CHAPTER-09

BIOMOLECULES

Introduction

A **biomolecule** or **biological molecule** is a loosely used term for molecules present in organisms that are essential to one or more typically biological processes, such as cell division, morphogenesis, or development. Biomolecules include large macromolecules(or polyanions) such as proteins, carbohydrates, lipids, and nucleic acids, as well as small molecules such as primary metabolites, secondary metabolites, and natural products.

How to analyze the chemical composition

We can continue asking in the same way, what type of organic compounds are found in living organisms? How does one go about finding the answer?

To get an answer, one has to perform a chemical analysis. We can take any living tissue (a vegetable or a piece of liver, etc.) and grind it in trichloroacetic (ClCCOOH) using a mortar and a pestle.

We obtain a thick slurry. If we were to strain this through a cheesecloth or cotton we would obtain two fractions. One is called the filtrate or more technically, the acid-soluble pool, and the second, the retentate or the acid-insoluble fraction.

Scientists have found thousands of organic compounds in the acid-soluble pool.

In higher classes, you will learn about how to analyze a living tissue sample and identify a particular organic compound. It will suffice to say here that one extracts the compounds, then subjects the extract to various separation techniques till one has separated a compound from all other compounds. In other words, one isolates and purifies a compound.

Analytical techniques, when applied to the compound give us an idea of the molecular formula and the probable structure of the compound. All the carbon compounds that we get from living tissues can be called ‘biomolecules’. However, living organisms have also got inorganic elements and compounds in them. How do we know this? A slightly different but destructive experiment has to be done.

One weighs a small amount of living tissue (say a leaf or liver and this is called wet weight) and dry it. All the water evaporates. The remaining material gives dry weight. Now if the tissue is fully burnt, all the carbon compounds are oxidized to gaseous form (CO, water vapour) and are removed. What is remaining is called 'ash'. This ash contains inorganic elements (like calcium, magnesium, etc).

Inorganic compounds like sulphate, phosphate, etc., are also seen in the acid-soluble fraction. Therefore elemental analysis gives the elemental composition of living tissues in the form of hydrogen, oxygen, chlorine, carbon etc.while analysis for compounds gives an idea of the kind of organic and inorganic constituents]present in living tissues.

TABLE 9.1 A Comparison of Elements Present in Non-living and Living Matter*

Element	% Weight of Earth's crust	% Weight of Human body
Hydrogen (H)	0.14	0.5
Carbon (C)	0.03	18.5
Oxygen (O)	46.6	65.0
Nitrogen (N)	very little	3.3
Sulphur (S)	0.03	0.3
Sodium (Na)	2.8	0.2
Calcium (Ca)	3.6	1.5
Magnesium (Mg)	2.1	0.1
Silicon (Si)	27.7	negligible

* Adapted from CNR Rao, *Understanding Chemistry*, Universities Press, Hyderabad.

TABLE 9.2 A List of Representative Inorganic Constituents of Living Tissues

Component	Formula
Sodium	Na^+
Potassium	K^+
Calcium	Ca^{++}
Magnesium	Mg^{++}
Water	H_2O
Compounds	NaCl, $CaCO_3$, PO_4^{3-}, SO_4^{2-}

From a chemistry point of view, one can identify functional groups like aldehydes, ketones, aromatic compounds, etc. But from a biological point of view, we shall classify them into amino acids, nucleotide bases, fatty acids, etc.

Amino acids

Called the "building blocks of life," amino acids can be obtained in healthy amounts by eating foods that contain them.

Amino acids are compounds that combine to form a polypeptide chain.

Naturally found in our bodies, they're often referred to as the "building blocks of life."

Amino acids are needed for the production of enzymes, as well as some hormonesacids and neurotransmitters.

They're also involved in numerous metabolic pathways within cells throughout the body.

You can obtain amino acids through the foods you eat.

After your body digests and breaks down protein, amino acids are left in the body to help do the following:

Break down food

Grow and repair body tissue

Provide a source of energy

Perform other bodily functions

Types of Amino Acids

Amino acids can be placed in three different groups:

Nonessential amino acids: These are produced naturally by your body and have nothing to do with the food you eat.

The following are examples of nonessential amino acids:

Alanine

Asparagine

Aspartic acid

Glutamic acid

Essential amino acids: These can't be produced by the body and must come from the food you eat.

If you don't eat foods that contain essential amino acids, your body won't have them. The following are essential amino acids:

Histidine

Isoleucine

Leucine

Lysine

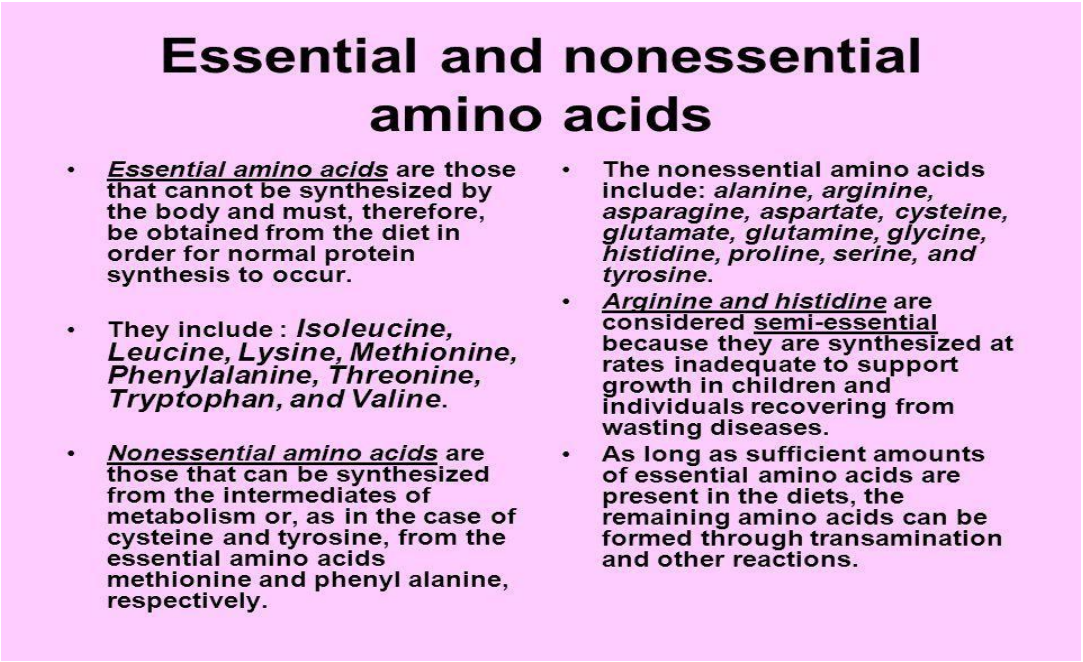
Methionine

Phenylalanine

Threonine

Tryptophan

Valine



Protein amino acids

Twenty types of amino acids and amides occur in proteins. They are called protein amino acids.

Rare amino acids

A protein may also possess noncoded amino acids. The latter is called a rare amino acid.

Ex:hydroxyproline,hydroxylysine

Non-protein amino acids

These are many. They occur both in the free state as well as in the combined state, but not in proteins.

Ring structure in R-groups makes certain amino acids aromatic. Depending upon structure and reaction, amino acids are differentiated into seven types.

Neutral amino acid:

Amino acids have one amino group and one carboxylic group (mono-amino monocarboxylic) with a noncyclic hydrocarbon chain.

Ex: glycine

Acidic amino acids :

The amino acids have an extra carboxylic group(mono-amino dicarboxylic)

Ex: glutamate

Basic amino acids;

They have an additional amino group without forming amides(diamino monocarboxylic)

Ex: lysine

Sulphur containing amino acids:

The amino acids possess sulphur.

Ex: methionine

Alcoholic amino acids:

They are amino acids having an alcoholic or hydroxyl group.

Ex: serine

Aromatic amino acids:

They possess a cyclic structure with a straight side chain bearing carboxylic and amino group.

Ex: tyrosine

Heterocyclic amino acids:

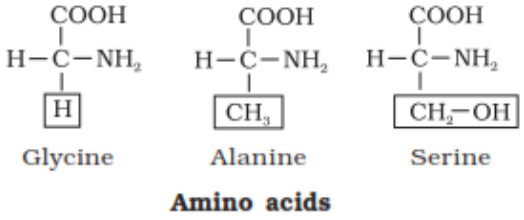
They have nitrogen in the ring structure.

Ex:histidine

Amino acids are organic compounds containing an amino group and an acidic group as substituents on the same carbon i.e., the alpha carbon. Hence, they are called alpha-amino acids. They have substituted methanes. Four substituent groups are occupying the four valency positions.

These are hydrogen, carboxyl group, amino group, and a variable group designated as R group. Based on the nature of the R group there are many amino acids. However, those which occur in proteins are only of twenty types. The R group in these proteinaceous

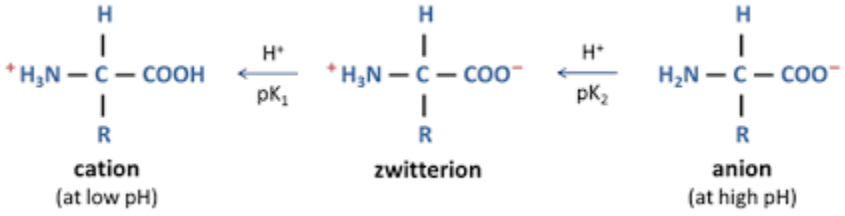
amino acids could be hydrogen(the amino acid is called glycine), a methyl group (alanine), hydroxymethyl(serine), etc.

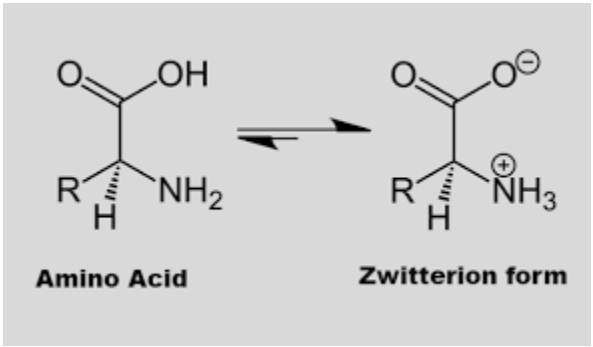


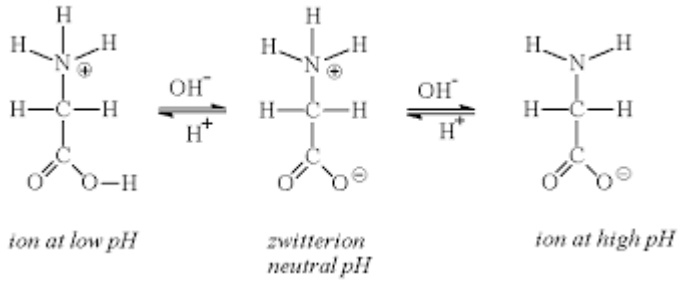
Amino acids

The chemical and physical properties of amino acids are essential for the amino, carboxyl, and the R functional groups. Based on the number of amino and carboxyl groups, there are acidic (e.g., glutamic acid), basic(lysine), and neutral (valine) amino acids. Similarly, there are aromatic amino acids (tyrosine, phenylalanine, tryptophan).

A particular property of amino acids is the ionizable nature of –NH and –COOH groups. Hence in solutions of different pH, the structure of amino acid changes.

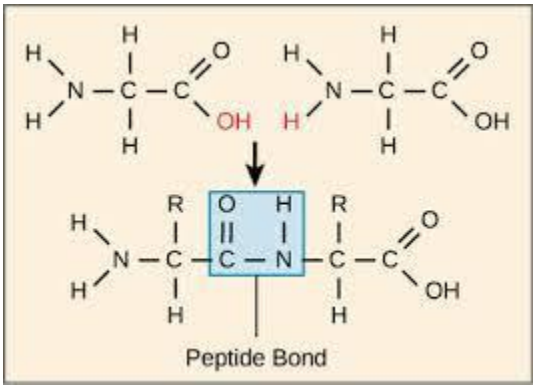






Peptide formation

A peptide bond is a chemical bond formed between two molecules when the carboxyl group of one molecule reacts with the amino group of the other molecule, releasing a molecule of water (H2O).



