotypes. In our model wildflower population, these frequencies are: AA=0.64 (64%) (320 out of 500 plants), Aa=0.32 (160/500), and aa = 0.04 (20/500).

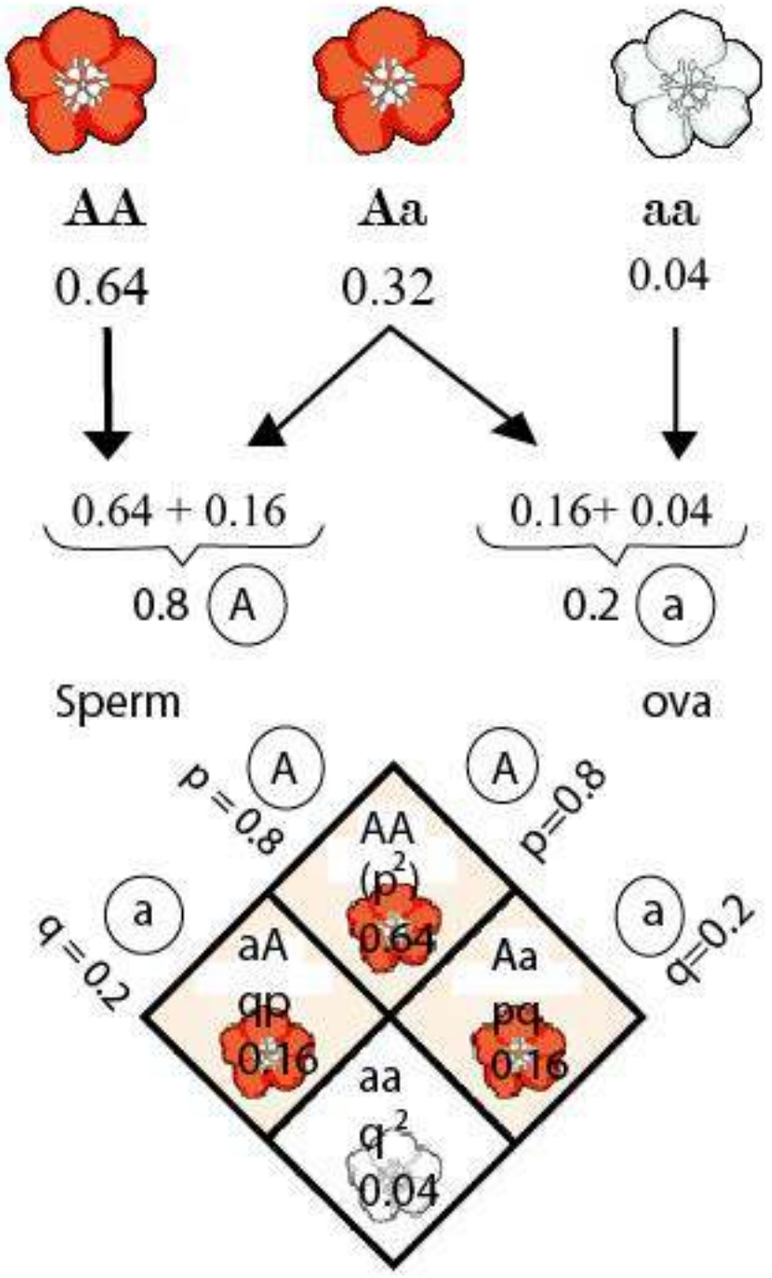



*Figure 24.4: The Hardy-Weinberg theorem. The genetic structure of a non evolving population remains constant over the generations. Sexual recombination alone will not alter the relative frequencies of alleles or genotypes, (p = frequency of A; q = frequency of a)*

## Hardy-Weinberg Theorem

The frequencies of genotypes of non evolving populations are described by Hardy-Weinberg theorem. Hardy-Weinberg theorem is named for the two scientists who derived the principle independently in 1908. It states that the frequencies of alleles and genotypes in a population's gene pool remain constant over the generations unless acted upon by agents other than sexual recombination. So shuffling of alleles due to meiosis and random fertilization has no effect on the overall genetic structure of a population. A general formula, called the Hardy- Weinberg equation is used for calculating the frequencies of alleles and genotypes in populations at equilibrium.

For a gene locus where only two alleles occur in a population, population geneticists use the letter p to represent the frequency of one allele and the letter q to represent the frequency of the other allele. In the imaginary wildflower population, p=0.8 and <7=0.2. Note that p+q= 1; the combined frequencies of all possible alleles must account for 100% of the genes for that locus in the population. If there are only two alleles and we know the frequency of one, the frequency of other can be calculated:

Ifp + q-1, then 1-p = q, or l-q - p

When gametes combine their alleles to form zygotes, the probability of generating an AA genotype is $p^2$. In the wildflower population, p-0.8, and $p^2$=0.64, the probability of an A sperm fertilizing an A ovum to produce an AA zygote. The frequency of individuals homozygous for the other allele (aa) is $q^2$, or 0.2x0.2=0.04 for the wildflower population. There are two ways in which an Aa genotype can arise, depending on which parent contributes the dominant allele. Therefore, the frequency of heterozygous individuals in the population is 2pq (2x0.8x0.2=0.32, in our example). If we have calculated the frequencies of all possible genotypes correctly, they should add up to 1:

$P + 2pq + q^2 = 1$

Frequency of AA | Frequency of Aa plus aA | Frequency ofaa

For our wildflowers,this is 0.64 + 0.32 + 0.04=1*

* In fact the Hardy-Weinberg equation is a binomial expansion: $(p+q)^2$ or $p^2+2pq+q^2$

## Factors affecting gene frequency

Many factors can alter gene frequency. Out of these five affect the proportion of homozygotes and heterozygotes enough to produce significant deviations form the proportion claimed by Hardy Weinberg principle. They are reflected in the table below.

**Table 24.2 Factors for evolutionary change**

| Factor | Description |
|---|---|
| Mutation | The ultimate source of all changes; individual mutations occur so rarely that mutation alone does not change allele frequency much. |
| Migration | A very potent agent of change, migration locally acts to prevent evolutionary changes by preventing populations that exchange members from diverging from one another. Emigration and immigration of members of a population, cause disturbance in the gene pool. |
| Genetic drift | It is the change in frequency of alleles at a locus that occurs by chance. In small populations, such fluctuations may lead to the loss of particular alleles. This may occur in a small population when a few individual fail to reproduce and then genes are lost from the population. |
| Non-random mating | Inbreeding is the most common form; it does not alter allele frequency, but lessens the proportion of heterozyote individuals. Individuals with certain genotypes sometimes mate with one another more commonly than would be expected on a random basis. This is called non-random mating, causing the frequencies of particular genotypes to differ greatly from those predicted by the 1 lardy-Weinberg principle. |
| Selection | Some individuals leave behind more progeny than others, and the rate at which they do so is affected by their inherited characteristics. This is called selection. Selection can be artificial selection or natural selection. In artificial selection, the breeders select for the desired characters. In natural selection, the environment plays this role, thus affecting the proportions of gene in a population. |

## ENDANGERED SPECIES

Extinction has been the fate of most plant and animal species. It is a natural process that will continue. In recent years, however, the threat to the welfare of wild plants and animals has increased dramatically—mostly as a result of habitat destruction. Tropical rain forests, the most threatened areas on the earth, have been reduced to 44% of their original extent. In certain areas, such as Ecuador, forest coverage has been reduced by 95%. This decrease in habitat has resulted in- tens of thousands of extinctions. Accurately estimating the number of extinctions is impossible in areas like rain forests, where taxonomists have not even described most species. We are losing species -that we do not know exist and we are losing resources that could lead to new medicines, foods, and textiles, Other causes of extinction include climate change, pollution, and invasions from foreign species. Habitats other than rain forest—grasslands,'marshes, deserts, and coral reefs—are also being seriously threatened.

*Animation 24.4: Endangeres Species*
*Source & Credit: TES*

An endangered species is in imminent danger of extinction throughout its range (where it lives). A threatened species is likely to become endangered in the near future. Saving species requires more than preserving a few remnant individuals. It requires a large diversity of genes within species groups to promote species survival in changing environments. This genetic diversity requires large populations of plants and animals. Preservation of endangered species depends on a multifaceted conservation plan that includes the following components:

1. A global system of national parks to protect large tracts of land and wildlife corridors that allow movement between natural areas.
2. Protected landscapes and multiple-use areas that allow controlled private activity but also retain value as a wildlife habitat.
3. Zoos and botanical gardens to save species whose extinction is imminent.

In Pakistan. Cheetah. Tiger. Asian lion. Indian rhino. Cheer pheasant. Crocodile and Gaviul have been declared extinct. While. Indus dolphin. Blackbuck, Common leopard. Great Indian bustard. Houbara bustard. White-headed duck and Marbled teal are among the animal near to extinction.

Deserts, Sub-mountianous tract and Wetlands are habitats in peril. We must protect them rapidly. Endangered species of plants have been recorded to more than 500.

*Animation 24.5: Endangeres Species*
*Source & Credit: Education World*

## EXERCISE

### Q1 Fill in the blanks.

1. Archaebacteria can tolerate high temperature sup to_____
2. The first eukaryote appeared about_____ years ago.
3. _____ presented the theory of the origin of species by means of Natural Selection.
4. _____developed a theory of natural selection essentially identical to Darwin's.
5. _____are considered to be the ancestors of all life.
6. A respiratory protein called_____is found in all aerobic organisms.
7. Total aggregate of genes in a population at any time is called its_____
8. Hardy Weinberg theorem describes a_____population.
9. _____ is a series of changes in the genetic composition of a population over time.
10. Level of classification between species and family is called_____.
11. Hardy Weinbeig equation is binomial expansion of_____.
12. An_____species is in imminent danger of extinction throughout its range.
13. A _____ is a localized group of individuals belonging to the same species.
14. The first photosynthetic organisms used_____as source of hydrogen for reducing carbon dioxide to sugars.
15. _____ published an essay on The Principle of Population'.

## Q.2 Short questions.

1. What are hydrothermal vents?
2. State Endosymbiont hypothesis.
3. Define population genetics.
4. How does fossil record provide evidence of evolution?
5. Explain the term homology with a suitable example.
6. What are vestigial organs? Give two examples.
7. How are evolutionary relationships reflected in DNA and proteins?
8. State Hardy Weinberg theorem.
9. What is the difference between endangered species and threatened species?
10. Name any five species, declared extinct in Pakistan.

## Q.4 Extensive Questions

1. What are the endangered species? What measures could be adapted for their preservation?
2. State and explain Hardy-Weinberg theorem.
3. Describe evidences of evolution from any five branches of biology.
4. How did evolution proceed from prokaryotes to eukaryotes? Analyze the Darwin's theory of natural selection as mechanism of evolution.

CHAPTER

25

# ECOSYSTEM

*Animation 25: Ecosystem*
*Source and Credit: Microbewiki*

## INTRODUCTION

The term ecology comes from the Greek words oikos. meaning “the family household”, and logy, meaning “ the study of”. The term originally was coined by the German zoologist Ernst Haeckel in 1866. He called it oecologic and defined it as the study of the relationship of animals (organisms) to their environment.

Environment includes not only the physical but also the biological conditions under which an organism lives. Relationship includes interactions with the physical world and with members of other species and the same species.

## ECOSYSTEM

The major unit of ecology is the ecosystem. Organisms interact with their environment within the confines of the ecosystem. The eco part of the word is related to the environment and the system part means a collection of related parts that function as a unit. The ecosystem consists of two basic interacting components, the living or biotic, and the physical or abiotic factors.(Fig.25.1)

Biotic components consist of animals, plants, fungi, micro-organisms etc. and abiotic components are atmosphere, climate, soil, and water.

The various kinds of organisms that inhabit an ecosystem make up populations. **Population** is a group of interbreeding individuals (same species) occurring together in space and time. Populations of plants and animals in the ecosystem do not function independently of each other.

*Animation 25: Ecosystem*
*Source and Credit: Water for Life*

Some populations compete with other populations for resources, such as food, water, or space. In some cases, one population is the food resource for another. Two populations may mutually benefit each other. All populations within an ecosystem are known as a **community** and are in one or another manner interconnected to one another.

