College of Engineering, Pune

(An Autonomous Institute of Government of Maharashtra)

Applied Science Department

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CT16002 – Biology for Engineers

UNIT I: Biomolecules and Biopolymers

Structure and Function: Organic and inorganic molecules; Unique Properties of Carbon; Carbohydrates, Amino Acids and proteins, Lipids, Nucleic Acids, Vitamins and Minerals; The Rise of Living Systems.

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1) BIOPOLYMERS & MACROMOLECULES

A living organism's body is built of and run by thousands of different types of molecules. As these are made chiefly by the living organisms they are known as biomolecules. Biomolecules have distinct properties and functions responsible for their selection and continuation in the course of evolution.

Many of the small molecules with low molecular weight, simple structure and high solubility are known as **micromolecules** (or monomers e.g. water, mineral, simple sugars, nucleotide etc.) form the building units for larger **macromolecules** (or polymers.e.g. protein, lipids etc.). The biomolecules are classified into organic and inorganic types based on their composition.

Thus, all cells are made up of biomolecules, these are organized in physico -chemical organizations and in isolation they do not have living characteristics. Biomolecules produce, maintain and perpetuate the living state and are continuously transformed i .e. synthesized and broken down.

Water, minerals and gases are important groups of inorganic bimolecules while lipids, carbohydrates, proteins and nucleic acids are the four important classes of organic compounds.

WATER

Physical & Chemical Properties of Water:

- Water is cohesive & adhesive
- Water has high specific heat
- Water has high thermal conductivity
- Water has high boiling point
- Water is good evaporative coolant
- Water has high freezing point and is less dense as a solid than liquid

In the biological rea ctions, two important features are observed,

- **polarity** (+ ve charge for H and – ve for O extend polarity to water molecule; water molecules form cluster around electrically charged molecules like PO_4 or COOH, that are

water soluble hence known as **hydrophilic** while water does not react with non charged molecules like lipids that are insoluble known as **hydrophobic**) and

- **ionization ability** (water molecule dissociates to form H and OH ions)

Significance of water in living system

- Life has doubtless origin from t he water.
- Water is the most abundant substance in living system making up more than 70% of the weight for most of the living organisms.
- Water provides liquid medium for colloidal protoplasm for chemical reactions and transport mechanism in the cell.
- The water molecule and its ionization products, H and OH influence the structure, properties and self assembly of all cellular components.
- Aqueous solutions of weak acids & bases with their salts act as buffer in pH change in biological system. It facilitates chemical reactions in the cells.
- The non covalent interactions responsible for the strength & specificity of biomolecules are decisively influenced by the solvent property of water. It is known as Universal solvent for most of the organic & inorganic molec ules.
- It absorbs heat and maintains body temperature.
- In green plants, it is a source for H + ve ions as a source of energy.
- Removal of waste material thus helps in maintaining **homeostasis**

MINERALS

Minerals are the nutrients required especially for the g rowth of plants that are absorbed from the soil. Some of these minerals are required in larger quantity and some in trace levels for the plant growth. Accordingly they are known as **micro** or **macronutrients** respectively. The role of some minerals in the cell metabolism is as follows,

Mineral	Function	Mineral	Function
N, S	Synthesis of Amino acids, proteins	**P**	Present in compounds like phospholipids, ATP, nucleotides etc.
K, Na	Constituents of Body fluids, nerve cells, blood plasma	**Ca**	Plays significant role in Blood coagulation & cell wall formation, propulsion of nerve impulses
Fe	Formation of haemoglobin	**Mg**	Formation of chlorophyll, enzymes, structural integrity of ribosomes
I	Functioning of thyroid glands	**Cu, Mo**	Activation of enzymes

Ions are required to maintain osmotic concentration of cellular as well as extra cellular fluids.

Gasses are significant for the basic cellular processes.

Gas	Function
O_2	Essential for respiration for all aerobic bacteria, combustion process, photosynthesis byproduct
N_2	Constituents of proteins, nucleic acid, fixation & release of nitrogen by bacteria for plants
CO_2	Used in photosynthesis, excess is dissolved in water

Carbohydrates –These are hydrates of carbon made up of C, H, O

Reducing sugars – Sugars with free aldehyde / ketone group

Non- reducing sugars- e.g. aldehyde region of glucose reacting with ketone region of fructose – form glycosidic bond – non – reducing sugar as free aldehyde / ketone groups are masked.

Aldoses: Glucose, Ribose, Deoxiribose, Mannose, Galactose etc.

Ketoses: Fructose, Ribulose, Xylulose etc.

According to number of monomers present in carbohydrate molecule

Monosaccharide**: Water soluble**

- Trioses (Dihydroxy acetone, glyceraldehydes)
- Tetroses (Threose, Erythrose)
- Pentoses (Ribose, Deoxyribose, Xylose, Ribulose, Arabinose)
- Hexoses (Glucose – also called blood sugar, grape sugar and Dextrose can be polymerized in to glycogen in animals and starch in plants; Fructose – Fruit sugar; Galactose, Mannose)
- Heptose (Sedoheptulose)

Oligosaccharides : 2-9 monomers

- Disccharides (Maltose, Sucrose, lactose etc)
- Trisaccharides (Raphinose, Pectin, Innulin)
- Polysaccharides (Starch, Cellulose, Glycogen, Chitin, Agar)

Homo-polymers: All the monomers same in given polysaccharides (Star ch, Hemicellulose, Cellulose, Glycogen)

Hetero-polymers: Two or more monomers in given polysaccharides (Agar, Chitin)

Monomers are linked by glycosidic bond during polymerization

Types & Function of Polysaccharides:

Storage polysaccharides: *Starch*, *inulin* stored in roots, tubers of plants; *Glycogen*: In animals and bacteria

Inulin is the smallest polysaccharide: not metabolized in human body filtered through kidney. ⟶ used in kidney testing.

Structural polysaccharides: *Cellulose, Hemicellulose, Pectin* – (in plants), Chitin (plant fibres & animal exoskeleton like insects, spiders, crabs etc.)

Chondrin sulphate in cartilage, tendon ligament

Hyaluronic acid – (glucoronic a.+ acetyl glucosamine) cementing subs. between animal cells. In diff body fluid – vitreous humor of eye,

sinusoidal fluid CSF e.g. *Keratan Sulphate* in cornea, skin, cartilage, bone, hair, nail

Mucopolysaccharide – slimy substances e. g. *Hyaluronic acid*

Agar – used in culture media, medicine, capsules and chromatography

Algin –used in Ice creams, cosmetics.

Carrageenin – used as a emulsifier, clearing agent – fruit juice.

Funori –used as adhesilve in hair curling

Heparin – used in blood bank as blood anti-coagulant

Husk of *Plantago ovata* – used as purgative / laxative

Aloegel – used as inflammation - relief, in hand lotion, shampoo, hair conditioner, sunscreen lotion.

PROTEINS:

Proteins make up more than 50 % of the dry mass of animals and bacteria and perform important functions in living organisms. They contain the elements carbon, o xygen, hydrogen, nitrogen and usually sulfur that makes a monomer of protein i.e. amino acid. All organisms contain 20 common amino acids as biological molecules.

Essential amino acids: cannot be synthesized by animals, so must be taken in diet. In man such amino acids are 8, in other animals are 7.

Non-Essential Amino acids: Can be synthesized by animals, so may not be taken in diet

Each amino acid (AA) has a carboxyl group (-COOH), amino group (-NH2) and a hydrogen atom bounded to a central carbon atom. The sequence of amino acids (linked by peptide bond) determines the overall shape and properties of proteins. Depending on number of amino acids in a chain oligopeptide (1 -10 AA), Polypeptides (11 -50 AA) and protein (>50 AA).

Various categories made for the classification of proteins based on the composition, structure etc. are as follows;

Structural organization of proteins:

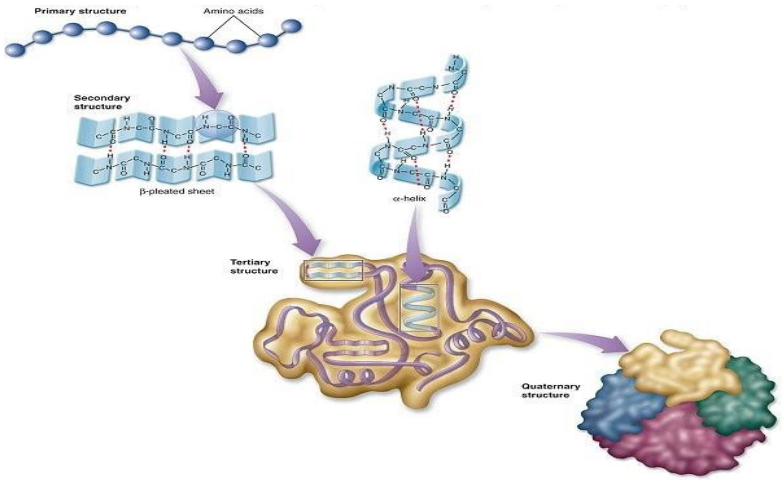
PrimaryProteins: two dimensional, simple chain of AA with peptide (covalent) bond e.g. Insulin

Secondary Proteins: Various functional groups exposed on outer surface interact with hydrogen bonds

- α- helix – e.g. keratin, hair, fur, clans, hooves
- β– pleated – B. keratin of feathers, silk fibroin
- Collagen helix – 3 α – helices coiled around one another

Tertiary Proteins: Additional bonds between functional groups, twisting of secondary protein, weak covalent and high energy disulphide bonds are formed e.g. Myoglobin

Quaternary P**roteins**: Formed as a result of 2 -more polypeptide chain and have specific orientation



Types of proteins according to structure:

Fibrous – collagen fibres, keratin, elastin, fibrin, fibroin, actin, myosin, bl. clot.

Globular – glutelin, protemine, globulin, albumin, glutenin, orygemin.

Intermediate – (myosin), fibrinogen.

Types of proteins according to chemical nature

Simple – only a.a. Albumin, globulin, protanine, fish, prolamine (corn, pl, wheat), histone (corn, wheat), glutelin (glutenin), keratin.

Conjugated – protein + non protein (prosthetic group) e.g. **Nucleoprotein** (nucleic acid), **chromoprotein** (Hb, cytochrome), **metallo** (with metals Zn, Fe), **lipoprotein** , **glycoprotein** etc.

Properties of proteins:

- Number: According to length,, number & types of polypeptides – thousands of proteins
- Specificity: High specificity in the individual but s hared with related species or group
- Molecular weight – ACTH (4500 daltons) to Pyruvate Dehydrogenase (4,600,000 daltons)
- Solubility: Some are insoluble due to large size, many form colloidal solution with water
- Amphoteric nature: Show both acidic & basic p roperties.
- Electrical reaction: Isoelectric point at which pH is neutral (Curdling of milk at pH 4.7 due to isoelectric point at acidic pH 4.7)

- Denaturation: Permanent or temporary loss of three dimensional structure caused due to UV, heat, strong acid & alkali, high salt concentration; within limit renaturation occur.

Role of protein:

Type of protein	Example	Function
Enzymes	Amylase	Converts starch into sugar
Structural	Keratin, Collagen Haemoglobin	Hair, wool, nail, horn, hoofs, tendons, cartilage Blood clotting
Hormones	Insulin, glucagons	Regulate glucose metabolism
Contractile	Actin, myosin	Contractile filaments in muscle, cilia & flagella (in lower organisms)
Amphoteric	All proteins	Maintain acid-base equilibrium
Storage	Ferritin, albumin Casin	Stores iron in spleen & egg yolk Milk
Transport	Haemoglobin Serum albumin	Carried oxygen in blood Carries fatty acid in blood
Energy	All proteins	Provides energy stored in peptide bonds
Metaloprotein	Cytochrome	Electron transport
Receptor	Adrenalin	Conduction of nerve stimulus
Nucleoprotein	Histones & non-histone	Stabilization of DNA coiling
Immunological	Antibodies	Forms complexes with foreign proteins
Toxins	Venum (Neurotoxin)	Blocks the nerve function

Proteins are masterpieces of molecular engineering and they are tailored to their functions by millions of years of natural selection.

LIPIDS:

Lipids are the organic compounds that share a distinguishing property of non polarity and so do not dissolve in water. They mostly contain carbon and hydrogen with very small portion of oxygen compare to carbohydrates. Some of them also incorporate phospho rus and nitrogen. Basically they are polymers of fatty acids & glycerol.

As lipids are insoluble in water they are vital components of the membrane that separate living cells from each other and their surrounding.

Lipids offer unique way to store energy as they possess very high proportion of energy rich carbon-hydrogen bonds in a concentrated form within the cells. They contain six times more energy than the carbohydrates and have become increasingly important as food reserves for organisms. (e.g. migra tory birds).

Fatty Acids: Simplest form of lipids consisting of a long hydrocarbon chain (non polar hydrophobic) with a carboxyl group at the end (which is hydrophilic). Because of this characteristic orientation, fatty acids significantly contribute in th e structure of cell wall.

