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F.Y. B.Sc. (Sem. II) (CBCS)

MICROBIOLOGY

[201]: BASICS OF BIOCHEMISTRY AND MICROBIAL CONTROL

Unit 2
INTRODUCTION TO BIOMOLECULES

Prepared By

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Biomolecules

Definition

Biomolecules are molecules that occur naturally in living organisms. Biomolecules include macromolecules like proteins, carbohydrates, lipids and nucleic acids.

It also includes small molecules like primary and secondary metabolites and natural products.

Biomolecules consists mainly of Carbon and Hydrogen with Nitrogen, Oxygen, Sulphur, and Phosphorus.

Biomolecules are very large molecules of many atoms, which are covalently bound together.

Classes of Biomolecules:

There are four major classes of biomolecules:

1. Carbohydrates
2. Lipids
3. Proteins
4. Nucleic acids

Carbohydrates

- Carbohydrates are good source of energy. Carbohydrates (polysaccharides) are long chains of sugars.

- Monosaccharides are simple sugars that are composed of 3-7 Carbon atoms.

- They have a free aldehyde or ketone group, which acts as reducing agents and are known as reducing sugars. Disaccharides are made of two monosaccharides. The bonds shared between two monosaccharides are the glycosidic bonds.

- Monosaccharides and disaccharides are sweet, crystalline and water-soluble substances. Polysaccharides are polymers of monosaccharides. They are un-sweet and complex carbohydrates. They are insoluble in water and are not in crystalline form.

- **Example:** glucose, fructose, sucrose, maltose, starch, cellulose etc.

Lipids

- Lipids are composed of long hydrocarbon chains. Lipid molecules hold a large amount of energy and are energy storage molecules. Lipids are generally esters of fatty acids and are building blocks of biological membranes.
- Most of the lipids have a polar head and non-polar tail. Fatty acids can be unsaturated and saturated fatty acids.
- Lipids present in biological membranes are of three classes based on the type of hydrophilic head present:
- Glycolipids are lipids whose head contains oligosaccharides with 1-15 saccharide residues.
- Phospholipids contain a positively charged head which are linked to the negatively charged phosphate groups.
- Sterols, whose head contain a steroid ring. Example steroid.
- **Example of lipids**: oils, fats, phospholipids, glycolipids, etc.

Nucleic Acids

- Nucleic acids are organic compounds with heterocyclic rings. Nucleic acids are made of polymer of nucleotides.
- Nucleotides consist of nitrogenous base, a pentose sugar and a phosphate group.
- A nucleoside is made of nitrogenous base attached to a pentose sugar. The nitrogenous bases are adenine, guanine, thymine, cytosine and uracil.
- Polymerized nucleotides form DNA and RNA which are genetic material.

Proteins

- Proteins are heteropolymers of stings of amino acids. Amino acids are joined together by the peptide bond which is formed in between the carboxyl group and amino group of successive amino acids. Proteins are formed from 20 different amino acids, depending on the number of amino acids and the sequence of amino acids.
- There are four levels of protein structure:

1. ***Primary structure of Protein*** - Here protein exist as long chain of amino acids arranged in a particular sequence. They are non-functional proteins.

2. ***Secondary structure of protein*** - The long chain of protein is folded and arranged in a helix shape, where the amino acids interact by the formation of hydrogen bonds. This structure is called the pleated sheet. Example: silk fibers.

3. ***Tertiary structure of protein*** - Long polypeptide chains become more stabilizes by folding and coiling, by the formation of ionic or hydrophobic bonds or disulphide bridges, these results in the tertiary structure of protein.

4. ***Quaternary structure of protein*** - When a protein is an assembly of more than one polypeptide or subunits of its own, this is said to be the quaternary structure of protein. Example: Hemoglobin, insulin.

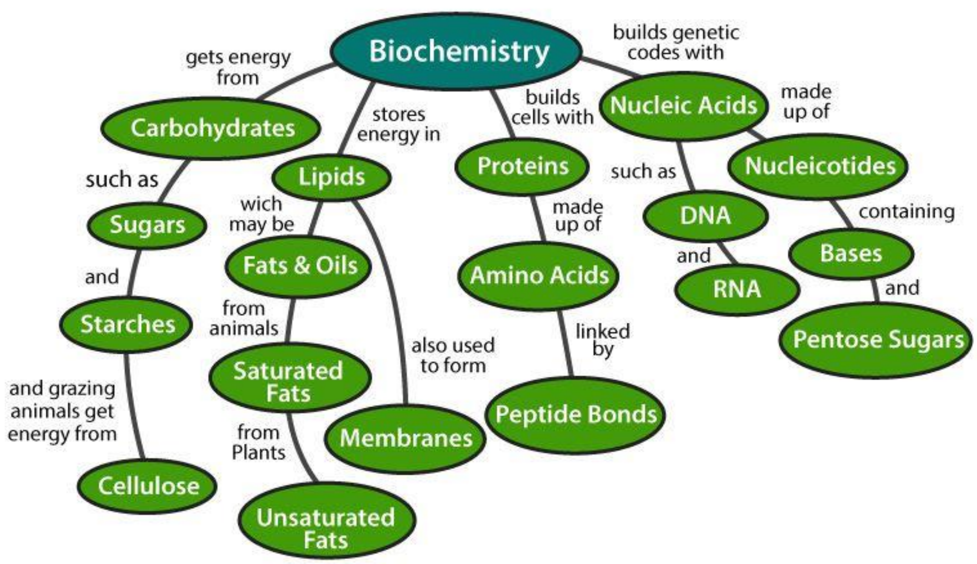
Functions of Biomolecules:

- ***Carbohydrates*** provide the body with source of fuel and energy, it aids in proper functioning of our brain, heart and nervous, digestive and immune system. Deficiency of carbohydrates in the diet causes fatigue, poor mental function.

- Each ***protein*** in the body has specific functions, some proteins provide structural support, help in body movement, and also defense against germs and infections. Proteins can be antibodies, hormonal, enzymes and contractile proteins.

- ***Lipids***, the primary purpose of lipids in body are energy storage. Structural membranes are composed of lipids which form a barrier and controls flow of material in and out of the cell. Lipid hormones, like sterols, help in mediating communication between cells.

- ***Nucleic Acids*** are the **DNA** and **RNA**; they carry genetic information in the cell. They also help in synthesis of proteins, through the process of translation and transcription.



CARBOHYDRATES

- Carbohydrate is an organic compound, it comprises of only oxygen, carbon and hydrogen.
- The oxygen: hydrogen ratio is usually is 2:1.
- The empirical formula being $\mathbf{C_n(H_2O)_n}$.
- Carbohydrates are hydrates of carbon; technically they are polyhydroxy aldehydes and ketones.
- Carbohydrates are also known as saccharides; the word saccharide comes from Greek word **sakkron** which means sugar.

CLASSIFICATION AND NOMENCLATURE OF CARBOHYDRATES

The carbohydrates are divided into three major classes depending upon whether or not they undergo hydrolysis and if they do, on the number of products formed.

1. ***Monosaccharides***: The monosaccharides are polyhydroxy aldehydes or polyhydroxy ketones which cannot be decomposed by hydrolysis to give simpler carbohydrates. e.g. Glucose, fructose, Galactose etc.

2. ***Oligosaccharides***: The oligosaccharides (Oligo: few) are carbohydrates which yield a definite number (2-9) of monosaccharide molecules on hydrolysis.

a) ***Disaccharides*** - Which yield two monosaccharide molecules on hydrolysis. Which have molecular formula is $C_{12}H_{22}O_{11}$. E.g., Sucrose, maltose etc

b) ***Trisaccharide*** - Which yield three monosaccharide molecules on hydrolysis and have molecular formula is $C_{18}H_{32}O_{16}$.

c) ***Tetrasaccharides*** - Which yield four monosaccharide molecules on hydrolysis and have molecular formula is $C_{22}H_{42}O_{21}$. E.g.: Stachyose [gal(α1→6) gal(α1→6) glu(α1↔2β)fru]

3. ***Polysaccharides****:* The carbohydrates which have higher molecular weight, which yield many monosaccharide molecules on hydrolysis. E.g., Starch, glycogen, Dextrin, Cellulose etc.