The ecosystem has many levels. On our level, individual organism, including man, both responds to and influences the physical environment. At the next level, individuals of the same species form population, that can be described in terms of number, growth rate, and age distribution. Further, individuals of these populations interact among themselves and with individuals of other species and form a community.

Major types of ecosystems, those that occupy broad geographical regions are called biomes. Each biome consists of a combination of plants and animals in the fully developed climax community, and is characterized by a uniform life-form of vegetation such as grass or coniferous trees. Some major terrestrial biomes are forest, grass land, and desert. Combined the biomes of earth together form the planetary ecosystem.

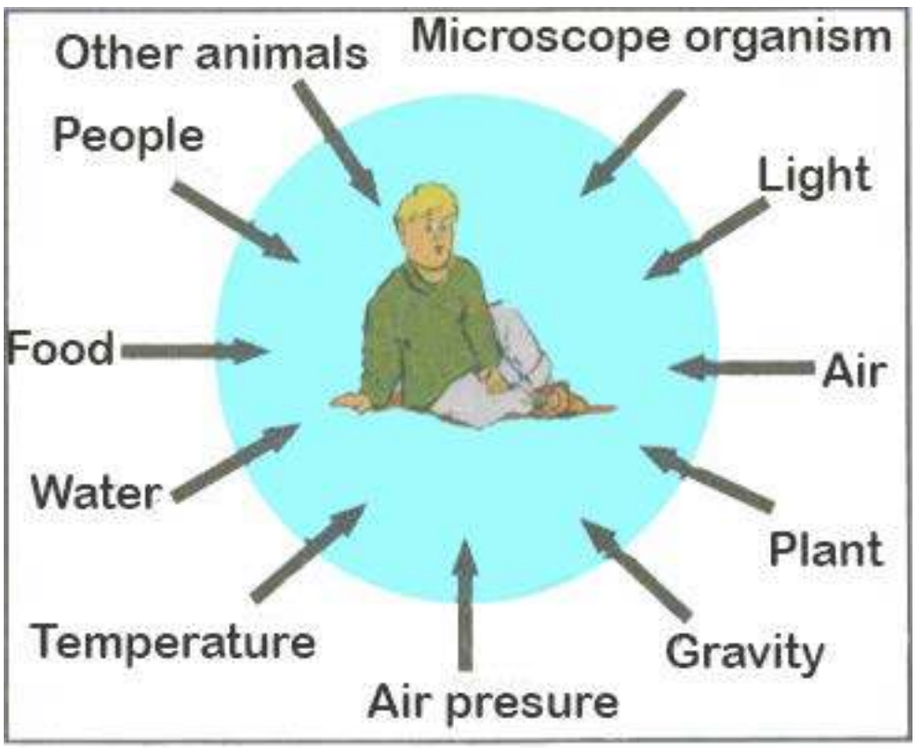



*Fig. 25.1 Your environment*

## Biosphere

Biosphere is a thin layer of earth in which all living organisms exist. Organisms within the biosphere not only adapt themselves to the environment but also interact to modify and control chemical and physical conditions of the biosphere. An organism lives in a habitat.

An organism responds to a variety of environmental factors, and only when all of them are within the range of tolerance, it can inhabit a location. The actual location of place where an organism lives is called its **habitat.**

In 1917, Joseph Grinnell an American ornithologist first proposed the term niche in ecology. The habitat and niche are closely related. Niche is defined as the ultimate distributional unit within which a species is restrained by the limitations of its physical structure and its physiology. Charles Eltan considered the niche, the basic role of an organism in the community-what it does in and for living community, its relationship to its food and enemies. In other words, he defined the niche as the species's occupation.

It refers to a profession or job of an organism. Ecosystems are composed of organisms with different jobs or ways of life, particularly concerned with feeding, the role of a particular species within an ecosystem, including all aspects of its interaction with the living and the non-living environment.

"A niche is defined as the role a species plays in a community including behavior and influence."

Ecological niche with habitat also specifies how the organism gets its supply of energy and materials - for example organism's predators, prey and competitors as well as its behavior and interactions are considered elements of its niche.

In addition, niche includes all the physical factors of the environment necessary for survival, such as range of temperature, amount of humidity, the pH of the water and soil.

## Autecology

Ecology is the study of relationship of living organisms to their environment. When you are studying a single population's relationship to its environment it will be called as autecology. For example, you are studying 50 to 100 plants of soybean in order to know the effect of water pollution on their growth and yield, you are studying the single or one population of soybean plant, this study is autecology.

## Synecology

Growth responses of individual plants to their environment are a complex factor. One factor can aggaravate the other factor. These factors interact with one another. Complexity of environment depends upon the combination of various factors. The study of the relationship of different communities (grouping of populations) to their environment is called **synecology** or **community ecology.**

When you study only one population, at different places in an environment it will be autecology. But when you see all the populations at the same time it will be synecology. In synecology (the study of a community) you have to see the various aspects of community like the origin, structure and composition of the community. You have to consider the history of community and also its dynamics because community is not a fixed entity but different changes are going to occur at different times. While studying the community we come across three levels of integration : (i) individual (ii) population (iii) community.

*Fig. 25.2(a) A population of birds*

*Fig. 25.2(b) A community*

## COMPONENTS OF ECOSYSTEM

As discussed earlier the ecosystem can be divided into two main components.

### 1. Biotic Components

Biotic components include all living organisms including plants and animals supported by biosphere. Biosphere is spread out over the surface of plant earth extending about 8-10 kilometers to the upper reaches of atmosphere and also the same distance into the depths of oceans.

*Animation 25.2:Biotic v/s Abiotic Components*
*Source and Credit: Ameoba Sisters*

## 2. Abiotic Components

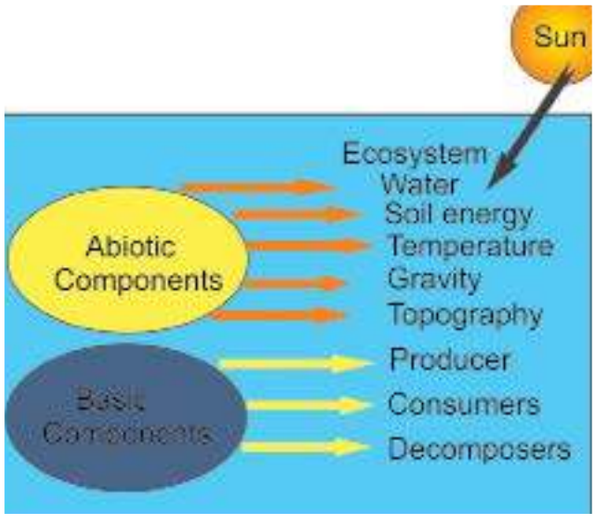
Abiotic components include all non-living components air, water, and soil. In ecological term they are called as : (a) atmosphere — (atmo - air, sphere - place) (b) hydrosphere — (hydro - water, sphere - place) (c) lithosphere — (litho - earth,soil, sphere - place).

## Processes in Ecosystem and Interaction between Biotic and Abiotic Components:

The main processes occurring in an ecosystem include feeding and the circulation of chemical elements, together with the energy flowing through the ecosystem.

An ecosystem is made up of three main components, the producers, the consumers and the decomposers. All are concerned with the feeding processes, the circulation of chemical elements and the flow of energy.

**Producers** are the autotrophs green photosynthetic plants, which capture and bring light energy into the ecosystem. They are able to manufacture organic food from simpler inorganic substances. They are autotrophic organisms.




**Consumers** are all the organisms, primarily animals, which obtain energy directly or indirectly from the producers as ready-made organic food. They are mainly heterotrophic organisms.

**Decomposers** are mainly the fungi and bacteria, which obtain their energy from the dead and decaying plants and animals. They release chemical elements as ions. The main chemical ions are nitrates, ammonia, phosphates, potassium and calcium.

## Food Chain

Basically, all animals depend on plants for their food. Eagle may eat blue bird, but blue bird eats insects like caterpillar and caterpillar feeds on grass or green leaves. This is an example of a simple food chain.

## Food Web

Food web is actually “the combination of many food chains”. Food webs are not really as simple as described in Fig. 25.3, because most animals eat more than one type of food at different times as fox does not feed entirely on rabbit but also takes beetles, rats etc.

All the food chains and food webs begin with a green plant (producer) and may consist of three to five links or trophic levels (Fig. 25.3).

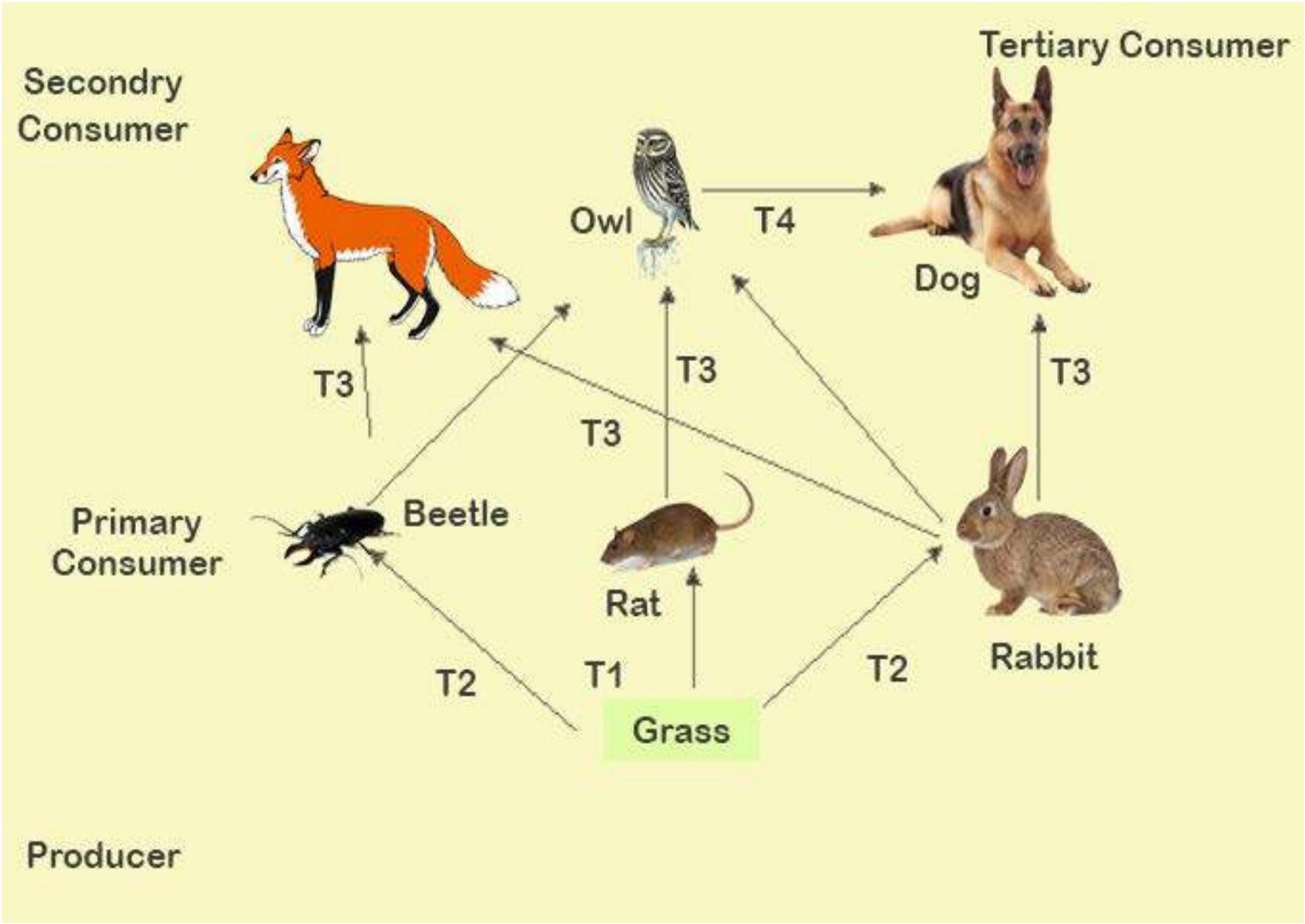



*Fig 25.3 Food Web and various trophic level*

In a food web you will find more complex trophic levels or food links. In fig (25.3). food chain $T_1$ is the first trophic producer level, Includes all green plants, grass, and phytoplankton; $T_2$ , second trophic level - primary consumers; $T_3$, third trophic level - secondary consumers; $T_4$ ,fourth trophic level - tertiary consumers.

