# 3<sup>RD</sup> SEM B.Sc. ZOOLOGY COMPLEMENTARY COURSE CALICUT UNIVERSITY

# THIRD SEMESTER B.SC. ZOOLOGY COMPLEMENTARY COURSE THEORY COURSE- III

PHYSIOLOGY AND ETHOLOGY

Charle Or CIOBAL SHIP

PREPARED BY,

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#### **SYLLABUS**

#### THIRD SEMESTER B.Sc. ZOOLOGY COMPLEMENTARY COURSE

Theory Course- III

#### PHYSIOLOGY AND ETHOLOGY

Code: ZOL3C03T

[54 hrs] [3 hours/week] [2 credits]

#### **COURSE OUTCOMES [COs]**

#### **COs Course Outcome Statements**

- CO1 Describe the structure of plasma membrane and the various trans-membrane transport mechanisms (3 hrs)
- CO2 Enumerate the constituents of normal diet and the mechanism of digestion and absorption of carbohydrates, proteins and lipids and the regulation of gastrointestinal function (4 hrs)
- CO3 Explain the mechanism of transport of respiratory gases, control of respiratory problems and artificial ventilation (6 hrs)
- CO4 Explain the structure and working of human heart and mechanism of regulation of
- heart beat; constituents of human blood and blood transfusion and cardiovascular problems (7 hrs)
- CO5 Illustrate the structure of human kidney, the mechanism of urine formation, hormonal control of kidney function and kidney disorders; osmoregulation and urea cycle (6 hrs)
- CO6 Enumerate the structure of myofibrils and myofilaments; muscle contractile and regulatory proteins and mechanism of muscle contraction (7 hrs)
- CO7 Explain different types of nerve cells and glial cells, maintenance of resting membrane potential, generation and propagation of action potential and synaptic transmission (7 hrs)
- CO8 Describe innate behavior, learned behavior, patterns of behavior and factors that affect behavior (8 hrs)
- CO9 Enumerate biological rhythms, communication in animals and social organization in mammals (6 hrs)

#### **SECTION A. PHYSIOLOGY (40 hrs)**

#### **MODULE 1. Trans-membrane transport mechanisms (3 hrs)**

Structure of Plasma membrane. Fluid mosaic model. Trans-membrane transport - passive & active mechanisms, vesicular transport

#### **MODULE 2. Nutrition (4 hrs)**

Constituents of normal diet. Digestion of carbohydrates, proteins and lipids.

Absorption of nutrients (brief account). Brief account on the neural and hormonal control of gastrointestinal function. BMR and obesity

#### **MODULE 3. Respiration (6 hrs)**

Gas exchange and transport. Respiratory pigment – haemoglobin – properties

Control of respiration – neural & chemical (brief account). Respiratory problems -hypoxia, asphyxia, CO poisoning. Respiratory problem of high altitudes.

Physiological adaptive mechanisms of diving mammals. Artificial ventilation; heart lung machine.

#### **MODULE 4. Body fluids and circulation (7 hrs)**

Constituents of human blood. Agglutination, coagulation of blood and haemostasis

Haemolysis. Blood transfusion (short notes). Brief account on the structure and working of human heart.

Pacemaker and conducting system of heart.

Cardiac cycle and regulation of heart beat. Blood pressure and pulse. Cardiovascular problems (brief account) - arteriosclerosis and atherosclerosis, myocardial infarction,

hypertension and thrombosis.

#### **MODULE 5. Osmoregulation and Excretion (6 hrs)**

Osmoconformers and osmoregulators. Water retention and conservation in desert

animals. Urea cycle. Ammonotelism, ureotelism and uricotelism. Hormonal control of kidney function.

Kidney disorders, renal hypertension, nephritis and renal failure.

Dialysis and kidney transplantation (short notes)

#### MODULE 6. Muscle Physiology (7 hrs)

EM structure of myofibrils and myofilament. Muscle - contractile proteins and major regulatory proteins.

Chemistry and mechanism of muscle contraction.

Energy for muscle contraction. Muscle twitch and muscle tetanus, isometric and isotonic contraction.

All-or-none law and summation of stimuli. Muscle fatigue and rigor mortis.

#### **MODULE 7. Nerve physiology (7 hrs)**

Mention different types of nerve cells and glial cells. Maintenance of resting membrane potential; generation and propagation of action potential. Threshold stimulus, all or none response. Synapse, types of synapses, synaptic transmission and neurotransmitters

#### MODULE: 1

#### TRANSMEMBRANE TRANSPORT

#### **PLASMA MEMBRANE**

- Limiting membrane of all living cells
- Also known as plasmalemma
- Elastic, porous, and selectively permeable living membrane, with lipoprotein composition, semi fluid consistency and laminar or micellar organization
- Serves as adynamic barrier or an interphase of materials between the interior and exterior of the cell
- Regulates exchange of materials
- Plasma membrane is externally invested with a cell wall in cyanobacteria, bacteria, fungi and plants
- In animal cell, cell wall is absent and in most cases, there is a cell coat (glycocalyx)
- Glycocalyx is a combination of glycoprotein + polysaccharides + glycolipids

#### CHEMICAL COMPOSITION

Highly organised, polyphasic and biologically active

C4	
Lipids (25-80%) – makes semi-permeable	
➤ Proteins (20-70%) — membrane transport and communication barrier	
Carbohydrates (1-10%) – cell recognition	_
➤ Water (20%)	

- Water forms the peripheral ageous layer
- Lipids and proteins forms non-aqeous layer
- Carbohydrates are restricted to outer surface
- Carbohydrates + lipids = glycolipids
- Carbohydrates + proteins = glycoproteins
  - 1) MEMBRANE LIPIDS

- Structural framework of biomembrane
- Forms permeability barrier
- Includes phospholipids(numerous), glycolipids, plasmalogens, sterols

#### 2) MEMBRANE PROTEINS

- Structural and functional molecule
- Serves the role as enzymes, carrier, receptor, antigen etc
- Amino acid residues may be polar or non-polar or amphipathic
- 2 types : globular and alpha helix proteins
- Nature of the protein determines the functional diversity among the membranes

#### 3) MEMBRANE CARBOHYDRATES

- Serve as glycocalyx or cellcoat
- 2 categories : complex polysaccharides ( seen in bacteria) and oligosaccharides (seen in other cells)
- Oligosaccharides form glycolipids and glycoproteins while polysaccharides remain free
- Carbohydrates helps in transmembrane message transmission, cell recognition, cell adhesion, cell interaction

#### **PHYSICAL PROPERTIES**

- Phase transition between sol and gel (by re-arrangement of fatty acids chain)
- When temperature is low, fattyacid chain are tightly packed and their mobility becomes restricted –
   GEL phase or crystalline phase

PLIEGE OF GLOBALS

 When temperature increases, interspace between phospholipids molecules expands and mobility increases – SOL phase

#### **MOLECULAR ORGANISATION**

- Lamellar or micellar organization
- <u>Lamellar organization</u>: membrane is formed of molecular laminations; sheet like molecular layers of lipids and proteins
- <u>Micellarorganization</u>: membrane is formed of globular sub-units or micelles of lipoprotein where lipids forms the central core and proteins form coat cover.
- Models,
  - Laminar or lamellar model: lipid bilayer model and tri laminar sandwitch model
  - ➤ Micellar models: Benson's model, Lenard and Singer model, mosaic membrane model and fluid mosaic model

#### **FLUID MOSAIC MODEL**

• Proposed by Singer and Nicolsonin 1972

According to FLUID MOSAIC MODEL, plasma membrane is a

" two dimensional quasifluid solution of organized lipids and globular proteins"

OR

Plasma membrane is a bimolecular quasifluid lipid structure in which proteins freely float, move about and interact.

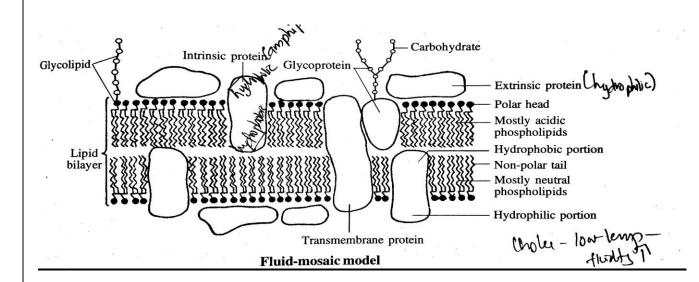
- Phospholipids have a continous arrangement
- Phospholipid layer makes the membrane semifluid
- Phospholipids are arranged side by side and back to back in two parallel rows,

forming a contionous lipid bilayer or bimolecular lipid layer

- Lipid bilayer forms the structural framework
- Polar heads of phospholipids are directed outward to the aqeous phase and nonpolar fatty acids tails directed inward to form non-aqueous core
- Lipid monolayers are linked with each other by their fattyacids tails through hydrophobic interactions
- Membrane phospholids are free to move laterally but not vertically
- Fluidity is directly related to the concentration of unsaturated fatty acids, the length of fatty acids chains and degree of molecular movement and stability of hydrophobic interaction, temperature, cholesterol

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- Membrane proteins are mostly globular without a symmetrical arrangement
- Randomly dispersed and discontinuous
- 3 types,
  - **Extrinsic proteins : completely outside the lipid bilayer and are hydrophilic**
  - > Intrinsic / integral proteins : penetrate the lipid bilayer and are usually amphipathic
  - > Transmembrane proteins: integral proteins which span the entire lipid bilayer
- Carbohydrates are entirely outside the lipid bilayer
- Forms glycolipids and glycoproteins



#### **Major features:**

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- 1. Plasma membrane is a dynamic structure, existing in a 'liquid crystalline' or quasifluid state with mosaic molecular organization and free molecular movements
- 2. Fluidity is directly proportional to the chain length and unsaturation of its fatty acids
- 3. Major components are held together through non-covalent interactions
- 4. Cohesive forces between lipids and also between lipids and proteins are weak hydrophobic interactions
- 5. Membrane lipids and proteins undergo free lateral diffusion
- 6. Vertical diffusion of proteins and lipids is very much restricted
- 7. Membrane phospholipids are arranged in a bilayer that serves as the structural framework, as a permeability barrier and also as a solvent for integral membrane proteins
- 8. Membrane lipids interact with proteins for the stabilization and proper

#### functioning of the membrane.

#### **MEMBRANE PERMEABILITY**

- Selectively and variably permeable
- Only selected types of molecules can cross themembrane at different rates
- Differential and variable permeability is due to the presence of specific molecular channels , gates , and pumps
- Highly impermeable to charged and hydrophilic molecules
- Permeable to lipophilic and hydrophobic molecules
- Smaller molecules penetrate faster than the larger ones

#### **FUNCTIONS OF PLASMA MEMBRANE**

- 1. Centre of cellular respiration and oxidative phosphorylation in prokaryotes
- 2. Serves as a dynamic selective gateway or permeability barrier
- **3.** Regulates inflow and outflow of materials
- **4.** Controls form and functioning of the cell
- 5. Maintains constancy of the intra cellular environment and keeps up a constant physiological condition inside the cell
- **6.** Selective transport of useful substances
- **7.** Elimination of wastes
- **8.** Expulsion of secretion
- 9. Transmission of impulses in excitable cells ( nerve and muscle cells )
- **10.** Recognition of foreign cells
- **11.** Recognition and binding of some hormones
- **12.** Chemoreception in bacteria
- 13. Signal transduction

#### TRANSMEMBRANE TRANSPORT

- Need based, directional and regulated
- Lipid soluble substances can easily diffuse
- Lipid insoluble ions and molecules: through special mechanisms
- Large molecules: by endocytosis
- Substances transported: water, sugar, amino acids, fatty acids, steroids, inorganic ions etc
- Impermeable to polar molecules

#### **Significance:**

- Regulate cell volume
- Maintains the intra cellular ionic concentration
- Determines functional properties of cells
- Enables intake of essential nutrients, fuel molecules
- Elimination of metabolic waste sand toxic substances
- Generates ionic gradients for the excitation of cells
- Regulates proper functioning of cell organelles
- Maintains normal intra cellular pH
- Brings about the transmembrane transport of lipophilic molecules
- Promotes inter cellular molecular traffic LEGE OF GLOBALS

#### **Mechanisms**

- > Passive transport
- > Active transport
- > Gradient-mediated transport
- > Vesicular transport

Different mechanisms of membrane transport			
(i) Passive transport			
(a) Osmosis (b) Simple diffusion	Free, energy-independent downhill flow of molecules through the lipid bilayer in a concentration or electrochemical gradient.		
(c) Facilitated diffusion	Energy-independent, channel-mediated or carrier- mediated transport of molecules in an electro- chemical gradient across the lipid bilayer.		
(ü) Active transport	Energy-dependent, carrier-mediated transport of molecules across the lipid bilayer, always coupled with ATP hydrolysis.		
(iii) Gradient-mediated potential and the concentration gradient to crease the driving force for the transport of i across the membrane.			
(iv) Vesicular transport	Bulk transport of large molecules or particles by endocytosis and exocytosis.		

#### 1. Passive transport (diffusion transport)

- Spontaneous, energy dependent "down hill " flow of substances in a concentration gradient or electrochemical gradient
- Occurs under the influence of osmotic forces
- 3 driving forces,
- Concentration gradient
  Potential gradient
  Force of solvent drag
- 3 process,



#### > Osmosis

- Net movement of water and other solvent molecules from a less concentrated to a more concentrated solution through a semi permeable membrane
- Hypotonic Hypertonic solution
- Driving force :gradient in the osmotic potential ( osmotic pressure) and tonicity (solute concentration)
- Endosmosis: inflow of water into cell
- Exosmosis : outflow of water
- Example: absorption of soil water by root hair cells, renal re-absorption of water

#### Passive diffusion

- Spontaneous flow of low-molecular weight metabolites in a concentration gradient, without energy utilization or carier molecule
- Rate is directly proportional to the concentration gradient and also to lipid solubility
- Inversely proportional to size and charge
- Slow much limited, less selective and non-stereospecific
- Example : flow of water and water-soluble molecules (O<sub>2</sub>)
- Charged particles diffuse through ion -channels (gated channels)
- Methods ,
  - i. Through lipid layer(small sized and non-polar)
  - ii. Through channel formed by single protein
  - iii. Through channel formed by clustering proteins
  - iv. Through statistical pores

#### Facilitated or carrier-mediated diffusion

- Transmembrane transport of metabolites in a concentration gradient with the help of a mobile –
   carrier called *permease or translocase* without energy utilization
- Example :transport of steroid hormones , hexose sugars
- Permease are very specific and selective
- Stereospecific
- Shows saturation kinetics

- faster
- rate-limited

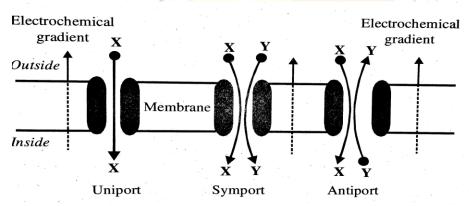
#### 2. Active transport

- Energy -dependent and carrier- mediated "up hill" flow of metabolites aginst concentration or electrochemical gradients and osmotic forces
- Source of energy: ATP hydrolysis and ions which exhibit an electro –chemical potential
- Stereospecific
- Operating against concentration, potential, osmotic forces utilizing energy
- Types,

UNIPORT: uni directional transport of only one molecules at a time

SYMPORT : simultaneous unidirectional transport of different kinds of molecules

ANTIPORT : simultaneous transport of different kinds of molecules in opposite directions

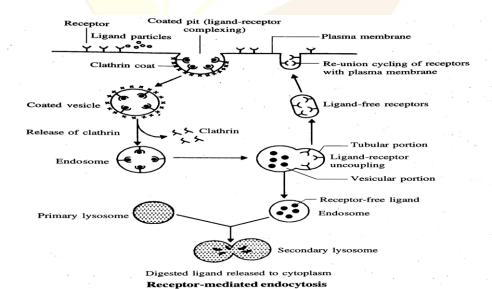


Different types of active transport

- Stages,
  - i. Recognition of the metabolite by the permease
  - ii. Conformational changes and inward movement of the permease metabolite complex
  - iii. Dissociation of the complex and release of metabolite into the cell interior



- Mechanisms,
  - i. Rotating or revolving carrier scheme
  - ii. Protein aggregate re-arrangement scheme
  - 3. Vesicular transport (bulk transport or cytosis)
- Bulk transport of large molecules and particles
- Material to be transported gets into a vesicle of the plasma membrane (transporting vehicle)
- 3 types,
  - > EXOCYTOSIS
  - > ENDOCYTOSIS
  - ➤ RECEPTOR-MEDIATED ENDOCYTOSIS



#### **EXOCYTOSIS**

Expulsion of cellular wastes and the export of some secretion products in large bulk from the cell to the extra cellular medium

example: secretion of hormones by endocrine glands, excretion of waste by contractile vacuoles

#### **ENDOCYTOSIS**

Taking in of large amounts of useful substances into the cell from th extra cellular medium.3types: phagocytosis, pinocytosis and micropinocytosis

example: leucocytes

#### RECEPTOR-MEDIATED ENDOCYTOSIS

Endocytosis which involves the mediation of certain intrinsic trans, embrane receptors (glycoproteins) seen in shallow depressions called coated pits

OF GLOBALS

example: transport of cholesterol into animal cells

- Endocytosis is of 3 types,
  - ➤ Phagocytosis : bulk intake of large sized solid substances
  - Pinocytosis: (cell drinking) is the intake of liquid and fluid substances and very minute particles
  - Micropinocytosis: transcellular transport of fluid substances, bypassing intracellular components
- Steps in endocytosis,
  - > Surface recognition
  - ➤ Membrane invagination , with the help of clathrin molecules and ATP
  - Vesicle formation
  - > Internalization of vesicle to form endosomes
  - Fusion of endosome with primary lysosome
  - Digestion of contents

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#### **MODULE: 2**

#### **NUTRITION**

# CONSTITUENTS OF A BALANCED DIET What is a balanced diet?

- Nutrients are the substances that provides nourishment essential for the maintenance of life and for growth.
- Nutrients can be *macronutrients and micronutrients*.
- A balanced diet should offer around 60-70% of total calories from carbohydrates, 10-12% from proteins and 20-25% of total calories from fat.
- A healthy balanced diet consists of 7 components.
- Although it's important to eat the correct types of foods, it is also essential to eat the correct portions and amounts too.
- By adopting a balanced diet not only will this boot your immune system and health, but it will also help with weight loss and management.
- *Calories* are a measure of energy that foods supply.
- The number of calories you need will depend on your sex, age, and activity level.

#### MACRONUTRIENTS VERSUS MICRONUTRIENTS

Macronutrients are the nutrients required in large amounts.	Micronutrients are the nutrients required in small amounts.
Protein, fat, fiber, water and carbohydrate are examples of macronutrients.	Phytochemicals and antioxidants, Vitamins and certain minerals are examples of micronutrients.
Cereals, legumes, meat, fish, yams, potatoes, nuts, oil seeds are rich in macronutrients.	Mainly vegetables, fruits, eggs, green leafy vegetables, fermented foods etc. are rich in micronutrients.
Macronutrients cont ribute to the bulk energy needed for the metabolic system. Pediaa.com	Micronutrients help various functions of the body, growth, and disease prevention.

#### i. CARBOHYDRATES

Carbohydrates provide fuel to all cells, organs and tissues in the form of glucose. Some of its sources include foods such as whole grains, fruits, vegetables and legumes. You may also get good amount of carbohydrates in foods like candies, pastries, cook2ies and flavoured beverages. Carbohydrate is one of the important components of a balanced diet. On an average, an adult should get about 45 percent to 65 percent of their calories from carbohydrates.



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#### ii. <u>VITAMINS</u>

Vitamins help with chemical reactions in the body and that is why the body needs 13 different vitamins to grow and develop. Each vitamin helps with certain functions. For example, vitamin A improves vision, vitamin C maintains healthy skin and vitamin D keeps the bones and teeth strong. You can get vitamins from fresh fruits and vegetables or from vitamin supplements.



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#### iii. FIBER

Fiber, often referred to as roughage, is a type of carbohydrate found in plant foods that the body is not able to digest or absorb. Eating a balanced diet that is high in fiber can keep your body systems regular and contribute to a lowered risk of chronic disease.(30g per day)



#### iv. <u>FAT</u>

Fat is an important part of a balanced diet. It contributes to around 25 percent to 35 percent of the daily caloric intake, however, the content of saturated fats should be kept to no more than 10 percent of the total fat intake. The healthiest fats come from mono saturated and polyunsaturated sources such as nuts, olive oil and fish.



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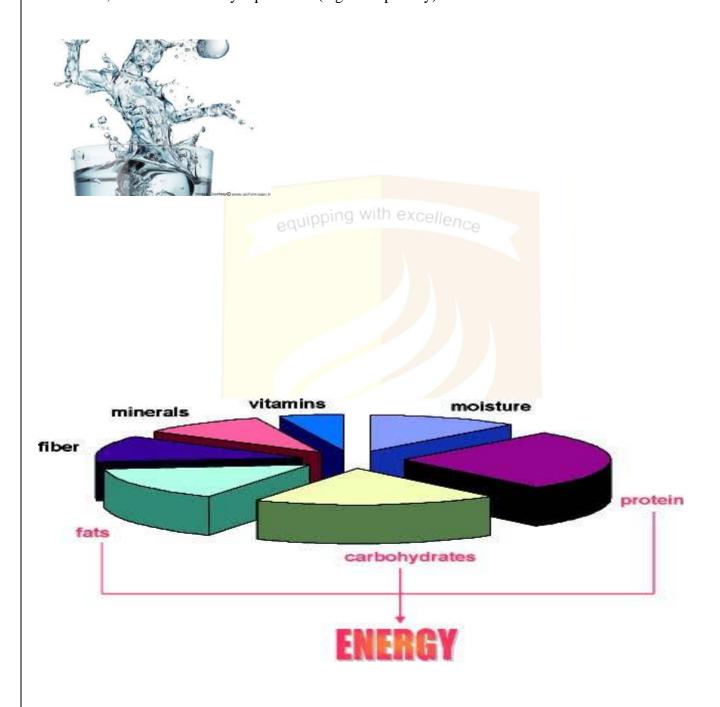
#### v. <u>MINERALS</u>

Minerals are very important for the body and they need to be delivered through food since the body can't make them. Many minerals, such as calcium, potassium and iron are vital to the proper functioning of the body and must be taken in relatively large amounts. Other trace minerals like zinc, selenium and copper are only needed in small amounts to maintain good health.