The function of amino acids

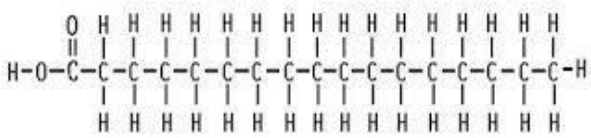
They are building blocks of proteins and enzymes.

Storage of nitrogen occurs in the form of amides.

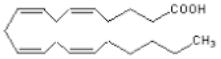
Lipids (Gk. Lipos-fat)

Lipids are generally water-insoluble. They could be simple fatty acids. A fatty acid has a carboxyl group attached to an R group. The R group could be a methyl (–CH), or ethyl (–CH) or a higher number of –CHgroups (1 carbon to 19 carbons).

For example, palmitic acid has 1 carbon including carboxyl carbon. Arachidonic acid has 20 carbon atoms including the carboxyl carbon.



Plamitic acid



Arachidonic acid

Fatty acids could be saturated (without double bond) or unsaturated (with one or more C=C double bonds).

Differences between saturated fats and unsaturated fats

Saturated fats

- Found mostly in animals
- Solid at room temperature

  Eg. Butter
- Fatty acid chains are straight

Unsaturated fats

- Found mostly in vegetables
- Liquid at room temperature

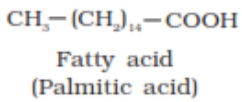
  Eg. Olive oil
- Fatty acid chains are bent in some places

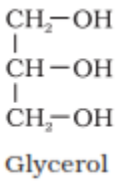
Another simple lipid is glycerol which is trihydroxy propane. Many lipids have both glycerol and fatty acids. Here the fatty acids are found esterified with glycerol. They can be then monoglycerides, diglycerides, and triglycerides.

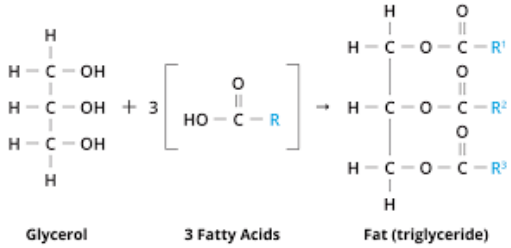
These are also called fats and oils based on the melting point. Oils have a lower melting point (e.g., gingelly oil) and hence remain as oil in winters.

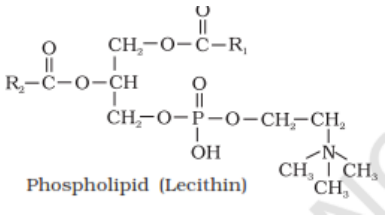
Some lipids have a phosphorous and phosphorylated organic compound in them. These are phospholipids. They are found in the cell membrane.

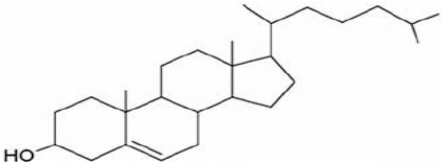
Lecithin is one example. Some tissues especially the neural tissues have lipids with more complex structures.











Classification of lipids

Primary and Secondary metabolites

Cells of a living organism are made of thousands of organic compounds. Besides these, many molecules are formed during metabolism. The compounds which are produced in or required for metabolism are called metabolites. All metabolites are biomolecules.

Metabolites are macromolecules usually which are involved in many cellular functions such as energy, stimulation, inhibition, protection, etc.

Metabolites are divided into two types, based on their role in cellular activities. A metabolite that is directly involved in physiological functions and helps in growth, reproduction, and maturity is called a primary metabolite.

Amino acids, saccharides, nitrogen bases, cholesterol, etc., are a few examples of primary metabolites. The metabolite which is produced from the primary metabolite and is not directly involved in the physiological functions is known as a secondary metabolite, e.g. pigments, pheromones, antibiotics, alkaloids, etc.

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Table 9.3 Some Secondary Metabolites

Pigments	Carotenoids, Anthocyanins, etc.
Alkaloids	Morphine, Codeine, etc.
Terpenoides	Monoterpenes, Diterpenes etc.
Essential oils	Lemon grass oil, etc.
Toxins	Abrin, Ricin
Lectins	Concanavalin A
Drugs	Vinblastin, curcumin, etc.
Polymeric	Rubber, gums, cellulose

Difference between primary and secondary metabolites

Primary metabolites	Secondary metabolites
They are involved in normal growth, development and reproduction.	They are not directly involved in the normal growth, development and reproduction.
Examples for primary metabolites are carbohydrates , fats and proteins.	Examples for secondary metabolites are alkaloids, tannis, resins, gums and latex etc.
They are not poisonous.	Some of these compounds are poisonous.

Biomacromolecules

Any carbon-containing molecule i.e., organic compounds present in a living cell, is called a biomolecule. Based on the molecular weight, biomolecules are classified into two, namely micromolecules and macromolecules.

Macromolecules are those biomolecules that have a molecular weight structure, of less than 10,000 Dalton (Da). This includes the primary metabolites and secondary metabolites. Macromolecules are acid-soluble and their molecular weights range from 18 to 800 Da.

Macromolecules are biomolecules which are characterized by their acid-insoluble property. Proteins, carbohydrates, lipids, nucleic acids are the macromolecules found in living organisms; they are also called biomacromolecules. They have a molecular weight of more than ten thousand daltons.

However, lipids are an exception. Though lipids have a molecular weight of less than 800 Da, they are classified as biomacromolecules because of their acid-insoluble property. Lipids are not strictly macromolecules.

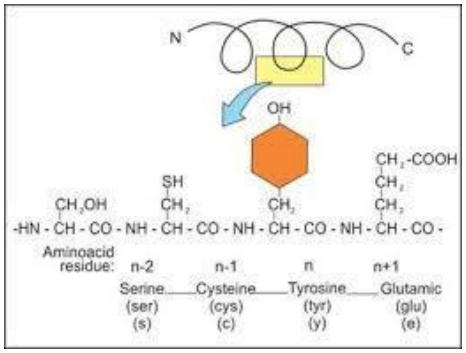
Proteins

Proteins are the most versatile macromolecules in living systems and serve crucial functions in essentially all biological processes. Proteins are variously folded linear heteropolymers of amino acids.

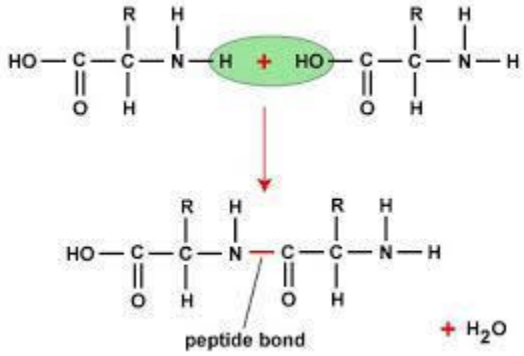
They function as catalysts, they transport and store other molecules such as oxygen, they provide mechanical support and immune protection, they generate movement, they transmit nerve impulses, and they control growth and differentiation.

Peptide bond in protein

A peptide bond is an amide-type of the covalent chemical bond linking two consecutive alpha-amino acids from C1 (carbon number one) of one alpha-amino acid and N2 (nitrogen number two) of another, along with a peptide or protein chain.



(Primary structure of a portion of a hypothetical protein)

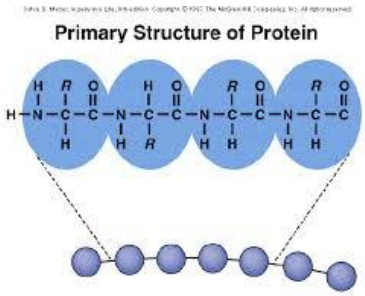


Classification of proteins (based on the structure)

Primary structure

This describes the arrangement of amino acids in polypeptides of a certain protein. This level determines the number, kind, and arrangement of the amino acids forming a protein. Amino acids, as their name indicates, contain both a basic amino group and an acidic carboxyl group. This di-functionality allows the individual amino acids to join together in long chains by forming peptide bonds: amide bonds between the -NH2 of one amino acid and the -COOH of another. Sequences with fewer than 50 amino acids are generally referred to as peptides, while the terms protein or polypeptide are used for longer sequences.

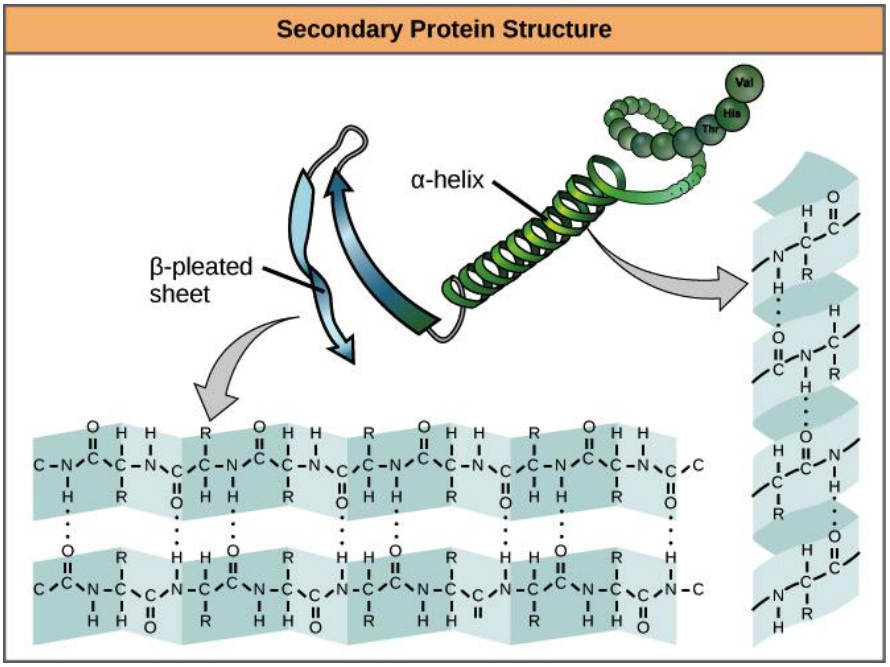
A protein can be made up of one or more polypeptide molecules. The end of the peptide or protein sequence with a free carboxyl group is called the carboxy-terminus or C-terminus. The terms amino-terminus or N-terminus describe the end of the sequence with a free α-amino group.



Secondary structure

The next level of protein structure, **secondary structure**, refers to local folded structures that form within a polypeptide due to interactions between atoms of the backbone. (The backbone just refers to the polypeptide chain apart from the R groups – so all we mean here is that secondary structure does not involve R group atoms.)

The most common types of secondary structures are the α helix and the β pleated sheet. Both structures are held in shape by hydrogen bonds, which form between the carbonyl O of one amino acid and the amino H of another.



In an **α helix**, the carbonyl (C=O) of one amino acid is hydrogen-bonded to the amino H (N-H) of an amino acid that is four down the chain. (E.g., the carbonyl of amino acid 1 would form a hydrogen bond to the N-H of amino acid 5.)

This pattern of bonding pulls the polypeptide chain into a helical structure that resembles a curled ribbon, with each turn of the helix containing 3.6 amino acids. The R groups of the amino acids stick outward from the α helix, where they are free to interact In a **β pleated sheet**, two or more segments of a polypeptide chain line up next to each other, forming a sheet-like structure held together by hydrogen bonds.

The hydrogen bonds form between carbonyl and amino groups of backbone, while the R groups extend above and below the plane of the sheet3. The strands of a β pleated sheet may be **parallel**, pointing in the same direction (meaning that their N- and C-termini match up), or **antiparallel**, pointing in opposite directions (meaning that the N-terminus of one strand is positioned next to the C-terminus of the other).