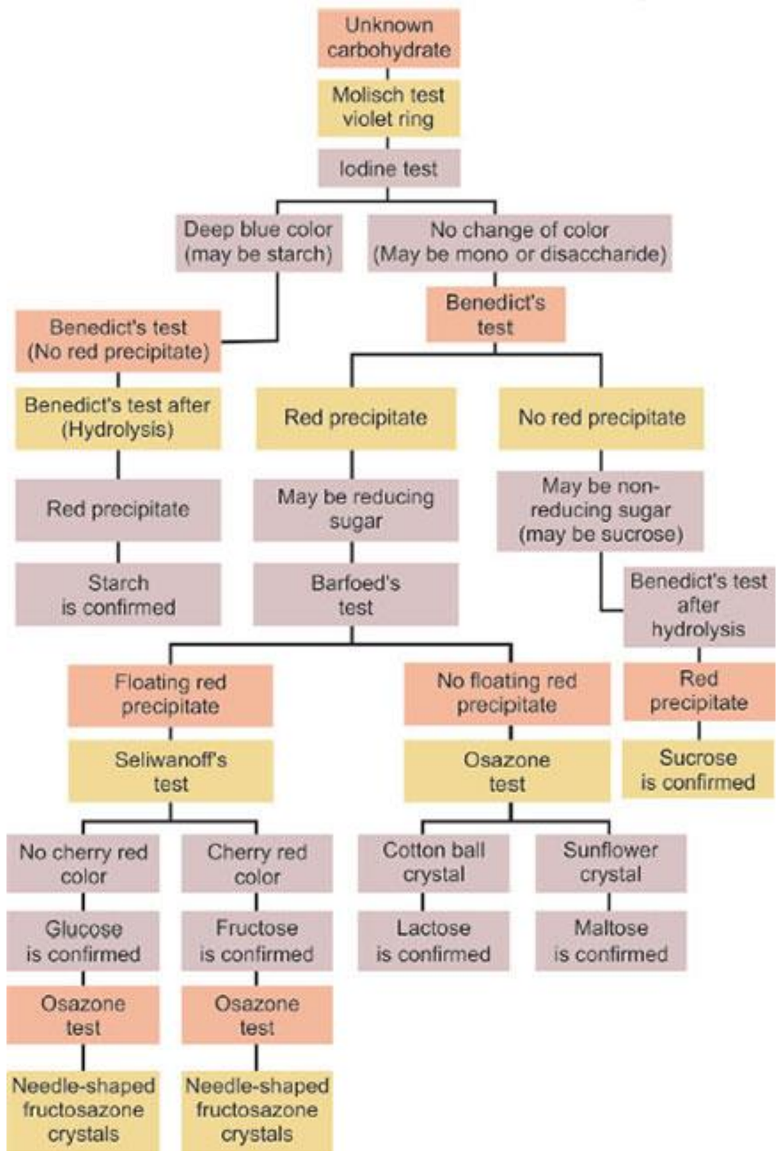
Difference between Mono and Polysaccharides

- In general monosaccharides and oligosaccharides are crystalline solids
- Soluble in water and Sweet to taste
- They are collectively known as sugars,
- The polysaccharides on the other hand are amorphous,

- Insoluble in water and tasteless,
- They are called non-sugars.

Different between monosaccharaides, oligosaccharides and Polysaccharide

Character	Monosaccharaides	Oligosaccharides	Polysaccharides
No. of sugar molecules	1	2-9	More than 9
Glycoside bond	Absent	Present	Present
Molecular Weight	Low	Moderate	High
Taste	Sweet	Minimally sweet taste	No taste
Solubility	Soluble	Soluble	Insoluble
Nature	Always reducing sugar	May or may not be	Always non reducing sugar
Example	Glucose, fructose, Galactose	Sucrose, Maltose, Lactose	Starch, Glycogen, Dextrin, Cellulose, Chitin



PROPERTIES OF CARBOHYDRATES

General properties of carbohydrates

- Carbohydrates act as energy reserves, also stores fuels, and metabolic intermediates.
- Ribose and deoxyribose sugars forms the structural frame of the genetic material, RNA and DNA.
- Polysaccharides like cellulose are the structural elements in the cell walls of bacteria and plants.
- Carbohydrates are linked to proteins and lipids that play important roles in cell interactions.
- Carbohydrates are organic compounds; they are aldehydes or ketones with many hydroxyl groups.

Physical Properties of Carbohydrates

- Stereoisomerism - Compound shaving same structural formula but they differ in spatial configuration. Example: Glucose has two isomers with respect to penultimate carbon atom. They are D- glucose and L-glucose.
- Optical Activity - It is the rotation of plane polarized light forming (+) glucose and (-) glucose.
- Diastereomer- It the configurational changes with regard to C2, C3, or C4 in glucose. Example: Mannose, galactose.
- Annomerism - It is the spatial configuration with respect to the first carbon atom in aldoses and second carbon atom in ketoses.

Chemical Properties of Carbohydrates

- Osazone formation with phenyl hydrazine.
- Benedict's test.
- Oxidation
- Reduction to alcohols

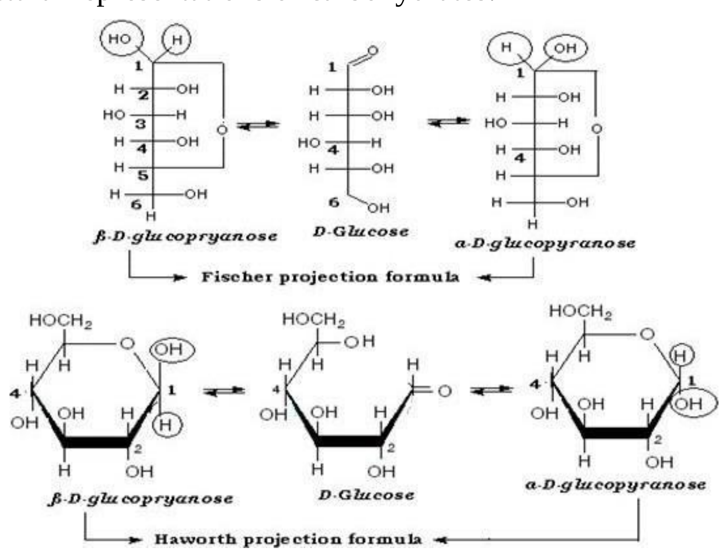
Structure of Carbohydrates

There are three types of structural representations of carbohydrates:

(i) Open chain structure.

(ii) Hemi-acetal structure.

(iii) Haworth structure.



FUNCTIONS OF CARBOHYDRATES

- Carbohydrates are chief energy source, in many animals; they are instant source of energy. Glucose is broken down by glycolysis/ Krebs cycle to yield ATP.
- Glucose is the source of storage of energy. It is stored as glycogen in animals and starch in plants.
- Stored carbohydrates act as energy source instead of proteins.
- Carbohydrates are intermediates in biosynthesis of fats and proteins.
- Carbohydrates aid in regulation of nerve tissue and are the energy source for brain.
- Carbohydrates get associated with lipids and proteins to form surface antigens, receptor molecules, vitamins and antibiotics.
- They form structural and protective components, like in cell wall of plants and microorganisms.
- In animals they are important constituent of connective tissues.
- They participate in biological transport, cell-cell communication and activation of growth factors.
- Carbohydrates those are rich in fiber content help to prevent constipation.
- Also, they help in modulation of immune system.
- Example of Carbohydrates:

  - Monosaccharides - Glucose, galactose, glycose, erythrose, ribose, ribulose, fructose.
  - Oligosaccharides - Maltose, lactose, sucrose, raffinose, stachyose.
  - Polysaccharides - Starch, glycogen, cellulose, pectin, inulin, hyaluronic acid.

- Food rich in carbohydrates are referred to as starchy foods. They are found in legumes, starchy vegetables, whole-grain breads and cereals. They also occur naturally with vitamins and minerals in foods like milk, fruits, and milk products. They are also found in refined and processed products like candy, carbonated beverages, and table sugar.

Examples of Polysaccharides

Name of the Polysaccharide	Composition	Occurrence	Functions
Starch	Polymer of glucose containing a straight chain of glucose molecules (amylose) and a branched chain of glucose molecules (amylopectin)	In several plant species as main storage carbohydrate	storage of reserve food
Glycogen	Polymer of glucose	Animals (equivalent of starch)	Storage of reserve food
Inulin	Polymer of fructose	In roots and tubers (like Dahlia)	Storage of reserve food
Cellulose	Polymer of glucose	Plant cell wall	Cell wall matrix
Pectin	Polymer of galactose and its derivatives	Plant cell wall	Cell wall matrix
Hemi cellulose	Polymer of pentoses and sugar acids	Plant cell wall	Cell wall matrix
Lignin	Polymer of glucose	Plant cell wall (dead cells like sclerenchyma)	Cell wall matrix
Chitin	Polymer of glucose	Body wall (exoskeleton) of arthropods. In some fungi also	Exoskeleton Impermeable to water
Murein	Polysaccharide cross linked with amino acids	Cell wall of prokaryotic cells	Structural protection
Hyaluronic acid	Polymer of sugar acids	Connective tissue matrix, Outer coat of mammalian eggs	Ground substance, protection
Heparin	Closely related to chondroitin	Connective tissue cells	Anticoagulant
Gums and mucilage	Polymers of sugars and sugar acids	Gums - bark or trees. Mucilage - flower	Retain water in dry seasons

LIPIDS

- Lipids are a heterogeneous group of water-insoluble (hydrophobic) organic molecules that can be extracted from tissues by nonpolar solvents, because of their insolubility in aqueous solutions, body lipids are generally found compartmentalized, as in the case of membrane-associated lipids or droplets of triacylglycerol in adipocytes, or transported in plasma in association with protein, as in lipoprotein particles or on albumin.
- Lipids are a major source of energy for the body, and they provide the hydrophobic barrier.

- Lipids serve additional functions in the body, for example, some fat-soluble vitamins have regulatory or coenzyme functions, and the prostaglandins and steroid hormones play major roles in the control of the body's homeostasis.

