# $2^{nd}$ YEAR Geology and Biology, Faculty of Education

# Lectures zoology 2

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# CHARACTERISTICS OF PHYLUM CHORDATA

Chordates possess four diagnostic characters either in the embryonic or adult stage

**1) Notochord**

It is a solid un-jointed, stiff but flexible rod-like structure situated on the dorsal side between the dorsal hollow nerve cord and the alimentary canal.

**2) Dorsal Hollow Nerve Cord**

The nerve cord of chordates is always hollow and lies dorsal to the notochord

**3) Pharyngeal Gill Slits**

All the chordates have at some stage of life, a series of paired narrow openings, the gill slits on the lateral sides of the pharynx.

**4) Tail**

It is a post-anal part of the body which is reduced or absent in many adult chordates.

**Additionally,** there are Other Characters of Chordates: these include bilateral symmetry, three germinal layers, segmentation, organ-system level of organisation, cephalization, coelom, endoskeleton, complete digestive tract, special organs for respiration and excretion, closed circulatory system, separate sexes, gonads with gonoducts and without asexual reproduction.

## Classifications of Phylum Chordata

### Sub-Phylum: Urochordata

(i) Adults are generally sedentary (fixed to substratum),

(ii) This sub-phylum is also called Tunicata because the adult body is enclosed within a leathery test or tunic formed of a cellulose-like organic substance termed tunicin.

(iii) The notochord is only present in the larva tail and disappears in the adult,

(iv) The dorsal tubular nerve cord is found in the larva. It is replaced by a dorsal ganglion in the adult,

(v) The pharynx is perforated by numerous apertures called stigmata formed by the larval gill slits. The stigmata open into an ectoderm lined cavity, the atrium, and

(vi) The larva (tadpole) is motile and undergoes retrogressive metamorphosis, i.e., change from better developed larva to less developed adult.

The Urochordata examples such as Herdmania (Sea Squirt), Ascidia, Ciona, Doliolum, Salpa, Botryllus (colonial urochordate), Molgula, Pyrosoma. Pyrosoma is bioluminescent colonial urochordate. Herdmania has valveless heart. The blood of Hardmania is green due to the presence of vanadium in blood.

**Ascidia**

It is closely similar to Herdmania. It is a marine, solitary and sedentary, living in temperate seas. The body is attached to the substratum by a foot. Test is thick and tough and branchial siphon and atrial siphon are short. There is a motile tailed tadpole (larva) which undergoes retrogressive metamorphosis to become sessile adult.

**Sub-Phylum: Cephalochordata (Gr. cephalos- head + chordata = notochord):**

(i) Both the adult and larva are motile,

(ii) The notochord extends up to anterior end of the body hence this subphylum is named,

(iii) The notochord persists throughout life,

(iv) Pharyngeal gill slits are more numerous and are better developed.

(v) Atrium is also present,

(vi) The tail is present throughout life,

(vii) It shows progressive metamorphosis (change from less developed larva to better developed adult).

The Cephalochordata example such as Branchiostoma here is the Amphioxus. Amphioxus has both ends pointed like lance hence it is commonly called lancelet. Amphioxus has numerous eye spots or ocelli which are sensitive to light. Subphyla Urochordata and cephalochordate are often referred to as protochordates or acrania (without cranium — brain box).

**Sub-Phylum: Vertebrate or Craniata**

Some of the important characters of vertebrata or Craniata as following:

(1) These are advanced chordates that have cranium (brain box) around brain.

(2) Notochord is only present in the embryonic stage; it is replaced by a cartilaginous or bony vertebral column in the adult forms.

(3) There is very high degree of cephalization (formation of head).

(4) The epidermis consists of many layers of cells. Epidermis may bear an exoskeleton of scales, feathers or hair.

(5) Three types of muscles, striped, un-striped and cardiac, are present.

(6) Coelom is well developed.

(7) Digestive tract is complete.

(8) The endoskeleton is formed of cartilage or of cartilage and bone.

(9) Heart is ventrally situated with two, three or four chambers. There is present hepatic portal system.

(10) There is closed circulatory system consisting of blood vascular and lymphatic systems. RBCs are present.

(11) Respiratory organs may be gills, skin, buccopharyngeal cavity and lungs.

(12) A pair of kidneys is present for excretion and osmoregulation.

(13) Nervous system consists of central nervous system (brain and spinal cord), peripheral nervous system (cranial and spinal nerves) and autonomic nervous system (sympathetic and parasympathetic nervous systems).

(14) Sense organs are eyes, ears, tongue, nasal chambers, and skin. In some vertebrates lateral line system is present.

(15) Cranial nerves are 8, 10 or 12 pairs.

(16) Endocrine glands are found in all vertebrates.

(17) Sexes are separating (unisexual) except hag fish, which is bisexual. There is no asexual reproduction.

The Subphylum vertebrate is divided into **two sections** which include the followings

**Section 1: Agnatha** (The lawless Vertebrates):

The mouth does not possess jaws hence named agnatha. Notochord persists throughout life. Vertebral column is represented only by small imperfect neural arches over the notochord. They do not have paired appendages. They have single nostril. Internal ear has one or two semi-circular canals.

**Section 2: Gnathostomata (The Jawed Vertebrates)**

Mouth has jaws hence it is named gnathostomata. Embryonic notochord is usually replaced in adult by a vertebral column. Paired fins or limbs are present. Paired nostrils are present. Internal ear has three semicircular canals.

Gnathostomata is divided into two super classes: Pisces and Tetrapoda.

**Super class 1: Pisces (Bear Fins)**

It includes true fishes and divided into **three classes**:

**Class 1. Placodermi**

Body had an external protective armour of bony scales or plates, e.g. Climatius.

**Class 2. Chondrichthyes**

This class includes cartilaginous fishes, e.g. Dogfish, Torpedo, Chimaera, etc.

**Class 3. Osteichthyes**

It includes bony fishes, e.g. Nile Bolti, Labeo, Hippocampus, etc.

**Super class 2: Tetrapoda (Bear Limbs)**

Typically all tetrapods (Gk. Tetra – four + podos = foot) possess two pairs of limbs.

## SECTION ONE: AGNATHA

The Agnatha (The lawless Vertebrates) are cold blooded and has two classes: Ostracodermi and Cyclostomata.

**Class Ostracodermi (Extinct):** They are earliest known vertebrates (all are extinct) which appeared in Ordovician period. They had well developed dermal scales which led to their names “Ostracoderms”— bony skin. They are also called “armoured fishes”.

**Class Cyclostomata:** The Circular mouthed fishes; Gr. cyklos-circularal; stome-mouth )

(1) They occur in the seas and large rivers.

(2) The mouth is circular and jawless. They are also called jawless fishes (not true fishes).

(3) They have 1-16 pairs of gill slits.

(4) Head and brain are poorly developed.

(5) Unpaired fins are present.

(6) Endoskeleton is cartilaginous.

(7) Kidneys are mesonephric.

(8) Stomach is absent.

(9) Respiratory organs are gills.

(10) Heart is two chambered (one auricle and one ventricle).

(11) There are 10 or 8 pairs of cranial nerves.

(12) Lateral line sense organs are present.

(13) Fertilization is external. Life history may include a larva named ammocoete. The Cyclostomata **examples** such as Petromyzon (Lamprey) and Myxine (Hagfish).

## Class Cyclostomata
## The Lamprey

The Lamprey, also called lamper eels belongs to family Petromyzontidae. They spend major part of their adult life in sea and are provided with a suctorial mouth. The larval phase, the Ammocoetes lives in fresh water and feed on microscopic food trapped in endostyle.

**Habit and Habitat:**

Life history of all lampreys includes two distinct stages, the ammocoete larva lives in fresh water, buried in the mud and is microphagous while the adult lamprey has a sucking mouth, and usually lives in the sea, where it feeds on the fishes and turtles. Adult lamprey migrate to the river for the purpose of spawning after which they eventually die.

**External Features:**

The head and trunk are nearly cylindrical and the tail is laterally compressed (**Figure 1**). The smooth, slimy body surface is devoid of scales. The upper surface, is usually dark and the lower surface white. A median dorsal fin divided into two unequal parts and a caudal fin continuous with posterior dorsal fin are present. The fins are sup-ported by fine cartilaginous fin rays.

A single median nostril and the pineal organ; closely behind it are present on the dorsal surface of the head. Eyes are paired, lateral, without eyelids but covered with a’ transparent skin (Fig. 2B, C).

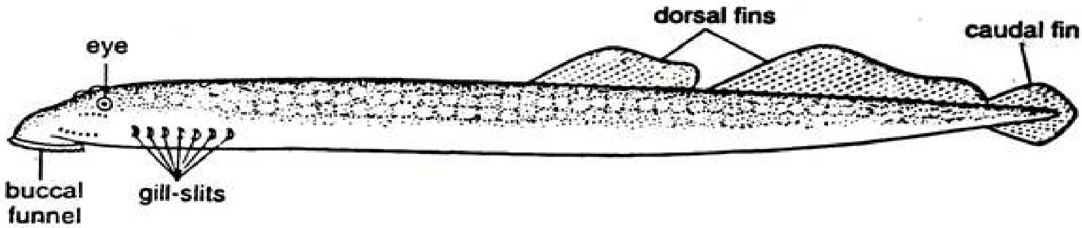



Fig. 1. Petromyzon sp.

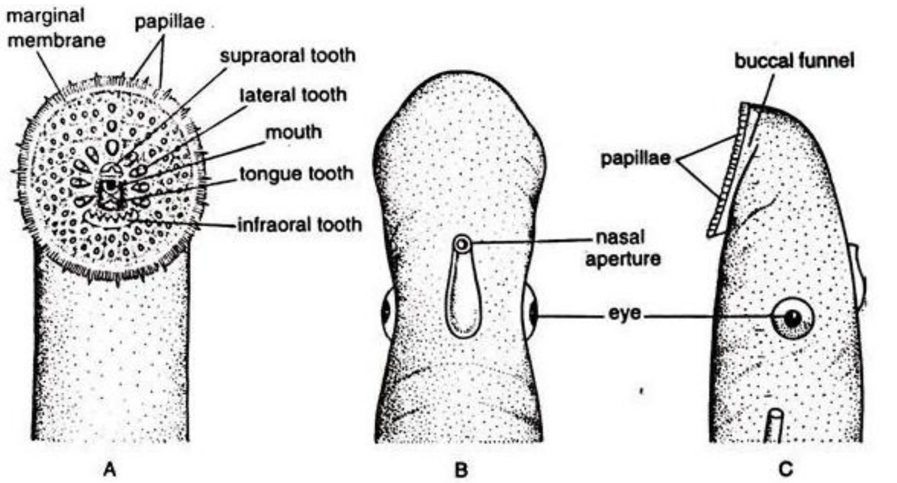



Fig. 2. Petromyzon sp. Anterior region. A. Ventral view showing buccal funnal. B. Dorsal view. C. Lateral view

At the anterior end a large downwardly directed basin-like depression, the buccal funnel is present (Fig. 2A). It is surrounded by a marginal membrane, overlapping the oral fimbrae and sensory cirri arising from outside the marginal membrane.

Radiating rows of yellow, homy teeth on cartilaginous pads are present in the buccal funnel. A prominence, the tongue bearing large, horny teeth projects from the bottom of the buccal funnel. The narrow mouth lies just above the tongue. Gill slits or gill pores are seven pairs of small openings on the sides of the head. The anus, a narrow opening lies in a small depression, the vent on the ventral surface at the junction of trunk and tail. A small papilla bearing urinogenital aperture lies immediately behind the anus. Segmental sense organs, the lateral line sense organs on either side of the body and head are exposed to the exterior, not enclosed in lateral line canals.

**The skin**

The skin of both ammocoetes and adult lampreys is soft and formed of multilayered epidermis and a dense dermis (Fig. 3).

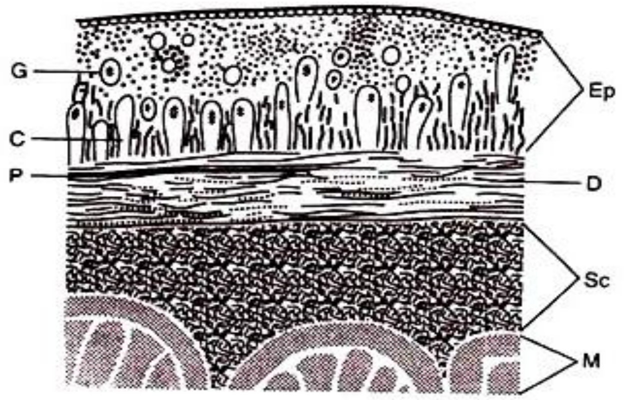



**Fig. 3 :** Section of skin of lamprey. [C, club cell; D, dermis, Ep, epidermis; G, granular gland cells; M, myotomal muscle; P, pigment cells; Sc, subcutaneous connective tissue.]

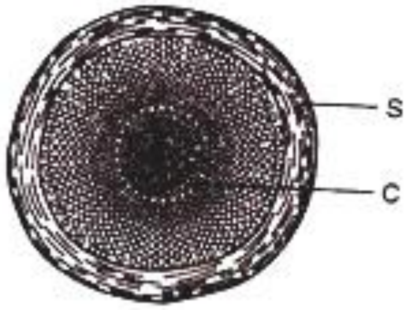



**Fig. 4 :** T-S of notochord of lamprey, showing fibrous sheath and vacuolated cells. [C, cells. S, sheath.]

Both the layers are separated from each other by connective tissue which contains blood capillaries and migratory pigment cells or the chromatophore. The epidermis consists of three or more layers of mucous cells, provided with large intracellular spaces. The outer layer of cells possesses brush border and stores mucus. Inner club shaped cells rest on the dermal layer and have a cytoplasmic cone. The dermis comprises circularly arran-ged bundles of collagenous and elastic fibres.

**Musculature:**

The trunk muscu-lature is well developed and consists of a series of myomeres, i.e. there are a series of myotomes separated by myocommas. Each myotome has a w-shape instead of the simple v-shape of Amphioxus. The muscle fibres are striated.

**Skeleton:**

The skeleton of lamprey consists of notochord and various cartilaginous structures. The notochord is well developed throughout life as a rod below the nerve cord. It consists of large turgid vacuolated cells, enclosed in a thick fibrous sheath (**Fig. 4**). Small, segmentally arranged, vertical cartilaginous rods are attached to the sides of the notochord bounding the spinal canal. In the caudal region the rods fuse to form a single plate bearing foramina for the spinal nerves and sends processes to the base of the fin.

**Cranium**

The cranium is primitive. The floor is occupied by a basal plate formed by paired parachordals and trabeculae. An incomplete box enclosing the brain and special sense organs is formed by pieces of cartilage attached to the basal plate (Fig. 5).

A large aperture, die basicranial fontanelle is present in front of the cranium. The roof of the cranium is made of membranous fibrocartilage, supported by a transverse bar. Auditory capsules are united with the posterior end of die basal plate and form the end of the neurocranium.

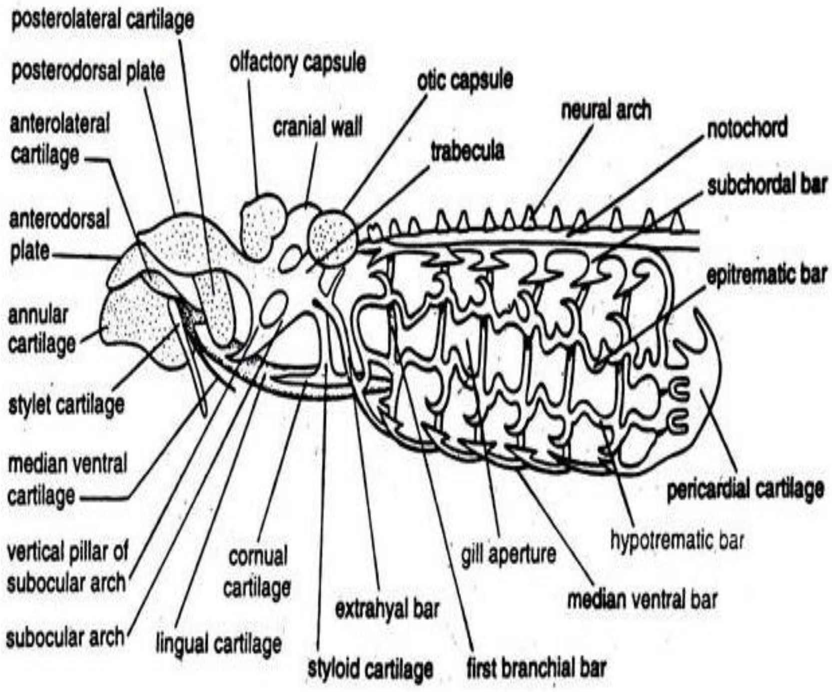



Fig. 5 Petromyzon sp. Skull and branchial basket (lateral view)

The olfactory capsule is an imperfectly paired concavo-convex plate, supporting the posterior wall of the olfactory sac. Fibrous tissue joins the capsule with the cranium.

A sub-ocular arch extends downward and outward from each side of the nasal plate to support the eye (Fig. 5). A slender styloid process hangs from the sub ocular arch and a small cornual cartilage is connected to its lower end. The skeleton of the buccal funnel and branchial basket are attached to the cranium. A ring-like annular cartilage supports the buccal funnel. The tongue is supported by a long, impaired lingual cartilage.

**Visceral skeleton:**

The visceral skeleton (Fig. 5) consists of a branchial basket of nine irregular, vertical cartilaginous bars or rods on each side. The first rod is located immediately posterior to the styloid process, the second in front of the first gill slit and the rest posterior to the remaining gill slits.The vertical bars are joined by longitudinal bars. Posteriorly the branchial basket extends to form a cup-like pericardial cartilage accom-modating the heart.

**Coelom**

The coelom is represented in two cavi-ties, a small, anterior pericardial cavity containing heart and a large posterior pleuroperitoneal cavity containing visceral organs.

**Digestive System of Lamprey**

An alimentary canal, a pair of buccal glands, a liver and patches of secretory cells constitute the digestive system:

Alimentary canal: It is a nearly straight tube starting at mouth and ending in anus.

Buccal funnel: A large, downwardly directed basin-like depression (Fig. 6) at the anterior end of the body. The mouth is a narrow opening above the tongue, projecting from the bottom of the buccal funnel. Radiating rows of horny, yellow teeth on cartilaginous pad are present in the buccal funnel.

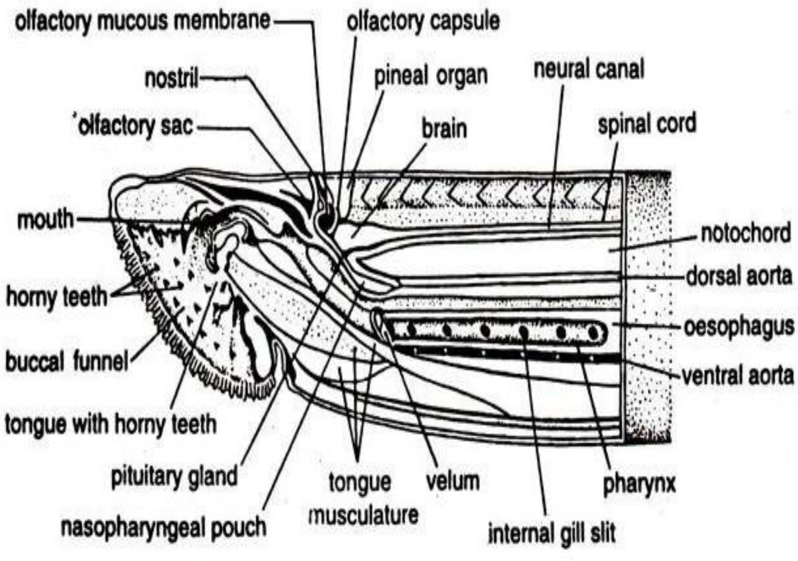


Fig. 6 Petromyzon sp. Anterior end (sagital section)

The teeth, when worn out, are succeeded by others developing at their bases. The tongue also bears large, horny teeth.

**Buccal cavity, oesophagus and res-piratory tube:**

The mouth leads into a buccal cavity, communicating behind with two tubes, placed one above the other (Fig. 6). The dorsal one is the oesophagus and the ventral one, respiratory tube, which is closed behind. The opening of the respiratory tube is guarded by a curtain-like velum bearing velar tentacles. The oesophagus leads into an unconvoluted intestine through a valvular aperture.

**Digestive glands:**

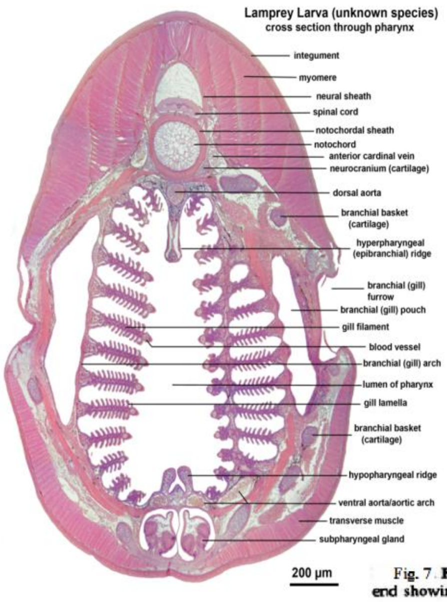
Paired buccal or salivary glands, a voluminous liver and patches of secretory cells in the epithelium of the anterior part of intestine constitute digestive glands.

**Feeding and digestion:**

The Petromyzon has a suctorial mouth, with a rasping apparatus. It clings to fishes and feeds on their tissues. The digestive enzymes secreted by the liver and proteolytic enzymes produced by zymogen granules in the so-called pancreatic acini help in digestion of carbohydrates and proteins.

**Respiratory System of Lamprey:**

The respiratory system consists of seven pairs of gill pouches or branchial pouches (Fig. 7). In the adult connection between the respiratory tube and oesophagus is lost. A gill pouch has the shape of a biconvex lens with numerous gill lamellae on the' inner surface. Gill pouches are separated from one another by inter-branchial septa. Each gill pouch opens to the exterior separately through gill pores or gill slits.



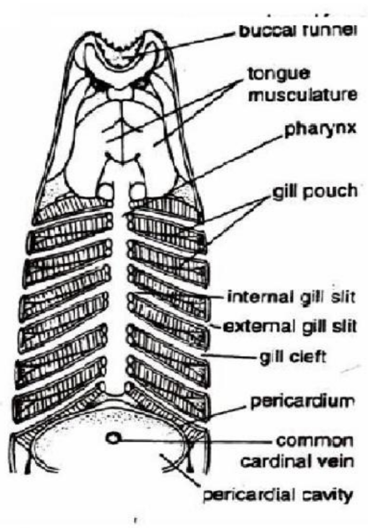




Fig. 7 **Petromyzon** sp. Frontal section of anterior end showing arrangement of gills (seen from below)

**Mechanism of Respiration:**

Both incurrent and ex-current streams of water pass through gill pouches. The branchial skeleton is elastic. With the expansion of the branchial basket water enters the respiratory tube through gill pores. The water is expelled through the same route by contraction of the branchial basket. Gaseous exchange takes place in the gill lamellae.

**Blood Vascular System of Lamprey**

The circulatory system is much advanced and consists of a heart, arterial and venous systems:

**Heart**

The heart is two-chambered (Fig. 8), enclosed in a pericardium and situated posterior to the last pair of gill pouches. The chambers are an atrium and a ventricle. The atrium lies left of the ventricle and receives blood from a small, thin-walled sinus venosus. The atrium opens into the thick-walled ventricle. The slightly dilated base of the ventral aorta arising from the ventricle is bulbous arteriosus.

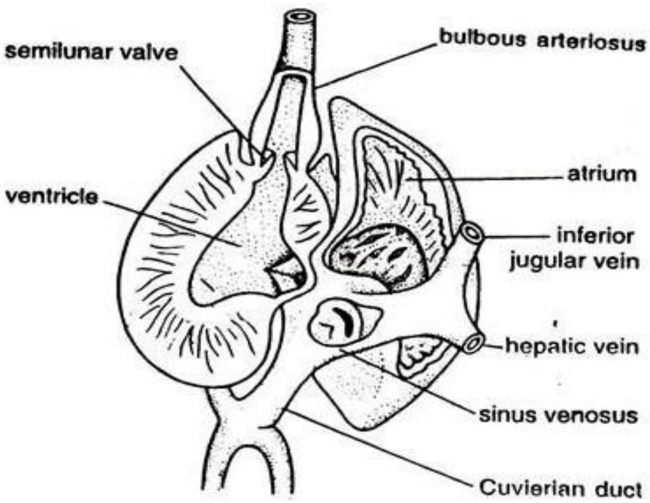



**Fig. 8** Petromyzon sp. Heart. Chambers exposed

The slit-like sinuatrial aperture is guarded by a pair of sinuatrial valves. The small atrioventricular aperture is guarded by atrioventricular valves. A single set of semilunar valves at the base of the bulbous prevents backflow of blood to the ventricle.

**Blood**

The colour of blood is red due to the presence of haemoglobin in erythrocytes, which is intermediate between the haemoglobin of invertebrates and gnathostomata. The red blood corpuscles are nucleated and circular. The white blood corpuscles are almost like the lymphocytes and polymorphs of higher vertebrates. The blood cells are formed in the tissues present in spiral valve, kidneys and spinal cord.

**Arterial system**

The ventral aorta with a slightly dilated base, the bulbous arteriosus arises from the ventricle between the last pair of gill pouches and runs anteriorly between the gill pouches. The ventral aorta gives eight afferent branchial arteries to the gill pouches. The afferent branchial arteries break up into capillaries in the gills. From the gills, the blood is collected by eight efferent branchial arteries (**Figs 9, 10**). These efferent branchial arteries open into the paired dorsal aortae.

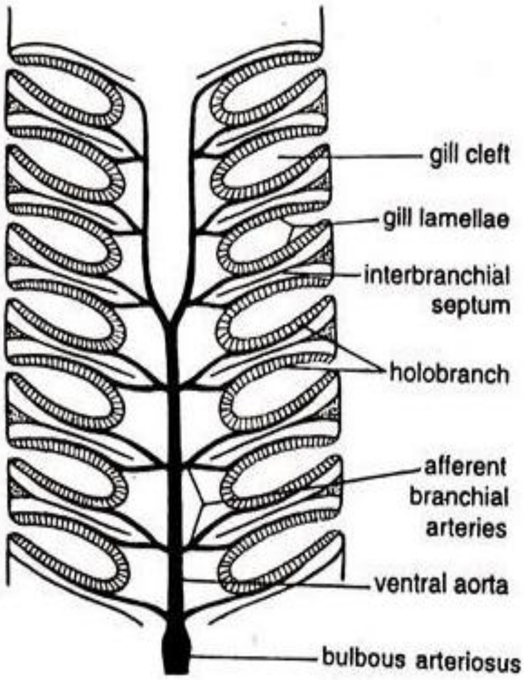



**Fig. 9** **Petromyzon sp. Afferent branchial system**

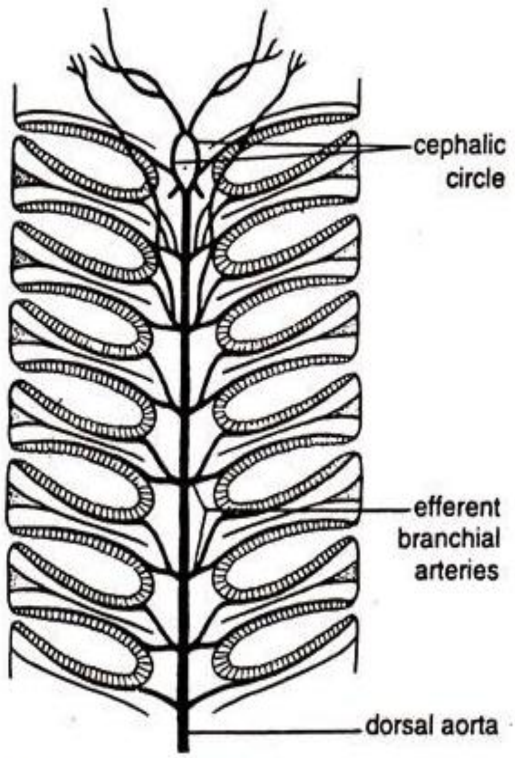



**Fig. 10** **Petromyzon sp. Efferent branchial system**

**Venous system**

The venous system consists of true veins and network of venous sinuses. The caudal vein bringing back blood from the tail region and running anteriorly divides into two posterior cardinal veins in the posterior end of the abdominal cavity. The cardinals receive blood from myotomes, kidneys and gonads and open into the heart by a single ductus Cuvieri on the right side (Fig. 8). The left ductus Cuvieri is absent in adult.

A pair of anterior cardinal veins (jugular) drain blood from the anterior region of the body. A large median inferior jugular vein brings back blood from the musculature of the buccal funnel and gill pouches. Renal portal system is absent. A hepatic portal vein drains blood from the gut and receives a vein from the head.

A contractile portal heart is present in the hepatic portal vein. A single hepatic vein collects blood from the liver and joins the sinus venosus.

The sinus venosus receives three vessels:

(a) A large single common cardinal vein on the dorsal side,

(b) A small inferior jugular vein on its anteroventral side and

(c) A small hepatic vein.

Only deoxygenated blood passes through the heart. Blood received from different parts of the body by sinus venosus is sent to atrium ventricle → ventral aorta → gills → body. It is a single type circulation.

**Excretory System of Lamprey**

The excretory system consists of a pair of kidneys and their ducts. The kidneys are mesonephric in origin. They are long, strap-shaped and lie on either side of the mid-dorsal line (Fig. 11), from which they are suspended by mesentery-like membrane.

The renal units of adult kidney are renal corpuscles. A mesonephric duct, the ureter, runs along the free edge of each kidney. In the adult, vestiges of pro- nephric ducts of larva are present anterior to the functional part, or mesonephric kidney.

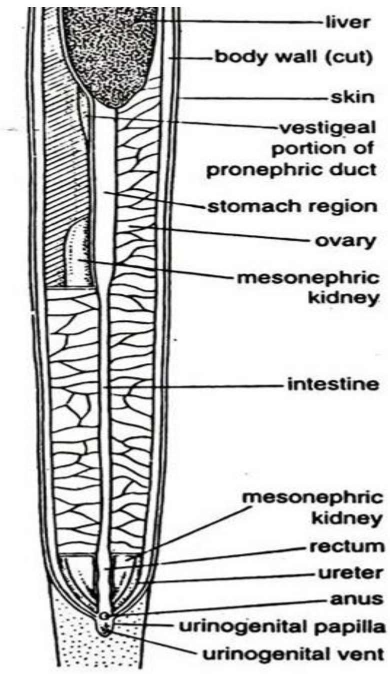


**Fig. 11** Petromyzon sp. Urinogenital system (ventral view). Female. Portion of ovary removed to expose kidney

The two ureters open into urino-genital sinus, a cavity within the uringenital papilla, just behind the rectum. The urinogenital papilla opens to the exterior by a urinogenital aperture, behind the anus in the vent. The urinogenital sinus is in com-munication with the coelom by genital pores, one on each side.

## Nervous System of Lampreys

The nervous system of lamprey is well- developed and the description of this system will represent an introductory account of the typical vertebrate nervous system (**Figure 10**).

## Brain

The neural tube becomes modified anteriorly into a complicated brain and the posterior part transforms into the spinal cord. The brain is divided into three primary parts — forebrain or prosencephalon, midbrain or mesencephalon and hindbrain or rhombencephalon.