Certain amino acids are more or less likely to be found in α-helices or β pleated sheets. For instance, the amino acid proline is sometimes called a “helix breaker” because its unusual R group (which bonds to the amino group to form a ring) creates a bend in the chain and is not compatible with helix formation4. Proline is typically found in bends, unstructured regions between secondary structures.

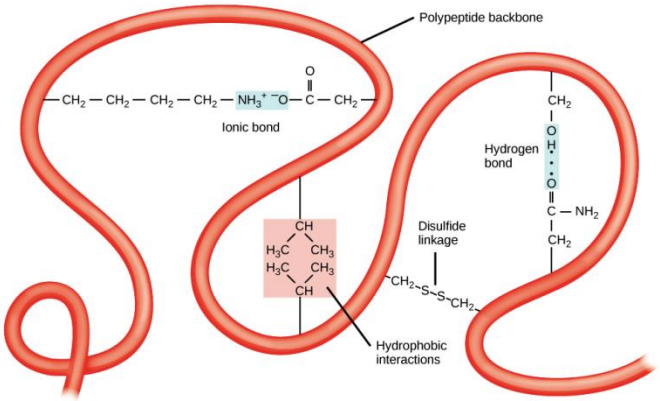
Similarly, amino acids such as tryptophan, tyrosine, and phenylalanine, which have large ring structures in their R groups, are often found in β pleated sheets, perhaps because of the β pleated sheet structure provides plenty of space for the side chains. Many proteins contain both α helices and β pleated sheets, though some contain just one type of secondary structure (or do not form either type).

Tertiary structure

The overall three-dimensional structure of a polypeptide is called its **tertiary structure**. The tertiary structure is primarily due to interactions between the R groups of the amino acids that make up the protein.R group interactions that contribute to the tertiary structure include hydrogen bonding, ionic bonding, dipole-dipole interactions, and London dispersion forces – basically, the whole gamut of non-covalent bonds.

For example, R groups with like charges repel one another, while those with opposite charges can form an ionic bond. Similarly, polar R groups can form hydrogen bonds and other dipole-dipole interactions.

Also important to the tertiary structure are **hydrophobic interactions**, in which amino acids with nonpolar, hydrophobic R groups cluster together on the inside of the protein, leaving hydrophilic amino acids on the outside to interact with surrounding water molecules. Finally, there's one special type of covalent bond that can contribute to tertiary structure: the disulfide bond. **Disulfide bonds**, covalent linkages between the sulfur-containing side chains of cysteines, are much stronger than the other types of bonds that contribute to tertiary structure. They act like molecular "safety pins," keeping parts of the polypeptide firmly attached.

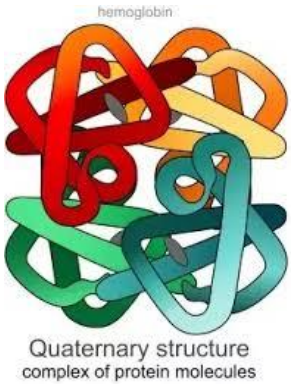


Quaternary structure

Many proteins are made up of a single polypeptide chain and have only three levels of structure (the ones we've just discussed). However, some proteins are made up of multiple polypeptide chains, also known as subunits.

When these subunits come together, they give the protein its **quaternary structure**. We've already encountered one example of a protein with quaternary structure: haemoglobin. As mentioned earlier, haemoglobin carries oxygen in the blood and is made up of four subunits, two each of the α and β types.

Another example is DNA polymerase, an enzyme that synthesizes new strands of DNA and is composed of ten subunits general, the same types of interactions that contribute to tertiary structure (mostly weak interactions, such as hydrogen bonding and London dispersion forces) also hold the subunits together to give quaternary structure.



Summary of Protein Structure

Linderstrom-Lang (1952) in particular first suggested a hierarchy of protein structure with four levels: central, secondary, tertiary, and quaternary. You are already familiar with this hierarchy because the most useful starting point for teaching basic protein structure is this structural grouping.

The **primary structure** of the protein is the hierarchy's basic level and is the particular linear sequence of amino acids comprising one polypeptide chain.

The secondary structure is the next level up from the primary structure and is the regular folding of regions into specific structural patterns within one polypeptide chain. Hydrogen bonds between the carbonyl oxygen and the peptide bond amide hydrogen are normally held together by secondary structures.

Tertiary structure is the next level up from the secondary structure and is the particular three-dimensional arrangement of all the amino acids in a single polypeptide chain. This structure is

usually conformational, native, and active, and is held together by multiple noncovalent interactions.

Quaternary structure is the next 'step up' between two or more polypeptide chains from the tertiary structure and is the specific spatial arrangement and interactions.

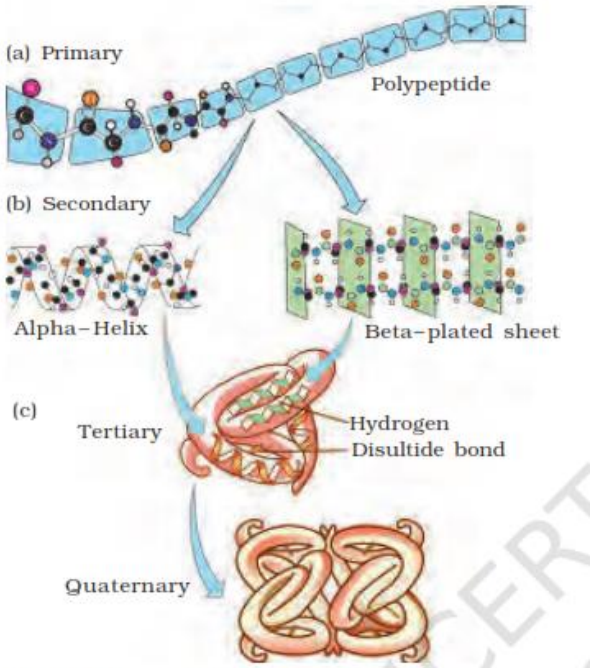


Figure 9.3 Various levels of Protein Structure

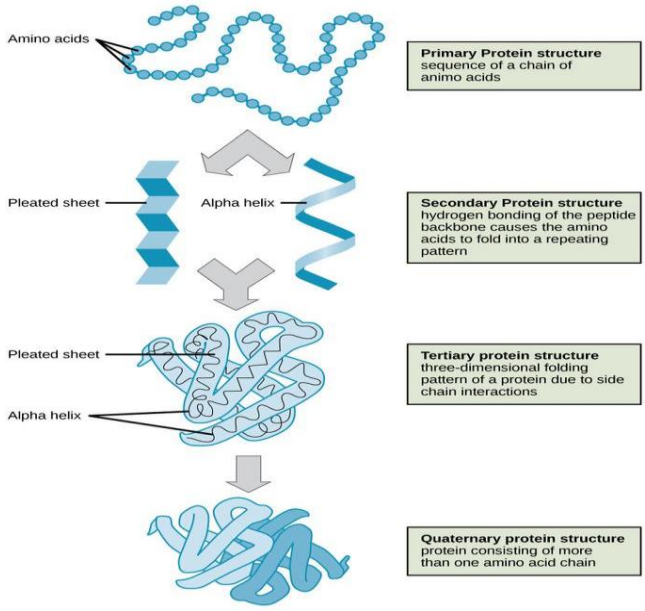
Difference between primary, secondary and tertiary proteins

The **main difference** between the primary secondary and tertiary structure of the protein is that **the primary structure of a protein is linear and the secondary structure of a protein can be either an α-helix or β-sheet whereas the tertiary structure of a protein is globular**.

Primary, secondary, tertiary, and quaternary are the four structures of proteins found in nature. The primary structure comprises the amino acid sequence. Hydrogen bonds formed between amino acids are responsible for the formation of the secondary structure of a protein while disulfide and salt bridges form the tertiary structure.

PRIMARY VS SECONDARY VS TERTIARY STRUCTURE OF PROTEIN

PRIMARY STRUCTURE	SECONDARY STRUCTURE	TERTIARY STRUCTURE
Linear sequence of amino acids	Folding of the peptide chain into an α-helix or β-sheet	Three-dimensional structure of a protein
Linear	Either an α-helix or β-sheet	Globular
Composed of peptide bonds formed between amino acids	Encompasses hydrogen bonds	Encompasses disulfide bridges, salt bridges, and hydrogen bonds
Formed during translation	Forms collagen, elastin, actin, myosin, and keratin-like fibers	Includes enzymes, hormones, albumin, globulin, and hemoglobin
Involved in post-translational modifications	Involved in forming structures such as cartilages, ligaments, skin, etc.	Involved in the metabolic functions of the body



Similarities between Primary, Secondary and Tertiary Structure of Protein

Primary, secondary, and tertiary structures are three, structural arrangements of proteins.

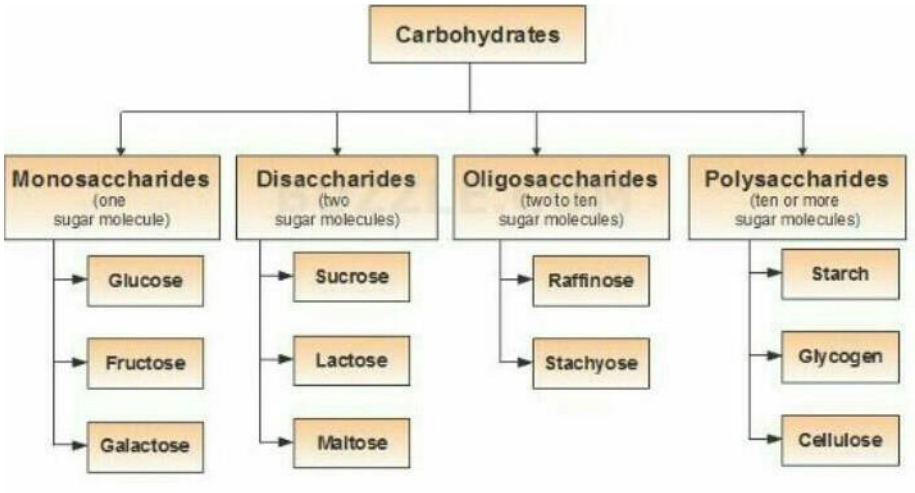
The basic unit of all of the structures is the amino acid sequence, which is the primary structure of the protein.

The secondary structure of the protein is formed from its primary structure, which in turn forms the tertiary structure.

Each type of structure has a unique role in the cell.

Carbohydrates

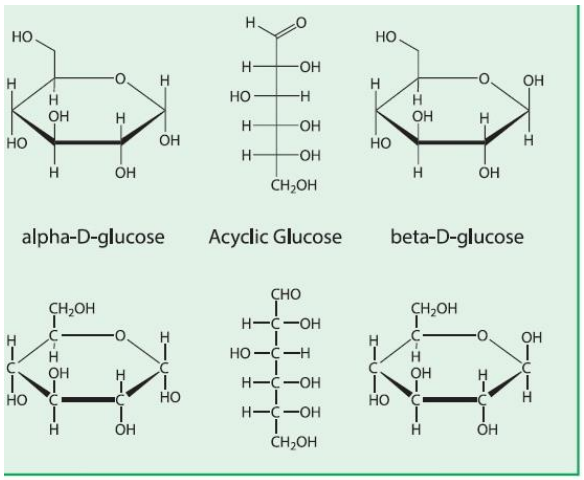
Polymers of monosaccharides and are branched or unbranched linear molecular chains.



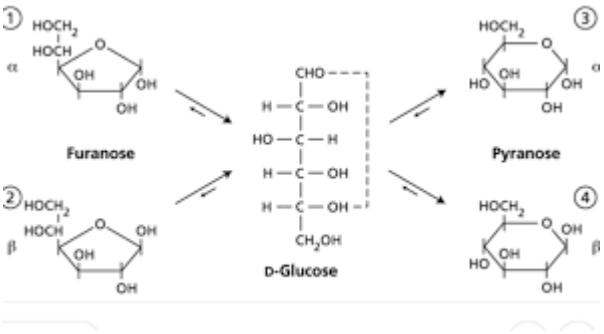
Monosaccharides These are any of the class of sugars (e.g. glucose) that cannot be hydrolyzed to give a simpler sugar.