The variety of pathways in a food web helps to maintain the stability of the ecosystem. For example, owls prey on rabbits and mice. If a disease reduces the rabbit population; fewer plants are consumed. The larger plant population produces more fruits and seeds, which, in turn, support a larger mouse population. The increased number of mice becomes the major food source for the owls. The rabbit population gradually increases, and these primary consumers once again become a food source for the owls. Thus nature maintains a balance.

## SUCCESSION

Succession is a squence of changes in the community structure of an ecosystem over a period of time. Community changes alter the ecosystem in ways that favours the competitors and species to replace their predecessors in somewhat predictable manner until a stable, self sustaining climax community is reached. Succession is a kind of “community relay” in which assemblages of plants and animals replace the earlier ones in a sequence that is at least somewhat predictable. The precise changes occurring during succession are as diverse as the environments in which succession occurs, but certain general stages can be recognized.

*Animation 25.3: Succession*
*Source and Credit: Ameoba Sisters*

In each case succession is initiated by a few hardy invaders called **pioneers** and it ends with a diverse and relatively stable **climax community.**

## Two Major Forms of Succession

Succession on dry land takes two major forms, primary succession and secondary succession. During **primary succession,** an ecosystem is forged from bare rock, sand or clear glacial pool where there was no trace of previous life.

The formation of an ecosystem from scratch is a process often requiring thousands of years. During secondary succession a new ecosystem develops after an existing ecosystem is disturbed as in case of forced fire or an abandoned farm field. Secondary succession happens much more rapidly than primary succession because the previous community has left its mark in the form of improved soil and seeds. Primary succession starting in a pond is called hydrosere and that on a dry soil or habitat is called xerosere. Plants growing in xeric condition are called xerophytes, which are able to withstand prolonged periods of water shortage. Succullent plants such as the cacti have water stored in large parenchyma tissue, others have leaf modification. Xerosere has the following different stages.

**Crustose lichen stage :** A crust is any external protective surface and crustose means crusts on the substratum. Special types of lichens get impregnated in the form of crust. They can live in extreme conditions. Sometimes, their surface is wet due to rain and dew- drops. They absorb water during dry season. They are quiescent or dormant, normally desiccated during dry season.

Foliage lichen stage: In this stage the lichens are just like crumpled leaves attached at one point. It produces shade to the crustose lichens as a result of which their growth is reduced or decreased. The area becomes rough , as more and more fissures and depressions develop. Common examples are, Dermatocarpon, Parmellia, etc. At this stage other plants invade called moss stage, because now soil is more porous with some litter of lichens.

Moss stage : This is the third stage with mosses like, Polytrichum, Tortula etc. They compete with lichens for water and penetrate much deeper into the soil as compared to the lichens, adding more humus to the soil.

Herbaceous (plant) stage : Small seedling of herbaceous plants now establish due to the more availability of moisture, humus and soil for anchorage.

Shrub stage : Shrubby plants now start growing, dominating and shadowing herbaceous plants which die to add more humus to the soil.

Climax forests: The soil is improved to an extent that it now allows the growth/ establishment of woody plants. The shade of these plants inhibits the growth of most plants other than mosses, lichens, a few ferns etc. Woody plants dominate and this stage in succession remains essentially the same if nothing changes in the environment to upset the balance. Because it is a stable stage in succession, the woody forest is considered to be the climax stage for this region (Fig. 25.4).

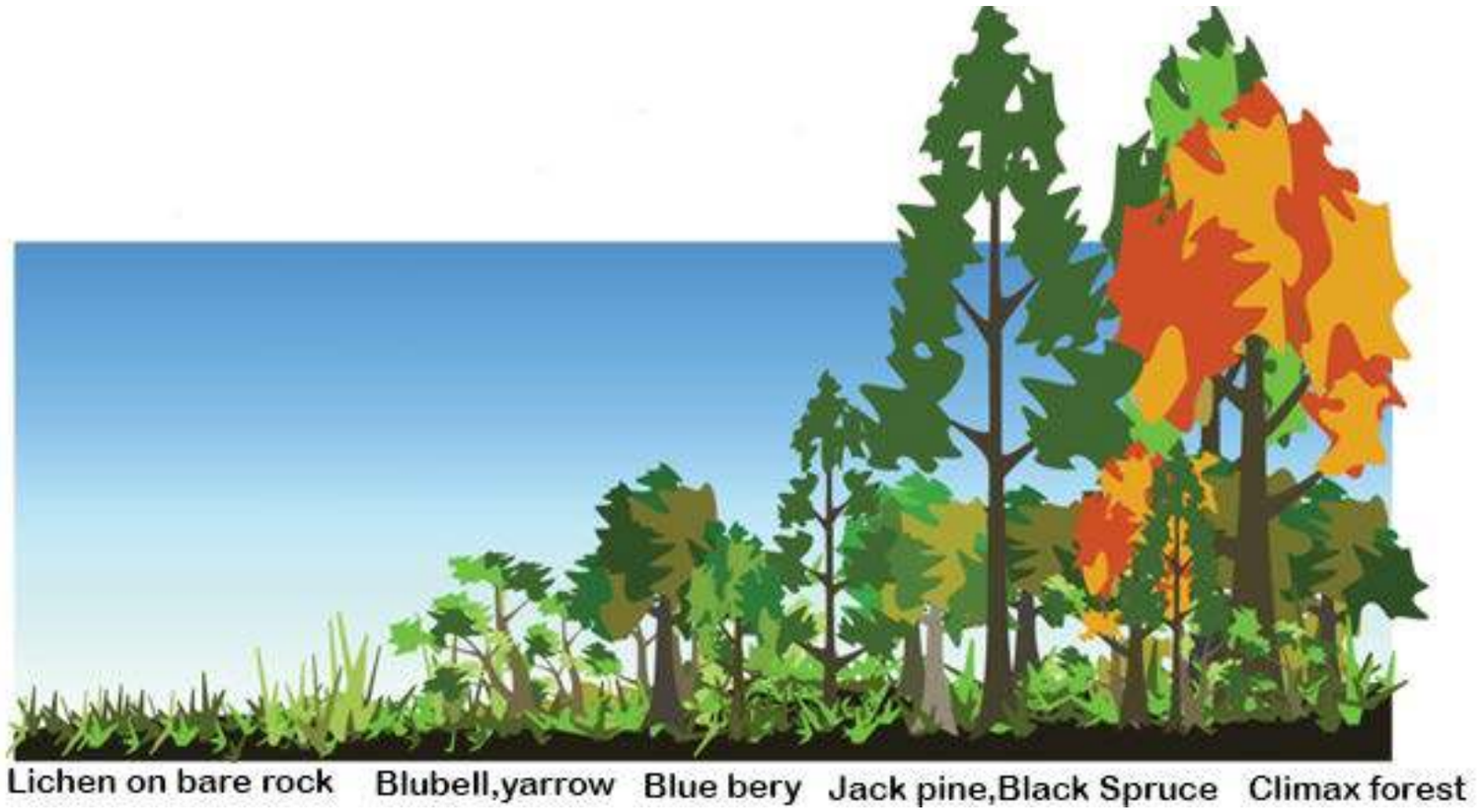



*Fig. 25.4 Primary Succession*

**Seral communities (seral stages)**

Bare ground → Lichens+algae → Mosses+ferns → Grasses → Shrubs → Trees

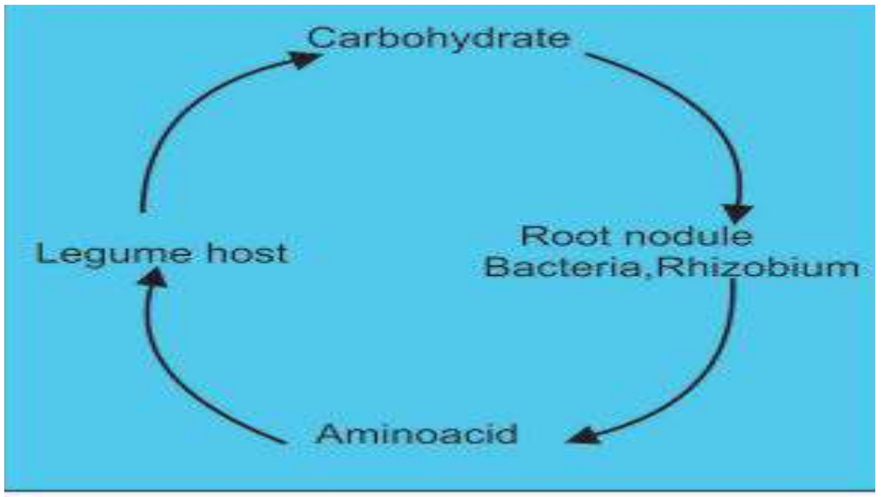
Pioneer community — Climax community

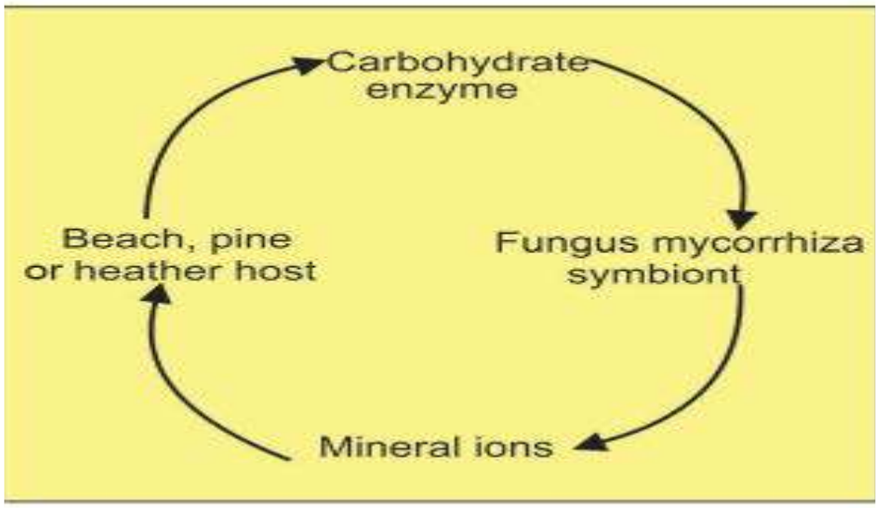
## Predation and its Significance

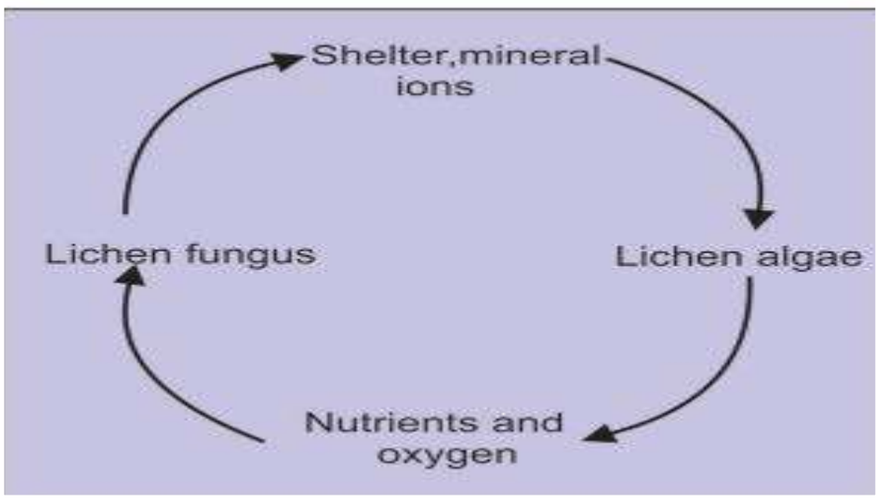
An animal that preys on other animals is a predator. A predator is a consumer. The animal that is caught and eaten is the **prey.** The over all process is called predation.

The sizes of populations of predator and prey are related to each other. The size of each population is determined by the size of the other. If the number of prey is large, this leads to an increase in the number of predators; as predator feeds upon the prey, the number of prey begins to fall. The number of predators also decreases, since they have smaller food supply. As the number of predators decreases, the number of prey begins to increase. This food relationship of predator - prey creates a "cycle".

Examples: cat/mouse, fox/rabbit, seal/fish, frog/mosquito, hawk/small birds etc.