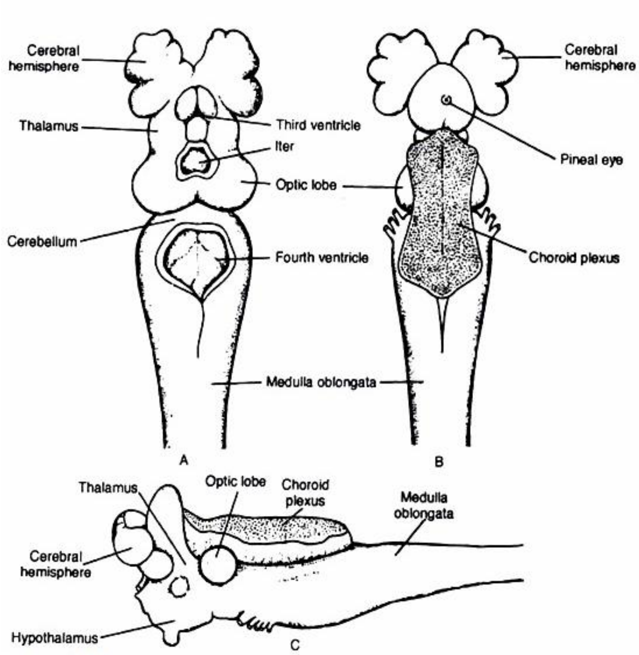



Figure 12 Brain of *Petromyzon* : A. Dorsal view having the choroid plexus intact. B. Dorsal view after removing the choroid plexus. C. Lateral view

## Spinal Cord

The spinal cord is a dorsoventrally flattened band-like structure. The spinal cord in lamprey is peculiar as no blood vessel is present within it. The nerve cell bodies are localised towards the centre and the peri-phery is composed of network of nerve fibres.

## Cranial Nerves

There are ten pairs of cranial nerves in lampreys. All these nerves emerge out from the mesencephalon and rhombencephalon except the olfactory and optic nerves. The general arrangement of the cranial nerves is almost similar to that of the gnathostomes with slight variation.

## Spinal Nerves

The spinal nerves are similar to that of Branchiostoma. The dorsal and ventral roots remain separate and do not join as observed in gnathostomes

The sympathetic nervous system is rep-resented by isolated nerve fibers running in both the roots of the spinal nerves. This sys-tem is quite diffused and ganglion formation is absent. All the nerve fibres of lampreys are devoid of myelin sheath; as a consequence the rate of conduction through such nerves is very slow.

**Lamprey Sense organs (Figure 11) include the Ear as** the auditory organs are represented by internal ears or membranous labyrinths; The eye is attached to the rim of the orbit; the eye ball nearly spherical; and the pineal apparatus consists of a larger, dorsally placed pineal eye and a ventral, smaller parapenial body. Both develop from evagination of the roof of the brain and are connected with epithalamus.

**Reproductive System of Lamprey**

The sexes are separate in the adult. Both spermatocytes and oocytes may be found in a single gonad in young lamprey. Sexual differentiation occurs at a late stage.

The single gonad, testis, made of sperm follicles or ovary (Fig. 12) extends the length of the pleuroperitoneal cavity, remaining suspended from the mid-dorsal body wall by a membrane, the mesorchium or mesovarium in male and female, respectively. Mature sperms or ova escape to the coelom with the rupture of the gonad and find their way through the genital pores to the urinogenital sinus and, thence, to the exterior.

**Fertilization and development**

In the breeding season the adults migrate from sea to river. During spawning the male wraps the posterior part of the female body and sheds sperms over the eggs released by the female. Fertilization is external. The egg is telolecithal with considerable amount of yolk in the vegetal pole. At about twenty-one days, young Ammocoete larva hatches out.

## SECTION TWO: GNATHOSTOMATA
## Super class: Pisces (Bears Fins)

### General Characteristics of Supper Class Pisces

This includes the **Cartilaginous fishes** such as sharks, rays and skates, which are exclusively marine vertebrates. Generally, they are characterised by the follow:

l-The skeleton is cartilaginous.

2-A Paired fins in the form of pectoral and pelvic fins are present.

3-The skin is covered with certain scales, known as the placoid scales and includes many mucus-secreting glands.

4-The mouth is ventral and is provided with strong teeth, There are two ventral nostrils which may be joined to the mouth by nasobuceal grooves, and upper and lower jaws are present. The intestine is provided with a spiral valve.

5-There are 5-7 pairs of gill-slits which are not covered with an operculum.

6-The heart is four-chambered, with a sinus **venosus, an auricle, a ventricle and a conus arteriosus**.

7-Sexes are separate and gonads are paired. Genital ducts open into a cloaca, and fertilization is internal. An example of this group is the **dogfish, *Scyliarhinus canicula***

## Class: Chondrichthyes
## The Dogfish (*Scyliarhinus canicula)*

**The Morphology----** (see figure 13 for System Organs)

The body is spindle-shaped, consisting of a dorso-ventrally compressed head, followed by the trunk, and then the tail.

There are two paired pectoral fins on both sides of the anterior end of the trunk region, two pelvic fins on both sides of the posterior part of the trunk, two median dorsal fins one behind the other, a ventral fin on the ventral side of the body, and a caudal fin surrounding the tail.

The mouth is a transverse crescent-shaped slit on the ventral surface oi the head. On either side and slightly anterior to the mouth there is a nostril which is connected with the mouth by a naso-buccal groove. The cloacal opening lies inbetween the 2 pelvic fins. ln the male‘ there is a pair of elongated claspers on each side of the clocal opening. There is an eye on either side of the head. guarded by two eyelids. Posterior to each eye there is a small aperture known as the spiracle, followed posteriorly by five narrow vertical gill-slits. The spiracle is considered a non-functioning gill — slit.

**The skin**

The skin is grey-coloured, covered with scaly structures known as the placoid scales. A placoid scale consists of a broad placoid classified basal plate embedded in the dermis, and a pointed spine directed posteriorly. The spine is formed of an inner dentine covered with a hard layer of enamel. Each scale has an inner cavity, known as the purp cavity. This cavity contains a mass of connective tissue richly supplied with blood capillaries which pass into the spine. The placoid scales on the jaws are modified into teeth which are used for holding and tearing the prey. A. lateral line runs along each side of the body. It contains minute sensory organs which may be concerned with the detection of the changes of pressure waves in water.

**The skeleton**

This is cartilaginous, and includes two main parts : axial skeleton and appendicular skeleton. The axial skeleton consists of the skull and vertebral colurnn. The skull includes the chondrocranium or brain case, two large anterior nasal capsules, two posterior auditory capsules, and the visceral skeleton made up of the jaws and the branchial arches which support the gill region. The vertebral column is built up of arnphicoelous vertebrae (with biconcave centra). The appendicular skeleton consists of the cartilages of the fins and those which support the pectoral and pelvic girdles".

**Digestive system**

The mouth leads to a large pharymx, into which open the spiracle and gill slits. The pharynx leads into a short wide oesophagus which opens into a u-shaped stornach. The proximal limb of the stomach is rather wide and is known as the cardiac portion. but the distal limb is narrow, tubular and is known as the **pyloric portion**. Posteriorly, the stomach is provided with a circular sphincter muscle, the pyloric valve. The stomach is followed by the intestine which is differentiated into a small duodenurn, large ileum and short rectum. The ileum contains a spiral fold of mucous rnembrane known as the **spiral valve**. At the junction between the ileurn and rectum, there is a small rectal gland. The rectum tenninates in the cloaca, which opens to the exterior by the cloacal opening.

The **liver** is a large bilobed structure which occupies most of the body cavity and is formed of two elongated lobes. A small gall bladder is embedded in the anterior part of the left lobe.A bile duct arises from the gall bladder, then passes posteriorly to open into the dorsal side of the duodenum.

The **pancreas** has two lobes; an elongated dorsal lobe which lir . between the pyloric stomach and the ileum, and a small ventral lobe lying close to the duodenum. A **pancreatic duct** carries the secretions of the pancreas to the proximal part of the ileum.

The **spleen** is a dark red flattened structure which is closely connected to the pyloric limb of the stomach.

**Circulatory system** '

The **heart** consists of four chambers: ***sinus venosus, auricle, ventricle and conus arteriosus.***

A **ventral aorta** extends anteriorly from the conus arteriosus carrying blood to the gills through five pairs of afferent branchial arteries. After being oxygenated in the capillaries of the gills, the blood is conveyed by the efferent branchial arteries to the dorsal aorta which extends posteriorly to supply the different parts of the body with oxygenated blood.

De-oxygenated blood is collected from the different parts of the body by certain veins which pour into the sinus venosus of the heart.

A **hepatic portal system** that transports the blood from the digestive canal, pancreas and spleen to the liver, and **a renal portal system**, which conveys blood from the posterior parts of the body into the kidneys, are found in the dogfish.

**Respiratory system**

**Gills** are the organs of respiration in the dogfish. The mouth is opened and the floor of the pharynx is lowered so that water is taken into the pharyngeal cavity. The mouth is then closed and the floor of the pharynx is raised, thus forcing the contained water into the gill pouches and driving it out through the gill-slits. Exchange of gases thus takes place between water and the blood in the fine tributaries of the afferent branchial arteries.

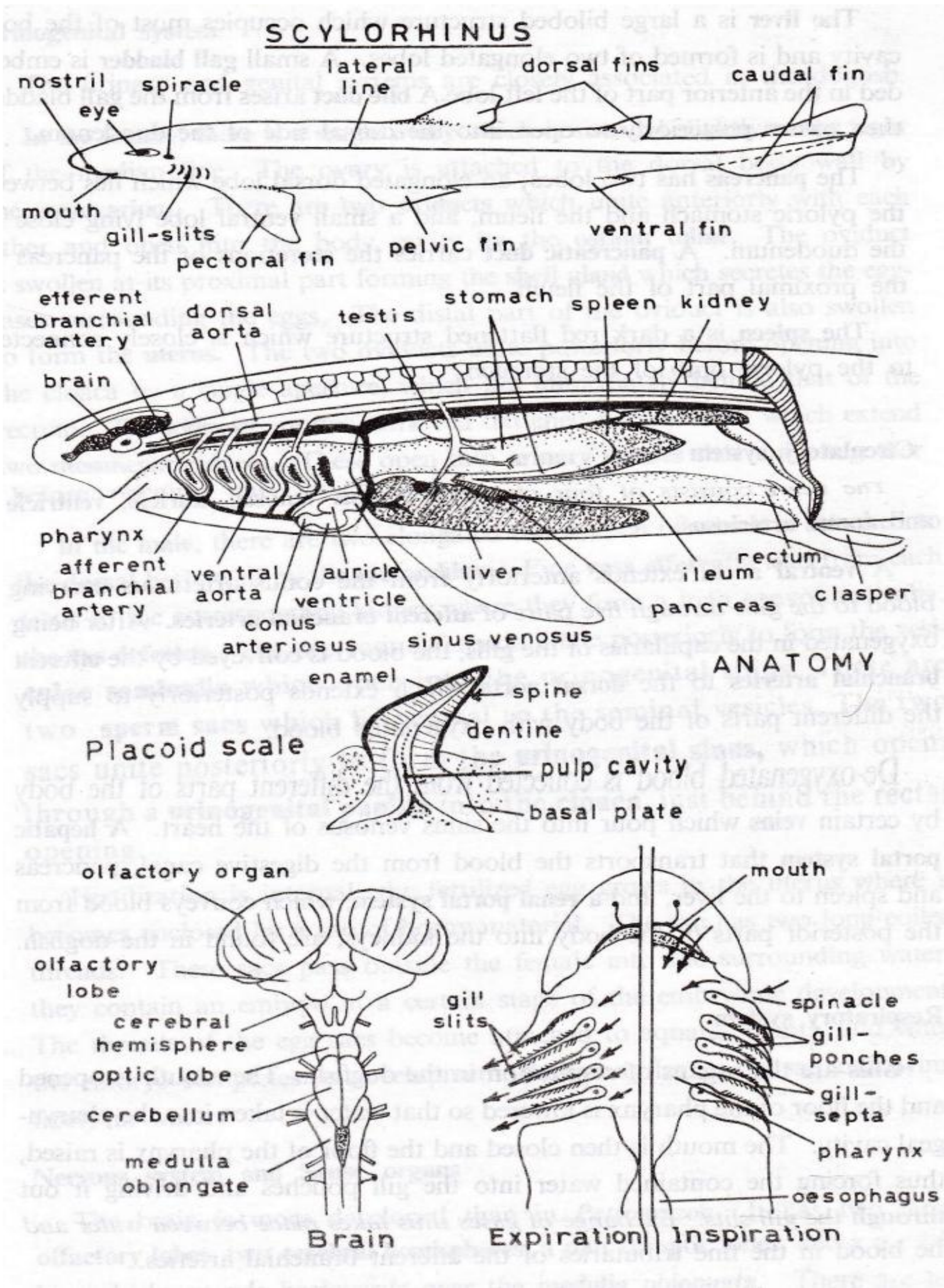



**Figure 13 Organ systems of the Dog Fish.**

**Urinogenital system**

The urinary and genital systems are closely associated in the dogfish. **In the female**, there is a single ovary which is situated slightly to the right of the median line. The ovary is attached to the dorsal body wall by the **mesovarium**. There are two **oviducts** which unite anteriorly with each other and open into the body cavity by the **ostium tubae**. The oviduct is swollen at its proximal part forming the **shell gland** which secretes the egg~ cases surrounding the eggs. The distal part of the oviduct is also swollen to form the uterus. The two **oviducts** unite posteriorly before opening into the cloaca by a single aperture, which lies immediately behind that of the rectum. The kidneys are two dark red flattened bodies, from which extend two mesonephric ducts. These open into urinary sinuses that unite together before opening into the cloaca.

ln **the male,** there are two elongated testes, each of which is attached to the dorsal body wall by the **mesorchium**. Fine vasa effrentia lead from each testis to the corresponding kidney where they form a long convoluted tube, the vas deferens. The two vasa deferentia dilate posteriorly to form the vesiculae seminalis which open into the urinogenital sinus. There are two sperm sacs which lie ventral to the seminal vesicles. The two sacs unite posleriorly to form the urinogenital sinus, which opens through a **urinogenital papilla** into the **cloaca**, just behind the rectal opening.

**Fertilization** is internal; the fertilized egg grows in the uterus. Where it becomes enclosed by a sac of horny material. The sac has two long coiled threads. These sacs pass outside the female into the surrounding water; they contain an embryo at a certain stage of the embryonic development. The threads of the egg sacs become attached to aquatic plants, and when the embryo completes its development. the young leaves the sac and swims freely in water.

**Nervous system and Sense organs** The brain is more developed than in Petromyzon. It has two large **olfactory lobes**, two **cerebral hemispheres**, a pair of **optic lobes**, and cerebellum which extends backwards over the **medulla oblongata**. There are 10 pairs of cranial nerves.

The **spinal cord** is a flattened tube with a narrow central canal. **Paired spinal nerves** arise from the spinal cord to innervate the different parts of the body. Sense organs include two large **olfactory sacs**, two **ears** each with three **semicircular canals**, and two well developed eyes. Certain sensory structures are also included in the lateral lines extending on both sides of the body.

## Class: Osteichthyes
## The Nile Bolti (*Tilapia nilotica*)

The Bony fishes class includes a wide variety of bony fishes which inhabit all sorts of waters. fresh. brackish or salty.

Generally, they are characterised by the follow

1-The skeleton is mainly formed of bone in the adults.

2-Paired and median fins are usually present.

3-The skin is provided with many mucous glands and is usually covered with bony scales which may be of the ganoid, cycloid or ctenoid types.

4-The mouth is usually terminal and provided with teeth. The jaws are well developed. No spiral valve is found in the intestine.

5-There are four gills which are included in a common gill chamber on each side of the pharynx. Gills on each side are covered with a bony operculum.

6-The heart is usually three-chambered, with a sinus venosus, an auricle and a ventricle.

7-Sexes are separate and gonads are paired. Fertilization is usually external.

8-There are ten pairs of cranial nerves. An example of this group is the **Nile Bolti**.

**Morphology----** (see figure 14 for Organ Systems)

**The body** is bilaterally compressed, and is clearly distinguished into **a head, a trunk and a tail.** The skin is covered with rounded scales, known as the **cycloid scales**, which have certain concentric rings indicating the age of the fish. The scales are arranged in successive rows; the hind part of a scale overlaps the front part of the following scale. In some other fishes, the posterior edges of the scales may be serrated. Such scales are known as the **ctenoid scales**. The fish has a pair of **pectoral fins**. a pair of **pelvic fins**. A **single dorsal** fin running along the dorsal edge, an **anal fin** at the posterior part of the ventral surface, and a **caudal fin** around the tail region.

**The mouth** is a narrow slit found at the anterior end of the head, surrounded by upper and lower jaws carrying small sharp teeth. The mouth leads into a buccal cavity which can be opened and closed during respiration by two membranous oral valves. Two minute nostrils open at the anterior end of the head above the mouth, and 4 pairs of gills are found on either side of the pharynx. They are enclosed in a gill chamber on each side, that is covered by a flattened bony plate, the **operculum**.

**The anus** lies on the ventral side of the body, at the beginning of the posterior third. A common **urinogenital aperture** is found in the male behind the anus, but in the female there are two separate openings: a genital opening formed behind the anus followed posteriorly by a urinary opening. Two large **rounded eyes** lie on both sides of the head. They are not provided with eyelids. There is a pair of lateral lines which extend on each side of the body and contain certain sensory cells.

**Digestive system**

The mouth leads into the **buccal cavity** which opens into the pharynx. Since there is no clear separation between the buocal and pharyngeal cavities, both form the **buccopharyngeal** cavity. This leads into a short oesophagus, followed by the stomach which is differentiated into **cardiac and pyloric portions**. The cardiac portion extends into a **blind sac or caecum**, while the pyloric portion opens into the intestine, which is a long coiled tube leading to the exterior by the **anus.**

**The liver** or hepatopancreas is bilobed; the left lobe is larger than the right. There is a membranous gall bladder from which extends a bile duct that opens into the anterior part of the intestine.

**The pancreas** is not found as a compact structure, but exists in the form of minute acini in the liver and mesenteries. A pancreatic duct collects from these acini and opens into the intestine, very close to the opening of the bile duct.

**The spleen** is a dark red organ which lies between the stomach and the left lobe of the liver.

**Circulatory system** The heart is enclosed in a pericardium. It consists of three chambers : **a sinus venosus, an auricle and a ventricle**. A ventral aorta extends from the ventricle to supply the gills with blood. At the beginning of the ventral aorta, there is a swollen non-contractile portion known as **the bulbus arteriosus**.

The **ventral aorta** gives off four pairs of **afferent branchial arteries** which pass to the gills. Four **efferent branchial arteries** collect blood from the gills on each side and open into a lateral dorsal aorta. The two lateral dorsal aorta unite to form a loop, **the circulus cephalicus**, from which a dorsal aorta passes backwards to supply different parts of the body. Dc-oxygenated blood is returned to the heart through 2 large **Cuvierian ducts** and 2 **hepatic veins**, all of which open into the **sinus venosus**.

**Respiratory system**

The respiratory organs are the **four pairs of gills** found on both sides of the pharynx. During inspiration, the oral valves are opened, the buccopharyngeal cavity is dilated and the opercula are closed; water thus enters the cavity through the mouth. In expiration, the oral valves become closed, and the buccopharyngeal cavity contracts, forcing the contained water to pass over the gills and then to the outside through the openings of the opercula. During the passage of the water over the gills, exchange of gases takes place.

**Swim (air) bladder**

A bony fish usually has an elongated organ known as the **swim or air bladder**. In Tilapia, the bladder is in the form of an elongated membranous sac which extends along the dorsal side of the body cavity below the vertebral column. It is regarded as a hydrostatic organ which acts to regulate the specific gravity of the fish.

**Urinogenital system**

The urinary system consists of two **elongated kidneys** which extend very close to the vertebral column. A short **mesonephrie duct** extends from the posterior end of each kidney, and the two ducts unite together forming a **common mesonephric** duct, that becomes dilated to form a small membranous **urinary bladder**. The common mesonephric duct opens to the exterior by a **urinogenital aperture** in the male, and by **a urinary aperture** in the female. The male has a pair of elongated testes from which arise **two vasa deferentia** that unite to form a common vas deferens. This opens together with the common mesonephric duct through the urinogenital aperture. The female has **two ovaries** from which arise two oviducts that unite to form a **common oviduct**, opening to the exterior through the female genital aperture. The Female lays a large number of eggs, which are fertilized outside the body. **i.e. fertilization is external.**

**Nervous System and Sense Organs**

The brain has two small **olfactory lobes**, **two large optic lobes** and a **cerebellum** which passes over the medulla oblongata. **There are l0 pairs of cranial nerves similar to those of the dogfish**. The spinal cord is a long flat tube which has a central canal. **Pairs of lateral spinal nerves** are given to the various parts of the body. Sense organs include the **olfactory sacs, taste buds and eyes**. The lateral lines include special sensory cells that can apparently detect slight changes in pressure or current movements.

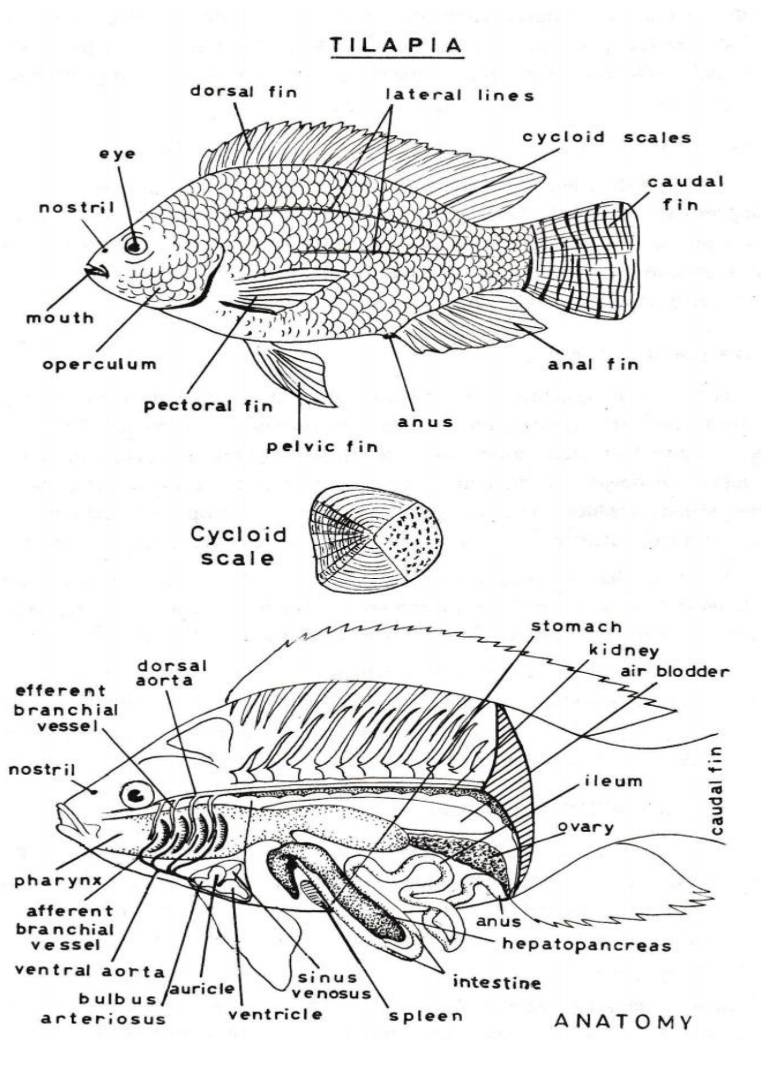



**Figure 14. Organ systems of the *Tilapia nilotica***

## Super class: Tetrapoda (Bear Limbs)

**General Characteristics of Supper Class Tetrapoda**

The Tetrapods are four-footed vertebrates (Gk. tetras = four; podus = foot). This group includes the remaining four classes of vertebrates assigned as **Anamniota** class of Amphibia, and **Amniota** classes of Reptilia, Aves and Mammalia. Although members of these classes exhibit a wide range of morphological and anatomical differences, yet they all agree in having two pairs of limbs which have a skeleton based upon a common plan, known as **the pentadactyl** limb skeleton. Their pectoral and pelvic girdles are also built up on the same generalized plan.

**The Pentadactyle limb organisation**

The fore- and hindlimbs of tetrapods (figure 15) are differentiated externally into regions or parts which are movable on one another. The forelimb is differentiated into **upper arm**, **fore-arm, wrist and hand**. The hind limb is also composed of the **thigh, shank, ankle and foot**.

**The skeleton of the fore-limp** includes the following bones 1]-**Humerus,** a long bone found in the upper arm. 2]-**Radius and ulna**, shorter bones which support the fore-arm. 3]-**Carpals**, nine bones found in the Wrist or carpus. They are arranged in three rows, these are:

a) A proximal row, formed of three bones: **radiale** near the end of the radius, **ulnare** near the end of the ulna. and **intermediurn** inbetween.
b) A median row, formed of a single bone, the **centrale**.
**c)** A distal row consisting of five small distal **carpals.**

4]-**Metacarpals,** five slender bones found in the palm of the hand or manus.

5]-**Phalanges**, form the skeleton of the lingers or digits. Their number is represented by the **digital formula** which indicates the number of phalanges in each finger. Typically, the digital formula for the digits of the hand is 2 : 3 : 3 : 3 : 3, starting with the first finger, the thumb.

**The skeleton of the hindlimb** includes bones which have precisely the same arrangement as those described in the forelimb, but are differently named: they are **l-Femur**, found in the thigh. **2-Tibia and fiiiula**, lie in the shank.

**3-Tarsals**, nine bones found in the ankle and are arranged in three rows :

a) A proximal row, formed of three bones : tibiale adjacent to the tibia fibulare adjacent to the fibula, and intermedium inbetween. b) A median row, formed of a single **centrale**. c) A distal row consisting of five small **distal tarsals**.

**3-Metatarsals**, five slender bones found in the foot.

5-**Phalanges**, in the fingers of the foot. Their number is also represented by the digital formula 2 : 3 :3 : 3 : 3, starting with the first finger, the hallux.

**The Girdles**

There are two girdles, **the pectoral girdle** which is found in the pectoral region, and **the pelvic girdle** which is found in the posterior trunk region. The pectoral girdle serves to attach and articulate the forelimbs with the pectoral region of the animal, while the pelvic girdle serves to the support of the animal as well as for the attachment and articulation of the hind-limbs with the vetebral column.

**The pectoral girdle** is formed of two similar halves, each of which includes three bones: a dorsal scapula, and two ventral bones, namely an **anterior precoracoid** and a **posterior coracoid**. At the region where the pre-coracoid and coracoid bones meet there is a **glenoid** cavity which acts as a socket for the articulation of the head of the humerus.

**The pelvic girdle** is also formed of two halves, each of which includes three bones: a dorsal ilium and two ventral bones; an anterior pubis and a posterior isehium. A cavity known as the acetabulum is found at the point where the pubis and ischium meet; it acts as a socket for the articulation of the head of the femur.

## The Anamniota

### Class: Amphibia

Amphibians are vertebrates that lead a double mode of life (Amphi = double; bios : life). They constitute a group of about 2,500 species of animals that spend their lives between land and water. Most of them start their life as fish-like individuals, the **tadpoles**, which breathe by gills and swim with a caudal fin. They gradually lose the gills and tail, and develop into lung-breathing, four-footed animals which leap from water to land. However, most of them return occasionally to water. Hence, their body organs are adapted for both aquatic and terrestrial modes of life.

General characters of Amphibia

**1-**They are **cold-blooded animals** in which the body temperature varies according to the surrounding medium.

**2-**They **hibernate** during winter, i.e. stop most of their activities, hide. and remain stationary between stones in pools and on river banks till the beginning of the next spring. During **hibernation,** pulmonary respiration stops, and breathing takes place by the skin. No food is taken by the hibernating animals, and they depend mainly on the food materials stored in their bodies. The body temperature decreases, almost reaching that of the surrounding medium, but they do not frost otherwise they die.

**3-**The body is covered by a coloured skin which can be easily matched with the surrounding habitat.

**4-**There are two **nostrils,** two eyes with movable eyelids and two ears.

5-Respiration takes place by gills in the early developmental (larval) stages. But gills disappear gradually and become replaced by lungs, which are the principal organs of respiration in the adult stages.

**6-**The **coelom** is distinguished into two main regions: pericardial cavity and peritoneal (abdominal) cavity.

**7-**The heart consists of 5 chambers : a sinus venosus, 2 auricles, a ventricle and a truncus arteriosus. There is a hepatic portal system and a renal portal system.

**8-**The kidneys are of the mesonephric type.

**9-**They have ten pairs of cranial nerves.

**l0-**Fertilization is external in some species and internal in others. An example of this group is the common Egyptian toad, ***Bufo regularis***.

## The Amniota

The Amniota include the remaining 3 classes of vertebrates: **Reptilia, Aves and Mammalia**. They are characterised by the following general characters:

**1-**The embryo has an embryonic membrane known as the ammion.

**2-**There is a neck (**cervical)** region following the head, and is supported by certain vertebrae, the **cervical vertebrae**.

**3-**The buccal cavity is divided into an upper air passage, and a lower food passage.

**4-**The thoracic region is protected by **ribs.**

**5-**The heart consists of **2 auricles and a ventricle**, which is a single chamber in some types, but is divided **into two chambers in others**.

**6-**The respiratory system includes a **larynx and trachea**.

**7-**The kidney is of the type known as the metanephros, which is the most advanced type of kidneys.

**8-**There are twelve pairs of cranial nerves.

### Class Reptilia

This class includes lizards, snakes, turtles, tortoises, chamaeleons and crocodiles. These are generally known as creeping animals. The name of the class refers to the mode of their locomotion (reptum: creep).

### General characters

1-The body is covered with horny scales which prevent the loss of water. In some kinds, there are bony plates. The skin, in most species, is dry and does not contain any glands. 2-There are two pairs of limbs, each with five fingers ending in horny claws. 3- Respiration is always by lungs. 4-The ventricle is incompletely divided, except in corcodiles where it is completely divided into two separate chambers. There are two aortic arches.

5-The red blood cells are oval and nucleated.

6-There is a single occipital condyle at the posterior portion of the skull.

7-Fertilization is internal and the eggs are markedly rich in yolk.

8- They are poikilothermic (cold-blooded) i.e the body temperature varies with that of the environment. An example of this group is the snake.

**Class Aves**

**General characters**

**l-**They body is covered with feathers.

**2-**The head is produced anteriorly into a beak, having various shapes in the different species.

**3-**The skin possesses a single gland, the oil gland, which is located at the base of the tail.

**4-**The fore-limbs are modified into wings.

**5-**The skull has a single occipital condyle.

**6-**Most of the vertebrae, particularly those of the trunk region, are fused together. Several other bones are also fused; a modification which helps in flight.

**7-**The digestive canal includes a wide sac-like structure, the crop, for the temporary storage of food. There is also a thick-walled muscular gizzard for grinding hard food materials.

**8-**The heart consists of 4 chambers : 2 auricles and 2 ventricles.

**9-**There is only one aortic arch which is the right one; the left aortic arch is lacking.

**l0**-Red blood cells are oval and nucleated.

**ll-**There are air sacs connected with the lungs.

**l2**-Birds possess a lower larynx, called the syrinx. at the basal region of the trachea.

**l3**-There is no urinary bladder, and excretory materials are semi-solid.

**l4-**The females possess a single ovary, which is the left one, and there is also one oviduct, the left oviduct. Fertilization is internal. The eggs are large in size, rich in yolk and are protected by hard calcareous shells. An example of this group is the Pigeon ***Columba livia***

**l5-**They are horniothermic (warm blooded), i.e the body temperature does not vary with that of the environment.

**Class Mammalia**

The name of this class is derived from the fact that animals belonging to it feed their young by milk produced by mammary glands Mammalia is the highest group in the Animal Kingdom. It includes about 15.000 species. Examples are: sheep, cattle, monkeys, bats and man.

