UNIT -2 AMINOACIDS AND PROTEINS

AMINOACIDS

Definition

Amino acid, any of a group of organic molecules that consist of a basic amino group ($-NH_2$), an acidic carboxyl group (-COOH), and an organic R group (or side chain) that is unique to each amino acid. The term amino acid is short for α-amino [alpha-amino] carboxylic acid. Each molecule contains a central carbon (C) atom, called the α-carbon, to which both an amino and a carboxyl group are attached. The remaining two bonds of the α-carbon atom are generally satisfied by a hydrogen (H) atom and the R group. The formula of a general amino acid is:

Amino Acids are the organic compounds that combine to form proteins; hence they are referred to as the building components of proteins. These biomolecules are involved in several biological and chemical functions in the human body and are the necessary ingredients for the growth and development of human beings.

The ingredients present in proteins are amino acids. Both peptides and proteins are long chains of amino acids. Altogether, there are twenty amino acids, which are involved in the construction of proteins.

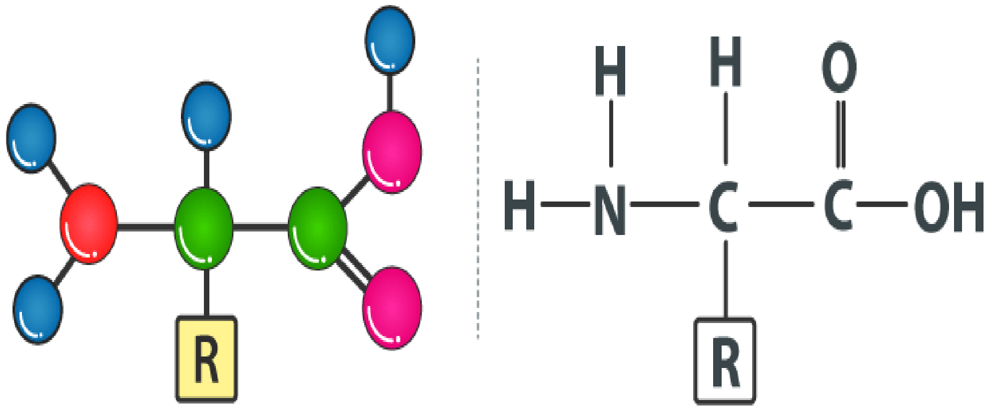
Structure of Amino acids

There are 20 naturally occurring amino acids and all have common structural features – an amino group ($-NH_2$), a carboxylate (-COOH) group and a hydrogen-bonded to the same carbon atom. They differ from each other in their side-chain called the R group. Each amino acid has 4 different groups attached to α- carbon.

These 4 groups are:

- Amino group,
- COOH,
- Hydrogen atom,
- Side chain (R).

The general structure of Amino acids is H_2NCH RCOOH, and it can be written as:



The amino acids differ from each other in the particular chemical structure of the R group.

Listed below are the names of twenty amino acids

Alanine	Cysteine	Leucine	Serine
Aspartic Acid	Glycine	Lysine	Tyrosine
Asparagine	Glutamine	Methionine	Threonine
Arginine	Histidine	Proline	Tryptophan
Cytosine	Isoleucine	Phenylalanine	Valine

General properties of Amino acids

- They have a very high melting and boiling point.
- Amino acids are white crystalline solid substances.
- In taste, few Amino acids are sweet, tasteless, and bitter.
- Most of the amino acids are soluble in water and are insoluble in organic solvents.

Essential and Non-essential Amino acids

Out of 20 amino acids, our body can easily synthesize a few on its own, which are called non-essential amino acids. These include alanine, asparagine, arginine, aspartic acid, glutamic acid, cysteine, glutamine, proline, glycine, serine, and tyrosine.

Apart from these, there are other nine amino acids, which are very much essential as they cannot be synthesized by our body. They are called essential amino acids, and they include isoleucine, histidine, lysine, leucine, phenylalanine, tryptophan, methionine, threonine, and valine.

Deficiency of Amino acids

Amino acids are the building blocks of proteins and proteins play a fundamental role in almost all life processes. Therefore, it is necessary to include all nine essential amino acids in our daily diet to maintain a healthy and proper function of our body. The deficiency of amino acids may include different pathological disorders, including:

- Edema.
- Anaemia.
- Insomnia (sleeplessness).
- Diarrhoea.
- Depression.
- Hypoglycaemia.
- Loss of Appetite.
- Fat deposit in the liver.
- Skin and hair related problems.
- Headache, weakness, irritability, and fatigue

Building blocks of proteins

Proteins are of primary importance to the continuing functioning of life on Earth. Proteins catalyse the vast majority of chemical reactions that occur in the cell. They provide many of the structural elements of a cell, and they help to bind cells together into tissues. Some proteins act as contractile elements to make movement possible. Others are responsible for the transport of vital materials from the outside of the cell to its inside. Proteins, in the form of antibodies, protect animals from disease and, in the form of interferon, mount an intracellular attack against viruses that have eluded destruction by the antibodies and other immune system defences. Many hormones are proteins. Last but certainly not least, proteins control the activity of genes.

Chirality

All the amino acids but glycine is chiral molecules. That is, they exist in two optically active asymmetric forms (called enantiomers) that are the mirror images of each other. One enantiomer is designated D and the other L. It is important to note that the amino acids found in proteins almost always possess only the **L-configuration**. This reflects the fact that the enzymes responsible for protein synthesis have evolved to utilize only the L-enantiomers. Reflecting this near universality, the prefix L is usually omitted. Some D-amino acids are found in microorganisms, particularly in the cell walls of bacteria and in several of the antibiotics. However, these are not synthesized in the ribosome.