General characters of lipids

- Lipids are relatively insoluble in water.
- They are soluble in non-polar solvents, like ether, chloroform, and methanol.
- Lipids have high energy content and are metabolized to release calories.
- Lipids also act as electrical insulators; they insulate nerve axons.
- Fats contain saturated fatty acids; they are solid at room temperatures. Example, animal fats.
- Plant fats are unsaturated and are liquid at room temperatures.
- Pure fats are colorless, they have extremely bland taste.
- The fats are sparingly soluble in water and hence are described are hydrophobic substances.
- They are freely soluble in organic solvents like ether, acetone and benzene.
- The melting point of fats depends on the length of the chain of the constituent fatty acid and the degree of unsaturation.
- Geometric isomerism, the presence of double bond in the unsaturated fatty acid of the lipid molecule produces geometric or cis-trans isomerism.
- Fats have insulating capacity; they are bad conductors of heat.
- Emulsification is the process by which a lipid mass is converted to a number of small lipid droplets. The process of emulsification happens before the fats can be absorbed by the intestinal walls.
- The fats are hydrolyzed by the enzyme lipases to yield fatty acids and glycerol.
- The hydrolysis of fats by alkali is called saponification. This reaction results in the formation of glycerol and salts of fatty acids called soaps.
- Hydrolytic rancidity is caused by the growth of microorganisms which secrete enzymes like lipases. These split fats into glycerol and free fatty acids.

Classification of lipids

1. Simple lipids: Esters of fatty acids with various alcohols.

- Fats: Esters of fatty acids with glycerol. **Oils** are fats in the liquid state.
- Waxes: Esters of fatty acids with higher molecular weight monohydric alcohols.

2. Complex lipids: Esters of fatty acids containing groups in addition to an alcohol and a fatty acid.

- **Phospholipids:** Lipids containing, in addition to fatty acids and an alcohol, a phosphoric acid residue. They frequently have nitrogen containing bases and other substituents, eg, in glycerophospholipids the alcohol is glycerol and in sphingophospholipids the alcohol is sphingosine.

- Glycolipids (glycosphingolipids): Lipids containing a fatty acid, sphingosine, and carbohydrate.
- Other complex lipids: Lipids such as sulfolipids and aminolipids. Lipoproteins may also be placed in this category.

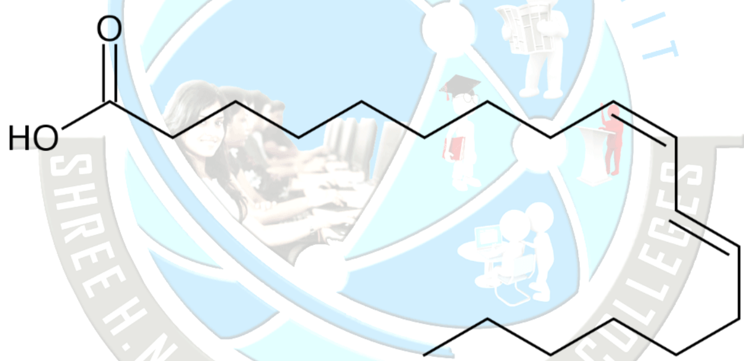
3. Precursor and derived lipids: These include fatty acids, glycerol, steroids, other alcohols, fatty aldehydes, and ketone bodies, hydrocarbons, lipid-soluble vitamins and hormones.

Essential fatty acids

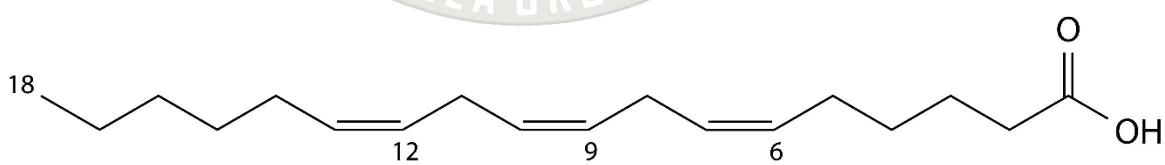
Two fatty acids are dietary essentials in humans.

- Linoleic acid, which is the precursor of arachidonic acid, the substrate for prostaglandin synthesis.
- α-linolenic acid is the precursor for growth and development.

Essential fatty acid deficiency can result in a scaly dermatitis, as well as visual and neurologic abnormalities.



Linoleic acid

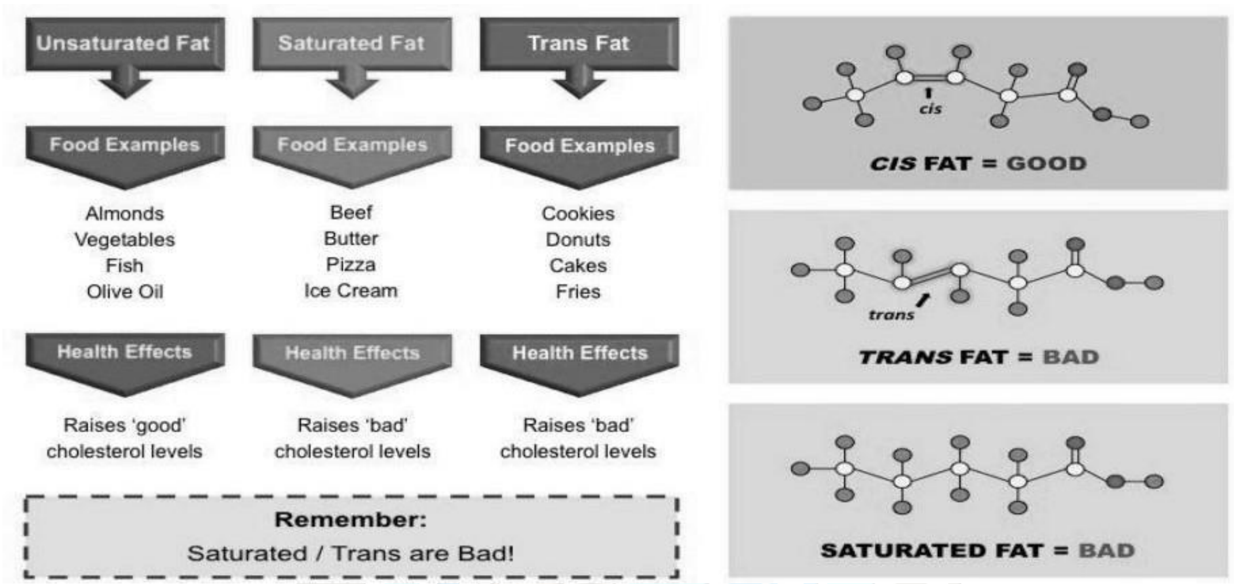


Linolenic acid

Regulating Blood Cholesterol Levels

- Fats and cholesterol cannot dissolve in blood and are consequently packaged with proteins (to form lipoproteins) for transport
  - Low density lipoproteins (LDL) carry cholesterol from the liver to the rest of the body
  - High density lipoproteins (HDL) scavenge excess cholesterol and carry it back to the liver for disposal

- Hence LDLs raise blood cholesterol levels ('bad') while HDLs lower blood cholesterol levels ('good')
- High intakes of certain types of fats will differentially affect cholesterol levels in the blood
  - Saturated fats increase LDL levels within the body, raising blood cholesterol levels
  - Trans fats increase LDL levels and decrease HDL levels within the body, significantly raising blood cholesterol levels
  - Unsaturated (cis) fats increase HDL levels within the body, lowering blood cholesterol levels.



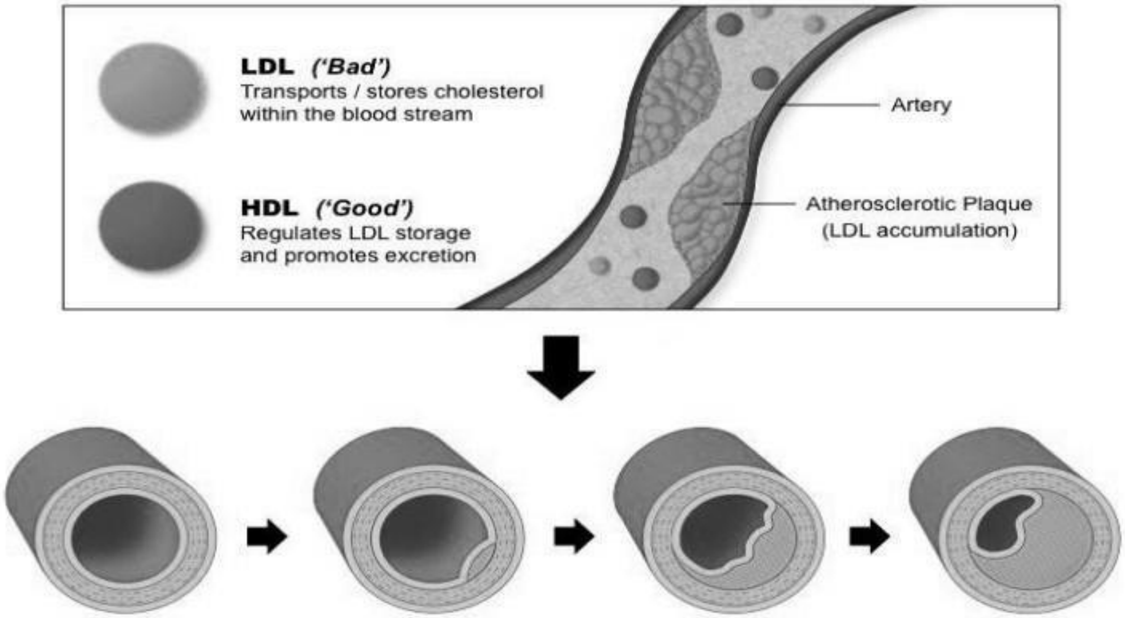
Lipid Health Claims

There are two main health claims made about lipids in the diet:

- Diets rich in **saturated fats** and ***trans* fats** increase the risk of CHD.
- Diets rich in **monounsaturated** and **polyunsaturated (*cis*) fats** decrease the risk of CHD.