**General characters:**

**l-**The body is distinguished into: **a head, neck, thorax and trunk**. A tail may be present in some forms.

**2-**The skin is covered with hair and possesses sweat glands, sebaceous glands, scent glands and mammary glands.

**3-**They possess 4 limbs; the foot has usually 5 toes modified for walking, running, climbing, burrowing, swimming or flying. They have horny claws, toes, nails or hoofs.

**4-**They are warm-blooded; i.e. their body temperature is kept constant.

**5-**The jaws are provided with similar or dissimilar teeth which arc arranged into a definite manner that are represented by a dental formula.

**6-**A muscular diaphragm separates the thoracic cavity from the abdominal cavity.

**7-**The heart is 4-chambered, and only the left aortic arch is present. Red blood cells are non-nucleated.

**8-**The skull has 2 occipital condyles.

**9-**There is a urinary bladder and urine is fluid.

**l0-**The testes are found in an external sac, the scrotum, lying outside the abdominal cavity.

**ll-**There is an external ear (pinna).

**l2-**A Fertilization is internal and the embryo develops inside the uterus till birth. Embryonic membranes (amnion, chorion and allantois) and placenta are present. An example of this group is the rabbit *Oryctologus cuniculs*

## Class Amphibia

**Scientific Classification of Amphibians**

Kingdom: Animalia

Phylum : Chordata

Subphylum: Vertebrata

Superclass: Tetrapoda

Class: Amphibia

Amphibians are cold blooded animals that belong to the class Amphibia which comprises of three orders. Amphibians are the most important class in the vertebrates group. Since they are the first tetrapods (four-legged vertebrates) The amphibians can be divided into three main orders. Each having its own species. The orders are as follows:

**Order Anura (Salientia).** The species that belong to this order are Frogs and Toads. The word "Anura" means "absence of tails". As the word implies frogs and toads do not have tails. Among the three orders that make up the amphibian class Anura is the biggest order. It has about 4500 species. These species are different from other two species since they have four legs and reproduce through external fertilization. Though frogs and toads belong to the same order they have different characteristics.

**Order: Gymnophiona** also called as Apoda. The specie that belong to this order is Caecilians. This typical amphibian specie resembles large worms and lack limbs. About 50 species of amphibians belong to this order. They are mostly found in the tropical forest and fresh water sediments. These are aquatic in nature and are found in Africa and south Asia and America. Gymnophiona species have short tails but lack the appendages.

**Order: Caudate** also called as Urodela. The species that belong to this order are Salamandera and Newts. About 500 species belong to this order. The species salamanders and newts are unique. The term Caudata means "tail". The species in this category have tails and four limbs. The presence of tail helps to easily identify the species of Caudata and Anura.

**Habit and Habitat of Toad**

Toad is a cold-blooded/poikilothermous or Exothermic i.e., the temperature of the body depends on the temperature of the external environment) vertebrate by the process of hibernation or winter sleep. An adult toad generally lives on land, and some time in water if necessary. Toad is a nocturnal carnivorous animal and catches insects by its sticky tongue. Males can produce croaking sound by the help of the vocal sac, specially during breeding season which occur in water.

**External Structures of Toad**

Toad has a short bilaterally symmetrical body as shown in figure (Fig. 17). There is no exoskeleton over the skin, i.e., the skin is naked. The skin is rough is texture. The dorsal side of the body is blackish-grey while the ventral side is yellowish grey as toad can change the colour of the body to match with the hues of its surroundings

The body is divisible into head and trunk. Distinct neck is absent. A postanal tail is absent in adult stage. The tail is present and well-developed in the larval condition 'tadpole'. The head is semicircular in outline. It is broad, depressed and has a blunt snout.

### The Skin of the Toad

The skin of toad is kept moist and frequently slimy. Besides its protective function, the skin of toad serves as an additional respiratory organ during hibernation. The skin is composed of an outer epidermis and an inner dermis (Fig. 18 separated by basement membrane, The epidermis  outermost layer is the stratum corneum.

## Glands

There are two types of skin glands in toad. These are: (a) Mucous glands secreting mucus and (b) Poison glands producing poison and the mucous glands are smaller than the poison glands. The products of the gland come out through duct to the outside.

## Colouration

The colour of toad depends upon the presence of pigment cells or chromatophores in the dermis. Some chromatophores also invade the epidermis. The chromatophores may be melanphores (containing black pigment) for production of blackish colour, guanophores (containing colourless crystals of guanine) producing diffraction effect, and lipophores (containing yellow pigment) cause yellowish effect. In general, the colour change in toad is rather a slow process controlled under the action of melanophore stimulating hormone (MSH) of the pituitary gland not under nervous control

## Muscular System

The muscular system is composed of muscles which are used primarily for the movement of the body. The muscles possess the power of contraction and relaxation. All the muscles are mostly arranged in opposing groups in such a fashion that when one set contracts, the opposing set remains in a relaxed state. This co-ordination is controlled by the nervous system. **The skeletal muscles** in Bufo regularis are grouped into the following general types depending on the mode ofaction: **(a) Flexor muscle**, this type of muscle bends one part on another such as Biceps flexes forearm towards upper arm; **(b) Extensor muscle**, this muscle extends or straightens a part such as triceps extends forearm on upper arm; **(c) Abductor muscle**, such a type of muscle draws a part away from the axis of the body or of a limb such as the Deltoid muscle draws arm forward; **(d) Adductor muscle**, this type of muscle draws a part toward the axis of the body or of a limb such as Latissimus dorsi muscle draws arm up and back; **(e) Depressor muscle**, this muscle lowers a part such as Depressor mandibular muscle moves lower jaw down for opening the mouth; **(f) Levator muscle**, this muscle raises or elevates a part such as Masseter muscle raises lower jaw to close the mouth and **(g) Rotator muscle**, this muscle rotates a part such as Pyriformis muscle raises and rotates the femur.

## Locomotion in Toad

In toad, the entire muscular and skeletal systems have become specialised for jumping and swimming. Besides jumping and swimming, toad is able to walk on land. The forelimbs manipulate and adjust the direction before each jump.

Swimming is done by the activity of the limbs which act as the propellers. The hind limbs are long and the digits are webbed. These limbs act like oars and enable the animal to swim.

## Digestive System

The digestive system is composed of the following parts (Figure 19)

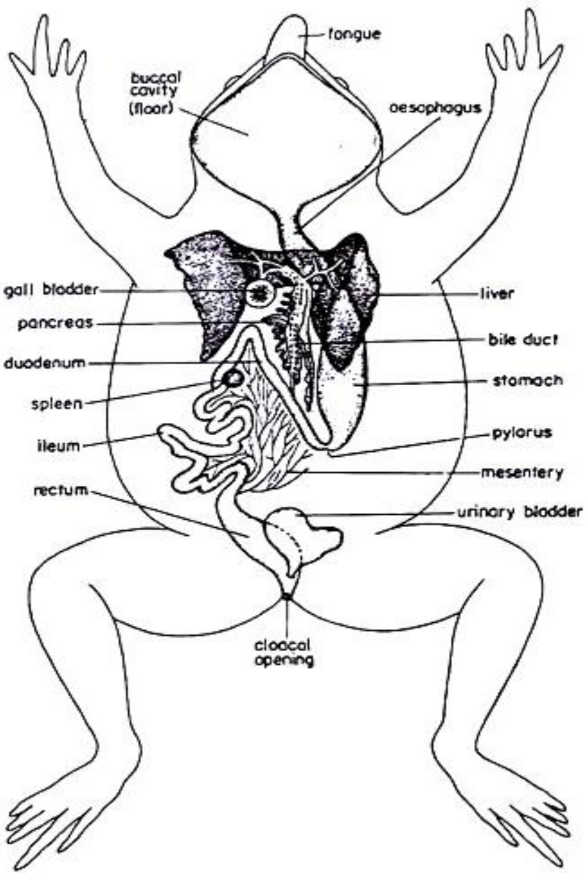
The **Mouth** which is a large, semicircular opening at the anterior end of the head and bounded by two toothless jaws.

The **Buccal cavity** that is a dorsoventrally compressed spacious chamber with a fleshy tongue on the floor with front-end attached tongue.

The **Pharynx** is the narrowed posterior region of the buccal cavity. While the Oesophagus is a short, narrow, muscular tube joining pharynx with the stomach.

The **Stomach** is a large, elongated, sa
side in the abdominal cavity and dorsal
cardiac, and the posterior narrow part is

The **Small intestine** is a constriction,
junction of the stomach and the intest
portion parallel to the stomach is the c
coiled part, the ileum.



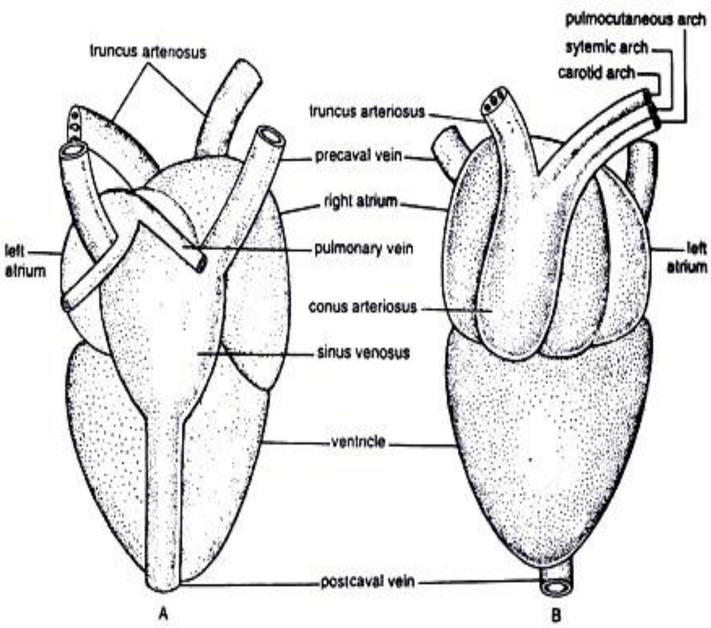

The **Rectum** is a short but wide tube, o
The **Liver** is a large, reddish-brown, b
median portion. The left lobe is larger t
spherical gall bladder is median in pos
duodenum while the **Pancreas is** epre
gland surrounding the common bile c
duodenum.

**The Circulatory System**

The heart, veins, arteries and capillaries constitute the circulatory system. The heart is partly venous and partly arterial. It is the major organ, both in the venous and arterial systems.

The Heart is a reddish, muscular structure and consists of five parts (Fig. 20).

The **Sinus venosus** is large, dorsally placed, thin walled, triangular sac. The **Atria (auricles)** are two thin walled chambers in front of the ventricle. The right one is larger in which the sinus venosus opens. The left atrium receives pulmonary veins. The **Ventricle** that is a highly muscular thick walled conical structure posterior to the atria, and finally the **Conus arteriosus** that is a very short but stout, whitish vessel, arises from the right side of the base of the ventricle. It continues forward and divides into two truncus arteriosus.




## The Venous System

This system is composed from the followings: (see Figure 21)

The **Pulmonary Veins**, returned the oxygenated blood from two lungs and open dorsally into the left auricle after uniting with each other.

**The Caval Veins,** returned the deoxygenated blood from the rest of the body by Precavals viens (**anterior venae cavae** and **posterior vena cavae**).

I)-Precavals or **Anterior Vena Cavae** that is formed by the union of three veins; **1-** External jugular receiving branches from the tongue (lingual) and floor of the mouth (mandibular), **2-**Innominate receiving branches from the brain and orbit (internal jugular), and from shoulder and back of arm (subscapular), **3-**Subclavian vein receiving branches from arm (brachial) and from skin and muscles of the abdomen and also mucous membrane of mouth and head muscles (musculo-cutaneous).

(II) Postcaval or **Posterior Vena Cava** that receives blood from the kidneys by 5 to 6 pairs of renal veins and a pair of gonadial veins (spermatic in male and ovarian in female) from gonads. It arises between the kidneys and runs forward ventral to the dorsal aorta in the mid-ventral line. Before it is communicated with the sinus venosus it also receives a pair of hepatic veins from the liver.

**The Renal Portal Vein** collect the blood from the posterior side of the body constitutes renal portal system. Two large veins, the femoral and sciatic, return the blood from each leg. On entering the body cavity each femoral vein divides into a ventral pelvic and a dorsal renal portal vein. The pelvic meets its fellow from the opposite side forming the anterior abdominal vein.

**The Hepatic Portal System** collects the blood from the alimentary canal through many branches and carries it to the liver where the veins break up into capillaries and the blood is collected by hepatic veins to pour into the postcaval.

## Arterial System

The **arterial System** includes all the arteries together and the heart constitute arterial system (Fig. 16.5), the **Conus arteriosus** is a stout vessel arising from the base of the ventricle at its right side, runs obliquely forward and divides into two truncus arteriosus. The **Truncus arteriosus**, Each of them divides into three vessels or arches:

**A) Carotid arch**, the anterior most one. It runs anterolaterally, forms a swelling, the carotid labyrinth and divides into two, an external carotid ends in throat and tongue and an Internal carotid goes to head.

**B) Systemic arch**, the middle arch and turns round the alimentary canal, courses dorsally and unites with its fellow of the other side to form dorsal aorta. The branches of the systemic arches are similar except oesophageal. It branched to **Laryngeal** supplies larynx, **Occipitovertebral** supplies head and vertebral column, **Subclavian** supply the fore limb and shoulder, **Oesophageal** origins slightly anterior to the beginning of the dorsal aorta, supplies blood to the oesophagus but present only in the left systemic arch and finally, the **Dorsal aorta** that runs posteriorly and sends following branches [**Coeliacomesenteric**, its anterior branch **coeliac** supplying stomach, pancreas, gall bladder and liver, and the posterior branch **mesenteric** supplies spleen, intestine and liver; **Urinogenital** is a number of small, paired arteries ending in the kidneys and the gonads and the **Iliac** that sends a branch, the epigastric to the ventral body wall and divides into two, the femoral and sciatic supplying the hind limb.

**C) Pulmocutaneous arch**

The vessel loops over the heart anterodorsally and divides into two branches, the **Cutaneous** to the skin of the back and the **Pulmonary** to the lung of the side.

**Toad Embryonic development**

The zygote undergoes rapid divisions known as cleavage (or segmentation) and results in the production of a large number of blastomeres (Fig. 23). The cells arrange blastula, goes for gastrula (gastrulation), and then to differentiation into three primary germinal layers; Ectoderm, Mesoderm and Endoderm where adult structures are developed out of these three primary germinal layers. After about two weeks a small embryo is seen moving and wriggling. The developing embryo gets nourishment from the yolk and eventually hatches as the tadpole larva which spend in aquatic medium for various amounts of time depending on hydro period, thermal range, predation, competition and other related factors.

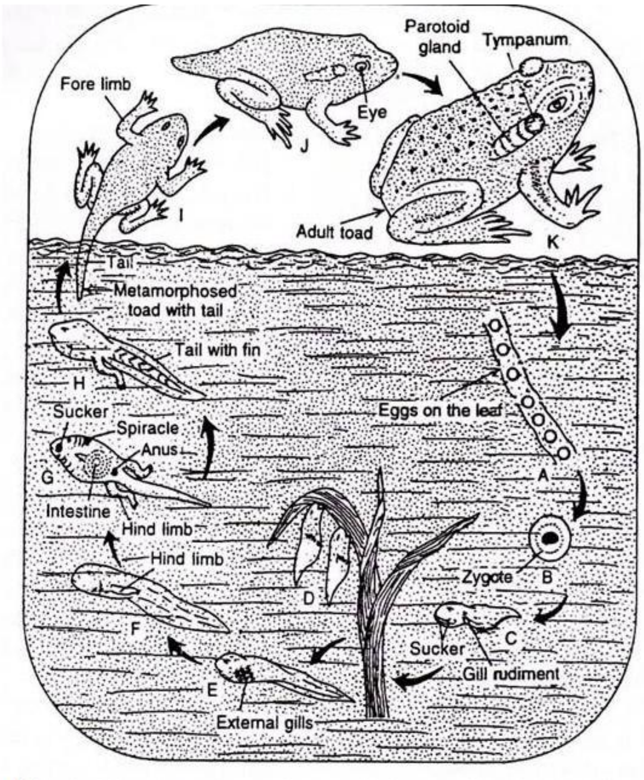


Fig. 23 Schematic representation of the larval development and metamorphosis

**Skeletal Structures of Toad**

There is no exoskeleton in toad. The skeleton that supports the soft parts lies internally and is designated as endoskeleton. It is chiefly made up of bones and cartilages. The endoskeleton (figure 24) is composed of the **axial skeleton** which comprise skull and the vertebral column while the **appendicular skeleton** form the skeletal frame of the paired limbs and the girdles.

**Urinogenital System**

The urinary and genital systems (see figure 25) are not completely separate in toad and the two are collectively described as urinogenital system. The organs are located in the posterior half of the coelom.

The **Urinary (Excretory)** System composed of **Kidneys**, two flat, somewhat elongate oval, slightly lobulated reddish bodies, one on each side of the vertebral column; the **Ureters**, thin walled ducts, arise from the outer border of the kidneys and run backward. Posteriorly forming a common duct opens into the cloaca on its dorsal surface; the **Urinary bladder** that is a thin walled, bilobed median sac anteroventral to the cloaca. It opens into the cloaca on the ventral surface.

The **male Genital System** consists of **Testes**, whitish, slightly elongated, paired bodies, attached to the ventral face of the kidneys near the anterior end; **Bidder's organ**, rounded bodies, one attached to the anterior end of each testis; and the **Urinogenital ducts** as in male, it functions as both vas deferens and ureter.

The **Female Genital System** includes **Ovaries**, two large, much folded, membranous, dark bodies with numerous white dot like structures; the **Oviducts**, two large, convoluted tubes and each ends in a funnel at the anterior end opening in the coelom; and the **Uterus** that is a posterior dilated portion of the oviduct and posteriorly form common genital duct opens into the cloaca on its dorsal surface.

## Nervous System

The nervous system of toad includes: (see Figure 25)

(a) The **central nervous system**,

(b) The **peripheral nervous system** and

(c) The **autonomic nervous system**.

The nervous system controls and co-ordinates the various activities of the body.

**a)**The **central nervous system** includes the brain and the spinal cord. It is essentially a hollow tube whose anterior portion becomes the brain and the posterior part narrows down to form the spinal cord. The cavity of the brain and the spinal cord is filled up with the cerebrospinal fluid. The brain and the spinal cord are made up of nerve cells (neurons) and nerve fibres. A collection of the extended processes of the neurons enclosed by a connective tissue sheath constitute the **nerves**.

**b)**The **Peripheral nervous system** includes the cranial and the spinal nerves arising from the cerebrospinal axis where there are two types of nerves; **(a) Afferent** or **Sensory fibres** which convey the information from the receptor organs to the central nervous system and **(b) Efferent** or **Motor fibres** which carry impulses from the central nervous system to the effector organs.

The **Cranial nerves** are Ten pairs of nerves (and the 0 nerve) originate from the brain while **Spinal nerves comprise ten pairs and** each spinal nerve has a **dorsal sensory root** and a **ventral motor root.**

The **first spinal** nerve is known as hypoglossal. It supplies the muscles of the tongue.

The **second and third** spinal nerves form the brachial plexus.

The **fourth, fifth and sixth** spinal nerves supply the integument and the muscles of the trunk region.

The **rest of the spinal** nerves form the sciatic plexus which gives origin to the large sciatic nerve and supplies the hind limb.

The **last spinal nerve** is insignificant.

**c)**The **Autonomic nervous system** consists of two sympathetic trunks one on either side of the dorsal aorta.

The sympathetic trunks start near the point of formation of iliac arteries and each trunk contains ten small ganglia connecting with the corresponding spinal nerve by ramus communicans.

# Class Reptilia

## Scientific Classification of Reptiles

Kingdom: Animalia

Phylum: Chordata

Subphylum: Vertebrata

Superclass: Tetrapoda

Class: Reptilia

Reptiles present in the world are classified into four main groups known as orders. These four groups are as follows:

**Order: Crocodilia**.

The large reptiles such as crocodiles, alligators, caimans and gavials belong to the order Crocodilia. The reptiles in the crocodilia are carnivorous and are mostly found in tropical and subtropical swaps and rivers. This order is the subclass of Archosauria (ruling reptile). Dinosaurs the extinct reptile belong to this order.

**Order: Sphenodonita**, this order composes of a single member called Tuatara that is lizard like reptile found in the lands of New Zealand.

**Order: Squamata,** includes the terrestrial reptiles such as lizards and snakes. The members of this species have the ability to creep with the help of their abdomen.

**Order:Testudines,** this comprise the turtle and tortoise creatures .These species have bony shell with horny plates for their protection. These are mostly aquatic and are the oldest living reptile in the world.

The **Reptilian class** consists of the amniotes, a group of vertebrates that are neither mammals nor birds. The amniotes are characterized by their eggs that feature an amnion or a double membrane allowing the embryo to respire on land. Other features that help to distinguish reptiles from other tetrapod animals are their scute or scale covered skin and their cold-bloodedness. They are found all over the world from rainforests to tropical and temperate regions.

**Reptile Morphology and Anatomy (**see Figures 27, 28)

**Eyes:** Most Reptiles are unable to see properly during nighttimes as their vision is mainly adapted to the daylight conditions. They have color vision with the visual depth perception being much more advanced than Amphibians and many Mammals. The vision is reduced in species like the Blind Snake, while some snakes have extra visual or sensory organs that make them sensitive to heat and infrared radiation.

**Skin:** The horny epidermis layer makes their skin watertight, allowing these animals to inhabit dry land. Reptiles have thinner skin compared to mammals and it also lacks the dermal layer present in mammal skin. The exposed skin areas are covered in scutes or scales which may have a bony base, creating their armors. In turtles, a hard shell made up of fused scutes covers the entire body.

**Respiratory System**

Reptiles use their lungs for breathing. The skin of the aquatic turtles is more permeable for allowing them to respire while the cloaca is modified in various species to increase the gas exchange area. Despite these adaptations, lungs remain a very important part of their respiratory system. The main Reptile groups accomplish lung ventilation in different procedures, for example Squamates are known to ventilate the lugs mainly by their axial musculature.

**Circulatory System**

Most of these animals have three chambers in their heart _ two distinctly divided atria and one ventricle, which may be variably partitioned in different species. They also have two aortas playing a major role in their systemic circulation. The oxygenated and deoxygenated blood may get mixed with each other in their three-chambered heart with the level of mixing depending on the species and the physiological state of the animal.

Reptiles circulatory system is capable of shunting back the deoxygenated blood to the body and the oxygenated blood to the lungs if necessary. Unlike other Reptiles, animals in the crocodilian subgroup have four-chambered hearts. But, their two systemic aortas are only capable of bypassing their pulmonary circulation. On the other hand, the three-chambered hearts in various lizard and snake species can function as the four-chambered ones during contraction.

## Digestive System

Majority of these animals have short digestive tracts because their diet mainly consists of meat, which is very simple to digest. Their digestion process is slower than that in mammals due to their inability of mastication and their low metabolism rate while resting. The energy requirements for their poikilotherm metabolism are very low which allows large animals from this class such as various constrictors and crocodiles to survive for months from one large meal, digesting it slowly. Herbivorous reptiles are also unable to masticate their food, which slows down the digestive process. Some species are known to swallow pebbles and rocks that help in grinding up plant matters within the stomach, assisting their digestion.

## Nervous System

The basic nervous system in the Reptiles is similar to that in the Amphibians. But, Reptiles have slightly larger cerebrum and cerebellum. Most of the important sensory organs are properly developed in these creatures. However, there are certain exceptions such as the absence of external ears in snakes (they have the inner and middle ears). Reptiles have twelve cranial nerve pairs. They have to use electrical tuning for expanding the range of their audible frequencies because they have short cochlea.

These animals are believed to be less intelligent compared to mammals and birds because the relative size of their brain and body is much smaller than that of the latter. However, the brain development can be more complex in some larger Reptiles. Modern species also have pineal glands in their brains.

## Skeletal System

Most of these animals are tetrapods, meaning they have four legs. Snakes are examples of legless Reptiles. Their skeletal system is similar to other tetrapods with a spinal column supporting their bodies

## Excretory System

Their excretory system consists of two small kidneys. The diapsid species excrete uric acid as the principal nitrogenous waste product. But, turtles excrete mainly urea. Some of these species use their colons for reabsorbing water, while some are able to absorb the water stored in their bladders. Certain Reptiles excrete the excess salts in their bodies through the lingual and nasal salt glands.

**The Amniotic Egg**

The amniotic egg: One of the key adaptations that has allowed reptiles (and eventually mammals and birds) to exploit terrestrial habitats. Key features include the followings: 1-Shell: provides protection and prevents dessication of egg on land; 2-Yolk: provides nutrients; 3-Allantois: site where toxic waste from metabolic processes are stored; 4-Albumin: protects embryo and provides water and 5-Amnion: extra membrane that protects the embryo from desiccation

**Class Aves**

**Scientific Classification of Aves**

The scientific classification of birds is as follows:

Kingdom: Animalia

Subkingdom: Eumetazoa

Phylum: Chordata

Subphylum: Vertebrata

Superclass: Tetrapoda

Class: Aves

Birds are winged, feathered, egg-laying, warm blooded (endothermic), two-footed (bipedal) vertebrates belonging to the class Aves. There are more than 10,000 extant species of birds (Birds examples, see figures 29A, 29B) which makes them the most speciose tetrapod vertebrate class in the world. All the living species of birds belong to the Neornithes subclass, inhabiting all types of ecosystems from the Arctic region to the Antarctic region. The extant species can vary greatly in size. The smallest living species is the Bee Hummingbird which grows no more than 2 inches (5 cm) in size while Ostrich is the largest extant species growing up to 9 feet (2.75 m) in size. The Condors are regarded as the largest birds of prey (fossil records) first birds emerged during Jurassic period, approximately 160 million years ago within the theropod dinosaurs. Birds are regarded as the only dinosaur clade succeeded in surviving the Cretaceous_Paleogene extinction event around 65.5 million years ago.

**Characteristics of Birds**

Modern birds are distinguished from other animals using characteristic features:

**1-Presence of feathers**: This is one of the main characteristics of modern birds as no other animal is known to possess feathers. Birds take care of their feathers through the processes of preening and molting. Preening, process of keeping the feathers waterproof using the oil produced by the oil glands located near their tails. Old/worn out feathers are replaced by new ones through the process of molting.

**2-Wings:** Their forelimbs are modified to form a pair of wings that allow them to fly. Even flightless birds have modified forelimbs that is another key characteristic feature that distinguishes birds from reptiles, amphibians, mammals and fishes.

**3-Ability to fly:** Birds are the only creatures capable of flying and gliding. There are certain other animals, such as Bats, who locomote by gliding, incapable of true flight. Birds have numerous adaptive features that assist them to fly.

**4-Characteristic mouth:** They do not have lips and teeth; instead they have keratinous beaks that help them to collect food and eat.

**5-Unique digestive system:** Their digestive system includes a muscular pouch known as crop for gizzard and storage. It contains stones that are swallowed by the creatures to aid in digestion. These stones help to grind the foods in the stomach, which makes up for the absence of teeth.

**6-High metabolic rate and high body temperature:** Birds need plenty of energy for flying. Their high metabolic rate ensures that they have enough energy for flight. The average body temperature of these creatures remains around 40C, which is 2C higher than the average human body temperature.

**7-Four-chambered heart:** The hearts of animals belonging to this class are distinctly divided into four chambers. This characteristic helps to differentiate them from reptiles (except the crocodilian species) and amphibians. However, mammals also have four-chambered hearts.

**8-Characteristic Skeletal System:** The light-weight yet strong skeletal system is another characteristic feature of these creatures.

**Shape and Size**

The spindle-shaped or fusiform body of Blue Rock Pigeon is about 33 cm in length and is well adapted for rapid movement through the air.

**Coloration**

Except the eyes and the feet which are pink, rest of the body of pigeon is a salty gray with glistening metallic green and purple sheen on the upper breast and around the neck. The wing has two black bars.

**Body Divisions**

The bilaterally symmetrical and compactly set body of pigeon (Figure 29C) is divisible into four regions- **head, neck, trunk and tail**. These body divisions are invested in a close covering of feathers which are directed backward and overlapping one another.

**1. Head**

The head is small, rounded and mobile and contains **(i) Beak** where the head is prolonged in front into a short, pointed, bill or beak; **(ii) Nostrils** where at the base of upper beak occurs a patch of naked, whitish, swollen area of soft skin, called operculum or cere. The cere overhangs on two oblique, slit-like external nares or nostrils which can be closed by the cere; **(iii) Eyes** are located on either lateral side of the head, eyes  are round and are guarded by upper and lower eyelids and a transparent third eyelid or nictitating membrane; and **(iv) Ear apertures**, where below and behind each eye is an external ear opening which leads to a short tube, the external auditory meatus, closed by the tympanic membrane.

**2. Neck**

The neck is long, flexible and well demarcated from head and trunk. It helps in handling of food and compensates the forelimbs which have modified into wings.

**3. Trunk**

The trunk is compact and spindle-shaped, bearing a prominent bony ridge, the keel or carina, at its mid-ventral line. It bears two pairs of pentadactyl type limbs:

**(i) Wings**, two forelimbs are modified into two powerful organs of flight, the wings. Each wing remains attached high on the antero-dorsal side of the trunk.

**(ii) Legs**, where the hindlimbs or legs arise somewhat anteriorly from the trunk to balance and support the entire weight of the body at rest and comprises three parts: the thigh, shank and foot. The thigh is short, closely bound to the trunk, and directed downwards and forwards. The shank is long and extends from the knee downwards and backwards.

**4. Tail**

A true tail is short, conical projection of the trunk, known as uropygium. It bears a group of elongated tail-feathers or rectrices. On the dorsal surface of uropygium is a papilla bearing on its summit the opening of a preen, coccygeal, or oil-gland which produces a specific recognition scent and it elaborates ergosterol that is transformed by sunlight to vitamin D when exposed feathers.

**Skin**

The skin (Figure 30) of pigeon is dry, loose, hard and thin. Histologically, it consists of an outer epidermis of ectodermal origin and an inner dermis of mesodermal origin.

Anatomy of these creatures shows unique adaptive features that facilitate flight.

**Skeletal System**

The bird skeleton comprises of lightweight bones, which keeps them light enough to fly easily. The pneumatic cavities (large cavities filled with air) in the bones connect them to the respiratory system. The skull bones in adult birds are fused and do not have visible cranial sutures. They have large orbits separated by one bony septum. The spinal column is divided into cervical, lumbar, thoracic and caudal regions. The number of the cervical vertebras may vary significantly from one species to another. The neck is highly flexible; however, movement is restricted in anterior thoracic vertebras and absent in later vertebras. The last few vertebras fuse with the pelvis and form the synsacrum. Birds have flattened ribs and a keeled sternum that attaches the flight muscles. But, this arrangement is not present in flightless birds.

**Excretory System**

Like animals from the reptile class, most birds are uricotelic. This means nitrogenous wastes are extracted from their bloodstream by the kidney and are excreted as uric acid, rather than ammonia or urea, through their ureters into their intestine.

These creatures do not have any external urethral opening or urinary bladder (apart from Ostrich), so the uric acid and the feces are eliminated as semisolid waste materials. However some species, such as hummingbirds, excrete majority of the nitrogenous waste material as ammonia.