Acid-base properties

Another important feature of free amino acids is the existence of both a basic and an acidic group at the α-carbon. Compounds such as amino acids that can act as either an acid or a base are called **amphoteric**. The basic amino group typically has a pKa between 9 and 10, while the acidic α-carboxyl group has a pKa that is usually close to 2. The pKa of a group is the pH value at which the concentration of the protonated group equals that of the unprotonated group. Thus, at physiological pH (about 7–7.4), the free amino acids exist largely as **dipolar ions** or "**zwitterions**".

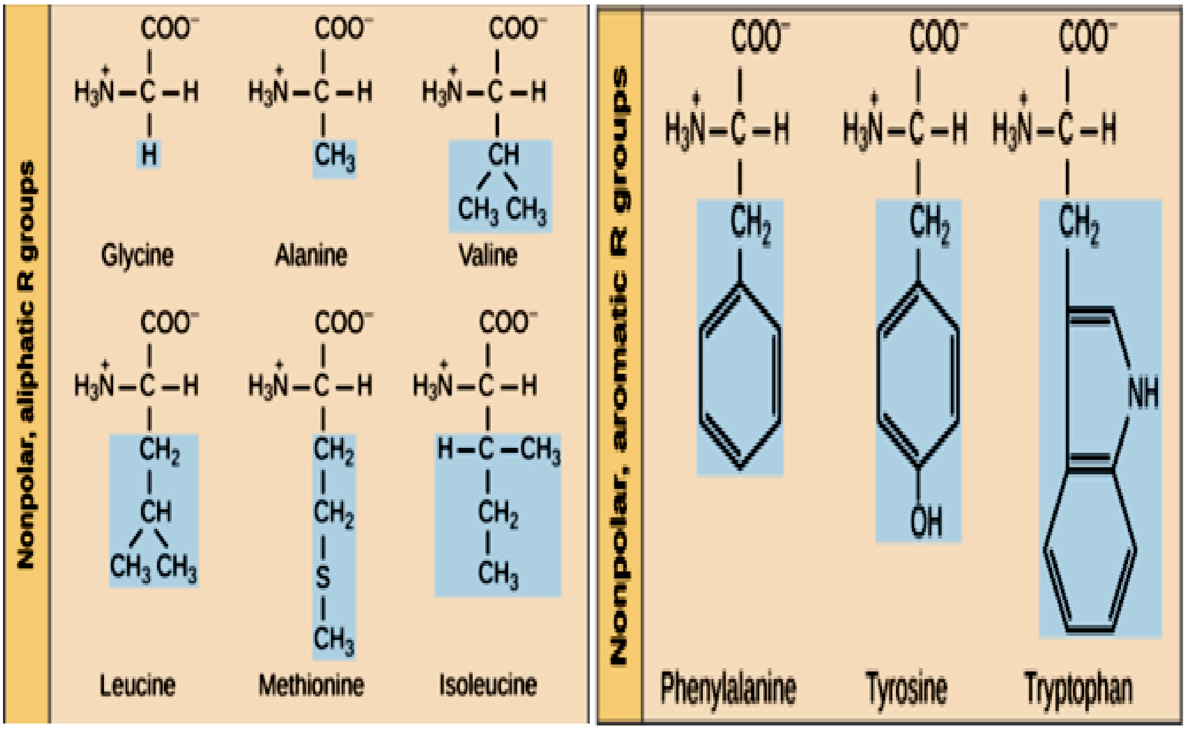
Any free amino acid and likewise any protein will, at some specific pH, exist in the form of a zwitterion. That is, all amino acids and all proteins, when subjected to changes in pH, pass through a state at which there are an equal number of positive and negative charges on the molecule. The pH at which this occurs is known as the **isoelectric point** (or isoelectric pH) and is denoted as pI. When dissolved in water, all amino acids and all proteins are present predominantly in their isoelectric form. Stated another way, there is a pH (the isoelectric point) at which the molecule has a net zero charge (equal number of positive and negative charges), but there is no pH at which the molecule has an absolute zero charge (complete absence of positive and negative charges). That is, amino acids and proteins are always in the form of ions; they always carry charged groups. This fact is vitally important in considering further the biochemistry of amino acids and proteins.

Standard amino acids

One of the most useful manners by which to classify the standard (or common) amino acids is based on the polarity (that is, the distribution of electric charge) of the R group (e.g., side chain).

Group I: Nonpolar amino acids

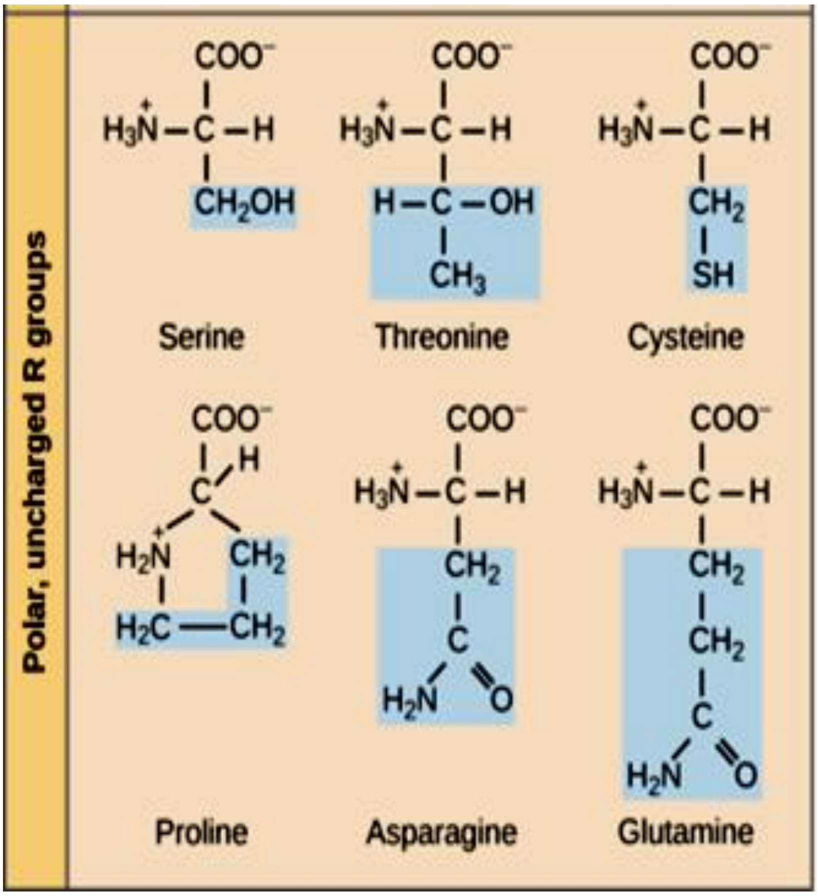
Group I amino acids are glycine, alanine, valine, leucine, isoleucine, phenylalanine, methionine, Tyrosine and tryptophan. The R groups of these amino acids have either aliphatic or aromatic groups. This makes them hydrophobic ("water fearing"). In aqueous solutions, globular proteins will fold into a three-dimensional shape to bury these hydrophobic side chains in the protein interior. The chemical structures of Group I amino acids are:



Isoleucine is an isomer of leucine, and it contains two chiral carbon atoms. Phenylalanine, as the name implies, consists of a phenyl group attached to alanine. Methionine is one of the two amino acids that possess a sulfur atom. Methionine plays a central role in protein biosynthesis (translation) as it is almost always the initiating amino acid. Methionine also provides methyl groups for metabolism. Tryptophan contains an indole ring attached to the alanyl side chain.

Group II: Polar, uncharged amino acids

Group II amino acids are serine, cysteine, threonine, tyrosine, asparagine, proline and glutamine. The side chains in this group possess a spectrum of functional groups. However, most have at least one atom (nitrogen, oxygen, or sulfur) with electron pairs available for hydrogen bonding to water and other molecules. The chemical structures of Group II amino acids are:

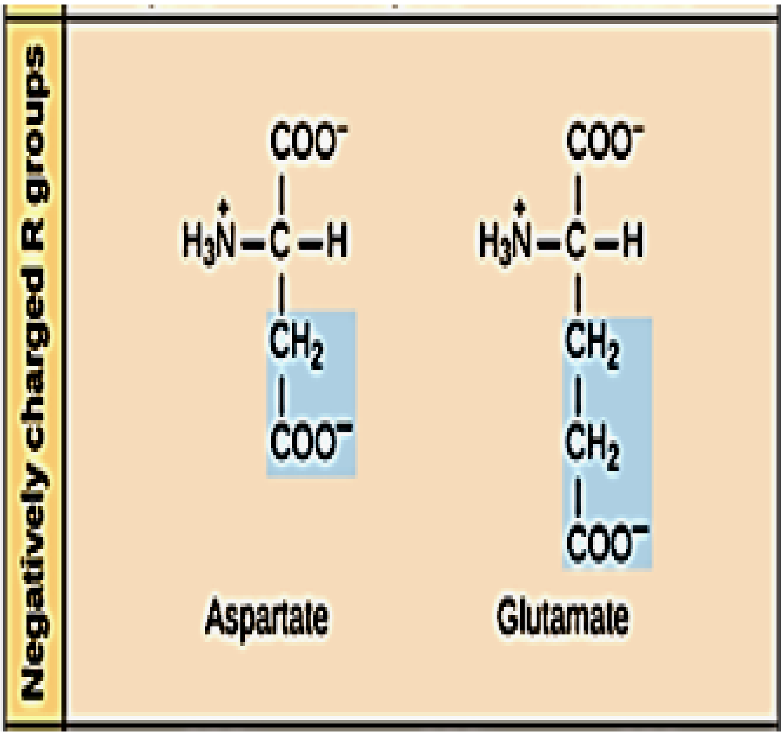


Two amino acids, serine and threonine, contain aliphatic hydroxyl groups Tyrosine possesses a hydroxyl group in the aromatic ring, making it a phenol derivative. The hydroxyl groups in these three amino acids are subject to an important type of post-translational modification: phosphorylation. Like methionine, cysteine contains a sulfur atom. Asparagine, first isolated from asparagus, and glutamine both contain amide R groups. The carbonyl group can function as a hydrogen bond acceptor, and the amino group (NH_2) can function as a hydrogen bond donor.

Proline is unique among the standard amino acids in that it does not have both free α-amino and free α-carboxyl groups. Instead, its side chain forms a cyclic structure as the nitrogen atom of proline is linked to two carbon atoms. (Strictly speaking, this means that proline is not an amino acid but rather an α-imino acid.)

Group III: Acidic amino acids

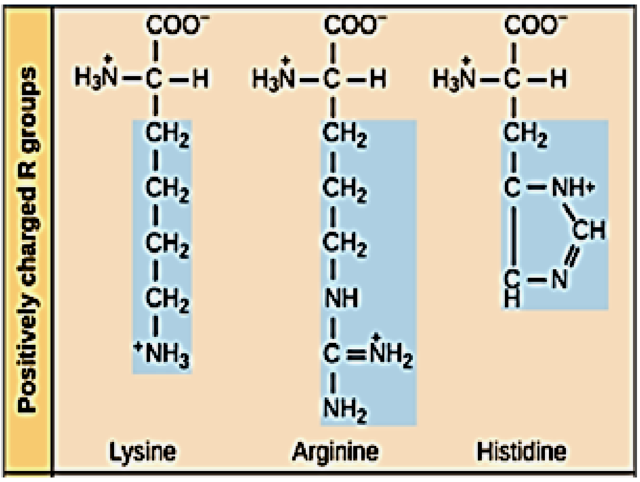
The two amino acids in this group are aspartic acid and glutamic acid. Each has a carboxylic acid on its side chain that gives it acidic (proton-donating) properties. In an aqueous solution at physiological pH, all three functional groups on these amino acids will ionize, thus giving an overall charge of −1. In the ionic forms, the amino acids are called aspartate and glutamate. The chemical structures of Group III amino acids are



The side chains of aspartate and glutamate can form ionic bonds. Free glutamate and glutamine play a central role in amino acid metabolism. Glutamate is the most abundant excitatory neurotransmitter in the central nervous system.