Types of Mono Saccharides

On the basis of Number of Carbon		On the Basis of Functional Group			
Carbon Atom		Aldehyde	Examples	Ketone	Examples
n=3, $C_6(H_2O)_6$	triose	Aldo triose	Glycerose	Keto triose	Dihydroxyaceton
n=4, $C_4(H_2O)_4$	tetrose	Aldo tetrose	Erythros	Keto tetrose	Erythrulose
n=5, $C_5(H_2O)_5$	pentose	Aldo pentose	Ribose, Xylose	Keto pentose	Ribulose, Xylulose
n=6, $C_6(H_2O)_6$	hexose	Aldo hexose	Glucose, Galactose, Mannose	Keto hexose	Fructose
n=7, $C_7(H_2O)_7$	heptose	Aldo heptose	Glucoheptulose, Galactoheptulose	Keto heptose	Pseudoheptulose

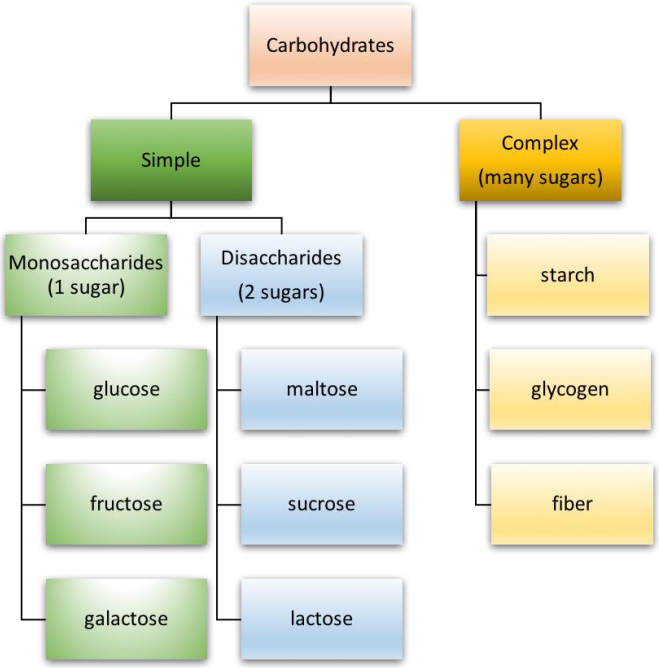


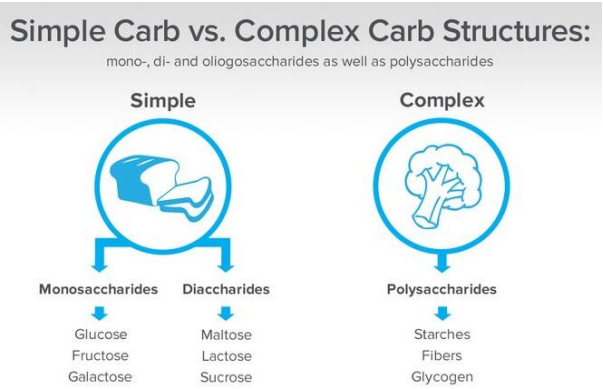
Structure of Glucose



Complex carbohydrates are present in foods such as bread and pasta. Simple carbohydrates are in foods such as table sugar and syrups.

Complex carbohydrates contain longer chains of sugar molecules than simple carbohydrates. The body converts these sugar molecules into glucose, which it uses for energy.

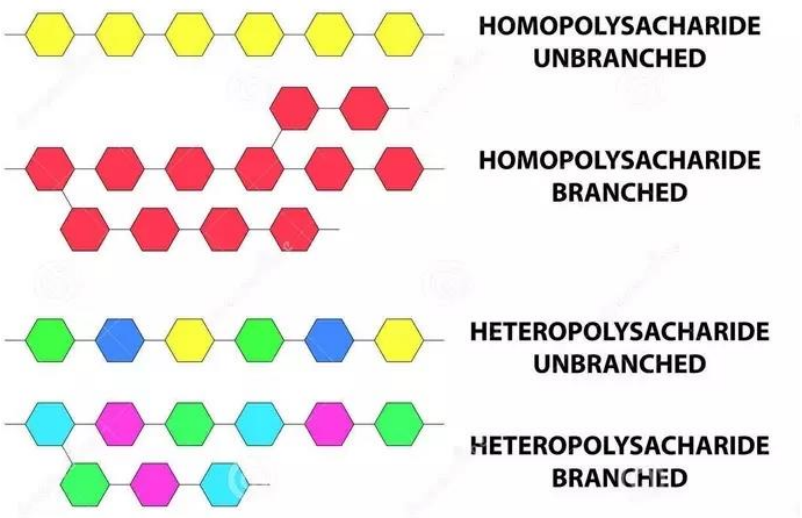




Classification of Polysaccharides: Based on the type of Monosaccharide present

Homopolysaccharides — only one type of monosaccharide present *e.g.* starch, glycogen and cellulose, fructan, xylan, arabinan.

Heteropolysaccharides — more than one type of monosaccharide present e.g. chitin, agar, arabinogalactans, arabinoxylan, etc.



Complex polysaccharides contain amino sugars and chemically modifies sugars (e.g., glucosamine, N-acetyl galactosamine, etc.).

Classification of Polysaccharides: Based on their Function

Polysaccharides can also be categorized as — storage (e.g. starch and glycogen), **structural** *(e.g.* chitin, cellulose), and **mucopolysaccharides***(e.g.* keratin sulfate, chondroitin sulfate, hyaluronic acid, agar, alginic acid, carrageen, and heparin).

Their formation requires the removal of many molecules of water from monosaccharides. This helps in condensing the bulk to be stored. Unlike small carbohydrates, polysaccharides are relatively easy to store. When necessary polysaccharides are broken down by enzymes for the release of energy.

Storage Polysaccharides - act as food storage polysaccharides

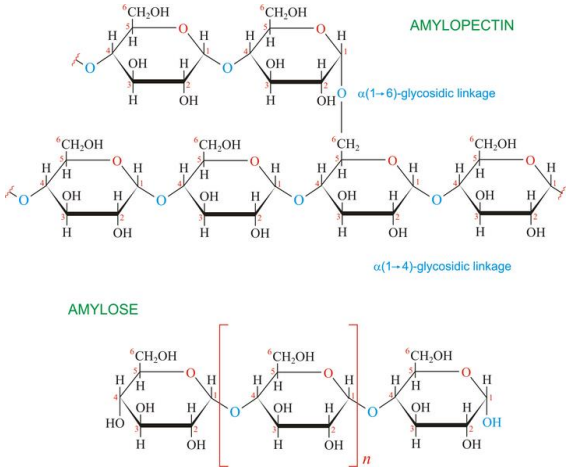
Starch

The polymer of glucose.

Major reserve food in plants.

Starch has two components **— amylase** (an unbranched polymer- the straight chain of 200 -1000 glucose units; 1-4 glycosidic linkage between a - D glucose molecules.) and **amylopectin**(a branched polymer -2000 – 200,000 glucose molecules branched after 25 glucose units; branching point has 1-6 glycosidic linkage.)

found abundantly in rice, wheat, and other cereal grains legumes, potato, tapioca and bananas



Glycogen

Animal equivalent of starch; fungi also store it. Glycogen turns red-violet with iodine. It consists of 30,000 glucose units joined by a, 1 - 4 bonds, much more branched than starch. The branching point has a, 1 - 6 linkage, branching occurs after 10 - 14 glucose units.

found in liver and muscles stores energy in mammals

Inulin

Unusual polysaccharide (a polymer of fructose). It is used as fructose, particularly in roots and tubers *(e.g. Dahlia* tubers), dietary fibre; used as a prebiotic agent to stimulate the growth of good intestinal bacteria.

Structural Polysaccharides -

important components of cell wall & cell membrane.

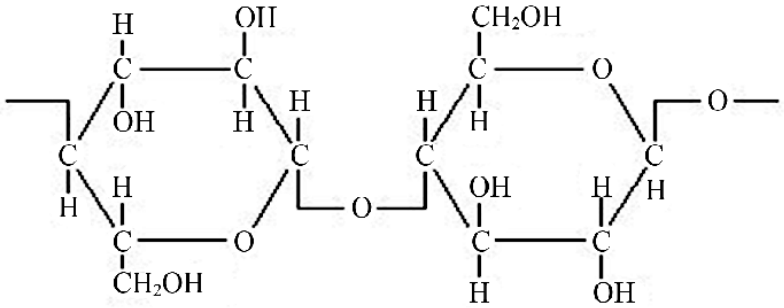
Cellulose

Main structural unbranched homopolysaccharide of plants.

Cellulose is the most abundant organic compound in the biosphere

One molecule of cellulose has about 6000 glucose residues.

Used for building the cell wall**.** Wood and cotton contain large quantities of cellulose.



Cellulose

Chitin

similar to cellulose but its basic unit is not glucose, but a nitrogen-containing similar molecule (N-acetylglucosamine) (NAG).

A polysaccharide found **in the exoskeletons** of fungi, insects & crustaceans.

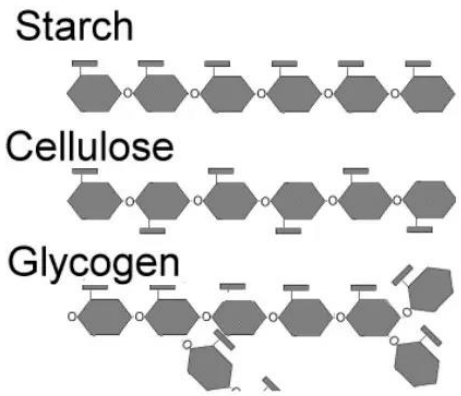
Soft and leathery, it becomes hard when impregnated with calcium carbonate or certain proteins.

Insoluble- helps to retain the form and to strengthen the structure of organisms.

Pectin and hemicellulose

Made up of**arabinose, galactose, and galacturonic acid.**

.Pectic acid is an acidic polysaccharide Of the methyl ester of D—galacturonic acid



Importance of carbohydrates

1.The chief source of energy

2.Important structural components in animal and plant cells.

3.An important part of nucleic acids free nucleotides and coenzymes.

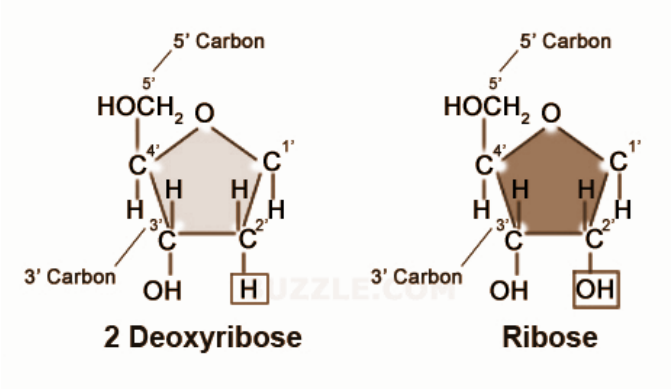
4. Major antigens are carbohydrates in nature,e.gblood group substance.

5.Biological role as a part of hormones and their receptors and enzymes.