#### vi. <u>WATER</u>

Water is essential to our survival and should be taken in adequate amounts. It keeps the body hydrated and let the body function properly. Water accounts for 55%-65% of body weight, but because the body can't store water, we must constantly replenish it.(8 glasses per day)



#### vii. <u>PROTEIN</u>

Proteins are nutrients that are essential to the building, maintenance and repair of body tissues such as the skin, the internal organs and muscles. Out of 22 protein types, the body can make 14, the other 8, called essential amino acids, can only be obtained from food. A balanced diet has to be rich in these 8 proteins. Fish, meat, poultry, eggs, cheese and other foods from animal sources provide all the eight essential amino acids.(50g per day)i



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#### **DIGESTION**

- Digestion is the breaking down of complex,unabsorbable,unassimilable and unmetabolizable organic macromolecules or macronutrirnts into simple absorbable,assimilable and metabolizablemicromolecules or micronutrients.
- Products of digestion are then absorbed for assimilation and oxidation.
- *Mechanism*: Digestion involves the enzymatic hydrolysis of large and complex fo9dimto small and simple constituents.

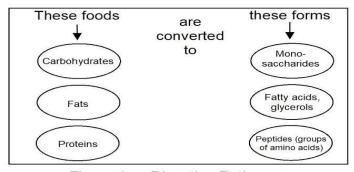


Figure 1 — Digestive Pathways

• Digestive enzymes: carbohydratases or amylases, proteases, lipases, nucleases.

#### **1.DIGESTION OF CARBOHYDRATES**

#### **Summary of carbohydrate digestion in mammals:**

a)Oral digestion :
i. Starchsalivary amylase>Dextrin,isomaltose and maltose
ii. Maltosesalivary maltase>Glucose
b)Intestinal digestion: i. Polysaccharidespancreatic amylase >Maltose,isomaltose,lactose,sucrose
ii. Maltoseintestinal maltase>Glucose
iii. Isomaltoseintestinal isomaltase>Glucose
iv. Lactoseintestinal lactase> Glucose and galactose
v. Sucroseintestinalsucrase>Glucose and fructose

#### **Digestion of cellulose:**

- Cellulose digesting enzymes are altogether absent in the digestive secretions of vertebrates.
- In all vertebrates and most invertebrates, cellulose digestion is carried by certain symbiotic microorganisms inhabiting their digestive tract.
- These org. Are believed to produce 2 enzymes , cellulase and cellobiase.
- Cellulasebreaks down cellulose to cellobiose
- *Cellobiase*hydrolyses cellobiase to glucose units.
- Examples:snails,termites,ruminant and non-ruminant herbivorous mammals etc.

# Summary of carbohydrate digestion in mammals (a) Oral digestion

- (i) Starch Salivary amylase  $\rightarrow$  Dextrins, isomaltose and maltose
- (ii) Maltose Salivary maltase → Glucose

#### (b) Intestinal digestion

- (i) Polysaccharides Pancreatic amylases Maltose, isomaltose, lactose, sucrose
- (ii) Maltose Intestinal maltase → Glucose
- (iii) Isomaltose Intestinal isomaltase → Glucose
- (iv) Lactose Intestinal lactase → Glucose and galactose
- (v) Sucrose Intestinal sucrase Glucose and fructose

### Summary of Carbohydrate Digestion

- 1. Salivary Amylase secreted in mouth;
   breaks starches into maltose (a disaccharide)
- 2. Pancreatic Amylase secreted into small intestine; breaks polysaccharides into disaccharides
- 3. Secreted into small intestine; breaks disaccharides into monosaccharides
  - Sucrase sucrose into glucose and fructose
  - Lactase lactose into glucose and galactose
  - Maltase maltose into glucose (2-3 molecules)

#### 2.DIGESTION OF PROTEIN

(Peptides into am	ino aci	ids)
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Summary of protein digestion in mammals:

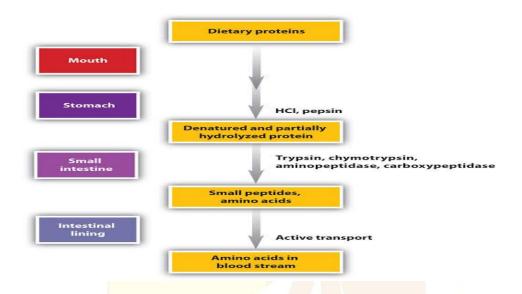
	Gast			

- **i.** Protein\_\_\_gastric pepsin\_\_\_>Oligopeptides
- iii. Casein\_\_\_\_\_gastric rennin+Ca2+\_\_>calcium paracaseinate

#### b)Intestinal digestion:

- *i.* Protein\_\_\_\_\_pancreaticendopeptidases\_\_>Oligopeptides
  - Protein\_\_\_\_pancreatic trypsin\_\_>Oligopeptides
  - Protein\_\_\_\_pancreatic chymotrypsin\_\_>Oligopeptides
  - Elastin \_\_\_\_\_pancreatic elastase\_\_>Oligopeptides
- ii. Oligopeptides\_\_\_Pancreatic and intestinal exopeptidases\_\_>Dipeptides
- iii. Tripeptides\_\_\_\_intestinal tripeptidases\_\_\_>Dipeptides and aminoacids

- iv. Dipeptides\_\_\_\_pancreatic and intestinal exopeptidases\_\_>Aminoacids
  - Dipeptides\_\_\_\_pancreaticcarboxypeptidases\_\_\_>Amino acids
  - Dipeptides\_\_\_\_\_pancreatic and intestinal aminopeptidases\_\_\_>Amino acids



## Summary of protein digestion in mammals

- (a) Gastric digestion
  - (i) Protein Gastric pepsin Oligopeptides
  - (ii) Casein  $\frac{\text{Gastric rennin} + \text{Ca}^{++}}{(\text{curdling of milk})}$  Calcium paracaseinate
- (b) Intestinal digestion
  - (i) Protein Pancreatic endopeptidases Oligopeptides
    - (a) Protein  $\frac{\text{Pancreatic trypsin}}{\text{Oligopeptides}}$
    - (b) Protein Pancreatic chymotrypsin Oligopeptides
    - (c) Elastin Pancreatic elastase Oligopeptides
  - (ii) Oligopeptides Pancreatic and intestinal exopeptidases Dipeptides
  - (iii) Tripeptides \_\_Intestinal tripeptidases > Dipeptides and armin
  - (iii) Dipeptides Pancreatic and intestinal exopeptidases Amino acids
    - (a) Dipeptides Pancreatic carboxypeptidases Amino acids
    - (b) Dipeptides Pancreatic and intestinal aminopeptidases Amino acids

#### 3.DIGESTION OF LIPIDS

(Lipids into fatty acids and glycerol)

breakdown of large and complex fat
globules to small and simple fat
droplets. These fat droplets form a
suspension, called emulsion. It occurs
instomach (by, pepsin/rennin) and small
intestine(by bile salts)

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#### Summary of lipid digestion:

#### a)Gastric digestion

- fat (triacylglycerol) pepsin/rennin > emulsified fat
- emulsified fat <u>gastric lipase</u> fatty acids + monoglyceride

#### b)Intestinal digestion

- fat (triglyceride) <u>bile salts</u> emulsified fat
- emulsified fat *intestinal lipase* fatty acids + monoglyceride
- monoglyceride <u>intestinal esterase</u>sfatty acid + glycerol

#### Summary of lipid digestion

- (a) Gastric digestion
  - (i) Fat (triacylglycerol) Pepsin/rennin → Emulsified fat
  - (ii) Emulsified fat Gastric lipase > Fatty acids + monoglyceride

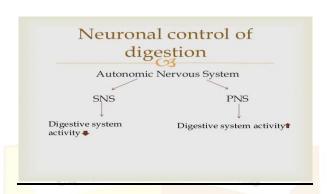
#### (b) Intestinal digestion

- (i) Fat (triglyceride) Bile salts → Emulsified fat
- (ii) Emulsified fat Pancreatic lipase Fatty acids + monoglyceride
- (iii) Emulsified fat Intestinal lipases Fatty acids + monoglyceride
- (iv) Monoglyceride \_\_Intestinal esterases > Fatty acid + glycerol

#### **ABSORPTION OF DIGESTED FOOD**

- Absorption is the uptake of water, minerals, vitamins and the end products of digestion to the body fluids
- Body fluid carries them to tissues for assimilation and oxidation

#### **NERVOUS CONTROL OF DIGESTION**

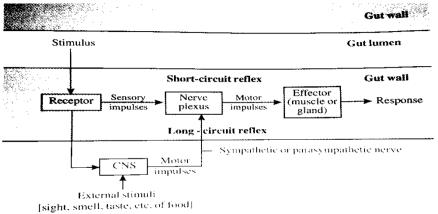


- Gut wall is innervated by *intrinsic* and *extrinsic* nerves
- Intrinsic forms the *enteric nervous system (ENS)*
- ENS consists of 2 plexus:
  - Outer myenteric plexus
  - Inner sub-mucous plexus

MYENTERIC PLEXUS	SUB – MUCOUS PLEXUS
Formed by intrinsic nerves	Formed by extrinsic nerve
Located in between the longitudinal and circular muscles	Located in the sub-mucosa
Controls gastro-intestinal peristaltic movements	Controls gastro-intestinal secretions

- Extrinsic nerves includes,
  - > Sympathetic systems
  - ➤ Para sympathetic system
- Extrinsic nerves enter the gutwall and forms synapse with the neurons of *myenteric* and *sub-mucosal* plexus
- Sympathetic innervations : inhibits motility of the gut wall
- Parasympathetic innervations : stimulates motility
- Basic electrical rhythm (BER) determines the rhythm and frequency of gastric contraction
- 2 types of reflexes:

- ➤ Short-circuit reflexes : impulses follow a receptor → nerve plexus → effector route
- ➤ Long-circuit reflexes : impulses follow a receptor CNS nerve plexus effector route

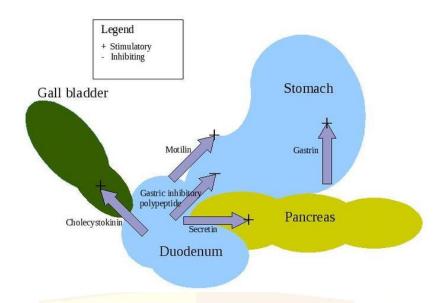


Neural control of digestion

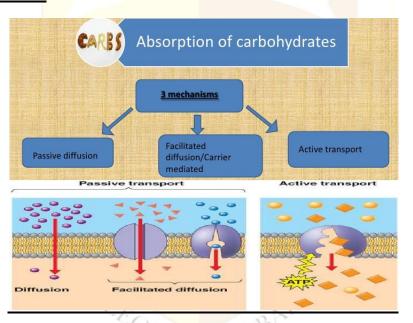
#### **HORMONAL CONTROL OF DIGESTION**

5 major hormones that control digestion:

- Sastrin is in the stomach and stimulates the gastric glands to secrete pepsinogen (an inactive form of the enzyme pepsin) and hydrochloric acid. The secretion of gastrin is stimulated by food arriving in the stomach.
- Secretin is in the duodenum and signals the secretion of sodium bicarbonate in the pancreas and it stimulates the secretion of bile in the liver. This hormone responds to the acidity of the chyme.
- ➤ Cholecystokinin (CCK) is in the duodenum and stimulates the release of digestive enzymes in the pancreas and stimulates the emptying of bile in the gallbladder.
- Sastric inhibitory peptide (GIP) is in the duodenum and decreases stomach churning in order to slow the emptying of the stomach. Another function is to induce insulin secretion.
- ➤ Motilin is in the duodenum and increases the migrating myoelectric complex component of gastrointestinal motility and stimulates the production of pepsin

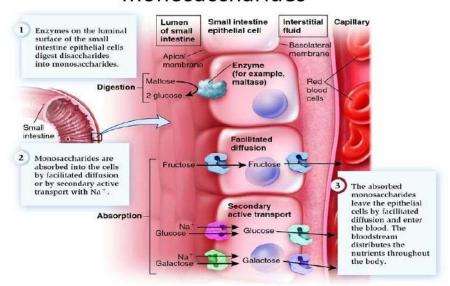


#### ABSORPTION OF SUGAR



- Absorption of sugars occurs mostly by active transport and, to a little extent, by passive transport
- absorbed mostly as monosaccharides.
- Disaccharides are only very scarcely absorbed, and polysaccharides are not at all absorbed as such.
- Disaccharides are hydrolysed to monosaccharide units within the intestinal epithelium before they are absorbed: accomplished by the disaccharases present in the brush border of intestinal epithelium.
- Polysaccharides are at first hydrolysed by amylases before they are acted upon by intestinal surface enzymes for final absorption.
- In general, mono and disaccharides are absorbed to the intestinal epithelial cells as sugar phosphates by *carrier-mediated active* transport
- Most sugars are absorbed by an active transport mechanism, called *co-transport or coupled transport* : the transport of two substances is accomplished together by a common or combined mechanism.
- Example; sodium-dependent carrier mechanism.
- Na <sup>+</sup> activates ATPase and thereby accelerates ATP hydrolysis to provide enough energy for active transport.

# Diagram showing absorption of monosaccharides



In the coupled transport or co-transport of glucose and sodium, the carrier molecule links with sodium and glucose and forms a carrier-glucose-sodium complex. This complexing Occurs on the outer surface of the plasma membrane. Plasma membrane 1s freely permeable to this complex. So, the carrier moves across the plasma membrane, carrying both the substrates. On reaching the inner surface of the membrane, the constituents of the complex dissociate from each other. The mobile carrier returns to the outer surface of the membrane for transporting another molecule of glucose. Glucose soon diffuses into the blood stream. Sodium pump removes sodium back to the outer surface of the membrane

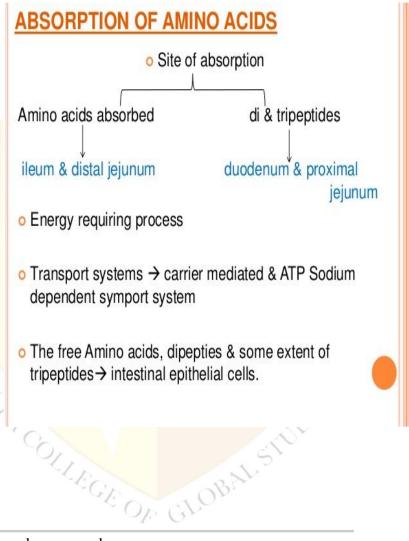
• The absorption preference among hexoses is as follows:

glucose > galactose > fructose > mannose

#### ABSORPTION OF PROTEINS AND AMINO ACIDS

- Absorbed mostly as amino acids and dipetides.
- Na +-dependent co-transpot or couple transport
- In human infants, small amounts of intact proteins, such as mik protein (casein and egg albumen, are directly absorbed through the intestinal mucosa
- In mammals, antibodies pass from maternal blood to foetal blood through the placen-
- Tal barrier
- Some amino acids, such as alanine, histidine, methionine and glycine, are absorbed more easily as dipeptides or tripeptides rather than as free amino acias.
- Intestinal absorption of amino acids takes place by active and passive mechanisms
- All L-amino acids (naturally occurring amino acids) are absorbed by carrier- mediated active transport.

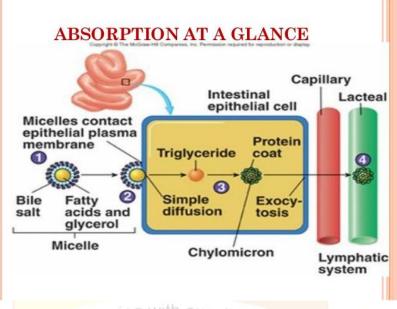
- D-amino acids, are absorbed by passive diffusion.
- Active absorption of amino acids is dependent on sodium and oxygen supply.
- Absorption of oligopeptides involves two major mechanisms. :
  - ➤ In one of them, the peptides undergo degradation with the help of brush border peptidases and release free amino acids. The released amino acids are then transported by carrier-mediated mechanism.
  - In the second mechanism, the peptides by pass brush border peptidases and directly get into the cell. They are soon hydrolysed by cytoplasmic peptidases.



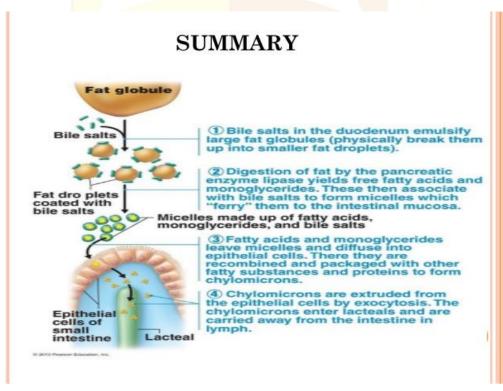
#### **ABSORPTION OF FATS**

- Passive diffusion across plasma membrane.
- Theories: *lipolytic theory* and *partition theory*
- Absorbed as:
  - > triglycerides
  - Diglycerides and monoglycerides
  - > Free fatty acids and glycerol

Absorbed into lymph vessel: lacteals



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- Three views are currently favoured as the reasonable explanations of fat neutral fats :
  - 1. Pinocytosis is the major mechanism for the absorption of neutral fats (triglycererides ) and phospholipids
  - 2. Fats are first absorbed as fatty acids, glycerol and mono and diglycerides. Then, neutral fats and phospholipids are synthesized from them in the villi before their transportation by the lymphatic system.
  - 3. The absorption of fatty acids, cholesterol and other lipids by diffusion occurs after their solubilization.

#### **BASAL METABOLIC RATE (BMR)**

- Basal metabolism is the overall cellular metabolism, taking place under a set of empirical conditions: basal conditions (during resting, sleeping, hibernation, aestivation etc)
- Basal metabolism represents the lowest metabolism that yields only the bare minimum energy required for the immediate maintenance of normal life processes
- The rate at which basal metabolism takes place: BMR
- Thyroxine is the primary regulating agent of BMR, in vertebrates
- BMR depends on age, sex, habits, pregnancy, diet, chemicals, pathological conditions.

#### **OBESITY**

- Excessive weight gain of the body due to heavy accumulation of fat in the adipose tissues beneath skin and around certain internal organs
- Body weight goes upto 20% of the ideal weight
- Causes:
  - Genetic factors
  - Personal habits
  - Overeating
  - Large intake of fluid
  - Malfunctioning of some endocrine glands
  - ➤ Hormonal imbalance
  - > Hereditary factors
  - ➤ Inert life style
- Clinical effects:
  - ➤ Mortality
  - ➤ High BP
  - > Type 2 diabetes
  - Osteoarthritis
  - > Sleep apnea
  - Breathing difficulties
  - > Fatigue
  - ➤ Mental illness
  - > Body and joint pain
  - Cancer
  - ➤ Liver and gall bladder disease

CLEGE OF GLOBALS

#### **MODULE: 3**

#### RESPIRATION

- All biological functions require energy.
- This energy is obtained in the form of ATP from cellular respiration or biological oxidation.
- Cellular respiration: intracellular oxidation of nutrients and fuel molecules to release their bond energy for biological functions.
- The molecules or compounds, oxidised during respiration, : respiratory substrates (e.g. sugars, fatty acids, organic acids, etc.).
- The energy, released during cellular oxidation, is conserved in a biologically available form in the energy bonds of ATP molecules.
- The energy bonds of ATP molecules are finally broken and active kinetic energy is made available for biological process

2 types,

- > AEROBIC
- > ANAEROBIC

#### ANAEROBIC RESPIRATION

- Also called anaerobic metabolism or fermentation: partial oxidation of fuel molecules in the absence of molecular oxygen.
- It releases only a small portion of the energy (In the anaerobic oxidation of glucose, only 20-30% of the energy store is released.)
- In anaerobic glucose oxidation 4 ATP molecules will be synthesised and two will be spent per one molecule of glucose. So, there is a net gain of 2 ATP molecules.
- Example: Anaerobic respiration is common among yeasts, some bacteria (e.g., lactic acid bacterium, tetanus bacterium) and several endoparasites (e.g., Taenia, Ascaris, Ancylostonma)
- It also occurs in skeletal muscles, mature mammalian erythrocytes and the cytoplasm of all cells (through glycolysis). ELEGE OF GLOBA
- 2 TYPES,
  - ➤ *Alcohol fermentation*
  - ► *Lactic acid fermentation*
- **Alcoholic fermentation**: fermentation of glucose to ethyl alcohol(alcoholic.fermentation),

Example : *yeast* (baking)

Lactic acid fermentation: fermentation of glucose and lactose to lactic acid

Example: Lacto Bacillus (milk to curd: bacteria) and the skeletal muscles of vertebrates

#### **AEROBIC RESPIRATION**

- Complete cellular oxidation of organic molecules utilizing molecular oxygen and releasing CO<sub>2</sub>
- Cellular centres: in eukaryotes: mitochondria; in prokaryotes: plasma membrane.

- Even in some aerobic animals, anaerobic respiration Occurs in some cells and tissues.
- For example, lactic acid fermentation occurs in the skeletal (striated) muscles of vertebrates.
- Mature mammalian erythrocytes are devoid of mitochondria. So, they carry out only anaerobic metabolism.

The most essential aspect of aerobic respiration is the step-by-step transfer of energised hydrogen through a chain of hydrogen acceptors within cells. Ultimately, the hydrogen combines with oxygen and forms water. Thus, oxygen is indispensable for aerobic respiration to serve as the terminal acceptor of hydrogen. Thus, the intake, transport and utilization of oxygen, and the transport and elimination of carbondioxide together constitute aerobic respiration.

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- Two broad phases,
  - **External respiration or organismic respiration**: External respiration is the exchange of respiratory gases (O<sub>2</sub>, and CO<sub>2</sub>) between the organism and its external medium.
  - ➤ Internal respiration or cellular respiration : cellular uptake of O<sub>2</sub>, and the oxidation of fuel molecules, releasing CO<sub>2</sub>, H<sub>2</sub>O and energy.
- External respiration in higher animals involves two major processes,

COLLEG

- Gas Exchange
- Gas Transport.

#### **GAS EXCHANGE**

- 2 sites:
  - 1. **Respiratory Surtace or Respiratory Organ**: takes place between the O <sub>2</sub> of the surrounding medium and the CO<sub>2</sub> of the blood or body fluid
  - 2. **Cells / Tissues**: between the O <sub>2</sub> of the extracellular fluid and the CO <sub>2</sub> produced within the cell.
- **Mechanism**: physical process, without energy expenditure: by simple diffusion diffusion
- Ventilation : for high rate and maximum intake of  $O_2$ , most organishms continuously move air or water over their respiratory surface.

#### **FACTORS INFLUENCING GAS EXCHANGE:**

- Pressure gradient or tension gradient of the gases.
- Solubility coefficient of the gas in liquid medium.

- Diffusion coefficient and diffusion capacity of the gas in relation to the cross sectional area, distance and viscosity of the liquid.
- Molecular weight of the gas.
- Ventilation perfusion ratio.
- Temperature.
- Thickness and surface area of the respiratory membrane.

The rate of gas exchange, in general, is directly proportional to temperature and the surface area of the respiratory membrane, and inversely proportional to the molecular weight of the gases and the thickness of the respiratory membrane.