Group IV: Basic amino acids

The three amino acids in this group are arginine, histidine, and lysine. Each side chain is basic. Lysine and arginine both exist with an overall charge of +1 at physiological pH. The guanidino group in arginine's side chain is the most basic of all R groups. As mentioned above for aspartate and glutamate, the side chains of arginine and lysine also form ionic bonds. The chemical structures of Group IV amino acids are



The imidazole side chain of histidine allows it to function in both acid and base catalysis near physiological pH values. None of the other standard amino acids possesses this important chemical property. Therefore, histidine is an amino acid that most often makes up the active sites of protein enzymes.

The majority of amino acids in Groups II, III, and IV are hydrophilic ("water loving"). As a result, they are often found clustered on the surface of globular proteins in aqueous solutions.

Uncommon amino acids and their Functions

In addition to the 20 common amino acids, there are several uncommon ones found:

1. Hydroxylysine and hydroxyproline. These are found in the protein collagen. Collagen is a fibrous protein made up of three polypeptides that form a stable assembly, but only if the proline and lysine residues are hydroxylated.
2. Thyroxine, an iodinated derivative of tyrosine, found in thyroglobulin (produced by thyroid gland; requires iodine in diet).
3. g-carboxyglutamic acid (i.e. glutamic acid with two carboxyl groups) found in certain blood clotting enzymes (requires vitamin K for production).

4. N-methyl arginine and n-acetyl lysine. Found in some DNA binding proteins known as histones.Serotonin (derivative of tryptophan) and g-amino butyric acid (a derivative of glutamic acid) are both neurotransmitters.

5. Histamine (derivative of histidine) involved in allergic response.

6. Adrenaline (derivative of tyrosine) a hormone.

7. Various antibiotics are amino acid derivatives (penicillin).

PROTEINS

The term ‘protein’ is derived from the Greek word - ‘Proteios’ meaning 'primary' or 'holding first place.' Proteins are the chief constituents of all living matter. They contain - C, H, N, and S and sometimes phosphorus also. Proteins are a diverse and abundant class of biomolecules, constituting more than 50% of the dry weight of cells. This diversity and abundance reflect the central role of proteins in virtually all aspects of cell structure and function. Biologically occurring polypeptides range in size from small to very large, consisting of two or three to thousands of linked amino acid residues.

Definition

1. Proteins may be defined as, 'the high molecular weight mixed polymers of α-amino acids, joined together with peptide (-CONH—) linkage.
2. It may also be defined as, 'the complex nitrogenous substances which are found in the all biological systems.

- **CLASSIFICATION OF PROTEINS :**

Proteins can be classified by two ways:

I. According to solubility

II. On the basis of increasing complexity into their structures.

I) **According to solubility:**

According to solubility, proteins are divided into two groups:

1) **Fibrous Proteins:**

These proteins appear like fibres made of linear molecules that are arranged roughly parallel to the fibre axis. The long linear chain proteins are held together by intermolecular hydrogen bonds.

These are highly resistant to digestion by proteolytic enzymes.These are insoluble in common solvents but are soluble in concentrated acids and alkalies.

Fibrous proteins include the proteins of silk, wool, skin, hair, horn, nails, hoofs, quills, connective tissue and bone.

2) **Globular Proteins:**

These are highly branched and cross-linked condensation products of basic or acidic amino acids. The polypeptide chains are held together by cross-linked groups or in an aggregate state. The aggregates may also be folded to three-dimensional structures by weak non-covalent bonds.

These are soluble in water and in dilute acids, alkalies and salts.Globular proteins include all the enzymes, oxygen carrying proteins, protein hormones, etc.

II) **On the Basis of Increasing Complexity into their Structures :**

According to this system of classification, proteins may be divided into three main groups:

1) Simple Proteins:

The simple proteins are those proteins which yield only amino acids on hydrolysis.

a) Albumins: These are -

i. Soluble in water
ii. Coagulated by heat
iii. Precipitated at high salt concentration

Examples - Serum albumin, plasma albumin, egg albumin, lactalbumin, legumelin, etc.

b) Globulins: These are -

i. Insoluble in water
ii. Coagulated by heat
iii. Precipitated by half saturated salt solutions.

Examples - Plasma globulins, serum globulins, vitellin, tuberin, legumin, myosinogen, etc.

c) Glutelins : These are –

i. Insoluble in water
ii. Soluble in acids and bases
iii. Coagulated by heat

Examples - Glutelin (Wheat), Oryzenin (Rice), etc.

d) **Prolamines:** These are -

i. Insoluble in water, but soluble in ethanol [a]
ii. Not coagulated.

Examples - Gliadin (Wheat), Zenin (Maize), etc.

e) Protamines: These are -

i. Soluble in water
ii. Not coagulated by heat

Examples - Salmine (Salmon sperm of fish)

f) Histones : These are -

i. Water soluble
ii. Not coagulated by heat

Examples - Globin of haemoglobin and thymus histones

g) Scleroproteins (albuminoids) : These are water insoluble.