Like many mammals, birds excrete creatine instead of creatinine. These waste materials along with the intestinal output emerge from the cloacal opening. Additionally, many bird species are known to regurgitate pellets.

**Digestive System**

The digestive systems (Figure 32) of most species of this class are very efficient and allow rapid digestion, which produces high amounts of energy to help in flying. The muscular crop plays a vital role in the digestion process by softening the foods in the stomach and storing them temporarily to regulate their flow through the digestive system. The shape and size of the crop often varies among different birds.

**Respiratory System**

Their respiratory systems are among the most complex ones in all animal groups. When they inhale, 75% of the air goes around the lungs to flow directly into their posterior air sac that extends from the lungs, connecting with the hollow spaces in the bones. This way, the bones get filled with fresh air. The rest of the inhaled air

(25%) flows directly to the lungs and takes part in the respiration process. During exhalation, the used air is eliminated from the lungs and is replaced simultaneously by the fresh air stored in the posterior air sacs.

Thus, the lungs of birds are constantly supplied with fresh air both during inhalation and exhalation.

**Circulatory System**

The heart of a bird (Figure 33) has four chambers like that of humans and most other mammal species. The origin of their main arteries carrying the blood from the heart lies in right aortic arch or the pharyngeal arch. The blood reaches the postcava from the bird's limbs via its renal portal system. Unlike in mammals, the nuclei are retained by a bird's circulating RBCs (red blood cells).

**Nervous System**

The nervous systems of birds are quite large compared to their body size. This explains their complex and advanced intelligence. The flight-related functions are controlled by the most developed region of their brains while their movements are coordinated by the cerebellum. The cerebrum part of their brains control their behavior patterns, mating, nest-building and navigation.

Sense of smell: Birds have poor sense of smell with notable exceptions including New World Vultures, Kiwis and Tubenoses.

**Eyes**

Birds have eyelids, but they do not use it for blinking. Their eyes are lubricated by a third eyelid or membrane named the nictitating membrane which moves horizontally. This membrane also protects the eye and allows aquatic birds to see under water by working as contact lenses. The retina of these creatures has a fan-shaped blood supply system called the Great Cormorant. In some species, the eyes are located at the sides of the heads which provides a very wide visual field. On the other hand, birds like owls have eyes in front of their heads which provides them with a binocular and enables them to estimate the depths of fields.

Most avian species have highly developed visual systems. Raptors and nocturnal birds have strong eye-sight that is eight times sharper compared to humans.

## Auditory System

Birds do not have external ears like other animals. Their ears lack the external pinnae; instead they are covered with feathers. In birds like Bubo, Otus and Asio, these feathers create tufts that resemble ears. The inner ears of birds have a cochlea, which is not spiral as that in mammal ears.

## Wings

The shape and size of the wings vary between the flying and the flightless birds. Bird wings are actually modified forelimbs with their anatomy being similar to human arms. The phalanges, metacarpus, carpus, radius, ulna, humerus and scapula fuses together to form the wings. The shoulder is formed with the shoulder blade or scapula, coracoids and humerus.

## Feathers and Scales

As mentioned above, feathers are a characteristic feature of avian species (though, studies have proved that some dinosaur species that are no longer considered as true birds also had feathers). Feathers can be of various types with each type taking part in some specialized function. All feathers grow from the epidermal skin layer, appearing only in some specific skin tracts known as pterylae. The appearance and arrangement of the feathers on the bodies of birds is referred to as plumage. The plumage is different from one species to another and can even vary within the same species depending on age, sex and social status.

Their toes and metatarsus (sometimes, also the ankles) are covered with scales composed of keratin like the claws, beaks and spurs.

**Class Mammalia**

**Scientific Classification of Mammals**

The scientific classification of Mammals is as follows:

Kingdom: Animalia

Subkingdom: Eumetazoa

Phylum: Chordata

Subphylum: Vertebrata

Superclass: Tetrapoda

Class: Mammalia

Mammals are the largest class in the animal world. Mammals are of different types and can be distinguished up into marine mammals, smaller mammals and larger mammals. Since mammals are of different types they are classified into three subclass based on their reproduction. They are Eutheria, Metatheria and Prototheria.

## I-Eutheria

Mammals that give birth to their young ones directly belong to the subclass Eutheria. The young ones form as an embryo in the mother stomach and grow there for a certain period of time. This subclass consists of 19 orders. Best example and well known of this class are humans, dogs and cats.

1-Insectivora (moles, shrews)

2-Dermoptera (flying lemurs)

3-Chiroptera (bats)

4-Cetacea (whales)

5-Carnivora (cats, bears, dogs, otters, seals, sea lions)

6-Tubulidentata (aardvarks)

7-Proboscidea (elephants)

8-Hyracoidea (hyraxes)

9-Primates (monkeys, lemurs, bush babies, aye-ayes)

10-Xenarthra or Edentata (armadillos, anteaters, sloths)

11-Pholidota (pangolins)

12-Lagomorpha (rabbits, hares, pikas)

13-Rodentia (mice, rats, squirrels, porcupines, beavers, voles, hamsters)

14-Sirenia (manatees, dugongs)

15-Perissodactyla (horses, donkeys, zebras, rhinoceroses, tapirs)

16-Artiodactyla(pronghorns, deer, camels, gnus, goats, giraffes, hippopotami, pigs,

17-peccaries, chevrotains, musk-deer, cows)

18-Scandentia (tree shrews)

19-Macroscelidea (Elephant Shrews)

**II-Metatheria**

Mammals that belong to this subclass also give birth to their young ones but the young ones are born immature. So they jump into their mother pouch and stay their till they are mature. Metatheria subclass contains seven orders with 250 species. Marsupials and kangaroo are the best example for this subclass

1-Didelphimorphia (New World opossums)

2-Paucituberculata (South American rat opossums)

3-Microbiotheria (colocolo)

4-Dasyuromorphia (dasyurids, thylacines)

5-Peramelemorphia (bandicoots)

6-Notoryctemorphia (marsupial moles)

7-Diprotodontia (kangaroos, koalas, wombats, possums)

**III-Prototheria**

Prototheria consists of egg laying animals and are also known as monotremes. This subclass consists of six species all in one order.

1-Monotremata (platypus and echidna)

Although mammals are classified in to class, subclass, and order the scientist have classified on the general basis. This general classification makes it easy to learn about the mammals class and their distinguished features.

**The Rabbit (*Oryctolagus cuniculus)***

The rabbit is a member of class Mammalia which include the most advanced vertebrates. It is so much like man in structure and function, thus it is a good example to study the human body.

**Rabbit Morphology**

The body is covered with soft hair or fur, and is divided into:

**The head** is rather rounded or oblong with anterior end/snout mouth and bounded by thin fleshy upper and lower lips; the upper lip has a longitudinal median cleft. The external nares or nostrils lie above the mouth and extend to the cleft of the upper lip. The eyes lie on both sides of the head. Each eye is protected by 3 eyelids; upper and lower eyelids with few eyelashes while the third is small and known as the nictitating membrane attached to the anterior angle of the eye and serves for cleaning the cornea of the eye. The vibrissae, extend around the eyes and on the snout, two long freely movable external ears or pinnae, are found on the dorsolateral sides of the head.

**The trunk** includes the thorax and abdomen and carries four limbs (2 pairs of pentadactyl limbs, see **Figure 35**). **The thorax** is enclosed by the ribs and the stemum. Four to five pairs of teats or nipples are found on the ventral surface of the thorax and abdomen in the adult female. At the tips of these teats open the ducts of the mammary glands.

**The anus** is situated at the base of the tail. A **urinogenital opening** lies just infront of the anus. In the male, it is found at the end of a short muscular organ, the penis, on both sides of which lie the scrotal sacs containing the testes. In the female, the urinogenital opening is a slit-like aperture, the vulva, which contains a short rod-like structure known as clitoris which is homologous to the penis of males.

Two hairless areas known as **inguinal depressions** are found on both sides of the anus. In these depressions open the duets of the perineal glands which produce a certain secretion responsible for the peculiar smell of the rabbit.

**The Skin**

The body of Rabbit is covered by skin. It consists of the 2 main layers characteristic of the vertebrate skin (Figure 36), a) Epidermis (thin); b) Dermis (thick).The dermis is followed by a loose connective tissue layer known as hypodermis or subcutaneous layer.

**The epidermis:** develops from the embryonic ectoderm and consists of stratified squamous epithelium, devoid of blood vessels, but is nourished by the blood capillaries lying in the dermis.

**The dermis:** is derived from the embryonic mesodcrm. It is formed of an outer layer of loose connective tissue, known as the papillary layer, and an inner thicker and denser layer, namely the reticulum layer, and is penetrated by small blood vessels and nerves.

**The hypodermis:** is composed of loose connective tissue rich in fat cells, and contains blood vessels and nerves.

**Skin Derivatives**

1-**Hairs** is one of the characteristic ***features of mammals***. The hair. The hair follicle is pierced by the hair papilla formed of some connective tissue fibres enclosing blood capillaries and nerve endings. The slender main part of the hair, known as the hair shaft, projects above the surface of the skin. The rest of the hair embeded in the skin is the hair root. The hair itself Is composed of three layers: the medulla in the centre, the cortex next to medulla containing pigment granules, and the outer cuticle composed of cornified horny scales.

A ***sebaceous gland*** opens in the hair follicle from the side, and a band of smooth muscle fibres, known as the erector muscle, inserts on the side of the hair follicle and causes the hair to assume an erect position during cold or fear.

**2-Skin glands** Mammals have variety of glands which include:

**Sweat glands**: are simple coiled tubular glands distributed all over the body except on the margins of lips and claws. They secrete a fluid, chiefly composed of water, containing a small amount of solutes, particularly sodium chloride.Sweat glands serve mainly to regulate the body temperature.

**Sebaceous glands:** they are simple branched alveolar glands which open into the hair follicles. They secrete a greasy substance which keeps the skin and hair glossy and soft.

**Mammary glands:** exist in all mammals, but their function is limited almost entirely to the females after birth of young.

**Lacrymal ortear glands:** produce a secretion which keeps the surface of the eye moist and clean.

**Perineal/scent glands:** secrete a substance which gives the rabbit its characteristic odour, by means of which the animal can distinguish its own kind.

**Functions of the skin**

**l-**It protects the underlying tissues against the effects of external environmental factors. **2-**It contains sensory receptors which respond to changes in the environment. **3-**The sweat glands in the skin serve mainly to regulate the body temperature. **4-**The skin may be coloured to protect the animal by a czamouliage pattern. **5-**Claws, as skin derivatives, are important for defence of the body and for catching preys. They are also used in climbing.

**RABBIT ORGAN SYSTEMS**

**SKELETAL SYSTEM**

The skeletal system of the rabbit is divided into; the exoskeleton which is formed of epidermal derivatives of the skin, such as **claws, hairs, etc.,** and the endoskeleton which comprises the internal skeleton of the body, the endoskeleton includes two main divisions: **Axial skeleton** and **Appendicular skeleton**.

**I. The axial skeleton** consists of; Skull, Vertebral column, Ribs; and Stemum

**A) The skull** of the rabbit is formed of the Cranium, Jaws, Sense capsules, Hyoid apparatus, and Cranium (brain case).

**1-The cranium** is formed of bones arranged mainly in a series of 3 bony rings, the occipital ring, parietal ring, and frontal ring (see figure 37 for details). The space between the exoocipital and alisphenoid on each side is filled by the cranial portion of the squamosal. Extending between the squamosal and the maxilla of each side, there is a bony arch known as the zygomatic arch, the anterior part of which forms the lower margin of the orbit, Some of the powerful jaw muscles lie between the posterior part of the arch and the cranium. The front of the cranial cavity is closed by the ethmoid.

**2-Sense capsules,** these include; **a)** the **auditory capsules** which are completely embedded in the Wall of the cranium and each consists of the periotic, tympanic enclosing the tympanic cavity; the neck of this bulla forms the external auditory meatus, while the auditoiy ossicles lie within the tympanic cavity, **b)** The **olfactory capsule** which encloses the respiratory channel, roofed by 2 flat bones ‘nasals’.The cavity of the capsule is divided into right and left halves by the partly cartilaginous mesethmoid, the anterior end of which forms the internasal septum. The mesethmoid rests on a V-shaped vomer bone. The outer sides and the floor of the nasal cavities are formed by the palatines, maxillae and premaxillae. The greater part of each cavity is occupied by thin, much folded turbinal bones which project from the walls into thc cavity and **c)** The **optic capsules** where there are no special bones forming these capsules. The eye is lodged in a wide orbital cavity limited dorsally by the supraorbital ridge of the frontal, and ventrally by the zygomatic arch.

**3-Jaws** this include: **a)** the upper jaw which is formed of bones fused to the cranium. These bones are the pterygoids, palatines (on the roof of the mouth), the premaxillae (each having 2 processes, a nasal process which passes backwards beside the nasal bone, and 21 palatine process), and the maxillae (from which arise the zygomatic and palatine processes). **b)** The lower jaw or mandible that is formed of a single bone called dentary. It consists of 2 lateral halves or rarmi united anteriorly at the symphysis mentis and diverging posterioly. Each ramus is formed of a horizontal portion which bears the teeth, and a vertical or ascending portion with a dorsal coronoid process, a condyle for articulation with the sqamosal, and a ventral angular process.

**4-Hyoid apparatus**. This is derived from the embryonic visceral arches and functions as a support for the tongue. It includes a median hyoid bone or basihyal, and a pair of long backwardly directed cornua or thyro-hyals.

**B. Vertebral Column**

The vertebral column consists of a chain of separate units, the vertebrae. These vertebrae are distinguished into 5 types; **cervical, thoracic, lumbar, sacral and caudal**. Despite the difference between these types of vertebrae, certain features are common to all and make it possible to describe a typical vertebra (see **figure** ).

Typically, the vertebra (Figure 38) consists of:

**1-A body (centrum)**, with a dorsal neural arch forming a ring around spinal cord.

**2-Neural foramen**, the opening through which the spinal cord extends.

**3-A Neural spine**, is a dorsal median process in the neural arch.

**4-Transverse processes** extend laterally on both sides of the vertebra and serve for muscle attachment.

**5-Zygapophyses**, are 4 small processes situated on both sides of the arch and serve for the articulation of the vertebrae. two infront (**prezgapophyses**) having flat surfaces facing upwards and two behind (**postzgapophyes**) having flat surfaces facing downwards to rest on the surfaces of the prezygapophyses of the next vertebra. This mode of articulation allows some flexibility in movement of the vertebral column.

**Types of vertebra:**

**1-Cervical vertebrae**: these are 7 in number'; **No.1** is cervical or **atlas** articulates with the skull. Which is very reduced centrum, which was detached during development and later fused with that of the second cervical vertebra to form an odontoid process. While, **No.2** cervical or axis is mainly characterised by presence of the odontoid process and absence of prezygapophyses.addationally, there are 5 normal cervical vertebrae.

**2-Thoracic vertebrae:** these are 12-13 in number, and are associated with the ribs. These are characterized by: Elongated spines; in the first 9 vertebrae, the spine is directed backward, in the 10th thoracic it is nearly vertical, while in the last 2 or 3 vertebrae, it is directed anteriorly. The spines serve for attachment of the ligaments of the neck, they have certain facets for articulation with the ribs, namely the tubercular and capitular facets".

**3-Lumbar vertebrae:** these are 7 large vertebrae, characterized by; **Long transverse** processes which are directed forward and outward; **Accessory processes**, as metapophyses, are situated in front over the prezygapophyses, and anapophyses project backward below the postzygapophyses.

**4-Sacral vertebrae:** include 3- 4 vertebrae fused into a single piece known as the **sacrum**. This fusion provides a firm basis for attachment of the pelvic girdle of the hindlimb. The first sacral is the largest and is characterized by; * **Broad wing-shaped** transverse process rigidly articulated with the ilium of the pelvic girdle; *A **pair of metapophyses** and * the anterior surface of the centrum is broader than the posterior surface. The other sacral vertebrae decrease successively in size.

**5-Caudal vertebrae:** these are l5-16 small bodies lying in the tail region. At the end of the tail, the neural arch, zygapophyses, ctc., become progressively reduced until the terminal ones consist only of rounded cylindrical centra.

**C-Ribs:** these are l2-13 in number, and form a bony cage surrounding the thorax. They articulate dorsally with the thoracic vertebrae and ventrally with the sternum. Each rib, therefore, has a **dorsal vertebral portion** and a **ventral sternal portion**. The vertebral portion has 2 broad heads: the dorsal head, or tubereulum, articulates with the transverse process, and the ventral head, or capitulum, articulates with two successive oentra. The first 7 ribs are directly attached to the sternum and are therefore called true ribs, while the sternal portions of the eighth and ninth ribs are fused with those of the seventh rib and are commonly called false ribs. The last three ribs do not reach the sternum and are termed the floating ribs.

**D. Sternum** The sternum is a median ventral rod-like structure lying in the thoracic region. lt is composed of 7 pieces called sternebrae. The last sternebrae ends by a thin round plate of cartilage termed Xiphoid cartilage. The sternum serves for attachment of ligaments and muscles.

**II-The Appendicular Skeleton:** It consists of the pectoral and pelvic girdles and the bones of the limbs (see figure 39).

**A-Pectoral girdle**: It comprises 2 pairs of bones, **1) the scapulae** (shoulder blades) and the clavicles (collar blades) and attached to the axial skeleton by ligaments and muscles. The scapula has a depression (**glenoid fossa**) serving for the articulation with the humerus. While on the outer surface, there is a ridge (**the spine**), with two projections, the **acromion** and **metacromion** processes. These provide insertions for the muscles moving the shoulder. The coracoid bone, present in lower tetrapods, is represented in mammals by a small coracoid process overhanging the glenoid cavity. 2) **The clavicle** is a small, slender curved bone suspended by ligaments to the acromion process and sternum.

**B-Bones of the Forelimb** The limb is formed of several regions built on the pentadactyl plan (figure ) and consists of the following bones are: **Humerus** supporting the upper arm; the **Radius and ulna**, these are the bones of the forearm; **Carpals** (bones of the wrist), these are 9 bones arranged in 3 rows; Metacarpals (bones of the hand), they are 5 long bones; **Digits** (or fingers), 5 in number expressed by the following digital formula 2 : 3: 3: 3: 3.

**C-Pelvic girdle**

The pelvic girdle is directly articulated to the vertebral column and is composed of 2 halves, called innominate bones, joined ventrally to form the **symphysis pubis**. Each innorninate is formed of 3 bones**, ilium, ischium and pubis**. The 3 bones share in the formation of a cup-shaped depression called **acetabulum** which receives the head of the femur.

**D-Bones of the Hindlimb**

The hind limb is formed from the following bones: **Femur** (or thigh bone), a long, strong and slightly curved bone with a large rounded head articulates with the **acetabulum**. **Femur** has two condyles for articulation with the tibia, and are partially separated by an intercondylar notch; **Tibia and fibula** supporting the shank; **Tarsals** (bones of ankle) 6 bones arranged in 3 rows; **Metatarsals** consisting of 4 long bones; **Digits** (or toes) with the digital formula 0: 3 : 3: 3: 3; and the **Joints.**

**Functions of the skeletal system**

The skeletal system has 5 major important functions, these are the followings:

**1-Protection:** the cranium and ribs protect the brain and vital organs in the chest.

**2-Shape:** gives shape to the body and makes you tall or short.

**3-Support:** holds your vital organs in place when playing sport. The vertebral column holds the body upright.

**4-Movement:** muscle are attached to bones, which are jointed. When the muscles contract the bones move.

**5-Blood production:** red blood cells (to carry oxygen) and white blood cells (to protect against infection) are produced in the bone marrow of some bones.

## RABBIT BODY CAVITY

The body cavity, or **coelom**, is divided in the mammalian body into **thoracic and abdominal cavities** which are separated by the diaphragm. The thoracic cavity contains the heart which is enclosed in the pericardial cavity, the lungs which are surrounded by the pleural cavities and the posterior part of the oesophagus while the abdominal cavity contains all the visceral organs.

The Rabbit **digestive system** (Figure 40) comprises the alimentary canal and the associated digestive glands.

**I) Alimentary Canal.**

It begins with the mouth which leads to the buccal cavity containing the teeth and the tongue.

**Teeth:** In most mammals, there are 2 sets of teeth, the **deciduous** or **milk teeth** which appears in the early stages of development, and later replaced by the **permanent** teeth that persist throughout the life of the animal.

As in other mammals, the teeth of the rabbit include the **Incisors**, **Premolars** and **Molars**. There is no canines, their place is represented by a space called **diastema**.

The Rabbit dental fommla of upper and lower jaws on one side is as follow: The dental formula for the rabbit is **2**x **i. 2/1, c. 0/0, p. 3/2, m. 3/3= 28** (where i.= **incisors**, c.= **canines**, p.= **premolars**, m.= **molars**). The formula may be simply written as follows: **2033/1023 x 2=28**.

**Tooth structure:** Each tooth is lodged in a socket in the gums, and is fixed to it by cement. It has a **root** embedded in the gums, and protruding part outside, the **crown**. The bulk of the tooth is made up of **dentine** substance penetrated with minute canals in which nerve endings and blood capillaries extend from the pulp cavity inside the tooth. The dentine is covered by a layer of enamel.

The mouth cavity is separated from the nasal or air passage by a horizontal partition composed of hard and soft palate. The **hard palate** represents an elongation of the premaxilla, maxilla and palatine bones which covered by a mucous membrane. The **soft palate** forms the posterior part of the roof of the mouth cavity and ends behind in a free soft flap.

**Pharynx:** The buccal cavity leads to the pharyngeal region which is common to both the digestive and respiratory systems. Its upper portion is called the nasopharynx, at the centre of which open the **Eustachian tubes**.

**The glottis:** is a slit-like opening located on the floor of the pharynx and leads to the larynx. Overhanging the glottis is a movable leaf-like cartilaginous called the epiglottis which closes the glottis during food passage.

**Osophagus:** This is a long narrow tube passing through the neck into the thoracic cavity, then piercing the diaphragm to open into the cardiac portion of the stomach.

**Stomach:** The stomach is an ovoid sac lying transversely in the abdomen behind the liver and a narrower pyloric portion ending with pyloric sphincter which regulates the passage of food materials from the stomach to the small intestine.

**Small intestine**: This is a narrow elongated coiled tube. Its first part, the **duodenum**, forms a U-shaped loop, in the mesentery of which lies the pancreas. The duodenum is followed by the **jejunum** which leads to a long coiled ileum. Along the whole length of the small intestine there are slightly thickened oval lymphatic nodules known as Peyer's patches. The small intesinc ends in a whitish rounded swelling called the sacculus rotundus which contains the ileo-caecal valve.

**Large intestine:** From the **sacculus rotundus** extend 2 tubes. The first is the caecum which is thin-Walled and marked by certain spiral constrictions showing the line of attachment of an internal spiral valve. The caccum terminates in a narrow blind **vermiform appendix**. The second tube is the large intestine, the first part of which is the colon. The walls of the colon is sacculated to increase its area. The colon leads to a smooth rectum, which ends in the anus.

**II) Digestive Glands** The digestive glands associated with the alimentary canal are **the salivary glands, the pancreas and the liver**.

**1-The Salivary glands**: are 4 pairs, namely, the parotid (below the external car), the sub mandibular (behind the lower jaw), the infraorbital (below the eye-ball) and the sublingual (at the floor of the mouth below the tongue) These glands open by ducts into the buccal cavity and secrete saliva.

**2-The pancreas:** is a diffused gland found in the mesentery lying, between the two limbs of the loop of the duodenum; its single pancreatic duct opens into the distal limb of the duodenum.

**3-The liver:** is a large gland attached to the diaphragm by 2 folds of the peritoneum. It is made up of 5 lobes, right central, left central, left lateral, caudate, and small Spigelian lobe. Thu gall-bladder lies in a depression in the right central lobe of the liver. The common bile duct, formed by the union of cystic duct form the gall bladder and the hepatic ducts from various part of the liver and runs to open in the duodenum near the pylorus.

**Function of the digestive system**

1-Ingestion: Food must be placed into the mouth before it can be acted on. This is an active, voluntary process called ingestion.

2-Propulsion: Foods must be propelled from one organ to the next using peristalsis which is involuntary and involves alternating waves of contraction and relaxation of the muscles in the organ wall

3-Food breakdown: mechanical digestion Mixing of food in the mouth by the tongue, churning of food in the stomach, and segmentation in the small intestine.

4-Food breakdown: chemical digestion The sequence of steps in which large food molecules are broken down to their building blocks by enzymes.

5-Absorption Transport of digested end products from the lumen of the GI tract to the blood or lymph is absorption.

6-Defecation which is the elimination of indigestible residues from the GI tract via the anus in the form of faeces.

## RABBIT CIRCULATORY SYSTEM

The circulatory system of the rabbit (Figure 41) consists of the blood system, including the heart and blood vessels, and the lymphatic system.

### I-Blood System

**The heart** lies in the pericardial cavity which is bounded externally by the pericardium. The lower border of the heart, forming a blunt point known is the apex, lies on the diaphragm and is slightly directed towards the left side. The pericardium is distinguished into 2 parts : **a) Serrous pericardium**, which is a double layer surrounding the heart. The inner layer, adhering to the heart surface is known as the visceral layer or **epicardium**, while the outer layer is known as the **parietal layer**. The narrow space between the 2 layers contains a small amount of pericardial fluid. **b) Fibrous pericardium**, forms a sac surrounding the serrous pericardium, and provides protection for the heart against friction.

**The heart** of the rabbit consists of four chambers, 2 auricles and 2 ventricles. The right auricle is larger than the left, but its walls are thinner. The inter-auricular septum which separates the two auricles bears an oval depression, the **fossa ovalis**. It marks the location of the foramen ovale, which is an opening between the two auricles normally present before birth.

The **ventricles** are considerably larger and thicker-walled than the auricles. Also, the left ventricle has thicker walls than the right, and includes the apex, it pumps blood through all the body vessels except those passing to the lungs, whereas the right ventricle sends blood only to the lungs.

The walls of the ventricles possess numerous muscular ridges, or **columnae carneae**, from which the papillary muscles arise. These muscles are connected to the valves guarding the openings between the auricles and ventricles by slender fibres or cords called chordae tendinae.

**Heart valves:** These are valves permit flow of blood in one direction only and include the follwings:

**a) Bicuspid valve:** it formed of two flaps between the auricle and left ventricle. **b) Tricuspid valve**: consists of 3 flaps guarding the opening between the right auricle and right ventricle. **c) Semilunar valves:** are two valves, one situated inside the base of the pulmonary artery, and the other at the base of the aorta. These valves are halt'-moon-shaped flaps, which close the opening when filled with blood.

**The Blood vessels:** There are 2 main types of blood vessels, arteries and veins.

**1] Arteries** which are vessels through which the blood flows from the heart to the organs. They have comparatively thick walls made up of three coats : **a) outer lunica adventitia**, is composed of oonnective tissue which prevents the artery from being much stretched when filled with blood. **b) middle tunica media**, is formed of smooth muscle fibres and elastic connective tissue, where muscle fibres contraction regulates the amount of blood sent to each organ, and elastic tissue keeps a continuous pressure on the blood to flow through the capillaries at the intervals between successive heart pulses. **c) inner tunica intima**, is made up of elaslic connective tissue and is lined with a layer of squamous endothelial cells. Inside the organs, the arteries divide into small branches, or arterioles, which further divide into finer arterial capillaries.

**2] Veins** which are vessels through which blood flows from the organs to the heart. Like arteries they have walls composed of three coats, but these coats are thin and contain fewer elastic and muscle fibres. **Unlike the arteries**, the veins, especially the medium-sized ones, possess valves which prevent any backward flow of the blood. The smallest veins are called venules, into which blood collects from fine venous capillaries. Veins which pass from the organs directly to the heart are called **proper veins** while those originate from one organ ending to another organ known as **portal veins** such as hepatic portal from alimentary canal to the liver.

**Capillaries** which are minute thin-walled vessels which consist of a single layer of endothelial cells where capillaries wall is continuous with the lining of arteries or veins. There are several hundred capillaries per square millimetre of tissue or organ. Exchange of nutrient material, oxygen and carbon dioxide take place between the blood and the tissue through the capillary walls. Part of the blood plasma passes also from the blood into the tissue in the form of **lymph.**

## Rabbit Venous System

The blood is collected from the different parts of the body by large veins, these are 2 **anterior venae cavae** (right and left) and a **posterior vena cavae**.

**Anterior vena cava** is formed of the following tributaries:

**l-Internal jugular vein:** arises in the brain, and runs in the neck. **2-External jugular vein:** is formed by the union of posterior facial veins, and drains blood from head and face. **3-Snbclavian vein**: receives blood from the forelimb. **4-Internal mammary vein:** extends from the lateral borders of sternum **5-Anterior intercostal vein:** drains blood from the anterior 4 or 5 intercostal spaces. **6-Azygos vein:** is a single vein, joining the right anterior vena cava only. It drains blood from the posterior 7-8 intereostal spaces of both sides.

**Posterior vena cava** collects blood from the posterior part of the body and receive the following veins: **l-Phrenic veins**, these are 2 small veins from the diaphragm. **2-Hepatic veins**, these are 3-4 veins draining the blood from the liver. **3-Renal veins**, these are 2 veins collecting blood from the kidneys. **4-Spermatic or ovarian** veins, these are 2 veins from the gonads (tests ovaries). **5-Illulumber veins**, these are 2 veins from posterior abdominal region. **6-External iliac veins**, these are 2 large veins from the hind limbs. The external iliac veins are continuations of the femoral veins coming from the thighs, each receives a vesical vein from the urinary bladder. **7-Internal iliac veins**, these are 2 veins from the back of the thighs.

**Hepatic portal vein:** This receives tributaries from the intestine and rectum (duodenal, anteriorvand posterior mesenteric veins) and from the stomach and spleen (lieno gastric vein).

**Pulmonary veins:** These are small veins which carry blood from the lungs and open into the left auricle.

**Coronary veins:** These arise from the Walls of the heart as numerous small veins which join together to form 2 main trunks, the right and left coronary veins. These in turn unite to enter the coronary sinus which opens into the right auricle. In addition, several cardiac veins open independently into the right auricle. Few veins may also enter the ventricle.

**Blood circulation inside the mammalian heart**

The anterior and posterior venae cavae bring blood to the right auricle from the anterior and posterior parts of the body. The blood then passes into the right ventricle. It is prevented from going buck into the right auricle by tricuspid valve. From the right ventricle, the blood goes to pulmonary arch which divide into right and left pulmonary arteries to the lungs. After being oxygenated in the lungs, the blood is carried back by the pulmonary veins to the left auricles. It is then passed to the left ventricle from which it is carried along the aortic arch to all parts of the body. The opening between the left auricle and left ventricle is guarded by the bicuspid valve. Semi lunar valves at the bases of both the pulmonary and aortic arches prevent the blood in these in these vessels from returning back to the ventricles.

On the surface of the heart itself there is a complex series of vessels called coronary arteries and veins. The coronary arteries arise from aorta just in front of of the semilunar valves. They supply the walls of heart itself with blood. The coronary veins collect this blood from the walls the heart and empty it into the right auricle, through a common opening.

## Rabbit Arterial System

Two major arteries originate from the heart, namely the pulmonary and the aortic arches.

**The Pulmonary** arch originates from the right ventricle and divides immediately into the right and left pulmonary arteries, supplying the right and left lungs respectively.

**The Aortic arch or Systemic aorta** arises from the left ventricle, and curves to the left side from the base of the arch giving the following vessels.