#### 1. Pressure gradient or tension gradient of gases:

- Gas exchange takes place by *simple diffusion in a pressure gradient or tension gradient* i.e. from a region of greater to a region of lower.
- Partial pressure: pressure of an individual gas in a gas mixture.
- Tension : pressure of a gas in a liquid.
- In mammals, pO<sub>2</sub> is always greater in the inspired alveolar air and the tension of pCO<sub>2</sub> is greater in the capillary blood. So, O<sub>2</sub> diffuses to blood from alveoli, and CO<sub>2</sub> diffuses from blood to alveoli.
- In tissues, the tension of O<sub>2</sub> is always greater in blood, and the tension of CO<sub>2</sub> is greater in tissue fluid. So,O<sub>2</sub> diffuses to tissue fluid and CO<sub>2</sub> diffuses to blood.

#### 2. Solubility coefficient of gases in a liquid medium:

- Solubility coefficient is the quantity of a gas absorbed by I ml of a liquid at a temperature of 0°C and a pressure of 760 mm Hg.
- The tension of a gas in a liquid is directly proportional to the volume of the dissolved gas and inversely proportional to its solubility coefficient.
- The volume of the dissolved gas, in turn, depends on pressure and solubility constant.

Volume of dissolved gas =Pressure x solubility coefficient.

Tension of disolved gas = Volume of gas in the liquid x 760

Solubility coeficient at 760 mm Hg

• The tension of gases is measured by the instrument tonometer.

#### 3. <u>Diffusion coefficient and diffusion capacity</u>

- The diffusion coefficient of a gas is the volume of the gas in I ml of the liquid, diffusing over a surface area of 1 sq cm  $(1 \text{ cm}^2)$  and along a distance of 0.001 mm.
- Diffusion capacity is the volume of the gas diffusing across the respiratory membrane every minute in a pressure gradient of 1mm Hg.
- Diffusion capacity is directly proportional to the cross sectional area of the membrane and the solubility of the gas in the liquid medium, but inversely proportional to distance

#### 4. Ventilation-perfusion ratio

- Gas exchange in the lungs depends markedly on a ratio between the air flow (ventilation) and blood flow (perfusion) into the lungs.
- Ventilation-perfusion ratio: The ratio between alveolar ventilation and alveolar vascularisation.
- Gas exchange is most efficient when each alveolus of the lungs is fully ventilated and fully

#### **RESPIRATORY PIGMENTS**

- Respiratory pigments are coloured and metal-containing conjugated proteins, involved in the uptake, storage and transport of respiratory gases.
- They have very great affinity for O<sub>2</sub>, At high pO<sub>2</sub>, they loosely and reversibly bind with O<sub>2</sub>, and form unstable and easily dissociable compounds. With excellent
- At low pO<sub>2</sub> these unstable compounds dissociate, releasing O<sub>2</sub>. The oxygen content of the blood of most animals is greatly increased by the combination of oxygen with respiratory pigment. SO, in the absence of respiratory pigment, the oxygen content of the blood would be very low.
- The commonest respiratory pigments include haemoglobin, haemocyanin, haemerythrin, chlorocruorin, echinocruorin and echinochromne.

#### **HAEMOGLOBIN:**

- found in both vertebrates and invertebrates
- In vertebrates, haemoglobin is a circulating respiratory pigment and myoglobin is a storage respiratory pigment.
- Haemoglobin is an iron-containing and oxygen-carrying red pigment.
- It is found in the erythrocytes of all vertebrates and in the blood plasma of some invertebrates (e.g., Ascaris).
- A modified type of haemoglobin, called *leg haemoglobin*, is found in the root nodules of leguminous plants.
- The normal haemoglobin, found in adult human beings, is called *haemoglobin A (HbA)*, and that of foetus is called *foetal haemoglobin (HbF)*
- Haemoglobin is a conjugated metalloprotein
- It is formed of a colourless and globular basic protein, called *globin*, and an iron-containing portion or prosthetic group, called *haem* (heme) or *haematin*

Globin + Heme = Haemoglobin

- Haem is the active group, taking part in O, transport.
- All the different kinds of haemoglobin have the same heme group, but different globins

#### **Molecular organization of haemoglobin:**

- A human haemoglobin-A molecule consists of one globin molecule and four haem (heme) molecules.
- The globin molecule, in turn, is a tetramer, formed of four polypeptide chains:
  - two alpha chains (each having 141 aminoacid units)
  - $\triangleright$  two beta chains ( $\alpha_2\beta_2$ ) in HbA (each having 146 aminoacid units)
  - > two alpha chains
  - $\triangleright$  two gamma chains  $(\alpha_2, \gamma_2)$  in HbF.
- Forces: weak non-covalent bonds, such as vanderWaal's forces, hydrogen bonds, salt linkages and hydrophobic interactions
- In adult, human beings, there is yet another type of haemoglobin, called haemoglobinA  $_2(HbA_2)$ ; globin part formed of two alpha chains and two deltachains ( $\alpha_2$   $\delta_2$ ).
- Haem molecule is an iron-porphyrin complex, formed of aniron atom and a divalent porphyrin molecule.
- Iron occurs in the ferrous (Fe<sup>2+</sup>) state.
- The porphyrin unit is a tetrapyrrole ring, formed of four pyrrole rings, with a centrally located ferrous iron. The ferrous iron is linked to the N atoms of the porphyrin ring

A haemoglobina (HbA) molecule consists of 574 amino acids, 4 polypeptide chains, 4 iron atoms, 4 porphyrin molecules and a vinyl group

#### Properties of haemoglobin:

- Haemoglobin has an active role in the transport of O<sub>2</sub> and CO<sub>2</sub>
- The most important property of haemoglobin is its affinity for O<sub>2</sub> for its ability to reversibly bind with oxygen.
- A haemoglobin molecule can bind with as many as four oxygen molecules
- Affinity for O, depends on temperature, pH, pO<sub>2</sub>, and pCO<sub>2</sub>, of the blood, and the concentration of 2, 3-diphosphoglycerate (2, 3-DPG) in the blood.

The ability of Hb to bind  $O_2$  enables it to serve as an oxygen-carrier of blood. This reaction is unique in that the iron of the haem remains in the ferrous (Fe<sup>2+</sup>) state

Oxygen only loosely and reversiblycombines with the ferrous iron without actually oxidising it to ferric iron (Fe). Thus, the iron atom gets only reversibly oxygenated and not oxidised.

- The bare, oxygen-free haemoglobin is called deoxyhaemoglobin.
- The affinity of Hb for O, and its oxygen-binding capacity, depend upon the physical state of its peptide chains.

- Each chain can exist in two reversible or interchangeable states,
  - > relaxed or R-state: favours oxygen-binding
  - > tensed or T-state : lowers oxygen-binding

The haemoglobin content of the blood of a normal human adult consists of about 97 % HbA , 2% Hb A  $_2$ , and 1% HbF. The normal level of HbA in blood is 14 to 16g/dl in male and 13 to 15g/dl in female.

#### **GAS TRANSPORT**

- In vertebrates, cardiovascular system serves as the transport system for the delivery of O<sub>2</sub> to tissues and the removal of CO<sub>2</sub> from tissues.
- In lung-breathing vertebrates, blood is the medium of transport of respiratory gases between lungs and tissues.
- It transports O<sub>2</sub> from lungs to tissues, and CO<sub>2</sub> from tissues to lungs

# 1. Transport of Oxygen

Blood transports  $O_2$  in two ways:

- in chemical combination with haemoglobin: 97%
- in physical solution in the water of plasma and corpuscles: 3%

#### a) Transport of 02 in physical solution:

- Transport of oxygen in physical solution depends on the solubility coefficient, pressure gradient and temperature.
- Normally, 1 ml of blood absorbs nearly 0.024 ml of oxygen at a temperature of 37°C and a pressure of 760 mm Hg.
- The partial pressure of oxygen inside the lungs is 100 mm Hg.
- So, at this pressure of oxygen, 1 ml of blood can carry **0.003** ml of oxygen in physical solution.

#### b) Transport of 0<sub>2</sub> by haemoglobin:

Properties of Hb to transport Oxygen:

- Can transport large quantities of O<sub>2</sub>
- Has high solubility
- Can take up and release oxygen at appropriate partial pressures
- Can serve as a powerful ph buffer.

During oxygen transport, Hb is only oxygenated, and never oxidized. During oxygenation, its iron atom stays in the ferrous state itself. If it is oxidized to ferric state, its oxygen-carrying capacity would be lost.

- Haemoglobin has great affinity for O, at high pO<sub>2</sub> and low pCO<sub>2</sub>
- Oxygenation of haemoglobin: At the high pO<sub>2</sub> in the capillaries of respiratory surfaces or lungs, it will readily accept oxygen and its Fe<sup>++</sup> ions will loosely and reversibly combine with O<sub>2</sub>, to form the unstable oxyhaemoglobin (Hb  $_4$  O<sub>2</sub>).
- High blood pH (low acidity) also enhances the oxygenation of haemoglobin
- The oxygenation reaction of haemoglobin is represented as,

$$Hb_4 + O_2 \iff Hb_4O_2$$

- Tension of loading: The pO<sub>2</sub> at which haemoglobin gets oxygenated
- 100% saturation of haemoglobin: haemoglobin molecule contains four iron atoms, it can bind with as many as four molecules of O<sub>2</sub> at a time. The condition in which all the binding sites of a haemoglobin molecule are simultaneously occupied by oxygen. It occurs at high tension of loading (i.e. at high pO<sub>2</sub>).

$$Hb_4+4O_2 \iff Hb_4O_8$$

- Haemoglobin exists in three conditions of oxygenation/saturation:
  - Unsaturated or unoxygenated
  - Partially saturated or partially oxygenated
  - Fully saturated or fully oxygenated.
- The degree of the saturation of haemoglobin with O<sub>2</sub> is directly proportional to the level of pO<sub>2</sub>.
- Percentage saturation of haemoglobin: The percentage of saturated Hb in the total haemogiobin
- Saturation of haemoglobin is a stepwise process

$$Hp^{1}0^{2}+0^{3} \rightleftharpoons Hp^{1}0^{2}$$

$$Hp^{2}0^{2}+0^{3} \rightleftharpoons Hp^{1}0^{2}$$

$$Hp^{3}0^{4}+0^{5} \rightleftharpoons Hp^{1}0^{2}$$

$$Hp^{4}0^{5}+0^{5} \rightleftharpoons Hp^{1}0^{5}$$

- 1 gm of haemoglobin can combine with as much as 1.34 ml of oxygen : oxygen-carrying capacity of haemoglobin.
- *Positive co-operativity*: Oxygenation of one haem group not only increases the affinity of the remaining haem groups for O<sub>2</sub> but also enhances their oxygen-binding capacity
- The oxygen-binding ability of Hb is directly proportional to the pO<sub>2</sub> level.

- Deoxygenanon or desaturation of haemoglobin: In the tissues, po 2 is very low and pco 2 is very high. Hence, oxyhaemoglobin dissociates and sets free O 2 forming deoxyhaemoglobin..
- Tension of unloading: The po 2, at which haemoglobin gets deoxygenerated
- Dissociation of oxyhaemoglobin is influenced by :
  - > acidity (low pH)
  - > the presence of 2,3-diphosphoglycerate (DPG)
  - > High temperature
  - ➤ High pCO 2

*Bohr effect*: Under acidic conditions, the equilibrium beween deoxyhaemoglobin and oxyhaemoglobin gets shifted in favour of the deoxygenation process. Consequently, oxygen dissociates more readily from haemoglobin.

#### 2. Transport of Carbondioxide

Blood transports CO, from tissues to lungs in three ways:

- in physical solution as carbonic acid:5%
- > as carbaminohaemoglobin:10%
- > as bicarbonates.:85%

#### a. Transport of CO, in physical solution as carbonic acid

- CO<sub>2</sub> reacts with plasma water and forms the weak carbonic acid.
- This occurs in tissue sites.
- On reaching the lungs, carbonic acid dissociates and releases CO 2The remaining 95%

#### b. Transport of CO<sub>2</sub> as carbaminohaemoglobin

- CO<sub>2</sub> first diffuses from plasma to RBC.
- Then, it reversibly combines with the amino(-NH<sub>2</sub>) group of the globin part of haemoglobin and forms
- carbaminohaemoglobin.
- The formation of carbaminohaemoglobin is greatly influenced by the high pCO 2 in the tissue capillaries.
- On reaching the pulmonary capillaries, where pCO <sub>2</sub> is very low, carbaminohaemoglobin dissociates, releasing CO <sub>2</sub>. This dissociation is catalysed by *carbonic anhydrase*.
- The CO<sub>2</sub> soon diffuses to pulmonary alveoli and then escapes to the outside

CO<sub>2</sub>+Hb.NH<sub>2</sub> Hb. NHCOOH

#### c. Transport of CO<sub>2</sub> as bicarbonates (isohydric transport)

- This occurs with minimum change in pH and is therefore termed isohydric transport.
- In this case, most of the CO <sub>2</sub> at first diffuses in a tension gradient from blood plasma red blood cells, due to the high pCO <sub>2</sub> in the plasma.

- In the RBC, it reacts with water and forms *carbonic acid*.
- Carbonic acid soon ionizes to hydrogen ions (H +) and bicarbonate ions (HC0 -)

# Carbonic anhydrase $CO_2 + H_2O$ $H_2CO_3$ $H^+ + HCO_3$

- The Hydrogen ions, formed by the ionization of H,CO, are soon buffered by
- deoxyhaemoglobin (oxygen-free haemoglobin) which acts as a proton acceptor.
- They immediately combine with *deoxyhaemoglobin* and form *haemoglobinicacid* (H.Hb).
- Haldane effect: The release of H<sup>+</sup> ions and their immediate buffering by deoxyhaemoglobin
- At the same time, bicarbonate ions diffuse to the plasma from red blood cells, when their concentration increases within the RBCs.
- This outward diffusion of HCO<sup>-</sup>, from RBC to plasma momentarily upsets the ionic equilibrium and the electrical balance between plasma and red cells.
- Chloride shift or Hamburger phenomenon: To regain the lost balance, and also to establish electrochenmical neutrality, an equal number of chloride ions diffuse into the red cells from plasma.
- Free chloride ions are made available by the dissociation of NaCl or KCl in the plasma.
- Inside the RBC chloride ions combine with K<sup>+</sup> and form KCl.
- The HCO 3<sup>-</sup> ions in the plasma combine with Na and form NaHCO 3
- Now, the deoxygenated blood returning to lungs, contains NaHCO, in the plasma, and haemoglobinic acid and KCI in the RBCs.
- When this blood reaches pulmonary capillaries, the whole series of events get reversed.

LEGE OF GLOBY

#### Summary of the transport of CO<sub>2</sub> as bicarbonate (i) In the blood of tissue site 1. CO, diffuses into RBC from plasma 2. $CO_2 + H_2O \rightarrow H_1CO_2$ (in RBC) 3. $H_2CO_3 \rightleftharpoons H^4 + HCO_3$ (in RBC) 4. $H^* + Hb \rightarrow H.Hb$ (in RBC) - Haldane effect HCO<sub>3</sub> diffuses to plasma, and Cl diffuses to RBC (chloride shift) $HCO_3^* + Na^* \rightarrow NaHCO_3$ (in plasma) 8. $Cl^- + K^+ \rightarrow KCl \text{ (in RBC)}$ Plasma contains NaHCO3 and RBC contain KC1 and HHb (ii) In the blood of lungs 9. NaHCO<sub>3</sub> $\rightarrow$ Na\* + HCO<sub>3</sub> (in plasma) 10. $KCl \rightarrow K^+ + Cl$ (in RBC) 11. HCO; diffuses to RBC, and Cl diffuses back to plasma (chloride shift) 12. $H.Hb \rightarrow H^++Hb$ (in RBC) 13. $H^+ + HCO_3^- \rightarrow H_2CO_3$ (in RBC) 14. $H_2CO_3 \rightarrow H_2O + CO_2$ (in RBC) 15. CO<sub>2</sub> diffuses to plasma from RBC

# REGULATION OF RESPIRATION

Breathing movements are controlled, ventilation rate is normalized, and the basic respiratory rhythm is established through the negative feed-back impulses from *respiratory receptors* to *respiratory centres*.

This regulation involves a rhythmic muscles.

This inherent rhythmicity arises within the *medulla oblongata*.

It may be influenced by the impulses from *pons Varolii, hypothalamus, cerebral cortex*, and the 9th and 10h *cranial nerves*.

#### **Respiratory receptors**

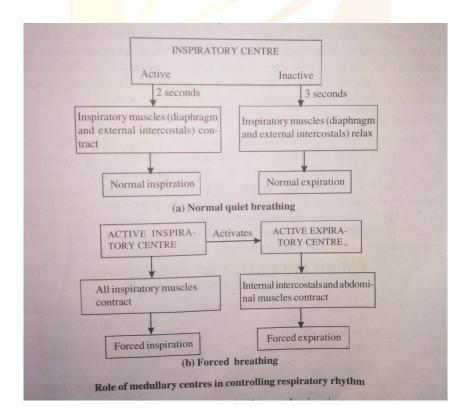
#### 2types:

- > Stretch receptors or Hering-Breuer receptors: located on the walls of trachea, bronchi and bronchioles.
- > Chemoreceptors: medullary receptors, aortic bodies and carotid bodies; located respectively in the medulla oblogata, wall of aorta and the wall of carotid sinus (dilated region of internal carotid artery).
- Chemoreceptors are sensitive to changes in the O<sub>2</sub> and CO<sub>2</sub> levels in blood, especially to low O<sub>2</sub> and high CO<sub>2</sub>levels.
- Stretch receptors are sensitive to high 0<sub>2</sub> and low CO<sub>2</sub> levels, and also to stretches in the lungs.
- Feedback impulses from stretch receptors are concerned with the mechanics of pulmonary ventilation

• From the chemoreceptors are concerned with the rate and depth of pulmonary ventilation.

#### **Neural control on respiration:** Respiratory centres and respiratory rhythm

- Respiratory centres control the mechanics of breathing.
- During breathing, respiratory muscles contract and relax in response to the impulses from the respiratory
- Centres in medulla oblongata and pons Varolii
- In human beings, 2 Respiratory centres:
  - > Medullary centre
  - > Pontine centre
- there are 2 medullary centre:
  - > Inspiratory centre
  - Expiratory centre
- Pontine centre includes :
  - Pneumotaxic centre
  - > Apneustic centre
- Pneumotaxic centre is *inhibitory*
- All others are *excitatory*



#### **RESPIRATORY PROBLEMS IN MAN**

# 1. Asphyxia

State of breathing arrest in which normal intake, distribution, utilization of oxygen get seriously impaired

#### 2. Hypoxia

Deficiency of oxygen at the tissue level

# 3. CO poisoning

- Excessive concentration of CO in blood
- It may cause hypoxia
- Hb combines (200x) more readily with CO to form *carboxyhaemoglobin*

#### RESPIRATORY PROBLEMS AND ADAPTATIONS AT HIGH ALTITUDES

- Problems at high altitudes :
  - Very low barometric (amospheric) Pressure
  - ➤ Insufficiency of O<sub>2</sub>;
  - Low partial pressure of atmospheric O<sub>2</sub> ;atmospheric pressure and the percentage and partial pressure of atmospheric O<sub>2</sub> decrease with increase inaltitude.
- Decrease in atmospheric pressure often causes decompression sickness
- In human beings, decrease in the partial pressure of O<sub>2</sub> at higher altitudes often causes arterial hypoxia.
- Prolonged and extreme hypoxia at higher altitudes may cause *periodic breathing* and *"mountain sickness*". ;characterised by recurring pauses between successive breaths ;considerably reduces the breathing rate and the intake of O<sub>2</sub>
- Mountain sickness, or altitude sickness, is a group of symptoms which appear when people reach great heights either in mountaineering or in air travel.
- Mountain sicknesss is of two types: acute and chronic.
- The former frequently affects people for several days after arriving at altitudes above 3000m. It is characterised by mental fatigue ,physical exhaustion, hallucnations, drowsiness, giddiness, unconsciousness, convulsions, headache, nausea, vomiting, dyspnea, bluish skin, lips and nails, etc. It may sometimes lead to coma and death.
- Chronic mountain sickness occasionally results from long-term stay at high altitudes. It is also characterized by fatigue, exercise intolerance, etc.

#### Adaptations at higher altitudes

High-altitude animals adjust themselves to hypoxic conditions by responsive mechanisms, which raise the red cell count, haemoglobin content and the oxygen- carrying capacity of blood, and maintain the high oxygen affinity of haemoglobin.

• The adaptive physiological responses at high - altitudes fall under two major Categories:

- ➤ Accommodation: Accommodation involves the initial adjustments of the body in response to hypoxia. It includes hyperventilation of lungs, tachycardia and increased concentration of diphosphoglycerate (DPG) in RBCs.
- ➤ Acclimatization: Acclimatization involves changes in the body in response to long-term exposure to hypoxia. Polycythemia (high red cell count), increased enzyme activity, etc. are some of such changes.

# PROBLEMS AND ADAPTATIONS OF DIVING MAMMALS

The major problems generally experienced by diving mammals are :

- lack of oxygen availability at depths
- ➤ difficulty for the elimination of CO<sub>2</sub> from tissues
- $\triangleright$  difficulty for the proper distribution of  $0_2$  to different parts
- depletion of the Oxygen storage
- the resulting hypoxia and anoxia
- bradycardia or low heart-rate
- > slow blood circulation to organs other than brain, heart and adrenal glands
- Oxygen toxicity
- > gas bubbling due to decompression sickness when the
- > animals ascend to the surface quickly.

## Adaptations of diving mammals

- Storage of oxygen in myoglobin and venous blood reservoirs
- Low metabolic rate and low oxygen requirement
- Low heart rate and low cardiac output
- Peripheral vasoconstriction and circulatory shunts to maintain blood flow to brain, heart, adrenal gland, etc. Large blood volume and high oxygen-carrying capacity of blood
- Low sensitivity of the respiratory and circulatory centres to increasing concentration of co 2 and lactic acid
- Tolerance to oxygen dept in muscles

The danger of hypoxia or anoxia, encountered by the under-water animals, is essentially the same as that encountered by the animals at high altitudes. However, the solution is different in the two habitats. At higher altitudes, the problem is solved by enhancing the rates of oxygen delivery to tissues, while in water the solution involves the temporary storage and judicious use of oxygen, and the capacity to deal with oxygen debt.

## **ARTIFICIAL VENTILATION**

- Ventilation is the passing of air into and out of the lungs along the respiratory tract.
- Artificial ventilation is a life-saving process, which ensures free ventilation of the lungs and re establishes the normal breathing rate and normal gas exchange.
- The automatic mechanical instrument, employed in artificial ventilation, is called *ventilator*.
- Ventilators are of two categories: conventional or classical ventilators and high frequency ventilators.