Examples - Keratin (Hair, horn, nail), collagen (Skin, bone tendons), Elastin (ligaments)

2) Conjugated Proteins:

These contain simple protein molecules united with non-protein group and on hydrolysis they yield other non-proteinous substances in addition to amino acids.

The non-proteinous moiety is referred as 'prosthetic group.'

a) Nucleoproteins: Proteins with nucleic acid e.g. Nucleoprotamines and nucleohistones

b) Lipoproteins: Proteins with lipids

e.g. Lipoproteins of egg yolk, milk and cell membranes and lipoptoteins of blood.

c) Glycoproteins: Proteins with carbohydrates e.g. Mucin (Saliva), Ovomucoid (egg yolk), etc.

d) Phosphoproteins: Contain phosphorus radical as prosthetic group.

e.g. Caseinogen (milk), Ovovitellin (egg yolk) etc.

e) Metalloproteins: Contain metal ion as prosthetic group, (i.e. Zn^{++}, Co^{++}, Fe^{++}, Cu^{++}, Mg^{++}, Mn^{++} etc.) e.g. Siderophillin (Fe^{++}), Ceruloplasmin (Cu^{++}) etc.

f) Chromoproteins: Contain porphyrin with a metal ion, as their prosthetic group.

e.g. Haemoglobin, myoglobin, catalase, cytochrome, peroxidase etc.

g) Flavoproteins: Contain riboflavin as prosthetic group e.g. Flavoproteins of liver and kidney.

3) Derived Proteins:

The derived proteins are the intermediate hydrolysis products, which are formed by the action of physical (heat), chemical or enzymatic agents on natural proteins.

a) **Primary derivatives :**

i) Proteans - e.g. fibrin from fibrinogen

ii) Metaproteins - e.g. acid and alkali meta proteins

iii) Coagulated proteins - e.g. cooked- proteins and coagulated albumin.

b) Secondary derivatives

i) Proteoses - e.g. albumose, globumose

ii) Peptones

iii) Peptides - e.g. glycyl-alanine, leucyl-glutamic acid

- **STRUCTURE OF THE PROTEIN MOLECULES**

The structure of protein is considered by the level of organization of the protein molecule, as:

1) Primary structure
2) Secondary structure
3) Tertiary structure
4) Quaternary structure

1) Primary Structure of Proteins

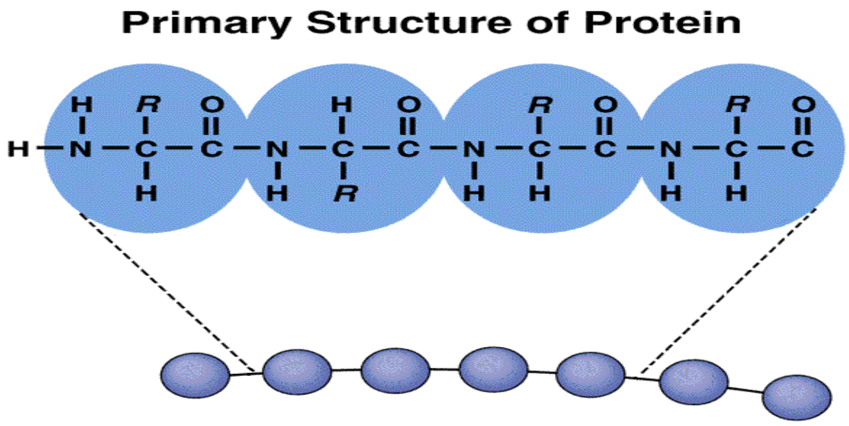
The primary structure of a protein is referred mainly to the number, nature and the sequence of amino acids along the polypeptide chains.

This sequence determines the further levels of organization of the protein molecule

While representing the primary structure:

— The N - terminal amino acid, i.e. amino acid either with free amino group, is always on the left end of the polypeptide chain, and

— The C - terminal amino acid, i.e. amino acid with free - COOH group, at the right end of the chain.



2) **Secondary structure**

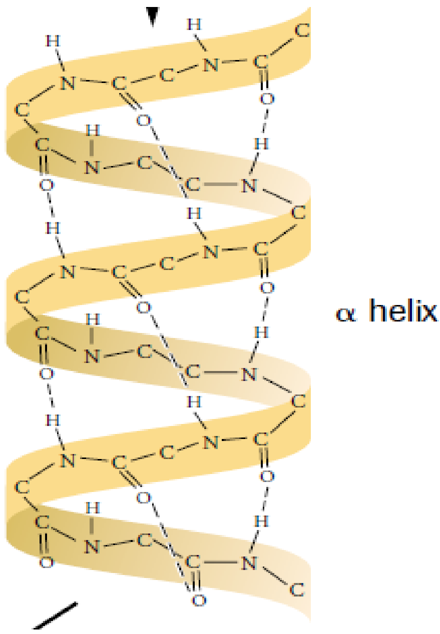
Most long polypeptide chains are folded or coiled in a number of ways. This brings about a second level of organization called the secondary structure. The most common form of coiling is the right handed α- helix,

α- Helical Structure: (Hell-Greek meaning 'sun')

In this helical form, there are 3- 6 amino acid residues per complete turn. The structure is stabilized by intramolecular hydrogen bonding, in such a way that, the N-H group of one amino acid comes into close proximity of the C = O group of the fourth amino acid residue in the peptide chain.