**1-Coronary arteries**, these are small arteries arising at the base of aorta and ramifying throughout the walls and septa of the heart.

**2-Innominate artery**, these arises from the top of the aortic arch and gives rise to the left and right common carotid arteries to the head. Each divides at the base of the head into external and internal carotid arteries.

Close to the origin of the right common carotid arteries, arise the right sub clavian artery to the right forelimb. The left subclavian that supplies the left forelimb arises from aortic arch itself. Each subclaivan artery gives rise to vertebral artery and an internal mammary artery.

## Rabbit Nervous System

The nervous system together with the endocrine system are responsible for the regulation and coordination of the physiological activities of the animal. The nervous system (see Figure 42) includes the following divisions:**I)Central nervous system**(CNS) comprising: Brain, and Spinal cord, **II)Peripheral nervous system** which consists of the nerves extending from the central nervous system including Cranial nerves and Spinal nerves. **III) Autonomic nervous system.**

### I) Central nervous system

**A-Brain** The brain lies within the cranium (brain case). It is covered by 3 distinct membranes; a) **Dura mater**, formed of strong white fibrous tissue adhering to the cranium. b) **Archnoid membrane**, a delicate layer of connective tissue. c) **Pia mater**, a transparent layer adhering to the brain and containing flood vessels. The brain arises as an anterior vesicle of the embryonic neural canal. During subsequent development, this vesicle becomes differentiated into 3 parts : the fore-brain, the mid-brain and the hind-brain. The brain of rabbit can be divided into three regions:

**(a) The forebrain** or prosencephalon which consists of a pair of olfactory lobes, a pair of cerebral hemispheres and an unpaired diencephalons, **(b) The midbrain** or mesencephalon that is largely covered by the cerebral hemispheres and consists of the optic lobes which are four in number, two on each side situated behind the pineal body and **(c) The hindbrain** or rhombencephalon, It consists of the cerebellum or metencephalon and medulla oblongata or myelencephalon and Pons Varolii.

**Ventricles of the brain:** The brain is not solid, but contains 4 internal cavities known as ventricles. **Two lateral ventricles** (or first and second) are located one in each cerebral hemisphere, and communicate with one another by the foramen of Monro. These ventricles join a **third ventricle** in the diencephalon, The **fourth ventricle** is found in the medulla oblongata. All these ventricles are filled with the cerebro-spinal fluid which provides nourishment for the tissues of the nervous system.

**B) Spinal Cord.** It is located in the vertebral or neural canal. It extends from the medulla oblongata and passes through the foramen magnum to the posterior end of the vertebral column as a long white cylindrical tube which is slightly thickenned in the brachial and lumbar regions. The posterior end of the spinal cord is cone-shaped and called conus terminalis. The spinal cord encloses a central canal filled with cerebro-spinal fluid, and is continuous with the brain ventricles. The spinal cord is surrounded by the dura mater, arachnoid membrane and the pia mater (see figure ). The spinal cord is mainly concerned with the conduction of nerve impulses and reflex activities.

## II) Peripheral Nervous System

This system includes the cranial and spinal nerves.

**A] Cranial nerves** as in all mammals, there are **twelve pairs** of cranial nerves which arise from the brain and pass through minute foramina in the skull to innervate different parts of the body; some of these nerves are purely sensory, some purely motor, and others are mixed. The cranial nerves on each side are:

I-Olfactory nerve; II-Optic nerve; III-Oculomotor nerve; IV-Trochlear nerve; V-Trigeminal nerve; VI-Abducens nerve; VII-Facial nerve; VIII-Auditory nerve; Xl-Spinal accessory nerve; and XII-Hypoglossal nerve.

**B]Spinal Nerves**, there are usually 37-38 pairs including; 8 cervical, 12-13 thoracic, 7 lumbar, 4 sacral, and 6 caudal spinal nerves. Each spinal nerve arises by a dorsal and a ventral root connected with the horns of the grey matter of the spinal cord. These roots unite within the neural canal to form a spinal nerve which passes out through an intervertebral foramen in the vertebral column. The dorsal root bears a dorsal root ganglion containing cell bodies of the sensory neurons. lt contains only sensory fibers, while the ventral root contains motor fibres whose cell bodies are located within the spinal cord. The first spinal nerve emerges out between the skull and the first vertebra, and the other spinal nerves extend out through the intervertebral foramina. The spinal nerves supply the skin and the muscles of the body.

### III) Autonomatic Nervous System

This system controls many internal functions that are not under the voluntary regulation such as the rate of heart beat, the secretion of digestive juices, muscular movements in the stomach and intestine, and other functions. The autonomic nerves are subdivided into two main divisions; **sympathetic** nerves which originate in the thoracic and lumbar regions, and the **parasympathetic** nerves which arise in the cranial and sacral regions.

The parasympathetic system continues as a pair of nerve cords which extend from the cranial nerves VII, IX and X to the hinder part of the body. In the neck region it passes close to the vagus and runs alongside the carotid artery. It bears anterior and posterior cervical ganglion in the thorax it runs just beneath the heads of the ribs, while in the abdomen it runs close to the centra of the vertebra. It bears ganglia, each is connected with the corresponding spinal nerve by a connecting branch called ramus communicans.

**SENSE ORGANS:** The sense organs (Figure 43) are specialized receptors developed for the detection of specific environmental changes. Some of these receptors are confined to regions close to the body surface and are called **cutaneous receptors** While others have some form of a capsule around them (smell and hearing). Some of these organs are sensitive to chemical changes and hence are known as chemoreceptors (smell and taste). These sense organs includes:

Cutaneous sense organs; Organs of taste; Organs of smell; Organs of vision; and organs of hearing (figure ).

**Function of Nervous System**

1- Gathers information from both inside and outside the body - Sensory Function

2-Transmits information to the processing areas of the brain and spine

3-Processes the information in the brain and spine – Integration Function

4-Sends information to the muscles, glands, and organs so they can respond appropriately.

5-The Motor Function is to controls and coordinates all essential functions of the body including all other body systems allowing the body to maintain homeostasis or its delicate balance.

# The DNA and Chromosomes

An organism's life depends on the ability of its cells to store, retrieve, and translate the genetic instructions required for its maintaining and continuity. This *hereditary* information is passed on from a cell to its daughter cells via process of the cell division, and from one generation of an organism to the next through the organism's reproductive cells. These information that determine the characteristics of a species as a whole are stored within genes in every living cell.

**DNA carries the hereditary information**

In 1940s, researchers discovered, from studies in simple fungi, that genetic information contain the instructions for making proteins, these macromolecules perform most cellular functions: they serve as building blocks for cellular structures (strucrural proteins) and form the enzymes that catalyze all of the cell's chemical reactions including regulation of gene expression (e.g functional proteins). These molecules also participate in cell movements and communication with each others. Therefore the cell's properties and functions are determined almost by their proteins contents expressed.

Before biologists understood the structure of DNA, they had recognized that genes are carried on *chromosomes*, which were discovered in the 19$^{th}$ century as threadlike structures in the nucleus of a eukaryotic cell that become visible as the cell begins to divide (Figure 12).



**Identification of DNA as the Genetic Material**

Chromosomes contain proteins as well as DNA, and it was initially thought that genes were proteins. The first evidence leading to the identification of DNA as the genetic material came from studies in bacteria. Experiments, carried out in the 1940s, showed that adding purified DNA to a bacterium changed its properties that was transmitted to bacterial subsequent generations.

The experiment was carried out using two closely related strains of the bacterium *Streptococcus pneumoniae* which differ from each other in both their appearance under the microscope and their pathogenicity. One strain appears smooth (S) and causes death when injected into mice, and the other appears rough (R) and is non lethal (no pathogencity).

The experiment (Figure 13; A) shows that a substance found in the S strain can alter the R strain into the S strain which then is inherited by subsequent generations of bacteria. When R strain (Figure 13, B) was incubated with different kinds of biological molecules obtained from the S strain, identifies the substance as DNA.

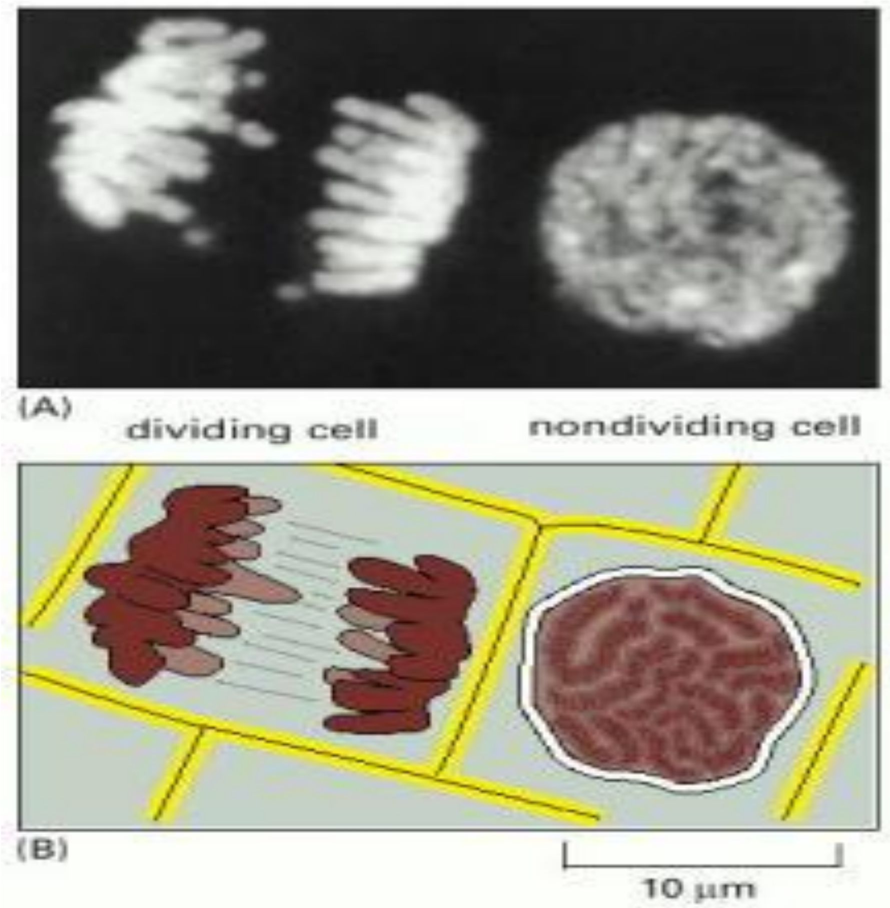



**Figure 12. Chromosomes in cells.** (A) A stained DNA with a fluorescent dye (DAPI). Chromosomal DNA become visible compact structures in preparation for cell division. Cell on the right, is not dividing, containing identical chromosomes, but are not clearly distinguished (using the light microscope), because they are in a more extended conformation. (B) Schematic diagram of the outlines of the two cells along with their chromosomes. [Alberts, B., *et al.*, 1998].

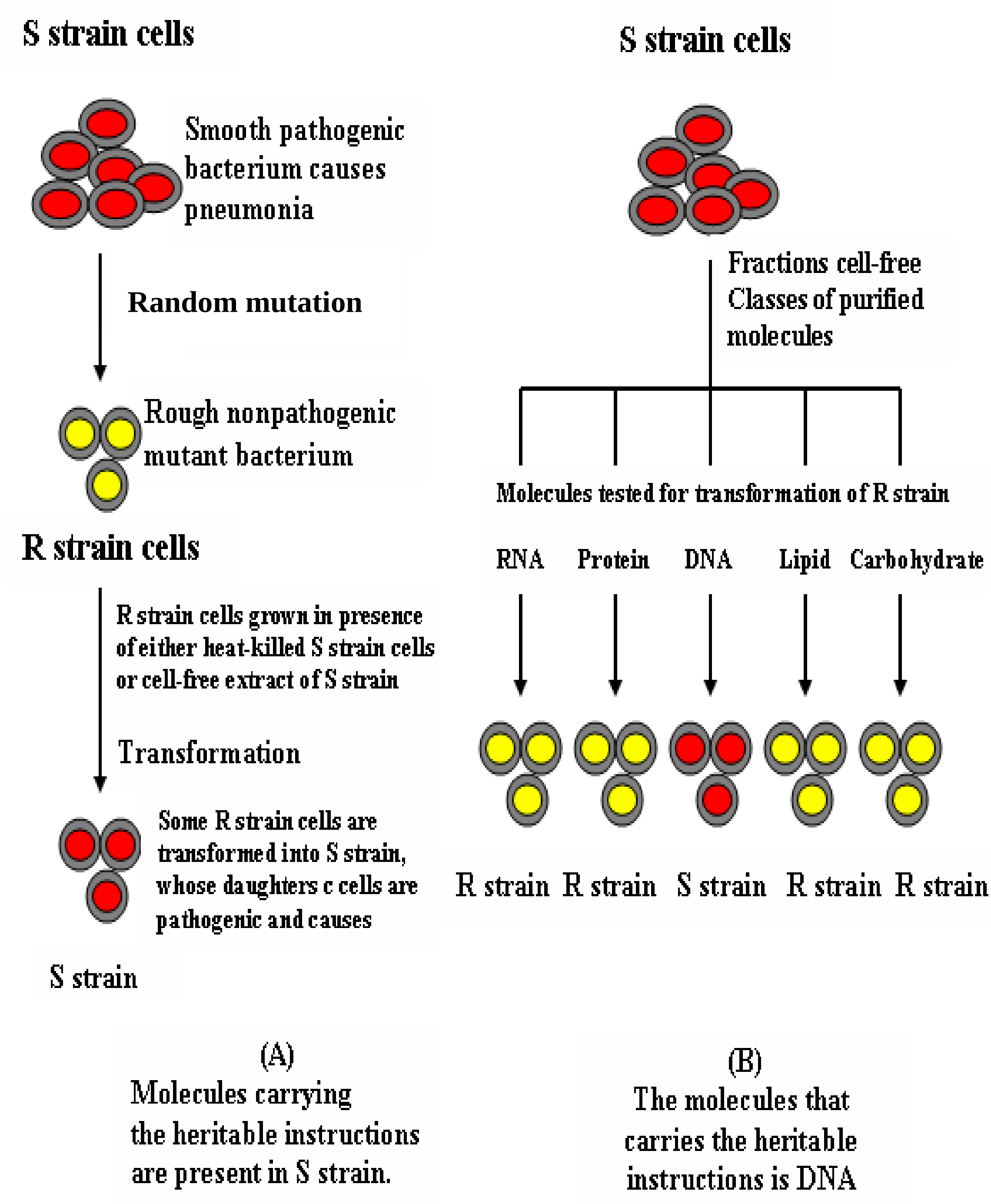



**Figure 13. Experimental demonstration that DNA is the genetic material.** Experiments, carried out in the 1940s, showed that adding purified DNA to a bacterium changed its properties, this change was passed on to subsequent bacterial generations.

**The Fine structure of DNA.**

DNA is a long polymer composed of four types of subunits. Early in the 1950s, DNA was first examined "Rosalind Franklin, 1951" using x-ray diffraction analysis (a technique for determining the three-dimensional atomic structure of a molecule). The X-ray diffraction results indicated that DNA is composed of two strands of the polymer twisted together to form a helix. The observation that DNA was double-stranded was an important step providing major clue that led to the Watson-Crick structure of DNA. Because of the proposal DNA model, DNA mechanisms such DNA replication and transcription become understandable issues.

A DNA molecule consists of two long polynucleotide chains composed of four types of nucleotide subunits. Each of these chains is known as a DNA *chain*, or a DNA *strand*. *Hydrogen bonds* between the base portions of the nucleotides hold the two chains together (Figure 14).



In a space-filling model of 1.5 turns of the DNA double helix. Each turn of DNA is composed of 10.4 nucleotide pairs and the center-to-center distance between adjacent nucleotide pairs is 3.4 nano meter ‘nm’. The coiling of the two strands around each other creates two grooves in the double helix. As indicated in the figure 14, the wider groove is called the major groove, and the smaller is the minor groove.

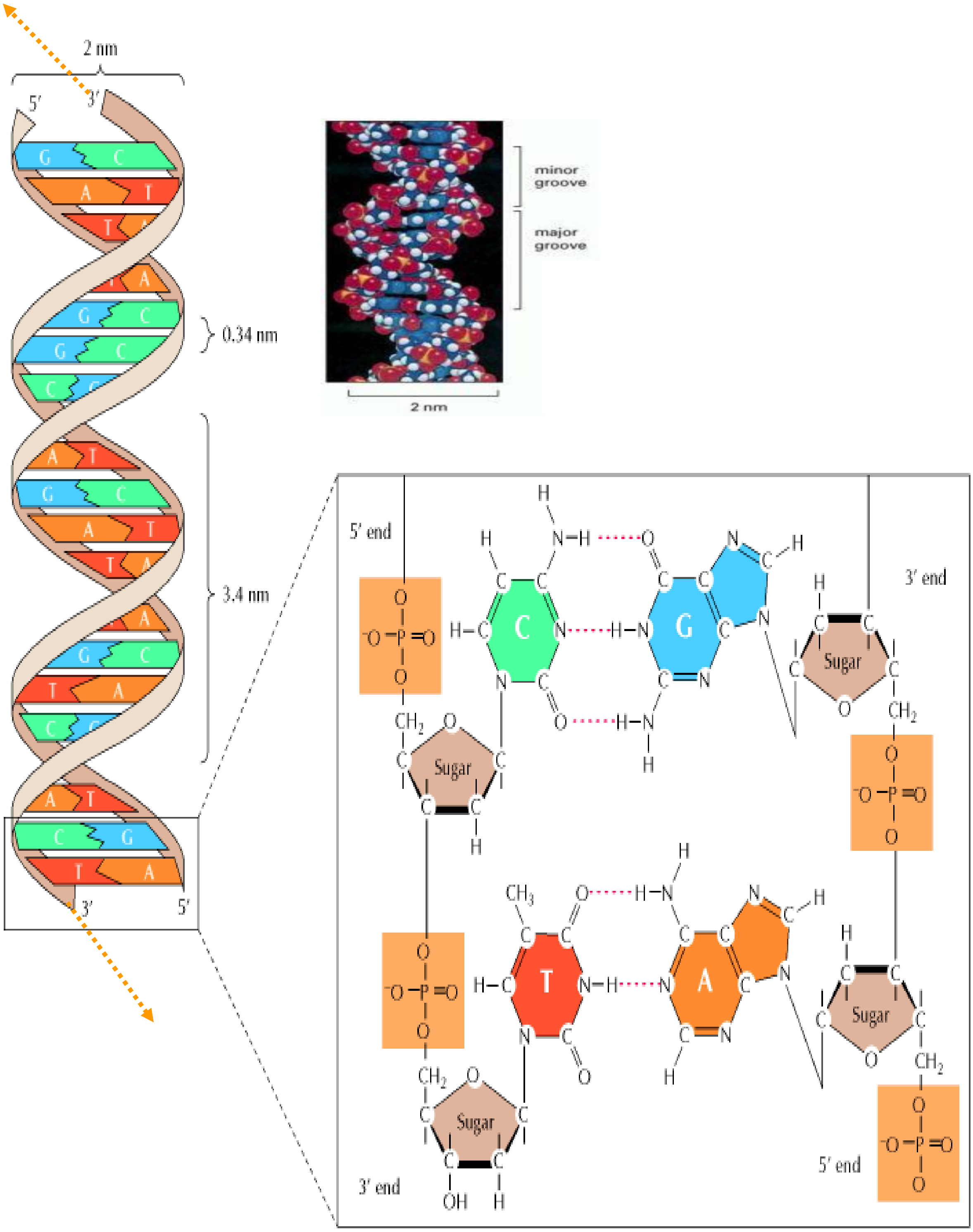



**Figure 14. The DNA and its building blocks.** DNA is made of four types of nucleotides, which are linked covalently into a polynucleotide chain (a DNA strand) with a sugar-phosphate backbone from which the bases (A, C, G, and T) extend. A DNA molecule is composed of two DNA strands held together by hydrogen bonds between the paired bases. The *arrowheads* at the ends of the DNA strands indicate the polarities of the two strands, which run antiparallel to each other in the DNA molecule. In the diagram shown, the DNA molecule is twisted into a double helix, as shown on the left. [Alberts, B., *et al.*, 1998; Cooper, G, M., 2000].

**The Nucleotides and DNA chemical composition**

The nucleotides are composed of a five-carbon sugar linked to a phosphate group and a nitrogen-containing base. In the DNA nucleotides, the sugar is deoxyribose attached to a single phosphate group (hence the name deoxyribonucleic acid), and the base may be: two purines (adenine [A] and guanine [G]) and two pyrimidines (cytosine [C] and thymine [T]. The nucleotides are covalently linked together in a chain through the sugars and phosphates, which thus form a "backbone" of alternating sugar-phosphate-sugar-phosphate (see Figure 15). The bases are on the inside, oriented such way that hydrogen bonds are formed between purines and pyrimidines on opposite chains.

The base pairing is highly specific: adenine (A) always pairs with thymine (T) "double hydrogen bonds" and guanine (G) with cytosine (C) "triple hydrogen bonds". Because only the base differs in each of the four types of subunits, each polynucleotide chain in DNA is similar  to a necklace (the backbone) with four types of beads (the four bases A, C, G, and T). Symbols 'A, C, G, and T are commonly used to stand for the four different nucleotides "the bases with their attached sugar and phosphate groups".



It important to the mind that, the nucleotides are linked together covalently by phosphodiester bonds through the 3′-hydroxyl (-OH) group of one sugar and the 5′-phosphate (P) of the next. Thus, each polynucleotide strand has a chemical polarity (its two ends are chemically different). The 3′ end carries an unlinked -OH group attached to the 3′ position on the sugar ring; the 5′ end carries a free phosphate group attached to the 5′ position on the sugar ring.

The way in which the nucleotide subunits are lined together gives a DNA strand a chemical polarity that is indicated by referring to one end as the *3′ end* and the other as the *5′ end*. (see Figure above). The members of each base pair can fit together within the double helix only if the two strands of the helix are antiparallel:-i.e  if the polarity of strands are oriented opposite to each other, the significance of the base-pairing make each strand of a DNA molecule is exactly complementary to the nucleotide sequence of its partner strand.

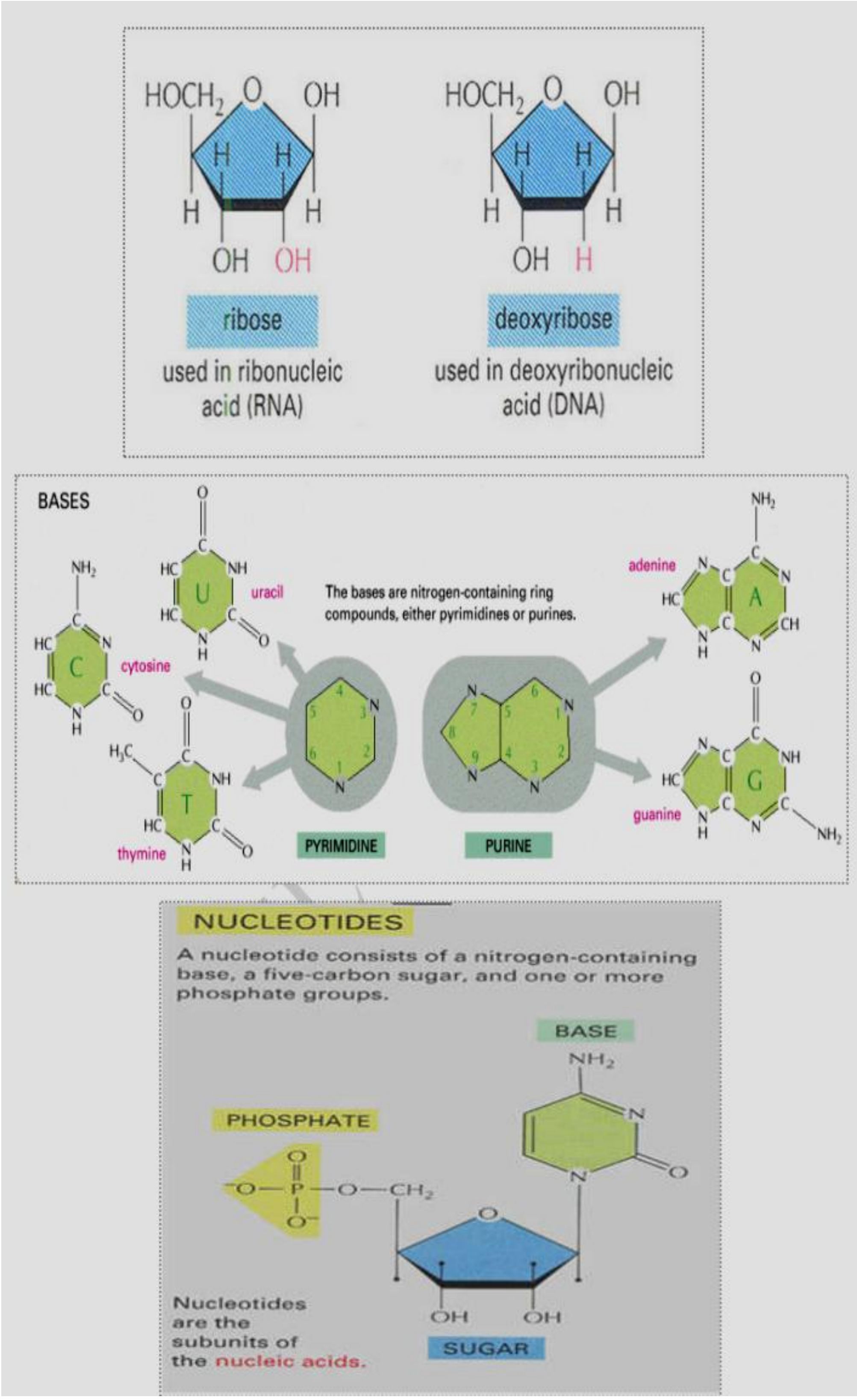



**Figure 15. Chemical compositions of a nucleotide**. DNA was known to be a polymer composed of four nucleic acid bases—two purines (adenine "A" and guanine "G") and two pyrimidines (cytosine "C" and thymine "T"). the nitrogen bases are linked to phosphorylated sugars (phosphor group attached to the sugar).[1].

## The Eukaryotic DNA  inside the Cell’s Nucleus

Nearly all the DNA in an eukaryotic cell is present in a nucleus, which occupies about 10% of the total cell volume. The nucleus is surrounded by a *nuclear envelope* formed from two phospholipid bilayer membranes that contain nuclear pores (NP), which transport molecules between the nucleus and the cytosol. The nuclear envelope is directly connected to the membranes of the endoplasmic reticulum (ER). It is also supported by two networks of intermediate filaments: $1^{ST}$ called the *nuclear lamina*, forms a thin sheetlike meshwork inside the nucleus, just beneath the inner nuclear membrane; while the $2^{nd}$ surrounds the outer nuclear membrane and is less regularly organized (Figure 16).

The nuclear envelope allows protein that act on DNA to be concentrated inside the cell and also keeps nuclear and cytosolic enzymes separate, this is important for the proper functioning of eukaryotic cells.

Genetic information is carried in the linear sequence of nucleotides in DNA that  is a double helix formed from two complementary strands of nucleotides helding together by hydrogen bonds between G-C and A-T base pairs. Duplication of the genetic information occurs by the use of one DNA strand as a template to produce a complementary strand. The genetic information stored in an organism's DNA contains the instructions for all the proteins contents of an organism.

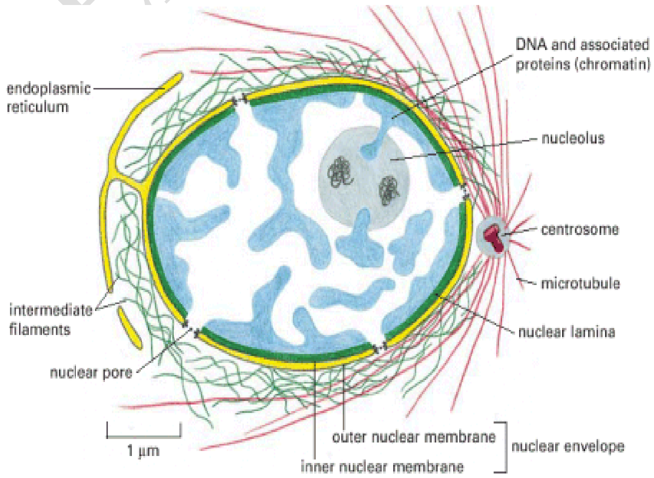



**Figure 16. A typical cell nucleus.** The nuclear envelope consists of two membranes, the outer one being continuous with ER membrane. The ER lumen is continuous with the space between the two nuclear membranes. The lipid bilayers of the inner and outer nuclear membranes are connected at each nuclear pore. The intermediate filaments inside the nucleus form a special supporting structure” *nuclear lamina*”.[1].

### Chromatin and Packaging DNA inside the cell.

The complexes between eukaryotic DNA and proteins are called chromatin, which typically contains about twice as much protein as DNA. The major proteins of chromatin are the histones. —small proteins containing a high proportion of basic amino acids (arginine and lysine) faciliting binding to the negatively charged DNA molecule. There are five major types of histones—called H1, H2A, H2B, H3, and H4—which are very similar among different species of eukaryotes and are extremely abundant proteins, their mass is approximately equal to that of the cell's DNA, additionally chromatin contains an approximately equal mass of a wide variety of nonhistone chromosomal proteins.

The packaging of DNA with histones yields a chromatin fiber approximately 10 nm in diameter that is composed of chromatosomes separated by linker DNA segments averaging about 80 base pairs in length, and this 10-nm fiber has the beaded appearance (using electron microscope) that suggested the nucleosome model (Figure 17). Packaging of DNA into such a 10-nm chromatin fiber shortens its length approximately sixfold. The chromatin can then be further condensed by coiling into 30-nm fibers, the structure of which still remains to be determined. Interactions between histone H1 molecules appear to play an important role in this stage of chromatin condensation.



Chromatin condensation varies during the life cycle of the cell. In interphase (nondividing) cells, most of the chromatin (called euchromatin) is relatively decondensed and distributed throughout the nucleus (See also Figure 16). During preparation for cell division, genes are transcribed and the DNA is replicated, most of the euchromatin in interphase nuclei appears to be in the form of 30-nm fibers, organized into large loops containing approximately 50 to 100 kb of DNA. About 10% of the euchromatin, containing the genes that are actively transcribed, is in a more decondensed state (the 10-nm conformation) that allows transcription. Thus chromatin structure is intimately linked to the control of gene expression in eukaryotes. In contrast to euchromatin, about 10% of interphase chromatin (called heterochromatin) is in a very highly condensed state that resembles the chromatin of cells undergoing mitosis. Heterochromatin is transcriptionally inactive and contains highly repeated DNA sequences, such as those present at centromeres and telomeres.