#### **HEART-LUNG MACHINE**

- *Heart-lung machine*, also known as *cardio-pulmonary bypass machine*, *or pump-oxygenator*, is the machine which carries out the functions of both heart and lungs during open heart surgery.
- It pumps out blood and oxygenates it throughout the body.
- The external pump and the oxygenator together form the heart-lung machine.
- Components: pumps oxygenator, heat exchanger and several accessory components for control and regulation

DE COULEGE OF GLOBALS

#### **MODULE: 5**

# OSMOREGULATION AND EXCRETION

- Osmoregulation is the active regulation of the osmotic potential through the maintenance of a proper & constant concentration of water & mineral ions in the body fluid.
- It is the energy consuming dynamic process which regulate the movement of water & salts between body fluids& external medium.
- They accomplish this by two physiological mechanisms, excretion & osmoregulation.
- It plays a vital role in homeostasis.
- Maintenance of a proper concentration of water is known as osmotic regulation.
- Maintenance of a proper concentration of mineral ions is known ionic regulation.
- Osmoregulation is carried out by different mechanisms :
  - 1) Regulation of the permeability of the body surfaces to salts & water.
  - 2) Active absorption or excretion of salts & water.
  - 3) Alterations in the tonicity of urine or excretory fluid.

# Osmoregulators & osmoconformers

- The internal osmotic & ionic concentrations of an animal remains constant, irrespective of changes in the surrounding medium. Such animals are called osmostable (homeosmotic or homoiosmotic) animals.
- They regulate their internal concentration through certain checks & controls to counterbalance the external changes. They are called *osmoregulators*.
  - Eg:- All vertebrates, most fresh water invertebrates.
- The animals which fluctuatetheir internal osmotic & ionic concentration in relation to the changes in the outside are called osmolabile animals.
- Since their internal concentration always conforms to that of the surrounding medium, they are called *osmoconformers*.
  - Eg:- Most marine invertebrates.

# Euryhaline & stenohaline animals

- Euryhaline animals can tolerate or withstand a wide range of salinity variations in the external medium, either by conformity or by regulation.
  - Eg:- Salmon, eel
- Stenohaline animals can tolerate only slight variations, they may not survive beyond a certain limit of salinity change in the medium.

#### Iso-osmotic, hyposmotic& hyperosmotic animals

- The body fluids of marine invertebrates & the sea water around them have the same osmotic concentration or osmotic potential, such animals are *iso-osmotic* in relation to medium. They will not normally have any osmotic stress.
- The body fluids of fresh water animals are osmotically more concentrated than the medium. They are *hyperosmotic animals*.
- The body fluids of marine vertebrates of high salinity waters are osmotically less concentrated than the medium. They are called *hyposmotic animals*.

- Hyposmotic& hyperosmotic animals have osmotic stress.
- Isosmotic animals are osmoconformers.
- Hyperosmotic &hyposmotic animals are osmoregulators, known repectively as *hyperosmoregulators&hyposmoregulators*.
- Hyperosmotic regulators are subjected to gain water by endosmosis & loss of salt by diffusion.
- Hyposmotic regulators are subjected to loss water by exosmosis& gain of salts by diffusion.

## Water retention & conservation in desert animals

## Adaptations for getting water

- Adaptations for drinking water from small springs.
- Herbivores are adapted to sustain on the juice of succulent plants they feed.
- Carnivores are adapted to sustain on the body fluids of their prey.
- Some desert animals are sustain on metabolic water (Kangaroo rats).
- Some animals are adapted to absorb atmospheric water by their hygroscopic skin, which act as a blotting paper (Australian lizard).

# Adaptations for conserving water

- Uricotelism in insects, reptiles & birds to reduce water loss.
- Storage of large quantities of water in the large intestine (Desert lizard).
- Great tolerance to high temperatures & extreme water deficit (Camels).
- Absence of sweat glands in desert mammals to reduce perspiration & water loss.
- Surface secretion & scaly or spiny covering to reduce evaporation.

#### Osmoregulatory adaptations of camels

- Camels deals with severe heat & extreme loss of water by virtue of their high tolerance to fluctuations in body temperature, changes in blood concentration loss of water.
- They can tolerate temperature fluctuation of as much as 6.5°C.
- Camels never sweat till their body temperature risesupto 41°C.
- When the water scarcity occur, camels produce concentrated urine & dry faeces& thereby considerably reduce water loss.
- When water is not available, they will not produce urine but will retain urea in tissues.
- When water is sufficiently available they may drink large quantities of water (upto 80 litres in 10 minutes).

# **Excretion of nitrogenous wastes**

- Excretion is the separation & elimination of metabolic wastes & the excess of essential materials from the body to maintain homeostasis.
- Oxidation of nitrogenous compounds produces toxic nitrogenous wastes (eg:- urea, uric acid, ammonia, creatinine,..).
- Apart from eliminating metabolic wastes, excretion is also significant in the regulation of volume, pH & the osmotic & ionic concentrations of the body fluids.

- Based on the nature of the excretory products, four major kinds of excretion can be recognized.
   They are
  - 1. Ammonotelism
  - 2. Ureotelism
  - 3. Uricotelism
  - 4. guanotelism

# **Ammonotelic excretion**

- It is the excretion of nitrogenous waste as *ammonia*.
- Animals which excrete ammonia are called *ammonotelic animals*.
- Eg:- Cnidarians, sponges, crustaceans,...
- Ammonia is *highly toxic & water soluble*.
- So it has to be immediately eliminated from the body or converted to less toxic urea & uric acid.
- The excretion of ammonia involves heavy loss of water & it is possible only in watery medium. So ammonotelic animals are aquatic forms.
- Ammonia is produced by the deamination of amino acids.
- Deamination is the removal of amino group from an amino acid, producing free ammonia &keto acid.
- Deamination is of two types :oxidative deamination & hydrolytic deamination.
- Oxidative deamination is catalyzed by the enzyme *amino acid dehydrogenases*. It is completed in two stages : oxidation & hydrolysis.
- Oxidation produces imino acid & hydrolysis yields keto acid & ammonia.
- Hydrolytic deamination is catalyzed by the enzyme amino acid hydrases or amino acid desulfhydrases.
- Amino acid hydrasesdeaminateshydroxy amino acids (serine, threonine).
- Serine dehydrationintermediate iminohydrolysispyruvic acid + NH<sub>3</sub>.
- +H<sub>2</sub>Ocompoundacid+H<sub>2</sub>O
- Amino acid desulfhydrasesdeaminates sulfur containing amino acids (cysteine, homocysteine).

- The action of dehydrases is completed in two stages: dehydration & hydrolytic deamination.
- Dehydration produces an imino acid & hydrolysis yield keto acid & ammonia.
- The action of desulfhydrases is completed in two stages :desulfhydration& hydrolytic deamination.
- Desulfhydration produces an imino acid & hydrolysis yield keto acid & ammonia.

## Uricotelic excretion

- It is the excretion of nitrogenous waste as *uric acid*.
- Animals which exhibit uricotelism are called *uricotelic animals*.
- Uric acid is produced by the metabolism of nucleic acids & purines.
- Uric acid is non toxic& water insoluble.
- Since it is non toxic, its prolonged retention in the body is not harmful to the animal.
- It is excreted as dry crystalline pellets, with little or no loss of water.
- It is an adaptation to minimize water loss.
- Uricotelic animals are completely terrestrial (lizards, snakes, birds,..).
- The droppings of these animals contain white & brownish- black materials.
- The white material consist of uric acid crystals, which are nitrogenous wastes, the brownish-black matter is the faecal matter.
- Pelicans excrete uric acid as a phosphorous rich faecal matter, called *guano*, which is used as a fertilizer.
- Though man is ureotelic, small amount of uric acid is produced in our body by purine metabolism. Normally it is eliminated through urine. When its level goes high, it precipitate as crystals & accumulate in joints causing acute pain. This condition is called *gout*.

#### Ureotelic excretion

- It is the excretion of nitrogenous wastes as *urea*.
- Animals exhibiting ureotelism are called *ureotelic animals*.
- Urea is water soluble & less toxic.
- Its elimination requires only a small quantity of water
- It is an adaptation for semi-terrestrial life.
- Eg:- mammals, earthworms, prawns, cartilaginous fishes,....
- Cartilagenous fishes can retain large amount of urea in their blood. This makes their blood almost isosmotic to the medium & prevents osmotic loss of water from the body.
- Ureotelic animals produce hypotonic urine when there is heavy intake of water, when there is only small intake of water, they produce hypertonic urine.
- Frog is ureotelic where as tadpole is ammonotelic.
- In summer lung fishes are ureotelic, typically they are ammonotelic.
- Crocodiles are uricotelic when they are on land, but ammonotelic when they remain in water.
- Earthworms are ammonotelic in rainy season & ureotelic in dry season.

# Urea cycle

- Urea is formed by the combination of two molecules of  $NH_3\&$  one molecule of  $CO_2$ , with the elimination of one molecule of  $H_2O$ .
- Urea is formed in cycle of reactions called Krebs *Henseleit cycle, urea cycle, ornithine cycle, ...*
- In mammals, liver is the major site of urea formation.
- Urea cycle is completed in five major steps,
  - 1. Formation of carbamyl phosphate from NH<sub>3</sub>& CO<sub>2</sub>.
  - 2. Formation of citrulline from carbamyl phosphate & ornithine.

- 3. Formation of arginino-succinate from citrulline& aspartic acid
- 4. Formation of arginine from argininosuccinate.
- 5. Formation of urea & ornithine from arginine.

#### i. Formation of carbamyl phosphate from $NH_3$ & $CO_2$ .

- The first step in the urea synthesis is the formation of enegy rich compound *carbamyl phosphate*.
- It takes place in *mitohondria*.
- It is catalyzed by the enzyme *Carbamyl phosphate synthetase 1*.
- It is a three step reaction
  - 1. Activation of CO<sub>2</sub> by ATP, forming *carboxyl phosphate*.
  - 2. Reaction of carboxyl phosphate with NH3, forming ammonium carbamate.
  - 3. Reaction of ammonium carbamate with another molecule of ATP, forming *carbamyl phosphate*.

(i) ATP + HCO<sub>3</sub>- 
$$\xrightarrow{\text{CPS-I, Mg}^{++}}$$
 "Active CO<sub>2</sub>" + ADP + Pi

(ii) Active 
$$CO_2 + NH_3 \xrightarrow{CPS-I, Mg^{++}} Ammonium carbamate$$

## ii. Formation of citrulline from carbamyl phosphate & ornithine.

- It is the second step takes place in mitochondria.
- Carbamyl phosphate enters the urea cycle, combines with ornithine & forms citrulline.
- It is catalyzed by the enzyme *Ornithine carbamyltransferase (OCT)*.

Carbamyl phosphate + Ornithine OTC Citrulline + Pi.

#### iii. Formation of arginino-succinate from citrulline& aspartic acid

- It is the cytoplasmic reaction.
- It is catalyzed by the enzyme *Arginino-succinate* synthetase.
- Citrulline combines with α-amino group of aspartic acid & forms arginino-succinic acid.

# iv. Formation of arginine from argininosuccinate.

- Argininosuccinate undergoes cleavage & forms arginine & fumarate.
- This is catalyzed by the enzyme *Arginino-succinate lyase*.

Arginino-succinic acid Argininosuccinase Arginine + Fumarate.

• Fumarate formed in this reaction inhibit the enzyme. To avoid this fumarate gets into mitochondria enters the TCA cycle &coverted into maleic acid& then to oxalo acetic acid. OAA undergoes transamination & forms aspartate, which may re-enter the urea cycle.

# v. Formation of urea & ornithine from arginine.

- It is the final step in urea cycle.
- In this reaction of arginine gives *urea & ornithine*.
- It is catalyzed by the enzyme *arginase*.
- Ornithine returns to mitochondrion & combines with carbamyl phosphate & repeats the cycle.

Arginine Arginase Urea + Ornithine +H<sub>2</sub>O

# **Hormonal control of kidney function**

- The functioning of kidney in urine formation is under nervous, hormonal & enzymatic control.
- The major hormones involved in the urine production includes aldosterone, adrenaline, vasopressin, thyroxine ,parathormone& atrial natriuretic hormone.

Hormonal control of urine production					
Hormone	Gland	<b>Function</b>			
1. Diuretic hormone	Pituitary	Stimulates urine production			
2. Aldosterone	Adrenal cortex	Stimulates tubular re-absorption of Na <sup>+</sup> & tubular secretion of K <sup>+</sup> .			
3. Epinephrine	Adrenal medulla	Inhibits glomerular filtration & thereby decreases urine production.			
4. Vasopressin (anti-diuretic hormone)	Hypothalamus	Stimulates tubular re-absorption of water & thereby reduces diuresis.			
5. Thyroxine	Thyroid gland	Reduces tubular re- absorption of water & thereby increases diuresis.			
6. Parathormone	Parathyroid gland	Promotes tubular reabsorption of Ca <sup>2+</sup> & Mg <sup>2+</sup> & inhibits tubular re-absorption of phosphates.			
7. Atriopeptin	Atrial wall cells	Inhibits tubular re- absorption of water & sodium & lowers the production of aldosterone.			

# Role of ADH in the dilution or concentration of urine

Level of body water	Solute potential of blood	ADH	DCT & Collecting duct	Urine
Loss exceeds uptake	Falls	Released	Permeable to water	Concentrated
Intake exceeds loss	Rises	Not released	Impermeable to water	Dilute

# **Renal disorders**

Kidney functions may be impaired by infections, lesions, tumours, electrolyte imbalances, kidney stone formations, chemical poisons,..

#### Renal failure

- Nephrons fail to function properly resulting in *oedema*, acidosis &uraemia.
- *Oedema* Swelling of body parts due to the retention of large amounts of sodium & fluids in tissues.
- *Acidosis* Acidity of body fluids resulting from the excessive production of beta- hydroxyl butyric acid &acetoacetic acid in the body, low glomerular filtration of hydrogen ions, reduced production of ammonia & phosphates, marked decrease in the alkali reserve of blood,...
- *Uraemia* Increased level of urea & other nitrogenous waste compounds in the blood that are normally eliminated by the kidney.
- Renal failure can be treated by dialysis or kidney transplantation.

# **Renal hypertension**

- It is the state of abnormally high blood pressure in the nephric blood vessels.
- It leads to arteriolarnephrosclerosis.
- It is the progressive thickening & eventual damage of renal arterioles.
- It reduces the blood supply to the kidneys, with the result in the damage of glomeruli.

# **Nephritis**

- It is the inflammatory disorder of kidney.
- Commonest & most serious forms are pyelonephritis (pyelitis) & glomerulonephritis.
- **Pyelonephritis** It is the acute inflammation of the pelvis region of the kidney due to bacterial infection.
- It damages the kidney tubules.
- It is accompanied by high fever & chill, severe back pain, presence of WBC in urine, high BP,...
- It is common among children, particularly girls & pregnant women.
- **Glomerulonephritis** Also called Bright's disease.
- It is the severe inflammation of the glomeruli.
- It results from the deposition of immune complexes in the capillary wall of glomeruli.
- Glomeruli become swollen,inflamed& engorged with blood.
- Glomerular membrane becomes highly permeable to most of the blood constituents leads to albuminuria, haematuria,...
- Focal or segmental glomerulonephritis- Glomerulonephritis affects only a limited number of glomeruli.
- The disease becomes chronic & results in the progressive damage of kidney & ultimate death.

## **Dialysis**

- In acute & chronic renal failures, kidneys are unable to properly excrete nitrogenous wastes & also to regulate the pH & electrolyte concentration of the plasma.
- As a result, blood gets charged with high levels of urea, creatinine& other wastes.
- In this condition kidney transplantation or dialysis is essential as a life saving measure.
- Dialysis is the process by which cystalloid substances are removed from a solution to pure water by interposing a semipermeable membrane between the two.
- Crystalloid substances pass to water across the membrane by simple diffusion until their concentration becomes the same in water & the solution.
- There are two types of dialysis, namely haemodialysis& peritoneal dialysis.

#### a) Haemodialysis

- *Haemodialysis* is the artificial removal of nitrogenous wastes from a patients blood with the help of a semipermeable membrane.
- *Dialyzer* The apparatus used for heamodialysis.
- Dialysing fluid The fluid used in a dialyzer for accepting the wastes from the blood.
- *Cellulose or cellophane* The semipermeable membrane, that seperates blood from the dialysing fluid.
- *Dialysate* The purified blood coming out of the dialyzer after clearing of its waste.

#### b) Peritoneal dialysis

- It is also called *Continuous ambulatory peritoneal dialysis* (CAPD).
- It is more convenient & time saving method of haemodialysis.
- Here peritoneum serves as semipermeable dialyzing membrane & dialyzing fluid is made to circulate through the abdominal cavity.
- Peritoneum permits the rapid bidirectional transfer of substances.

# **Kidney transplantation**

- It is the replacement of defective, diseased or damaged kidney by a functional kidney from a donor.
- When medication &haemodialysis fails this gives a satisfactory result.
- For kidney transplantation the donor & recipient should be either identical twins or immunologically matching individuals.
- *Kidney rejection or tissue rejection* During the transplantation, the immune system of the recipient produces antibodies against the proteins of the transplanted kidney, if the proteins are mismatching. These antibodies react with the kidney transplant & destroy it.
- *Immuno suppressive drugs* Kidney rejection can be avoided by administering this drug. This suppress the immune power of the recipient.
- The success of kidney transplantation depends upon the genetic similarity between the donor & the recipient.
- Accepting kidney from the identical twin will be most reliable & safest & from siblings will be safer.

## **MODULE: 6**

# **MUSCLE PHYSIOLOGY**

- Muscles are the contractile tissue concerned with the body movements, including locomotion.
- Muscle constitute 45% of body weight & 35% of body proteins, they carry out nearly 50% of total metabolic activities of a resting body.
- Fundamental properties of muscles are
- **Excitability** ability to perceive & respond to the stimuli.
- **Contractility** ability to shorten & thicken when sufficiently stimulated.
- **Extensibility** ability to stretch or extend
- **Elasticity** ability to extension & recoil

Muscles have three major functions:-

- 1. Motion
- 2. Maintenance of posture
- 3. Heat production

#### Muscle cells

- Also called musclefibres.
- Long, slender &fibre like.
- Plasma membrane sarcolemma.
- Cytoplasm sarcoplasm, it contains nucleus, mitochondria, sarcoplasmic reticulum, myofibrils,...
- Myofibril is formed of myofilaments.
- Myofilaments two types thick - myosin &thin - actin.

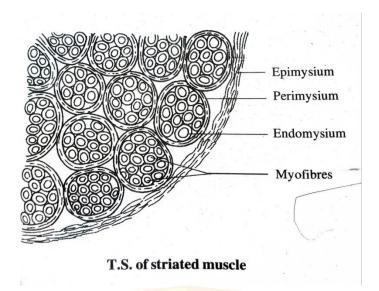
#### EM structure

- Striated muscles are arranged in thick bundles known as fascicles.
- Fasciculus.

Swollen middle portion – *belly*.

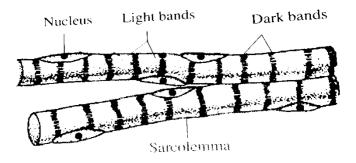
Two narrow ends attaches to a bone through tendon.

- When the tendon is flat & broad, called *aponeurosis*.
- *Epimysium* The entire muscle is wrapped within a fibrous connective tissue covering.
- *Perimysium* within the muscle each muscle bundle is enclosed within a connective tissue sheath.
- *Endomysium* each muscle cell in a bundle is surrounded by a connective tissue packing.



# Ultra structure of striated muscles

- Muscle bundles are formed of long, cylindrical multinucleate muscle cells called *muscle fibres*.
- Muscle fibre is formed by the fusion of uninucleate embryonic cells called *myoblasts*.
- Sarcoplasm containsnucleus, mitochondria, sarcoplasmic reticulum, myofibrils, glycogen reserve, myoglobin, transverse tubules,....
- *Transverse tubules* (*T tubules*) are the extensions of sarcolemma & they open to the outside of the fibre. They run transversly through the fibre& perpendicular to the sarcoplasmic reticulum. It contains a fluid rich in Ca<sup>2+</sup>.
- One T tubule & a pair of sarcoplasmic vesicles together form a *triad*.
- The specialized regions of SR which are in contact with the T tubules are called *terminal cisternae*.
- Muscle fibres have alternate dark and light bands, known as stripes or striations.
- The light bands are called *isotropic bands or I-bands*.
- The dark bands are called *anisotropic bands or A-bands*.
- Each I-band is bisected by an **Z-line**(Z-zone or Krause's membrane).
- Each A-band by an *H-zone*(Hensen's zone).
- In the centre of the H-zone, is the *M-line*.
- Each muscle fibre is formed of a large number of cylindrical, unbranched and longitudinal *myofibrils* (*sarcostyles*).



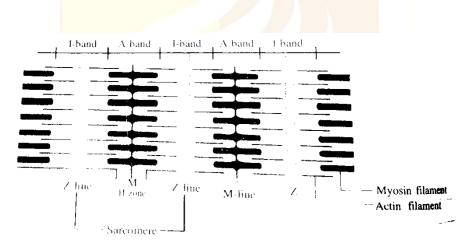
Striated muscle fibre

- Each of them, in turn, is formed of still delicate protein filaments, called *myofilaments*. Myofilaments are arranged in repeating bundles, called *sarcomeres*.
- Sarcomeres are the structural units of muscle fibres.

- Adjacent sarcomeres are separated by the narrow Z-zone.
- So, repeating Z-lines divide the muscle fibre into a <u>series of</u> sarcomeres.

# **Myofilaments and muscle proteins**

- Myofilaments of striated muscles are of three kinds, *thick*, *thin and elastic*.
- They are formed of *contractile*, *globular and fibrous proteins*.
- Thick filaments are formed by the protein *myosin*.
- Thin filaments are formed mostly by *actin*.
- Elastic filaments are formed by a long, thin, coiled and spring-like protein, called *titin*.
- Myosin filaments have projecting *cross bridges* for linking with actin filaments.
- Actin & myosin filaments are arranged separately in alternating bundles.
- Actin filaments from the two sides overlap the myosin filaments & interlock with them
- Acin filaments extend between the boundary of the H-zone & the boundary of Z line.
- Myosin filaments extend between the two boundaries of the same A-band.
- In the I-band, only actin filaments are present.
- In the H-zone of the A-band only myosin filaments are present.



Arrangement of myofilaments (diagrammatic)

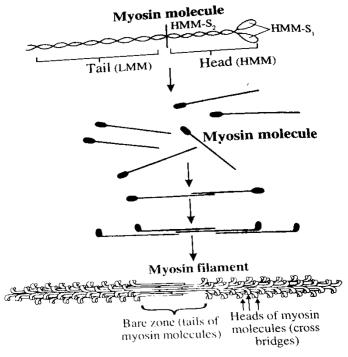
# Chemistry of skeletal muscles

- Nearly 75-80% of skeletal muscles is formed of water.
- The remainder consists of proteins, lipids, glycogen and inorganic ions.
- Muscle proteins are of different types.
- Nearly 20% of them consists of collagen and elastin.
- Another 20% includes enzymatic proteins.
- The remaining muscle proteins include *myosin*, *actin*, *titin*, *troponin* and *tropomyosin*, which are actively involved in muscular contraction.
- Myosin has enzymatic ATP-ase activity also, while the others have no ATP-ase activity.
- In vertebrate muscles, the high-energy phosphate compound *creatine phosphate*, *or phosphocratine*, is present as an energy reservoir.