Fats & Oils: These are the energy store reserves for the plant & animal cells. Fats are formed by the condensation of fatty acid molecules and are characteristically non polar. They are classified into **saturated** (butter, coconut oil) which are solid at room temperature and without double bond and **unsaturated** (from olive, corn, safflower, peanut etc.) which are liquid at room temperature and with double bond. Usually, animals use saturated fatty acids against the plants with unsatu rated fatty acids.

Phospholipids: These are similar to fats except one or two fatty acids are replaced by phosphate group which in turn are linked to nitrogen containing group.

Steroids: They differ from lipids in structure but insoluble in water. Cholesterol is most commonly known steroid forming essential component of animal cell membrane. It also served as a raw material for the production of vitamin D and steroid hormones.

In general the steroids carry chemical messages between the cells.

Properties:

- Saturated & unsaturated
- Insoluble in water and soluble in organic solvents like alcohol
- Low specific gravity hence float on water

- On hydrolysis give fatty acids and glycerol
- Neutral fat s or triglycerides are colour less, odder less, taste less
- Rancidity: Naturally occurring unsaturated fats undergo partial hydrolysis by the action of enzyme lipase. Oxidation at double bond produces aldehydes and carboxylic acids. This develops foul test and odder to the fats. **Types of Lipids –**

1. Simple Lipids – These are neutral or true fats. Solid at room temperature, on hydrolysis give three faty acids and one glycerol e.g. waxes

R C O R ← esters of fatty acids with different alcohols.

e.g. tripalmitin, diplamitin are hard fats, solid at room temp.

2. Compound / Conjugated lipids –

Phospolipids – Cephalin – act as insulation for nerves
Lecithin – cell permeability

Glycolipds – Cerebrosides – brain cells – cell mem. gangliosides – grey matter.
Sphingomyelins –in myelin sheath.
Sphingosine ⟶ amino alcohol.

Lipoproteins – found in milk, egg yolk, blood plasma, tissues, cell surfaces.
Cutin – from cuticle.
Suberin – due to it cell wall impermeable to H_2O.
Chromolipds – e.g. carotenoids.

3. Derived Lipids –Formed from hydrolysis of simple & comp. lipids, Include f.a., steroids, prostaglandins, terpenes.

Prostaglandins – Hormone – like unsaturated fatty acids / local hormones, present in amniotic and tissue fluid

- Circulate in blood
- Cause acid production in stomach
- Stimulate contraction of smooth muscles.

Steroids – solid wax like alcohols e.g. ergosterol – yeast. Cholesterol - animal cell mem., blood, bite. When bl. level of chole. rises – Cholesterol and its esters form bond with fats secreted by endothelium of arteries. And thus deposited on wall of arteries.

It is precursor for hormone progesterone, testosterone, cortisol, estradiol, androsteron Produces bile salts, vitamin D by action o f U V rays of sunlight.

- React with protein in nucleus
- Trigger changes in gene expression and metabolism

Role of lipids:

- Reserved food: In plants oilseeds like groundnuts, mustard, coconut are the stores of fats. Animals contain adipocytes which are the ce lls containing the fat droplets as stored food.
- Structural component: Phospholipids, glycolipids and sterols are the structural components of the cell membranes.
- Synthesis: Take part in the synthesis of steroids, hormones, Vit D etc.
- Energy source: Rich so urce of energy. 9.3 kcal/ gram
- Insulation: Provide electrical and thermal insulation. Deposited below the skin and around the internal organs to lessen the heat loss. Also work as shock absorbers.
- Solvent: Fats are the solvents for fat soluble vitamins like A, D, K, E.
- Waxes are water proof agents e.g. fur, feathers, insect exoskeleton, bee wax, ear wax (cerumen), skin wax (sebum), paraffin wax & plant waxes

NUCLEIC ACIDS :

1st reported by Friedrich Miescher. from pus cells nuclei. Called them nuclein. Altman called N.A. Feulgen developed staining tech. of N.A. with fusch.

DNA – Deoxyribo nucleic acid

Made up of three components –

i) Deoxyribose sugar – (pentagonal shape with 5 C atoms)

ii) Nitrogen containing bases –

Purine – Adenine (A), Guanine (G).

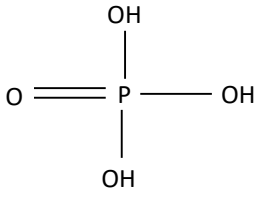
Pyrimidine – Cytosine (C), Thymine (T)

Pentose suger + N base ☐☐☐ nucleoside

Glycosidic bond between 1st C of sugar and nitrogen at 3rd position in pyrimidine base and 9th position in purine base.

iii)) Phosphoric acid –

OH – 3 acid groups.

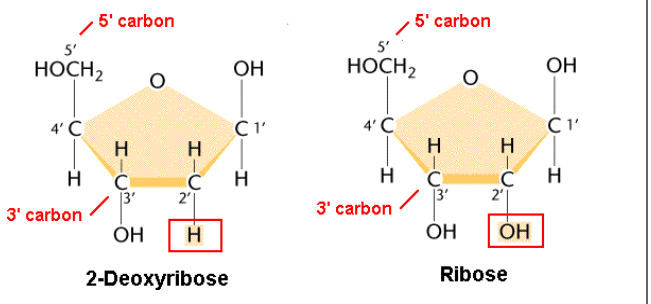


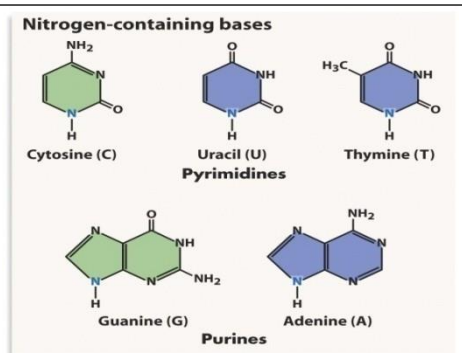
Nucleoside + P group at 5' position by **phosphor-diester bond**.

Nucleoside + Phosphate group ☐☐☐ nucleotide.

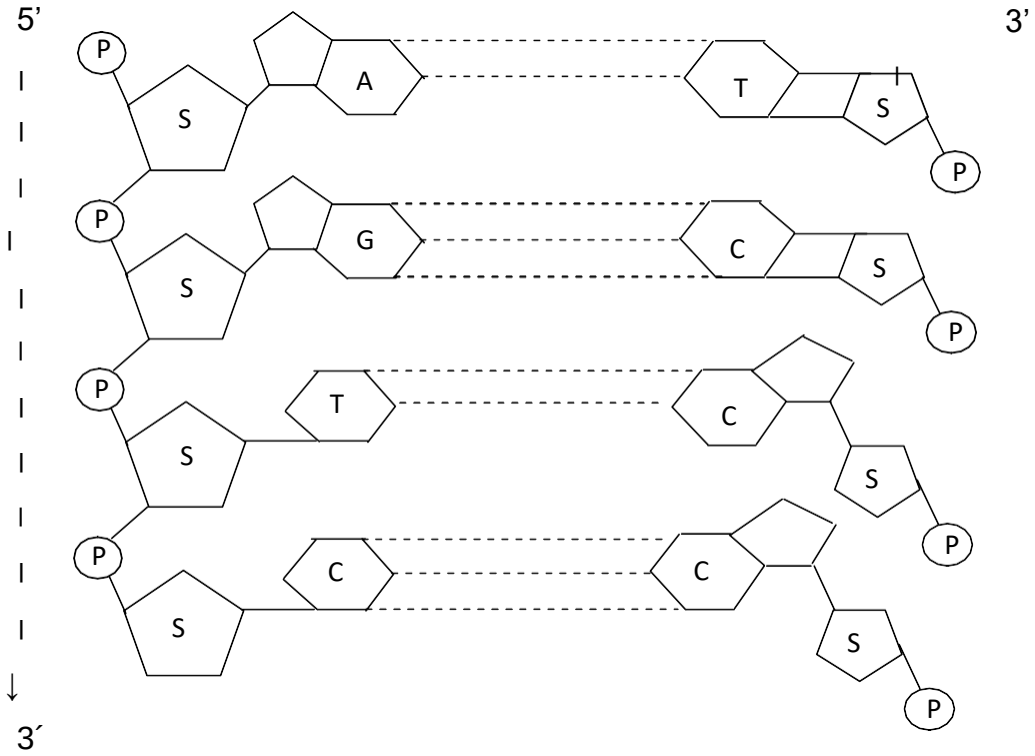
Amount of DNA measured by picogram = 10^{-12} g., 1 Pg DNA has 31 cm length.

Human cell – contains 5.6 Pg DNA – 174 cm long.





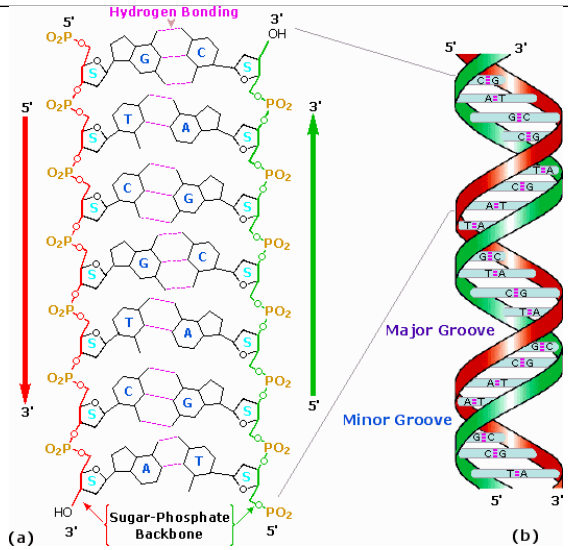
Chain of nucleotides – **poly nucleotide chain**



Characteristics / Properties – DNA

- It has several thousand Nucleotides.
- Back bone of it by alternate d sugar and PO_4 gr.
- Nitrogen bases are inside at right angle to longitudinal axis.
- PO_4 gr. Attached 5^{th}, 3^{rd} C atom.
- By phosphodiester bond.
- 2 chains joined by weak H bond – A = T, G = C specific pairing. H of one base linked to O_2 / N_2 of another base.
- 2 strands anti parallel i.e. 3', 5' phosphor -------- link in opp. direction.
- Pairing specific — 2 chain complementary.
  i.e. sequence of N_2 bases in one chain will decide it on other chain.
- Diameter of DNA – 20 A°

- **Erwin Chargaff's rule** – regardless of source - purine, pyrimidine components occur in equal amounts in a DNA mole.

1) A = T, G = C from this it is also seen 2) $\frac{A}{T} = \frac{C}{G} = 1$ 3) A +G = T + C 4) A + C = G + T but 5) A + T not always G + C necessarily.	

James Waston & Francis Crick – suggested three dimensional molecular model based on X ray crystallography technique; according to this model DNA comprises of

1) 2 right Handed helices.
2) Each turn has – 10 nitrogen base pairs
3) One spiral each 3.4 A°
4) Distance between 2 nitrogen bases 3.4A °

Denaturation and Renaturation of DNA –

1) If DNA solution heated / exposed to alkaline PH or acidic PH, H bonds break and 2 strands uncoil this is known as **denaturation** or **DNA melting**.
2) If above solution gradually cooled / neutralized – new base pair formation begins, it becomes thermally / chemically stable finally double stranded DNA formed which is called as **renaturation**.

Linear DNA with ends free **with histones** (eukaryotes) and circula r DNA 2 ends covalently linked **without histones (** prokaryots).

Repetitive DNA –

- The part of DNA which contains same sequence of N bases repeated several times in tandem (one behind another)
  e.g. A A T C G G A A T C G G A A T C G G
- It occurs specifically near telomeres (ends), centromeres,
- Area with long sequence of repetitive DNA is called satellite DNA as it separates out during density gradient ultra centrifugation.
- Microsatellite DNA — 1 – 10 base pairs repeat units
  Minisatellit e DNA — 11 – 60 base pairs repeat units, it is hypervariable (it is known as VNTR variable Number of Tandom Repeats discovered by Jeffreys et al., specific for each individual therefore used in DNA finger printing.

Palindromic DNA –

DNA duplex has areas with sequence of nucleotides same reading forward or backward from central axis of symmetry G A C T G C G T C A G

AND MADAM DNA

(Restriction endo -nuclease commonly recognize DNA sequences that are palindromes.

RNA – Ribo Nucleic Acid –

It is also made up of three components;

i) Ribose sugar – Pentose sugar

ii) Nitrogen containing bases – **Purine** – Adenine, Guanine & **Pyrimidine** – Cytosine, Uracil.

Sugar + N. B. ⟶ Nucleoside

Genetic in some pl. viruses TMV yellow MV animal viruses – influenza, poliomyelitis, HIV;

Animal, Plant viruses ⟶ single stranded

Reovirus of some plant ⟶ Double stranded.

Non- genetic RNA –

Mainly in nucleolus, cytoplasm, ribosome, mitochondria, chloroplast, in association with chromo.

Found both in pro & eukaryots

Synthesis in N on one of the DNA strand by transcription.

Thus carries genetic inf. from DNA.

Structure – Single stranded. Hence does not follow Chargaff's rule.