Health Risks of High Cholesterol

- High cholesterol levels in the bloodstream lead to the hardening and narrowing of arteries (*atherosclerosis*).
- When there are high levels of LDL in the bloodstream, the LDL particles will form deposits in the walls of the arteries.
- The accumulation of fat within the arterial walls leads to the development of plaques which restrict blood flow.
- If coronary arteries become blocked, **Coronary Heart Disease** (**CHD**) will result – this includes heart attacks and strokes.



Examples of Lipids

- ***Fatty acids*** - Oleic acid, Linoleic acid, Palmitoleic acid, Arachidonic acid.
- ***Fats and Oils***
  - **Animal fats** - Butter, Lard, Human fat, Herring oil.
  - **Plant oils** - Coconut oil, Corn, Palm, Peanut, Sunflower oil.
- ***Waxes*** - Spermaceti, Beeswax, Carnauba wax.
- ***Phospholipids*** - Lecithin, Cephalins, Plasmalogens, Phosphatidyl inositol, Sphingomyelins.
- ***Glycolipids*** - Krasin, Phrenosin, Nervon, Oxynervon.
- ***Steroids*** - Cholesterol.
- ***Terpenes*** - Monoterpenes, Sesquiterpenes, Diterpenes, Triterpenes.
- ***Carotenoids*** - Lycopene, Carotenes, Xanthophylls.

BIOLOGICAL ROLE OF LIPIDS

- **Food material:** Lipids provide food, highly rich in calorific value. One gram lipid produces 9.3 kilocalories of heat.
- **Food reserve:** Lipids provide are insoluble in aqueous solutions and hence can be stored readily in the body as a food reserve.
- **Structural component:** Lipids are an important constituent of the cell membrane.
- **Heat insulation:** The fats are characterized for their high insulating capacity. Great quantities of fat are deposited in the subcutaneous layers in aquatic mammals such as whale and in animals living in cold climates.

- **Fatty acid absorption:** Phospholipids play an important role in the absorption and transportation of fatty acids.
- **Hormone synthesis:** The sex hormones, adrenocorticoids, cholic acids and also vitamin D are all synthesized from cholesterol, a steroidal lipid.
- **Vitamin carriers:** Lipids act as carriers of natural fat-soluble vitamins such as vitamin A, D and E.
- **Blood cholesterol lowering:** Chocolates and beef, especially the latter one, were believed to cause many heart diseases as they are rich in saturated fatty acids, which boost cholesterol levels in blood and clog the arterial passage. But researches conducted at the University of Texas by Scott Grundy and Andrea Bonanome (1988) suggest that at least one saturated fatty acid stearic acid, a major component of cocoa butter and beef fat, does not raise blood cholesterol level at all. The researchers placed 11 men on three cholesterol poor liquid diets for three weeks each in random order. One formula was rich in palmitic acid, a known cholesterol booster; the second in oleic acid; and the third in stearic acid. When compared with the diet rich in palmitic acid, blood cholesterol levels were 14% lower in subjects put on the stearic acid diet and 10% lower in those on the oleic acid diet.
- **Antibiotic agent.** *Squalamine*, a steroid from the blood of sharks, has been shown to be an antibiotic and antifungal agent of intense activity. This seems to explain why sharks rarely contract infections and almost never get cancer.

PROTEINS

- Proteins are large biomolecules, or macromolecules, consisting of one or more long chains of amino acidresidues.
- Proteins are known as building blocks of life.
- Proteins are the most abundant intracellular macro-molecules. They provide structure, protection to the body of multicellular organism in the form of skin, hair, callus, cartilage, ligaments, muscles, tendons. Proteins regulate and catalyze the body chemistry in the form of hormones, enzymes, immunoglobulin’s etc.

General Characteristics of Proteins

- Proteins are organic substances; they are made up of nitrogen and also, oxygen, carbon and hydrogen.
- Proteins are the most important biomolecules; they are the fundamental constituent of the cytoplasm of the cell.
- Proteins are the structural elements of body tissues.
- Proteins are made up of amino acids.
- Proteins give heat and energy to the body and also aid in building and repair.

- Only small amounts of proteins are stored in the body as they can be used up quickly on demand.
- Proteins are considered as the bricks, they make up bones, muscles, hair and other parts of the body.
- Proteins like enzymes are functional elements that take part in metabolic reactions.
- Antibodies, blood hemoglobin are also made of proteins.
- Proteins have a molecular weight of 5 to 300 kilo-Daltons.

Physical Properties of Proteins

- Proteins are colorless and tasteless.
- They are homogeneous and crystalline.
- Proteins vary in shape; they may be simple crystalloid structure to long fibrillar structures.
- Protein structures are of two distinct patterns - Globular proteins and fibrillar proteins.
- Globular proteins are spherical in shape and occur in plants. Fibrillar proteins are thread-like, they occur generally in animals.
- In general proteins have large molecular weights ranging between 5×10^3 and 1×10^6.
- Due to the huge size, proteins exhibit many colloidal properties.
- The diffusion rates of proteins are extremely slow.
- Proteins exhibit Tyndall effect.
- Proteins tend to change their properties like denaturation. Many a times the process of denaturation is followed by coagulation.
- Denaturation may be a result of either physical or chemical agents. The physical agents include, shaking, freezing, heating etc. Chemical agents are like X-rays, radioactive and ultrasonic radiations.
- Proteins like the amino acids exhibit amphoteric property i.e., they can act as Acids and Alkaline.
- As the proteins are amphoteric in nature, they can form salts with both cations and anions based on the net charge.
- The solubility of proteins depends upon the pH. Lowest solubility is seen at isoelectric point, the solubility increases with increase in acidity or alkalinity.
- All the proteins show the plane of polarized light to the left, i.e., levorotatory.

Chemical Properties of Proteins

- Proteins when hydrolyzed by acidic agents, like conc. HCl yield amino acids in the form of their hydrochlorides.
- Proteins when are hydrolyzed with alkaline agents leads to hydrolysis of certain amino acids like arginine, cysteine, serine, etc., also the optical activity of the amino acids is lost.

- Proteins with reaction with alcohols give its corresponding esters. This process is known as esterification.
- Amino acid reacts with amines to form amides.
- When free amino acids or proteins are said to react with mineral acids like HCl, the acid salts are formed.
- When amino acid in alkaline medium reacts with many acid chlorides, acylation reaction takes place.
- **Xanthoproteic test** - On boiling proteins with conc. HNO3, yellow color develops due to presence of benzene ring.
- **Folin's test -** This is a specific test for tyrosine amino acid, where blue color develops with phosphor molybdian tungstic acid in alkaline solution due to presence of phenol group.

Structure of Proteins

- Proteins are constructed by polymerization of only 20 different amino acids into linear chains.
- Proteins are the polymers of L-a-amino acids. The structure of proteins is rather complex which can be divided into 4 levels of organization.