- In invertebrate muscles, arginine phosphate is present, instead of creatine phosphate.
- The inorganic ions of muscles include Ca<sup>2+</sup>, Mg<sup>2+</sup> and K<sup>+</sup>.
- In resting muscle fibres, sarcoplasmic reticulum stores large amounts of Ca<sup>2+</sup>.
- When the muscle gets stimulated for contraction, sarcoplasmic reticulum releases Ca<sup>2+</sup>.
- This activates the enzyme ATP-ase and thereby initiates muscle contraction.
- Mg<sup>2+</sup> ions are important for muscular contraction and relaxation, though they do not initiate contraction.
- K ions are essential for the maintenance of the normal physical and physiological states of actin and myosin.

# Organization of myosin filaments

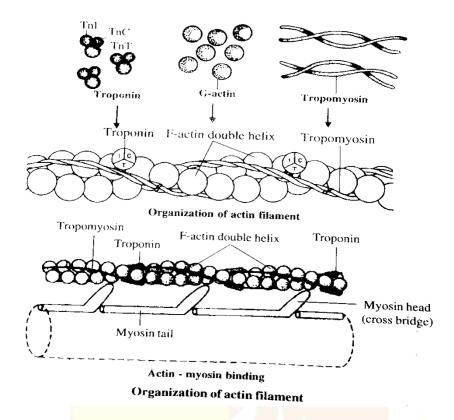
- Myosin (thick) filaments are polymers of the contractile protein myosin.
- Myosinamounts to more than 50% of the total contractile protein content of skeletal muscle.
- It exists in two forms, namely partially folded alpha form  $(\alpha myosin)$  and fully folded beta form  $(\beta myosin)$ .
- Myosin molecule is adipeptide, formed of two spirally twisted polypeptide chains.
- It is almost rod-like, with a globular head and a filamentar "tail".
- Myosin headis called heavy meromyosin (HMM), and myosin tail is called light meromyosin(LMM).
- Head has two sub-units, namely aglobular sub-unit, called heavy meromyosin— $S_1$  (HMM- $S_1$ ), and a helical rod, called heavy meromyosin- $S_2$  (HMM- $S_2$ ).
- S<sub>1</sub> is the most important part of the myosin molecule in that it forms a projecting cross bridge for binding with actin filament.
- It contains binding sites for the enzyme ATPase which hydrolyses ATP to ADP.
- Thus, HMM-S<sub>1</sub> has both actin-binding and ATPase activities.
- Cross bridges are arranged in pairs in a spiral pattern around the main axis of the myosin filament.
- Projecting cross bridges are absent in the middle portion of the filament, which is called bare zone.



Organization of myosin filament

# Organization of actin filaments

- Thin myofilaments are formed mainly of the globular protein *actin*.
- Actin is the second major protein of skeletal muscle.
- It is contractile, but elastic.
- Actin amounts to nearly 25% of the total proteins of skeletal muscles.
- Each actin filament is formed of two beaded strings, called *F-actin* (*fibrous actin*).
- They remain helically twisted, forming an actin double helix.
- Each F-actin is a polymer, formed of several globular actin monomers, called *G-actin* (*globular actin*).
- Thus, actin exists in polymeric and monomeric forms, known respectively as F-actin and G-actin.
- In skeletal muscles, actin exists mostly asF-actin.
- Polymerisation of G-actin to form F-actin requires ATP.



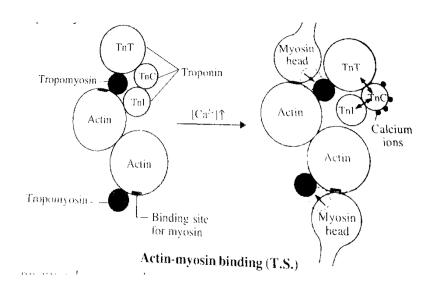
- Associated with the F-actin double helix are some accessory proteins also.
- The important ones among them are tropomyosin, troponin, alpha-actinin and beta-actinin.
- *Tropomyosin and troponin act as regulator proteins* and control the movement of actin filaments during muscular contraction.
- They inhibit actin-myosin interaction in the absence of Ca<sup>2+</sup> ions.
- On the other hand,  $\alpha$  and  $\beta$ -actinins regulate the polymerisation of G- actin monomers.

#### **Tropomyosin**

- Tropomyosin is a rod-shaped, contractile fibrous protein.
- It amounts to 5-10 % of the total contractile proteins of skeletal muscle.
- It exists as two helically twisted longitudinal filaments, enclosed in the groove of the F-actin double helix.
- Tropomyosin plays an important role in sensitizing actin and myosin molecules to Ca<sup>2+</sup> ions.
- The tropomyosin of vertebrate striated muscles is called *tropomyosin-B*, and that found in the non-striated muscles of many invertebrates is called *tropomyosin –A or paramyosin*.

#### **Troponin**

- Troponin occurs at intervals on actin filaments.
- It takes up calcium ions from sarcoplasm to initiate muscle contraction.
- Troponin is a complex globular protein with *three sub-units*, *namely troponins T*, *C* and *I*.
- Troponin-T (TnT) binds to tropomyosin.
- Troponin-C (TnC) reversibly binds to Ca<sup>2+</sup> ions.
- *Troponin-I (Tnl) is an inhibitory component*, capable of inhibiting any interaction between actin and myosin.



#### **Titin filaments**

- Titin filaments, or elastic filaments, are remarkably long and thin.
- They are formed of a special type of exceptionally large., extremely long and thin, and excessively coiled and spring-like.contractile protein, called *titin*.
- Titin is the *largest of all known single polypeptides*.
- Titin filaments extend between the Z line and the myosin filaments.
- Titinfilarments are significant in three respects:
  - (i) They hold the actin and myosin <u>filaments in</u> tight alignment with each other.
  - (ii) Facilitate the anchorage of myosin filaments to the Z line.
  - (iii) Serve as a molecular spring and thereby provide passive elasticity to the muscle.

# Chemistry & mechanism of muscle contraction

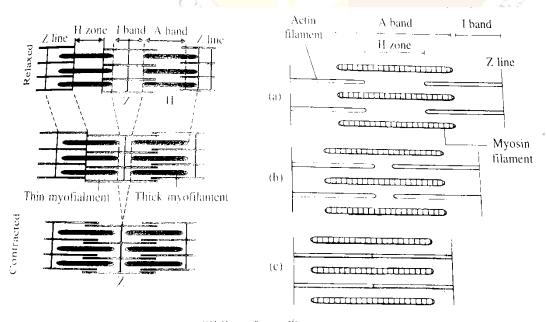
- Muscular contraction is the shortening of myofibrils, in response to a nervous stimulation.
- During this, actin filaments slide over myosin filaments and link with them, forming *acto-myosin complexes*.
- During muscular relaxation, they delink and move away from each other.
- During muscular contraction, an action potential reaching the axon endings of a motor neuron, spreads to the muscle fibres and excites them.
- As a result, a post synaptic action potential is produced in the motor end plate of each muscle fibre.
- This leads to muscular contraction.
- The triggering of muscular contraction by the excitation of nerve fibres and the generation of a post-synaptic action potential is called *excitation-contraction coupling* (*ECC*) *or electrochemical coupling*.

#### **Contraction of skeletal muscles**

• The contraction of skeletal (striated) muscles involves two sets of events, namely ultrastructural changes and physiological or biochemical changes.

#### Ultrastructural changes

- The ultrastructural changes during muscular contraction include the regular and cyclic attachment and detachment between the myosin cross-bridges and the actin filaments.
- These changes are best explained by the "sliding-filament theory of muscle contraction"
- According to this theory, muscle fibres become short and thick during contraction by the shortening of their sarcomeres.
- The shortening of the sarcomeres is not due to the contraction and shortening of myofilaments, but by their sliding and overlapping.
- Actin filaments slide inward from adjacent Z-zones to the H-zone in between.
- In the H-zone, they completely overlap the myosin filaments and link with them, forming actomyosin chains.
- This inward movement of actin filaments brings the Z-zones closer and closer together.
- So, the length of the I-band and that of the sarcomere become progressively shorter and shorter.
- Actin filaments from the two sides ultimately meet together at the H-zone.
- The H-zone also becomes shorter and finally it disappears.
- Thelength of the A-and remains unchanged.
- During muscular contraction, the head of the myosin filament functions as a hook.
- It attaches to a binding site in the F-actin, forming a cross-bridge.
- It pulls the actin filament further towards the H-zone in the A-band.
- Now, the myosin head detaches from the actin, returns to its original form and shape and then reattaches to a new site a little ahead in the actin filament.
- This shortens the sarcomere up to 30 % of its length.



Sliding of myofilaments

• The energy required for the actin-myosin interaction is obtained by ATP breakdown.

- It has been suggested that the binding of actin with myosin occurs at a site different from the ATPase site of myosin.
- The formation of actomyosin is believed to activate the ATPase site by an allosteric mechanism.
- This, in turn, results in ATPhydrolysis.
- The free energy of this hydrolysis is utilized for the detachment of myosin head.

# The sequence of events occuring during cross-bridge binding are the following:

- 1. Myosin head first attaches to a stable site in the actin filament.
- 2. This binding produces a rocking or rotatory movement of the myosin head and causes it to exert a pull on the myosin filament.
- 3. Consequently, tension is transmitted to the myosin filament and this causes the sliding of the actin filament over the myosin filament.
- 4. Once the rotation of the myosin head is over, ATP is hydrolysed by ATPase.
- 5. The free energy of ATP hydrolysis is used for the detachment of the myosin head.
- 6. Soon, the head attaches to the next binding site in actin and the whole cycle of events is repeated untill the actin filament reaches the centre of the sarcomere.

# Physiological changes

- The physiological mechanism involved in the contraction of skeletal muscles is known as *electrochemical coupling or excitation-contraction coupling (ECC)*.
- The contraction of skeletal muscles requires nervous stimulation.
- When a motor impulse reaches the myo-neuronal synapse, the synaptic vesicles of the axon ending get activated and they release the transmitter substance acetylcholine to the synaptic cleft.
- Acetylcholine diffuses towards the muscle fibre and binds to specific receptor sites in the sarcolemma.
- This stimulates the sarcolemma and temporarily enhances its permeability to ions, especially to Na<sup>+</sup> and K<sup>+</sup>.
- As a result, sodium <u>channels open, heavy</u> influx of Na<sup>+</sup> follows, and there develops an endplate potential.
- This leads to the post-synaptic depolarisation of the sarcolemma and the generation of apost synaptic action potential at the motor end-plate.
- Acetyl choline is soon hydrolysed to *choline and ethanoic acid* by the enzyme *choline esterase* to prevent overstimulation and the sustained or persistent post-synaptic depolarisation.
- The end-plate action potential soon spreads deep into the interior of the muscle fibre along the Ttubules.
- This excites the whole set of fibrils and triggers muscular contraction by releasing Ca<sup>2+</sup> from sarcoplasmic reticulum and T- tubules.
- During this, there is the coupling of the electrical events of excitation with the ultrastructural events of muscular contraction. This is called *excitation contraction coupling*.

- During muscular contraction, free Ca<sup>2+</sup> ions diffuse from the <u>sarcoplasm in to</u> the myofilaments and bind to troponin C (TnC).
- The TnC-Ca<sup>2+</sup>complex soon interacts with Tnl.
- This causes conformational changes and also reverses the inhibitory influence of the troponin <u>system</u> on actin-myosin interaction
- As a result of the reversal of the inhibitory effect, actin gets 'switched on' and its myosin-binding sites are free for actin-myosin interaction and cross-bridge cycle.
- The active state of actin and the high level of free sarcoplasmic Ca<sup>2+</sup> stimulate the ATPase activity of myosin.
- ATP hydrolysis follows to provide energy for <u>muscular contraction</u>.
- Simultaneously, myosin cross bridges attach to actin filaments and undergo interaction.
- This causes the myosin heads to rock against the actin filament, pulling the filaments away from each other.
- Actin filaments slide over myosin filaments, leading to muscular contraction.
- When the excitation of the sarcomere ceases Ca<sup>2+</sup> ions are actively pumped back to the sarcoplasmic reticulum and T-tubules by an ATP-driven calcium pump.
- The free energy of ATP hydrolysis is used to detach the myosin head from the actin.
- The myosin head is now free to attach to the next site in the actin filament and thereby to repeat the attachment-detachment cycle.
- If the active transport of Ca<sup>2+</sup> from sarcoplasm to sarcoplasmic reticulum is inhibited, relaxation does not occur. This results in a state of sustained contraction, called *muscle contracture*.

#### Muscular relaxation

- Relaxation of the sarcomere begins when the concentration of Ca<sup>2+</sup> ions in the sarcoplasm fall below the threshold level.
- During relaxation, most of the calcium ions would be absorbed back to the SR from sarcoplasm.
- At a low calcium level, the enzyme ATPase becomes less active.
- As a result, the breakdown of ATP and the release of energy for muscular contraction come to an end.
- During relaxation, the cross-bridges between actin and myosin filaments undergo reorganization.
- As a result, the actin filaments delink from myosin filaments and slide out from the H-zone.
- This pushes the Z-lines away from each other, causing the lengthening of the muscle fibres.
- The muscle fibres return to their original physical form and physiological state.

# **Energy for muscular contraction**

- Muscular contraction requires a sustained supply of energy.
- <u>This</u> energy supply is maintained by a series of biochemical reactions, known as *Lohmann scheme of reactions*.

The major energy-related biochemical events are,

- 1. Breakdown of ATP to provide immediate energy for the contraction of muscle fibres.
- 2. Breakdown of creatine phosphate to provide phosphate and energy for the re-synthesis of ATP.

- 3. Anaerobic oxidation of muscle glycogen to lactic acid to provide ATP for the re-synthesis of creatine phosphate.
- 4. Aerobic oxidation of a part of the lactic acid to provide energy for the re-synthesis of muscle glycogen.
- 5. Re-synthesis of glycogen from the remaining lactic acid.

#### **Breakdown of ATP**

- The enzyme *ATPase breaks ATP to ADP* and inorganic phosphate (Pi).
- A portion of its energy store is liberated as active kinetic energy.
- This free energy facilitates actin-myosin interaction.
- This leads to the sliding of myofilaments and the shortening of muscle fibres.

ATP ATPaseADP +Pi- Energy for muscular contraction

# Breakdown of creatine phosphate and re-synthesis of ATP

- For continued muscular activity the spent ATP has to be quickly re-synthesised.
- For this, energy and inorganic phosphate are made available by the *break down of creatine* phosphate (phosphocreatine), with the help of the enzyme creatine phosphatase.
- During this, the high-energy phosphate splits off from creatine and combines with ADP to *form*ATP.

Creatinecreatine + High energy phosphate for the resynthesis of ATP. phosphatephosphatase

ADP+High energy phosphatecreatine ATP. phosphotransferase

# Anaerobic breakdown of muscle glycogen to lactic acid

- For repeated muscular contraction creatine phosphate also has to be re-synthesized from creatine and ATP.
- Muscle glycogen is oxidized to lactic acid in a chain of reactions known as *muscle glycolysis or lactic acid fermentation*.
- At first, glycogen is oxidized to pyruvic acid through several intermediate reactions and products.
- Pyruvic acid is soon transformed to lactic acid.
- Inthe course of muscle glycolysis, ATPissynthesised.
- Creatine combines with it and *forms creatine phosphate*.

Muscle glycogen <u>lactic acidLactic acid + ATP</u> for re- synthesisingcreatine phosphatefermentation

Creatine + ATP — Creatine phosphate + ADP

#### Aerobic oxidation of lactic acid

- 1/5 of the lactic acid produced is aerobically oxidized to CO<sub>2</sub>, H<sub>2</sub>Oand energy through a cycle of reactions, known as *Krebs Cycle*.
- Lactic acid first gets converted to pyruvic acid.
- Pyruvic acid is soon transformed to an energy-rich compound, called acetyl co-enzyme A (acetyl CoA).
- Acetyl CoA enters the Krebs Cycle.
- The energy released from Krebs Cycle is utilized for re-synthesizing muscle glycogen from the remaining 4/5 of the lactic acid.
- Lactic acid 

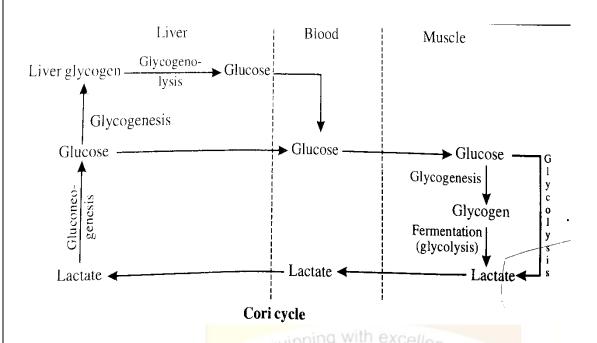
  Pyruvic acid 

  Acetyl CoA Krebs CO<sub>2</sub> +H<sub>2</sub>O+ energy for reCycle synthesizing

  Muscle glycogen

# Re-synthesis of muscle glycogen from lactic acid

- 4/5 of the muscle lactic acid is used for the re-synthesis of muscle glycogen.
- This *occurs in liver*, since the enzymes necessary for it are absent in muscles, but present in liver.
- At first, muscle lactic acid passes to blood and reaches liver. Here, it gets converted to glucose through gluconeogenesis.
- A part of this liver glucose may be converted to liver glycogen. This is called *glycogenesis*.
- The rest is released to blood and it reaches the muscle.
- A part of the liver glycogen is converted to glucose by the process of *glycogenolysis* and then discharged to blood.
- This blood glucose also reaches muscles.
- In the muscle, glucose gets converted to muscle glycogen (by *glycogenesis*). The cycle of reactions by which muscle lactic acid is transformed to muscle glycogen is known as *Cori cycle or lactate-glucose cycle*.



#### Muscle twitch& muscle tetanus

- Muscle twitch- The sum total of muscle events, occurring during a single contraction.
- Three stages:

Latent phase – time interval between the initial stimulation & the beginning of actual contraction.

- No physical changes occur, several biochemical changes takes place.
- Transmission of action potential to the sarcoplasmic reticulum.
- Release of Ca<sup>2+</sup> from sarcoplasmic reticulum.

## Contraction phase

- Muscle shortens & its tension increases.

#### Relaxation phase

- Muscle returns to its original physical state & physiological condition.
- It lasts longer than contraction phase.
- Myograph apparatus which can measure muscle twitch.
- **Myogram**—the record produced by the myograph.
- *Muscle tetanus* sustained hyper contraction of muscles due to the fusion of numerous twitches with no time for relaxation between stimuli
- Continuous stimuli results in the overlapping or fusion of successive twitches to form a large single twitch.
- Two types :

*Incomplete or unfused tetanus*— stimuli are spaced so that the muscle can relax partially. *Complete or fused tetanus*— stimuli are fused so that relaxation is altogether absent in between successive stimuli.

#### **Isomeric & isotonic contractions**

- *Isomeric contraction* muscular contraction in which the tension on the muscle increases sharply.
  - Only minimal muscle shortening.
  - No movement is produced.
  - Energy is utilized.
- *Isotonic contraction* muscular contraction in which the force on the muscle remains same or constant.
  - Muscle shortens.
  - Pulls on another structure such as bone.
  - Produce movement
  - Energy is utilized.

#### All or none law

- The magnitude of muscle contraction is independent of the intensity of the stimulus, & muscle contraction never be partial, but will always be complete.
- This implies that either there will be maximal contraction, or there will be no contraction.

#### **Summation of stimuli**

- Superpositioning of one contraction over the previous one.
- Results in excessive contraction or extreme shortening of the muscle, much greater than in a single stimulus.
- Tension developed during summation would be much greater than that of a single twitch.
- If two stimuli are too close, the second one will have no effect. This is because muscle membranes will be in the refractory period, & will not able to elicit a contraction triggering action potential.

# Muscle fatigue & Rigor mortis

- *Muscle fatigue* muscle loses its power for contraction, fails to respond to stimuli, & becomes relaxed & flabby.
- Cardiac muscles are immune to fatigue.
- ATP ,phosphocreatinine& glycogen becomes almost exhausted.
- Release of Ca<sup>2+</sup> from SR is very slow & much reduced.
- Accumulation of lactic acid & other wastes.
- The neuromuscular junction gets fatigued before the muscle is fatigued.
- *Rigor mortis* temporary condition in which all the muscles of a dead individual become rigid, non elastic& permanently contracted.
- The body becomes stiff.
- *Rigor* is a state of muscular rigidity due to the depletion of ATP, creatine phosphate,...
- After death enzyme stops functioning, ATP synthesis become impossible.
- Energy is not available for the relaxation of muscle fibres, & they remain in the contracted state.
- Rigor mortis commences 3 hours after death, reaches maximum stiffness after 12 hours, & then gradually disappears.

#### **MODULE: 7**

#### **NERVE PHYSIOLOGY**

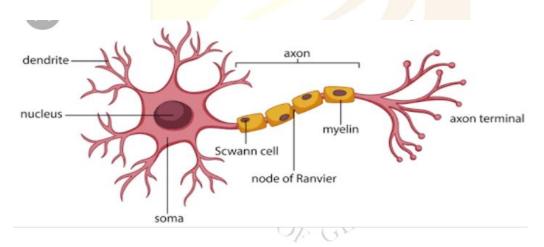
- The physiological activities of higher animals are directed, controlled & co-ordinated by two systems, namely nervous system & endocrine system.
- Nervous system act as an *electrical co-ordinator*& endocrine system act as a *chemical co-ordinator*.
- The two systems form a functional complex called *neuro endocrine system*.
- Nervous system stimulates the synthesis & release of some hormones &nervous functions are stimulated by some hormones.

#### **Components of nervous system**

• Nervous system has three main components, namely nerve cells, glial cells & nerve fibres.

#### Nerve cells or neurons

- They are the structural & functional units of the nervous tissue.
- They are the longest cells in the animal body, specialized for the generation & transmission of messages.
- They have no powers for mitotic multiplication.
- A neuron has three parts, namely cyton, dendron & axon.



# Cyton

- Cyton (soma) is the cell body.
- Its cytoplasm is called neuroplasm. It contains nucleus, all cell organelles except centrioles, numerous long & thin neurofibrils& a pigment called *lipofuscin*.
- Mitochondria are numerous to meet the high energy needs for the transmission of impulses.
- *Nissl granules / chromatoid bodies*—ribosomes are seen in clusters on rough ER.
- Lipofuscin is a by-product of lysosomal activity & its concentration increases with ageing.