Types – three types of RNA - all are synthesized in nucleus

1) m – RNA / messenger / template : linear, longest molecule with 900 – 1500 nucleotides

Function: To carry genetic information in the form of codons from DNA to site of protein synthesis i.e. ribosomes.

2) r – RNA / ribosomal RNA – folded.

Function:

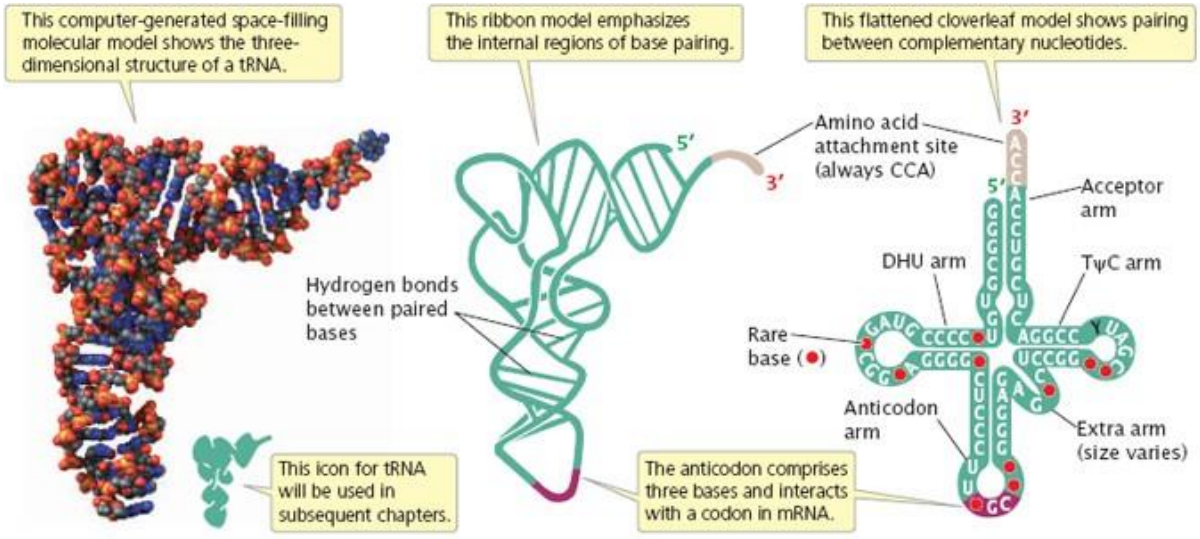
- Proper orientation of mRNA
- Formation of ribosomal complex by the attachment of smaller & larger subunit and further ribosomal complex with m RNA
- relese of t RNA from ribosome complex after transfer of AA to polypeptide chain

3) t - RNA / transfer RNA/ soluble RNA (can't be precipitated by ultracentrifugation)

Structure: According to shape two models are explained viz. clover leaf and hair pin

Function:

- To bring AA at the site of protein synthesis
- Transfer of AA to polypeptide chain



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CT16002 – Biology for Engineers

UNIT II: Levels of Organization of Life

Cell as basic unit of life, prokaryotic and eukaryotic cells, microbes, plant and animal cells; Cell organelles – structure and function; Levels of organization of life - tissues, organs, systems and organism.

LEVELS OF ORGANIZATION OF LIFE

Cell as basic unit of life, prokaryotic and eukaryotic cells, microbes, plant and animal cells;

CELL ORGANELLES

Present in all eukaryotic cells. Absent in prokaryotic cells, secondarily lost in mammalian RBC.

MITOCHONDRION

Also called as power houses, energy coins. Present in all eukaryotic cells, except mammalian RBC where secondarily lost.

No. per cell variable, 1 in primitive eukaryotes, 5,00,000 insect flight muscles.

Size 1.5—10 μm in length, 0.25 μm in diameter.

Shape cylindrical common, may be spherical, tubular, branched, discoidal.

Ultrastructure : --

1) 2 membranes : **Outer** – limiting, permeable, smooth, **Inner** – selectively permeable thrown into folds called cristae / trabeculae.

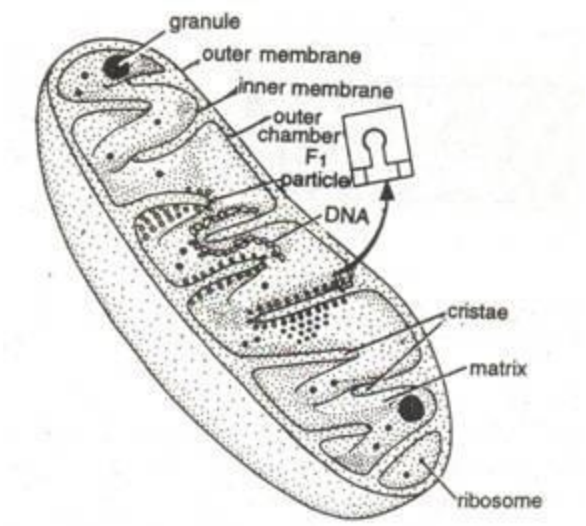


Fig. 2 Structure of mitochondrion cut longitudinally.

2) In between two membranes peri – mitochondrial space, filled with homogenous fluid called cytosol, contains H_2O, minerals.

3) Inner mitochondrial cavity has dense, homogenous gel like matrix with high conc. of soluble proteins, nucleotides, lipids, circular DNA called mitochondrial/ mt DNA, ribosomes of 70s type, K^+, HPO_4, Mg^{++}, Mn^{++}, Cl^-, SO_4^-, RNA (3 types), riboflavin vitamin.

4) Inner cavity divided into many compartments due to cristae, which are more in active cells. Inner membrane has 2 faces, outer face called C/cytosl face, inner M/matrix face. On inner surface of inner membrane i.e. at M face, numerous knob like elementary particles / F_1 paticles / oxysomes / Fernandez – Moran subunits.

Oxysome :- composed of base, stalk, head piece.

Head piece – contains F_1 – subunit, spherical, contains enzyme ATPase / ATP synthatase

Function – oxidative phosphorylation, oxidation of food, ATP release.

Base – contains Fo – particle / subunit , rectangular ,embedded in inner mitochondrial membrane, contains coezymes of ETC.

Stalk – contains F5, F6 subunit.

Mitochondria:- self duplicating, New one formed by division of existing one.

Semi autonomous organelle –

Mitochondria – have own genetic information, in mitochondria DNA is independent of cell's nuclear DNA., capable of s elf replication, capable of forming 3 types of RNA. Mitochondria has its own ribosomes. Hence can, form its own structural proteins. Few subunits of mitochondria & enzymes are formed by itself from ribosomes. Remaining subunits from cytosol. Hence mitocho ndrion is a semiautonomous organelle.

Functions:-

1) Power house / storage batteries / ATP mills of cells.
2) Bring about oxidation of carbohydrates, fats., proteins.
3) Capable of self – replication.
4) Site for synthesis of haemoglobin(protein in blood), myoglobin (protein in muscles).
5) Site for thermiogenesis (heat production).

PLASTIDS – FOOD FACTORIES & STORE HOUSES

On the basis of colour pigments plastids are classified in to ch loroplasts (green), chromoplast (Yellow, orange etc.) and amyloplasts (White)

Chloroplast: Present in green parts of plant like leaves, skin of raw fruits, flower in bud condition, young stem.

Shape – Cup shaped, Spiral ,Girdle, Branched, Starlike ,Reticul ate, Spherical, Oval, Discoidal in higher plants. **Number** – 1 to several hundreds. Size – 4 – 6 μm.

Ultra structure –

1)Covered by 2 membranes. Outer one permeable with less proteins. Inner one semi permeable with more proteins.

2) Periplastidial space of 25 – 75 A° between 2 membranes.

3) Matrix / stroma **–** Ground substance, colourless, granular with proteins, lipids, 70 s ribosomes, circular DNA, (called as chloroplast/ct – DNA), RNA (3types), enzymes.

4) In stroma no. of membranous sheets calle d lamellae. Lamellae form closed oval sacs called thylakoids.

5) Each thylakoid has intra thylakoid space / loculus. In loculus no. of para crystalline rounded bodies called quantosomes present which trap quantum of light. Each quantosome contains 230 chlorophyll pigment molecules. In higher plants quantosomes contain chlorophyll a & b, carotene, xanthopyll. Thylakoids also contain various electron carriers like cytochrome f, b, ferredoxin, plastocyanin, plastoquinone.

In eukaryotes – thylakoids are superi mposed like a pile of coins and form granum. In each granum 10 – 100 (average 20 – 50) thylakoids. In each chloroplast about 40 – 60 grana . Adjacent grana interconnected by stroma lamellae / frets / intergranal lamellae.

Semi – autonomous organelles

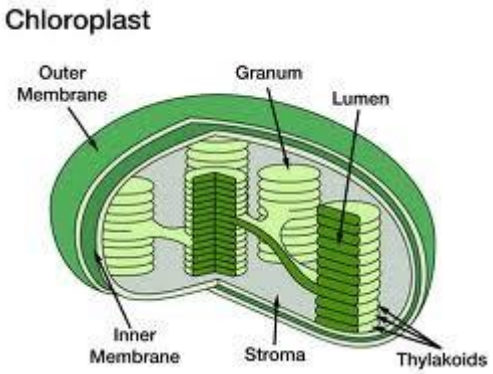
Circular DNA, 70 S ribosome, RNA (3 types) present, hence can form another chloroplast using some enzymes from cytoplasm.

Functions- 1. Photosynthesis.

2. O_2 replenished in atmosphere.

3.Starch storage.

4.Natural greenery



Endoplasmic Reticulum – (ER)

ER has inter connected membrane bound vacuoles / cavities , concentrated in endoplasmic portion of cytoplasm (Cytoplasm has 2 regions – outer homogenous--ectoplasm, inner granular – endoplasm), hence called ER,

Occurrence –

Well developed in fully differ entiated, metabolically active eukaryotic cells – e.g. liver, pancreas. Absent in prokaryotic cells, secondarily lost in matured mammalian erythrocytes (RBC).

Ultra structure –Composed of 3 shapes

1) Cisternae – Near nucleus. Long, flattened, saclike, un branched tubules. Lie one upon the other, interconnected & studded with ribosomes.

2) Vesicles – oval / rounded, vacuolar structures, scattered in cytoplasm.

3) Tubules – branched, form reticular structure along with cisternae and vesicles. Near cell membrane. .

Types:-

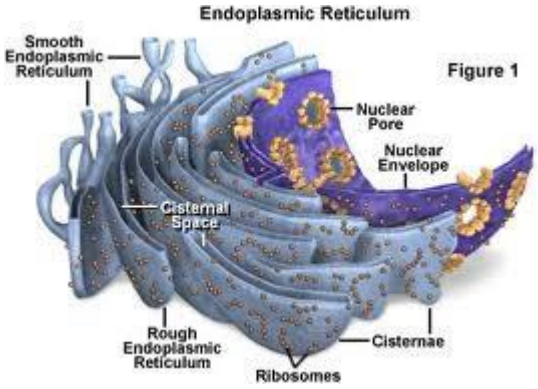


Figure 1

1) Agranular / Smooth ER – SER

Ribosomes absent on outer membrane. Present near cell membrane. Generally in the form of tubules.

2) Granular / Rough ER / RER –

Ribosomes attached to outer membrane. Generally in the form of cisternae.

Functions of Endoplasmic Reticulum–

2) Fluid filled vacuolar system. Acts as endoskeleton; gives support to colloidal protoplasm.
3) Active, passive transport of material.
4) Divides cytoplasm into many compartments, thus cell activities take place separately in each compartment. Various organelles remain stationed.
5) Increase surface area for absorption / chemical reactions within cell.
6) Contain variety of enzymes.

Golgi Complex: Molecular sorting & finishing area

Ultrastructure -

Present in three shapes / forms --

a) Cisternae **-** Flat / curved , piled up one above other, with swollen ends. Outer convex surface associated with nuclear membrane/ ER. It is called – forming / cis / entry face Inner concave surface, called maturing / trans / exit face.

b) Vacuoles –Formed by fusion of small vesicles / large parts of broken cisternae. Generally associated near concave surface.

c) Vesicles – Pinched off from edges of cisternae hence near edges / concave surface.

Chemical composition – Proteins – 60%, Phospholipids – 40% , Enzymes.

Origin – mostly from SER as cisternae connected to E.R.

Functions –

1) Secretion – Mainly secretion of enzymes, hormones, glycoprotein, Ab(antibody).

2) Storage and Synthesis – Store proteins, lipids in the form of glycoprotein & glycolipid.

3) Packing and forwarding center for enzymes, mucus, hormones in small vesicles.

4) Cell plate formation in cell division.

5)Formation of primary lysosomes – Hydrolytic enzymes are formed in ER, then come to cisternae, packed and budded off as primary lysosome.