Nucleic Acid

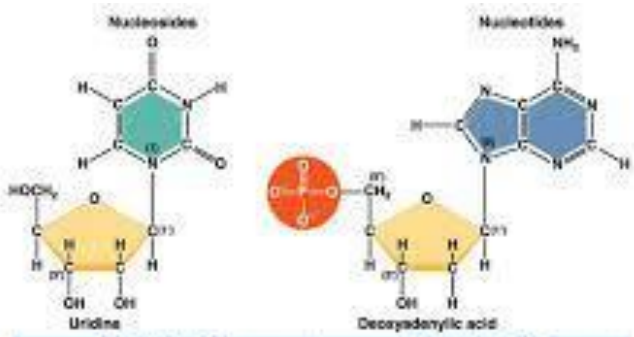
Nucleic acids are long-chain polymeric molecules. The monomer or the repeating unit is known as the nucleotides and hence sometimes nucleic acids are referred to as polynucleotides. Nucleic acids can be defined as organic molecules present in living cells.

It plays a key factor in transferring genetic information from one generation to the next. Nucleic acids comprise of DNA-deoxyribonucleic acid and RNA-ribonucleic acid that form the polymers of nucleotides.



In the nucleus, nucleotide monomers are linked together comprising of distinct components namely a Phosphate Group, Nitrogenous Bases or Ribose and Deoxyribose. Pyrimidines and Purines are two types of nitrogenous bases.

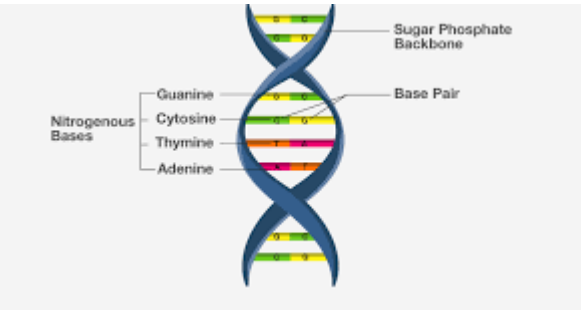
Pyrimidines are composed of cytosine and thymine. Purines are composed of guanine and adenine. Thymine is replaced by Uracil in ribonucleic acid whereas deoxyribonucleic acid comprises of all four bases.



Ribonucleosides	Ribonucleotides
Adenosine Cytidine Guanosine Uridine	Adenylic acid Cytidylic acid Guanylic acid Uridylic acid
Deoxyribonucleosides	**Deoxyribonucleotides**
Deoxyadenosine Deoxycytidine Deoxyguanosine Deoxythymidine	Deoxyadenylic acid Deoxycytidylic acid Deoxyguanylic acid Deoxythymidylic acid

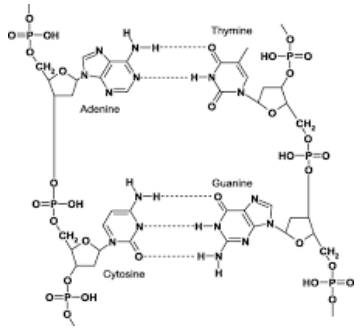
DNA Structure

DNA consists of instructions that monitor the performance of all cell functions. It is a cellular molecule that is organized into chromosomes. They are present in the nucleus of the cells and contain cellular activities.



It is a double helix formed by 2 polynucleotide chains that are twisted. There are 2 strands of DNA which are parallel to each other. Hydrogen bond binds two helices and the bases are bundled within the helix. Due to the presence of phosphate groups, DNA is negatively charged.

Chemically, DNA is composed of a pentose sugar, phosphoric acid, and some cyclic bases containing nitrogen. The sugar moiety present in DNA molecules is β-D-2-deoxyribose. The cyclic bases that have nitrogen in them are adenine (A), guanine (G), cytosine(C), and thymine (T). These bases and their arrangement in the molecules of DNA play an important role in the storage of information from one generation to the next one.



(molecular structure of DNA)

DNA —The Thread of Life: Watson-Crick Model, Characteristics

DNA is the largest macromolecule that represents the genetic material of the cell.
Chemically, DNA is a double helix of two antiparallel polynucleotide chains. Each polynucleotide chain is a linear mixed polymer of four deoxyribotides i.e. deoxyadenylate, deoxyguanylate, deoxycytidylate, and thymidylate.

Watson-Crick model of DNA:

In 1953, J.D. Watson (an American biologist) and F.H.C. Crick (a British Physicist) proposed the three-dimensional model of physiological DNA (i. e B-DNA) based on X-ray diffraction data of DNA obtained by Franklin and Wilkins. For this epoch-making discovery, Watson, Crick, and Wilkins got Nobel Prize in medicine in 1962. Term DNA was given by Zacharias.

The important features of the Watson – Crick Model or double helix model of DNA are as follows:

- The DNA molecule consists of two polynucleotide chains or strands that spirally twisted around each other and coiled around a common axis to form a right-handed double-helix.
- The two strands are antiparallel i.e. they ran in opposite directions so that the 3' end of one chain facing the 5' end of the other.
- The sugar-phosphate backbones remain on the outside, while the core of the helix contains the purine and pyrimidine bases.
- The two strands are held together by hydrogen bonds between the purine and pyrimidine bases of the opposite strands.
- . Adenine (A) always pairs with thymine (T) by two hydrogen bonds and guanine (G) pairs with cytosine (C) by three hydrogen bonds. This complimentarily is known as the base-pairing rule. Thus, the two strands are complementary to one another.
- The base sequence along a polynucleotide chain is variable and a specific sequence of bases carries the genetic information.
- The base compositions of DNA obey Chargaff s rules (E.E. Chargaff, 1950) according to which A=T and G=C; as a corollary ∑ purines (A+G) = 2 pyrimidines (C+T); also (A+C) = (G+T). It also states that the ratio of (A+T) and (G+C) is constant for a species (range 0.4 to 1.9)
- The diameter of DNA is 20nm or 20 A. Adjacent bases are separated 0.34 nm or by 3.4 A along the axis. The length of a complete turn of helix is 3.4 nm or 34 A i.e. there are 10bp per turn. (B- DNA-Watson rick DNA)
- The DNA helix has a shallow groove called minor groove (-1,2nm) and a deep groove called major groove (- 2.2nm) across.

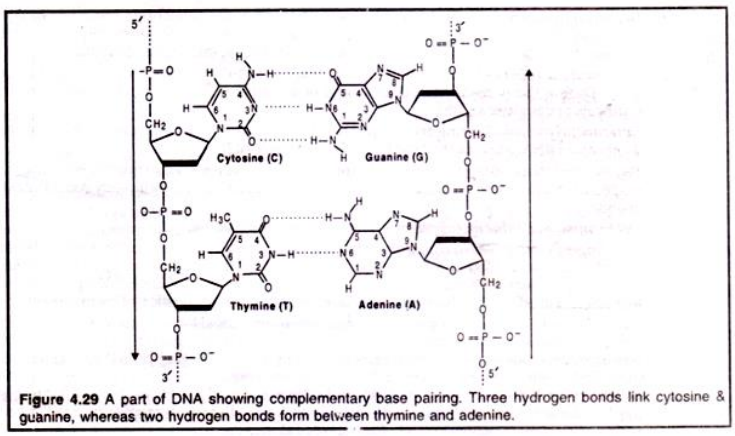


Figure 4.29 A part of DNA showing complementary base pairing. Three hydrogen bonds link cytosine & guanine, whereas two hydrogen bonds form between thymine and adenine.

Some other characteristics of DNA

- The amount of DNA per nucleus is constant in all the somatic cells of a given species.

- The total amount of DNA in a haploid genome is a characteristic of each organism and is known as C-value.
- Only a small fraction of DNA is functional in eukaryotes.
- DNA is the chemical basis of heredity and is organized into genes or cistrons.
- DNA replicates to form DNAs and transcribes to form RNAs.
- DNA replication occurs in the S-phase of the cell cycle.
- DNA replication is semi-conservative in which two daughter DNA molecules formed; each receives one of parental strand and one new strand.
- One strand of DNA directs the synthesis called a template strand, or antisense, or a non-coding strand. The other strand is called coding or non-template of sense strand which has the same sequence as the RNA transcript except for T in place of U.
- DNA has many repeated base sequences, some of which are mobile.
- DNA can easily undergo denaturation (melting) and renaturation with any change in pH, temperature, and salt concentration. DNA with a high G+ G content is more resistant to thermal melting than A + T rich molecules.
- DNA can be synthesized in vitro (in the laboratory).
- DNA can be measured by the unit picogram (lpg= 10 g)

RNA Structure

RNA plays a vital role in the synthesis of proteins that mainly involves decoding and translation of genetic code and transcription to produce proteins.

The RNA molecule is also composed of phosphoric acid, a pentose sugar, and some cyclic bases containing nitrogen. RNA has β-D-ribose in it as the sugar moiety. The heterocyclic bases present in RNA are adenine (A), guanine (G), cytosine(C), and uracil (U).

In RNA the fourth base is different from that of DNA. The RNA generally consists of a single strand which sometimes folds back.

There are several different types of RNA and each has a specific function.

Ribosomal RNA– It is one of the components of ribosomes that are involved in protein synthesis.

Transfer RNA– It is essential for the translation of mRNA in protein synthesis.

Messenger RNA– It is the RNA transcript that is produced during DNA transcription.

Functions of Nucleic Acids

- Nucleic Acid is responsible for the synthesis of protein in our body

- RNA is a vital component of protein synthesis.
- Loss of DNA content is linked to many diseases.
- DNA is an essential component required for transferring genes from parents to offspring.
- All the information of a cell is stored in DNA.
- DNA fingerprinting is a method used by forensic experts to determine paternity. It is also used for the identification of criminals. It has also played a major role in studies regarding biological evolution and genetics.

The dynamic state of body constituents-concept of metabolism

Metabolism

Metabolism is defined as the total amount of the biochemical reactions involved in maintaining the living conditions of the cells in an organism. All living organisms require energy for different essential processes and for producing new organic substances.

The entire process of nutrition has two main parts- ingestion of food and utilization of food for energy. In every living organism, let it be a simple prokaryotic bacterial cell or a eukaryotic cell, the process of nutrition is the same.

The concept of metabolic reactions concentrates on the utilization of food for energy. Ingested food needs to be utilized for the turnover. Nutrition is the key and energy extraction is the target of metabolism. The dynamic state of body constituents and the concept of **metabolism** are discussed below in detail.

Concept of Metabolism

Metabolism is the total of all the chemical reactions taking place in the cells of the living organisms. This involves both breaking and making of biomolecules. Catabolism and anabolism are two types of metabolism.

Catabolism (breaking of bonds) involves the breaking of biomolecules while anabolism (making of bonds) is the building of new compounds required by the cells.

The food which we eat happens to be useless until and unless it undergoes metabolic changes. During metabolism, **biomolecules** present in the food get utilized to extract the energy from the cell. Besides, conversion and formation of the biomolecules take place.

In other words, the transformation of one compound results in the formation of another molecule. For example, the proteins we obtained from the food are metabolized into amino acids, which are later utilized to synthesize another protein required by the cell.

All metabolic changes take place in multiple reactions and follow a particular pathway called the metabolic pathway. The metabolic pathway includes a series of reactions.

The metabolite flow, the rate, and direction at which metabolism takes place are called the dynamic state of body constituents. All metabolic reactions are catalyzed by a set of proteinaceous compounds called enzymes.

Hence, metabolism is an enzyme-catalyzed reaction that provides biomolecules, needed by the cells, for growth, maintenance, and repair, etc. Let us summarize the purposes of metabolic pathways in the below three points:

To extract energy from the food for cellular activities.

To convert food to building blocks, to synthesize biomolecules such as carbohydrates, proteins, lipids, and nucleic acids.

To eliminate waste and toxic products.

Metabolic basis for living

Metabolic pathways can lead to a more complex structure from a simpler structure (for example, acetic acid becomes cholesterol) or lead to a simpler structure from a complex structure (for example, glucose becomes lactic acid in our skeletal muscle). The former cases are called biosynthetic pathways or anabolic pathways.

The latter constitute degradation and hence are called catabolic pathways. Anabolic pathways, as expected, consume energy. Assembly of a protein from amino acids requires energy input. On the other hand, catabolic pathways lead to the release of energy. For example, when glucose is degraded to lactic acid in our skeletal muscle,

energy is liberated. This metabolic pathway from glucose to lactic acid which occurs in 10 metabolic steps is called glycolysis. Living organisms have learned to trap this energy liberated during degradation and store it in the form of chemical bonds.