1. Primary structure:

- The linear sequence of amino acids forming the backbone of proteins (polypeptides).
- Examples of protein with a primary structure are ***Hexosaminidase, Dystrophin.***

2. Secondary structure:

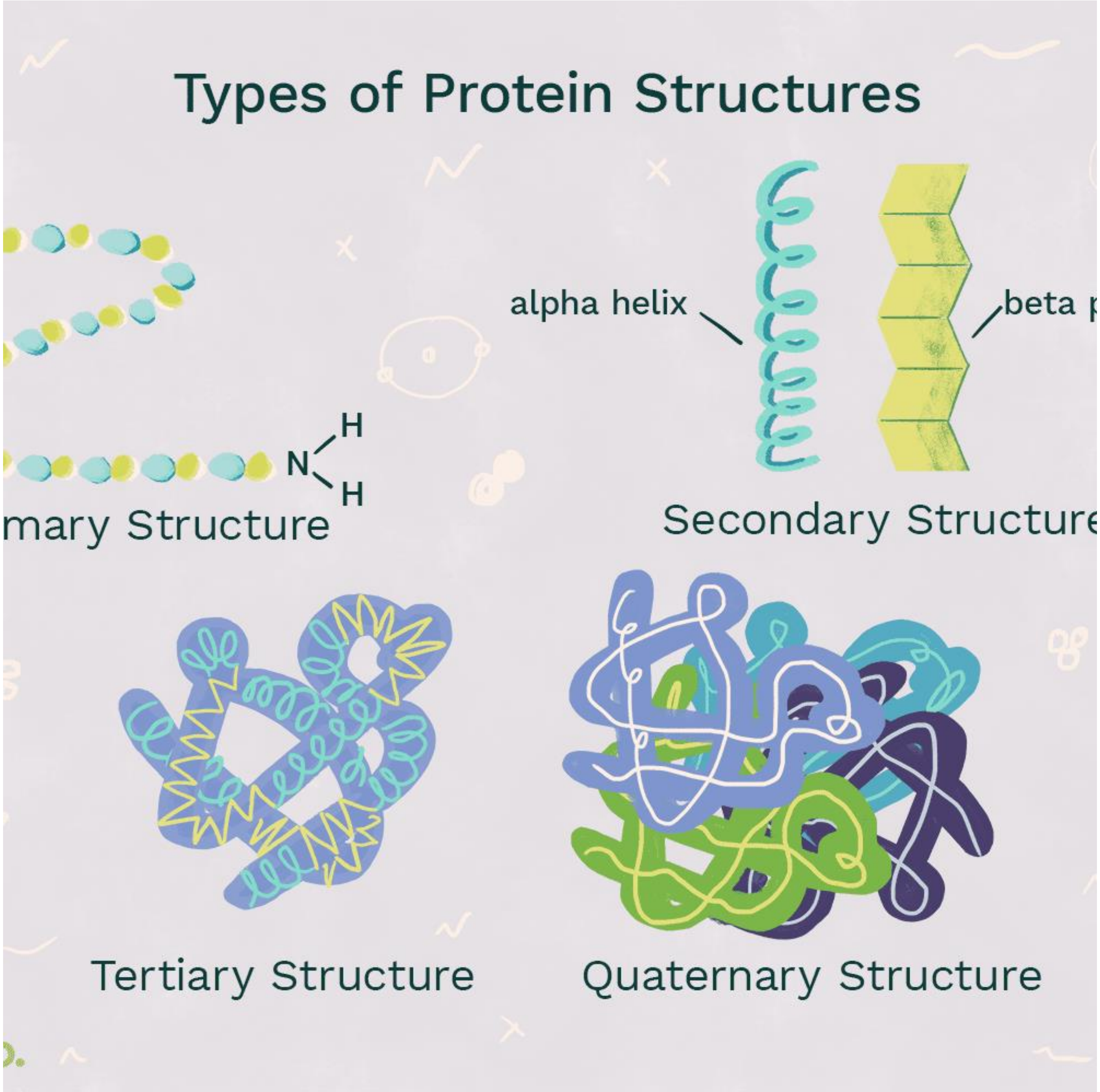
- The special arrangement of protein by twisting of the polypeptide chain.
- Example of protein with a secondary structure is ***Myoglobin.***

3. Tertiary structure:

- The three-dimensional structure of a functional protein.
- Number of forces act to hold the polypeptide chain in this final configuration:
    - Polar/Nonpolar Interactions
    - Hydrogen Bonds
    - Van der Waals Forces
    - Ionic Interactions
    - Disulfide Bonds
- Examples of protein with a Tertiary structure are ***Globular Proteins*** (Enzymes) and ***Fibrous Proteins***.

4. Quaternary structure:

- Some of the proteins are composed of two or more polypeptide chains referred to as subunits. The special arrangement of these subunits is known as quaternary structure.
- Examples of protein with a Quaternary structure are ***DNA polymerase***, and ***ion channels***.



Secondary Structure of Proteins

- **Shape**
  - ***Alpha Helix:*** Alpha Helix is a right-handed coiled rod-like structure.
  - ***Beta Pleated Sheet:*** Beta sheet is a sheet-like structure.

- **Formation**
  - ***Alpha Helix:*** Hydrogen bonds form within the polypeptide chain in order to create a helical structure.
  - ***Beta Pleated Sheet:*** Beta sheets are formed by linking two or more beta strands by H bonds.

- **Bonds**
  - ***Alpha Helix:*** Alpha helix has n + 4 H-bonding scheme. i.e. Hydrogen bonds form between N-H group of one amino residue with C=O group of another amino acid, which is placed in 4 residues earlier.
  - ***Beta Pleated Sheet:*** Hydrogen bonds are formed in between the neighboring N-H and C=O groups of adjacent peptide chain

- **R group**
  - ***Alpha Helix:*** -R groups of the amino acids are oriented outside of the helix.
  - ***Beta Pleated Sheet:*** -R groups are directed to both inside and outside of the sheet.

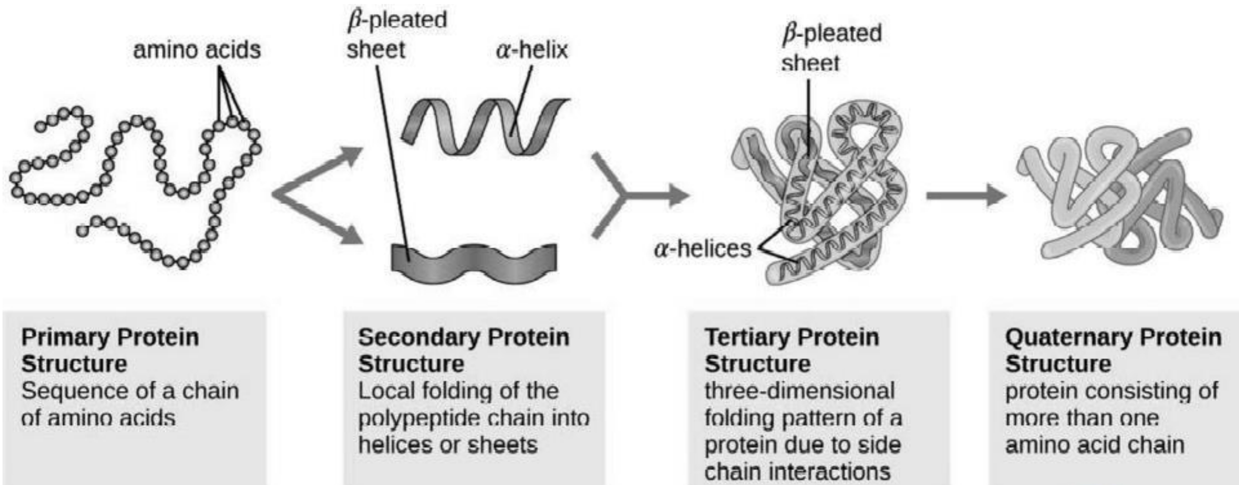
- **Number**
  - ***Alpha Helix:*** This can be a single chain.
  - ***Beta Pleated Sheet:*** This cannot exist as a single beta strand; there are must be two or more.

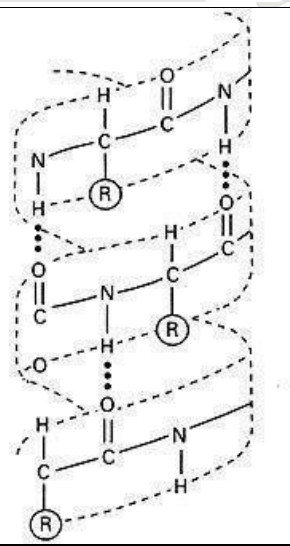
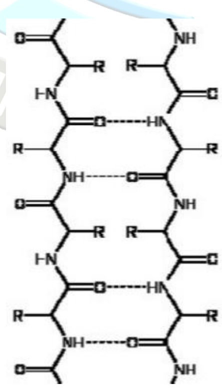
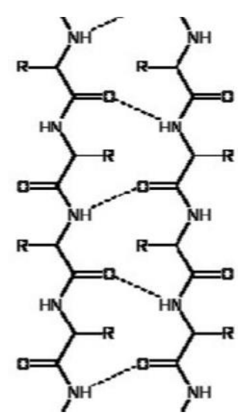
- **Type**
  - ***Alpha Helix:*** This has only one type.
  - ***Beta Pleated Sheet:*** This can be parallel, anti-parallel or mixed.

- **Qualities**
  - ***Alpha Helix:*** 100o rotation, 3.6 residues per turn and 1.5 Ao rise from one alpha carbon to the second
  - ***Beta Pleated Sheet:*** 3.5 Ao rise between residues

- **Amino Acid**
  - ***Alpha Helix:*** Alpha helix prefers the amino acid side chains, which can cover and protect the backbone H- bonds in the core of the helix.
  - ***Beta Pleated Sheet:*** The extended structure leaves the maximum space free for the amino acid side chains. Therefore, amino acids with large bulky side chains prefer beta sheet structure.

- **Preference**
  - ***Alpha Helix:*** Alpha helix prefers Ala, Leu, Met, Phe, Glu, Gln, His, Lys, Arg amino acids.
  - ***Beta Pleated Sheet:*** Beta sheet prefers Tyr, Trp, (Phe, Met), Ile, Val, Thr, Cys.