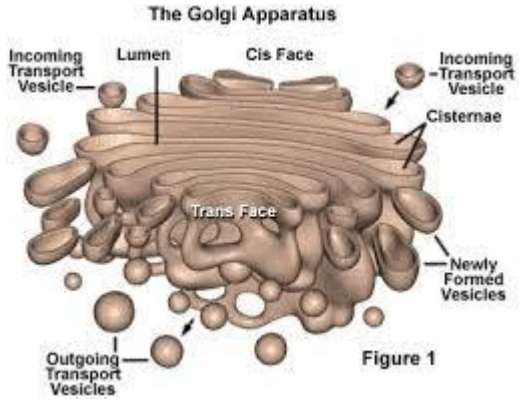


Figure 1

Lysosomes : Sacs of hydrolytic enzymes

Structure – These are small membrane bound (unit membrane) vesicles. Contain hydrolytic enzymes.

*** Hydrolytic enzymes are stored in crystalline / fluid form. Membrane of lysosome is impermeable to enzyme. But ruptures during O_2 deficiency / exposure to poisonous substances. Then enzymes are released and cell itself is destroyed. Hence lysosomes are also known as suicidal bags of cells.***

Types of Lysosomes

1) Primary lysosome - / storage granules – Derived from G.C. Contain only hydrolytic enzymes in inactive form. In the form of small vesicles.
2) Secondary lysosome / Digestive vacuoles / Heterophagosomes – Pinosome (vacuole with liquid) / phagosome (vacuole with solid) fuse with primary lysosome. Hence contain enzyme + material to be digested.
3) Residual Bodies / Tertiary lysosome / Telolysosome – Undigested mateial remain in. Now called residual body. Come near plasma membrane, throw out their contents out side thro' ephagy / exocytosis. If contents not discharged, the cells are loaded with it, cause nephritis, hepatitis, arthritis, gout, lung fibrosis.
4) Autophagosomes / Autolysosomes **–** Cell organelles like ER, Mitochondria get worn out. Its degradation by lysosome called as autophagy. Primary lysosome + worn out cell organelle form autophagosomes.

Function –

1) Digestion – by hydrolytic enzymes.

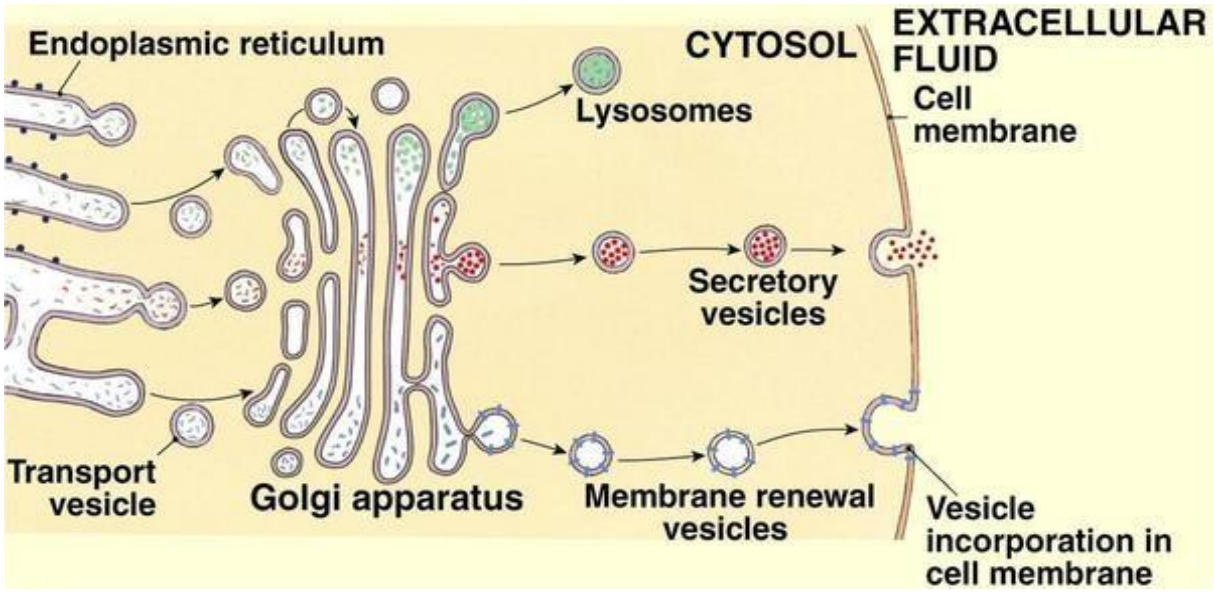
Extracellular – enzymes are released in surrounding medium by exocytosis.

Intracellular – by formation of secondary lysosomes or autophagosomes. E.g. phagocytes in higher animals, degeneration of tail in tadpole larva of frog by enzyme cathepsin.

Heterophagy – digestion of foreign substance,

Autophagy – digestion of self substances. Thus lysosomes are self disposal units, also bring about physiological rejuvenation. Digestion of reserve food during starvation is also called as Autophagy.

2) Initiate cell division by removing repressors of this process.
3) By breaking thyroglobulins, thyroid hormone(thyroxin) is produced.
4) In joint disorder like gout, arthritis -- macrophages come here & release lysosomes which causes inflammation.
5) Accidental / pathological release of lysosome enzyme causes chrom osome breakage, abnormal distribution of chromosomes during mitosis, which may lead to blood cancer.



Ribosomes: Work benches for protein analysis

Occurance -- both in pro and eukaryotic cells, except mature RBC.

Types of Ribosomes – According to size, sedimentation coefficient ($S = 1 \times 10^{-13}$ cm / sec / dyne / gm) 2 types.

1) 70 S ribosoms –found in mitochondria, chloroplast of eukaryotic & prokaryotic cells
2) 80 S ribosomes – " in eukaryotic plant & animal cells.

Structure – Not covered by unit membrane, but porous, hydrated, 2 subunits. Larger & smaller. 70 S ribosome has 50 S and 30 S subunits & 80 S ribosome has 60 S and 40 S subunits which are separated by a narrow cleft. 2 subunits remain separated, join only

during protein syn thesis. In high conc. of Mg^{++} ions $\longrightarrow$ 2 subunits remain united & called as dimmer. Smaller sub unit fits like a cap on larger subunit. Larger subunit – dome – shaped, 2 binding sites Peptidyl / P site / donar site, Amino – acyl / A site / acceptor site. It has protuberance, ridge and stalk. Smaller subunit – ellipsoidal shape, cap like. It has a platform, cleft, head & base.

Polyribosome / polysomes – It is chain of ribosomes as formed during protein synthesis on m-RNA.

Functions –

1) Protein factories / engines of cell as site of protein synthesis.
2) Free ribosome produce non – secretary proteins like enzymes for intra cellular use (e.g. in muscle cells, skin cells)
3) Bound ribosome like present on RER synthesize secretory proteins e.g. enzymeA

After synthesis of proteins, proper folding of proteins is assisted by specific proteins **chaperons** which also assist transport of proteins into organelles like mito chondria

Nucleus: Genetic message centre

Ultrastructure -

Contains nuclear membrane, nucleolus, nucleoplasm, chromatin

Nuclear membrane / karyotheca / Nuclear envelop / Nucleolemma.

- It is an outer envelop
- Present in all eukaryotic N Absent during late cel l division.
- Consists of 2 unit membrane, between them perinuclear space of 75 A °.
- Outer membrane continuous with RER, studed with ribosome on outer side.
- Nuclear openings or pores in it to maintain nucleo – cytoplasmic connection.
- Outer membrane called as ectokaryotheca, inner called as endokaryotheca.
- Each nuclear pore has cylindrical annulus with pore complex.
- Through pore complex / basket movement of substances takes place.
- mRNA come out through them into cytoplasm.
- Dissociates during early cell division, reappears at end of cell division.

Nucleous –

Appears spherical, dense, colloidal, no limiting membrane. No. 2 -- 5

Parts – i)Granular region -- protein granules ii)Fibrillar region – proteinaceous fibrils iii)Amorphous matrix – less dense called 'pars amorpha'. iv)Chromatin fibres are perinucleolar and intranucleolar.

Nucleoplasm – nuclear sap / nucleoplasm / karyolymph.

Transparent., semi – solid, granular, acidophilic.Composed of – Nucleic acids, enzymes, minerals.

Chromatin –

Hereditary part. Network of fibres. During cell division organizes as chromosome.

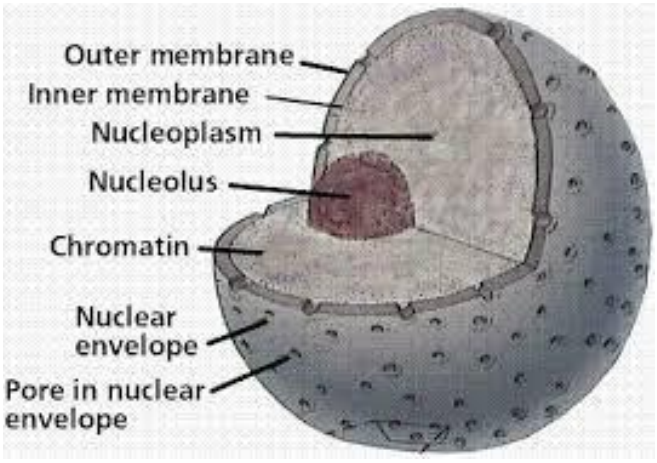
.Heterochromatin – Show thick regions, darkly staining where DNA is condensed. Lies near nuclear membrane. Contain late replicating genes. Inactive genetically.

Euchromatin – Thin regions, less darkly staining, DNA loose, genetically active.

Chromatin thread composition – DNA, RNA, proteins (histones., non – histones.)

Functions --

1) Contain hereditary material in the form of chromosomes
2) Transfer genetic characters from one genera tion to another
3) Control cell division
4) Control all physiological activities of the cell.



EVOLUTION OF BIOLOGICAL MACHINES

Major changes that occurred when prokaryotes gave rise to eukaryotes -

- Cells acquired more DNA.
- DNA folded compactly into discrete complexes with specific proteins to divide it equally between daughter cells at cell division.
- Specialized proteins stabilize folded DNA (chromosomes).
- A system of intracellular membranes and a double membrane surroundi ng the DNA was developed.
- Early eukaryotic cells enveloped aerobic bacteria or photosynthetic bacteria to form endosymbiotic associations that became permanent. Some aerobic bacteria evolved into mitochondria of modern eukaryotes and some photosynthetic ba cteria became plastids like chloroplasts and likely ancestors of modern plant cells.
- It was advantageous to cluster together for acquiring greater motility, efficiency, or reproductive success than their free -living, single-celled competitors.
- Specialization within the colony – to cellular differentiation.
- It led to even more complex and highly differentiated organisms, in which some of them carried out the sensory functions, others the digestive, photosynthetic or reproductive functions so forth.

Principles of generating diverse body plans and design in nature :

The major events include the changes in

a. Size of organisms
b. Form and complexity
c. Expansions in diversity
d. Production of many shapes of macroscopic life.

The evidences for the process of evolution are usually obtained from fossil records which is also the data at the time of origin.

Inferences about direction of evolution:

a. Multicellularity evolved independently many times and in all parts of life i.e. plan ts, animals and microorganisms.
b. Multicellularity evolved from different unicellular ancestors.
c. These multicellular organisms have new body plans and physiologies
d. They represented more complex features.

These complex forms then diversified so that varied k inds appeared over a long period.

Figure: Evolution of eukaryotes through endosymbiosis:

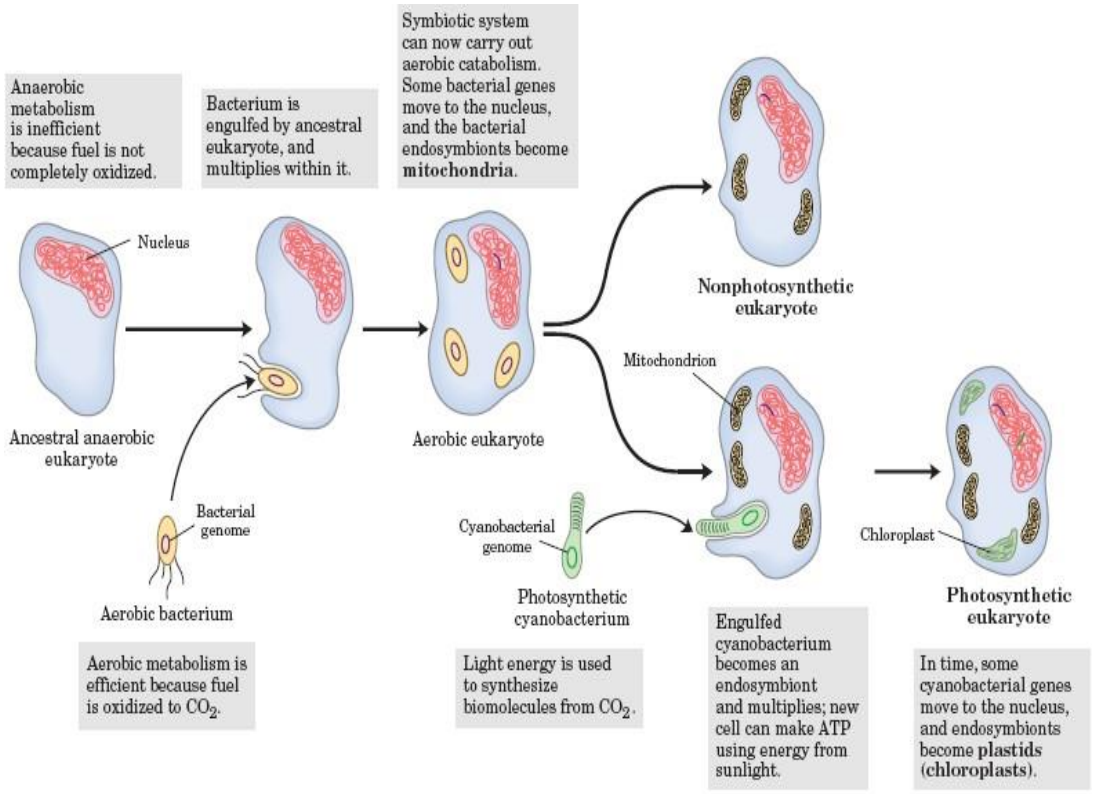


FIGURE 1-36 **Evolution of eukaryotes through endosymbiosis.** The earliest eukaryote, an anaerobe, acquired endosymbiotic purple bacteria (yellow), which carried with them their capacity for aerobic catabolism and became, over time, mitochondria. When photosynthetic cyanobacteria (green) subsequently became endosymbionts of some aerobic eukaryotes, these cells became the photosynthetic precursors of modern green algae and plants.