#### **Dendrons**

- They are the short processes radiating from the cyton.
- They may contain mitochondria, ribosomes & other cell organelles.

- Dendrons end in small branches called dendrites.
- Dendrons& dendrites transmit impulses towards the cyton.

#### Axon

- Axon is a long & axial process of cyton.
- It transmits impulses away from the cyton.
- Axolemma or axon membrane plasma membrane of axon.
- Axoplasm protoplasm of axon. It contains numerous neurofibrils.
- Axon hillock thick & conical area in between cyton& axon.
- Axon terminals / axonites /telodendrons axons ends in fine branches.
- Synaptic knob / end bulb terminal knob of axonites. It contains mitochondria & membrane bound secretory bodies called synaptic vesicles.
- Neurotransmitters the chemicals synthesized & stored by synaptic vesicles. It helps in impulse transmission. Eg :- Acetylcholine. ing with excellence
- Collateral axons lateral branches of axons.

#### **Classification of neurons**

# **Based on the number of processes**

#### 1. Apolar neurons

Non polar neurons has no definite dendron or axon.

Nerve impulses radiate in all directions.

Eg:-Hydra

## 2. Unipolar neurons

Monopolar neuron has an axon, but no dendrons.

Eg:- Invertebrates

#### 3. Bipolar neurons

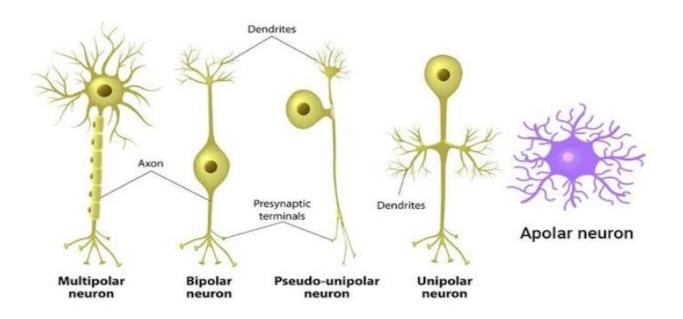
Bipolar neuron has an axon at one end & a Dendron at the opposite end.

Eg:- Retina, inner ear & the olfactory epithelium of vertebrates

#### 4. Multipolar neurons

It has one axon & several dendrons.

Eg:- Brain & spinal cord.



# Based on the nature & direction of impulses

# 1) Sensory neurons

Receptor or afferent neurons.

Transmits sensory impulses from receptor organ to brain or spinal cord.

#### 2) Motor neurons

Effector or efferent neurons

Transmits motor impulses from brain or spinal cord to effector organs, such as muscles & glands.

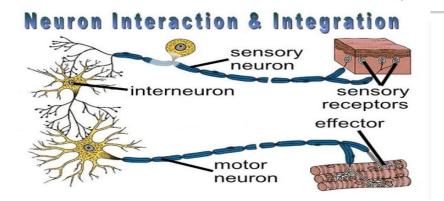
#### 3) Connecting neurons

Internuncial or association neurons.

They serve as the link between sensory & motor neurons.

They are located in brain & spinal cord.

The processes of sensory & motor neurons are arranged in bundles. Such bundles are called *nerves* in PNS, & nerve tracts in CNS.



## Glial cells

- Also called *neuroglia*.
- These are the unexcitable, non nervous, supporting & protective connective tissue cells.
- They are present in the CNS, nerve ganglia & also around nerve fibres.
- They provide mechanical & metabolic support to brain & spinal cord.
- They repair the damages of nerves & nerve fibres.
- Glial cells are of two main groups :microglial cells &macroglial cells.
- Microglial cells are mesodermal &macroglial cells are ectodermal in origin.
- (i) Microglia

Also called brain macrophages.

Phagocytic glial cells.

Protect the neurons of CNS by phagocytising cellular debris & invading microbes.

(ii) Macroglia

Larger glial cells of the CNS. inpping with exceller

They include astrocytes, oligodendrocytes, ependymal cells, radial glial cells Schwann cells & satellite cells.

- a. Astrocytes
  - Largest & numerous of all glial cells with numerous processes..
  - They form the supporting network around the neurons of brain & spinal cord.
  - Attach neurons to blood vessels.
  - Regulate external chemical environment of neurons by removing excess ions, mainly K<sup>+</sup>.
  - Play significant role in recycling the neurotransmitters.
  - Two type of astrocytes:
    - 1. Protoplasmic astrocytes found in grey matter of CNS.
    - 2. Fibrous astrocytes found in the white matter.
- b. Oligodendrocytes
  - Similar to astrocytes, but with only fewer & shorter processes.
  - They are involved in the formation of myelin sheath.
  - Support the neurons of brain & spinal cord.
- c. Ependymal cells, radial cells & Schwann cells
  - Also called *ependymocytes*.
  - They are single layer of squamous or columnar or ciliated cells.

# **Propagation of nerve impulse**

Nerves & nerve fibres are excitable and are capable of transmitting messages as electric pulses, called nerve impulses or nerve signals.

Excitability is the ability of nerve cells to respond to stimuli & to convert them as nerve impulses.

Nerve impulses are electrochemical excitation waves, passing along the membranes of stimulated neurons.

Transmission of impulses involves three fundamental processes, namely

1. Maintenance of membrane potential

- 2. Generation of action potential
- 3. Propagation of action potential

# Maintenance of membrane potential

- The plasma membrane of a neuron is electrically unstable, dynamic & polarized.
- *Membrane potential*: the potential difference existing across a nerve membrane is known as membrane potential or bioelectric potential.
- It is established & maintained by the operation of three molecular mechanisms, namely anion trap, ion leak channels & sodium- potassium pump.

### a) Anion trap

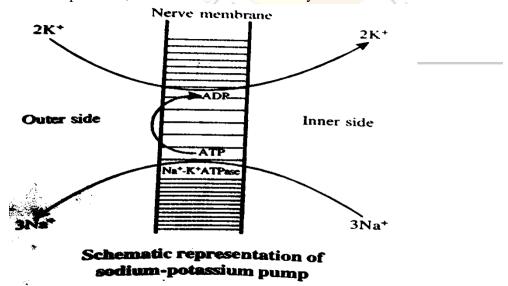
- It is the mechanism by which the negatively charged ions & molecules remain trapped inside the cell in large abundance. Trapped ions are called *fixed ions*.
- They are too large to diffuse out & so they remain trapped within the cell, contributing –ve charge inside.

### b) Ion leak channels

- These are the transmembrane ion channels which permit the selective facilitated diffusion of ions.
- Eg:- sodium & potassium channels.
- Potassium channels are more numerous than sodium channels.
- So outward diffusion of K<sup>+</sup>ions will be much greater than the inward diffusion of Na<sup>+</sup>ions.
- This contribute inward negativity.

# c) Sodium- potassium pump

- Also called sodium potassium transmembrane pump or transmembrane cation pump.
- It is an ATP dependent active transport mechanism.
- A non stimulated neuron is called resting neuron & a stimulated one is called an active neuron.
- Resting potential membrane potential of a resting neuron.
- Action potential membrane potential of an active neuron.
- In resting potential, the membrane is electrically –ve inside & +ve outside.
- In action potential, the membrane is electrically +ve inside & -ve outside.



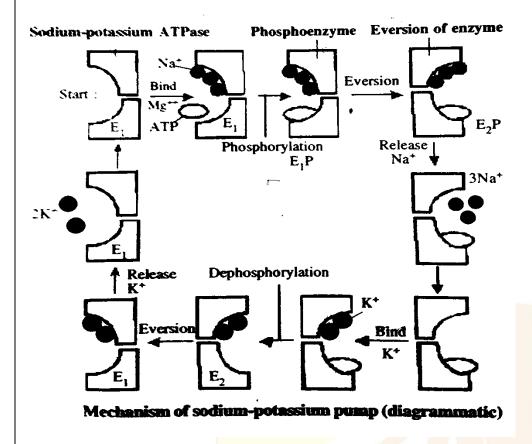
• The cytoplasm inside the membrane has more K<sup>+</sup> ions than outside, & the extracellular fluid outside has more Na<sup>+</sup> ions than inside.

- This unequal distribution creates an electro-chemical gradient across the membrane.
- These processes are maintained by the sodium-potassium pump with the aid of *sodium-potassium ATPase*.
- By this Na<sup>+</sup> ions are actively transported outward & K<sup>+</sup> ions inward across the membrane against concentration gradient.
- In a resting membrane, potassium channels remain wide open, & sodium channels remain almost closed.
- The free outward diffusion of K+ ions that is mainly responsible for the inside negativity & the maintenance of the resting potential.

# Mechanism of Na<sup>+</sup> - K<sup>+</sup> pump

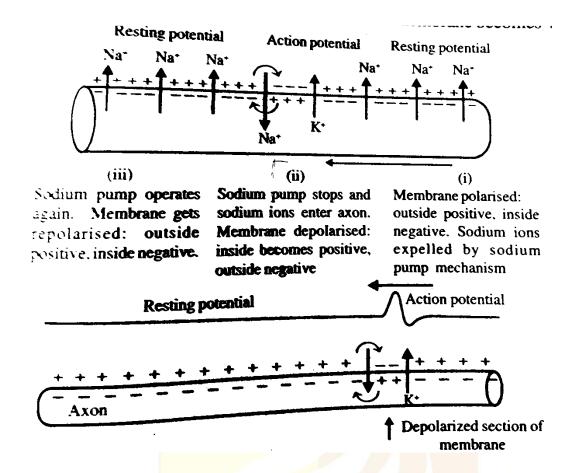
- It operates in a step by step manner.
- One molecule of ATP & three Na<sup>+</sup> attach to the membrane bound enzyme sodium-potassium ATP ase (E<sub>1</sub>).
- The enzyme gets phosphorylated in the presence of  $Na^+\& Mg^{2+}$  ions& becomes a phosphoenzyme  $(E_1P)$ .
- E<sub>1</sub>P undergoes conformational change & transforms to E<sub>2</sub>P by a revolving door mechanism.
- This brings the bound Na+ ions to the outer surface of the membrane.
- E<sub>2</sub>P then undergoes dephosphorylation in a K<sup>+</sup> dependent process & the three Na<sup>+</sup> ions are replaced by two K<sup>+</sup> ions.
- Dephosphorylation causes a reverse conformational change in the enzyme  $(E_2 E_1)$  & the enzyme transports the two K+ ions into the cell interior where they are released.
- The free  $E_1$  is again available to repeat the cycle.
- The outer surface of the membrane becomes positively charged in relation to the inner surface because for every 3Na<sup>+</sup> ions expelled, only 2K<sup>+</sup> ions are taken in.

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# Generation of action potential

- Changes in the permeability of the nerve membrane to K<sup>+</sup>& Na<sup>+</sup> ions lead to the changes in the potential differences across the membrane. This results in the formation & propagation of nerve impulses.
- When a resting neuron gets stimulated or excited, a cyclic series of electro chemical changes takes place. This is known as *action potential*.
- Action potential is very rapid & short living. After that resting potential is regained.
- In the stimulated point sodium-potassium pump stops functioning for a short period, sodium gates open widely & the membranes freely permeable to Na<sup>+</sup> also.
- Heavy influx of Na<sup>+</sup> occurs by diffusion. This increases sodium conductance & reverses the resting potential.
- Interior of membrane becomes +ve& the exterior becomes -ve.



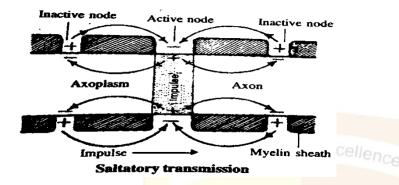
- *Depolarization*: The reversal of resting potential.
- Depolarisation is the beginning of action potential & the generation of nerve impulses.
- Depolarisation lasts for a short period, afterwards the sodium potassium pump resumes functioning, the sodium gates get closed & the membrane becomes impermeable to Na<sup>+</sup>.
- Na<sup>+</sup> conductance decreases & K<sup>+</sup> conductance increases. This regains the resting potential.
- **Re-polarisation**: restoration of resting potential.
- Depolarization & repolarization together constitute action potential.
- *Refractory period*: time interval between depolarization & repolarization.

# Propagation of action potential

- Transmission of impulses involves the propagation of a wave of depolarization or action potential.
- Action potential excites the next resting area.
- Initial depolarization is accompanied by local currents & local potentials of graded intensity.
- This establishes an electric circuit in between depolarized & resting area called *mini circuit*.
- Current flows inward from the resting area to the depolarized area & outward from the depolarized area to the resting area.
- The outward current stimulates the next resting area.
- Thus action potential gets shifted to that point.
- In this manner it moves the whole length of the neuron rapidly without any change in its amplitude.
- It can be transmitted over an infinite distance & so they are called *non decremental*.

### **Saltatory transmission**

- This is the jumping of nerve impulses through axoplasm& extracellular fluid from one node to the next in medullated nerve fibres.
- In medullated nerve fibres only the uncovered nodes of Ranvier are excitable & capable of generating action potential.
  - Advantages of saltatory transmission
- Enhances the transmission velocity & ensures the fastest transmission of impulses.
- It is energy efficient, in that energy requiring depolarization occurs only at nodes



# Threshold stimulus & all or none law

- All or none law: The magnitude of a nerve impulse is independent of the intensity of the stimulus and the action potentials are never partial or week, but are always maximal or are altogether absent.
- Threshold stimulus: The lowest intensity of a stimulus, that can generate an action potential.
- Sub threshold stimulus: A stimulus below the threshold level, that can never initiate an action potential.
- *Hyper threshold stimulus*: Stimulus above the threshold intensity, which can produce a full-fledged action potential.
- Any increase in the intensity of the stimulus, beyond an optimum level, will not change the character or magnitude of the action potential.
- The amplitude of the action potential is always constant.

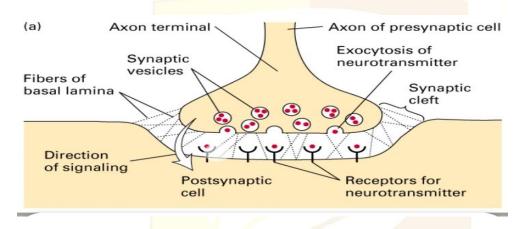
# **Synapse**

- It is the functional junction either between two neurons (neuronal synapse), or between a neuron & a muscle cell (neuro muscular junction).
- *Pre-synaptic neuron*: The neuron, which transmits impulses to a neuronal synapse.
- **Post-synaptic neuron**: The neuron which receives impulses from the neuronal synapse.

There are morphologically three different types of neuronal synapses.

- 1. *Axodendricsynapses*: Neuronal synapses occur between the axon endings of the pre-synaptic neuron & dendrites of the post-synaptic neuron.
- 2. *Axosomaticsynapses*: Neuronal synapses occur between the axon endings of the pre-synaptic neuron &cyton of the post-synaptic neuron.
- 3. *Axoaxonicsynapses*: Neuronal synapses occur between the axon endings of the pre-synaptic neuron & axon hillock of the post-synaptic neuron.
- Most invertebrate synapses are axodentric, whereas most vertebrate synapses are axosomatic.

- *Synaptic knobs*: Knob like terminals of axon endings. It is packed with mitochondria, smooth endoplasmic reticulum, microfilaments & synaptic vesicles.
- *Synaptic vesicle*: Membrane bound secretory bodies which synthesise& secrete neurotransmitters. Transmits neurotransmitters to the synaptic cleft, which brings about the transmission of impulses across the synapse. Mitochondria provides energy for its synthesis & release.
- *Synaptic cleft*: A synaptic knob is separated from the post synaptic neuron by a narrow, fluid filled gap.
- Synaptic cleft is bounded by the pre-synaptic membrane & post synaptic membrane.
- *Sub synaptic membrane*: The portion of the post synaptic membrane, directly under the pre synaptic membrane.
- Pre synaptic membrane is specialized for the attachment of synaptic vesicle & release of the neurotransmitter to the synaptic cleft.
- Post synaptic membrane is modified for the binding of the neurotransmitters.



Functionally there are three types of synapses.

- 1. Chemical synapses: Transmission of nerve impulses occurs with the help of neurotransmitters.
- 2. Electrical synapses: Transmission of nerve impulses across synapses is by electrical activity
- 3. Conjoint synapses: Transmission across synapses is bot electrical & chemical.

### Functions of synapses

- 1. Slow down the flow of impulses.
- 2. Allow impulses to travel only from pre synaptic neuron to post synaptic neuron.
- 3. Selectively transmits certain impulses & inhibit others.

# **Synaptic transmission**

- Transmission of impulses across synapses is called *synaptic transmission*.
- Some synapses are *excitatory* & some are inhibitory.
- Synaptic transmission occurs by two mechanisms, electrical transmission & chemical transmission.

### a) Electrical transmission

- It occur through specific points, called *tight junctions*.
- At these points pre-synaptic & post synaptic membranes are in close contact with each other.
- Tight junctions act as electrical rectifiers.
- The depolarization from the presynaptic neuron very easily spreads to the post synaptic neuron.

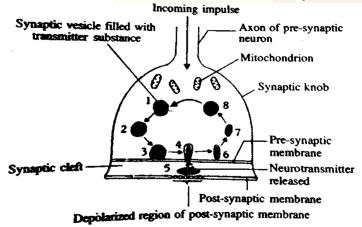
- Action potential from the post synaptic neuron will not travel to the pre synaptic membrane, since tight junctions offer resistance to the counter flow.
- Synaptic transmission is always unidirectional.

### b) Chemical transmission

- Chemical transmission is effected by the neurotransmitter.
- When action potential reaches the synaptic knob, the pre synaptic membrane gets excited, depolarized & permeability to Ca<sup>2+</sup> increases.
- *Excitation secretion coupling*: Ca<sup>2+</sup> diffuses into the knob, this activates certain enzymes which inturn activates synaptic vesicle to secrete neurotransmitter to the synaptic cleft.
- The vesicle then return to the axoplasm to refill the neurotransmitter.
- Neurotransmitters attaches to the receptors on the post synaptic membrane. This causes post synaptic depolarization.
- Finally the neurotransmitter will be hydrolyzed by a specific enzyme.

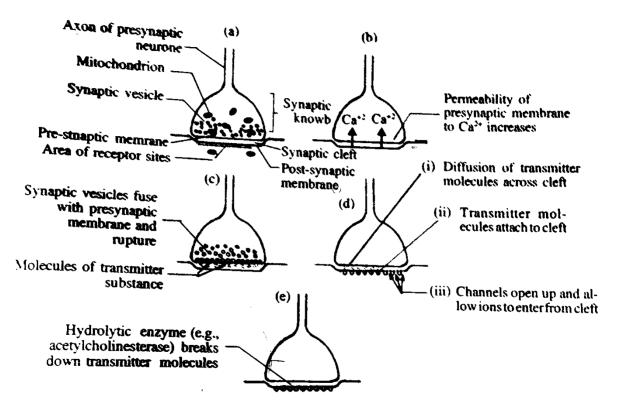
# i) Excitatory chemical transmission

It occurs when the neurotransmitter is excitatory in action.



**Excitatory chemical transmission** 

- It stimulates post synaptic membrane, as a result sodium channels open widely permitting an influx of Na<sup>+</sup> ions.
- This lowers the post synaptic resting potential, causes depolarization & elicits a post synaptic action potential, called excitatory post synaptic potential (EPSP).
- Excitatory transmitter receptor interaction *occurs by two mechanisms*.
- 1. Neurotransmitter binds to specific receptor proteins called neurotransmitter receptors. This causes the increase in the permeability of sodium channels. Heavy influx of Na+ leads to post synaptic depolarization & the initiation of EPSP.
- **2.** The neurotransmitter receptor binding activates an enzyme in the post synaptic membrane called *adenylcyclase*. The activated enzyme mediates the conversion of ATP to cyclic AMP (cAMP). This inturn activates the enzyme which causes the opening of the sodium gates & thereby increases the permeability to sodium leading to the initiation of EPSP.
- Summation : combined or cumulative effect of neurotransmitters released simultaneously, will initiate an EPSP.



# Stages of excitatory chemical transmission

### ii) Inhibitory chemical transmission

- It occurs when the neurotransmitter is inhibitory in action.
- Inhibitory neurotransmitter binds with the receptor site & prevents post synaptic depolarization.
- *Hyperpolarization*: The inhibitory transmitter-receptor binding raises the post synaptic resting potential & thus prevents post-synaptic depolarization.
- In hyperpolarization, the cell interior becomes more negative than outside making the generation of an action potential rather impossible.
- Inhibitory post synaptic potential (IPSP): The more negative post synaptic resting potential which can inhibit depolarization.

#### Synaptic delay

Delay in the transmission of impulses across the synapse. It is due to the delay in releasing the neurotransmitter & also due to the time taken for its diffusion & post synaptic depolarization.

# Synaptic fatigue

Continuous transmission of impulses across a synapse eventually leads to a momentary suspension of synaptic transmission. It may due to the exhaustion of neurotransmitter.

### **Neurotransmitters**

- They are the chemicals involved in the synaptic transmission.
- They can amplify, modulate & transmit impulses.
- Two kinds : Excitatory & Inhibitory.
- Neurotransmitter act as both excitatory & inhibitory.

# Eg:-Acetylcholine

- ° Excitatory in neuronal synapses & in neuromuscular junctions of skeletal muscles.
- ° Inhibitory in the neuromuscular junctions of cardiac & visceral muscles.
- Excitatory neurotransmitters :Dopamine, adrenaline, serotonin, histamine,...
- Inhibitory neurotransmitters : Gamma amino butyric acid (GABA), enkephalins, beta-endorphin,...

# Acetyl choline

- ° Released by many neurons outside CNS & some neurons inside the brain & spinal cord.
- ° Cholinergic synapses: The synapses which make use of acetyl choline for synaptic transmission.
- ° After depolarisation of post synaptic membrane, Ach ishydrolysed by acetyl choline esterase.

### Noradrenaline

- ° Also called norepinephrine, quipping with excellence
- ° Released from sympathetic nerve endings, brain & spinal cord.
- Soon after EPSP, it is pumped back to the synaptic knob.
- ° It is destroyed by the enzymes catechol methyl transferases& monoamine oxidase or recycled back to the synaptic vesicles.

### Gamma amino butyric acid (GABA)

- An inhibitory neurotransmitter.
- ° It brings about hyperpolarization in the post synaptic membrane.
- ° Generates IPSP to prevent further transmission of impulse.

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### **SECTION B. ETHOLOGY (14 hrs)**

### **MODULE 8. Behaviour (8 hrs)**

#### **Innate behaviour**

Orientation, taxes and kinesis, simple reflexes and instincts, drive and motivation

### Learned behaviour

Habituation, conditioned reflex, trial and error learning, latent learning, imprinting, insight learning

### **Patterns of behaviour**

Habitat selection, sexual selection, co-operation, territoriality, aggression, courtship and agonistic behaviour.