		
Alpha Helix Secondary Structure of Proteins	**Beta pleated Antiparallel**: when the adjacent polypeptide chains run in opposite direction	**Beta pleated Parallel**: Adjacent polypeptide chains running in the same direction

Protein Classification

Classification of Proteins Based on Shape

- **Globular or Corpuscular Proteins**
  - Globular proteins have axial ratio less than 10 but not below 3 or 4.
  - They are compactly folded and coiled and possess a relatively spherical or ovoid shape.
  - They are usually soluble in water and in aqueous media.
  - **Example**: Insulin, plasma albumin, globulin enzymes.

Axial ratio, for any structure or shape with two or more axes, is the ratio of the length (or magnitude) of those axes to each other - the longer axis divided by the shorter.

In chemistry or materials science, the axial ratio (symbol P) is used to describe rigid rod-like molecules. It is defined as the length of the rod divided by the rod diameter.

- **Fibrous or Fibrillar Proteins**
  - These proteins have axial ratio more than 10, hence, they resemble long ribbons or fibers in shape.
  - They are mostly found in animals, and are not soluble in water or in solution of dilute acids.
  - Fibrous proteins aid in protection and structural support.
  - **Example:** Collagen, Keratin, Elastin, Fibroin

Classification of Proteins Based on Composition and Solubility

- **Simple Proteins or Holoproteins:**
- These proteins are made of only one type of amino acid, as structural component, on decomposition with acids, they liberate constituent amino acids. They are mostly globular type of proteins except for scleroproteins, which are fibrous in nature.
- Simple proteins are further classified based on their solubility.

1. **Protamine and histones**
   - These proteins occur only in animals and are basic proteins.
   - They possess simple structure and low molecular, are water soluble and are not coagulated by heat.
   - They are strongly basic in character due to the high content of lysine, arginine.

- **Example:** Protamine - salmine, clupine, cyprinine; Histones - nucleoshistones, globin.

2. **Albumins**

- They are widely distributed in nature, mostly seen in seeds.
- They are soluble in water and dilute solutions of acids, bases and salts.
- **Example:** Leucosin, legumeline, serum albumin.

3. **Globulins**

- They are of two types, pseudo globulins which are soluble in water,
- Other is euglobulin which are insoluble in water.
- They are coagulated by heat.
- **Example:** Pseudo globulin, serum globulin, glycinin. etc.

4. **Scleroproteins or Albuminoids**

- These occur mostly in animals and are commonly known as animal skeleton proteins.
- They are insoluble in water, and in dilute solution of acids, based and salts.

- **Conjugated or Complex Proteins or Heteroproteins:**

- These are proteins that are made of amino acids and other organic compounds. The non-amino acid group is termed as prosthetic group.
- *Complex proteins are further classified based on the type of prosthetic group present.*

Metalloproteins:

- These are proteins linked with various metals.
- Example: casein, collagen, ceruloplasmin, etc.

Chromoproteins

- These are proteins that are coupled with a colored pigment.
- Example: Myoglobin, hemocyanin, cytochromes, flavoproteins, etc.

Glycoproteins and Mucoproteins

- These proteins contain carbohydrates as the prosthetic group.
- Example: Glycoproteins - egg albumin, serum globulins, serum albumins; Mucoproteins - Ovomucoid, mucin etc.

Phosphoproteins

- These proteins are linked with phosphoric acid.
- Example: casein.

Lipoproteins

- Proteins forming complexes with lipids are lipoproteins.
- Example: lipovitellin, lipoproteins of blood.

Nucleoproteins

- These are compounds containing nucleic acids and proteins.
- Example: Nucleoproteins, nucleohistones, nuclein.

Derived Proteins

- These are proteins that are derived from the action of heat, enzyme or chemical reagents.
- Derived proteins are of two types, primarily derived proteins and secondary derived proteins.

  - ***Primary derived proteins***
    - Derivatives of proteins, in which the size of the protein molecule is not altered materially.,.
    - Primary derived proteins are classified into three types - **Proteans**, **Infraproteins** and **Coagulated proteins**.
    - **Example:** edestan, coagulated egg-white.

  - ***Secondary derived proteins.***
    - While in secondary derived proteins, hydrolysis occurs, as a result the molecules are smaller than the original proteins.
    - They are further classified into 3 types - Proteoses, Peptones and Polypeptides

EGG PROTEINS COMPOSITION OF EGG WHITE		
Protein		***Percentage***
Total protein		10-11% (on wet basis); 82.8% (on dry basis)
Ovalbumin		70% of total proteins
Conalbumin		9%
Ovomucoid		13%
Globulins	Lysozyme (G1)	2.6%
	Lysozyme (G2)	7%
	Lysozyme (G3)	7%
Mucin		2%
Avidin		0.06%

Classification of Proteins on Biological Function

- **Enzymic Proteins**
  - They are the most varied and highly specialized proteins with catalytic activity. Enzymes catalyze a variety of reactions.
  - **Example:** Urease, catalase, cytochrome C, etc.

- **Structural Proteins**
  - These proteins aid in strengthening or protecting biological structures.
  - **Example:** Collagen, elastin, keratin, etc.

- **Transport or Carrier Proteins**
  - These proteins help in transport of ions or molecules in the body.
  - **Example:** Myoglobin, hemoglobin, etc.

- **Nutrient and Storage Proteins**
  - These proteins provide nutrition to growing embryos and store ions.

- **Contractile or Motile Proteins**
  - These proteins function in the contractile system.
  - **Example:** Actin, myosin, tubulin, etc.

- **Defense Proteins**
  - These proteins defend against other organisms.
  - **Example:** Antibodies, Fibrinogen, thrombin.

- **Regulatory Proteins**
  - They regulate cellular or metabolic activities.
  - **Example:** Insulin, G proteins, etc.

- **Toxic Proteins**
  - These proteins hydrolyze or degrade enzymes.
  - **Example:** snake venom, ricin.

MILK PROTEINS

- Milk Protein contains about 0.6–0.7% protein which is not precipitated on acidification to pH 4.7.
- This represents about 20% of the protein contained in skim milk. These whey proteins are separated into 2 fractions: ***lactalbumin*** and ***lactoglobulin***.
- The name ***casein*** is assigned to the fraction precipitated by acidifying milk to a pH of 4.7. It is present in cow's milk (3-3.5%) and human milk (0.3-0.6%). Casein may be further purified by redissolving and precipitating again. It is of 3 types: **α**, **β** and **γ**.

Function of Proteins

- Proteins are seen in muscles, hair, skin and other tissues; they constitute the bulk of body's non-skeletal structure. *Example:* The protein keratin is present in nails and hair.
- Some proteins are hormones and regulate many body functions. *Example:* Insulin hormone is a protein and it regulated the blood sugar level.
- Some proteins act enzymes, they catalyze or help in biochemical reactions. *Example:* Pepsin and Trypsin.
- Some proteins act as antibodies; they protect the body from the effect of invading species or substances.
- Proteins transports different substances in blood of different tissues. *Example:* Hemoglobin is an oxygen transport protein.
- Contractile proteins help in contraction of muscle and cells of our body. *Example:* Myosin is contractile protein.
- Fibrinogen a glycoprotein helps in healing of wounds. It prevents blood loss and inhibits passage of germs.

Function of proteins

Class of Protein	Function in the Body	Examples
Structural	Provide structural components	*Collagen* is in tendons and cartilage. *Keratin* is in hair, skin, wool, and nails.
Contractile	Movement of muscles	*Myosin* and *actin* contract muscle fibers.
Transport	Carry essential substances throughout the body	*Hemoglobin* transports oxygen. *Lipoproteins* transport lipids.
Storage	Store nutrients	*Casein* stores protein in milk. *Ferritin* stores iron in the spleen and liver.
Hormone	Regulate body metabolism and nervous system	*Insulin* regulates blood glucose level. *Growth hormone* regulates body growth.
Enzyme	Catalyze biochemical reactions in the cells	*Sucrase* catalyzes the hydrolysis of sucrose. *Trypsin* catalyzes the hydrolysis of proteins.
Protection	Recognize and destroy foreign substances	Fibrinogen helps blood clotting

NUCLEIC ACIDS

These are important organic substances found in nucleus and cytoplasm. They control the important biosynthetic activities of the cell and carry hereditary information from generation to generation.

Thus, nucleic acids are macromolecules of the utmost biological importance.

They are associated with the chromosomes and transmit various information to cytoplasm.

All the hereditary (genetic) information of the cell (i.e., all the information necessary to reproduce and maintain a new organism) is stored in coded form in molecules of DNA. DNA is replicated and distributed to daughter cells during cell division, and in this way all the hereditary information accumulated over billions of years of evolution is passed from cell to cell and from one generation of an organism to another.

With the aid of RNA, this information is expressed as specific patterns of protein synthesis. These nucleic acids are of two types: (i) deoxyribonucleic acid (DNA) and (ii) ribonucleic acid (RNA). DNA is the major store of genetic information. This information is transmitted by transcription into RNA molecules, proteins are then synthesized in a process involving translation of the RNA.

DNA → transcription RNA→ translation Protein

In higher cells, DNA is localized mainly in the nucleus as part of the chromosomes. A small amount of DNA is present in the cytoplasm and contained within mitochondria and chloroplasts. RNA is found both in the nucleus, where it is synthesized, and in the cytoplasm, where the synthesis of proteins takes place.