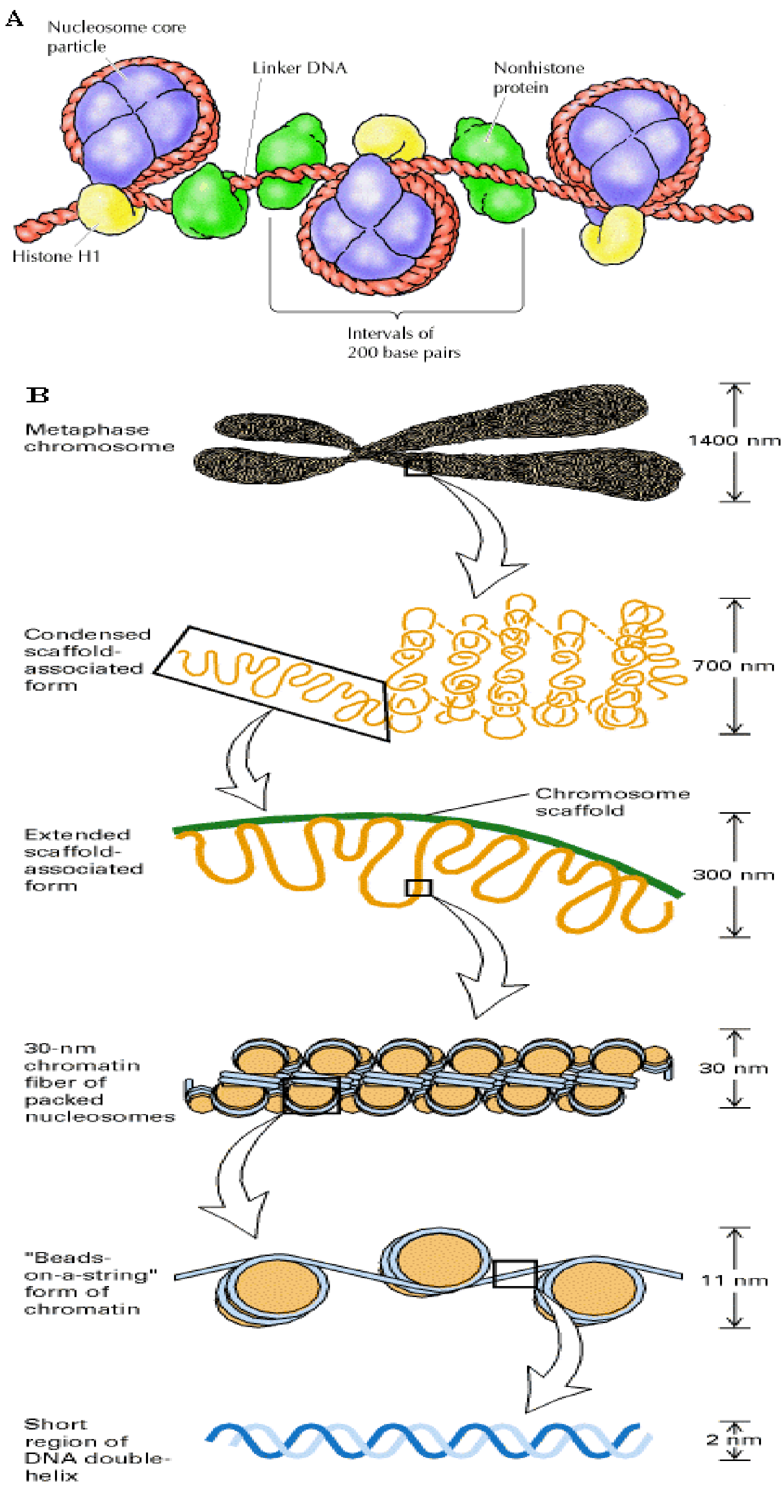



**Figure 17. Chromatin packing and the chromosome scaffold in metaphase chromosome.** The DNA is wrapped around histones in nucleosome core particles and sealed by histone H1. Nonhistone proteins bind to the linker DNA between nucleosome core particles. In interphase chromosomes, long stretches of 30-nm chromatin loop out from extended scaffolds. In metaphase chromosomes, the scaffold is folded into a helix and further packed into a highly compacted structure, whose precise geometry has not been determined. B) This model shows some of the many levels of chromatin packing postulated to give rise to the highly condensed mitotic chromosome. [Cooper, G, M., 2000; Lodish, H.; *et al.*, 1999].

**Gene Organization**

The human genome has the large average gene size of 27,000 nucleotide pairs. As typical gene carries in its linear sequence of nucleotides the information for the linear sequence of the amino acids of a protein. Only about 1300 nucleotide pairs are required to encode a protein of average size (about 430 amino acids in humans). Most of the remaining DNA in a gene consists of long stretches of noncoding DNA that interrupt the relatively short segments of DNA that code for protein. The coding sequences are called *exons*; the intervening (noncoding) sequences are called introns (see Figure 18 A and B). In addition to introns and exons, each gene is associated with *regulatory DNA sequences*, which control the gene expression. In humans, the regulatory sequences for a typical gene are spread out over tens of thousands of nucleotide pairs. As would be expected, these regulatory sequences are more compressed in organisms with compact genomes.

The majority of human genes thus consist of a long string of alternating exons and introns, with most of the gene consisting of introns. In contrast, the majority of genes from organisms with compact genomes lack introns. This accounts for the much smaller size of their genes (about one-twentieth that of human genes), as well as for the much higher fraction of coding DNA in their chromosomes.



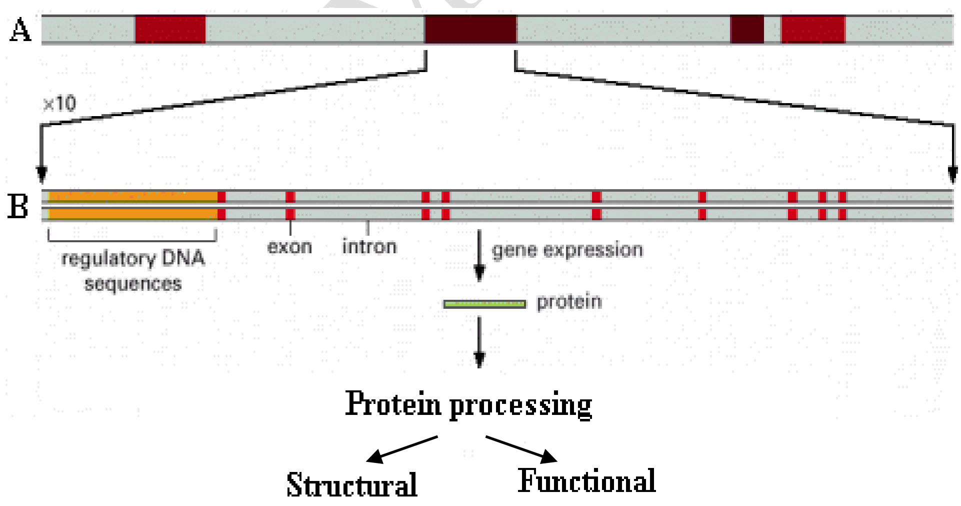



**Figure 18.A. Genes organization on a human chromosome.** (A) An expanded part of a chromosome shows the entire length of several genes. (B) The intron-exon arrangement of a typical gene is shown after a further tenfold expansion. Exon codes for a particular protein, that can be structural or functional. Intron-exon organization of a typical human gene is shown.

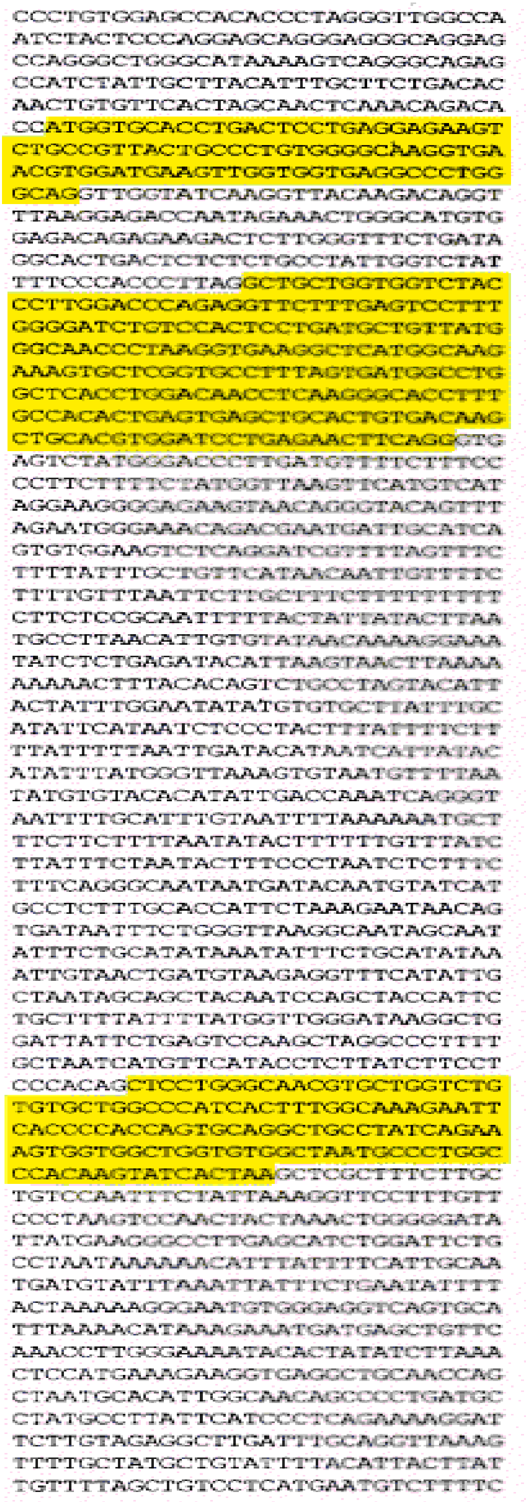



**Figure 18.B. The nucleotide sequence of the human β-globin gene. the human β-globin gene** carries the information for the amino acid sequence for one of the two types of subunits of the hemoglobin molecule, which carries oxygen in the blood. The DNA sequences highlighted (yellow) show the three coding regions of the gene that specify the amino sequence for the β-globin protein. Only one strand of DNA double helix containing the β-globin gene is shown; the other strand has the exact complementary nucleotide sequence [Alberts, B., *et al.*, 1998].

**DNA: Mechanism for Heredity**

Genes carry biological information that must be copied accurately for transmission to the next generation when a cell divides to form two daughter cells. How can the information for specifying an organism be carried chemically, and then to be copied accurately? Once, the DNA structure was discovered in twentieth-century, an immediate answers resolving the problem of heredity were suggested. As we know by know that DNA encodes information through the nucleotides sequence along each strand. Each base; A, C, T, or G can be considered as a letter in a four-letter alphabet that carries biological messages in the chemical structure of the DNA. Organisms differ from one another as they have different nucleotide sequences and, consequently, carry different biological messages.

It was known well before the structure of DNA was determined that genes contain the instructions for producing proteins. The DNA messages must therefore somehow encode proteins (Figure 19). This relationship immediately makes the problem easier to understand. The properties of a protein, which are responsible for its biological function, are determined by its three-dimensional structure, and its structure is determined in turn by the linear sequence of the amino acids of which it is composed.



The linear sequence of nucleotides in a gene must therefore somehow read out the linear sequence of amino acids in a protein. The exact correspondence between the four-letter nucleotide alphabet of DNA and the twenty-letter amino acid alphabet of proteins can not be seen from the DNA structure, and took over a decade to be worked out after DNA discovery.

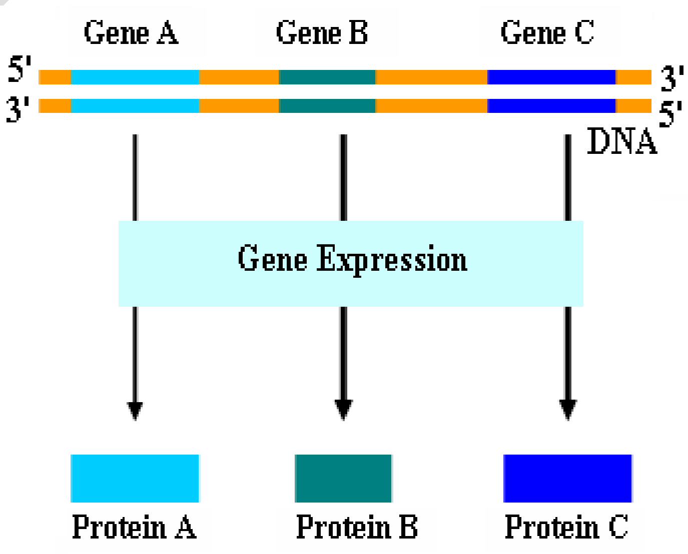



**Figure 19. A diagram showing relation from Genes to Proteins.**

## The DNA Replication

The ability of cells to maintain a high degree of efficiency throughout its life depends on the accurate duplication of vast quantities of genetic information. For that a process known as *DNA replication* must occur with extraordinary accuracy before a cell can produce two genetically identical daughter cells. By means of an elaborate “replication machine” the DNA is duplicating at rates as high as 1000 nucleotides per second.

In the DNA replication, each of the two old DNA strands serves as a template for the formation of an entire new strand. Because each of the two daughters of a dividing cell inherits a new DNA double helix containing one old and one new strand (Figure 20), the DNA double helix is said to be replicated “semiconservatively” by DNA polymerase.

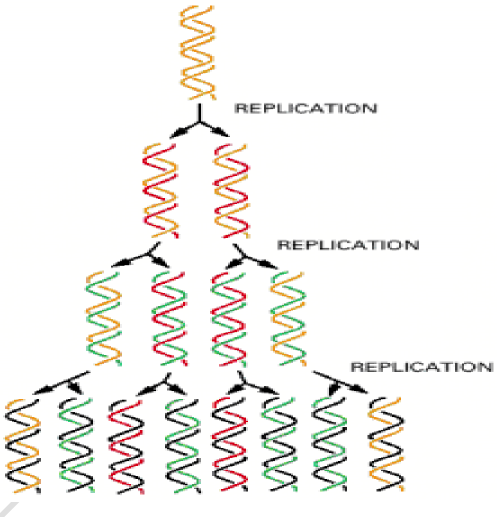



**Figure 20. The semiconservative nature of DNA replication**. In replication, each of the two strands of DNA is used as a template to form a complementary DNA strand. The original strands therefore remain intact through many cell generations.

The *DNA templating* allows the nucleotide sequence of a DNA strand to be copied by complementary base-pairing (A with T, and G with C) into a complementary DNA sequence (Figure 21). This process entails the recognition of each nucleotide in the DNA *template strand* by a free (unpolymerized) complementary nucleotide, and it requires that the two strands of the DNA helix be separated. This separation allows the hydrogen-bond donor and acceptor groups on each DNA base to become exposed for base-pairing with the appropriate incoming free nucleotide, aligning it for its enzyme-catalyzed polymerization into a new DNA chain.

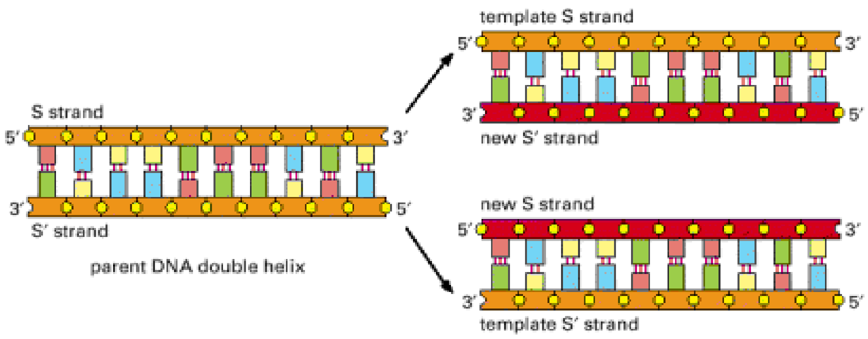



**Figure 21. The DNA double helix acts as a template for its duplication.** Each strand of DNA serve as a template to specify the sequence of nucleotides in its complementary strand by DNA base-pairing. In this way, a double-helical DNA molecule can be copied precisely.[1].

In the early 1960s, analysis on whole replicating chromosomes revealed a localized region of replication that moves progressively along the parental DNA double helix. Because of its Y-shaped structure, this active region is called a replication fork (Figure 22). At a replication fork, the DNA of both new daughter strands is synthesized by a multienzyme complex including the DNA polymerase.



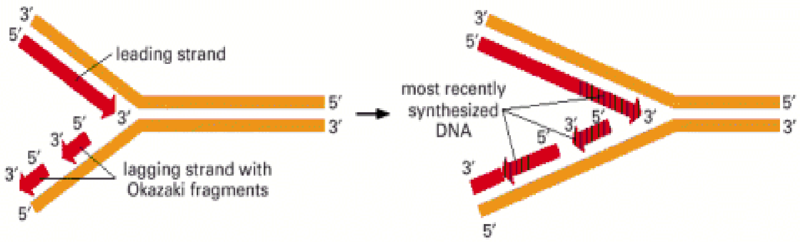



**Figure 22. The structure of a DNA replication fork.** Because both daughter DNA strands are polymerized in the 5′-to-3′ direction, the DNA synthesized on the lagging strand must be made initially as a series of short DNA molecules, called *Okazaki fragment*.[1].

At the replication fork, a self-correcting DNA polymerase enzyme catalyzes nucleotide polymerization in a 5′-to-3′ direction, copying a DNA template strand with remarkable fidelity. Since the two strands of a DNA double helix are antiparallel, this 5′-to-3′ DNA synthesis can take place continuously on only one of the strands at a replication fork (the leading strand). On the lagging strand, short DNA fragments must be made by a "backstitching" process. Because the self-correcting DNA polymerase cannot start a new chain, these lagging-strand DNA fragments are primed by short RNA primer molecules that are subsequently erased and replaced with DNA

DNA replication requires the cooperation of many proteins. These are: 1) DNA polymerase and DNA primase to catalyze nucleoside triphosphate polymerization; 2) DNA helicases and single-strand DNA-binding (SSB) proteins to unwind the DNA helix to be copied; 3) DNA ligase and an enzyme to degrades RNA primers to link the discontinuously synthesized lagging-strand DNA fragments; and 4) DNA topoisomerases to help relieving helical winding and DNA tangling problems. Many of these proteins associate with each other at the replication fork to form a highly efficient "replication machine," with high level of coordination (Figure 23).

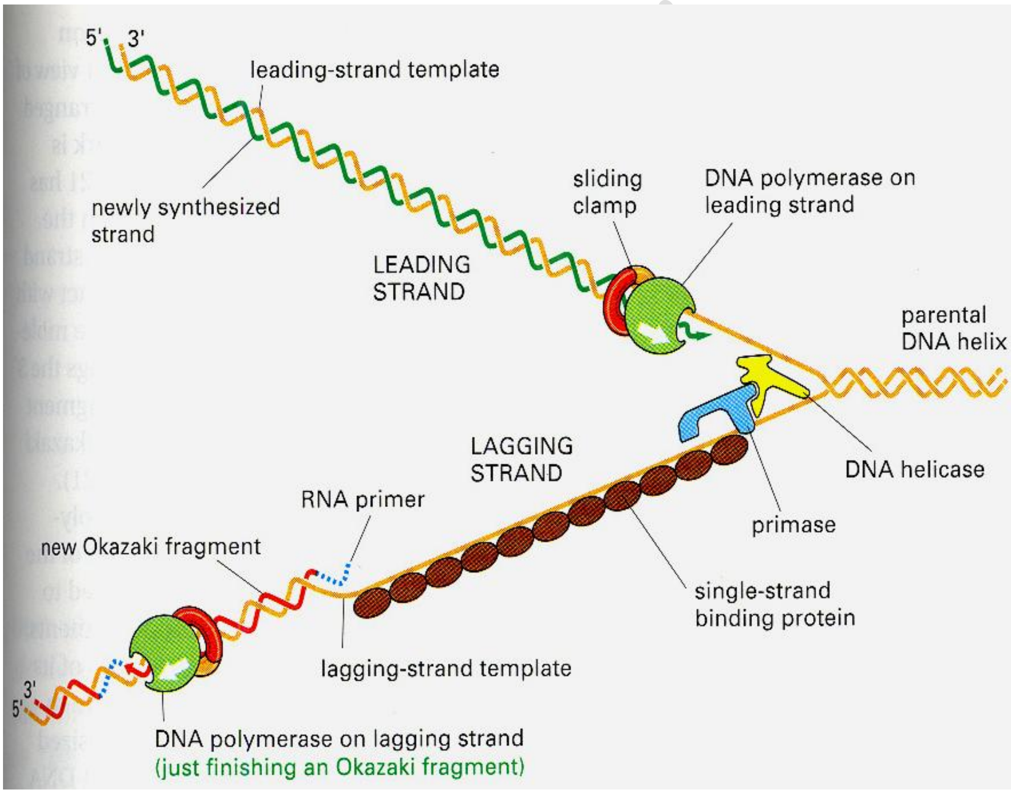



**Figure 23. Replication machinery operating at a mammalian replication fork.** DNA replication requires the cooperation of many proteins:-DNA polymerase, DNA primase; DNA helicases and single-strand DNA-binding (SSB) proteins; DNA ligase and degrading enzyme for RNA primers; and DNA topoisomerases. Many of these proteins associate with each other at the replication fork to form a highly efficient "replication machine," that is highly coordinated. [Alberts, B., *et al.*, 1998].

# From DNA to Protein

When the cells (from bacteria to humans) need a particular protein, the nucleotide sequence of appropriate portion of DNA molecule in a chromosome is copied into RNA molecule (a process called *transcription)* which is used directly as templates to direct the synthesis of the protein (a process called *translation).* The flow of genetic information in cells is therefore from DNA to RNA to protein (Figure 24) is termed the ***Central dogma*** of molecular biology.

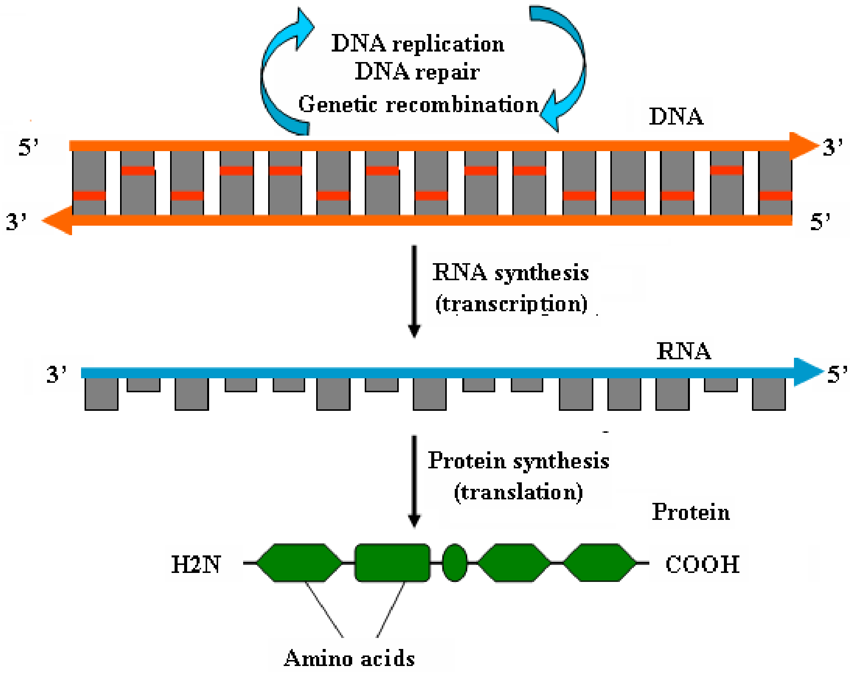



**Figure 24. From DNA to protein.** The flow of genetic information from DNA to RNA (transcription) and from RNA to protein (translation) occurs in all living cells.

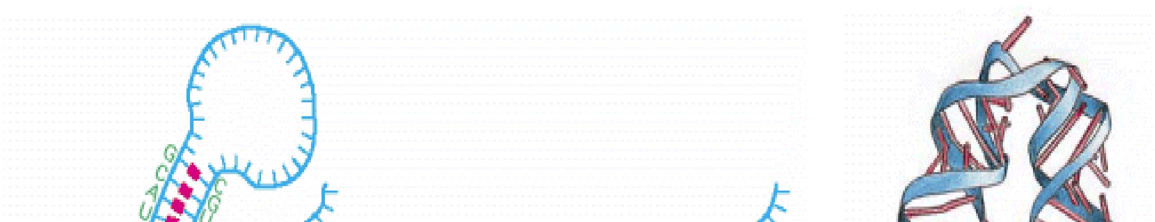
There are important variations in the way information flows from DNA to protein. Principally, RNA transcripts in eukaryotic cells are subject to a series of processing events in the nucleus, including *RNA splicing*, before exported from the nucleus and be translated into protein. These processing steps can critically change the “meaning” of an RNA molecule and are therefore crucial for understanding how eukaryotic cells read the genome. Many of these RNAs molecules fold into precise three-dimensional structures that have structural and catalytic roles in the cell; i.e structural or functional proteins.

**RNA (Ribonucleic acid) molecules and transcription.**

When a cell requires part of its genetic instructions, cell copy the DNA nucleotide sequence of that portion “gene” into an RNA nucleotide sequence. The information in RNA, although copied into another chemical form, but it has the same language of a nucleotide sequence as in the DNA

Like DNA, RNA is a linear polymer made of four different types of nucleotide subunits linked together by phosphodiester bonds. It differs from DNA chemically in two respects: (1) the nucleotides in RNA are *ribonucleotides as* they contain the sugar ribose (hence the name *ribo*nucleic acid) rather than deoxyribose; 2) Like DNA, RNA contains the bases adenine (A), guanine (G), and cytosine (C), but instead of the thymine (T) in DNA, it contains the base uracil (U). Since U, like T, can base-pair by hydrogen-bonding with A (Figure 25), the complementary base-pairing properties described for DNA apply also to RNA (in RNA, G pairs with C, and A pairs with U). It is not uncommon, however, to find other types of base pairs in RNA: for example, G pairing with U occasionally.

Despite these small chemical differences, DNA and RNA differ quite dramatically in overall structure. Whereas DNA always occurs in cells as a double-stranded helix, RNA is single-stranded. RNA chains therefore fold up into a variety of shapes, just as a polypeptide chain folds up to form the final shape of a protein (Figure 25).



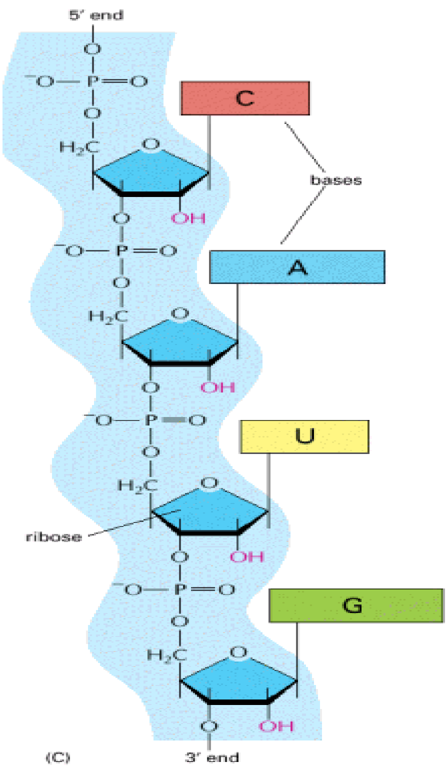



**Figure 25. Features of RNA molecules.** RNA is largely single-stranded, also can form conventional base-pairs with complementary sequences found on the same molecule (A); or with both conventional and nonconventional base-pair interactions (B). It is also can fold into a three-dimensional structure (C). (D) The chemical structure of RNA showing the sugar ribose, which differs from deoxyribose and contains the base uracil, the phosphodiester chemical linkage between nucleotides in RNA is also shown. [Alberts, B., *et al.*, 1994].

## The DNA transcription.

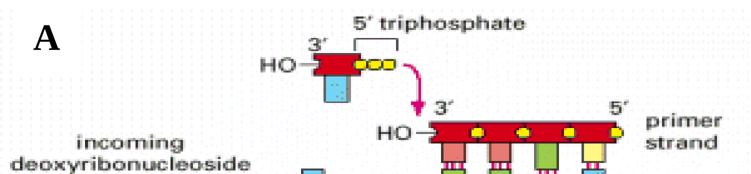
The transcription begins with the opening and unwinding of a small portion of the DNA double helix to expose the bases on each DNA strand. One DNA strand of the

DNA double helix then acts as a template for the synthesis of an RNA molecule. As in DNA replication, the nucleotide sequence of the RNA chain is determined by the complementary base-pairing between incoming nucleotides and the DNA template. The incoming ribonucleotide is covalently linked to the growing RNA chain in an enzymatically catalyzed reaction. The RNA chain produced by transcription ‘the *transcript’* is therefore elongated one nucleotide at a time, and it has a nucleotide sequence that is exactly complementary to the strand of DNA that was used as the template (Figure 26).

Transcription, however, differs from DNA replication in several crucial ways. Unlike a newly formed DNA strand, the RNA strand does not remain hydrogen-bonded to the DNA template strand. Instead, just behind the region where the ribonucleotides are being added, the RNA chain is displaced and the DNA helix re-forms. Thus, the RNA molecules produced by transcription are released from the DNA template as single strands. In addition, because they are copied from only a limited region of the DNA, RNA molecules are much shorter than DNA molecules. A DNA molecule in a human chromosome can be up to 250 million nucleotide-pairs long; in contrast, most RNAs are no more than a few thousand nucleotides long, and many are considerably shorter.

The enzymes that perform transcription are called RNA polymerases that catalyze the formation of the phosphodiester bonds that link the nucleotides together to form a linear chain. The RNA polymerase moves stepwise along the DNA, unwinding the DNA helix just ahead of the active site for polymerization to expose a new region of the template strand for complementary base-pairing. In this way, the growing RNA chain is extended by one nucleotide at a time in the 5′-to-3′ direction (Figure 26). The substrates are nucleoside triphosphates (ATP, CTP, UTP, and GTP); as for DNA replication, a hydrolysis of high-energy bonds provides the energy needed to drive the reaction forward. In contrast to bacteria, which contain a single type of RNA polymerase, eucaryotic nuclei have three types; these are *RNA polymerase I, RNA polymerase II,* and *RNA polymerase III*. The three polymerases

are structurally similar to one another (and to the bacterial enzyme). RNA polymerases I and III transcribe the genes encoding transfer RNA, ribosomal RNA, and various small RNAs. RNA polymerase II transcribes the vast majority of genes, including all those that encode proteins.



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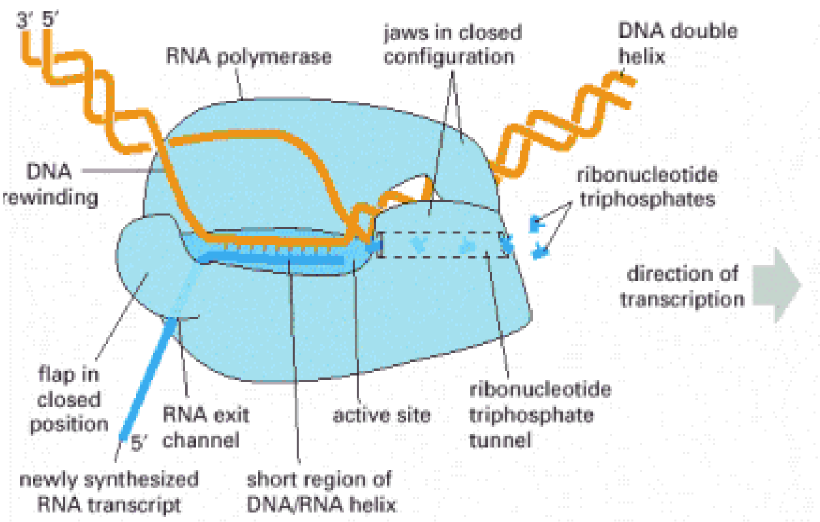



**Figure 26. DNA synthesis catalyzed by DNA polymerase.** (A) As indicated, DNA polymerase catalyzes the stepwise addition of a deoxyribonucleotide to the 3′-OH end of a polynucleotide chain, the *primer strand*, that is paired to a second *template strand*. The newly synthesized DNA strand therefore polymerizes in the 5′-to-3′ direction as shown in the previous figure. Because each incoming deoxyribonucleoside triphosphate must pair with the template strand to be recognized by the DNA polymerase, this strand determines which of the four possible deoxyribonucleotides (A, C, G, or T) will be added. (B) The structure of an *E. coli* DNA polymerase molecule, as determined by x-ray crystallography. This drawing illustrates a DNA polymerase that functions during DNA repair. Note that the enzymes that replicate DNA have similar features. [Alberts, B., *et al.*, 1998].

