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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 the 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 molecules.
- 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 growth 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)

Monosaccharides are simple sugars that serve as essential building blocks of carbohydrates in biology. They are the smallest and most basic units of carbohydrates, commonly referred to as single sugar molecules.

The molecular formula of monosaccharides is usually (CH2O)n, where "n" represents the number of carbon atoms in the molecule. These sugars can vary in size, ranging from three to seven carbon atoms, with the most common monosaccharides having five or six carbons.
Monosaccharides play vital roles in various biological processes. They serve as a primary source of energy for organisms, particularly glucose, which is the most abundant monosaccharide. Glucose is involved in cellular respiration, where it undergoes metabolic processes to produce adenosine triphosphate (ATP), the energy currency of cells.

Additionally, monosaccharides are crucial for the formation of complex carbohydrates, such as disaccharides and polysaccharides. Through dehydration synthesis reactions, monosaccharides can combine to form glycosidic bonds, creating larger carbohydrate molecules. For instance, two glucose molecules can join to form maltose, a disaccharide.

Monosaccharides also contribute to the structural integrity of living organisms. In plants, cellulose, a polysaccharide composed of repeating glucose units, forms the cell walls, providing rigidity and support. Chitin, another polysaccharide composed of modified glucose units, constitutes the exoskeletons of arthropods and cell walls of fungi.

In summary, monosaccharides are small, single sugar molecules that serve as the fundamental units of carbohydrates in biology. They provide energy, participate in the formation of complex carbohydrates, and contribute to the structural framework of living organisms.

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

Polysaccharides are large, complex carbohydrates composed of repeating units of monosaccharides. They play important roles in biology, serving as energy storage molecules and structural components in living organisms.

Polysaccharides are formed through the process of dehydration synthesis, where monosaccharides are joined together by glycosidic bonds. The number and arrangement of monosaccharide units in a polysaccharide determine its specific properties and functions.

One significant function of polysaccharides is energy storage. For example, in animals, glycogen is a highly branched polysaccharide made up of glucose units. It is stored in the liver and muscles and serves as a readily available source of glucose for energy during times of high demand.

In plants, starch is the primary energy storage polysaccharide. It consists of two forms: amylose, a linear polymer of glucose units, and amylopectin, a branched polymer. Starch is stored in plant cells, particularly in roots, tubers, and seeds, and can be hydrolyzed to release glucose when needed.

Polysaccharides also fulfill structural roles. Cellulose, a linear polymer of glucose units, is a major component of plant cell walls. It provides rigidity and strength to the cell wall structure, enabling plants to maintain their shape and resist mechanical stress.

Chitin is another important structural polysaccharide found in the exoskeletons of arthropods, such as insects and crustaceans, and the cell walls of fungi. It is composed of modified glucose units and provides support and protection to these organisms.

In summary, polysaccharides are large carbohydrates composed of repeating units of monosaccharides. They serve as energy storage molecules and contribute to the structural integrity of organisms. Examples include glycogen and starch for energy storage, cellulose for plant cell walls, and chitin for exoskeletons and fungal cell walls.

Types & Function of Polysaccharides:

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

Insulin 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, oxygen, 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:

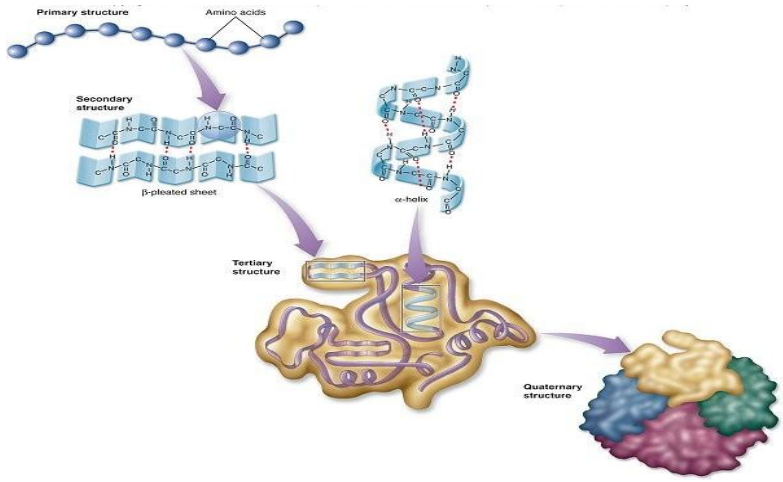
Primary Proteins: two dimensional, simple chain of AA with peptide (covalent) bond e.g. Insulin

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 Proteins: 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 shared 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 properties.
- 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.