#### **Proximate factors**

Neurological basis of behaviour, mention hormonal, biochemical, environmental and genetic factors that influence behaviour.

# MODULE 9: Biological clocks/rhythms (6 hrs) with excellence

Photoperiod, circadian rhythm, migration, navigation and homing instinct, diapause, hibernation and aestivation.

Communication in animals. Social organization in mammals – Elephant as example



# **SECTION B: ETHOLOGY**

### **MODULE8**

### **BEHAVIOUR**

### **INNATE BEHAVIOUR**

- Innate behaviour is the inborn, inherited & genetically programmed behaviour, governed by specific genes.
- It is mostly stimulus bound.
- A particular pattern of stimuli triggers a sequence of responses.

### Major components of innate behaviour

- 1. Orientation
- 2. Simple reflexes
- 3. Instincts.

### Orientation

- It is the directional movement of animals, induced by external or internal stimuli & initiated by endogenous activity.
- It involves the positioning of whole body or parts of it.
- Orientation is of two kinds,
  - Taxes
  - Kinesis

### a) Taxes or taxic movements

- It is the directional orientation or locomotor movement of an animal towards or away from the source of stimulus.
- It is continuously & specifically guided by an external stimuli.
- Taxicmovement are of two major categories,
- **Positive taxis** movement of animals towards the stimulus.
- ➤ **Negative taxis** movement of animals away from the stimulus.

### 1)Klinotaxis

- It is the form of orientation achieved by the successive comparison of the intensity of the stimulus in the nearby parts of body.
- It involves the lateral swinging of the head or the whole body for detecting the direction of stimulus.
- It is essential for providing continuous supply of information, since the animal lack long term memory.
- Klinotaxis is exhibited by *Euglena*, earthworm,...

### 2)Tropotaxis

- Type of orientation in which there is simultaneous comparison of the intensity of the stimulus received at two or more receptors.
- Bilateral receptors are used for the comparison.
- This enables the animal to move towards or away from stimulus without lateral swings.
- Tropotaxis is exhibited by many insects.

#### 3)Telotaxis

- This is the directional taxic movement which does not rely on the simultaneous comparison of the stimulation for two receptors.
- If there are two stimuli, the animal will select one of them and moves towards or away from it, and never in a median direction.
- Eg:- orientation of dragon fly towards its prey.

#### 4)Menototaxis

- This is the light compass response in which orientation towards the source of the stimulus occurs at a definite angle to the direction of the stimulus.
- Eg:- navigation of many insects, fishes,...

### b) kinesis

- kinesis is the random, non directional orientation of the animal in which the rate of the movement is determined by the intensity of the stimulus, rather than by its direction.
- Stimulus produces only a change in the speed of the movement, rate of turning,...
- Eg:- Woodlouse moves quickly in dry atmosphere to form aggregations in moist places. On the other hand I damp atmosphere, it moves slowly.
- There are two major categories of kinesis.
  - Klinokinesis

#### 2) Orthokinesis

### Klinokinesis

It is the orientation in which the rate of change of direction or angular velocity increases in proportion to the increase in the intensity of external stimuli.

#### **Orthokinesis**

It is the orientation in which the speed of locomotion is directly proportional to the intensity of the stimulus and the linear velocity of the body, and independent of the spatial properties of the stimulus.

# Simple reflexes

- Reflexes are stereotyped and involuntary responses of the part of an organism to environmental stimuli.
- They are determined by the inherent pattern of neurons in brain & spinal cord. So there are two major kinds of reflexes,
- **Cranial reflexes** initiated by neurons in brain.
- **Spinal reflexes** initiated by neurons in spinal cord.

- Although they are involuntary responses they can be modified by brain in accordance with previous experiences.
- Eg:- blinking of the eyes when strong light flashes
- Reflexes are of two classes,
- Tonic reflexes slow and long lasting & they maintain muscular tone, body posture and equilibrium.
- **Phasic reflexes** rapid and short living & they mainly deal with emergencies.

#### **Instincts**

- Instincts are complex, inborn, inherited, unlearned and species specific behaviour patterns, produced in response to sudden changes in the environment.
- They are genetically determined and governed by complex genes.
- The signals which elicit instinctive responses or reactions in an animal are called *releasers*.

# Eg:- Mating behaviour of three spinedstrickle back fish

The male fish chooses a mating area and drives away conspecific males from there. He collects plants & make tunnel with it. Then he puts on his colourful sexual attire. The most attractive aspect of his nuptial colouration is his bright red belly & bluish-white back. He then starts to court females & performs a zigzagging dance. Female lays eggs in the nest & male fertilizes the egg. He protects the egg & young ones.

# **Motivation or drive**

- Motivation is the cause for a spontaneous change in the behaviour of an organism which occurs independently of any external stimulus.
- Drive is a type of motivation which has specific readiness, urge or push to perform a behaviour.
- So, motivation is the psychic & physiological state, mood, passion, urge or readiness of an organism for a goal oriented activity.
- It is determined by external & internal stimuli, hormones, nervous stimulation,...
- Many behavioural responses are associated with reproduction.
- There are two categories of motives or drives,
- Innate motives biological motives result from the basic needs of the body for food, water, sleep,...
- **Psychological motives** they are acquired and they result from experience. Psychological motives of man include curiosity about the success of career, passion to love or hate ,...

### **LEARNED BEHAVIOUR**

# **Learning and memory**

- Learning is simply the acquisition of the information.
- Learning can be considered as an adaptive change or modification in individual behaviour as a result of experience.

• Memory is the ability to store & retrieve or recall the effects, impressions & information gained through learning & experience.

# Learned behaviour

- ❖ It is the pattern of behaviour gained in life through experience & interaction with environment.
- It is best evolved in man.
- Types of learning
  - 1. Selective learning
  - 2. Insight learning
  - 3. Latent learning
  - 4. Habituation
  - 5. Conditioned reflex
  - 6. Imprinting

# Selective learning (Trial & Error) poing with excellence

- Also called trial & error learning, operant learning, instrumental learning,...
- In this learning animal learns after several trials & errors.
- It is common among animals, which are prone to make mistakes in dealing with environmental & social conditions. It has been termed *operant conditioning by Skinner*.
- In Selective learning, trial motor activities produce responses with positive or negative results, known respectively as rewards & punishments.
  - Eg:- Not to touch hot stoves, how to play a musical instrument, how to write & type.

# **Insight learning**

- Also called abridged learning.
- This is the learning behaviour in which an animal learns how to solve complex problems easily & quickly.
- This is rare in invertebrates & common in mammals.
- It is the highest form of learning.
- It relies more on advanced mental abilities, such as thought & reasoning.

Eg:-Kohler's experiment,

A chimpanzee was placed in a room with scattered boxes and a banana hanging from the ceiling beyond the reach of chimpanzee. Facing the problem for the first time , the chimpanzee responded by stacking the boxes one above the other climbing up and grabbing the banana.

# **Latent learning**

- Also called exploratory learning.
- An animal explores new circumstances & new surroundings and learns information which may be useful later on & not immediately.
- It is a kind of pre- adaptation for a life in later stage.
- Latent learning enhances the fitness & survival value of organisms.

- It reveals that not all behavioural activities are "appetite behaviour", apparently meant for satisfying a need, or for obtaining a reward.
  - Eg:- 1) A student is taught how to perform a special type of addition, but does not demonstrate the knowledge until an important test is administered.
- 2)A dog is taught to sit but does not do so until offered a treat as a reward.

### Habituation

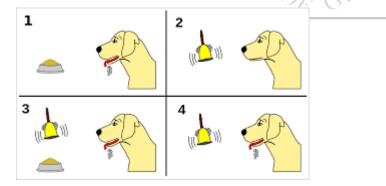
- It is the simple form of learning in which repeated application of stimulus, without reward or punishment, decreases the probability of any response to that stimulus.
- So, it is the learning not to respond to a stimulus, or to ignore insignificant stimuli. Eg:- 1) Certain noises in a house cause a new born baby to cry, until he/she becomes desensitized to the noises &they no longer frighten the child.
  - 2) A turtle raws its head back into its shell when its shell is touched. After being touched repeatedly, the turtle realizes it is not in danger & no longer hides.

### **Conditioned reflexes**

- Also called classical conditioning.
- These are complex, uninherited& learned or acquired cranial reflexes, evolved in the life time of an animal.
- They result from experience & memory.
- Conditioned reflexes result in response to stimuli called conditioned stimuli/signals.
- Biological significance:
  - 1. Ensure adaptation of organisms to the external environment in the course of life.
  - 2. They enable better orientation in changing conditions.
  - 3. Play important part in the physiology of learning.
  - 4. Help animal to find food, to avoid danger & to eliminate harmful influences.

Pavlonian conditioning

• Ivan P. Pavlov is considered as the father of conditioned reflexes.



Eg:- Pavlov first exposed dogs to food. They produced saliva as a reflex action. Next he rang a bell without giving food. The dog did not secrete saliva as a reflex action. Next he introduced the two stimuli (food & sound) together repeatedly several times. After repeated exposure to the combined

stimuli, dog started secreting saliva in response to bell, even in the absence of food. This means that the dog got conditioned to the sound stimulus.

# **Imprinting**

- The term imprinting was coined by *Konrad Lorenz*.
- Imprinting is a simple, irreversible & unique form of species-specific learning that occurs only during a critical receptive or sensitive stage in the early life of animals.
- It occurs only during a short, sensitive period.
- Usually it takes place soon after hatching or birth & often results in a strongly fixed attachment, very difficult to change.
- If it does not take place during the critical period, it will not probably takes place at all any time in future life.
- There are two major type of imprinting, 9 with excellence
  - 1. Sexual imprinting
  - 2. Filial imprinting
- Sexual imprinting is the phenomenon by which early experiences influences the sexual preferences or the choice of the sexual partners of adults. This is common among birds.
- Filial imprinting is the phenomenon which enables the recognition of close kins and members of the same species by adults mainly through early parent fixation.
- Imprinting establishes a bond b/w offspring & parent, particularly the mother.
- It also have marked effects on social relationship, mate selection, food selection, habitat selection....



• Lorenz experiment – goslings & ducklings deprived of their parents very shortly after hatching, would follow the moving object they see first & would use it as a substitute parent, ignoring their real parents. The moving object can be a human being, any other animal, or even a toy. Once registered in the brain imprinting is irreversible.

### PATTERNS OF BEHAVIOUR

Different animals exhibit different patterns of behaviour. The range & complexity of behaviour varies with species. The different patterns of behaviour that animals exhibit includes habitat selection, sexual selection, territorial behaviour, courtship behaviour, agonistic behaviour, co-operation, protection,...

### **Habitat selection**

- It is the choice of a particular habitat by an organism in preference to others.
- It is the place where an organism lives, enjoying the benefits of all favourable conditions that are essential for its success & survival.
- In a habitat, each species has a specific range of tolerance to environmental factors.
- Animals will have a natural preference of some habitats over others & every kind of animals is adapted to survive & multiply only in a particular habitat.
- Eg:- Nymphs of mayflies inhabit the under side of stones in fast flowing streams & burrow in sediments in shallow waters.

# Significance of habitat selection

- 1. Maximizes the chances for exploitation of the useful resources of the favourable habitats.
- 2. Minimizes the chances of exposure to the harmful conditions of the unfavourable habitats.
- 3. Brings about species dispersal, avoids overcrowding, promotes racial propagation & reduces intraspecific competition.
- 4. Minimizes the chances for interbreeding.

### **Sexual selection**

- It is the special form of natural selection which determines mating success through sexual competition or sexual struggle between members of one sex for acquiring mating partners.
- Sexual selection depends not on a struggle for existence, but on a struggle between the individuals of one sex generally the males, for the possession of the other sex.
- There are two kinds of sexual struggle

<u>Intrasexual selection or male rivalry</u>: Males directly compete with each other by agonistic displays, some type of ritualized combat or by actual fight, in order to drive away or kill the challenging rivals for success in mating.

The winner gets the female. The female simply remain passive.

It is found in some polygamous species where one male mates with many females.

In this male may have special armaments such as horns, antlers,... to increase fighting power & winning chances.

<u>Intersexual selection/epigamic selection/female choice</u>: Males compete with each other only indirectly to attract & excite the females with the help of spectacular gestures, attractive displays, skillful movements, fascinating colouration, alluring adornments & so on.

The female never remains passive, she select the more attractive or more agreeable partners for mating.

Females prefer males having attractive tail, strong body & most likely it forms hindrance in escaping from predators.

- Darwin proposed the theory of sexual selection by holding that the morphological &behavioural adaptations in sexual selection have some survival value in the struggle for existence.
- Fisher proposed *runaway selection hypothesis*, gives a different explanation of sexual selection. This holds that female selection of a particular male trait over several successive generations would favour its extreme development. This in turn reduces the fitness of the male. Eventually males become overspecialized as to bring the species to extinction.

# **Co-operation**

- It is the behaviour in which the members of a species co-operate with co-ordination for mutually beneficial activities, such as hunting, protection, defence, communication, reproduction, parental care,...
- Co-operation between members of different species is known as *symbiosis*.
- Co-operative behavior requires effective communication & some degree of altruism among the inividuals, especially in alertness, vigilance & alarm.
- Highest degree of co-operation is found in social animals with division of labour, leadership & altruism.
- The commonest co-operative patterns include mating, parental care, group formation & altruism.
- Eg:- hunting of wild dogs, social life of colonial insects.

### a) Mating

- Among sexually reproducing animals mating & reproduction is a universal phenomenon.
- Establishment of pair bonds is common among birds & mammals to ensure co-operative behaviour in mating & rearing young ones.
- There are three types of mating systems,
  - I. Monogamy

Every adults mates with only one member of the opposite sex.

Monogamy is usually found in those species in which both the parents are required to raise the offspring.

It is common among birds & some primates.

II. Polygamy

Every adult may have two or more breeding mates, either simultaneously or successively. It is the common type of mating system.

III. Promiscuity

In this both males & females routinely mate with more than one member of the opposite sex. In them pair bonds are absent & parental care is minimal.

### b) Parental care

- Parental care is the care & attention taken by the parents to aid the development of the offspring, to protect, nurse & nurture the young ones, & to increase their fitness.
- Among fishes & amphibians there is a wide spectrum of parental care. It ranges from external fertilization & abandonment of eggs to ovo-viviparity through various type of egg guarding.
- Male *Hippocampus* carries eggs in his brood pouch.
- Toads carry eggs & tadpoles in the pockets of their skin.

- Fishes makes nest for their eggs & young ones.
- Birds build & guard nests, incubate the eggs & rear the young ones.
- Parental care is highly evolved in crocodiles. Females makes elaborate nests & guard them, & transports the young ones in her mouth to the edge of the water.
- Ovo-viviparity is found in sharks, bony fishes, some amphibians & a few snakes.
- Mammals look after their young ones until they are capable of leading an independent life.
- Female marsupials keep the young ones in their marsupium& feed them with milk.
- It is the form of altruism in which the parents protect the offspring & increase their fitness by spending much time & energy.
- In some cases, only one parent is involved, & in others both the parents take active roles.
- Parental care is prolonged in primates & much elaborate among human beings.
- The degree of parental care varies with species. It depends on the number of offspringsproduced, type of mating system,....
- In parental care, female usually spends more time & energy than does the male

# c) Group formation

- Many animals lead solitary life, in them males & females co-operate only for mating.
- In some animals, individuals come to a collective life & form various kind of groups. These groups include loose aggregations,, small families & highly organized societies or colonies.
- Loose aggregations are common among gregarious animals. These are temporary or long lasting formations.

Eg:- schools of fishes

- Families are small group of animals usually headed by a male.
  - He may be monogamous or polygamous.
  - ° Family may be temporary or life long.
  - ° A monogamous male lives in the partnership of only one mating female at a time. This partnership lasts either for a single breeding season or throughout life. Eg:- foxes.
  - ° A polygamous male lives with a harem of mating females. Eg:- lions.
- *Societies / colonies*: Animals such as ants, termites, wasps & honeybees, live in organized societies or colonies.
  - ° They are characterized by leadership, division of labour, altruism & high degree of social order.
  - Honey bee colony consist of three kinds of members, namely queen, workers & soldiers.
  - ° Queen is the leader of the colony.
  - Worker bees are altruistic.

# **Advantages of group formation**

- 1. It gives high offensive & defensive powers & great protection against predators.
- 2. They are less vulnerable to predation than individuals.
- 3. Predators rarely attack an individual of a close-knit group.
- 4. Groups have better food finding abilities than single individuals.

- 5. Members share the foods.
- 6. Groups have high ability & success in hunting.
- 7. Societies have more tolerance than solitary individuals.
- 8. Chances for mating & sexual reproduction are higher.
- 9. It provides safety & protection through parental care, altruism & collective defence.

### Disadvantages of group formation

- 1. Severe intraspecific competition for space, food & shelter.
- 2. Increased intrasexual competition for mates.
- 3. Increased risk of disease transmission.
- 4. Greater conspicuousness to predators.
- 5. Greater risk of cannibalism of the young ones.
- 6. Environmental pollution due to waste accumulation.

### d) Altruism

- It is the selfless service rendered by an animal to increase the evolutionary fitness & survival value of the other members of its species without increasing its own fitness & survival value.
- It is the co-operative social behaviour.
- In altruism, an individual works hard or sacrifices its interests for the benefit of others.
- The beneficiaries of altruism are mostly the offsprings& genetically close kiths&kins of the altruists.
- Eg:- Worker bees

# **Territoriality**

- It is the form of defence to safeguard food sources, homesites, breeding grounds,..against the members of the same species.
- This behaviour is accomplished by aggression, threat displays, scent markings, vocal declaration , direct fight, scent markings, fleeing from rivals,...
- This is common in areas where food & space are short in availability.
- This is commonly expressed by males, the territory contains vital resources required by females & males aquire females by controlling such resources.
- *Home range*: Definite geographical area restricted to an animal or a breeding pair.
- They comes out this region very seldom or never leaves it during the breeding season.
- *Territory*: Defended area within the home range occupied by a single member or a breeding pair or a group of members of same species from conspecific rivals. Territories are established seasonally or permanently.
- Home ranges of different members may overlap, but never the territories do overlap.
- The size of territory may vary from season to season depending upon the abundance & availability of environmental resources.
- Some species use territory only for breeding purposes, & most of the time they are outside the territory for feeding.
- Among birds territorial behaviour is usually accomplished by songs & visual displays.

- In mammals, boundaries are defined by *scent posts*, which are marked by urination, defecation or secretion of pheromone.
- Leks: Male defend territories, where the females come for mating.

There is a dominant male & several subordinate males.

Females arrive the lek, move around & chooses a suitable male for mating.

Eg:- Humming birds

### Economy of territoriality

- 1. Encourage uniform dispersion & spacing of organisms.
- 2. Reduces conflicts for food, shelter & mates.
- 3. Ensure the normal availability & utilization of environmental resources.
- 4. Controls population growth.
- 5. Provides freedom from disturbance during pair formation.

# Aggression

- It is the hostile behaviour of an animal which often amounts to intimidation, attack injury, damage or threat to other members of species.
- It is the evolved behavioural adaptation for obtaining or defending resources such as food, territory, mates...
- Aggression does not always involve physical encounters or attacks.
- It involves threat postures, warning signals, ritual displays & occasionally physical attacks.
- Bird song, scent marking, facial expression,..are different forms of aggressive behaviour.
- In locusts & social insects aggression is promoted by pheromones.

### Significance of aggression

- 1. It serves as a mean for defending or obtaining resources such as food, territory, mates,...
- 2. It enables the displacement of conspecific rivals from an area.
- 3. It avoids fierce fighting by resorting to threat postures & ritual contests of strength.
- 4. It involves communication, assessment, opportunism, escape & fighting ability.

# Courtship behaviour

- Courtship is the instinctive, ritualistic & mating related behavioural interaction between male & female, occurring before sexual act.
- It is a heterosexual behaviour pattern, designed to stimulate animals for mating.
- It involves pair bond formation&establishment of territory by males.
- Courtship rituals are species specific, elaborate & prolonged.
- The first display of courting male evokes a counter behaviour by a conspecific female. This in turn stimulates additional male behaviour. This repeats until the partners are physiologically & psychologically ready for sexual act.
- Courtship ceremony involves the exchange of information between partners. The communication signals are species- specific & hence understandable only t conspecific members.
- Communication signals includes visual, auditory, olfactory & tactile.

- Vocalization, colour display, attractive postures, pleasing gestures & rhythmic movements, release of pheromones,... are common types of courtship signals.
- Auditory signals : Croaking of male frogs
- Visual signals : Dancing movement of peacocks
- Olfactory signals : Sex attractant pheromones
- Courtship behavior is controlled primarily by the motivational stimuli & culminates in mating.
- Mating is under the control of two sets of stimuli,
  - Releasing stimuli initiates mating behaviour.
  - Terminating stimuli terminates mating by release of sperms by the male.

# Significance of courtship

- 1. Plays an important role in advertisement, mate attraction, mate selection & sexual coordination.
- 2. Provides an opportunity for females to assess the quality or fitness of males.
- 3. Stimulates animals for sexual act.
- 4. Ensures that an animal mates only with a member its own species.
- 5. Serve as a sign signal to trigger nest building or ovulation.
- 6. Inhibits aggressive tendencies & promotes co-operative behaviour.

# **Agonistic behaviour**

- This is the ritualistic behaviour during encounters between two rival individuals of the same species.
- It involves aggression, threat, appeasement, subordination, avoidance, displays,...
- It reduces or avoids intraspecific conflicts & fights between members of the same species

### **PROXIMATE FACTORS**

The causes behind animal behavior fall under two broad categories, namely ultimate causes & proximate causes.

- Ultimate causes are the evolutionary processes which have shaped &moulded the patterns of animal behaviour over long geological time, primarily through natural selection.
- Proximate causes are the immediate internal & external factors which trigger behavioural patterns. They are not evolutionary in nature.
- Proximate factors which regulate animal behaviour include a combination of neurological, endocrinological, biochemical, environmental & genetic factors.
- Behaviour may be the direct response to the external stimulus, its underlying mechanisms are internal.

# Neurological basis of behaviour

- Nerve cells form the matrix of behaviour.
- The study of behaviour is an analysis of the potentialities of the nervous system.
- The main function of nervous system is to control the release of energy through muscular contraction & glandular secretion.

- Nervous system regulates other forms of energy such as light (fire fly) & electromotive force (electric eel).
- Nervous system perceives & records environmental changes, assesses the information thus recorded & co-ordinates the activities of various effector organs.
- This enables the animal to react or respond to the environmental stimuli most effectively for its survival.
- The ability of the brain to learn & remember is vital in selecting behavioural pattern.
- Animal behaviour appears to result from the interplay of nervous system &effetor organs.