## Parasitism and its Significance

This is an association between a host and a parasite, which involves providing the parasite with food, protection and conditions for its survival. The parasite may or may not harm the host. Diseases in living organisms, which are caused by parasites are called **infestations.** Parasites may be **ectoparasites,** living outside the body of the host e.g. fungi causing dandruff in hair and **endoparasites,** living inside the body of the host e.g. tape worm in intestine of man.

## Symbiosis

It is an association between two organisms, which brings benefit to both the organisms.

Root Nodules: The legume plant , pea and bean, are the hosts to symbiont bacteria, which inhabit the roots forming root nodules. The bacteria in the root nodules fix nitrogen in soil from air, converting it into amino acid, which the host uses. In return, host provides bacteria with food and protection.

Mycorrhiza : Mycorrhiza is an association between the roots of plants growing in acid soil and certain fungi. The host is pine, beech or heather and it provides the fungus with an enzyme to digest carbohydrates in leaf litter. In return, the fungus symbiont passes mineral ions from the soil to the host.

## Mutualism:

It is the relationship between two organisms in which both the organisms benefit from each other. Lichens are an example of mutualism between a fungus and an alga. The relationship between insects and flowering plants is another example. The insect gets nectar from the flower; the flowers are able to reproduce because the insects carry pollen from flower to flower.

### Lichens:

Lichen is a dual organism composed of symbiotic association of an alga living within a fungus mycelium. The lichens grow on exposed rock surfaces and are important colonizers of bare ground.

## Commensalism

In this type of relationship only one organism benefits from the relationship. The other is not affected at all. For example, sharks may have small fish called remoras attached to them. As the shark feeds, the remoras pick up the scraps. The remoras benefit . from this relationship, the shark is not affected at all.

## Grazing

Many animals like rabbits, goats, sheeps, cows, buffaloes and horses feed on grasses. This mode of feeding is called grazing and these animals are called grazers. These animals live in pastureland where they feed on grasses, herbs and shrubs. If too many animals are kept on pasture, they eat the grasses down to the root though grasses are more resistant than herbaceous plants and have ability to regrow very fast, but the hooves of grazing animals trample the soil into hard layer as a result of which rain water will not penetrate this soil. It runs off from the upper surface removing the fertile topsoil with it. The final result of over - grazing is totally barren land. Grazing is very important factor in determining the ecosystem. Moderate grazing is very helpful to maintain grassland ecosystem. It destroys the competitors and helps the grass to grow well. Over grazing may lead to the transformation of a grassland into a desert.

## BIOGEOCHEMICAL CYCLES

The chemical elements essential for life in living organisms are called biogenic elements or nutrient elements. Macronutrients are elements required by organisms in large amount like water, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur and calcium. Micronutrients are elements required by organisms in small quantity or in trace amount like zinc, molybdenum, iron, iodine. The nutrient cycles are also called biogeochemical cycles as the nutrients move from living to nonliving to living portions of ecosystem in a cyclic manner.

### The Nitrogen Cycle

The chief reservoir of nitrogen is the atmosphere; in fact nitrogen makes up 78 percent of the gases in atmosphere. Since most living things, however, cannot use elemental atmospheric nitrogen to make amino acids and other nitrogen containing compounds, they are dependent on nitrogen present in soil minerals. So, despite the abundance of nitrogen in the atmosphere, shortage of nitrogen in the soil is often the major limiting factor in plant growth. The process by which this limited amount of nitrogen is circulated and re-circulated throughout the world of living organisms is known as the nitrogen cycle (Fig. 25.5).

*Animation 25.4: Nitrogen Cycle*
*Source and Credit: MicrobeWiki*

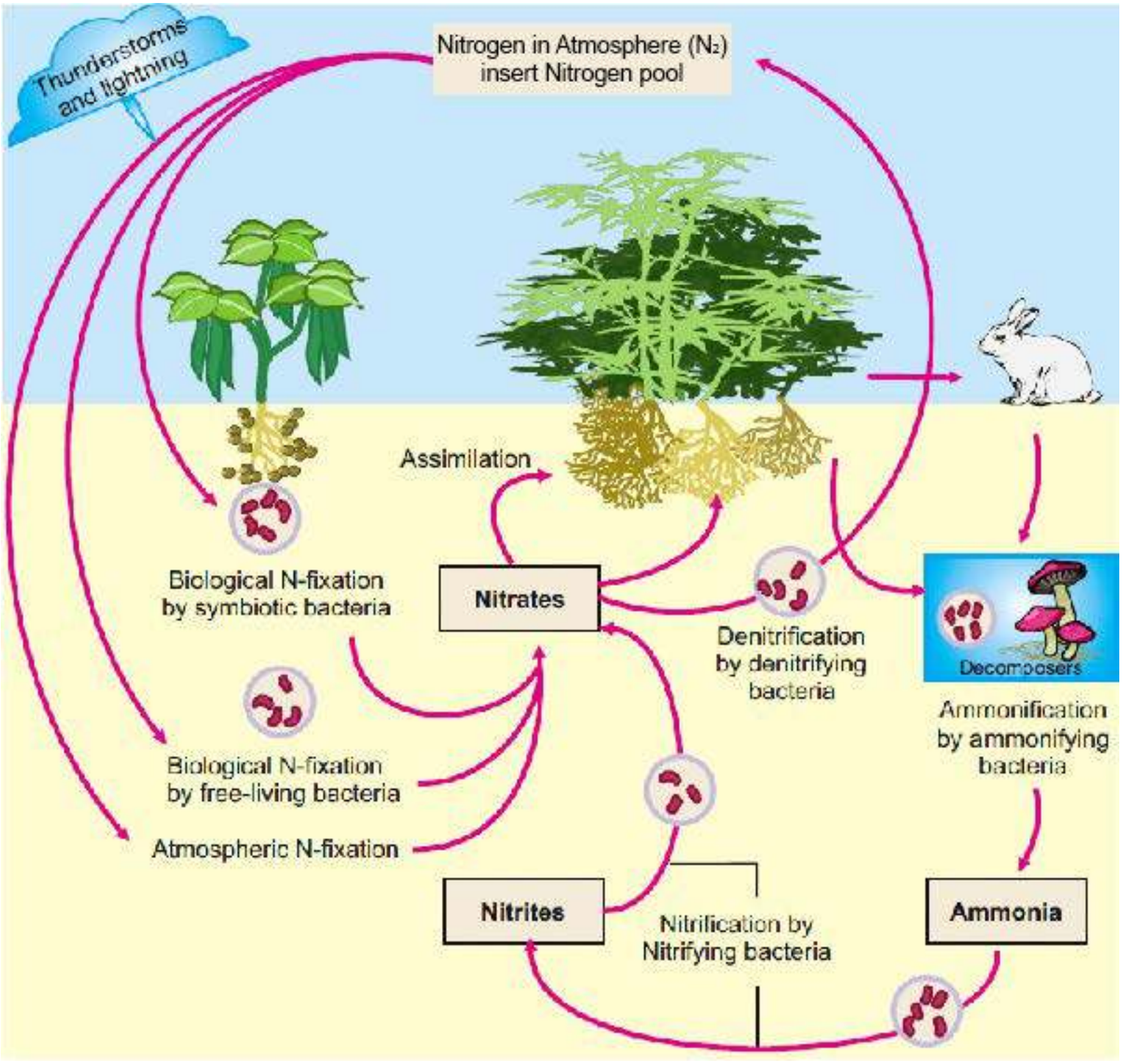



*Fig 25.5 The Nitrogen Cycle*

Three principal stages of this cycle are, **ammonification, nitrification, and assimilation.**

Much of the nitrogen found in the soil is the result of the decomposition of organic materials and is in the form of complex organic compounds, such as proteins, amino acids, nucleic acids and nucleotides. These nitrogenous compounds are usually rapidly decomposed into simple compounds by soil-dwelling organisms chiefly bacteria and fungi. These microorganisms use the proteins and amino acids and release excess of ammonia ($NH_3$) or ammonium ions ($NH_4^+$ ). This process is known as ammonification.

Several bacteria in soil are able to oxidize ammonia or ammonium ions, this oxidation is known as nitrification.

Although the plants can utilize ammonium directly, nitrate is the form in which most nitrogen moves from the soil into the roots. Once nitrate is within the plant cell, it is reduced back to ammonium. In contrast to the nitrification, this assimilation process requires energy. The ammonium ions thus formed are transferred to carbon - containing compounds to produce amino - acids and other nitrogenous organic compounds needed by the plant.

*Animation 25.5: Nitrogen Cycle*
*Source and Credit: OrganicSoilTechnology*

## Nitrogen Depletion and its Remedies

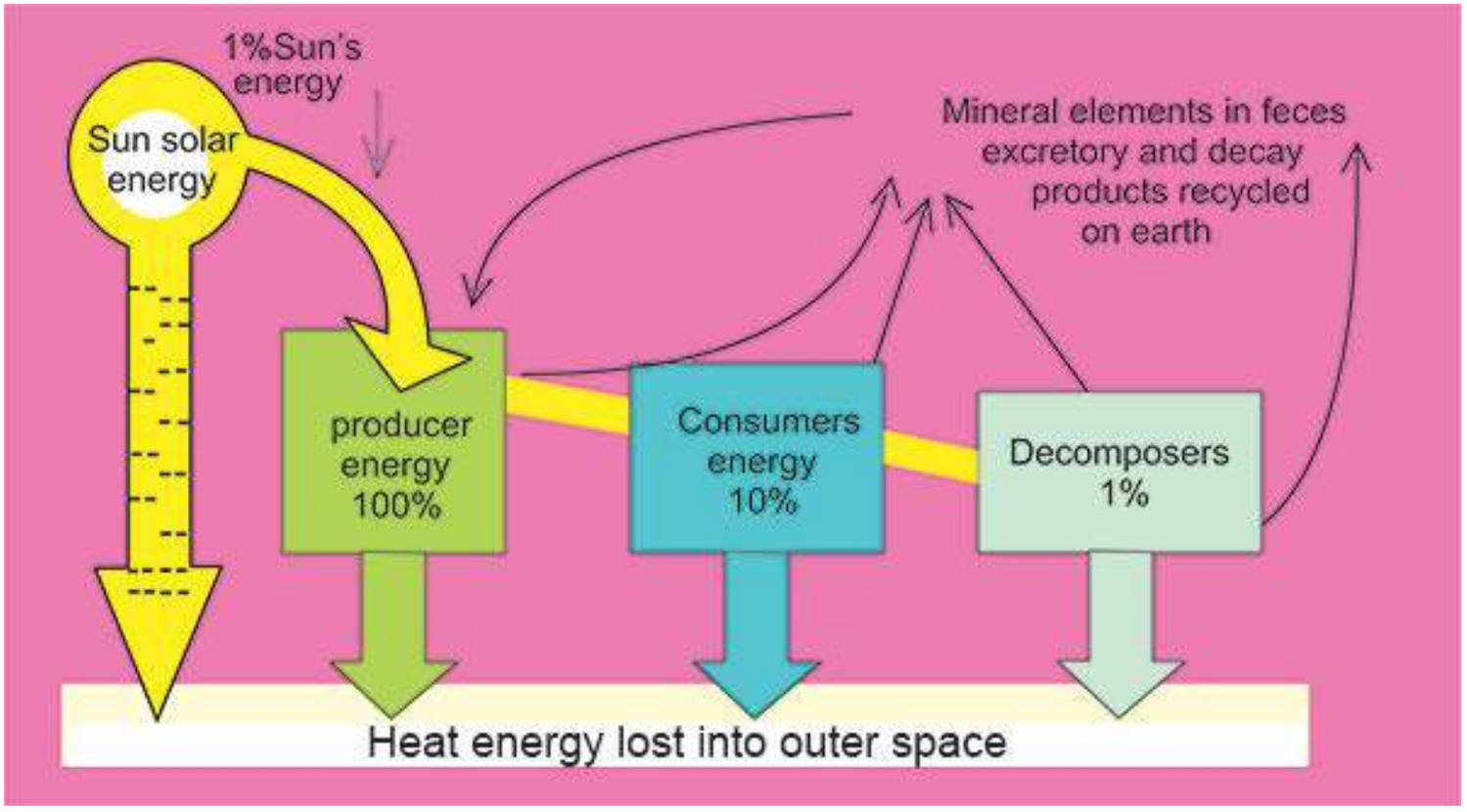
Although the nitrogen cycle appears complete and self - sustaining, nitrates are steadily lost due to the soil erosion, fire and water percolating down through the soil. Nitrates are also lost as a result of the activities of certain soil bacteria; in the absence of oxygen these bacteria break down nitrates releasing nitrogen back into the atmosphere and using the oxygen for their own respiration. This process is known as denitrification, in poorly drained (poorly aerated) soils. The cycle is maintained despite these losses primarily by the activities of the nitrogen - fixing bacteria, which incorporate gaseous nitrogen from air into organic nitrogen containing compounds. Just as all organisms are ultimately dependent on photosynthesis for energy, they all depend on nitrogen fixation for their nitrogen. Soil nitrogen resources are also strengthened by the addition of nitrogen ferlitizers by the man himself.