As and when needed, this bond energy is utilized for biosynthetic, osmotic, and mechanical work that we perform. The most important form of energy currency in living systems is the bond energy in a chemical called adenosine triphosphate (ATP).

The living state

At this level, you must understand that the tens and thousands of chemical compounds in a living organism, otherwise called metabolites, or biomolecules, are present at concentrations characteristic of each of them.

For example, the blood concentration of glucose in a normal healthy individual is 4.2 mmol/L–6.1 mmol/L, while that of hormones would be nanograms/mL. The most important fact of biological systems is that all living organisms exist in a steady-state characterized by concentrations of each of these biomolecules.

These biomolecules are in metabolic flux. Any chemical or physical process moves spontaneously to equilibrium. The steady-state is a non-equilibrium state. One should remember from physics that systems at equilibrium cannot perform work. As living organisms work continuously, they cannot afford to reach equilibrium.

Hence the living state is a non-equilibrium steady-state to be able to perform work; the living process is a constant effort to prevent falling into equilibrium. This is achieved by energy input. Metabolism provides a mechanism for the production of energy. Hence the living state and metabolism are synonymous. Without metabolism, there cannot be a living state.

Enzymes

The human body is composed of different types of cells, tissues, and other complex organs. To function efficiently, there are certain chemicals released by our body to speed up the biological processes like digestion, respiration, excretion, and other metabolic activities to maintain a healthy life. Thus, enzymes play an important role in all living organisms by regulating all the biological processes.

What Are Enzymes?

"Enzymes can be defined as biological polymers that catalyze biochemical reactions."
The vast majority of enzymes are proteins with catalytic capabilities that are essential for maintaining various life processes. Metabolic processes and other chemical reactions in the cell are carried out by a set of enzymes that are necessary to sustain life.

The initial stage of the metabolic process depends upon the enzymes, which react with a molecule and is called the substrate. Enzymes convert the substrates into other distinct molecules and are called the products.

The regulation of enzymes has been a key element in clinical diagnosis because of their role in maintaining life processes. The macromolecular component of all enzymes consists of protein, except in the class of RNA catalysts called ribozymes.

The word ribozyme is derived from the ribonucleic acid enzyme. Many ribozymes are molecules of ribonucleic acid which catalyze reactions in one of their bonds or among other RNAs.

Enzymes exist in all fluids and tissues of the body. Intracellular enzymes catalyze all the reactions that occur in metabolic pathways.

The enzymes in the plasma membrane regulate catalysis in the cells in response to cellular signals and enzymes in the circulatory system regulate clotting of blood. Almost all the significant life processes are based on the enzyme functions.

Enzyme Structure

Enzymes are a linear chain of amino acids that generate the three-dimensional structure. The sequence of amino acids enumerates the structure, which in turn identifies the catalytic activity of the enzyme. The structure of the enzyme denatures when heated, leading to loss of enzyme activity, which is typically connected to the temperature.

Enzymes are larger than their substrates, and their size varies, which range from sixty-two amino acid residues to an average of two thousand five hundred residues present within fatty acid synthase.

Only a small section of the structure is involved in catalysis and is situated next to binding sites. The catalytic site and binding site together constitute the enzyme's active site. A small number of ribozymes exist which serve as an RNA-based biological catalyst. It reacts in complex with proteins.

Chemical Reactions

Chemical compounds undergo two types of changes. A physical change simply refers to a change in shape without breaking of bonds.

This is a physical process. Another physical process is a change in the state of matter: when the ice melts into water, or when water becomes a vapour. These are also physical processes. However, when bonds are broken and new bonds are formed during transformation, this will be called a chemical reaction.

For example $Ba(OH)2 + H2SO4 \rightarrow BaSO4 + 2H2O$ is an inorganic chemical reaction. Similarly, hydrolysis of starch into glucose is an organic chemical reaction. The rate of a physical or chemical process refers to the amount of product formed per unit time.

It can be expressed as rate $=\delta P/\delta t$

The rate can also be called velocity if the direction is specified. Rates of physical and chemical processes are influenced by temperature among other factors. A general rule of thumb is that rate doubles or decreases by half for every 10°C change in either direction.

Catalyzed reactions proceed at rates vastly higher than that of uncatalyzed ones. When enzyme-catalyzed reactions are observed, the rate would be vastly higher than the same but uncatalyzed reaction.

For example CO_2 + H_2O → H_2CO_3

carbon dioxide water carbonic acid .

In the absence of an enzyme, this reaction is very slow, with about 200 molecules of H2CO being formed in an hour. However, by using the enzyme present within the cytoplasm called carbonic anhydrase, the reaction speeds dramatically with about 600,000 molecules being formed every second.

The enzyme has accelerated the reaction rate by about 10 million times. The power of enzymes is incredible indeed!3 There are thousands of types of enzymes each catalyzing a unique chemical or metabolic reaction. A multistep chemical reaction, when each of the steps is catalyzed by the same enzyme complex or different enzymes, is called a metabolic pathway.

For example Glucose → 2 Pyruvic acid

$C_6H_{12}O_6 + O_2 \rightarrow 2C_3H_4O_3 + 2H_2O$

is a metabolic pathway in which glucose becomes pyruvic acid through ten different enzymes catalyzed metabolic reactions. When you study respiration in Chapter 14 you will study these reactions.

At this stage, you should know that this very metabolic pathway with one or two additional reactions gives rise to a variety of metabolic end products. In our skeletal muscle, under anaerobic conditions, lactic acid is formed.

Under normal aerobic conditions, pyruvic acid is formed. In yeast, during fermentation, the same pathway leads to the production of ethanol (alcohol). Hence, in different conditions different products are possible.

How do Enzymes bring about such High Rates of Chemical Conversions?

To understand this we should study enzymes a little more. We have already understood the idea of an ‘active site’. The chemical or metabolic conversion refers to a reaction. The chemical which is converted into a product is called a ‘substrate’.

Hence enzymes, i.e. proteins with three-dimensional structures including an ‘active site’, convert a substrate (S) into a product (P). Symbolically, this can be depicted as:S→P It is now understood that the substrate ‘S’ has to bind the enzyme at its ‘active site’ within a given cleft or pocket. The substrate has to diffuse towards the ‘active site’.

There is thus, an obligatory formation of an 'ES' complex. E stands for the enzyme. This complex formation is a transient phenomenon. During the state where the substrate is bound to the enzyme active site, a new structure of the substrate called transition state structure is formed.

Very soon, after the expected bond breaking/making is completed, the product is released from the active site. In other words, the structure of the substrate gets transformed into the structure of the product(s).

The pathway of this transformation must go through the so-called transition state structure. There could be many more 'altered structural states' between the stable substrate and the product.

Implicit in this statement is the fact that all other intermediate structural states are unstable. Stability is something related to the energy status of the molecule or the structure.

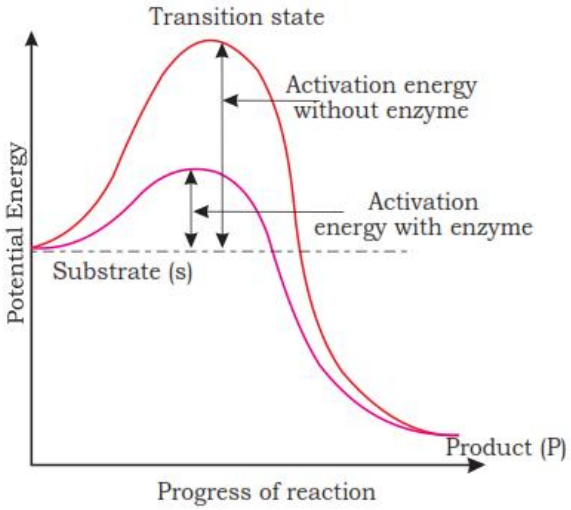


Figure 9.6 Concept of activation energy

The y-axis represents the potential energy content. The x-axis represents the progression of the structural transformation or states through the 'transition state'. You would notice two things. The energy level difference between S and P. If 'P' is at a lower level than 'S', the reaction is exothermic. One need not supply energy (by heating) to form the product.

However, whether it is an exothermic or spontaneous reaction or an endothermic or energy-requiring reaction, the 'S' has to go through a much higher energy state or transition state.

The difference in the average energy content of 'S' from that of this transition state is called 'activation energy'. Enzymes eventually bring down this energy barrier making the transition of 'S' to 'P' easier.

Activation Energy:

Most of the chemical reactions do not start automatically because the reactant molecules have an energy barrier to become reactive.

The energy barrier may be on account of:
(i) Mutual repulsion due to the presence of electrons over their surfaces,
(ii) Solvation or holding of reactants in solution form by hydrogen bonds,
(iii) Reaction sites of the reactive molecules being small, precise collisions do not occur.

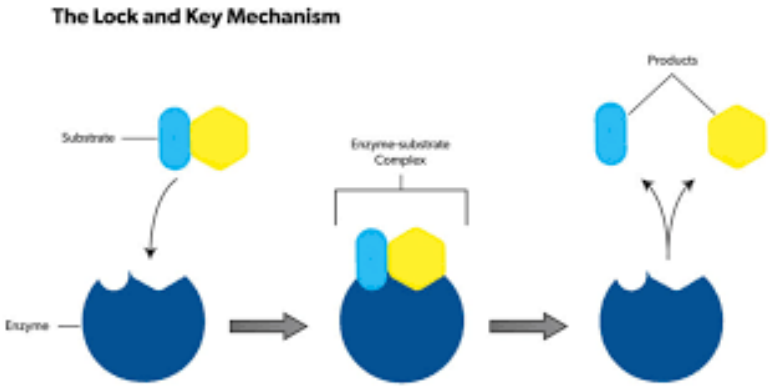
Therefore, an external supply of energy is needed for the start of the chemical reaction. It is called activation energy. Activation energy increases the kinetic energy of the system and brings about forceful collisions between the reactants. The requirements for colouration, energy are quite high. For example, acidic hydrolysis of sucrose requires 32000 cal/ mole of energy.

Nature of enzyme action

Lock and Key Theory:

The specific action of an enzyme with a single substrate can be explained using a **Lock and Key** analogy first postulated in 1894 by Emil Fischer. In this analogy, the lock is the enzyme and the key is the substrate. Only the correctly sized **key (substrate) fits** into the **keyhole (active site)** of the **lock (enzyme)**.

Smaller keys, larger keys, or incorrectly positioned teeth on keys (incorrectly shaped or sized substrate molecules) do not fit into the lock (enzyme). Only the correctly shaped key opens a particular lock.