C=0-H-N<

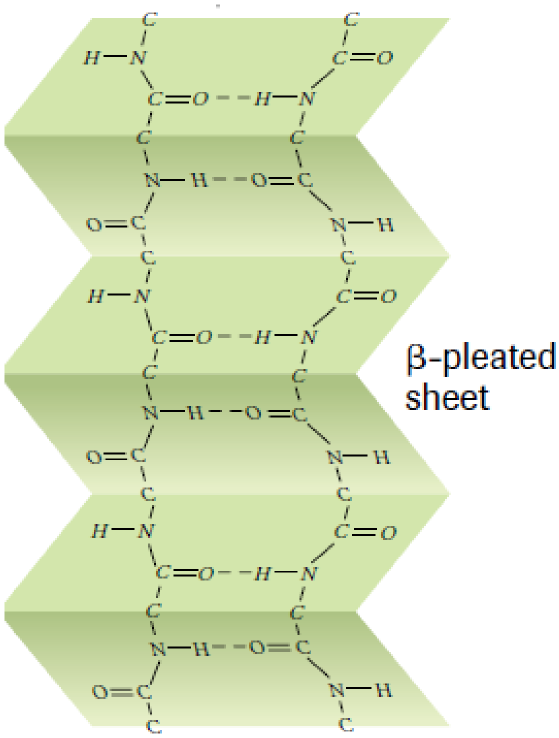
Although the hydrogen bond is fairly weak, the large numbers of bonds involved maintain a stable structure. All the amino acid side chains are accommodated into the cc-helix, since their side chains project away from the coil.



Polypeptide chain in α - helix configuration

β- Pleated sheet:

It is another form of secondary structure. This results from hydrogen bonding between two peptide chains. The chains may be parallel or antiparallel. In a parallel chain (i-pleated sheet, the 'N[1] atoms point is in the same direction while in the antiparallel chain ^-pleated sheet, alternate chains are oriented in the same direction.



β- Pleated sheet

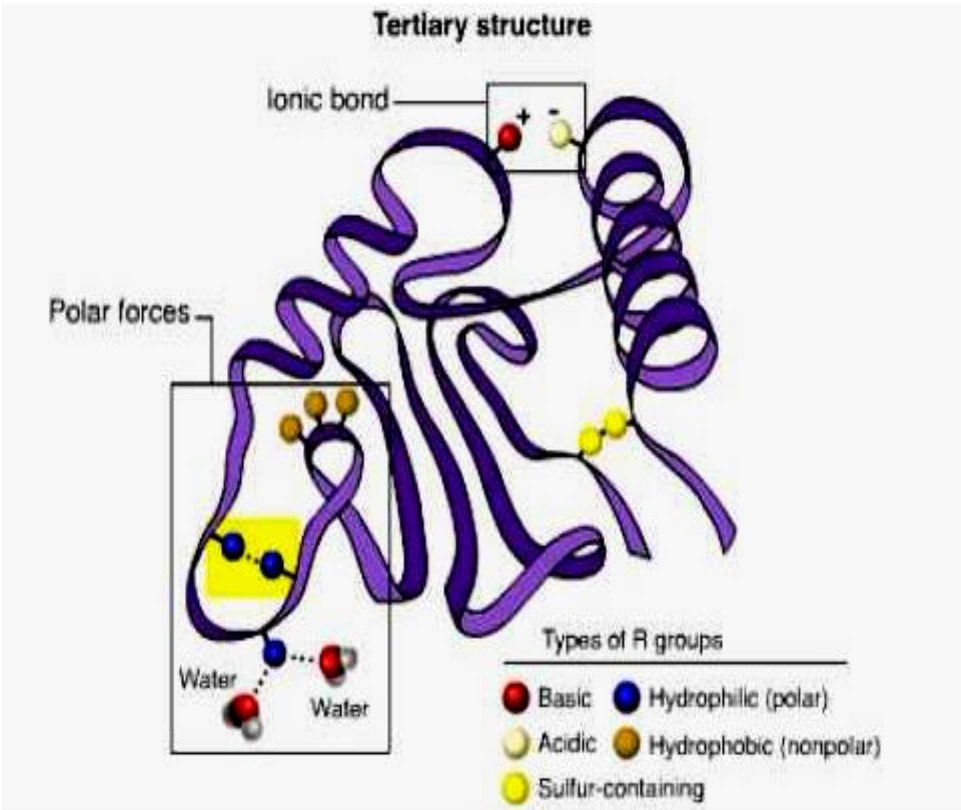
In this structure, the polypeptide chains are held together by hydrogen bonds, so as to give a sheet-like structure and hence are called as (i-pleated sheet conformations.

3) Tertiary Structure

The polypeptide chain may undergo coiling and folding to produce the 'tertiary' structure of proteins. The secondary structure will take on a three dimensional shape in which there is folding, looping and binding of the chain, including all its secondary structures, i.e. the helix, the reverse turn and the pleated sheets, in such a way as to expose most polar groups to the surface and most non-polar group to interior.

The final shape may be ellipsoid, a globe or any irregular shape and is entirely determined by the intermolecular forces and bonds in the polypeptide chain. These forces are hydrogen bonds, ionic (electrostatic) bonds, hydrophobic interactions and other similar forces.

The folding, which is formed, brings together active amino acids, which are otherwise scattered along the chain, and may form a distinctive cavity or cleft in which the substrate is bound.