## The flow of Energy in Food Chain of an Ecosystem

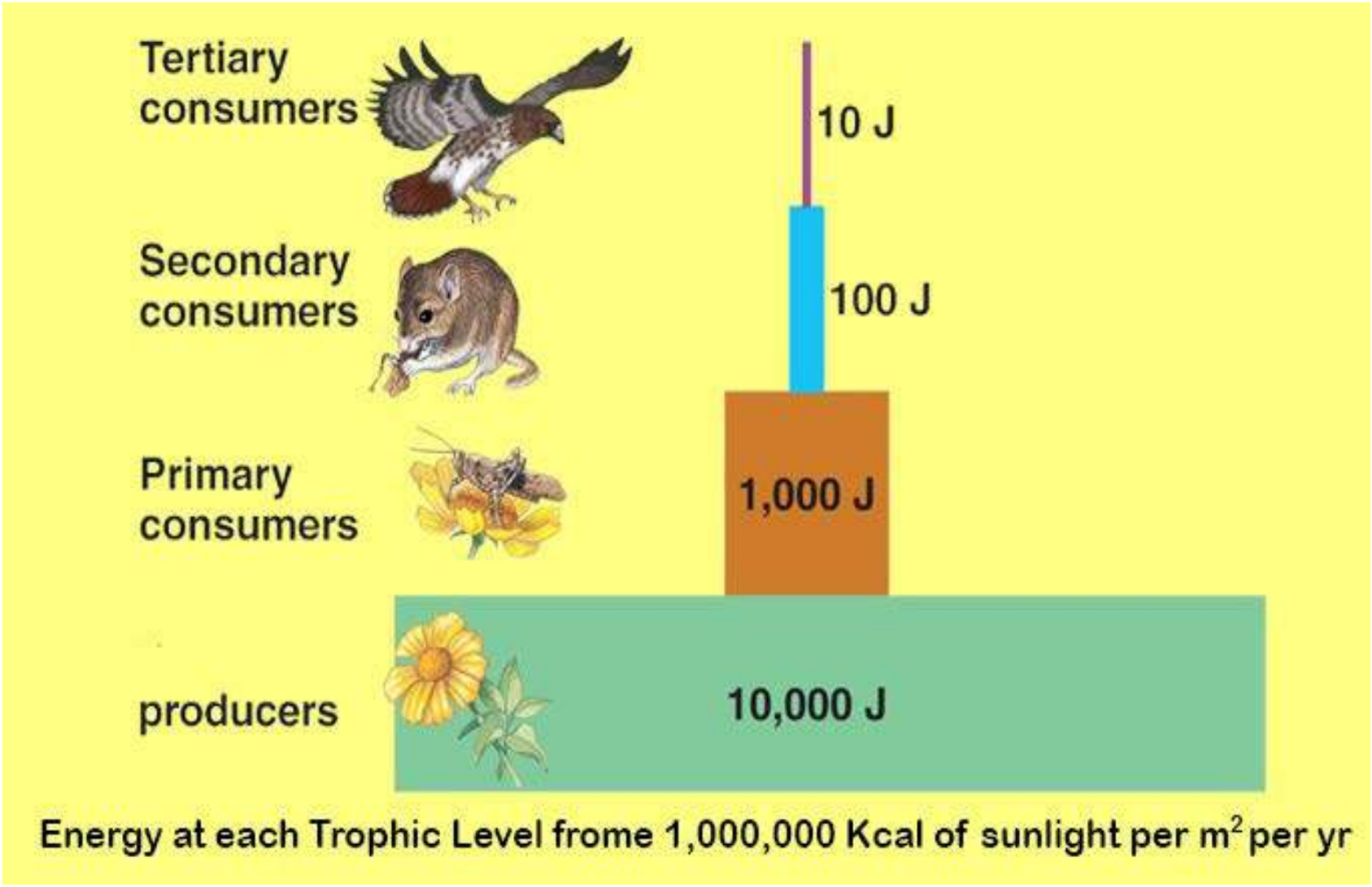
Energy in the form of radiant heat and light from the sun flows through an ecosystem passing through the different trophic levels (links) and radiates again back into outer space. The total amount of energy fixed by plants is gross primary production. The amount of energy left after plants have met their respiratory needs is net primary production, which shows up as plant **biomass.**

*Animation 25.6:Flow of Energy*
*Source and Credit: Steemit*

About 1% of the total energy from the sun is trapped by the producers in an ecosystem. The remaining 99% of solar energy is used to evaporate water, heat up soil and is then lost to the outer space. As energy is transferred from one trophic level to the next, from producer to primary consumer, between 80 to 90% of last as the original energy is heat as a by product of respiration. However, a continuous flux of energy from the sun prevents ecosystem from running down. A pyramid of energy can be constructed showing energy transfer in a community of organisms.



A short food chain of two or three links supports a community more efficiently than a long chain of five Links where much of the original energy from the producers would never reach those organisms at higher trophic levels. Decomposers are able to obtain energy by converting plant and animal tissues and waste into inorganic mineral ions.




*An Energy Pyramid*

## EXERCISE

### Q1 Fill in the blanks.

1. A group of similar organisms living together in space and time is called_____ .
2. Organisms which can synthesize their own food are called_____ .
3. Animals, non-green plants and microorganisms directly or indirectly depend upon green plants for their food so they so are called_____ .

### Q.2 Write whether the statement is true or false and write the correct statement if false.

1. At different places in an environment when you study only one population, it will be synecology.
2. Abiotic components include all living components.
3. Primary succession starting in a pond is called xerosere.
4. The animal that is caught and eaten is the predator.
5. Endoparasites live inside the body of the host.

### Q.4 Short questions.

1. What are the biogeochemical cycles?
2. Sketch three mainsteps in nitrogen cycle.
3. Define grazing.
4. What percentage of sun energy reaches to plants?
5. What is autecology?
6. Define synecology.

## Q.5 Extensive Questions.

1. Define environment. What must environment supply for insects, green plants, birds, animals and people?
2. What factors in the environment can affect all living things? Are they important to survive in a biome?
3. What can you conclude about all the physical and biological factors in an environment?
4. What is biosphere? What must the biosphere provide for living things? Why is a biosphere absent on moon?
5. Define succession. Discuss succession on land.

CHAPTER

26

# Some Major Ecosystems

*Animation 26: Some major Ecosystem*
*Source & Credit: Wikispaces*

In the previous chapter, you have learned about the ecosystem. In this chapter, we will discuss the aquatic and terrestrial ecosystems, climate and weather.

## CLIMATE

Life on earth, specially on land, is affected by both weather and climate. Weather refers to short-term fluctuations in temperature, humidity, cloud cover, wind and precipitation over periods of hours or days. Climate, in contrast, refers to overall patterns of weather that prevail from year to year even century-to-century in a particular region.

## AQUATIC OR HYDROSPHERIC ECOSYSTEM

Hydrospheric ecosystem is a "system in water where living and non-living components exchange materials and transfer of energy also takes place within water". Salt-water ocean and sea are the largest ecosystems on the earth forming about 71% of its surface. Fresh water ecosystems, in contrast, covers less than 1%. The unique properties of water lend some common features to aquatic ecosystem.

1. Temperature: Water changes its temperature slower than air, so temperature in aquatic ecosystem is more moderate to support life.
2. Absorption of energy: Although water may appear quite transparent, it absorbs a considerable amount of the light energy that sustains life. Even in clearest water, the intensity of light decreases rapidly with depth, so at the depth of 600 feet or more, a little light is left to power photosynthesis.
3. Nutrients : The nutrients in aquatic ecosystem tend to be concentrated near the bottom sediments supporting life where light levels often are too low to support photosynthesis.
4. Abundant water with appropriate temperature : Water is an essential requirement for life. It is available abundantly in aquatic ecosystem to support life. The major factors that detennine the quantity and type of life in aquatic ecosystems are energy and nutrient. Appropriate temperature is present in aquatic ecosystem to carry out all metabolic processes.

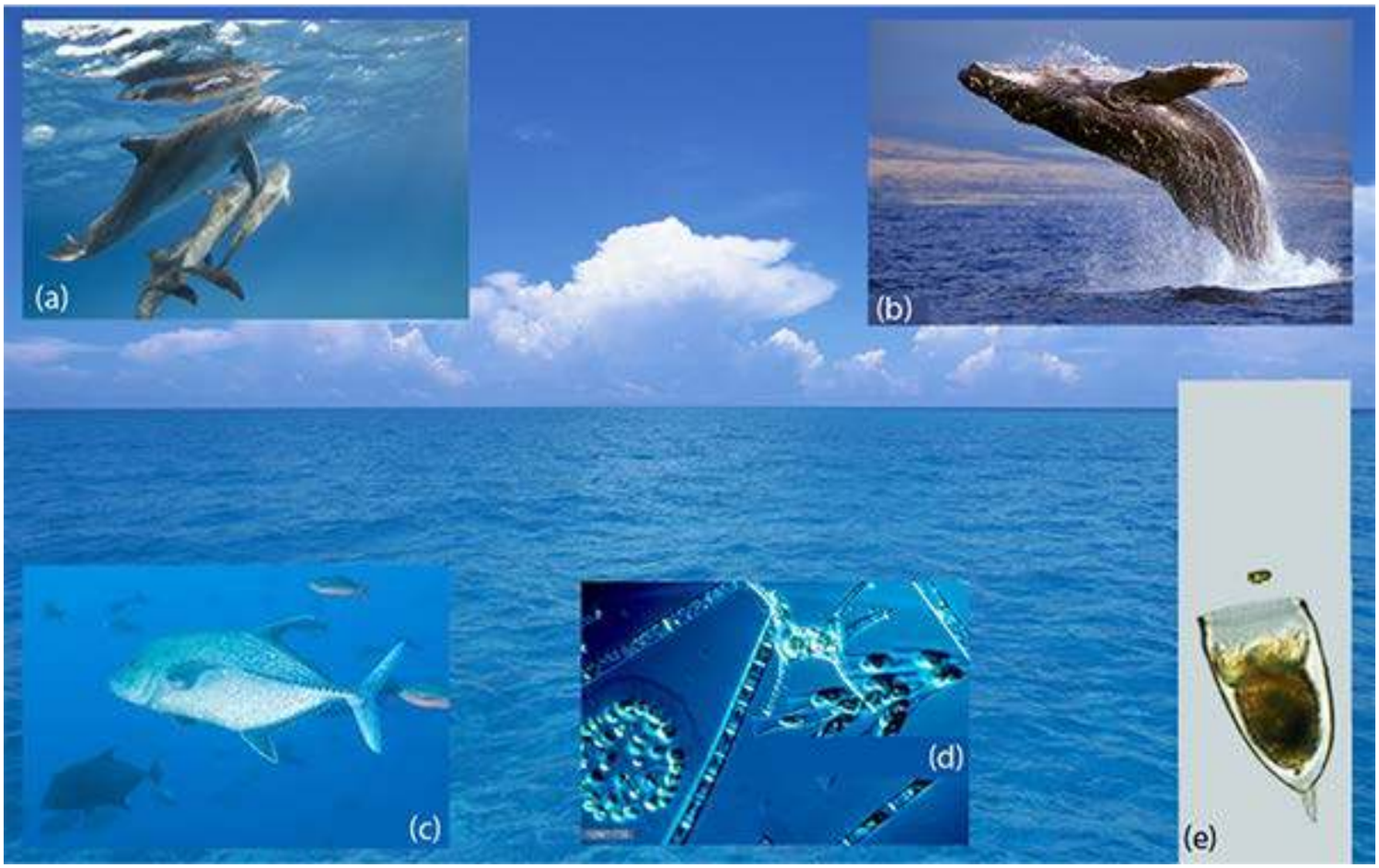



*Fig. 26.1 The open ocean (a) Porpoises skim the surface, (b) rare humpback whales leap on the clear water (c) and fish such as this blue jack swim, (d) the photosynthetic phytoplankton are the producers on which most other life ultimately depends, (e) phytoplankton are eaten by zooplankton, represented by this microscopic crustacean, a copepod. The spiny projections on these planktonic creatures help to keep them from sinking below the photic zone.*

*Animation 26.1: Aquatic Ecosystem*
*Source & Credit:Water System*

## Productivity of Aquatic Ecosystem

The productivity can be indicated by consumption of $C0_2$ and evolution of oxygen in the process of photosynthesis.