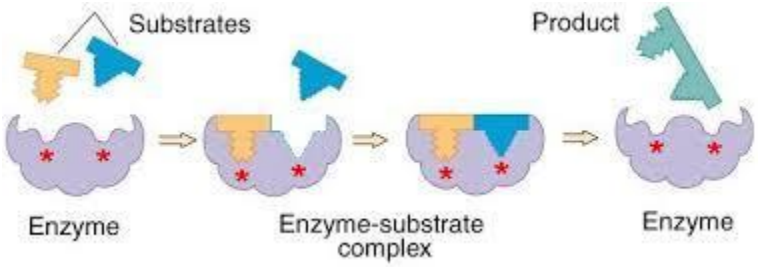
Induced Fit Theory:

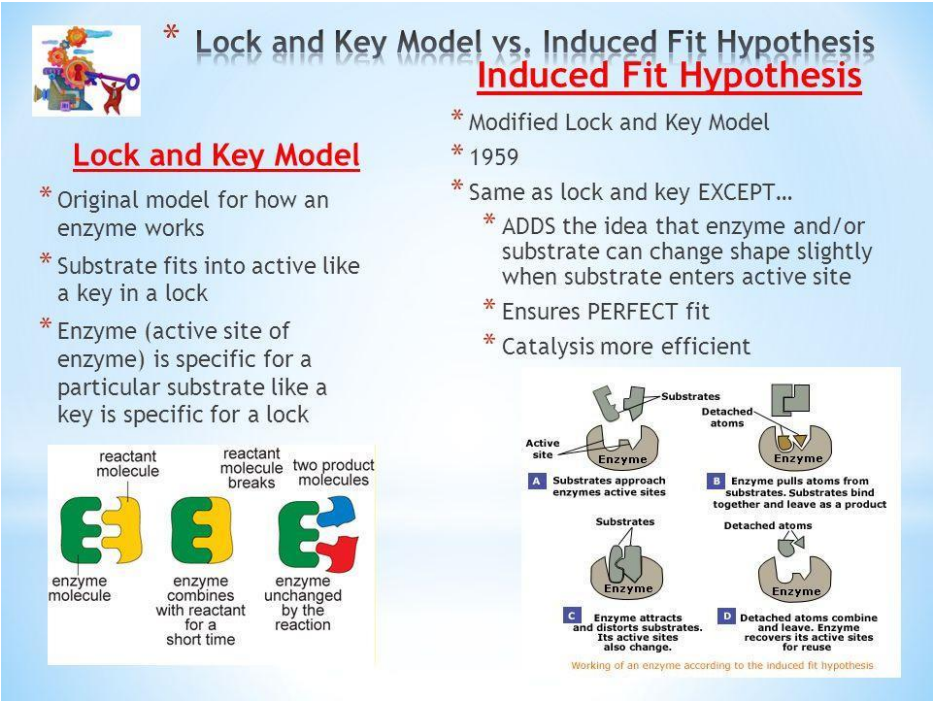
Not all experimental evidence can be adequately explained by using the so-called rigid enzyme model assumed by the lock and key theory. For this reason, a modification called the induced-fit theory has been proposed(Koshland in 1959).

The induced-fit theory assumes that the substrate plays a role in determining the final shape of the enzyme and that the enzyme is partially flexible. This explains why certain compounds can bind to the enzyme but do not react because the enzyme has been distorted too much.

Other molecules may be too small to induce the proper alignment and therefore cannot react. Only the proper substrate is capable of inducing the proper alignment of the active site.

In the graphic on the left, the substrate is represented by the magenta molecule, the enzyme protein is represented by the green and cyan colors. The cyan coloured protein is used to more sharply define the active site. The protein chains are flexible and fit around the substrate


Substrates
Product
Enzyme
Enzyme-substrate complex
Enzyme


* Lock and Key Model vs. Induced Fit Hypothesis
Lock and Key Model
* Original model for how an enzyme works
* Substrate fits into active like a key in a lock
* Enzyme (active site of enzyme) is specific for a particular substrate like a key is specific for a lock
reactant molecule
reactant molecule breaks
two product molecules
enzyme molecule
enzyme combines with reactant for a short time
enzyme unchanged by the reaction
Induced Fit Hypothesis
* Modified Lock and Key Model
* 1959
* Same as lock and key EXCEPT…
* ADDS the idea that enzyme and/or substrate can change shape slightly when substrate enters active site
* Ensures PERFECT fit
* Catalysis more efficient
Substrates
Active site
Enzyme
A Substrates approach enzymes active sites
Detached atoms
B Enzyme pulls atoms from substrates. Substrates bind together and leave as a product
C Enzyme attracts and distorts substrates. Its active sites also change.
D Detached atoms combine and leave. Enzyme recovers its active sites for reuse
Working of an enzyme according to the induced fit hypothesis

Each enzyme (E) has a substrate (S) binding site in its molecule so that a highly reactive enzyme-substrate complex (ES) is produced. This complex is short-lived and dissociates into its product(s) P and the unchanged enzyme with an intermediate formation of the enzyme-product complex (EP).

The formation of the ES complex is essential for catalysis.

$E + S \Leftrightarrow ES \rightarrow EP \rightarrow E + P$

The catalytic cycle of enzyme action can be described in the following

steps:

- First, the substrate binds to the active site of the enzyme, fitting into the active site.
- The binding of the substrate induces the enzyme to alter its shape, fitting more tightly around the substrate.
- The active site of the enzyme, now nearby of the substrate breaks the chemical bonds of the substrate, and the new enzyme- product complex is formed.
- The enzyme releases the products of the reaction and the free enzyme is ready to bind to another molecule of the substrate and run through the catalytic cycle once again.

Factors Affecting Enzyme Activity

The conditions of the reaction have a great impact on the activity of the enzymes. Enzymes are particular about the optimum conditions provided for the reactions such as temperature, pH, alteration in substrate concentration, etc.

Generally, an increase in temperature increases the activity of enzymes. Because enzymes function in cells, the optimum conditions for most enzymes are moderate temperatures. At elevated temperatures, at a certain point activity decreases dramatically when enzymes are denatured. Purified enzymes in diluted solutions are denatured more rapidly than enzymes in crude extracts. Incubation of enzymes for long periods may also denature enzymes. It is more suitable to use a short incubation time to measure the initial velocities of the enzyme reactions.

The International Union of Biochemistry recommends 30 °C as the standard assay temperature. Most enzymes are very sensitive to changes in pH. Only a few enzymes function optimally below pH 5 and above pH 9. The majority of enzymes have their pH-optimum close to neutrality. The change in pH will change the ionic state of amino acid residues in the active site and the whole

protein. The change in the ionic state may change substrate binding and catalysis. The choice of substrate concentration is also crucial because, at low concentrations, the rate is dependent on the concentration, but at high concentrations, the rate is independent of any further increase in substrate concentration.

Temperature and pH

Enzymes generally function in a narrow range of temperature and pH (Figure 9.7). Each enzyme shows its highest activity at a particular temperature and pH called the optimum temperature and optimum pH. Activity declines both below and above the optimum value. Low temperature preserves the enzyme in a temporarily inactive state whereas high temperature destroys enzymatic activity because proteins are denatured by heat.

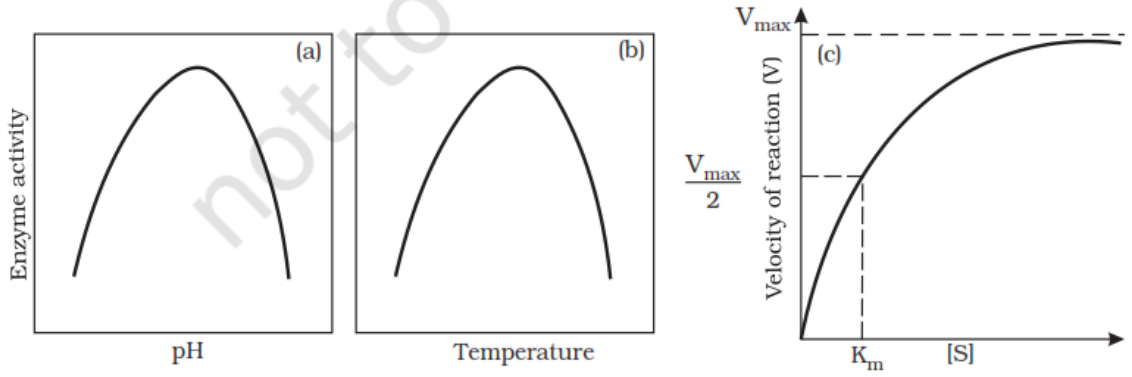


Figure 9.7 Effect of change in : (a) pH (b) Temperature and (c) Concentration of substrate on enzyme activity

Concentration of Substrate

With the increase in substrate concentration, the velocity of the enzymatic reaction rises at first. The reaction ultimately reaches a maximum velocity(V) which is not exceeded by any further rise in the concentration of the substrate. This is because the enzyme molecules are fewer than the substrate molecules and after saturation of these molecules, there are no free enzyme molecules to bind with the additional substrate molecules (Figure 9.7)

The activity of an enzyme is also sensitive to the presence of specific chemicals that bind to the enzyme. When the binding of the chemical shuts off enzyme activity, the process is called **inhibition,** and the chemical is called an inhibitor. When the inhibitor closely resembles the substrate in its molecular structure and inhibits the activity of the enzyme, it is known as

a competitive inhibitor. Due to its close structural similarity with the substrate, the inhibitor competes with the substrate for the substrate-binding site of the enzyme. Consequently, the substrate cannot bind and as a result, the enzyme action declines, e.g., inhibition of succinic dehydrogenase by malonate which closely resembles the substrate succinate in structure. Such competitive inhibitors are often used in the control of bacterial pathogens.

Classification nomenclature of enzymes

In older times enzymes were classified into two broad categories:

(i) Hydrolyzing:

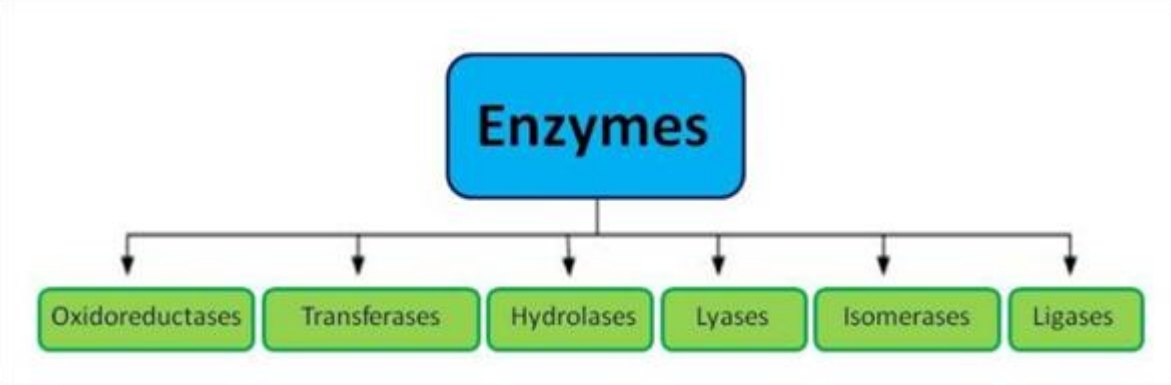
Catalyzing hydrolysis of larger molecules into smaller ones, e.g., carbohydrates or amylases, proteases, lipases, esterases, phosphorylases, amidases. Digestive enzymes are hydrolyzing in nature. They are often grouped into three types— proteolytic, amylolytic and lipolytic,

(ii) Desmolysing:

Catalyzing reactions other than hydrolysis, e.g., aldolases, dehydrogenases, oxidases, peroxidases, catalases, carboxylases, etc.

According to the International Union of Biochemists (I U B), 1961, enzymes are divided into six functional classes and are classified based on the type of reaction in which they are used to catalyze. The six types of enzymes are oxidoreductases, hydrolases, transferases, lyases, isomerases, ligases.