Size and multicellularity:

For first 2500 million years of life on the earth, most species w ere generally much smaller and rarely exceeded 1mm in size. The bacterial microfossils obtained from 3500 million years had 5mm diameter.

The early microfossils of eukaryotes were 40 -200 mm in size for first 600 -800 million years

Cellular dimension are limited by oxygen diffusion:

A bacterial cell is 1 -2 mm long and animal/plant cell is 5 -100 mm long. The upper limit of cell size is set by the rate of diffusion of solute molecules in aqueous system.

Consider the example of a bacterial cell -

It depends upon oxygen consuming reactions for energy production. So it has to obtain molecular oxygen by diffusion across its plasma membrane. The cell is small and the ratio of its surface area to its volume is large hence every part of its cytoplasm is easily recei ving the diffused oxygen.

But as cell size increases, surface-to-volume ratio decreases. The rate of consumption of oxygen is faster than that of its diffusion because if the metabolism of the cell. So when the cell size goes on increasing, the oxygen demand for metabolism increases to such a point that the metabolism becomes impossible. This puts a theoretical upper limit for the cell size and cell cannot increase above this point.

Complexity: It is referred to as number of different cell types or the no./ functional specialization of parts.

There are four types of complexity –

1. the number of different physical parts e.g. genes, cells, organs and organisms in a system..
2. the no. of different interactions between the above mentioned parts
3. the no. oflevels
4. the no. of parts or interactions in a specific condition

Diversity: Actually the diversity of life has expanded from its origin but it doesn't cause continuous increase. For the organisms those are made entirely of soft tissues or of small size, it cannot be said whether the total diversity increased or decreased over a long period of time.

Levels of Organization

Within multi-cellular organisms there is division of labor. Division of labor means that the work (labor) of keeping the organism alive is divided (division) among the different parts of the body. Each part has a job to do and as each part does its special job, it works in harmony with all the other parts.

The arrangement of specialized parts within a living thing is referred to as levels of organization.

First Level :-Cells

Cells of course, are the first level of organization

Second Level:- Tissues

Tissues are the second level of organization. In any multi-cellular organism, cells rarely work alone. Cells that are similar in structure and function are usually joined together to form tissues. There are four basic/major types of tissues in the human body: Muscle tissue (skeletal, smooth, cardiac muscles), nerve tissue (brain, spinal nerves, cranial nerves), connective tissue (bone, cartilage, blood), and epithelial tissue (skin, other body p arts coverings).

Third Level :- Organs

Organs are the third level of organization.

When a bunch of different types of tissues work together, they form an organ . E.g. Brain, liver, stomach, heart etc.

Fourth Level :- Organ System

Organ systems are the fo urth level of organization.

Each organ in human body is a part of an organ system, a group of organs that work together to perform a major function. E.g. heart, blood vessels are parts of circulatory system, likewise digestive, excretory, respiratory syst ems.

Fifth Level :-- Organism/ Individual

Organisms with many systems form fifth level of organization.

Single cell to multi cellular organism

- Unicellular organisms formed colonies by remaining together after each cell division.
- Division of labor, made it possible to exploit resources in better way.
- For formation of multicellular organism, cells remain bound together. In animals extracellular organic matrix binds cells together as cell wall, plasmodesmata are absent.
- Such fundamental arrangement is seen in epithelial tissue sheets.
- From a group of cells, some cells differentiated from others and adopt different structure, chemistry, function usually in response to cues from neighbouring cells.
- Cells have memory i.e. cell and its progeny usually persist in their differently specialized state even after disappearance of original stimuli.
- Final character of animal not determined by its final environment but entire sequences of influences to which cells are exposed during development.
- As body grows and matures, progressively finer details of the adult body pattern become specified, complex organisms are formed in long developmental history.
- Though more and more complex organisms are formed, early developmental stages very similar though adult stage radically different.
- Specialization of cells depend on gene expression and not on loss or acquisition of genes. As specialization also involves loss of genetic material. E.g. RBC – lost nucleus during differentiation.
- In eukaryotes sophisticated mechanisms for controlling gene expression has evolved.
- Groups of genes activated or repressed in response to external and internal signals.
- Radical differences of character between cell types reflect stable changes in gene expression.

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CT16002 – Biology for Engineers

UNIT III: Bioenergetics and Metabolism

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1. **Energy Dynamics in Biology –**
    a. Photosynthesis and energy assimilation: aerobic and anaerobic systems. Applications
    b. Respiration and Electron Transport Chain: Mitochondria and respiration, ATP generation.
2. **Bioenergetics:** Thermodynamic principles applied to biology, negative entropy changes in biological systems, Free Energy, Chemical Equilibrium

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1) PHOTOSYNTHESIS

(PHOTOSYNTHETIC ELECTRON TRANSFER, CALVIN CYCLE)

Introduction:

Solar energy is the prime source of energy to entire living world. 2] All living organisms require energy for their life processes. 3] Solar energy can't be utilized by organisms.

Important Features of Photosynthesis:

1) It is an intracellular process. 2) It takes place only in green cells of plant 3) During this process organic food is synthesized. 4) It utilizes solar or light energy. 5) It uses CO_2 & H_2O as raw materials. 6) Solar energy is converted into chemical energy. 7) Only 1 to 5% of solar energy received by earth is utilized in photosynthesis. 8) It is redox reaction where water is oxidized to oxygen & CO_2 is reduced to carbohydrates. 9) At first simple sugar like glucose is formed & then complex food like starch, proteins, fats are formed. 10) Chlorophyll acts as a catalyst.

Definition:- It is a biochemical process in which organisms prepare complex organic food from simple, inorganic substances like CO_2 & H_2O with the help of chlorophyll & light energy, releasing O_2 as by product.

Overall reaction: -

$$\mathbf{6CO_2 + 12H_2O \xrightarrow{\text{Chlorophyll, Light energy}} C_6H_{12}O_6 + 6H_2O + 6O_2}$$

Photosynthesis is an anabolic (biosynthetic) & endergonic (E dependent) process.

Pigments and their role :--1] Photosynthetic pigments of chloroplast in higher plants are chlorophyll & carotenoids.

2] Chlorophyll : - Each chlorophyll molecule looks like a kite or tennis racket with head & tail. Head is made up of 4 pyrol rings with Mg in center. It is hydrophilic Tail is made up of phytol which is long chain alcohol. It is lipophilic, hydrophobic.

3] Chlorophyll a : - It is bluish green, with molecular formula C 55 H 72 O 6 N 4 Mg, absorbs – blue, yellow, red wave lengths of light.

4] Chlorophyll b – It is yellowish green, molecular formula $C_{55}H_{70}O_6N_4Mg$,absorbs – blue, orange wave lengths of light.

5] Carotenoids are carotenes & xanthophylls. Carotenes are yellowish orange with molecular formula $C_{40}H_{56}$. Xanthophylls are yellow with molecular formula C40H56O2 Carotenoids are long chain hydrocarbons. They don't have definite shape.

6] All photosynthetic pigments trap light energy in form of photons.

7] Chlorophyll b, Crotenes & Xanthophylls transfer trapped light energy to chlorophyll a by resonance transfer, do not participate actively in photosynthesis. Hence they are called as accessory pigments/antennae pigments/light gatherers. These accessory pigments avoid photo-oxidation of reaction center in intense light.

8] Chlorophyll a collects light energy from these pigments. It also absorbs light energy. It uses light energy for formation of ATP. Hence it is called as active pigment. It acts as a center of chemical reaction. It shows fluorescence.

9] Middle region of quantosomes are called as photocentres or reactive centers.

10) Chlorophyll a has two pigment systems called photosystems i.e. PSI , PSII are involved . PS I absorbs far red light of wavelength 700 nm & PSII absorbs short red light of wavelength 680 nm. Each system has its own type of chlorophyll a i.e. P700 & P680. Both system work in cooperation to capture radiant energy.

PS I – 670 , 683, 700. P – 700 is Reaction center. PSII – 680, 673. P – 680 is Reaction center. PSI – lies on outer surface of thyllacoid, PSII – lies in inner surface of thyllacoid.

Mechanism of Photosynthesis --

Reaction of photosynthesis takes place in two phases i.e. photochemical phase & biochemical phase.

I] Primary Process / Photochemical phase / Light reaction

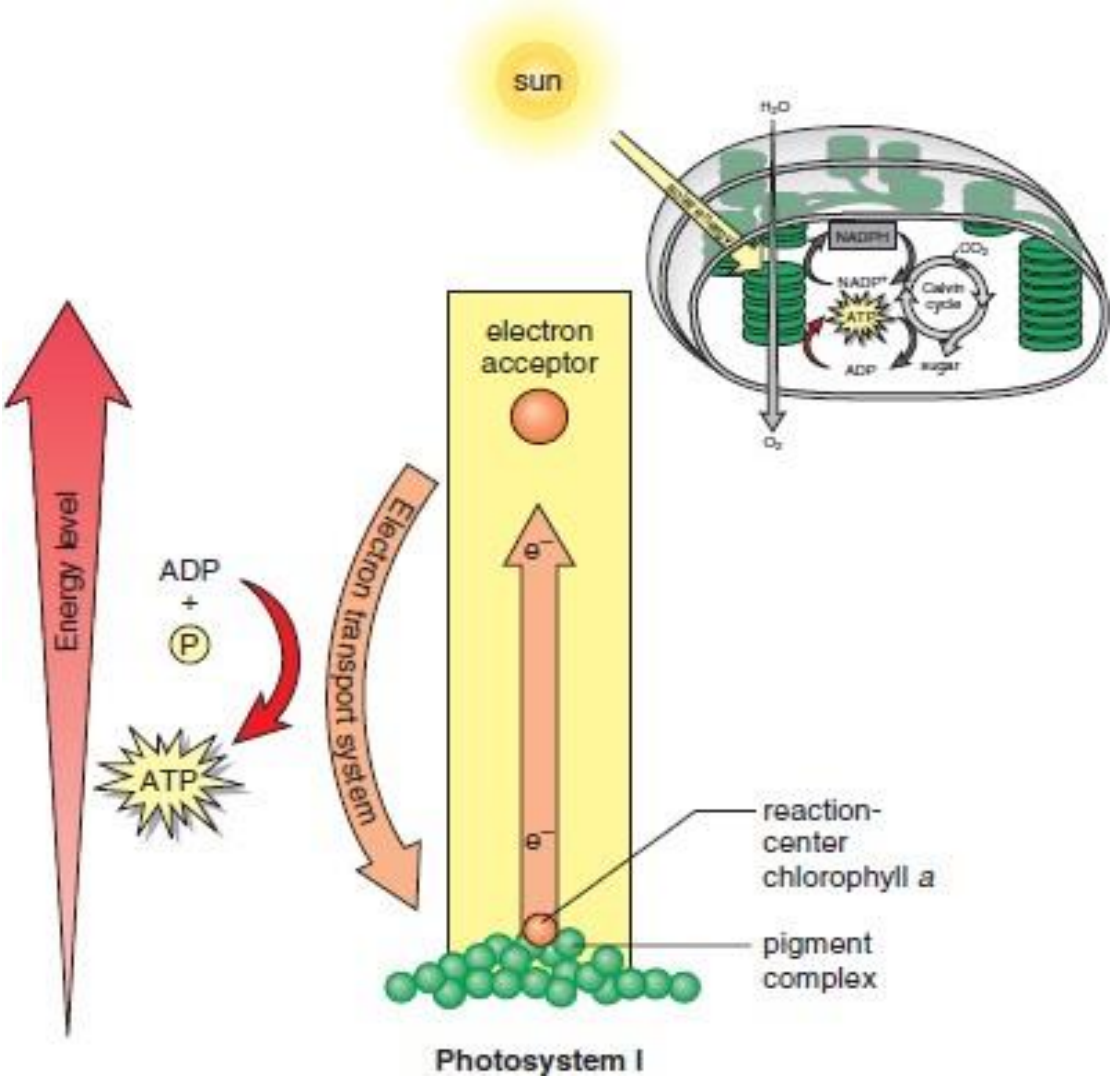
1) It takes place in presence of solar energy i.e. light & only in granna of chloroplast. Hence it is light reaction.
2) Light energy is converted into chemical energy with formation of ATP & NADPH2. Hence it is photochemical phase.
3) ATP is formed by addition of 1 inorganic phosphate to ADP with the help of energy. This is called as phosphorylation.
4) Energy required for phosphorylation is obtained from light in form of photons. Hence it is called as photophosphorylation.
5) During this process e ○ s are transfered through a system of e ○ acceptors.