**Types of RNA molecules.**

The majority of genes carried in a cell's DNA specify the amino acid sequence of proteins; the RNA molecules that are copied from these genes (which ultimately direct the synthesis of proteins) are called messenger RNA (mRNA) molecules. The RNAs, like proteins, serve as enzymatic and structural components for a wide variety of processes in the cell. Some *small nuclear* RNA (*snRNA*) molecules direct the splicing of pre-mRNA to form mRNA, that *ribosomal* RNA *(rRNA)* molecules form the core of ribosomes, and that *transfer* RNA *(tRNA)* molecules form the adaptors that select amino acids and hold them in place on a ribosome for incorporation into protein (Table 1).

In eukaryotes, a transcription unit typically carries the information of one gene, and therefore codes for either a single RNA molecule ‘single protein’ or group of related proteins if the initial RNA transcript is spliced in more than one way to produce different mRNAs. In bacteria, a set of adjacent genes is often transcribed as a unit; therefore the resulting mRNA molecule codes instructions for several different proteins.

Overall, RNA makes up a few percent of a cell's dry weight. Most of the RNA in cells is rRNA; mRNA comprises only 3–5% of the total RNA in a typical mammalian cell. The mRNA population is made up of tens of thousands of different species, and there are on average only 10–15 molecules of each species of mRNA present in each cell.

**Table 1. Different Types of RNAs Produced in Cells [1]**

| TYPE OF RNA | FUNCTION |
|---|---|
| mRNAs | messenger RNAs, code for proteins |
| rRNAs | ribosomal RNAs, form the basic structure of the ribosome and catalyze protein synthesis |
| tRNAs | transfer RNAs, central to protein synthesis as adaptors between mRNA and amino acids |
| snRNAs | small nuclear RNAs, function in a variety of nuclear processes, including the splicing of pre-mRNA |
| snoRNAs | small nucleolar RNAs, used to process and chemically modify rRNAs |
| Other noncoding RNAs | function in diverse cellular processes, including telomere synthesis, X-chromosome inactivation, and the transport of proteins into the ER |

## The RNA Processing

The first step in RNA processing is the RNA *splicing* in which a series of reactions including the covalent modification of both ends of the RNA and the removal of *intron sequences* (GT—AG rule) that are discarded from the middle of the RNA transcript (Figure 27). Secondly, the modifications of the ends of eucaryotic mRNA, are *capping* on the 5′ end and third the *polyadenylation* of the 3′ end (Figure 28). These special ends allow the cell to assess whether both ends of an mRNA molecule are present (and the message is therefore intact) before it exports the RNA sequence from the nucleus for translation into protein. The RNA splicing is the critically important step in which the different portions of a protein coding sequence are joined together and also provides higher eukaryotes with the ability to synthesize several different proteins from the same gene.

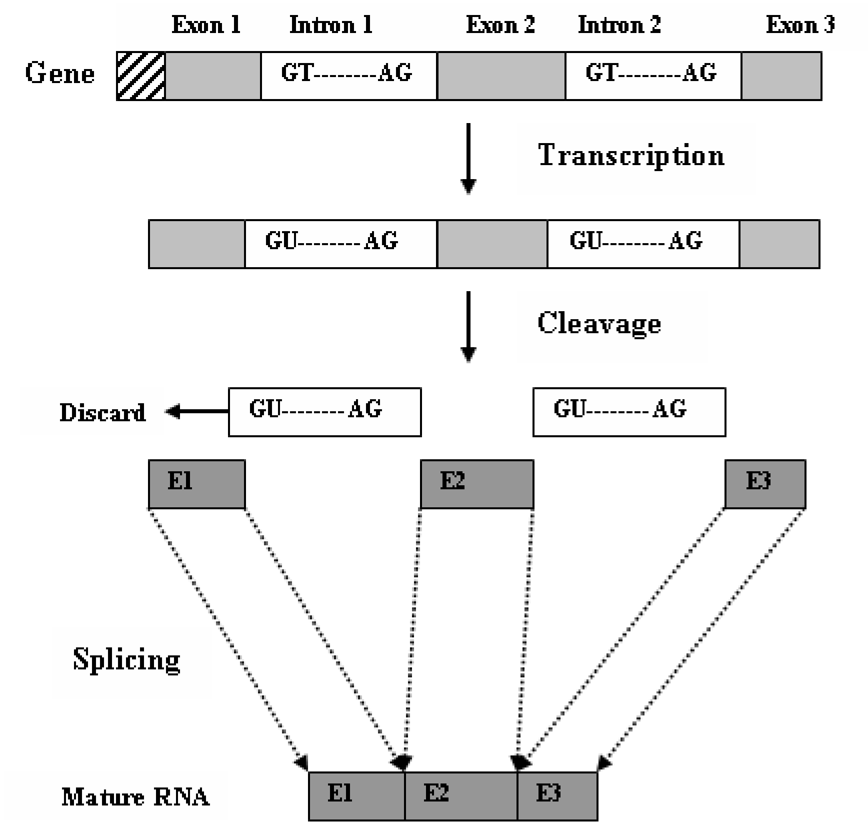



**Figure 27. The *RNA splicing processing.*** The coding sequence exons are spliced from the primary RNA transcript by the spliceosome that recognizes the splicing signals on a pre-mRNA molecule.

## The DNA Translation

Once an mRNA is produced, the information present in its nucleotide sequence is used to synthesize a protein through the process termed as the *translation*. The nucleotide sequence of a mRNA gene, is translated into the amino acid sequence of a protein by rules that are known as the genetic code (Figure 29) that was deciphered in the early 1960s. As there are only four different nucleotides in mRNA and twenty different types of amino acids in a protein, the sequence of nucleotides in the mRNA molecule is read consecutively in groups of three. RNA is a linear polymer of four different nucleotides, so there are 4 × 4 × 4 = 64 possible combinations of three nucleotides: the triplets AAA, AUA, AUG, and so on. Each group of three consecutive nucleotides in RNA is called a codon, and each codon specifies either one amino acid or a stop to the translation process.

The genetic code is used universally in all organisms, but there is a few slight differences. For instance, the mitochondrial DNA have their own transcription and protein synthesis systems that operate quite independently from those of the rest of the cell, also their small genomes have been able to accommodate minor changes to the genetic code for their own.

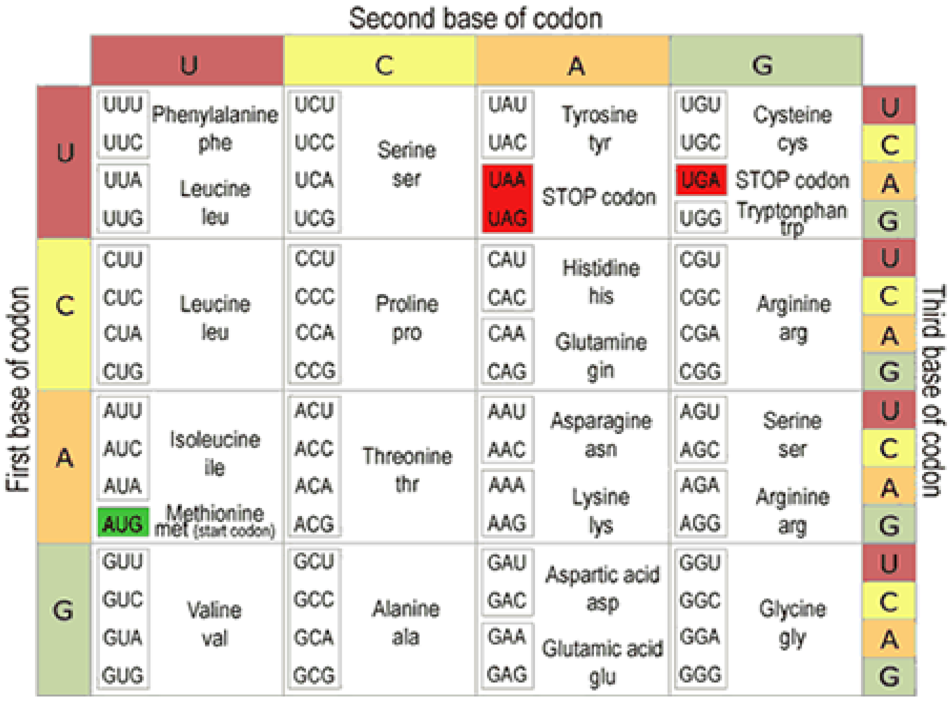



**Figure 29. The Universals genetic code**

The translation of the nucleotide sequence of an mRNA molecule into protein takes place in the cytoplasm on a large ribonucleoprotein assembly called a ribosome. The amino acids used for protein synthesis are first attached to a family of tRNA molecules (Figure 30), each of which recognizes, by complementary base-pair interactions, particular sets of three nucleotides in the mRNA (codons). The sequence of nucleotides in the mRNA is then read from one end to the other in sets of three according to the genetic code.

To initiate translation, a small ribosomal subunit binds to the mRNA molecule at a start codon (AUG) that is recognized by a unique initiator tRNA molecule (Figure 30). A large ribosomal subunit binds to complete the ribosome and begin the elongation phase of protein synthesis. During this phase, aminoacyl tRNAs—each bearing a specific amino acid bind sequentially to the appropriate codon in mRNA by forming complementary base pairs with the tRNA anticodon. Each amino acid is added to the C-terminal end of the growing polypeptide by means of a cycle of three sequential steps: aminoacyl-tRNA binding, followed by peptide bond formation, followed by ribosome translocation. The mRNA molecule progresses codon by codon through the ribosome in the 5′-to-3′ direction until one of three stop codons is reached. A release factor then binds to the ribosome, terminating translation and releasing the completed polypeptide (see figures 32, 33).

Eucaryotic and bacterial ribosomes are closely related, regardless of differences in the number and size of their rRNA and protein components. The rRNA has the dominant role in translation, determining the overall structure of the ribosome, forming the binding sites for the tRNAs, matching the tRNAs to codons in the mRNA, and providing the peptidyl transferase enzyme activity that links amino acids together during translation.

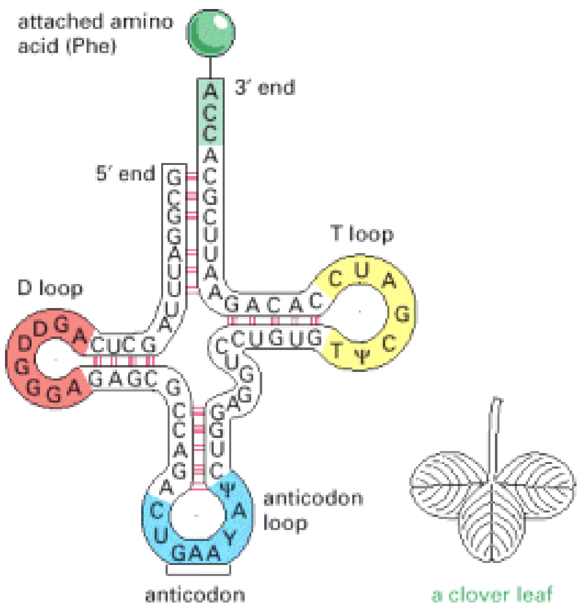



**Figure 30. A tRNA molecule.** The cloverleaf structure, a convention showing the complementary base-pairing *(red lines)* that creates the double-helical regions of the molecule. The anticodon is the sequence of three nucleotides that base-pairs with a codon in mRNA. The amino acid matching the codon/anticodon pair is attached at the 3′ end of the tRNA. tRNAs contain some unusual bases, which are produced by chemical modification after the tRNA has been synthesized (e.g pseudouridine, Ψ). Here the example of tRNA molecule is for tRNA specific for the amino acid phenylalanine (Phe). [Alberts, B., *et al.*, 2002].

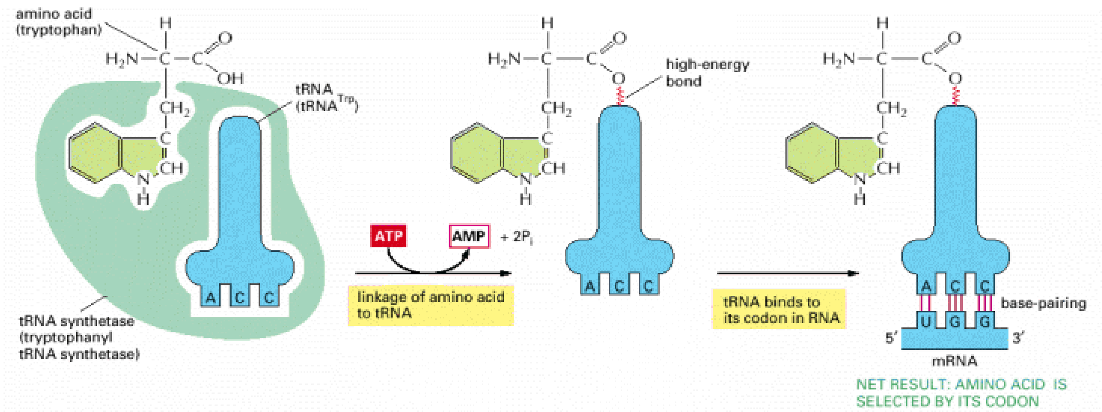



**Figure 31. Translating the genetic code using adaptors.** The first adaptor is the aminoacyl-tRNA synthetase adaptor couples a particular amino acid to its corresponding tRNA. The 2[nd] adaptor is the tRNA molecule itself, whose *anticodon* forms base pairs with the appropriate *codon* on the mRNA. Note that it is very precise operation as an error in either step would incorporate the wrong amino acid into a protein chain. As shown in the figure, the amino acid tryptophan (Trp) is selected by the codon UGG on the mRNA. [Alberts, B., *et al*., 1998].

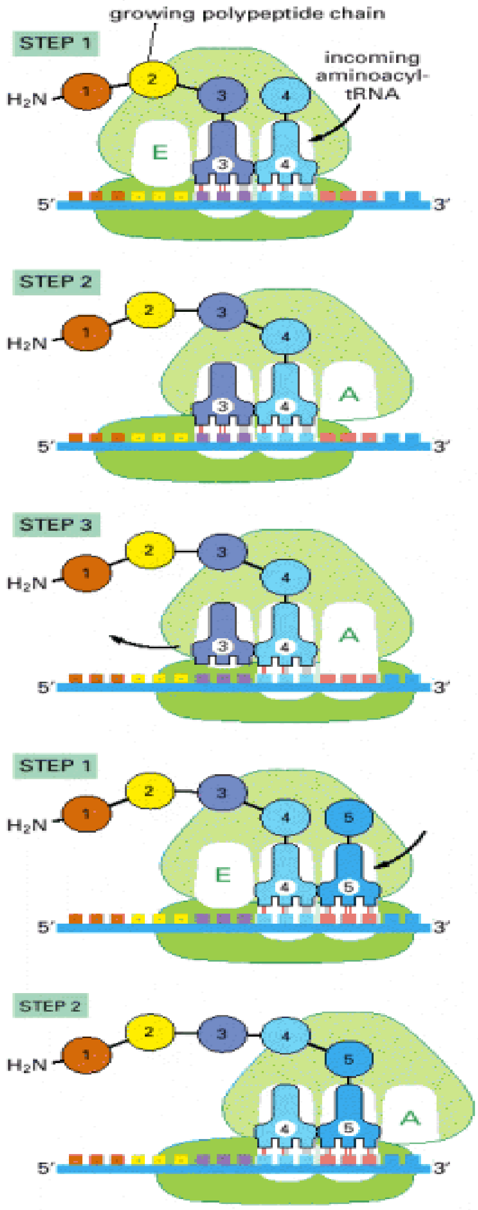



**Figure 33. Translating an mRNA molecule.** Each amino acid added to the growing end of a polypeptide chain. This is selected by complementary base-pairing between the anticodon on its attached tRNA molecule and the next codon on the mRNA chain. The codon determines the specific amino acid to be added to the growing polypeptide chain. The three-step cycle shown is repeated over and over during the synthesis of a protein: 1) an aminoacyl-tRNA molecule binds to a vacant A-site on the ribosome; 2) a new peptide bond is formed, and 3) the mRNA moves a distance of three nucleotides through the small-subunit chain, moving away the spent tRNA molecule and "resetting" the ribosome for the next aminoacyl-tRNA molecule.

As indicated, the mRNA is translated in the 5′-to-3′ direction, and the N-terminal end of a protein is made first, with each cycle adding one amino acid to the C-terminus of the polypeptide chain. The position at which the growing peptide chain is attached to a tRNA does not change during the elongation cycle; it is

# Mendel Principles  for genetics

Modern genetics is based on the concept of the gene, the fundamental unit of heredity. In 1866 Gregor Mendel published the results of his investigations of the inheritance of "factors" in pea plants. As a result of his experiments with the garden pea, Mendel was the first to recognize the existence of genes. Therefore, it is very important to understand that the analysis of genetic crosses depends upon an understanding of Mendel's principles (laws).

**1-**The principle of segregation that is known as “the First Law”: The two members of a gene pair (alleles) segregate (separate) from each other in the formation of gametes. Half the gametes carry one allele, and the other half carry the other alelle.

**2-** The principle of independent assortment that is known as “the Second Law”: Genes for different traits assort independently of one another in the formation of gametes.

In practice, the manifestation of Mendel's laws is seen by characteristic ratios of phenotypic classes, such as 3:1 and 9:3:3:1. The Mendelian principles include the simple assumption that one allele is dominant to the other allele. However, there are extensions to Mendelian principles (see page 67), including the fact that some alleles are incompletely dominant, that some genes are sex-linked, and that some pairs of genes do not assort independently because they are physically linked on a chromosome.

**The Law of Segregation.**

Mendel worked with pea plants and selected seven traits for studying, each trait occurred in two different forms. For instance, one trait was pod color. Some pea plants have green pods and others have yellow pods. Since pea plants are capable of self fertilization, Mendel was able to produce true-breeding plants. A true-breeding yellow-pod plant for example would only produce yellow-pod offspring. Mendel then began experimentation to find out what would happen if he cross-pollinated a true-breeding yellow pod plant with a true-breeding green pod plant. He referred to the two parental plants as the parental generation (P generation) and the resulting offspring were called the first filial or F1 generation. When Mendel performed cross-pollination between a true-breeding yellow pod plant and a true-breeding green pod plant, he noticed that all of the resulting offspring 'F1 generation' were green (Figure 40).

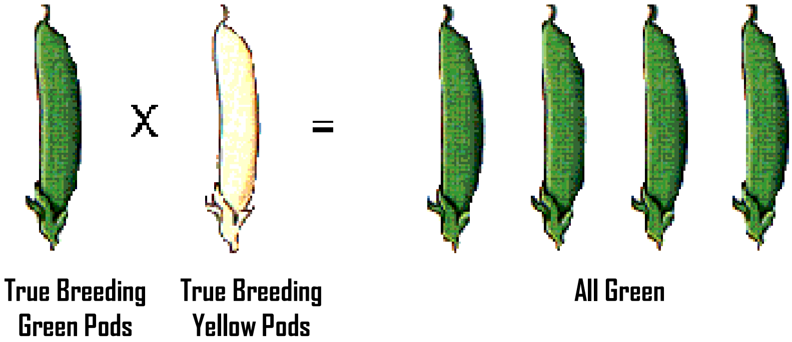



**Figure 40. A cross-pollination between a true-breeding yellow pod plant and a true-breeding green pod plant.**

When Mendel allowed all of the green F1 plants to self-pollinate (their offspring's F2 generation), a 3:1 ratio in pod color was obtained. About 3/4 of the F2 plants had green pods and about 1/4 had yellow pods(Figure 41) .

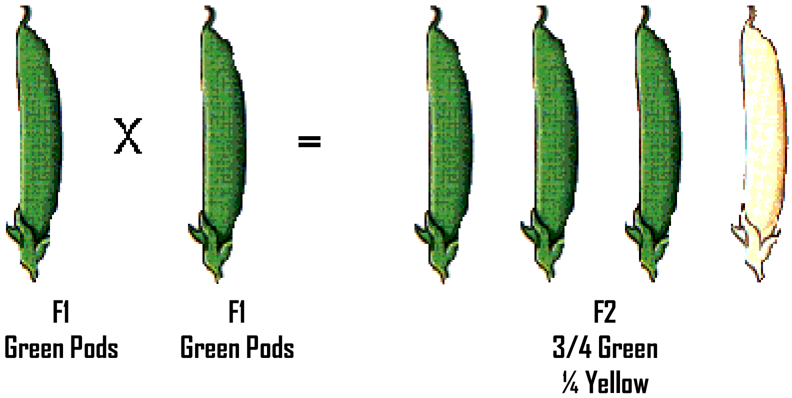



**Figure 41. A self-pollination of the green F1 plants.**

From these experiments Mendel concluded that allele pairs separate or segregate during gamete formation, and randomly unite at fertilization. Therefore, there are four main concepts:

**1**-Genes can be found in alternative forms, meaning a gene can exist in more than one form (e.g  a gene for pod color can either be (G) for green or (g) for yellow.

**2-**For each characteristic or trait, organisms inherit two alternative forms (alleles) of that gene, one from each parent. The F1 plants in Mendel's experiment each received one allele from the green pod parent plant and one allele from the yellow pod parent plant. True-breeding green pod plants have (GG) alleles for pod color, true-breeding yellow pod plants have (gg) alleles, and the resulting F1 plants have (Gg) alleles (Figure 42).

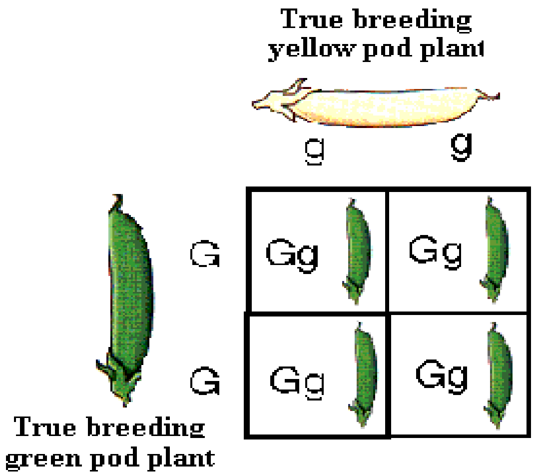
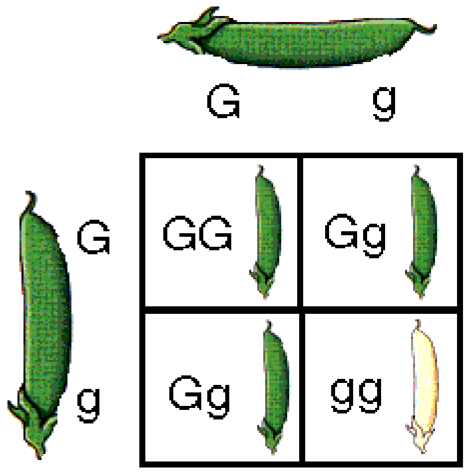



**Figure 42. Genotype and phenotype of the green F1 plants**

**3-**When gametes (sex cells) are produced, allele pairs separate (segregate) leaving them with a single allele for each trait. This means that sex cells contain only half the compliment of genes. When gametes join during fertilization the resulting offspring contain two sets of alleles, one allele from each parent. For example, the sex cell for the green pod plant had a single (G) allele and the sex cell for the yellow pod plant had a single (g) allele. After fertilization the resulting F1 plants had two alleles (Gg).

**4.**When the two alleles of a pair are different, one is dominant and the other is recessive. This means that one trait is expressed or shown, while the other is hidden. For example, the F1 plants (Gg) were all green because the allele for green pod color (G) was dominant over the allele for yellow pod color (g). When the F1 plants were allowed to self-pollinate, 1/4 of the F2 generation plant pods were yellow (Figure 43). This trait had been masked because it is recessive. The alleles for green pod color are (GG) and (Gg). The alleles for yellow pod color are (gg).




Two plants from F1 generation are self-pollinated

**Figure 43. Genotype and phenotype of the F2 generation plant pods**

**2-Mendel's Law of Independent Assortment.**

Mendel performed dihybrid crosses (mating of parent plants that differ in two traits) in plants that were true-breeding for two traits. For example, a plant that had yellow round seeds was cross-pollinated with a plant that had green wrinkled seeds. In this cross, the traits for yellow seed color (YY) and round seed (RR) are dominant. Green seed color (yy) and green wrinkled seed (rr) are recessive. The resulting offspring or F1 generation were all heterozygous for yellow round seed (YyRr) (Figure 44).

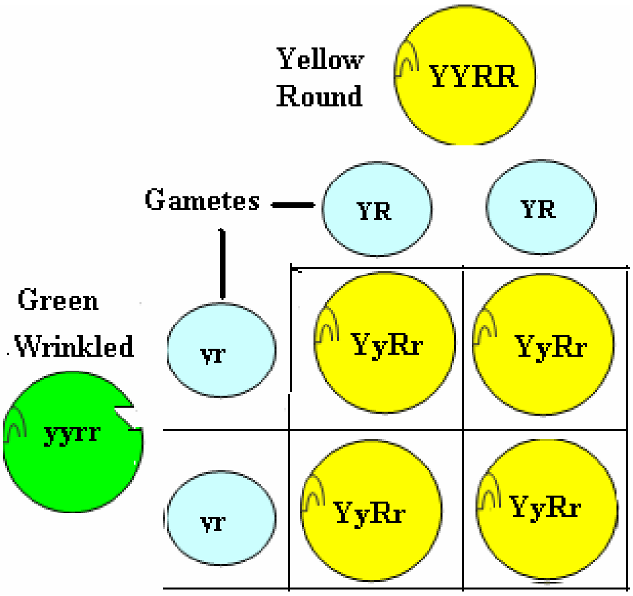



**Figure 44. A heterozygous F1 offspring's for green pod color and yellow seeds.**

Mendel then allowed all of the F1 plants to self-pollinate. He referred to these offspring as the F2 generation. Mendel noticed a 9:3:3:1 ratio. About 9 of the F2 plants had yellow round seeds, 3 had yellow wrinkled seeds, 3 had green round seeds and 1 had green wrinkled seeds (Figure 45).

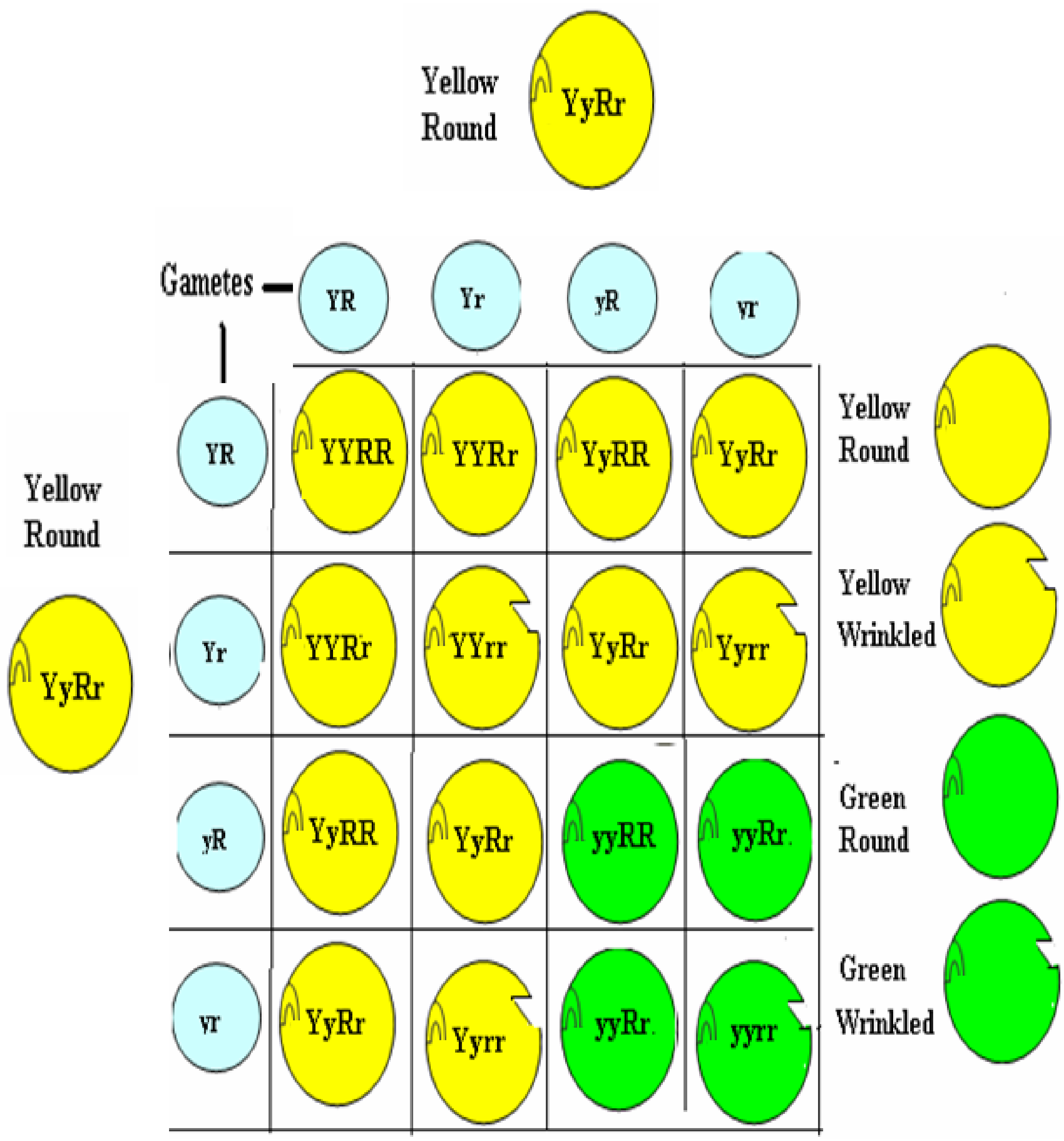



**Figure 45. Genotype and phenotype of the F2 generations.**

Mendel performed similar experiments focusing on several other traits like pod color and pod shape, and flower position and stem length. He noticed the same ratios in each case. From these experiments Mendel formulated what is now known as Mendel's law of independent assortment. This law states that allele pairs separate independently during the formation of gametes. Therefore, traits are transmitted to offspring independently of one another.

**Genotype and Phenotype/Mendel's experiments**

From Mendel's law of segregation, the alleles for a trait separate during gamete formation (through the meiosis) which are then randomly united at fertilization. If a pair of alleles for a trait are the same they are called **homozygous**. If they are different they are called **heterozygous**. In the first example, the F1 plants were all heterozygous for the pod color trait. Their genetic makeup or genotype was (Gg). Their phenotype or expressed physical trait was green pod color.

The F2 generation pea plants showed two different phenotypes (green or yellow) and three different genotypes (**GG, Gg, or gg**). The genotype determines the phenotype that is expressed. The F2 plants that had a genotype of either (GG) or (Gg) were green. The F2 plants that had a genotype of (gg) were yellow. The phenotypic ratio that Mendel observed was 3:1, 3/4 green plants to 1/4 yellow plants. The genotypic ratio however was 1:2:1. The genotypes for the F2 plants were 1/4 homozygous (GG), 2/4 heterozygous (Gg), and 1/4 homozygous (gg).