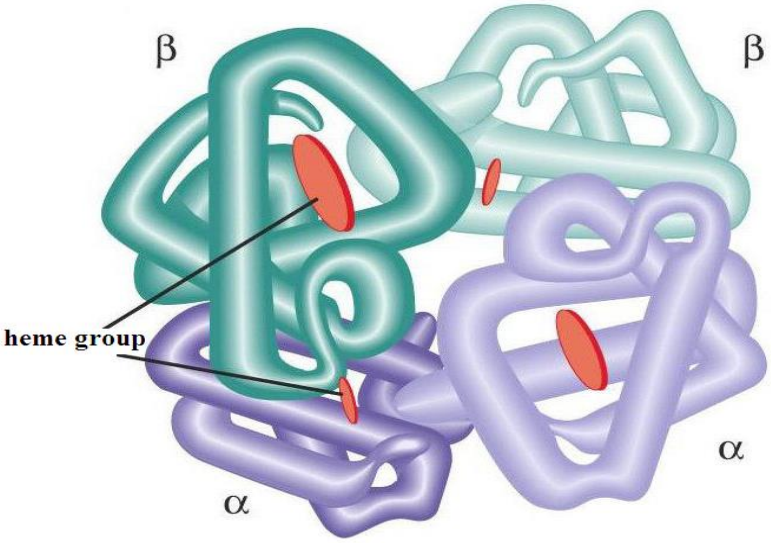


4) Quaternary Structure

Two or more polypeptide chains may associate to give rise to the quaternary structure. The association may be brought by hydrophobic interactions, hydrogen bonds and electrostatic bonds.

If the protein consists of identical units, it is said to have a 'homogeneous' quaternary structure. If the units are dissimilar the protein is said to have a 'heterogeneous' quaternary .structure.

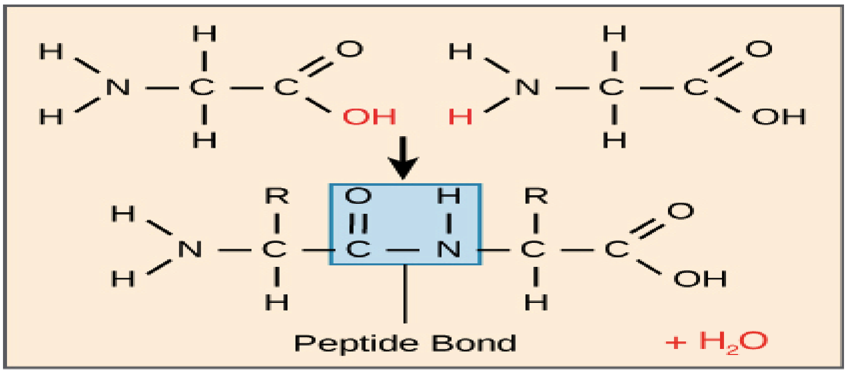
Proteins, such as - haemoglobin', which consist of more than one polypeptide chain are said to possess quaternary structure.



Quaternary Protein Sructue: Three-dimensional assembly of subunits

PEPTIDES AND POLYPEPTIDES

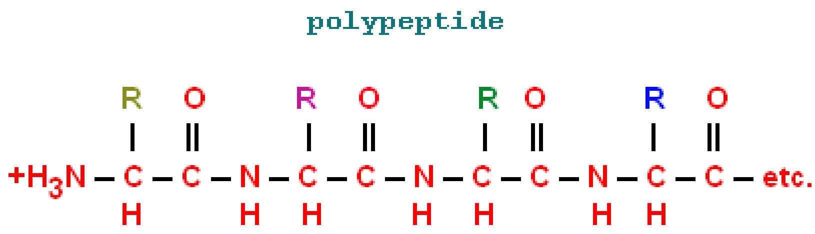
A peptide is the condensation product of two or even more amino acids, wherein two amino acids, -the α- amino group of one amino acid is condensed with the cc-carboxyl group of another with the removal of one mole of water during formation of peptide bond.



Two amino acids will condense to form dipeptide, while three and four amino acids will unite to form tri and tetrapeptide respectively.

The term peptide is for 2 to 20 amino acids and compounds with 100 or more amino acids are normally called proteins.

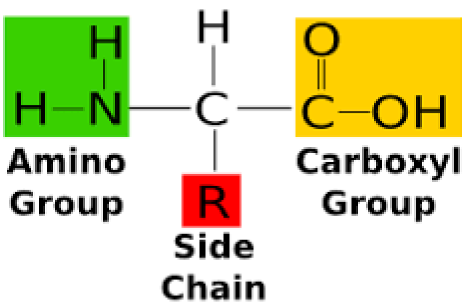
Polypeptides are the compounds containing 20 to more than 50 amino acids. Polymers of 100 amino acids are termed polypeptides.Polypeptides are formed by long peptide chains containing large numbers of peptide bonds. The N - terminal, (i.e. amino terminal) amine acid is always shown at the left and C - terminal (- COOH terminal) amino acid at-the right of the polypeptide chain.



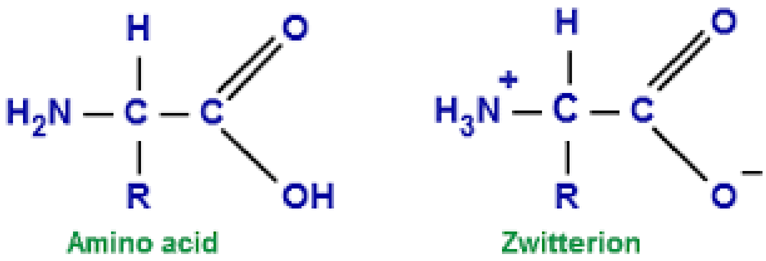
Isoelectric point and Amphoteric Nature of Protein

The properties of proteins as electrolytes are determined by the ionizable group in the molecule.

As each protein chain contains one free a-NH_2 group (amino acid) and one free - COOH (carboxyl) group.



The ionization of these groups depend on the pH of the system and the R - groups of amino acids upon ionization in solution, producing both anions and cations. Thus the protein molecule exists as a 'Zwitter ion' in solution, ['Zwitterion' is an ion that containing both the positive and negative regions of chargest] and it can combine with both acids and bases. Thus is an amphoteric substance.



For every protein in solution, there exists a particular pH, at which the no. of anions formed is exactly equal to the no. of captions, and the solution remains electrically neutral. That pH is called the 'isoelectric point and pH' of that protein.