### Hormonal factors that influence behaviour

- Hormonal influence is very significant in reproductive, sexual, maternal aggressive, territorial,...
- In mammals the readiness for mating & fertilization is governed by hormones.
- Hormones increase the attractiveness of females to evoke sexual responses in male.
- It increase the pereptivity of females either to evoke their sexual desire or to arouse their sexual drive.
- It increases sexual excitement in males & stimulate erection & ejaculation.
- The production of milks & the maternal habit of feeding are governed by pituitary hormone *prolactin*.
- Progesterone stimulates the maternal habit of incubating eggs.
- Oestrogen& progesterone stimulate nest building habit in birds.
- High level of blood prolactin stimulates maternal care of young ones by mice.
- Males are more aggressive than females. This male aggressiveness is under the control of hormones released from pituitary, gonad & adrenals.
- High level of testosterone intensifies the male aggressiveness.
- Leutinizing hormone controls aggressive behaviour in red billed weaver birds.

# Biochemical factors that influence behaviour

- Pheromones are the chemicals used by the animals for various purposes.
- Territory is marked by the scenting pheromones.
- Sex attractant pheromones attract & excite opposite sex.
- Homing, alertness, alarm reactions, withdrawal are under the control of chemicals.
- Male copulatory behaviour such as erection & ejaculation are influenced by ACTH & other related peptides.

### **Environmental factors that influence behaviour**

- The surroundings of an animal influences its behaviour.
- If the environment of a man is quite calm then he possess good attitude towards others.
- Man from bad atmosphere, also reflects in his character.

## Genetic factors that influence behaviour

- Animal behaviour has a genetic basis.
- Innate behaviours are purely based on genes.

• Development of various behaviourpattern is influenced by genes, natural selection may probably favour only those gene combinations &behaviour patterns which would enhance the survival value of animals.



### **MODULE:9**

# **BIOLOGICAL CLOCKS / RHYTHMS**

- Internal clock is an internal timing mechanism
- It is an endogenous physiological mechanism that probably produces regular & periodic changes in behaviour or physiology in response to daily, lunar, seasonal & annual periodicities.
- It runs continuously till death, free from the external environment.
- Environment neither initiates nor stops its functioning.
- Biological clock enables organisms to determine how & when to respond to daily, seasonal, annual & lunar periodicities.
- The exact nature of physiological mechanism that runs the internal timing machine is not quite clear.
- Biological timing mechanism is accomplished in three ways.
- 1. Through direct response to the changes in the external (exogenous) geophysical conditions.
- 2. Through an internal (endogenous) rhythm
- 3. Through a synchronization mechanism which is a combination of these two mechanisms.
- Animals use many features of the external environment to gain information about the passage of time.
- The most important one is the movement of celestial bodies.
- They may get cues from environmental temperature, altitudinal pressure & magnetic phenomena.
- The activities of organisms must change in relation to natural cycles. So, organisms must have an internal timing machine to sense the environmental cycles. It is called biological clock.

### Pineal gland

• The exact site or location of the biological clock is not definitely understood.

OLLEGE

- In vertebrates, pineal gland probably act as a biological clock.
- In many birds, fishes, amphibians & reptiles pineal serve as "third eye".

# **Biological rhythm**

- Major external factor that regulates bioperiodicity is photoperiod
- Many behavioural activities of animals occur at regular intervals.
- Regularity & rhythmicity in the activities of organisms is known as biological rhythm (biorhythm) or biological periodicity.

- Eg:- nesting habits & migration of birds, aestivation & hibernation of mammals, diapause in insects,....
- Endogenous rhythm—biorhythm involving an internal clock or pacemaker system.
- Exogenous rhythm biorhythm controlled by external factors.

# **Photoperiodism**

- Earths rotation results in day & night changes.
- Revolution of earth causes change in seasons.
- The relative duration of the light & dark periods of a day, which may favour the optimum functioning of an organism is known as photoperiod.
- The behaviour of organisms in response to the periodic or rhythmic changes in the relative length or intensity of day light is known as photoperiodism.
- Breeding, aestivation, hibernation, are determined by photoperiodism.
- Two phases of photoperiodic cycle
  - 1. Photophase: represents the light phase.
  - 2. Scotophase: represents the dark phase.

### Biorhythm are of three major categories,

- 1. Seasonal / circannual rhythm,
- 2. Lunar rhythm
- 3. Circadian rhythm

# Seasonal rhythm

- It refers to the rhythmic activity of an organisms, regulated by seasonal periodicity, i.e., by changing seasons
- Eg:- Breeding of birds in summer, seasonal migration of fishes & birds for breeding & feeding purposes, hibernation & aestivation of some mammals.

# Lunar rhythm

- It is the rhythmic activity or behaviour of animals in relation to lunar periodicities & tidal cycles.
- It has less than 29.5 days (one lunar month).
- During new moon & full moon days ,in seas high tides are extremely high & low tides are extremely low. They are called spring tides.
- During quarter moon &half moondays, they are moderate tides, known as neap tides.
- Eg:- the reproductive period of some marine organisms are restricted to spring tide days & some are to neap tide days.

# Circadian rhythm

• It is the regularity & rhythmicity in 24 hour day to day routine biological activities.

- It is also called daily or diel periodicity.
- The rhythmic patterns persist even after the expiry of 24 hour exposure. It becomes slightly longer or shorter than 24 hours.
- Circadian rhythm is believed to be controlled by an endogenous biological clock.
- Three types of circadian rhythm
  - A. *Diunnal*: animals active during day time are called diunnal animals & they follow diunnal rhythm.
  - B. *Nocturnal*: animals active during night are called nocturnal animals & they follow nocturnal rhythm.
  - C. *Crepuscular rhythm*: animals active in twilight hours of dawn & dusk are called crepuscular animals & they follow crepuscular rhythm.

Eg:- Singing of birds at dawn, the coming out of diurnal animals from their shelters to begin activities at dawn, return of nocturnal animals to their shelters at dawn,.....

### Conditions for circadian rhythm

- 1. The period of rhythm should not be exactly 24 hours.
- 2. Rhythm must continue under normal environmental conditions.
- 3. The phase of rhythm should be liable to shifted & subsequent new phase should be retained under uniform environmental conditions.
- 4. The rhythm must be elicited by a single stimulus.
- 5. The phase of rhythm should be delayed under anaerobic or hypoxic conditions.

# Circadian rhythm in human beings

- Body temperature reaches its highest daily level in the evening at 4.00 5.00 pm, and lowest in the morning at 4.00 5.00 am.
- Heart rate, blood pressure, hormone secretion, rate of excretion of Na & K, waking & sleeping shows circadian peaks & valleys.

### Jet lag

People move fast through earth's time zone via jet travel, their biological clock often get seriously out of phase with the local day night cycle. This situation is termed as *jet lag*. It produces uncomfortable subjective feelings, with decreased alertness and disturbed eating & sleeping schedule. Normal circadian rhythm is regained several days or weeks later.

# Migration

- Migration is the seasonal or semi annual, back & forth mass movement of animals between their breeding & feeding grounds, in correlation with environmental periodicities & internal physiological rhythms, to secure optimum environmental conditions.
- It is one of the most fascinating aspects of animal behaviour.
- It is found among butterflies, locusts, salmons, birds, bats...

- Some species migrates in response to changes in environmental conditions (desert locust), some others migrate on the basis of a circum annual rhythm, rather than a response to environmental changes (migratory birds).
- Migration is believed to result from a complex series of events which may involve an integration of physiological processes &behaviouralmeechanisms, and an interplay of environmental, gonadal & hormonal factors.
- Environmental factors includes, scarcity of food, photoperiod, temperature variations, pressure changes, weather conditions,....

### Advantages

- Enables animals to escape from adverse environmental conditions.
- Enables the exploitation of the resources of new habitat.
- Ensures sufficient food supply &favourable environmental conditions through out the year.
- Provides increased opportunity for sexual reproduction & thereby promotes racial propagation & population expansion.
- Increases opportunity for gene exchange, which in turn enriches the gene pool & increases genetic diversity.
- Reduces predation pressure.
- Increases the adaptability by exposing the migrants to diverse environmental conditions.
- Heavy mortality during migration prevents overpopulation & there by regulates population size.

### **Disadvantages**

- Migration is highly expensive in terms of time & energy.
- It causes heavy casualities due to fatigue, exhaustion, predation & environmental hazards.

#### Orientation

- It is the positioning of the body, or parts of body of an animal in relation to the environment, or in response to an external stimulus, that triggers & directs it.
- Two major classes of orientation are
  - 1. Positional orientation proper positioning of the body in response to the external stimulus such as gravity, light, temperature, chemicals, contact,...
  - 2. Course orientation directional movement of the body with or without external cues, such as prominent land marks, sun compass, magnetic compass, echolocation,...
  - *Drift angle* In the course orientation of flying animals, the angle between the track & animals heading direction is called drift angle.
- Track angle the angle between the track & the direction of the wind is called track angle.
- *Kinaesthetic senses* detection of changes within an animals own body by internal sense organs.
- The information gained through kinaesthesis is called *idiopathic information*.
- Eg:- navigation of desert ant.
- Course orientation, based on external cues, makes use of either intensity information (kinesis) or directional information (taxis).

# Navigation

- It is the goal oriented, long distance movement of animals towards a destination, using different cues other than the recognition of landmarks.
- Earth's magnetic field, apparent changes in the position of sun, moon & stars in relation to the position of earth are the orienting aids in navigation.
- Three aspects of navigation are,
  - 1. *Pilotage* steering of a course using familiar landmarks.
  - 2. Compass orientation movement of animals in a given compass direction without reference to landmarks.
  - 3. *True navigation* it is the orientation towards a definite goal, such as home or a breeding ground, using cues other than the recognition of landmarks.
- Light compass mechanism animals make use of the sun, keeping the angle between the direction of movement & the direction of the light stimulus almost constant.
- Eg:- bees use this while returning to their hive.
- Salmon locates home rivers by smell.
- Birds use celestial navigation using sun & stars as compass.

# **Homing**

- It is the return of animals to their home from great distances after foraging trip or seasonal migration.
- An important aspect of homing is time.
- Many animals use their internal biological clock to keep track of personal time.
- Navigational cues used by homing animals include visual landmarks, polarization of sunlight, pattern of stars at night, changes in earth's magnetic field,...
- Birds exhibit high degree of homing instincts.
- Pigeons do use sun or stars to take the right direction.
- Some bacteria are capable of magnetic navigation.
- Bats orient themselves by means of a sonar system.
- Cetaceans employ an echolocation system.
- Electric fishes generate weak electric fields around their bodies to orient themselves in water.

### Diapause

- It is a genetically determined state of dormancy, or a form of arrested or suspended development during the embryonic, larval, pupal or adult life of an animal.
- This is common among insects.
- Diapause is an adaptive mechanism for dormancy during unfavourable environmental conditions, such as low winter temperature, extreme summer heat, drought, lack of food, depletion of stored body fat,...
- It begins long before the onset of the unfavourable conditions & persists even after the disappearance of the unfavourable conditions.
- Reversal of dormancy normally occurs long after the return of favourable conditions.
- There are two basic types of diapause,
  - 1. *Obligatory* it occurs at a definite stage as an inborn custom, without any compelling conditions. It is a part of its life cycle. It is common among *univoltine* species.

- 2. Facultative it occurs only when unfavourable conditions call for its onset.
- The major environmental factor that induces diapause is photoperiod (day length).
- Unfavourable conditions of food supply, temperature & moisture may also promote diapause.
- Cool days & shorter day length induce diapause in temperate regions.
- Longer day length & dry season trigger diapause in tropics.
- Diapause hormone in silk moth determines whether the egg will undergo diapause or not.
- Long photoperiod stimulate brain to release diapause hormone from a pair of neuroseretory cells situated in the sub- oesophageal ganglion. This directly influences the ovary to produce darkly pigmented diapause eggs. Short photoperiod doesn't influence the production of diapause hormones.

# Hibernation

- Also known as winter dormancy or winter sleep.
- It is an inactive, sleep like dormant state of some animals during winter.
- It is characterized by minimal metabolism, low heart rate & breathing rate, low energy expenditure, fall in body temperature, slow growth & development,...
- It is a physiological &behavioural adaptations that enables animals to survive the extreme cold condition & severe scarcity of food by bringing down the energy demands to a very low level.
- Arousal on the advent of favourable conditions, they awake from the sleep-like state, resume their normal activities & functions, & return to their active life.
- True seasonal hibernation occurs in monotremes, some marsupials, insectivorous bat,...
- Pseudohibernation— some animals which show some form of sleep. They include salamander, frog, toad, lizard, snakes,....
- Among birds, seasonal hibernation is known only in a single family, namely goatsuckers (Caprimulgidae).
- The onset of hibernation is related to fall in environmental temperature & decrease in photoperiod.
- Hibernating animals adopt a sleeping posture & choose a typical sleeping site. Curling of their body helps in reducing the surface area & also in conserving heat.
- Many hibernating animals awake periodically to eat or drink.
- Brown fat specialized fat storing adipose tissue of mammals.
- During hibernation, it progressively loses weight. After that, body weight progressively increases until the onset of the next hibernation.
- *Nocturnal hibernation* Birds & mammals have extremely high metabolic rate. To survive difficult cold periods, they lower their body temperature at night when they do not normally feed.it is common among humming birds & small insectivorous bats.

# Aestivation

- Also known as summer dormancy or summer sleep.
- It occurs during extreme hot seasons or dry periods.
- It is common among desert animals.
- Aestivating mammals lie in buried moist soil or mud insulating their body against heat gain & water loss.
- During this period they slow down their breathing, heart beat & other life processes.
- This reduction in metabolic activity decreases the need for more food & water.

• The animal can thus survive hot & dry periods in which it otherwise might die. Eg:- Lung fishes, desert tortoises, Californian red legged frog,....

# Significance of hibernation & aestivation

- 1. Help to survive long periods of temperature extremes.
- 2. Enable to overcome prolonged & extreme shortage of food & water during unfavourable seasons.
- 3. Help to avoid intraspecific & interspecific competitions during some period every year.
- 4. Serve as a passive adaptation to escape predation

### **Communication in animals**

- Animal communication is the passing of information from one individual to another through visual, auditory, olfactory, tactile & electrical clues and signals to influence the behaviour of the recipient.
- Communication system has a source & a receiver.
- The source transmits the signal in an encoded form & the receiver perceives the signal and decodes it.
- Communication signals fall under five major categories,
  - 1. Visual
  - 2. Auditory
  - 3. Olfactory
  - 4. Electrical
  - 5. Tactile

### Visual signals

- Form & shape of body, morphological structures, colour patterns, gestures, bodily movements,... are visual signals.
- Eg:- dancing movement of honey bees.

### **Auditory signals**

- ➤ Includes croacks, grunts, songs, cries, speech,...
- Communication through language is the highest level of vocal communication.
- Eg:- singing of birds.

### **Olfactory signals**

- It occurs through the secretion of certain chemical compounds, called *pheromones*.
- ➤ It can be detected by smell or taste.
- ➤ Pheromones are found in urine, faeces& the facial gland secretion of some mammals, sexual attractants released by some insects & mammals,...

#### **Electrical signals**

- ➤ Some fishes use electrical pulses for communication & navigation simulating the vocal communication of birds.
- Fishes sing electrical songs.

#### **Communication rituals**

• Many animal activities undergone ritualization in the course of evolution to serve a communication function.

### Chemical communication

- Most widespread mode of communication.
- Used for attracting opposite sex & also for marking signal posts in their territory.
- Odorous chemicals are mostly pheromones & scenting substances.
- Conspecific members would sense them & appropriately respond them.
- It is highly evolved in social insects.

#### **Pheromones**

- They are chemical substances secreted to the external environment from some glands of certain animals to evoke specific behavioural or physiological responses in conspecific members.
- They are also called *etohormones*.
- It was first detected by Karlson Butenandt but the term pheromone was coined by Karlson Luscher.
- Pheromones play a significant role in maintaining the orderliness of the colony, coordinating the activities of members & also for sexual mating.
- The behavioural responses by pheromones include sexual excitement, homing, alertness, alarm reactions, withdrawal,...
- Response to pheromones is an instinctive behaviour, and never the result of learning & memory.

# Classification of pheromones

Three major classes of pheromones are releasers, primers & imprinters.

### 1.Releaser pheromones

They are the signaling pheromones which evoke quick, specific & transitory responses through the mediation of CNS.It includes trail, recognition, marker, alarm & sex attractant pheromones.

- i. Trail pheromones
  - Signaling pheromones which lead the members of a colony to a source of food or a place of shelter by providing olfactory, visual & tactile clues.
  - They are common among social insects.
  - The trail pheromones of ants is a typical example.
  - Eg:-geraniol by worker bee, guides other worker bees to the food.
- ii. Recognition pheromones
  - Signaling pheromones which enable the members of the colony or species to recognize each other.
- iii. Alarm pheromones
  - Signaling pheromones which keep the members of the colony on the alert to face an imminent threat or danger.
  - When an ant is disturbed by an enemy, it discharges alarm pheromone, this quickly diffuses in all directions. Others smell out the danger & rush to the scene for a counter offence.

- When enemies intrude into a termite colony, some resident members of the colony release an alarm pheromone. It communicates the message to all soldiers of the colony. Quickly they march to the scene to defend the colony.
- The alarm pheromones produced by some fishes & amphibians have a frightening effect in the perceivers.

### iv. Marker pheromones

- These are the scent marks released at the boundary of territories. And also the road posts which indicate the route to a specific destination.
- Ants commonly release marker pheromones to indicate the route to their nests, termites
  release them to indicate the route to termitaria, bees release markers to mark their air tracts to
  & from their hives.
- Territorial mammals release marker pheromones to fix the boundaries of their territory.

### v. Sex attractant pheromones

- Signaling pheromones which attract & excite the opposite sex.
- These are found among mammals & insects.
- Bombykol is produced by female silk moth at night to attract the male for mating.
- *Glypeure* produced by female gypsy moth.
- Seducin produced by male cockroaches & male crickets.
- *Muscone* produced by musk deer.
- Civetone produced by civet cat.
- *Exaltone* produced by musk rat.
- Urine of horse, dog, deer,..has been shown to contain sex attractant pheromones.

### 2. Primer pheromones

- ✓ The pheromones which trigger hormonal & nervous actions and therby bring about slow, steady & long lasting or permanent physiological changes in other members of species.
- ✓ Adult locust secrete maturation pheromone, which hasten the growth & maturation of young ones.
- ✓ Queen honey bee secretes an inhibition pheromone, which inhibits the development of functional ovaries in developing females.

### 3. Imprinting pheromones

✓ These are the pheromones which act on the CNS of the neonate, causing permanent modification in the reproductive behaviour of adult.

### Significance of pheromone

- 1. Recognition of conspecific members.
- 2. Integration & regulation of colony.
- 3. Sexual attraction & stimulation.
- 4. Spoting out of food & mating partners.
- 5. Defence& protection.

### **Advantages of pheromones**

- 1. Little energy is required to synthesize pheromones.
- 2. Conspecific members have receptors to perceive & interpret the molecular language of pheromones.

3. Pheromones are effective even in darkness.

### **Disadvantages of pheromones**

- 1. Pheromones contain limited informations.
- 2. The transmission of message is very slow.

### Visual communication

- This is a common form of communication among arthropods, fishes, reptiles, birds & mammals.
- > It depends on visual sense.
- The visual channels include the colour, shape & size of the body, posture, gesture displays,...
- > Fireflies produces intermittent pulsed flashes.
- > Specific flight movement of female butterflies attract males to her.
- ➤ Honey bees perform dancing movements.
- Octopus perform sexual displays by rapid colour changes.

# Auditoy communication

- ➤ Vocal communication is common among several group of animals.
- Vocal cords appear for the first time in the course of evolution, is anurans.
- Mammals use *larynx* for barking, roaring, growling, howling, speaking & many other vocal forms.

equipping with excellence

- ➤ Birds use their syrinx for singing. They make alarm calls for alerting the flock mates.
- Fishes produce ultrasonic sounds by the contraction of muscles in their gas bladders.
- Male frogs can croak louder with the help of their vocal sacs.
- Rattle snake produces sound by the rapid vibration of its rattle.
- Insects produce sounds by rubbing their body parts together. Eg:- crickets, cicadas,...

### Tactile communication

- These are effective even in darkness.
- ➤ Cave dwelling fishes have elaborate mechanoreceptors in their skin for prey detection, communication & sexual signaling.
- Grooming behaviour in monkeys is a way of conveying information.
- Insects possess mechanoreceptors in their antennae for detecting food substances.
- > Social insects use tactile communication for passing information (ants).
- In mammals it play a major role in colony organization & parental care.

### Social organization in mammals

- In mammals, social behaviour arisen along two evolutionary pathways, familial &parasocial pathways.
- Familial pathway formation of clusters consisting of only parents & close relatives. Firstly they care for young ones later their collective activity progressed into defence against predators, hunting, foraging,...

• *Parasocial pathway* – association of unrelated adults enabled better use of resources. Regardless of their origin, the behaviour patterns predominating in social groupings include co operation, territoriality, dominance, hierarchies, leadership, parental care,...

# **Social life of elephants**

- ❖ Elephants are highly social animals & they lead an elaborate social life.
- **\Delta** Each herd contains 100 or more members.
- ❖ Herds are *matriarchial*& headed by the wisest & strongest female.
- ❖ Leader goes ahead, followed by females & juveniles. Males moves last.
- ❖ When alarmed or threatened males quickly form a circle around the weaker members to protect them.
- ❖ If a member is sick, they stop their journey.
- ❖ A wounded member is always helped by others.
- ❖ Elephant corridors elephant move in herds from one forest range to another along definite tracts.
- ❖ Breeding occurs during rainy season. ing with excellence
- Polygamy is the mating system.
- ❖ Gestation period, Asiatic elephant 600 days, African elephant 660 days.
- ❖ Attains sexual maturity at the age of 13 or 14.

### Elephants in musth

- State of musth youthful elephant bulls may become unbalanced, erratic, ruttish& aggressive in behaviour.
- *Musth fluid/ madaexudes* from two minute openings near the temples of the animal. It is secreted by the temporal glands located either side of the head, between eye & ear.
- During the state of musth these glands enlarge, temples swell & the apparatus becomes more marked.
- Musth fluid is a thick & oily substance, dark brown in colour& with an unpleasant smell.
- The flow of must occurs first in life around the age of 15 or 16 years.
- Upto the age of 30-35 years this flow is not abundant & the behaviour of the bull may not be very much affected.
- At the age of 35-45 years the discharge become profuse &maximal, and the behaviour of bull become violent.
- *Musth period*-The flow may continue over nearly 40 days. Towards the middle ofthis period the flow begins to decline & it altogether dries up towards the end.
- The whole must period is marked by frequent urination & the animal goes on urinating almost all the time.
- Behavioral changes appear in the elephant nearly 40 days before the musthseretion begins & they continue for 40 days after the musth secretion has caesed. So, the musth period lasts for nearly 120 days.