In Mendel's experiment with seed color and seed shape, we see that the genotype or genetic makeup of the F1 plants is **YyRr**. The phenotypes or expressed physical traits are yellow seed color and round seed shape. Both of these traits are dominant.

The F2 generation pea plants (Table 3) show two different phenotypes for each trait. The seed color is either yellow or green and seed shape is either round or wrinkled.

**Table 3. Genotype and phenotype of the F2 generations.**

| Number of Individuals | F2 Genotypes | F2 Phenotypes |
|---|---|---|
| **1** | **YYRR** | **Homozygous yellow round** |
| **2** | **YYRr,YYRr** | **Heterozygous yellow round** |
| **2** | **YyRR,YyRR** | |
| **4** | **YyRr,YyRr,YyRr,YyRr** | |
| **9** | | **Yellow round** |
| | | |
| **1** | **YYrr** | **Homozygous yellow wrinkled** |
| **2** | **Yyrr, Yyrr** | **Heterozygous yellow wrinkled** |
| **3** | | **yellow wrinkled** |
| | | |
| **1** | **yyRR** | **Homozygous green round** |
| **2** | **yyRR, yyRr** | **Heterozygous green round** |
| **3** | | **Green round** |
| | | |
| **1** | **yyrr** | **Homozygous green wrinkled** |
| | | |
| **16** | **Phenotypic ration is 9:3:3:1** | |

# Pedigree Analysis

All of the conclusions regarding gene action (dominant/recessive; co-dominant) we have seen so far as result of and obtained from the controlled crosses. In situation which be short of performing controlled crosses (eg human genetics studies), another approach “called pedigree analysis) can be used to study the inheritance of genes in humans and in any given population.

In genetics, a pedigree is a diagram of a family tree showing the relationships between individuals together with relevant facts about their medical histories. A pedigree analysis is the interpretation of these data that allows a better understanding of the transmission of genes within the family. Usually, at least one member of the family has a genetic disease, and by examining the pedigree, clues to the mode of inheritance of the disorder and the potential risk to other family members can be obtained. Additionally, Pedigree analysis is useful when progeny data from several generations is limited also when studying species with a long generation time.

The pedigree is started by using a symbol to represent the proband or individual looking for counseling. immediate family members (parents, siblings, spouse, children) are added next, followed by aunts, uncles, cousins, grandparents, and others in the proper orientation. Males are indicated as squares and females as circles. The square or circle is filled in for any affected individuals to reflect their disease status. When two people marry or have children together, a single line is drawn between them. A vertical line descends from this marriage line and then connects to another horizontal line, the sibship line. Short vertical lines descend from the sibship line, one for each of the children of this union.

In the pedigree diagram, all members of one generation are shown adjacent to one another in a row, with preceding generations above and later generations below. In figure 46) there are a series of principal symbols are used to represent different aspects of a pedigree when drawing a pedigree.

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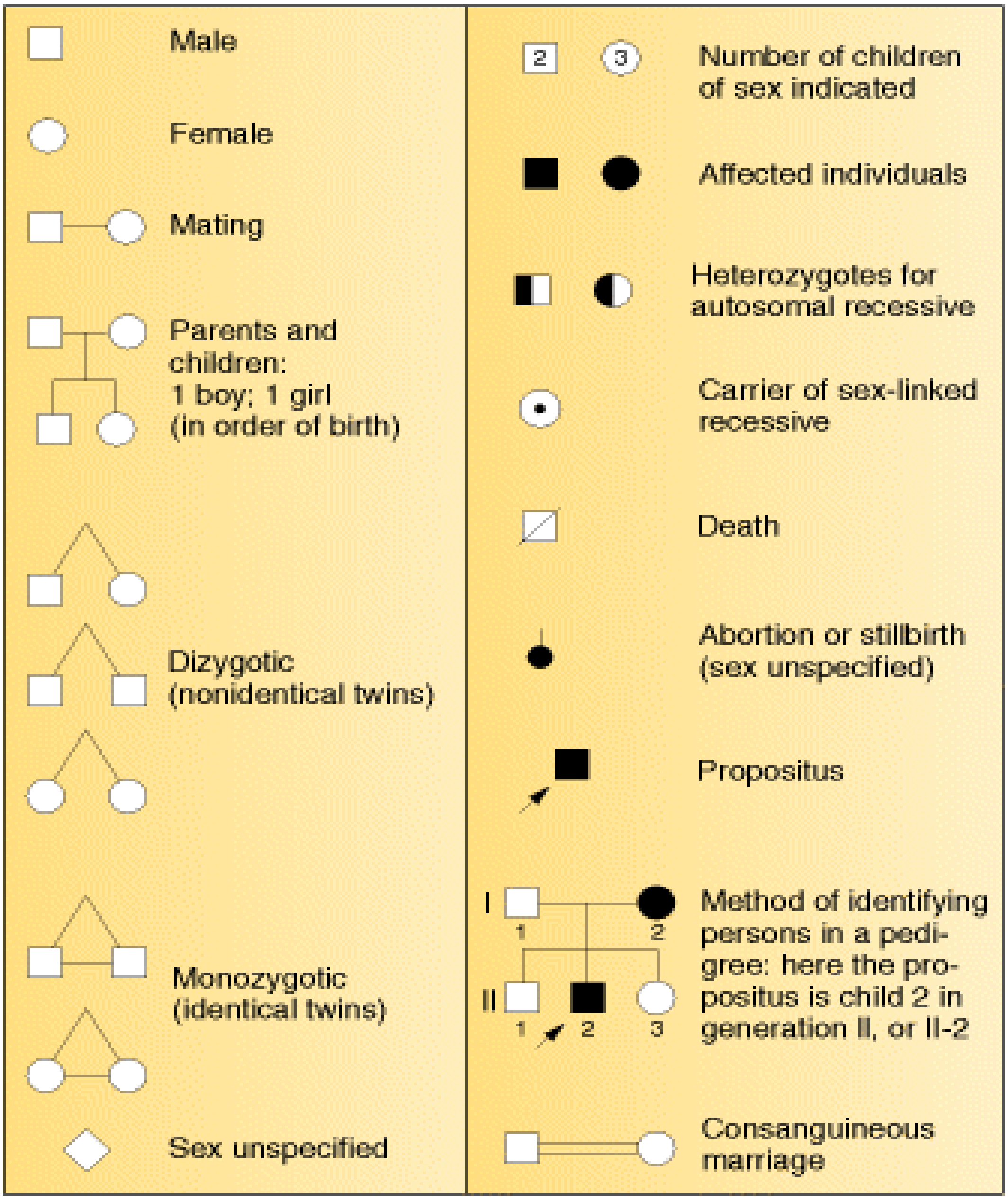



**Figure 46. The** Symbols used in human pedigree analysis. (After W. F. Bodmer and L. L. Cavalli-Sforza, *Genetics, Evolution, and Man.* 1976, (W. H. Freeman and Company.)

## The basic mendelian pedigree patterns

The Mendelian characters may be determined by loci on an autosome or on the X or Y sex chromosomes. Autosomal characters in both sexes and X-linked characters in females can be dominant or recessive. Nobody has two genetically different Y chromosomes (in the rare XYY males, the two Y chromosomes are duplicates). Thus there are five basic pedigree patterns

### A) Autosomal dominant inheritance

An affected person usually has at least one affected parent. This type affects and transmitted either sex by either sex.

### B) Autosomal recessive inheritance

Affected people (either sex ) are usually born to unaffected parents which are usually asymptomatic carriers. After the birth of an affected child, each subsequent child has a 25% chance of being affected.

### C) X-linked recessive inheritance

Affects mainly males and these affected males are usually born to unaffected parents; the mother is normally an asymptomatic carrier and may have affected male relatives. Females may be affected if the father is affected and the mother is a carrier, or occasionally as a result of non-random X-inactivation. There is no male-to-male transmission in the pedigree (but matings of an affected male and carrier female can give the appearance of male to male transmission

### D) X-linked dominant inheritance

Affects either sex, but more females than males, Females are often more mildly and more variably affected than males. The child of an affected female, regardless of its sex, has a 50% chance of being affected. For an affected male, all his daughters but none of his sons are affected.

### E) Y-linked inheritance

Affects only males and these affected males always have an affected father (unless there is a new mutation). All sons of an affected man are affected.

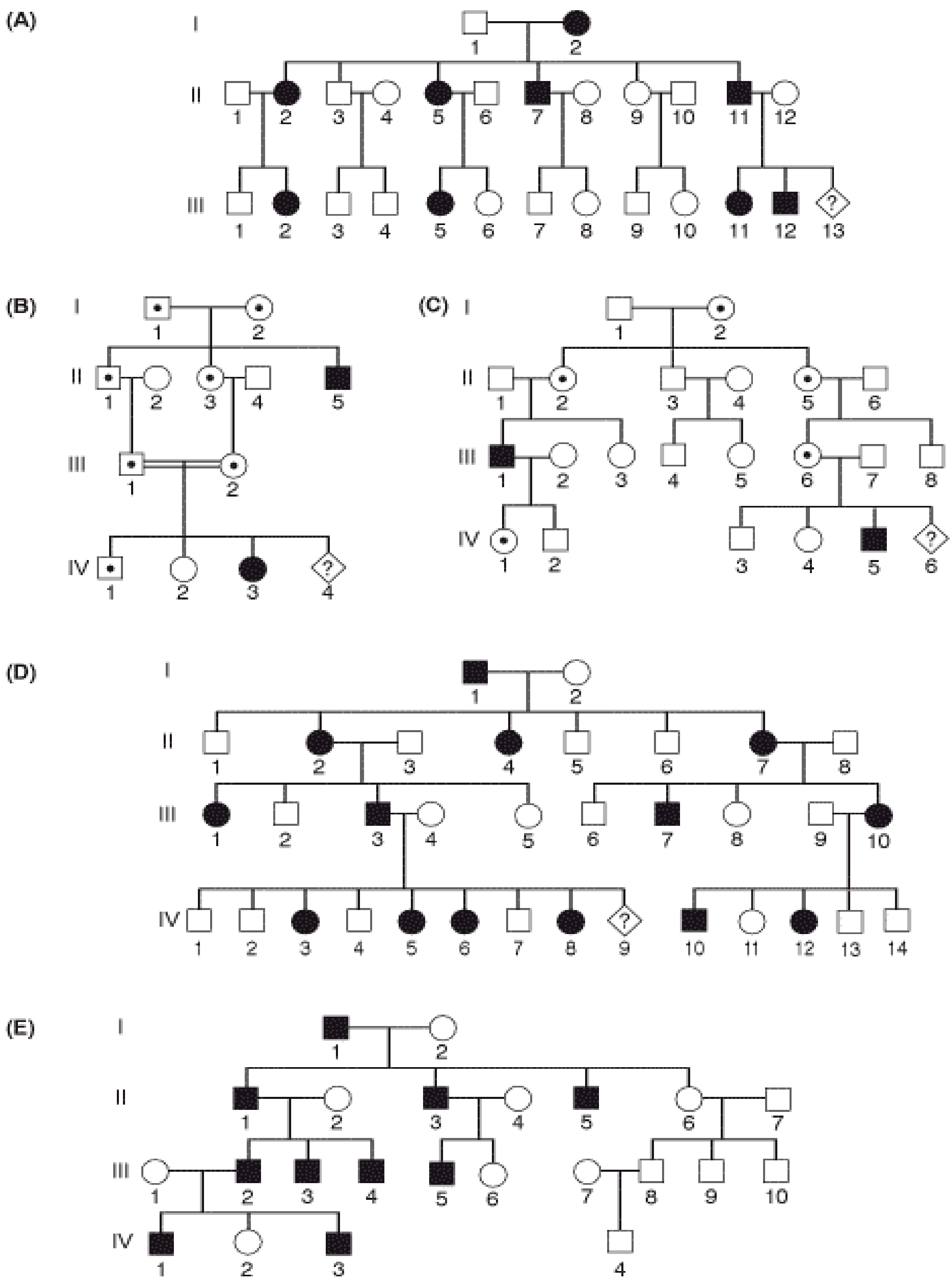



**Figure 47. Basic mendelian pedigree patterns** (**A**) Autosomal dominant; (**B**) autosomal recessive; (**C**) X-linked recessive; (**D**) X-linked dominant; (**E**) Y-linked. The risk for the individuals marked with a query are (A) 1 in 2, (B) 1 in 4, (C) 1 in 2 males or 1 in 4 of all offspring, (D) negligibly low for males, 100% for females. (From Strachan, T., and Read, A.P., 1996).

**Non-Mendelian inheritance patterns**

As the information stored in any gene is extensive, mutations can modify the gene in many ways. Such change has the potential for producing a different alleles which create a unique mode of inheritance therefore an allele act to influence a given phenotype altering it in different ways therefore there are some sort of deviations to the Mendel rules,  such types of inheritance referred as exceptions for simple inheritance. Here there are some types for such inheritances.

**Incomplete dominance:**
A cross between parents with contrasting traits may generate offsprings with an intermediate phenotypes. The inheritance pattern in which a trait is expressed in the phenotype of heterozygous individuals as an apparent blend or an intermediate expression.  For instance, in primroses white flowers (Figure 48)  are homozygous recessive (WW), red ones are homozygous dominant (RR), and pink ones are heterozygous (RW) .

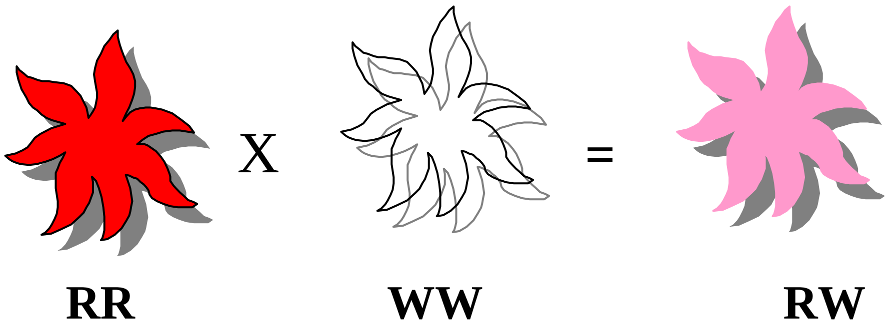



**Figure 48. the inheritance pattern in primroses flowers.**

**Co-dominance:**
For some traits, two alleles can be co-dominant.( the two different alleles for a trait are expressed unblended in the phenotype of heterozygous individuals)  That is to say, both are expressed in heterozygous individuals.  An example of this is people who have an AB blood type for the ABO blood system.  When they are tested, these individuals actually have the characteristics of both type A and type B blood. Their phenotype is not intermediate between the two (see genetic in medicine).

**Multiple-allele series:**

An inheritance pattern in which a gene has more than two alleles.The ABO blood type system is an example of a trait that is controlled by more than just a single pair of alleles.  In other words, it is due to a multiple-allele series.  In this case, there are three alleles (A, B, and O), but each individual only inherits two of them (one from each parent), 'see  genetic in medicine'.

**Polygenic Trait**:

These are traits which are determined by the combined effect of more than one pair of genes.  These are referred to as polygenic, or continuous, traits.  An example of this is human stature.  The combined size of all of the body parts from head to foot determines the height of an individual.  There is an additive effect.  The sizes of all of these body parts are, in turn, determined by numerous genes.  Human skin, hair, and eye color are also polygenic traits because they are influenced by more than one allele at different loci.  The result is the perception of continuous gradation in the expression of these traits.

In the plant kingdom, the example (shown below) of the Kernal color in wheat is determined by two gene pairs,  'polygenes' that produce a range of colors from white to dark red depending on the combinations of alleles. Dark red plants are homozygous  AABB and white plants are homozygous aabb.  When these homozygotes are crossed the F1 offspring are all double heterozygotes  AaBb.  Thus crossing individuals with the phenotype extremes yield offspring that are a 'blend' of the two parents. Notice that there are 5 phenotypic classes you can see that  1/16th of the offspring are dark red and 1/16 are white (Figure 49).

| | AB | Ab | aB | ab |
|---|---|---|---|---|
| AB | AABB | AABb | AaBB | AaBb |
| Ab | AABb | AAbb | AaBb | Aabb |
| aB | AaBB | AaBb | aaBB | aaBb |
| ab | AaBb | Aabb | aaBb | aabb |

.

**Figure 49. The inheritance of the Kernal color in wheat.**

## Problems

**1-**Consider three yellow, round peas, labeled A, B, and C. Each was grown into a plant and crossed to a plant grown from a green, wrinkled pea. Exactly 100 peas issuing from each cross were sorted into phenotypic classes as follows:

| | |
|---|---|
| A: | 51 yellow, round |
| | 49 green, round |
| B: | 100 yellow, round |
| C: | 24 yellow, round |
| | 26 yellow, wrinkled |
| | 25 green, round |
| | 25 green, wrinkled |

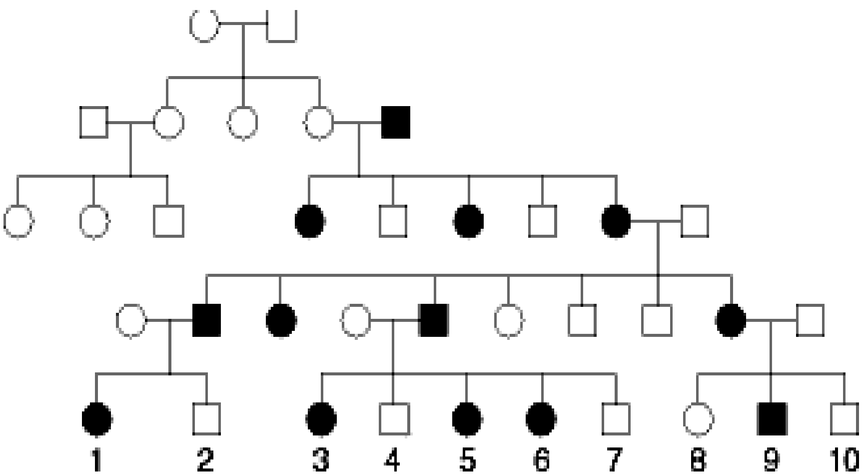
What were the genotypes of A, B, and C? (Use your own gene symbols).

**2-**A couple intends to have children but consults a genetic counselor because the man has a sister with PKU (Phenylketonuria (PKU) is a human hereditary disease, caused by a recessive allele with simple Mendelian inheritance) and the woman has a brother with PKU. There are no other known cases in their families. They ask the genetic counselor to determine the probability that their first child will have PKU. What is this probability?.

**3**-A snapdragon plant that produces red flowers is crossed with a snapdragon plant that has white flowers. Their offspring all had pink flowers. Two of the pink flowers were crossed to produce the $F_2$ (second) generation. 15 of the $F_2$ offspring had pink flowers, 8 had red flowers and 7 had white flowers. Illustrate this inheritance with Punnett squares and identify the inheritance pattern of this genetic cross.

**4**-In a given population, only the "A" and "B" alleles are present in the ABO system; there are no individuals with type "O" blood or with O alleles in this particular population. If 200 people have type A blood, 75 have type AB blood, and 25 have type B blood, what are the alleleic frequencies of this population (i.e., what are p and q)?

**5-** A rare human disease afflicted a family as shown in the accompanying pedigree.




**A.** Deduce the most likely mode of inheritance.

**B.** What would be the outcomes of the cousin marriages 1×9, 1×4, 2×3, and 2×8?

# Genes within Population/Hardy-Weinberg Law

The goal of population genetics is to understand the genetic composition of a population and type of forces that influence that composition. In any species, the genetic variation between populations arises from the existence of various alleles at different gene loci. Therefore a fundamental measurement in population genetics is the frequency at which the alleles are found at any gene locus of interest. In a given population, the frequency of a given allele can be changed by recurrent mutation, selection, or migration or by random sampling effects. However, an idealized population where no forces of change are acting, a randomly interbreeding population would show constant genotypic frequencies for a given locus. To relating the basic individual-level processes to population genetic composition, several aspects would play a role:

1-The effect of the *mating pattern* on different genotypes in the population, where individuals may mate randomly or preferentially with close relatives (*inbreeding*) or preferentially on the basis of their genotypic or phenotypic similarity (*assortative mating*).

**2-**The population composition can be changed due to immigration of *individuals* from other populations.

**3-**The rate of introduction of genetic variation into the population by *mutation* and *recombination.*

**4-**The influence of the differential rate of reproduction by different genotypes, also the differential chance of survival offspring (genetically different).

**5.**Consequences of *random fluctuations* in the actual reproductive rates of different genotypes because individual has a few offspring with limited population size.



**Hardy-Weinberg Principle:** Based on Mendel's principles of inheritance, G.H. Hardy and Wilhelm Weinberg (1908), independently developed the concept that is known nowadays as the 'Hardy-Weinberg Equilibrium' or 'Hardy-Weinberg Principle', which states: "In a large, randomly breeding (diploid) population, allelic frequencies will remain the same from generation to generation; assuming no unbalanced mutation, gene migration, selection or genetic drift." When a population meets all of the Hardy-Weinberg conditions, thus said to be in Hardy-Weinberg equilibrium. This equilibrium can be mathematically expressed based on simple binomial (for two alleles) or multinomial (multiple allele) distribution of the gene frequencies. For the equilibrium to remain, the following five conditions must be met:

1) No mutations must occur so that new alleles do not enter the population; 2) no gene flow can occur (i.e. no migration of individuals into, or out of, the population); 3) random mating must occur (i.e. individuals must breed by chance); 4) the population must be large enough: i.e no genetic drift (random chance) can cause the allele frequencies to change; and 5) no selection can occur so that certain alleles are not selected for, or against.

The Hardy-Weinberg formulas allow us to detect some allele frequencies that change from generation to generation, thus allowing a simplified method of determining that evolution is occurring. The Hardy-Weinberg formulas are:

$$\mathbf{p^2 + 2pq + q^2 = 1} \textbf{\textit{ and }} \mathbf{p + q = 1}$$

Where:

p = frequency of the dominant allele in the population

q = frequency of the recessive allele in the population

$p^2$ = percentage of homozygous dominant individuals
$q^2$ = percentage of homozygous recessive individuals
2pq = percentage of heterozygous individuals



**The Hardy-Weinberg equilibrium**

If the frequency of allele *A* is *p* in both the sperm and the eggs (figure 50) and the frequency of allele *a* is $q = 1 - p$, then the consequences of random unions of sperm and eggs are shown in the adjoining figure. The probability that both the sperm and the egg will carry *A* is $p \times p = p^2$, so this will be the frequency of *A*/*A* homozygotes in the next generation. In like manner, the chance of heterozygotes *A*/*a* will be $(p \times q) + (q \times pq) = 2pq$, and the chance of homozygotes *a*/*a* will be $q \times q = q^2$ The three genotypes, after a generation of random mating, will be in the frequencies $p^2{:}2pq{:}q^2$. As the figure 48 shows, the allelic frequency of *A* has not changed and is still *p*. Therefore, in the second generation, the frequencies of the three genotypes will again be $p^2{:}2pq{:}q^2$, and so on, forever.

## Genetic variation and Sources of variation.

Mendel's concept of the gene was based on the analysis of hereditary variants where organisms show identifiable and persistent differences for specific characters. Mendel was the first to establish rules for the genetic analysis of such distinct variants. It is logic to understand that most genetic analysis begins with variants of some type. What causes the variation *between* species, how these can be determined *within* a species? How genes participate, their role in such operations?. As you may know that species is a unique due to the unique set of genes that it posses. Although there is considerable overlap in the genomes of different species, the genome of each species is unique. One of the goals of genetics is to understand accurately how genes outline the characteristics of a species. This becomes more attainable through advances in understanding the molecular nature of genes and how they work.

What is the variations? Variation within a species is a common daily observation. Such observation can be used to identify individuals, and to distinguish their pets from those of others. What are the causes of variation? – two possible causes, variation of genes and variation of the environment. A measurement for the relative components of variation is of beneficial and vital. Importantly, is it possible for there to be variation of the gene set which is characteristic of a species? but the question is, if all members of a species have the same gene set, how the genetic variation can be there? Basically, genes come in different forms called **alleles.** For instance, there may be a single gene for flower color, but several alleles, each producing a flower of a different color. In a population there can be from one to many different alleles of one gene, but since organisms carry only one or two chromosome sets per cell, any individual can carry only one or two alleles of a gene.

The alleles of a given gene will always be found at the same chromosomal position. Therefore alleles of a gene represent different levels of activity, new activity, or no activity of that gene. In addition, an allele is produced by mutation, involving changes of one or more nucleotide pairs in its DNA. This allelic variation is the basis for hereditary variation.

The analysis of variants in populations is very important, there are two types of variations: a discontinuous variation and continuous one (Figure 51), to both the allelic variation contribute and play a role.

In **discontinuous variation** a character is found in a population in two or more distinct and separate forms. The expressed form of a character is called the **phenotype.** These phenotypes are often found to be encoded by the alleles of one gene. A good example is albinism in humans, which concerns phenotypes of the character of skin pigmentation. In most people, the cells of the skin can make a dark brown or black pigment called melanin, the substance that gives human skin its color ranging from tan color (Europeans ancestry) to brown or black (tropical and subtropical ancestry). Although always rare, albinos are found in all races; they have a totally pigmentless skin and hair. The difference between pigmented and unpigmented is caused by two alleles of a gene that involves in melanin synthesis. The gene has two alleles, the allele coding for ability making melanin is "***A***" while the allele coding for the inability to make melanin (resulting in albinism) is designated "***a***". The allelic constitution of an organism is its genotype (internal make up), that is the hereditary expressing the phenotype. Because humans have two sets of chromosomes in each cell, genotypes can be either *A*/*A*, *A*/*a*, or *a*/*a*). The phenotype of *A*/*A* is pigmented, *a*/*a* is albino, and *A*/*a* is pigmented. The *ability* to make pigment is expressed over *inability* (*A* is said to be dominant).

Generally, the phenotypes are determined by different alleles of a single gene, while the specific set of alleles carried by an individual is called the **genotype,** which is the hereditary basis of the phenotype. To have any influence on phenotype, the DNA of an allele of a single gene must act in a cell jointly with other genes and with the environment.

The range of phenotypic influence of a genotype under different genetic and environmental backgrounds is called 'norm of reaction'. In most cases of discontinuous variation those based on alleles of a single gene, norms of reaction of the different alleles are normally nonoverlapping which results in a predictable one-to-one relationship between genotype and phenotype in most environments and genetic backgrounds. This is why the discontinuous variation has been successfully used by geneticists to identify the underlying alleles and their cellular functions.

In a natural population, the existence of two or more *common* alternative phenotypes is called polymorphism (Greek: "many forms"); an example is shown in Figure 52 a. The various phenotypes are sometimes called **morphs.** Often such morphs are determined by the alleles of a single gene. Why do populations show genetic polymorphism? Special types of natural selection can explain a few cases, but in other cases the morphs seem to be selectively neutral.

In rare, exceptional discontinuous variant phenotypes are ' *mutants'*, whereas the more common "normal" companion phenotype is called the wild type (Figure 52b). Again, in many cases the wild type and mutant phenotypes are determined by alleles of one gene. Mutants can occur spontaneously in nature, or can be obtained after treatment of laboratory population with mutagenic chemicals or radiation.

In **Continuous variation**, a character shows an unbroken range of phenotypes in the population. Metric characters such as height, weight, and color intensity provide good examples of continuous variation. Intermediate phenotypes are generally more common than extreme phenotypes. When phenotypic frequencies are plotted as a graph, a bell-shaped phenotypic distribution is observed. (see Figure 51). Some continuous variation is environmental and has no genetic basis at all, others show genetic component caused by allelic variation of a small or a large number of genes while in most cases there is both genetic and environmental variation. In continuous distributions the norms of reactions of individual genotypes are complex and there is no one-to-one correspondence of genotype and phenotype (Figure 51). For this reason little is known about the types of genes underlying continuous variation. However, recently new and more powerful molecular techniques have become available for identifying and characterizing them.

Continuous variation is more common than discontinuous variation in everyday life. Many examples of continuous variation in plant or animal populations can be observed (fruit size, crop yield, etc.), and it is important in plant and animal breeding. Many of the characters that are under selection in breeding programs, such as seed weight or milk production, show continuous variation in populations. Animals or plants from one extreme end of the range are chosen and selectively bred. Before undertaking such selection, it is necessary to perform analyses to estimate the sizes of the genetic and environmental components of the variation.

Some *discontinuous* variant phenotypes have a **complex inheritance** that resembles that of continuous variation. For examples, in Human populations provide, heart disease, diabetes, cleft lip and palate, and pyloric stenosis (blocked exit from the stomach). The risk of a child's being born with these conditions is higher in families in which relatives are affected; hence, there seems to be a genetic component, but the inheritance does not follow the simple allelic pattern shown by Mendel. It is believed that these phenotypes are based on multiple gene and environmental interactions, with some type of physiological threshold beyond which the variant phenotype is expressed.

## Molecular basis of allelic variation

Looking back to the albino example in humans (page 76), where the albino phenotype is due to lake in melanin production. The dark pigment melanin is the end product of a biochemical synthetic pathway through which several steps are incorporated. Each step is a conversion of one molecule into another, leading to the progressive formation of melanin. Each step is catalyzed by a separate enzyme protein encoded by a specific gene. Most cases of albinism result from changes in one of these enzymes – tyrosinase. The enzyme tyrosinase catalyzes the last step of the pathway, the conversion of tyrosine into melanin [---- tyrosine (not a pigment)/ tyrosinase ---- melanin (pigment)]. To perform this task, tyrosinase binds to its substrate, a molecule of tyrosine, and facilitates the molecular changes necessary to produce the pigment melanin. There is a specific "lock-and-key" fit between tyrosine and the active site of the enzyme. The active site is a pocket formed by several crucial amino acids in the polypeptide. If the DNA of the tyrosinase-encoding gene changes in such a way that one of these crucial amino acids is replaced by another amino acid or lost, then there are several possible consequences. First, the enzyme might still be able to perform its functions but in a less efficient manner. Such a change may have only a small effect at the phenotypic level, so small as to be difficult to observe, but it might lead to a reduction in the amount of melanin formed and, consequently, a lighter skin coloration. Note that the protein is still present more or less intact, but its ability to convert tyrosine into melanin has been compromised. Second, the enzyme might be incapable of any function, in which case the mutational event in the DNA of the gene would have produced an albinism allele, referred to earlier as an a allele. Hence a person of genotype a/a is an albino. The genotype A/a is interesting. It results in normal pigmentation because transcription of one copy of the wild-type allele (A) can provide enough tyrosinase for synthesis of normal amounts of melanin. Alleles are termed haplosufficient if roughly normal function is obtained when there is only a single copy of the normal gene. Alleles commonly appear to be haplosufficient, in part because small reductions in function are not vital to the organism. Alleles that fail to code for a functional protein are called null (“nothing”) alleles and are

The mutational site in the DNA can be of a number of types. The simplest and most common type is nucleotide-pair substitution (see page 88), which can lead to amino acid substitution or to premature stop codons. Small deletions and duplication also are common. Even a single base deletion or insertion produces widespread damage at the protein level; because mRNA is read from one end “in frame” in groups of three, a loss or gain of one nucleotide pair shifts the reading frame, and all the amino acids translationally downstream will be incorrect. Such mutations are called *frameshift mutations.*



At the protein level, mutation changes the amino acid composition of the protein. The most important outcomes are change in shape and size. Such change in shape or size can result in no biological function (which would be the basis of a null allele), or reduced function. More rarely, mutation can lead to new function of the protein product.

*It is important to note that, new alleles formed by mutation can result in no function, less function, or new function at the protein level.*