When a protein solution is maintained at a pH equal to its isoelectric pH, protein molecules do not migrate when subjected to an electric field. Thus, at the isoelectric pH, the number of positive charges equal to the number of negative charges, giving a net charge of 'zero'.

Viscosity of protein solutions

Solutions of fibrous proteins, e.g. fibrinogen, are highly viscous compared to globular proteins like albumin.

Hydration of Proteins

When kept in contact with water, protein molecules absorb water and swell up. The polar groups like - COOH, - NH_2, and - OH become hydrated.

Electrolytes, alcohols, or sugars in high concentration will compete for water for hydration and dehydrate the protein and precipitate it from the solution.

Precipitation OR 'Salting In' and 'out' of Proteins

In the presence of small concentrations of various neutral salts, the solubility of many proteins increases. This is referred to as 'salting in' of proteins. This is probably due to the forces of attraction between salt and protein at low concentration leading to increased solubility.

As the concentration of the neutral salt is increased, the solubility increases to maximum and then starts decreasing and finally the protein is precipitated. This is referred as 'salting out'. This probably, is due to the competition for water between the protein and the salt at high concentrations.

Coagulation of Proteins

Most proteins, when heated in solution, become insoluble and get precipitated in the form of coagulum. Coagulation occurs best when the protein solution is kept at its isoelectric pH. During coagulation the protein molecules undergo a change described as 'denaturation.'

Oxidation of Proteins

Proteins get oxidized by **puterfaction**, (i.e. enzymatic decomposition) processes to form the products such as amino nitrogen compounds, CO_2 and water, depending upon conditions employed. This results in the production of bad foul-smelling of the dead and decaying bodies.

FUNCTIONS OF PROTEINS

Proteins are the agents of biological function. Virtually every cellular activity is dependent on one or more particular proteins. Thus, a convenient way to classify the enormous number of proteins is by the biological roles they fill. The various functions of proteins are as follows.

1. Enzymes

By far the largest class of proteins is enzymes. More than 3000 different enzymes are listed in Enzyme Nomenclature, the standard reference volume on enzyme classification. Enzymes are catalysts that accelerate the rates of biological reactions. Each enzyme is very specific in its function and acts only in a particular metabolic reaction. Virtually every step in metabolism is catalysed by an enzyme.

2. Regulatory Proteins

A number of proteins do not perform any obvious chemical transformation but nevertheless can regulate the ability of other proteins to carry out their physiological functions. Such proteins are referred to as regulatory proteins. A well-known example is **insulin,** the hormone regulating glucose metabolism in animals. Insulin is a relatively small protein and consists of two polypeptide chains held together by disulfide cross-bridges. Other hormones that are also proteins include pituitary **somatotropin** and **thyrotropin,** which stimulates the thyroid gland.

3. Transport Proteins

A third class of proteins is the transport proteins. These proteins function to transport specific substances from one place to another. One type of transport is exemplified by the **transport of oxygen** from the lungs to the tissues by haemoglobin or by the **transport of fatty acids** from adipose tissue to various organs by the blood protein serum albumin. **Membrane transport proteins** take up metabolite molecules on one side of a membrane, transport them across the membrane, and release them on the other side. Examples include the transport proteins responsible for the uptake of essential nutrients into the cell, such as glucose or amino acids.

4. Storage Proteins

Organisms have exploited proteins as a means to provide sufficient nitrogen in times of need. For example, **ovalbumin,** the protein of egg white, provides the developing bird embryo with a source of nitrogen during its isolation within the egg. **Casein** is the most abundant protein of milk and thus the major nitrogen source for mammalian infants. The seeds of higher plants often contain as much as 60% storage protein to make the germinating seed nitrogen-sufficient during this crucial period of plant development. In corn (Zea mays or maize), a family of low molecular weight proteins in the kernel called **zeins** serve this purpose. **Ferritin** is a protein found in animal tissues that binds iron, retaining this essential metal so that it is available for the synthesis of important iron containing proteins such as hemoglobin.

5. Contractile and Motile Proteins

Certain proteins give cells with unique capabilities for movement. Cell division, muscle contraction, and cell motility represent some of the ways in which cells execute motion. Examples include **actin and myosin,** the filamentous proteins forming the contractile systems of cells, and **tubulin,** the major component of microtubules.

6. Structural Proteins

An apparently passive but very important role of proteins is their function in creating and maintaining biological structures. Structural proteins provide strength and protection to cells and tissues. Monomeric units of structural proteins typically polymerize to generate long fibers (as in hair). α-Keratins are insoluble fibrous proteins making up hair, horns, and fingernails. **Collagen,** another insoluble fibrous protein, is found in bone, connective tissue, tendons, and **cartilage,** where it forms inelastic fibrils of great strength. One-third of the total protein in a vertebrate animal is collagen.

7. Scaffold Proteins (Adapter Proteins)

. These proteins, the scaffold or adapter proteins have a modular organization in which specific parts (modules) of the protein's structure recognize and bind certain structural elements in other proteins through protein–protein interactions.

8. Protective and Exploitive Proteins

Prominent among the protective proteins are the **immunoglobulins or antibodies** produced by the lymphocytes of vertebrates. Antibodies have the remarkable ability to specifically recognize and neutralize "foreign" molecules resulting from the invasion of the organism by bacteria, viruses, or other infectious agents.

Another group of protective proteins is the **blood-clotting proteins**, thrombin and fibrinogen, which prevent the loss of blood when the circulatory system is damaged. Arctic and Antarctic fishes have antifreeze proteins to protect their blood against freezing in the below-zero temperatures of high-latitude seas. Another class of exploitive proteins includes the toxins produced by bacteria, such as diphtheria toxin and cholera toxin.