6) Two pathways are there of e ○transfer i.e. cyclic & non cyclic

(A) **Cyclic e ○transfer / Cyclic photophosphorylation**

(1)It involves PS I (Pigment system I). (2) Light strikes chlorophyll-a i.e.P – 700 trap(3) It absorbs quantum of light energy. (4)As a result it is exited i.e. its energy level increases.(5) Hence it emits a pair of high energy electrons. (6)Energy rich e leave chlorophyll molecule & hence the chlorophyll molecule becomes +vely charged (ionized) i.e. unstable.(7)Electrons move through various electron acceptors such as FRS(Z) , ferredoxin, cytochrome b6, cytochrome f & plastocyanin.(8)As energy rich electrons move through electron acceptors, they loose some of their energy which is used for synthesis of ATP from ADP & inorganic phosphate. (9)Finally de-energised electrons return to unstable chlorophyll a molecule which becomes stable. (In one millionth of a second) (10)Thus the electrons lost by chlorophyll molecules return to the same chlorophyll molecule. Hence it is called as cyclic electron transfer.

Cyclic electron transfer occurs when light intensity is low, CO_2, O_2 low.



B] Non cyclic photophosphorylation / Non cyclic e^- transfer

1) It involves pigment system I & II i.e. PS I & PS II
2) Light strikes chlorophyll – a of PS I & PSII i.e. P-- 700 trap & P680 trap.
3) They absorb quantum of light energy .
4) As a result they are exited i.e. their energy level increases.
5) Hence they emit a pair of high energy electrons
6) Energy rich e^-s leave chlorophyll a molecule which becomes + vely charged (Ionised) i.e. unstable.
7) These e^-s from PS II system, which is the primary electron donor, move through various e^- acceptors such as FRS, ferredoxin and finally accepted by NADP, that from PS I through plastoquinone, cytochrome b6 , Cytochrome f, plastocyanin.
8) As energy rich electrons move through electron acceptors, they loose some of their energy which is used for synthesis of ATP from ADP & inorganic phosphate.
9) In presence of light & chlorophyll a molecule photolysis of water takes place & two electrons , two H + ions & O_2 are released. O_2 is released outside. These electrons are accepted by chlorophyll –a of PS II & it becomes stable. H ions are accepted by NADP.
10) Two electrons emitted from PSII are accepted by chlorophyll- a of PS I after it emits two e – s when light strikes on it. Thus chlorophyll-- a of PS I becomes stable.
11) Finally two H + ions released by photolysis & two e – s released by PSI combine together & reduce NADP to $NADPH_2$

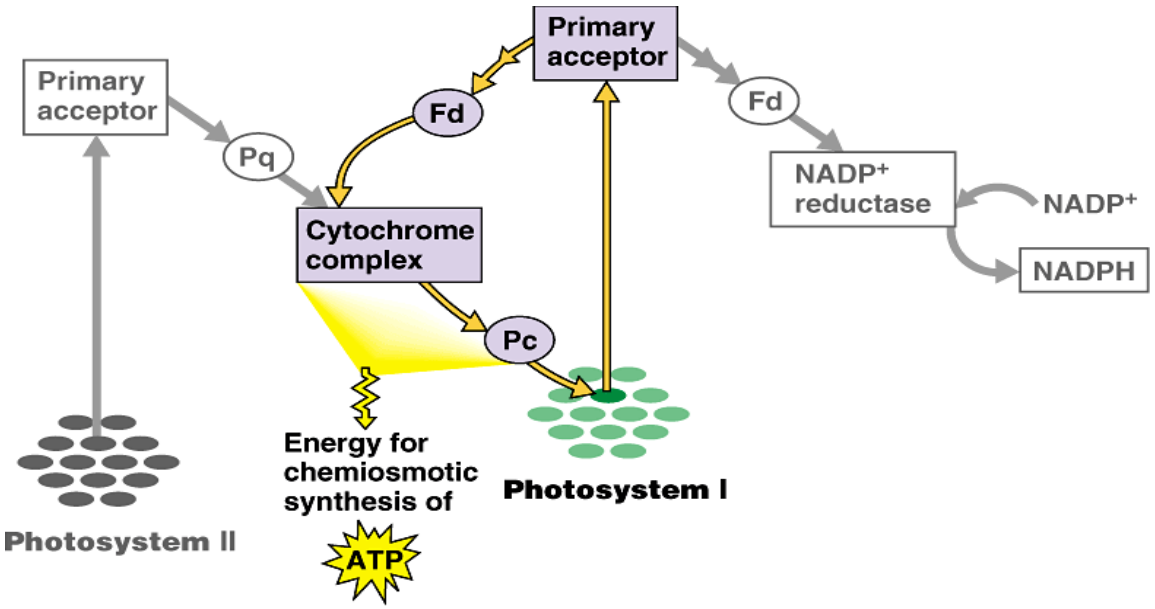
12) Thus e^- s emitted from one pigment system don't return to it. Hence it is called as non cyclic e^- transfer.

FRS – ferredoxin reducing system

Ferredoxin – Fe containing flavo protein

Cytochromes – Fe containing proteins

Platocyanin – Cu " "



Significance of Non cyclic e ⁻ transfer :-

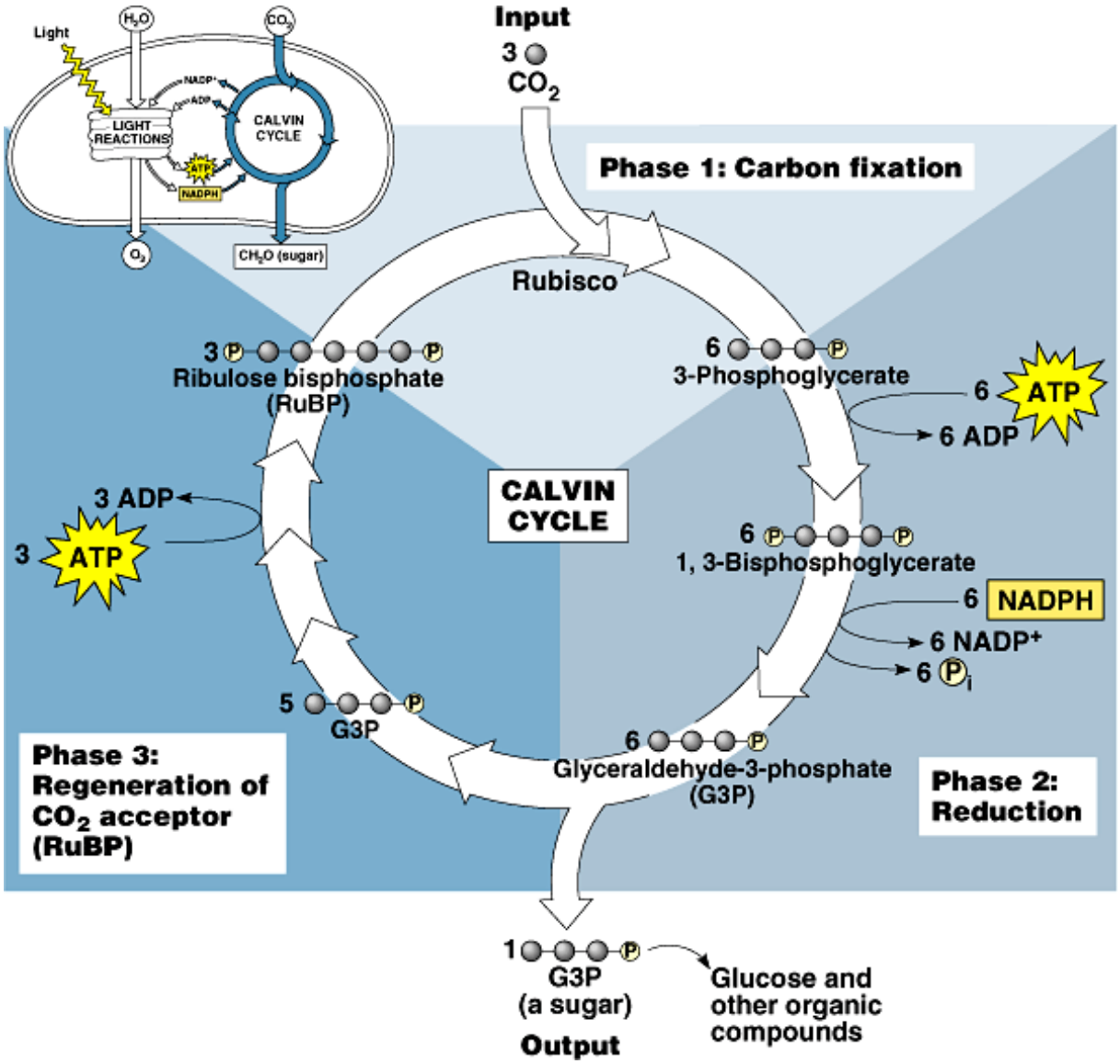
1] In this pathway ATP & NADPH2 are formed.

2] ATP acts as an energy donar in dark reaction
3] NADPH2 acts as a hydrogen donar in dark reaction
4] Photolysis of water takes place.
5] Oxygen is liberated as bi product.
6] It is more efficient than cyclic photophosphorylation.

Cyclic Photohosphorylation	**Non cyclic Photophosphoryltion**
1. e⁻s return to same chlorophyll molecule from which they are emitted. 2. Photolysis of water doe not take place. 3. O_2 is not evolved 4. $NDPH_2$ is not formed 5. NADP doesn't take part. 6. Only pigment system I is involved 7. Less efficient as less energy is formed. 8. Primary acceptor is FRS (Z) 9. It takes place in photosynthetic bacteria 10. Occurs in low intensity light, anaerobic condition, less CO_2 available	1. e⁻s don't return to same chlorophyll molecule from which they are emitted. 2. Photolysis of water take place. 3. O_2 is evolved as bi product. 4. $NADPH_2$ is formed 5. NADP takes part as e - acceptor 6. Both pigment systems I & II are involved. 7. More efficient as more energy is formed. 8. Primary acceptor is FRS (Z) & plastoquinone . 9. It takes place in green plants. 10. Occurs in normal light, aerobic condition, sufficient CO_2

II) Secondary Process / Biochemical Phase / Dark Reaction

1) It takes place in stroma of chloroplast, independent of chlorophyll
2) Light is not required for it. Hence it is known as dark reaction.
3) ATP, $NADPH_2$ formed during light reaction are used in dark reaction for reducing & fixing CO_2 in carbohydrate i.e. hexose sugar. Hence it is also known as CO_2 fixation or synthetic phase.
4) Energy in ATP is used for various reactions.
5) Enzymes & coenzymes necessary for dark reaction are present in stroma of chloroplast.
6) Blackman in 1950 observed this reaction first. Hence it is also called as Blackman's reaction



7) Melvin Calvin & Benson traced path of carbon during dark reaction. They were awarded Nobel prized in 1961.
8) During their experiment they fed unicellular algae chlorella & Scenedesmus with radio active carbon isotope i.e. $C^{14}O_2$ Algae were allowed to carry photosynthesis. At different time intervals algal cell extract was chemically analysed by paper chromatography to find out compound containing C 14. On the basis of products obtained they suggested a cycle for dark reaction which is called as Calvin Cycle. It has three phases

A] Carboxylation Phase B] Reduction Phase C] Regeneration & Synthetic Phase.

A] Carboxylation Phase.

i) Atmospheric CO_2 is taken by stroma of chloroplast.
ii) RuMP (Ribulose Mono Phosphate) – 5 carbon compound is present in stroma. It is phosphroylated into RuDp (RuDP—Ribulose Di Phosphate) It is called as CO_2 acceptor
iii) RuDP absorbs atmospheric CO_2 & forms unstable 6 C compound.
iv) 6 C compound immediately undergoes hydrolysis & splits into 2 molecules of 3C compound i.e. 3 PGA. This is first stable compound in Calvin Cycle. Hence it is also called as C_3 Cycle.