Following are the enzymes classifications in detail:



Oxidoreductases:

They take part in oxidation and reduction reactions or transfer of electrons.

$$S \text{ reduced} + S' \text{ oxidised} \xrightarrow{\text{oxido reductase}} S \text{ oxidised} + S' \text{ reduced}$$

Oxidoreductases are of three types— oxidases, dehydrogenases, and reductases, e.g., cytochrome oxidase (oxidizes cytochrome), succinate dehydrogenase, nitrate reductase.

$$2AH_2 + O_2 \xrightarrow{\text{oxidase}} 2A + 2H_2O$$

$$AH_2 \xrightarrow{\text{dehydrogenase}} A + 2(H)$$

$$A + 2(H) \xrightarrow{\text{reductase}} AH_2$$

Transferases:

They transfer a group from one molecule to another e.g., glutamate- pyruvate transaminase (transfers amino group from glutamate to pyruvate during the synthesis of alanine). The chemical group transfer does not occur in the Free State.

$$S - G + S' \xrightarrow{\text{transferase}} S + S' - G$$

$$\underset{\text{(amino acid)}}{\text{Glutamic Acid}} + \underset{\text{(organic acid)}}{\text{Oxaloacetic Acid}} \xrightarrow{\text{transferase}} \underset{\text{(organic acid)}}{\alpha\text{-ketoglutaric Acid}} + \underset{\text{(amino acid}}{\text{Aspartic A}}$$

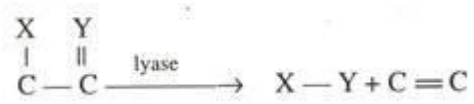
Hydrolases:

They catalyze the hydrolysis of bonds like ester, ether, peptide, glycosidic, C-C, C halide, P—N, etc. which are formed by dehydration condensation. Hydrolases break up large molecules into smaller ones with the help of hydrogen and hydroxyl groups of water molecules. The phenomenon is called hydrolysis. Digestive enzymes belong to this group, e.g., amylase (hydrolysis of starch), sucrase, lactase.

$$\underset{\text{maltose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{maltase}} \underset{\text{glucose}}{2\,C_6H_{12}O_6}$$

Lyases:

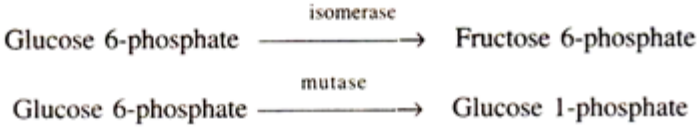
The enzymes cause cleavage, removal of groups without hydrolysis, the addition of groups to double bonds, or removal of a group producing double bond, e.g., histidine decarboxylase (breaks histidine to histamine and CO2), aldolase (fructose-1, 6-diphosphate to dihydroxyacetone phosphate and glyceraldehyde phosphate).



Fructose 1, 6-diphosphate – aldolase → Dihydroxyacetone phosphate + Glyceraldehyde phosphate.

Isomerases:

The enzymes cause rearrangement of molecular structure to effect isomeric changes. They are of three types, isomerases (aldose to ketose group or vice-versa like glucose 6-phosphate to fructose 6-phosphate), epimerases (change in position of one constituent or carbon group like xylulose phosphate to ribulose phosphate) and mutases (shifting the position of side group like glucose-6-phosphate to glucose-1- phosphate).

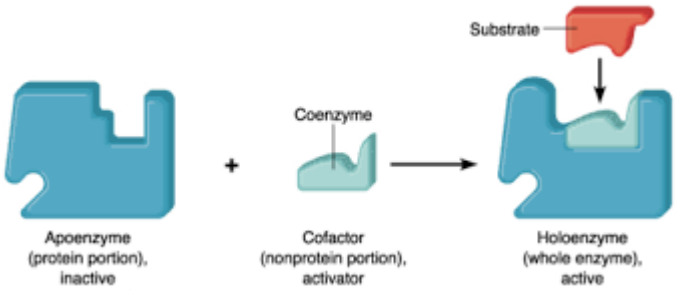


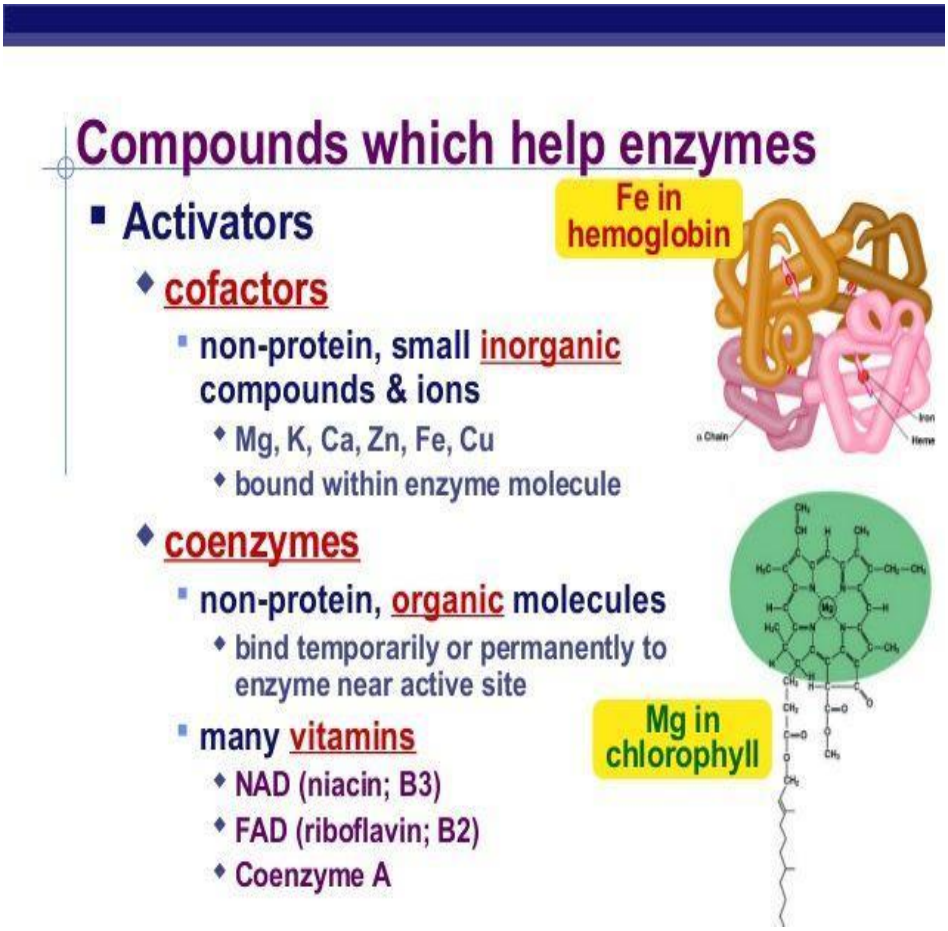
Ligases (Synthetizes):

The enzymes catalyze bonding of two chemicals with the help of energy obtained from ATP resulting in the formation of such bonds as C-O, C-S, C-N, and P-O, e.g., pyruvate carboxylase. It combines pyruvic acid with CO2 to produce oxaloacetic acid.

Cofactors

Cofactors are non-proteinous substances that associate with enzymes. A cofactor is essential for the functioning of an enzyme. An enzyme without a cofactor is called an apoenzyme. An apoenzyme and its cofactor together constitute the holoenzyme.





Difference between coenzyme and cofactor

COENZYME	COFACTOR
Meaning	
It carries chemical groups between enzymes	They bind to an enzyme
Also known as	
Cosubstrates	Helper molecules

Bind	
Coenzyme loosely bound to enzymes	Some cofactors covalently bind the enzyme
Removal	
Can be easily removed	It can be removed only by denaturation
Form	
Chemical molecule	Chemical compound
Characteristic	
Organic substances	Inorganic substances
Types	
It is a type of cofactor	Two types of cofactors: Coenzyme and prosthetic groups
Function	
They act as carriers	Increase the speed of reaction
Examples	
Biotin, Vitamin, Coenzyme A	Metal ions such as k+, Zn 2

There are three kinds of cofactors present in enzymes:

Prosthetic groups: These are cofactors tightly bound to an enzyme at all times. A fad is a prosthetic group present in many enzymes.

Coenzyme: A coenzyme is bound to an enzyme only during catalysis. At all other times, it is detached from the enzyme. NAD is a common coenzyme.

Metal ions: For the catalysis of certain enzymes, a metal ion is required at the active site to form coordinate bonds. Zn2+ is a metal ion cofactor used by some enzymes.

Important terms

Biomolecules	A molecule that is produced by a living organism.
Biomicromolecules	A molecule that is relatively smaller (than a macromolecule), or of low molecular weight that may regulate a biological process
Biomacromolecules	A molecule containing a very large number of atoms, such as a protein, nucleic acid, or synthetic polymer.
Metabolites	Metabolites are the intermediate products produced during metabolism, catalyzed by various enzymes that occur naturally within cells. Eg., antibiotics, and pigments. The term metabolites are usually used for small molecules.
Primary metabolites	These are the chemical compounds produced during the growth and development, processes.
Secondary metabolites	Secondary metabolites also called Specialized Metabolites, secondary products or Natural Products are organic compounds produced by bacteria, fungi, or plants that are not directly involved in the normal growth, or development of the organism.
Amino acids	Amino acids are organic compounds that contain amine and carboxyl functional groups, along with a side chain specific to each amino acid. The key elements of an amino acid are carbon, hydrogen, oxygen, and nitrogen, although other elements are found in the side chains of certain amino acids.
Proteins	Proteins are large biomolecules, or macromolecules, consisting of one or more long chains of amino acid residues
Carbohydrates	A carbohydrate is a biomolecule consisting of carbon, hydrogen, and oxygen atoms, usually with a hydrogen-oxygen atom ratio of 2:1 and thus with the empirical formula C□□. This formula holds for monosaccharides.

Mono-saccharides	Monosaccharides also called a simple sugar, are the simplest form of sugar and the most basic units of carbohydrates. They cannot be further hydrolyzed into simpler chemical compounds.
Poly-saccharides	Polysaccharides are long chains of carbohydrate molecules, specifically polymeric carbohydrates composed of monosaccharide units bound together by glycosidic linkages. This carbohydrate can react with water using amylase enzymes at catalyst, which produces constituent sugars.
Lipids	Any of a class of organic compounds that are fatty acids or their derivatives and are insoluble in water but soluble in organic solvents. They include many natural oils, waxes, and steroids.
Nucleic acid	Nucleic acids are the biopolymers, or large biomolecules, essential to all known forms of life. The term nucleic acid is the overall name for DNA and RNA.
Nucleotides	Nucleotides are organic molecules consisting of a nucleoside and a phosphate. They serve as monomeric units of the nucleic acid polymers deoxyribonucleic acid and ribonucleic acid, both of which are essential biomolecules within all life-forms on Earth
Nucleosides	Nucleosides are glycosylamines that can be thought of as nucleotides without a phosphate group. A nucleoside consists simply of a nucleobase and a five-carbon sugar whereas a nucleotide is composed of a nucleobase, a five-carbon sugar, and one or more phosphate groups.
DNA	Deoxyribonucleic acid is a molecule composed of two polynucleotide chains that coil around each other to form a double helix carrying genetic instructions for the development, functioning, growth, and reproduction of all known organisms and many viruses. DNA and ribonucleic acid are nucleic acids.
RNA	Ribonucleic acid is a polymeric molecule essential in various biological roles in coding, decoding, regulation, and expression of genes. RNA and DNA are nucleic acids. Along with lipids, proteins, and carbohydrates, nucleic acids constitute one of the four major macromolecules essential for all known forms of life.
Enzymes	Enzymes are proteins that act as biological catalysts. Catalysts accelerate chemical reactions. The molecules upon which enzymes may act are called substrates, and the enzyme converts the substrates into different molecules known as products.
Co-factors	A cofactor is a non-protein chemical compound or metallic ion that is required for an enzyme's activity as a catalyst, a substance that

	increases the rate of a chemical reaction. Cofactors can be considered "helper molecules" that assist in biochemical transformations.
Co-enzymes	A non-protein compound that is necessary for the functioning of an enzyme.
Prosthetic group	A non-protein group forming part of or combined with a protein.
Peptide bond	A peptide bond is an amide-type of the covalent chemical bond linking two consecutive alpha-amino acids from C1 of one alpha-amino acid and N2 of another, along a peptide or protein chain.
Glycosidic bond	Aglycosidic bond or glycosidic linkage is a type of covalent bond that joins a carbohydrate (sugar) molecule to another group, which may or may not be another carbohydrate.
Phosphodiester bond	A chemical bond of the kind joining successive sugar molecules in a polynucleotide.
Allosteric enzymes	Allosteric enzymes are enzymes that change their conformational ensemble upon binding of an effector which results in an apparent change in binding affinity at a different ligand binding site
Isoenzymes	Isozymes are enzymes that differ in amino acid sequence but catalyze the same chemical reaction. These enzymes usually display different kinetic parameters or different regulatory properties.