The productivity of aquatic ecosystem is basically determined by the light and nutrients. Light intensity and quality vary with the water depth, so the primary productivity also varies with light. The amount of nutrients also changes with season. Productivity also varies from zone to zone. Aquatic environment can easily be classified into fresh water and marine (salty) water.

## Fresh Water Lakes

Fresh water lakes vary tremendously in size, depth, and nutrient content, including distinct life zones and temperature stratification.

Life zones are based on access to light and nutrients : The distribution of life in lakes depends on access to light, to nutrients and to place for attachment. The lake ecosystem can be divided into three main zones.

Littoral zone (Near-shore): In this zone, the water is shallow, and plants find abundant light, anchorage and adequate nutrients from the bottom sediments. Plants in littoral zone communities are the most diverse; water lilies and entirely submerged vascular plants and algae flourish at the deepest region of the littoral zone.. The plants of this zone trap sediments carried by stream, increasing the nutrient content in.this region. Living among the anchored plants are microscopic organisms called **plankton**. These can be divided into two groups. **Phytoplankton** (Greek “drifting plants”): these include photosynthetic protista, bacteria and algae. **Zooplankton** (Greek “drifting animals”): such as protozoa and tiny crustaceans. The greatest diversity of animals in the lake is also found in this zone. Littoral invertebrate animals include small crustaceans, insect larvae, snails flatworms, Hydra; vertebrates include frogs, aquatic snakes and turtles. As the water increases in depth farther from the shore, plants are unable to anchor to the bottom and still collect enough light for photosynthesis. This open water area is divided into two regions: the upper limnetic zone and the lower profundal zone.

As the water increases in depth farther from the shore, plants are unable to anchor to the bottom and still collect enough light for photosynthesis. This open water area is divided into two regions: the upper limnetic zone and the lower profundal zone.

Limnetic zone : In this zone enough light penetrates to support photosynthesis. Here, phytoplankton includes cyanobacteria (blue green algae) which serve as producers. These are eaten by protozoa and small crustaceans, which in turn are consumed by fishes.

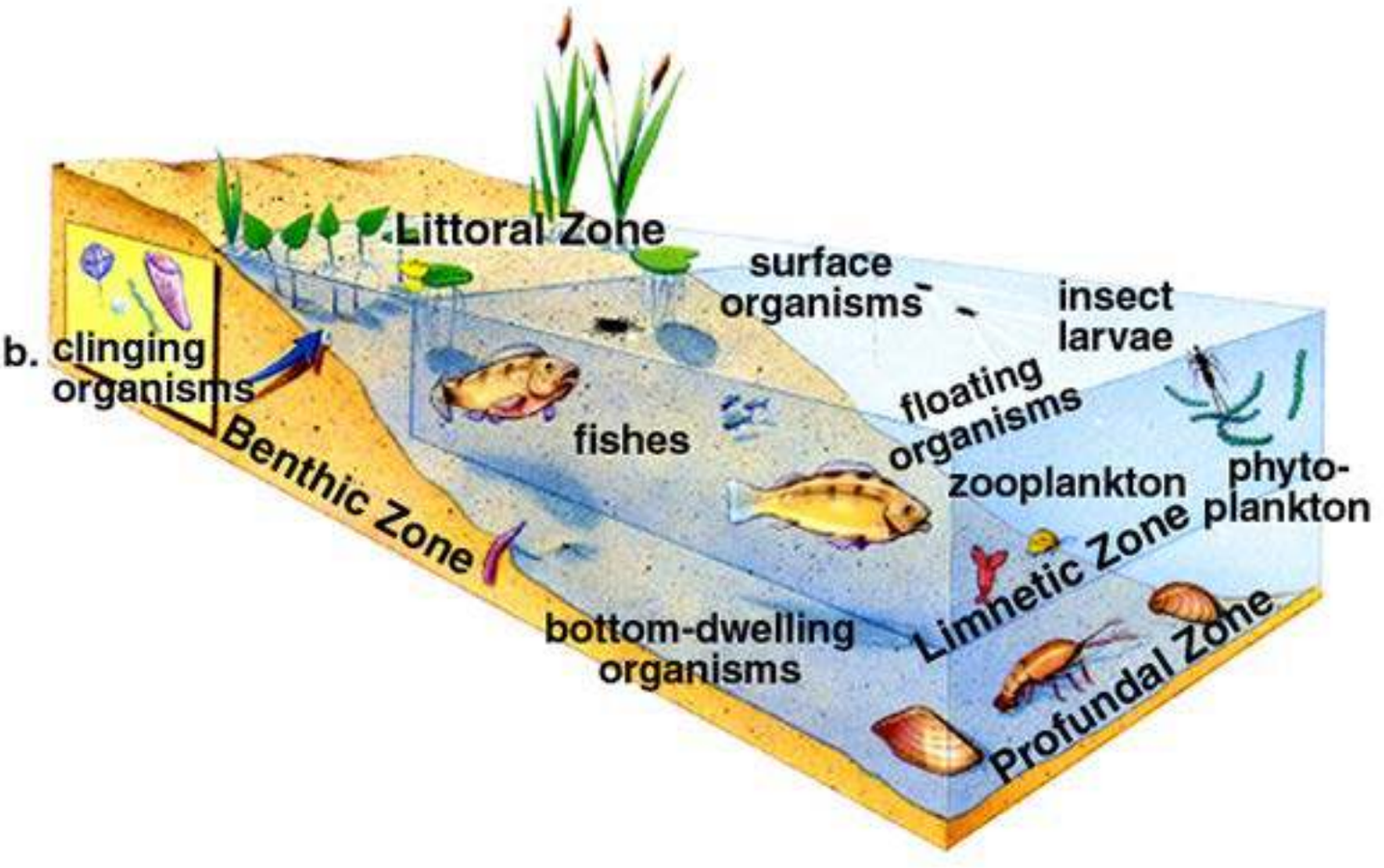



*Fig. 26.2 Lake, life zones There are three life zones in a typical lake : a near-shore littoral zone with rooted plants, an open-water limnetic zone, and a deep, dark profundal zone.*

Profundal zone : Here, light is insufficient to support photosynthesis. The organisms of this zone are mainly nourished by detritus that falls from the littoral and limnetic zone and by incoming sediment. Decomposers and detritus feeders, such as, snails and certain insect larvae, bacteria, fungi and fishes, inhabit it.

## Intervention of Man in Aquatic Ecosystem

Human activities may greatly accelerate the process of eutrophication (adequate nurition), because nutrients are carried into lakes from farm feedlots and sewage. Even if solid wastes are removed, water discharged from sewage treatment plant is often rich in phosphate and nitrates dissolved from wastes and detergents. Rain water washes off fertilizer from fields where the manure of thousands of cattle is accumulated. The water therefore, becomes highly enriched. The added nutrients support excessive growth of phytoplankton. Producers like blue-green algae form a scum on the lake surface, depriving the submerged plants of sun light; as a result they die. The dead plants bodies are decomposed by bacteria, utilizing the oxygen present in the water, deprived of oxygen, fish, snails and insect larvae die and their decaying bodies fuel more bacterial growth, further depleting oxygen. Even without oxygen, certain bacteria that produce foul smelling gases thrive. Although it is full of life and nutrients, polluted lake smells bad. Most of the trophic levels including the fish are eliminated and the bacteria and blue- green algae dominate the community. Another very serious cause of polluted water is the acid produced by burning of fossil fuels, which poses a different threat to fresh-water ecosystem. Few organisms can withstand the low pH of acidified lakes.

# TERRESTRIAL OR LITHOSPHERIC ECOSYSTEM

## Light, Nutrients and Water

The ecosystem present on land or soil is called terrestrial or lithospheric ecosystem. Terrestrial ecosystem receives plenty of light, and the soil provides abundant nutrients. Water, however, is limited and very unevenly distributed both in place and in time. Factors which influence life on land are given below :

Temperature: Like water, favourable temperatures are very unevenly distributed on land in place and time. On poles, the average temperature is below freezing. In temperate zones, only during certain seasons of the year it is quite favorable, but in tropical zones uniformly, warm, moist climate is present.

Air: In terrestrial ecosystem, air is in constant motion, so its composition is more uniform. The amount of 0 2 and C 02 in air is much constant and most beneficial to terrestrial ecosystem.

## Adaptations for Terrestrial Ecosystem

Plants and animals shifting from water to land developed various types of adaptations for land habitat e.g.

Supporting tissues : Both plants and animals have evolved supporting tissues like vascular bundles (xylem-phloem) in plants and skeleton in animals to support them on land against the force of gravity.

Conservation of water : Plants and animals evolved various methods to conserve water in their body e.g. homeostasis. The mechanism of temperature regulation was developed by land plants and animals by developing bark and skin respectively.

## Division of Terrestrial Ecosystem

It can be divided into following main types such as

1. Forest ecosystem. It is further sub-divided into :
   (a) tropical rain forests (b) temperate deciduous forests
   (c) coniferous alpine and boreal forests

2. Grass land ecosystem. 3. Desert ecosystem. 4. Tundra ecosystem.

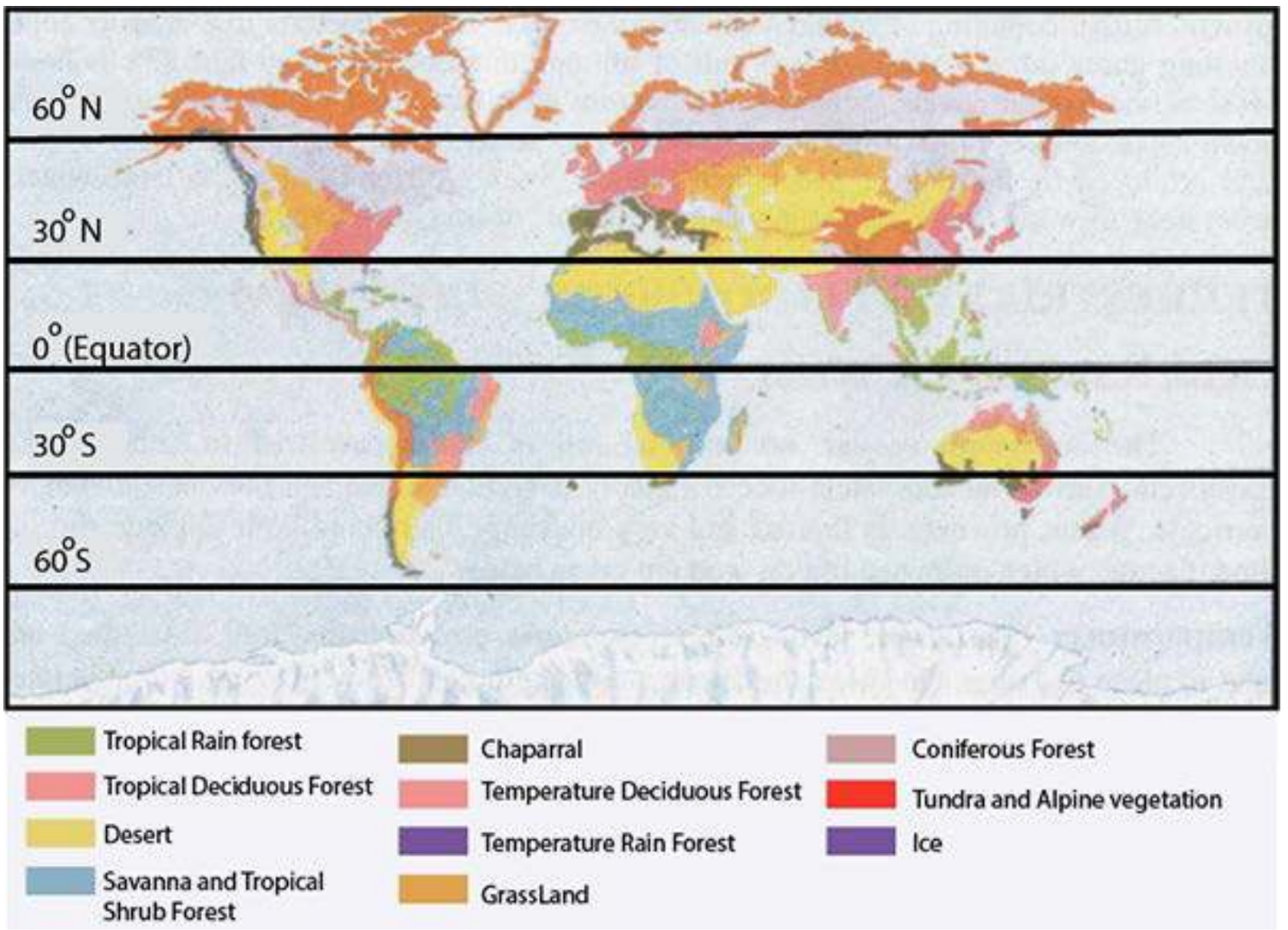


*Fig. 26.3 The distribution of biomes Although mountain ranges and the sheer s >f the continents complicate their pattern, note the overall consistencies. Tundra and coniferous forest always occur in the northernmost parts of the Northern Hemisphere, while the deserts of Mexico, the Sahara, Saudi Arabia, South Africa, and Australia are located around 20° to 30° North and South latitude*