B] Reduction Phase –

i) 3PGA is phosphorylated to 1, 3 DPGA(Di Phospho Glyceric Acid)
ii) 1, 3 – DPGA is reduced to 3 – PGAL (Phospho Glyceraldehyde) by using hydrogen from $NADPH_2$ & in this reaction one inorganic phosphate is released. The process is reverse of oxidation in glycolysis. Hence it is known as glycolytic reversal.

C] Regeneration & Synthetic Phase

i) 10 molecules of 3 – PGAL are used for regeneration of RuMP through various phases with formation of 10C, 9C, 8C ..... compounds.
ii) Two molecules of 3PGAL are used to form hexose sugar i.e. glucose which is converted into starch by polymerization.

Action spectrum – rate of photosynthesis at different wavelengths of light.

Absorption spectrum – absorption of light of different wave lengths.

Quantun requirement – no. of photons/quanta required to release 1 molecule of O2

Emerson & Lewis showed that it is 8 quanta.

Red drop – sudden fall in photosynthesis yield beyond red region of spectrum. Showed by Emerson & Lewis.

Emerson's enhancement effect – if simultaneously shorter & longer wave lengths are provided, rate of photosynthesis is higher than total rate from the beams separately.

RESPITATION

Introduction - Living beings need regular supply of energy for vital functions or activities like cell division, transport of materials, locomotion, digestion etc .

Definition :– It is an intracellular oxidation -- reduction reaction in which complex organic substances are broken down stepwise to release chemical energy in the form of ATP & CO_2 & H_2O are given out as byproducts.

Important features :-- Overall Reaction

$$\mathbf{C_6H_{12}O_6 + 6O_2\downarrow \rightarrow 6CO_2\uparrow + 6H_2O + E\ (38ATP,\ 277.44\ Kcal)}$$

- In biochemical process the reaction is not so simple.
- Free molecular oxygen does not combine directly with substrate like in combustion.
- Hydrogen is gradually removed from the substrate & the electrons released ($H_2 \rightarrow 2H + 2e^-$) are transferred through a series of e^- carriers to generate energy in the form of ATP (exergonic -- energy producing, catabolic – breakdown process)
- The process occurs at cellular temperature.
- Gases are exchanged in liquid medium by blood, tissue fluid etc.
- CO_2 & H_2O are given out as byproducts.
- All energy in glucose molecule is not converted into ATP but some of it is lost as heat energy.

ATP –The Energy Currency of the Cell

These are bio-molecules which store energy in biologically usable form.

ATP – Adenosine Tri Phosphate

It is composed of a) Adenosine – which is made up of adenine [Nitrogen base] + Ribose Sugar [Pentose sugar] b) 3 phosphate groups

$$\text{Adenine----- Ribose sugar----} \overset{\alpha}{PO_4} \sim \overset{\beta}{PO_4} \sim \overset{\gamma}{PO_4}$$

Second & Third phosphate groups are attached to ribose sugar by high energy bonds, when cell needs energy it breaks the third high energy bond & even the second phosphate bond of ATP forming ADP & AMP respectively

ATP → ADP + iP + E

All living cells generate ATP by using energy trapped in glucose molecule during photosynthesis. During this process glucose molecule is oxidized. In this reaction CO_2 & H_2O are given out as by products. This is called as cellular respiration. Energy released is trapped in ATP molecule by attaching phosphate group. This is called as phosphorylation. As glucose molecule is oxidized it is called as oxidative phosphorylation.

Significance : 1] It stores energy in biological usable form. 2] It supplies energy in

various cellular activities by breaking phosphate bond in between 2nd & 3rd and

even 1st & 2nd phosphate groups. 3] It acts as a phosphate donar in various biochemical reactions.

- Cellular respiration is oxidation of food material into CO_2 and H_2O.
- During this oxidation E released is trapped in ATP (1ATP traps 7.28 k cal)for using in all cell activities.

This oxidation occurs in three phases.

1) **Glycolysis** – Breakdown of glucose to pyruvic acid (pyruvate). It occurs in cytosol i.e. cytoplasm. Hence mitochondria are not necessary. In occurs in prokaryotes as well as eukaryotes. As O_2 is also not required it is common to aerobic as well as anaerobic organisms. In glycolysis 2 ATP and 2 NADH + H^+ also formed.

2) Citric Acid Cycle / Krebs cycle -

- Decarboxylation of pyruvic acid to CO_2 and H_2O along with formation of NADH + H^+ and $FADH_2$.
- In eukaryotes it occurs in mitochondrial matrix. Matrix has complex mixture of soluble enzymes for decarboxylation of pyruvic acid.

At the end $3CO_2 \uparrow$, 4 NADH + H^+, 1 $FADH_2$ are formed (when $2e^-$ are removed from malic acid transferred to NAD^+ reducing it to NADH + H^+, same way 2 e^- removed from saccinic acid and reduces FAD. To $FADH_2$

Outer membrane – contains many complexes of integral membrane proteins that form channels – porins through which many molecules and ions move in and out of mitochondria.

- e^- from NADH and $FADH_2$ are transferred to next phase i.e. respiratory chain.

3) Electron Transport Chain / Respiratory Chain -

- Inner membrane of mitochondria contains complexes of integral membrane proteins.

  NADH dehydrogenase complex

  Succinate dehydrogenase complex

  Cytochrome c reductase complex

  Cytochrome c oxidase cpmplex

  ATP synthase complex

- It also consists ubiquinone, cytochrome a,b,c, which shuttle electrons from one complex to another.

  Inner membrane is selectively permeable.

  (NADH carries e^- from catabolic reactions to respiratory chain.

  NADPH supplies e^- to anabolic reactions.)

- Stepwise transfer of e^- from NADH, Ubiquinone, Cytochromes and then finally to O_2 to form H_2O takes place. Neither NADH nor NADPH can cross inner mitochondrial membrane, but the e^- carried by them can shuttle across.

- During e^- transfer E is released.

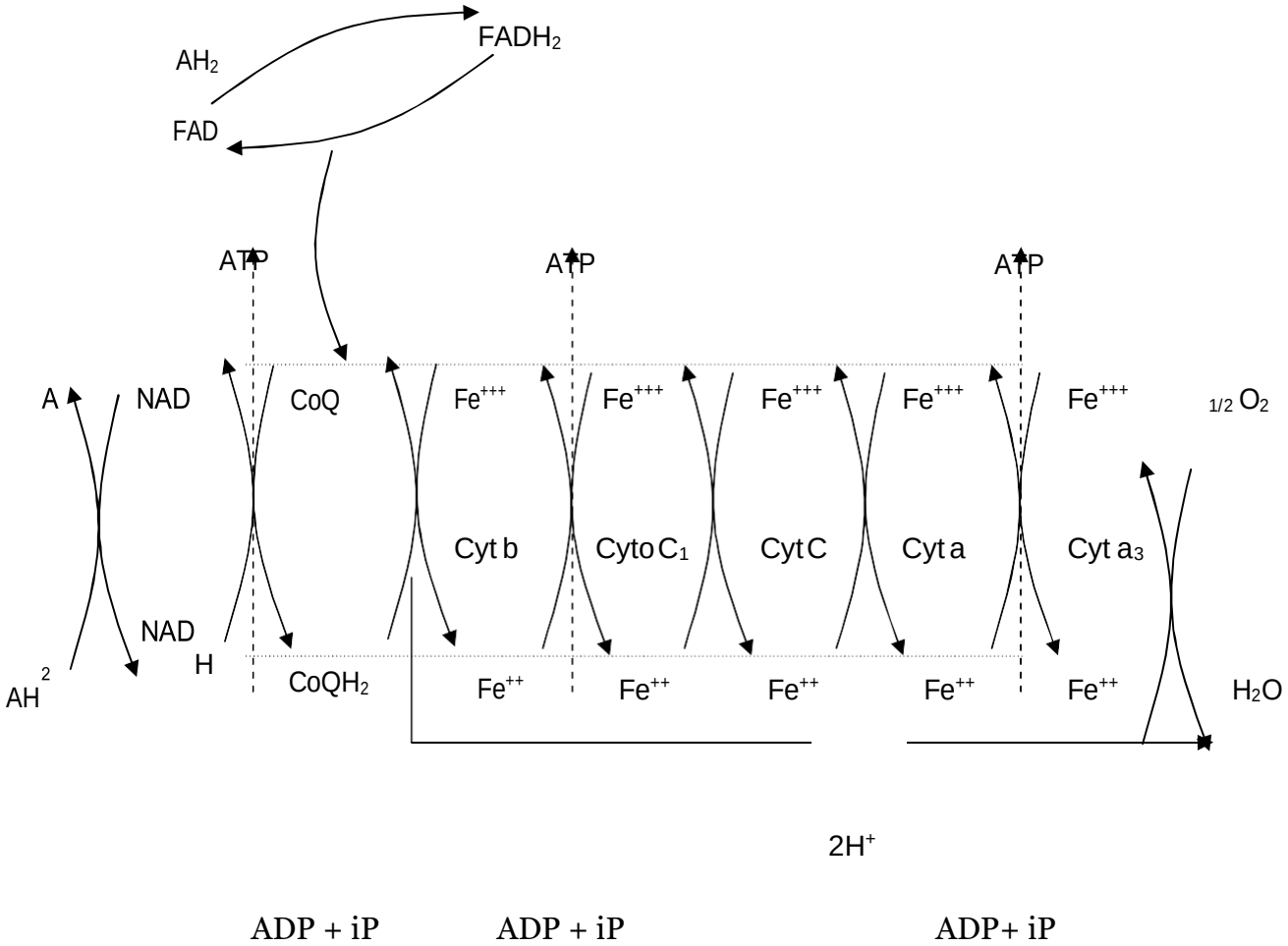
- It is used to transfer/ pump H^+ (protons) from matrix into inter membrane space by active transport.

- Thus matrix becomes – vely charged and inter membrane space +vely charged.

- Gradient of protons formed across the inner membrane forms a miniature battery. (Mitochondria contain 3 classes of cytochromes – a,b,c which absorb different light spectra)

[Plastoquinone is like ubiquinone. Ubiquinone (Coenzyme Q) ⟶ small, hydrophobic, hence freely diffusible in lipid bilayer of inner mitochondrial membrane and can shuttle reducing equivalents between other less mobile electron carriers in the membrane. Cytochromes ⟶ proteins with iron – heme group; show strong absorption of visible light.)

- In mitochondrial respiratory chain, e^- move as follows – NADH / $FADH_2$ ⟶ Co.Q ⟶ Cytochrome b ⟶ Cytochrome C_1 ⟶ Cytochrome C ⟶ Cytochrome a ⟶ Cytochrome a_3 ⟶ O_2.



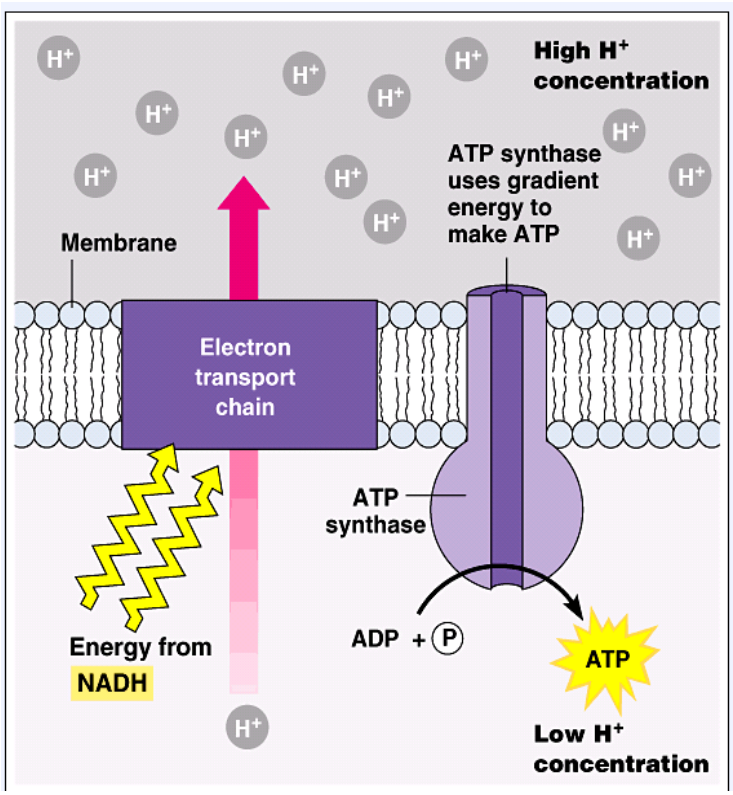
Chemiosmosis in Mitochondria:-

- As e^- pass from NADH + H^+ / $FADH_2$ down the gradient to O_2, E is released.
- This E is used to pump H^+ (protons)from matrix into inter membrane space against conc. / electrochemical gradient by active transport
- As proton conc. increases in inter membrane space; a strong diffusion gradient is set up.

- These protons can only exit through ATP synthase complex into matrix .