Nucleic acids consist of a sugar (pentose), nitrogenous bases (purines and pyrimidines), and phosphoric acid. A nucleic acid molecule is a linear polymer in which nucleotides are linked together by means of phosphodiester ‘bridges or bonds.

These bonds link the 3′ carbon in the pentose of one nucleotide to the 5′ carbon in the pentose of the adjacent nucleotide. Thus, the backbone of a nucleic acid consists of alternating phosphates and pentoses. The nitrogenous bases are attached to the sugars of this backbone.

Nucleic acids are basophilic, i.e., stain readily with basic dyes. After a mild hydrolysis the nucleic acids are decomposed into nucleotides.

Deoxyribonucleic acid (DNA):

It forms about 9% part of nucleus as found by spectrophotometric analysis. Chemically it consists of mainly three components: phosphoric acid, sugar, and bases.

1. Phosphoric acid:

It may occur also as phosphate and forms the backbone of DNA molecule along with sugar molecule. It links the nucleotides by joining the deoxyribose (pentose sugar) of two adjacent nucleotides with an ester-phosphate bond. These bonds connect carbon 3′ in one nucleotide with carbon 5′ in next. This acid is a channel for the chemical energy used by the molecule.

2. Pentoses:

These are of two types: ribose in RNA and deoxyribose in DNA. DNA has one oxygen atom less than that of RNA. The pentose sugar in nucleic acids is always ribose-, in RNA it is D-ribose and in DNA, it is deoxyribose. It is always the OH on C-l carbon which is the point of attachment of the base.

This linked to the 1-nitrogen atom in case of pyrimidines and to 9-nitrogen atom in purines. Both deoxyribose and ribose (pentose sugars of nucleic acids) have a pentagonal ring with five carbons, among which two (i.e., 3′ and 5′) are attached to phosphoric acid and three (Γ) to the base.

3. Bases:

These may be of two types:

(a) Purines and

(b) Pyrimidines.

(a) Purines:

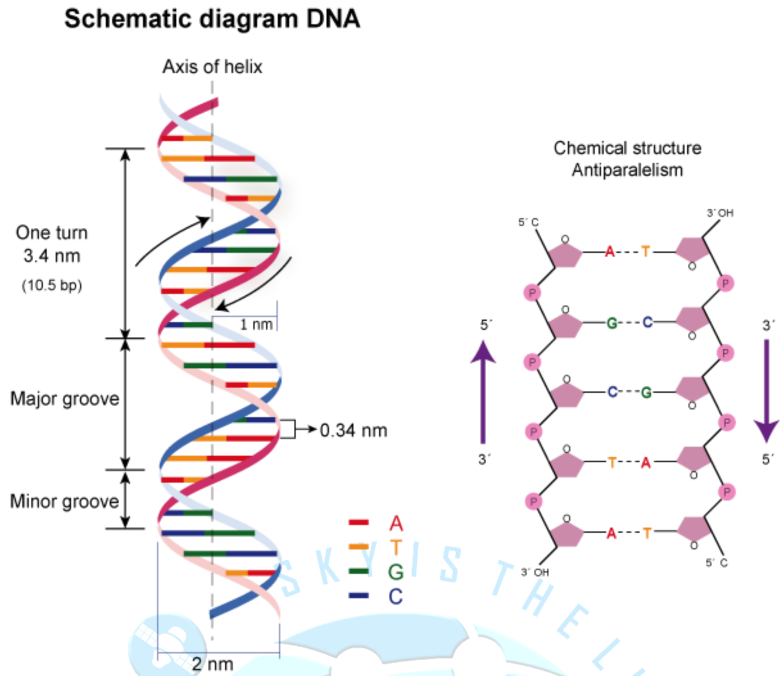
These are characterized by the presence of two fused benzene rings. They may be adenine (A) and guanine (G). RNA contains uracil (U) instead of thymine. The combination of base plus a pentose, minus the phosphate, forms a nucleoside. For example, adenine is a purine base; adenosine (adenine + ribose) is the corresponding nucleoside, i.e., deoxyadenosine and deoxyguanosine.

b) Pyrimidines:

These are characterized by the occurrence of single benzene ring. They are thymine (T) and cytosine (C).

Nucleotides:

Nucleotides are phosphate esters of nucleosides, purine or pyrimidine bases linked to sugars. In the nucleotides, the 3-nitrogen of the pyrimidine bases or the 9-N of the purine bases is attached to the 1-carbon atom of the sugar, and the phosphoric acid residue is attached to the 5′ carbon atom of the sugar.



Thus, nucleotides of purines are deoxyriboadenylic acid and deoxyriboguanylic acid, and of pyrimidines are deoxyribothymidylic acid and deoxyribocytidylic acid.

DNA:

Purines and pyrimidines are weak bases. Adjacent nucleotides of the nucleic acids are connected by a linkage between the phosphoric acid residue of one nucleotide and the 3′ carbon atom of the sugar on the next nucleotide. Both the bases and sugars have an approximately planar structure. In polynucleotides the planes are oriented with respect to one another at an angle of 70° to 75°.

In addition to four common bases, a number of unusual bases are found is .DNA. DNA of animal origin contains trace amounts of 5-methy- lcytosine, while large amounts of this base are found in DNA of plant origin. Similarly, 6-methyl aminopurine is found in DNA from bacteria and viruses.

Cytosine in DNA of T-even bacteriophages of E.-coli is replaced by 5-hydroxymethylcytosine, to which glucose or other sugars may be linked at the hydroxyl group. In some viral DNA’s, the rare base 5-hydroxy— methyl uracil substitutes for thymine.

DNA base composition:

DNA in living organisms is found as a linear molecule of extremely high molecular weight. For example, in E-coli it is a single circular DNA molecule weighing about 2.7 × 109 daltons and its length is 1.4 mm. In higher organisms the amount of DNA may be several thousand times larger. For example, in a single human diploid cell its total length when fully extended is 1.7 meters.

All the genetic information of a living organism is stored in its linear sequence of the four bases. Therefore, a four-letter alphabet (A, T, G, C) must code for the primary structure (i.e., number and sequence of 20 amino acids) of all proteins. The base composition vary from one species to another, but in all cases amount of adenine is equal to amount of thymine (A=T).

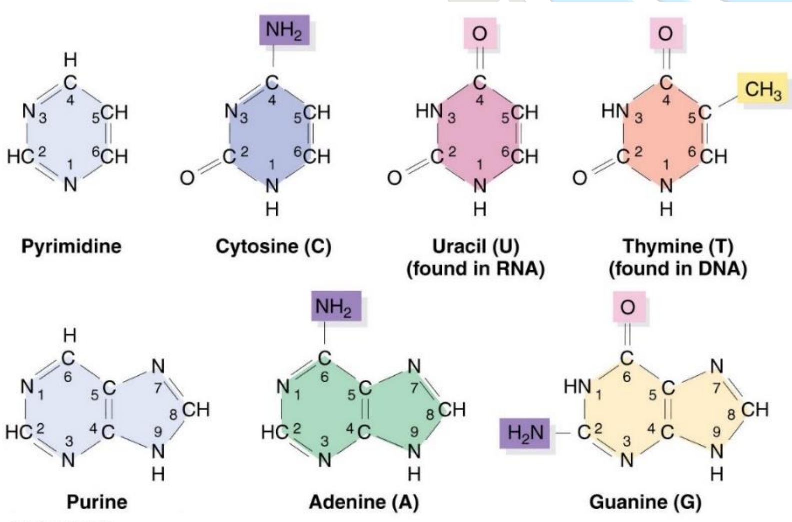
Similarly amount of cytosine is equal to guanine (C=G). Consequently, total quantity of purines equals the total quantity of pyrimidines (i.e., A+G=C+T). On the other hand, AT/GC ratio varies considerably between species.

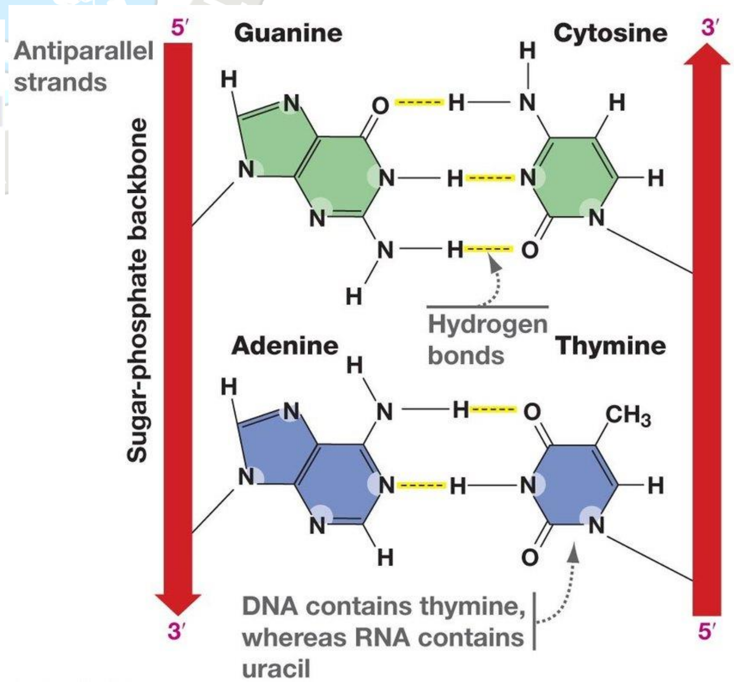
DNA is double helix:

On the basis of X-ray diffraction data of Wilkins and Franklin, Watson and Crick (1953) proposed a model for DNA structure. It is composed of two right-handed helical polynucleotide chains that form a double helix around the same central axis. The two strands are antiparallel, meaning that their 3′, 5′ phosphodiester links run in opposite directions. The bases are stacked inside the helix in a plane perpendicular to the helical axis.