## SOME MAJOR ECOSYSTEMS IN PAKISTAN

Pakistan has a variety of seasons and climate ranging from hot dry in plains to cold snowy on mountains. Some major ecosystems existing in Pakistan are;

| S. No. | *Major Terrestrial Ecosystems* | Location in Pakistan |
|---|---|---|
| 1 | Temperate Deciduous Forests. | Shogran and Neelam valley. |
| 2 | Coniferous Alpine and Boreal Forests | Northern mountains of Kaghan, Malam Jabba (Swat) Dir and Chilas |
| 3 | Grassland Ecosystem. | Gilgit and Kashmir. Waziristan, lower Chitral and North Kallat. |
| 4 | Desert Ecosystem | (Mianwalli, Bakhar) (Fort Abbas, Bahawal Nagar, Yazman, Bahawal Pur, Khan Pur and RahimYar- Khan. Sind. |
| 5 | Tundra Ecosystem. | Mountains Kara-Koram and Hindukush. |

## Temperate Deciduous Forests

In Pakistan, temperate moist conditions are present in Neelam valley and Shogran. These forests originally covered India, Southeast Asia, eastern North America, Europe, China, Australia, Japan, North and South America. Slightly farther away from the equator, the rainfall is not nearly as constant, and there are pronounced wet and dry seasons that means distinct summer and winter seasons. During dry season, the trees cannot get enough water from the soil to compensate for evaporation from their leaves. As a result, the plants have adapted to the dry season by shedding their leaves, thereby minimizing water loss. If the rains fail to return on schedule, the trees delay forming new leaves until the drought passes.

Rain fall: The average rainfall is between 750 - 1500 mm.

Temperature : Moderate temperature ranges from 4°C - 30°C.

Plants : Some dominant plants are Taxus baccata, Pinus wallichiana, Berberis lyceum. Many herbs and shrubs are with height of 5m. Some grasses, ferns and other herbaceous plants make up field layer. At the bottom or floor level many mosses liverworts and lichens covered with litter layer are present.

Animal life : Some very common animals are *Macca multata*(rhesus monkey), *Solenorctos ubetanus* (black bear), *Felis bengalensis* (leopard cat), deer, and wolves with various types of microorganisms to convert the litter into organic matter such as bacteria, fungi, and earthworms.


*Fig. 26.4 Temperate deciduous forest (a) White tailed deer is the largest herbivore, (b) Woodland wildflowrs (c) Blue Jay (bird)*

Soil condition : The soil of temperate deciduous forest is grayish brown in colour, very fertile and rich in organic matter, with maximum water holding capacity.

Human impact : On temperate deciduous forest large mammals such as black bear, deer, wolves, bobcats and mountain lions were formerly abundant, but the predators have been largely wiped out by humans. Need of lumber and its use in agriculture has reduced many deciduous forests from the world.

## Coniferous Alpine and Boreal Forests

In Pakistan these forests are in upper Kaghan, Dir and Chilas, Malam Jaba in Swat valley. In the world, they stretch across Eurasia (Europe + Asia) and North America, Canada just south of the tundra. Northern coniferous forests are also called Taiga. Conditions in taiga are harsher than those in the temperate deciduous forest. The winters are longer and colder, and the growing season is shorter. The few months of warm weather are too short to allow trees the luxurious growth of regrowing. As a result, evergreen coniferous trees populate this type of forest, almost entirely with small waxy needles. The waxy coating and small surface area of the needles reduce water loss by evaporation during cold months, and leaves remain on the trees year around. Coniferous forests located at high altitude are called alpine while coniferous forests located at high latitude are called boreal. Can you differentiate between altitude and latitude?

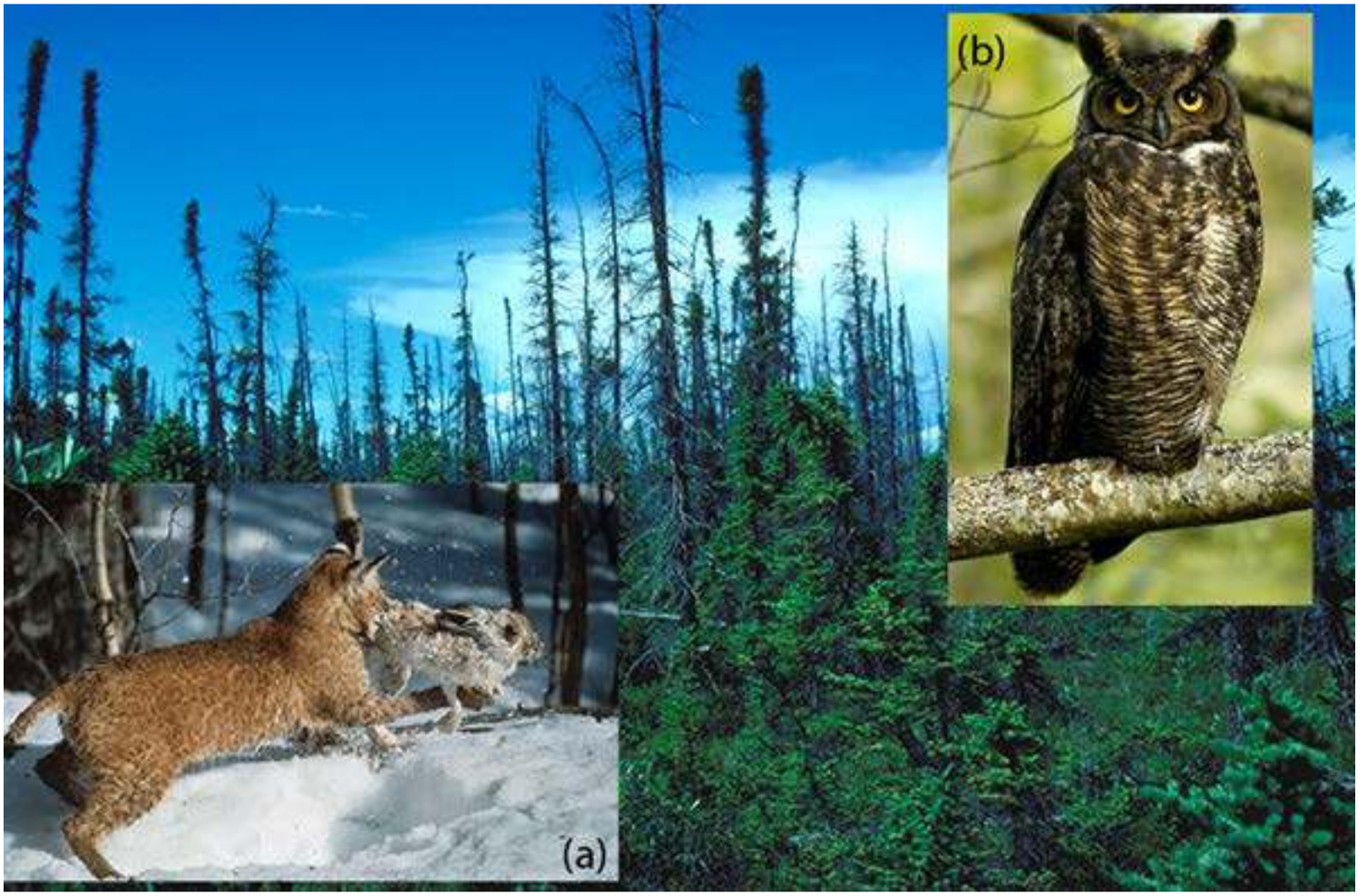



*Fig. 26.5 The Taiga The small needles and pyramidal shape of conifers allows them to shed heavy snows. Winter is a challenge not only for the trees but also for animals such as this snowshoe hare and the bobcat that preys on it (a). The hare is also prey for the great home owl (b). Taiga animals face diminished food supply but increased energy requirements during subfreezing weather.*

Snow cover and temperature : There is a constant cover of snow characterized by long severe winter. Temperatures may be below freezing point, up to 10 °C.

Animal and plant life : Because of its harsh climate, the diversity of life is much low. Large mammals, bison, wolf, black bear, deer, Marco polo sheep and smaller animals such as small Kashmir flying squirrel, snowshoe hare, wolverine, crossbills, are present.' Plants like *Pinus wallichiana, Pirius roxburgii, Abies pindrow, Picea smithianci Cederous deodara* are present.

Human impact : Due to severity of climate and remoteness most of the coniferous forests remains undisturbed, but these forests are major source of lumber for construction, so forests have been cleared in the world.

## The Grass Land Ecosystem

Grassland ecosystems are found in Gilgit, Kashmir, Waziristan, lower Chitral and North Kallat. In the world, you can see a large grassland in the center of Eurasian continents. Grassland present in temperate climates are also called Prairies, such as Prairies of North America, Pampas of Argentina. These grasslands do not have woody plants so they are known as Prairies. But the grassland in tropical climates have woody trees and are called Savanna.


*Fig. 26.6 Grass land ecosystem (a) Pronghorn antelope (b) Prairie dogs (c) Bison herds (d) Coneflower*

Rain fall: The grasslands usually face severe droughts(26.7).Annual rainfall is about 250 to 750 ml. In tropical and subtropical grasslands, rainfall eaches about 1500 mm (60 inches). Thus grassland occurs in regions where mean annual rainfall is midway between a forest and a desert. In general, they have a continuous cover of grass and virtually no trees at all except along the rivers. Water and Fire are the crucial factors in die competition between grasses and trees.

Plant life: The dominant spebies are graminoids i.e. grasses, and grass-like plants. Certain forbs such as composites, legumes and many other herbaceous plant species are also associated with grasses.

Layering : Layering is the characteristic of grassland. Tall grasses (Andropogon, Panicum) form the first) layer, mid high grasses (Stipa, Sporobolus, Oryzopsis) form the second layer and third layer is formed by short grasses and forbs and warfare species (Poa, Bromus) with mosses and lichens.


*Fig 26.7*

Soil conditions : The soil moisture is limited on account of low precipitation and high evaporation. Upper soil layer in which grasses are rooted is normally moist but deeper layers are constantly dry. The soil of grassland is basically impermeable with excessive salinity.

Animal life : Dominant species are herbivores; invertebrates including insects are very numerous, grasshoppers become so numerous that they can compete with other herbivores for plant foliage. The predators are reptiles, amphibians and mammals. For example, lizards, toads and turtles prey on insects; foxes and wolves among mammals are very common. Among decomposers many bacteria, actinomycetes and fungi like molds, yeasts, mushrooms, bracket fungi are most common. Large animals like zebras, wild horses, bisons are important.