- E is released as protons flow down their conc. gradient through specific protein channels in inner membrane. This free E is utilized for ATP synthesis. The process catalyzed by a membrane protein complex ATP synthase. ATP synthase is present in elementary particles of inner membrane. Mitochondrial ATP synthase is an F-type ATP ase . ATP synthase has two distinct components : F1 → peripheral membrane protein & Fo → integral to above membrane. Fo has a proton pore through which protons leak as fast as they are pumped by e^- transport. Without a proton gradient the F1 depleted vesicles can't make ATP. On the other hand isolated F1 catalyze ATP hydrolysis (reversal of synthesis) hence originally called as F1 ATP ase. When purified F1is added back to depleted vesicles, it reassociates with Fo plugging its proton pore & restoring membrane's capacity to couple e^- transfer & ATP synthesis.

- This transfer of protons along concentration gradient from inter membrane space to matrix is called chemiosmosis. It is an example of facilitated diffusion.



- Peter Mitchell proposed chemiosmotic model. According to this model transmembrane differences in proton concentration are the reservoir for E extracted biological oxidation reactions.

- Inhibitors of e^- transfer to O_2, like cyanide, CO, antimycin A, block ATP synthesis and vice versa. (oligomycin inhibits ATP synthase activity.) Thus these two processes show obligatory coupling.

Mitochondrial DNA:-

- Human mitochondrion contains 5 – 10 circular DNA molecules – mt – DNA.
- Mutation in mt – DNA causes human diseases; affecting mainly brain and muscles.
- In mammals 99.99% of mt DNA is inherited from mother. This is because in zygote paternal mitochondria are only about 100, while maternal are 100,000.

2) BIOENERGETICS

Living cells and organisms must perform work to stay alive and to reproduce themselves. The synthetic reactions that occur within cells, like synthetic processes in any factory, require the input of energy. Energy is also consumed in the motion of a bacterium or an Olympic sprinter.

Although the characteristic composition of an organism changes little through time, the population of molecules within the organism is far from static. Small molecules, macromolecules, and supra-molecular complexes are continuously synthesized and then broken down in chemical reactions that involve a constant flux of mass and energy through the system. The hemoglobin molecules carrying oxygen from your lungs to your brain at this moment were synthesized within the past month; by next month they will have been degraded and entirely replaced by new hemoglobin molecules. The amounts of hemoglobin in the blood remain nearly constant because the rate of synthesis balances the rate of its breakdown, the constancy of concentration is the result of a dynamic steady state, a steady state that is far from equilibrium. Maintaining this steady state requires the constant investment of energy; when the cell can no longer generate energy, it dies and begins to decay toward equilibrium with its surroundings.

Metabolism –The sum of all chemical transformations taking place in a cell /organism.

Metabolic pathways – A series of enzyme catalyzed reactions. Each step in it brings about specific, small chemical change like removal, transfer / addition of a particular atom / functional group.

Metabolites – Metabolic intermediates which convert precursors into products.

Intermediary metabolism – Combined activities of all metabolic pathways that interconvert precursors, metabolites & products of low molecular weight

Catabolism --The degradative phase of metabolism in which organic nutrient molecules (carbohydrates, fats, and proteins) are converted into smaller, simpler end products (such as lactic acid, CO_2, NH_3). Catabolic pathways release energy, some of which is conserved in the formation of ATP and reduced electron carriers (NADH, NADPH, and $FADH_2$); the rest is lost as heat.

Anabolism –(also called biosynthesis) Small, simple precursors are built up into larger and more complex molecules, including lipids, polysaccharides, proteins, and nucleic acids. Anabolic reactions require an input of energy.

Bioenergetics - The quantitative study of the energy transductions that occur in living cells and study of the nature and function of the chemical processes underlying these transductions. Biological energy is not in the form of heat mechanical or light energy therefore word thermodynamics is not used but word bioenergetics is used. This energy is termed as free energy and defined as energy available for work. It symbolizes change in energy and not the absolute energy.

Two approaches to study physical or chemical processes:

Kinetic molecular approach: In this, process is studied in terms of molecules and atoms.

Thermodynamic approach: Process id studied by considering energy changes involved. Thermodynamics means study of heat flow. But actually not only relation between heat and work but also deals with all kinds of inter conversion of one kind of energy in to the other. Most of the energy forms are ultimately converted in to heat.

Thermodynamics help to forecast whether certain physical or chemical transformations are possible or not. Under given set of conditions of temperature, pressure, concentration etc. But it can not give any information of time required for completion of change as well as rate of reaction.

If the system exchanges neither matter nor energy with its surroundings, it is said to be **isolated**. If the system exchanges energy but not matter with its surroundings, it is a **closed system**; if it exchanges both energy and matter with its surroundings, it is an **open system.**

A living organism is an open system; it exchanges both matter and energy with its surroundings. Living organisms derive energy from their surroundings in two ways:

1) They take up chemical fuels (such as glucose) from the environment and extract energy by oxidizing them; or

2) They absorb energy from sunlight.

Homogenous system – System with same chemical composition throughout.

Heterogenous system – System with two or more phases which are homogenous themselves but separated from each other by definite boundary. (ice and water)

State of a system: Variable of a state are temperature, pressure, volume, composition

Gas Equation: PV = nRT

Therefore if 2 values are known the third can be determined thus state of a simple homogenous system can be defined. Physical properties of a system are of two types:

Extensive properties: Depend on quantity of matter in the system under consideration e.g. mass, volume, energy

Intensive properties: Depend on nature of substance and independent of its amount e.g. temperature, pressure, viscocity, refractive index

Thermodynamic equilibrium: It is said to achieved when observable properties like temperature, pressure, volume does not change with time. For thermodynamic studies a system must be in in 3 types of equilibria which must exist simultaneously.

a) **Thermal equilibrium**

b) **Chemical equilibrium**

c) **Mechanical equilibrium:** No movement of particles of the constituents of system itself and between itself and surroundings.

Isothermal process: Temperature remains same

For Exothermal process – heat evolved give out immediately to surroundings to maintain the temperature. For endothermic process required amount of heat enters the system from surroundings to maintain the temperature.

Adiabatic process – heat neither enters nor leaves the system during the process.

Thermodynamic laws and living organisms

The molecular complexity and orderliness of structure of living organisms is much higher in contrast to the randomness of non living matter.

The first law of thermodynamics, fully valid for biological systems

Photosynthetic cells absorb light energy and use it to drive electrons from water to carbon dioxide, forming energy-rich products such as glucose ($C_6H_{12}O_6$), starch, and sucrose and releasing O2 into the atmosphere:

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

(light-driven reduction of CO_2)

Non – photosynthetic cells and organisms obtain the energy they need by oxidizing the energy-rich products of photosynthesis and then passing electrons to atmospheric O_2 to form water, carbon dioxide, and other end products, which are recycled in the environment:

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

(energy-yielding oxidation of glucose)

DNA, RNA, and proteins are informational macromolecules. In addition to using chemical energy to form the covalent bonds between the subunits in these polymers, the cell must invest energy to order the subunits in their correct sequence. It is extremely improbable that amino acids in a mixture would spontaneously condense into a single type of protein, with a unique sequence. This would represent increased order in a population of molecules; but according to the second law of thermodynamics, the tendency in nature is toward ever- greater disorder in the universe: the total entropy of the universe is continually increasing. To bring about the synthesis of macromolecules from their monomeric units, free energy must be supplied to the system (in this case, the cell).

Second law of thermodynamics

How living organisms can create and maintain their intricate orderliness in an environment that is relatively disordered and becoming more with the time ? Living organisms do not constitute exceptions to thermodynamic laws. Their high degree of molecular orderliness must be paid for in some way since it can not arise spontaneously from disorder.

Living organisms have following characteristic properties such as,

1) **Use free energy**: Living organisms absorb useful form of energy that is free energy from surrounding under specific temperature and pressure and return less useful form of energy to the environment in equal amount. The useful form of energy returned by the living organisms is heat or other form that is quickly randomized in the environment and thus increase the entropy.

2) **Open system**: living organisms are not in equilibrium with the environment

3) **Steady state**: Cell is non equilibrium open system, a machine for extracting free energy from the environment which it causes to increase in randomness. The

rate of transfer of energy and matter from environment in to system is equal to transfer of energy and matter from system to environment.

4) **Non equilibrium**: Open system in steady state can do work in non equilibrium. Process under non equilibrium can be regulated. This is orderly state of an open system.

5) **Isothermal system**: The living system is essentially isothermal that is at any given time all parts of the cell have the same temperature. Furthermore, there are no significant differences in pressure between one part of the cell and another. For this reason, cells are unable to use heat as a source of energy, since, heat can do work at constant pressure only if it passes from a higher to a lower temperature zone.

6) **Isothermal chemical engines**: energy absorbed from environment id transformed to carry out synthesis of cell components, osmotic work, transport of material into cell, nerve conduction, muscle contraction etc. which takes place at constant struggle against the tendency to produce entropy. Synthesis of large and information rich macromolecules, the information of intricately structured cells, development of an organization, all these are powerful anti entropic doom imposed on all natural phenomenons. Under the second law of thermodynamics, living organisms choose the least evil – they produce entropy at a minimum rate by maintaining steady state.

An attempt to produce a machine which could produce more mechanical work than the equivalent energy used is failed. This compels to accept the first law of thermodynamics in biological systems.

Mathematical formulation of first law

Suppose some amount of heat is put in the system, Since heat can not be lost it must remain either partial or whole in the system, or can used up by the system in doing mechanical work.

In general case, when both happen,

Heat absorbed = increase of internal energy + work done by the system

If final and initial internal energy of the system is E2 and E1 respectively, then increase internal energy is $\mathbf{\Delta E = E2 - E1}$

If heat absorbed is **q** and work done is **w** then

$\mathbf{\Delta E = E2 - E1 = q - w}$ (this is first law of thermodynamics)

Although the heat absorbed / the work done by the system might vary the path by which the change is affected ΔE is always same.

Second law of thermodynamics:

1. First law explains the equivalence between heat and work but imposes no condition on their mutual convertibility. It never explains under what circumstances and to what extent it is possible to convert one form of energy in to other.

2. It also explains about the amount of heat lost by a hot body must be equivalent to the gain by cold body. But is does not explains that heat has to flow spontaneously from hot to cold body and not in reverse direction.

3. Different forms of energy can be readily and completely converted in to heat but not possible to convert back heat completely in to work. Hence, there must be some other law besides the first law that governs the direction of flow of heat and extent of its convertibility in to work. This limitation forms the basis for second law of thermodynamics. **The total entropy of a system must increase if the process has to occur spontaneously**.

Entropy: The quantitative expression for randomness or disorder of the components of a chemical system is expressed as entropy, S.

When the products of a reaction are less complex & more disordered than the reactants, the reaction proceeds with a gain in entropy. Any change in randomness of the system is expressed as **entropy change, □S**, which by convention has a positive value when randomness increases. **J. Willard Gibbs**, who developed the theory of energy changes during chemical reactions, showed that the **free energy content, G,** of any closed system can be defined in terms of three quantities:

Enthalpy, H – heat content of reacting system, reflecting the number and kinds of chemical bonds in the reactants & products; **Entropy, S**; and the **absolute temperature, T** (in degrees Kelvin).

The definition of free energy is G = H – TS.

When a chemical reaction occurs in biological system at constant temperature & pressure, the free-energy change, ΔG, is determined by the enthalpy change, ΔH, reflecting the kinds and numbers of chemical bonds and non covalent interactions broken and formed, and the entropy change, ΔS, describing the change in the system's randomness:

$\Delta G / \Delta F = \Delta H - T\,\Delta S$ (F → Heltmoz free E, T→ absolute temp.)

Also $\Delta G / \Delta F = \Delta E - T\,\Delta S$ (E/Q → internal energy)

Hence total energy of the system is $\Delta E = \Delta G + T\,\Delta S$

If **ΔG is negative**, the reaction would proceed spontaneously with loss of free energy that is exergonic reaction. If in addition, ΔG is of great magnitude, the reaction goes virtually to completion and is essentially irreversible.

If **ΔG is positive**, the reaction can not occur spontaneously and would proceed only if the free energy can be gained that is endergonic.

If **ΔG is zero**, the system is at equilibrium and no net change takes place.

Relationship between equilibrium constant and standard free energy change in a model reaction. Thus, in a reaction, **A + B ↔ C + D**

$$\Delta G = \Delta G^{o} + RT \ln \frac{[C]\,[D]}{[A]\,[B]}$$

When the concentration of [A] [B] [C] [D] ΔG is 0.1 M, ΔG^{o} known as standard free energy change. At equilibrium, $\Delta G^{o} = 0$

i.e. $\Delta G = \Delta G^{o} + RT \ln \frac{[C]\,[D]}{[A]\,[B]}$

For biochemical reactions, a standard state is defined as having a pH of 7. the standard free energy change at this standard state is denoted by ΔG^{o} since the equilibrium constant under standard condition is;

K'eq = [C] [D] / [A] [B]

Substitution gives $\Delta G^{o} = - RT \ln K'$ eq

Thus, the standard free energy change can be calculated from the equilibrium constant K' eq it is important to note that ΔG may be larger or smaller than $\Delta G^{o'}$ depending on the concentration of various reactants.