Functions: Locomotion, sensory information, enzymes, Messaging, Toxin, Antibodies, Transport Layer (Carry Oxygen), Storage

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 phosphorus 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 the 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 unsaturated 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 fatty 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 oil-seeds like groundnuts, mustard, coconut are the stores of fats. Animals contain adipocytes which are the cells 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).

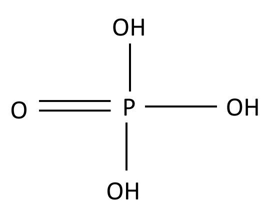
Pyrimidine – Cytosine (C), Thymine (T)

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.

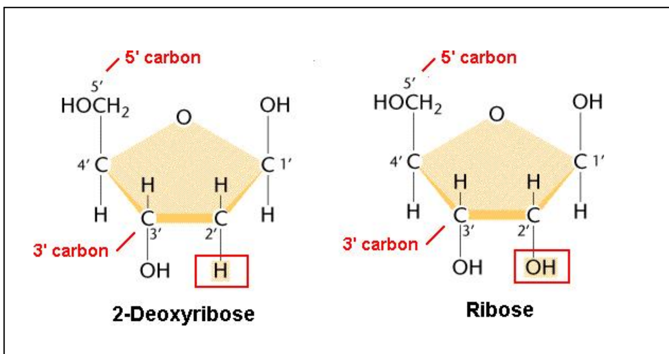


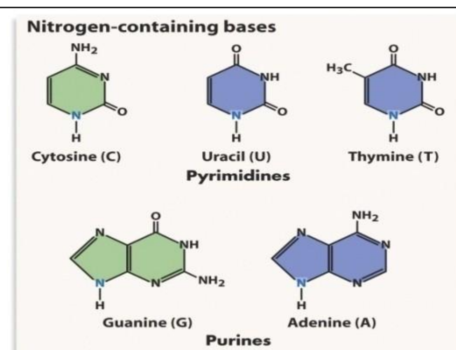
Nucleoside + P group at 5' position by **phosphor-diester bond**.

Nucleoside + Phosphate group nucleotide.

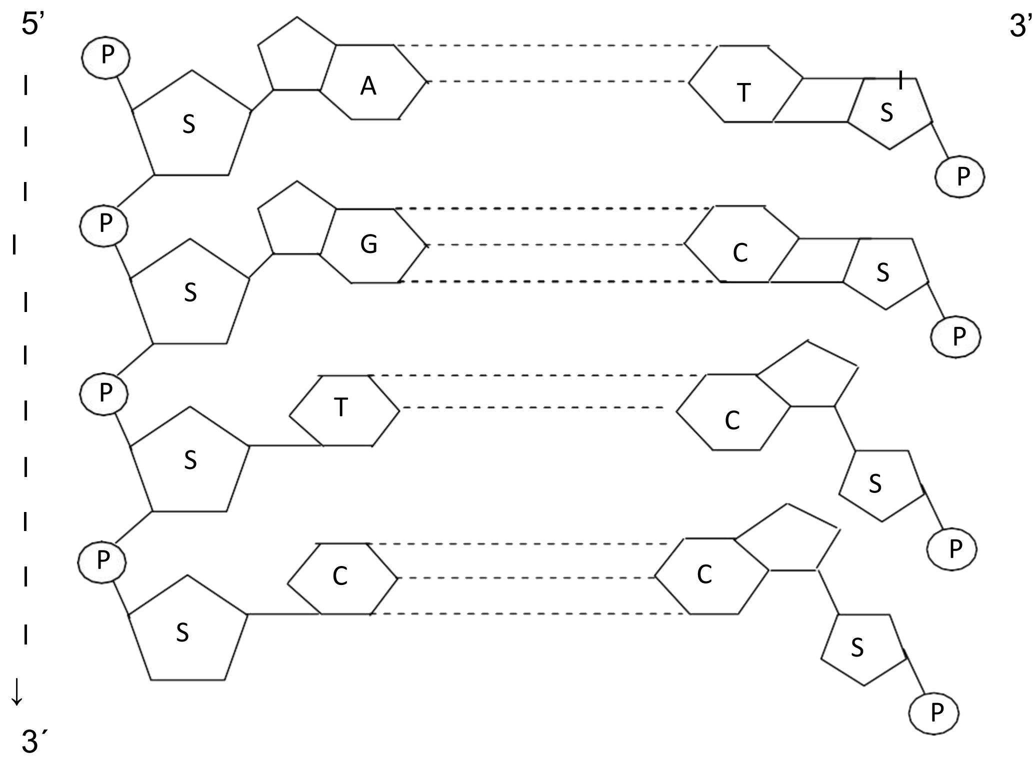
Amount of DNA measured by picogram = 10^{-12} g., 1 Pg DNA has 31 cm length.