Productivity ; In temperate grassland the rate of primary production is about 700 - 1500 g/m$^2$ annually. In sub-humid tropical grassland it is more than 4000 g/m$^2$ . In annual grasslands, large grazing animals consume relatively small amount (5 - 10%) of the total herbage produced. Invertebrates, rodents and birds may consume an equal amount or a little more.

Human impact: The natural grasslands in the world are used for crop production and live stock management. Only a small fraction of the world's grasslands has been in cultivation due to acid climatic condition with soil erosion and salinity. Grazing has prominent effects on grassland; over-grazing causes reduction in herbage cover and result is soil erosion. Many lands are converted into deserts by a process called desertification due to over grazing

## Desert Ecosystem

In Pakistan you can find the desert ecosystem in western Punjab (Mianwali and Bukhar) where it is known as "Thai".

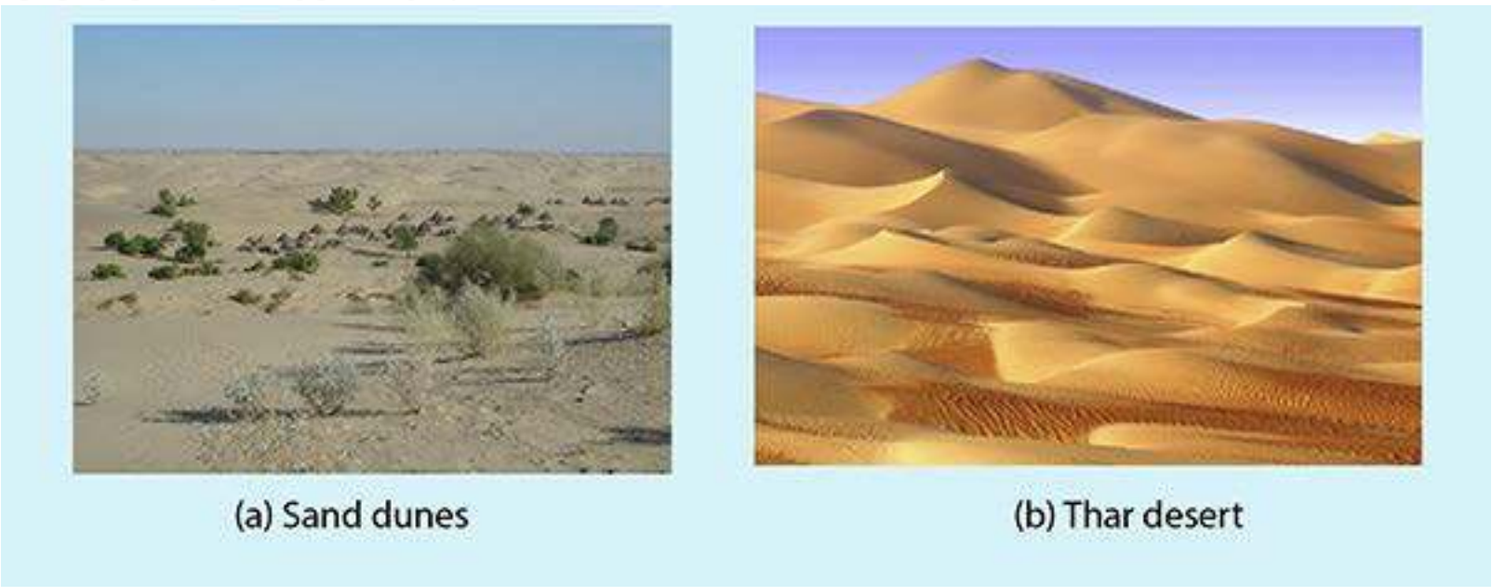



*Fig 26.8*

In southern Punjab, areas like Fort Abbass, Bahawal Nagar, Yazman, Bahawal Pur (Cholistan), Khan pur and Rahim yar khan also have deserts.

In Sindh, this desert ecosystem is called "Thar".

These biomes are found on every continent often around 20 to 30 north and south latitude and also in the rain shadows of major mountain ranges. Desert includes a variety of environments. At one extreme are certain areas of the Sahara or Chile, where it virtually never tains and there is no vegetation at all (Fig. 26.8a).

The more common deserts, however, are characterized by widely spaced vegetation and large areas of bare ground.

Rain fall: Less than 25 to 50 cm (10 - 20 inches) or not at all.

Plant life: The plants are often spaced evenly as if planted by hand (Fig 26.8b) Frequently, the perennial plants are bushes or cacti with large shallow root systems.

Plants are covered with the waterproof waxy coating to prevent evaporation of precious water. Water is stored in thick stems of cacti and other succulents. Desert plants conserve water in a variety of ways. Cacti and Euphorbia have fleshy stems in which water is stored for use during the period of drought.

Animal life: Like plants, animals are also specially adapted to survive on little water. Most deserts appear to be almost completely devoid of animal life during day, because the animals seek relief from the sun and heat in cool under ground burrows. In the dark, when desert cools down, homed lizards, snakes and other reptiles emerge to feed, as do mammals siich as kangaroo, rat, and birds such as burrowing owl.

Most of the smaller animals survive without ever drinking at all, getting all the water they need from their food and what produced during cellular respiration in their tissues. Large animals such as desert bighorn sheep and camel are dependent on permanent water holes during the driest times of the year.

Human im pact: While human activities are reducing the extent of many biomes, they are causing the spread of deserts, a process called desertification.

A dramatic example is occurring in the Sahel, which borders the southern edge of the Sahara desert in Africa. Twenty-five years of below average rainfall, coupled with rapid growth of the human population have caused a steady southward spread of desert. The Sahel is an example of a human population exceeding the carrying capacity of the land. The loss of the productivity of the ecosystem is nearly irreversible and massive famines, such has occurred in Ethiopia in the mid 1980s are a tragic result.

## Tundra Ecosystem

The last biome seen before reaching the polar ice-caps is the arctic tundra, a vast treeless region bordering the Arctic ocean. It is used to describe types of vegetation in treeless high latitudes between taiga and polar ice caps, and at high altitude across the mountain above timberline such as mountain of Karakoram and Koh Hindu Kush in Pakistan.


*Fig. 26.9 Tundra : Vegetation and animals, (a) Caribou (b) Arctic foxe (c) Dwarf clover (wild flower)*

Aractic tundra stretches across Northern North America, Northern Europe and Siberia (with high latitude).

Plant and animal life : The ground is carpeted with small perennial flowers and dwarf willows no more than a few centimeters tall often with large lichen called reindeer moss. The standing pools provide superb mosquito habitat. The mosquitoes and other insects provide food for numerous birds (ducks and geese) most of which migrate a long distance to nest and raise their young during the brief summer feast. The tundra vegetation supports lemmings, which are eaten by wolves, snowy owls, arctic foxes and even grizzly bears.

Human impact: The tundra is perhaps the most fragile of all the biomes because of its short growing season. A willow 10 centimeter (4 inches) high may have a trunk 7 centimeter (3 inches) in diameter and be 50 years old. Human activities in the tundra leave scars that persist for centuries. Fortunately, for the tundra inhabitants, the impact of civilization is localized around oil drilling sites, pipelines, mines and military bases.

## Humans and Ecosystems

The expanding human population has left relatively few ecosystems undisturbed. Our impact on natural ecosystem are so diverse and wide ranging that they far exceed the scope of this book. Ecosystems dominated by people tend to be simple, that is, they have fewer species and fewer community interactions than an undisturbed ecosystem

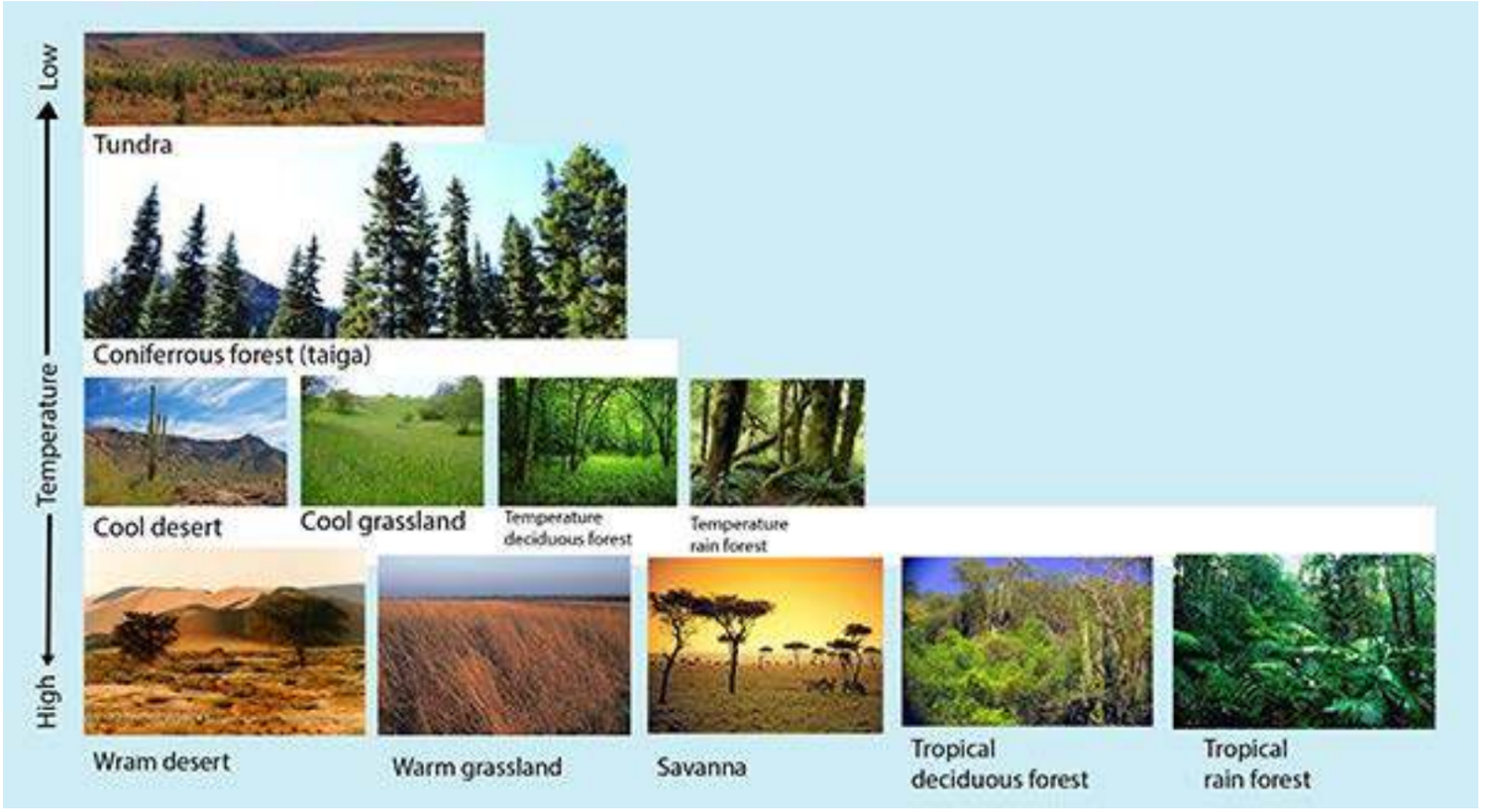



*Fig. 26.10 Temperature and rainfall influence on biome distribution*

## EXERCISE

### Q1 Fill in the blanks.

1. Water is slower to heat and _____than air.
2. The distribution of life in lakes depends on access to_____, and to place for attachment.
3. Ecosystem on land is also known as_____ ecosystem.
4. Ecosystem in water is also called as_____ ecosystem.

### Q.2 Short questions.

1. Defnle productivity of an ecosystem.
2. List four adaptations in plants and animals for terrestrial ecosystem.
3. Name three zones in lake ecosystem.
4. How many biomes are present in the world, name only five of them.
5. Give the names of some major ecosystems on land in Pakistan.

### Q.4 Extensive Questions

1. What are the four major requirements for life? Which two are limiting in terrestrial ecosystem?
2. List some adaptations of
3. (a) desert plants (b) desert animals to heat and drought.
4. Where is life in oceans (hydrospheric ecosystem) most abundant and why?
5. Distinguish between three different zones in the lake - ecosystem.