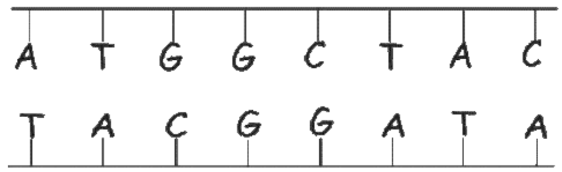
The two strands are held together by hydrogen bonds present between pairs of bases. Since there is a fixed distance between two pentose sugars in the opposite strands, only certain base pairs can fit into the structure.

As shown in figure 5 two hydrogen bonds are formed between A and T, three are formed between C and G, therefore a CG pair is more stable than AT pair. In addition to hydrogen bonds, hydrophobic interactions established between the stacked bases are important in maintaining the double helical structure.





The axial sequence of bases along one polynucleotide chain may vary considerably, but on the other chain the sequence must be complementary, as given below —



Because of this property, order of bases on one chain, the other chain is complimentary. During duplication the two chains dissociate and each one serves as a template for the synthesis of a new complementary chain.

Separation of DNA strands:

DNA double helix is preserved by weak interactions (i.e., hydrogen bonds and hydrophobic interactions between stacked bases); two strands may be separated by heating or alkaline pH. This separation is called melting or denaturation of DNA. The melting point depends on AT/GC ratio. Breakage of GC pairs needs higher temperature to that of AT pairs.

If DNA is cooled slowly after denaturation, double helical conformation will be restored. This process is called renaturation or annealing and this is the base-pairing properties of nucleotides.

DNA renaturation can be used to estimate the size (number of nucleotides) of the genome of a given organism. A large genome (e.g., calf) take more time to reanneal than a small genome (e.g., E. coli). This is because the individual sequences take longer time to find the correct partners.

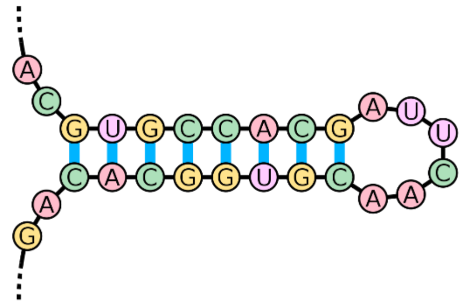
Single stranded DNA will also anneal to complimentary RNA, resulting in a hybrid molecule in which one strand is DNA and the other is RNA. Molecular hybridization is a very powerful method for characterizing RNAs since RNA; molecule will hybridize only to DNA from which it was transcribed.

Ribonucleic acid (RNA):

RNA is present in considerable amounts in the nucleolus and is also found in small amounts on chromosomes. The major part of the cell’s RNA is in the cytoplasmic ribosomes. A small amount of RNA is also present in mitochondria and chloroplasts.

Transfer RNA and mRNA are present in solution in the cytoplasmic matrix unless affixed to the ribosomes. The RNA content of nucleus and cytoplasm varies with activity cycles of the cell. The cytoplasmic RNA increases in quantity during cell growth preceding mitosis and is partitioned equally between the daughter cells.

RNA accumulates in both nucleus (especially in nucleolus) and cytoplasm during high metabolic activity or growth, as in regenerating nerve cells, active neurons, gland cells, cells infected with virus and tumor cells. Actively metabolizing yeast cells contain a large amount of RNA, but starved yeast cells have little RNA. In fact, starved cells in general show RNA depletion.



RNA also varies with other physiological conditions such as lack of oxygen and presence of metabolic poisons. RNA is labile in dividing cells and also in active cells that are not dividing.

Structure of RNA:

RNA is a long-chain molecule built up of repeating nucleotide units linked by 3′ to 5′ phosphate diester bonds. Sugar component of RNA is ribose and three out of four bases, adenine, guanine and cytosine are the same as in DNA, and the fourth base is uracil in place of thymine of DNA, Uracil has one methyl group less.

Nucleotides:

RNA nucleotides are formed from pentose sugar ribose, phosphoric acid and either adenine guanine, cytosine or uracil (U). Nucleotides are regarded as phosphorylated derivatives of nucleosides. Nucleosides are combinations of a nitrogenous base and a pentose sugar without an attached phosphate group.

A nucleotide unit consists of a molecule of sugar, a base and a phosphoric acid. A single nucleic acid contains a large number of nucleotide units consisting of high molecular weight (about 8,000,000).

Nucleotides are the monomeric units of the nucleic acid macromolecule. The nucleotides result from the covalent bonding of a phosphate and a heterocyclic base to the pentose. Within the nucleotide, the combination of a base with the pentose forms a nucleoside.

For example, adenine is a purine base; adenosine (adenine+ ribose) is the corresponding nucleoside, and adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP) are nucleotides. Nucleotides, thus constitute the building blocks of nucleic acids and they are also used to store and transfer chemical energy.

Polynucleotide:

Nucleotides are joined together to form a polynucleotide chain by a covalent linkage between the phosphoric acid residue of one nucleotide and 3′ carbon of the sugar on the next nucleotide. This linkage is often called a 3′, 5′ phosphodiester bond, because the phosphate is esterified to two OH groups, one attached to the 3′ carbon and one attached to the 5′ carbon.

The backbone of a polynucleotide chain thus consists of alternating sugar and phosphate units.

The sequence of nucleotides in DNA and RNA is the key to their genetic functions, just as the sequence of amino acids determines the biological activity of a particular protein. Even though both DNA and RNA are usually composed of only four different nucleotides, the number of possible sequences of nucleotides is enormous in a large polymer.

RNA usually exists as a single-stranded polynucleotide chain and have no regular helical configuration. The linear chain is thought to be folded in many ways, with certain nucleotides pairing off and forming short double-stranded regions.

Kinds of ribonucleic acid:

The ribonucleic acids are of three types —

1. Messenger RNA:

This ribonucleic acid is of nuclear origin and conveys genetic information from DNA in the nucleus to the ribosomes in the cytoplasm, where amino acids become grouped to form proteins.

2. Transfer or adapter RNA:

It is another important type of ribonucleic acid which is present in the cytoplasm, helping there in protein synthesis. It has been recently found that t-RNA originates from nucleus near the nucleolar region.

3. Ribosomal RNA:

This ribonucleic acid is the major component of cytoplasmic particles called ribosomes. Ribosomal RNA comprises up to 80% of the cellular RNA of Escherichia coli. It is the site of amino acids union.

Significance of nucleic acids:

Deoxyribonucleic acids and ribonucleic acids are the key centers which control all the metabolic activities of cell and in turn the whole organism.

(1) If there occurs any deficiency in the DNA amount, nucleus loses its capacity to support adenosine triphosphate (ATP) synthesis.

(2) Nucleus also becomes inefficient to incorporate amino acids into proteins.

(3) Besides, DNA is the main genetic material constituting genes and chromosomes which carry hereditary information from generation to generation. DNA helps in the RNA synthesis in the cell. If the loops of amphibian oocytic chromosome (lamp brush) are exposed to actinomycin (which has the property to fuse with DNA and thereby causing decrease in DNA amount), RNA synthesis is inhibited.

(4) Recently, McConnell and Cameron (1968) have produced the evidence that RNA amount increases the intelligence and learning capacity of men.

Molecular arrangement of components in nucleic acids:

In deoxyribonucleic acid (DNA), nucleotides are arranged in the form of helixes or chains spirally coiling around each other. According to Watson and Crick (1962), DNA consists of two helixes coiled about each other. The chain of each helix is made of sugar and phosphate group.

These two helixes are interconnected by the bases through hydrogen bonds. Generally, one purine becomes attached with one pyrimidine to form base connection between the chain. Thus, adenine along with thymine, and cytosine along with guanine becomes connected with the sugar molecule of chain alternately.

The direction of one helix is opposite to the other. In DNA one helix serves as a template for the formation of complementary helix, i.e., adenine in one helix forms the thymine in new helix and similarly cytosine effects the formation of guanine in new helix.

In ribonucleic acid (RNA), the nucleotides are not arranged in double helical model but for the most part RNA exists as a single strand. Sometimes it may form also smaller helices in some parts due to folding and convolutions. These secondary helical structures in RNA are regular according to recent research. In the formation of helix, bases become hydrogen-bonded like DNA except uracil substitutes thymine.