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





Chain of nucleotides – **poly nucleotide chain**

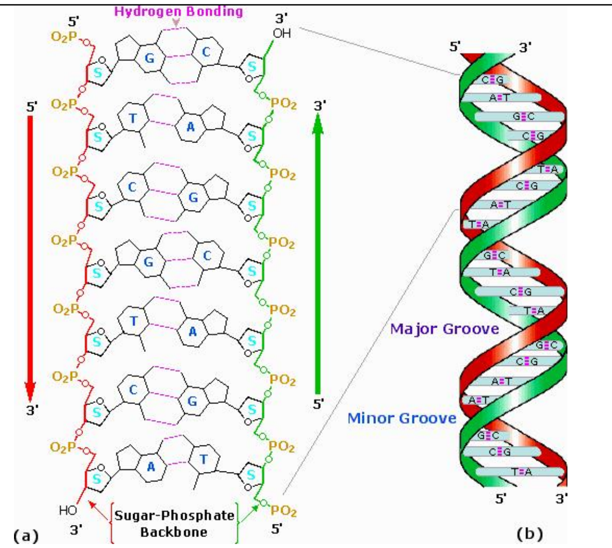


Characteristics / Properties – DNA

- It has several thousand Nucleotides.
- Back bone of it by alternated sugar and PO_4 gr.
- Nitrogen bases are inside at right angle to longitudinal axis.
- PO_4 gr. Attached 5th , 3rd 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 circular 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. $\longrightarrow$ Nucleoside

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

Animal, Plant viruses $\longrightarrow$ single stranded

Reovirus of some plant $\longrightarrow$ 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:

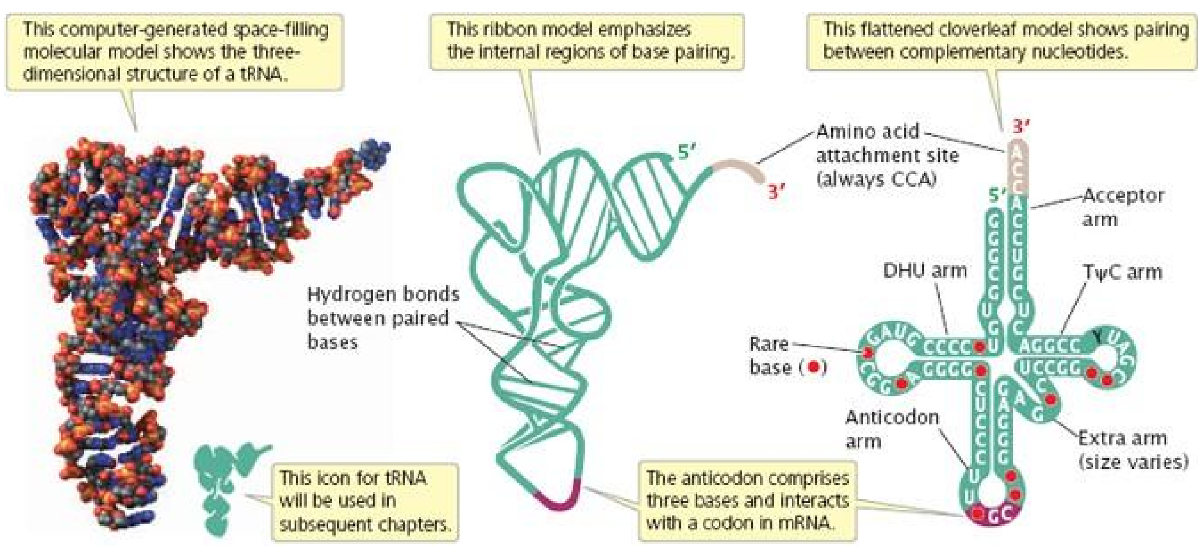
- Proper orientation of mRNA
- Formation of ribosomal complex by the attachment of smaller & larger subunit and further ribosomal complex with m RNA
- release of tRNA from ribosome complex after transfer of AA to polypeptide chain

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



Sugar can exist in two forms: reducing and non-reducing. The classification depends on the presence or absence of certain chemical groups in the sugar molecule.

Reducing sugars have a free aldehyde or ketone functional group, which allows them to undergo a chemical reaction known as a reduction. This functional group is capable of donating electrons and reducing other substances. Examples of reducing sugars include glucose, fructose, and lactose.

Non-reducing sugars, on the other hand, lack a free aldehyde or ketone group and therefore cannot undergo the same reduction reaction. Instead, they have their carbonyl group involved in a glycosidic bond, linking them to other sugar molecules or non-sugar components. Examples of non-reducing sugars include sucrose and trehalose.