Biochemistry 1

Amino acids

For 2nd year students,
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الكيمياء حياتية ١

الاحماض الامينية

المرحلة الثانية- قسم علوم الحياة
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Amino acids (A.As)

Amino acids (A.As) is a group of organic molecules consists of a basic amino group (—NH_2) at one end, an acidic carboxyl group (—COOH) at the other end, and an organic R group (side chain), which could be drawn as NH_2-RCH-COOH. Amino acid is a short term for *α-amino - carboxylic acid*. Each A.A molecule contains a central carbon atom (C) called the α-carbon, to which both an amino and a carboxyl group are connected. The general formula of A.As is shown in Figure 1:

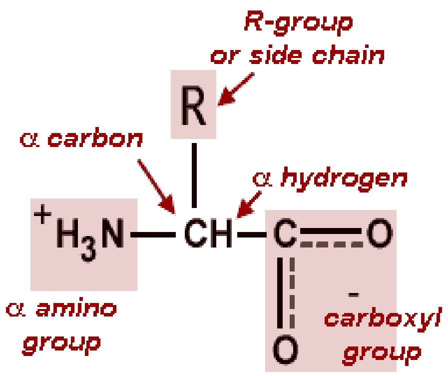


Figure 1. The general formula of amino acids (A.As) where the amino group and carboxylic group are attached to α-carbon at the left and right hand side, respectively.

Importance of amino acids

Amino acids as a simple unit is the building block of a larger molecule which is called "protein". Proteins are of one of the most important functional molecule in the life. Proteins could catalyze many chemical reactions inside the cells. They act as structural elements where they bind cells together into tissues.

Some proteins are transporting and others act as defense proteins to protect the living cell against viruses. More details about protein functions will be illustrated in protein lecture.

Proteins vary markedly in their overall size, shape, and charge, however, when they hydrolyzed they converted to a simple molecule which is A.As.

In the mid-1950s scientists agreed that there are 20 amino acids, which are also called standard or common amino acids. The 20 A.As had been considered to be the essential building blocks of all proteins.

Classification of amino acids

The structure of the 20 common A.As in Nature is shown in Figure 2.

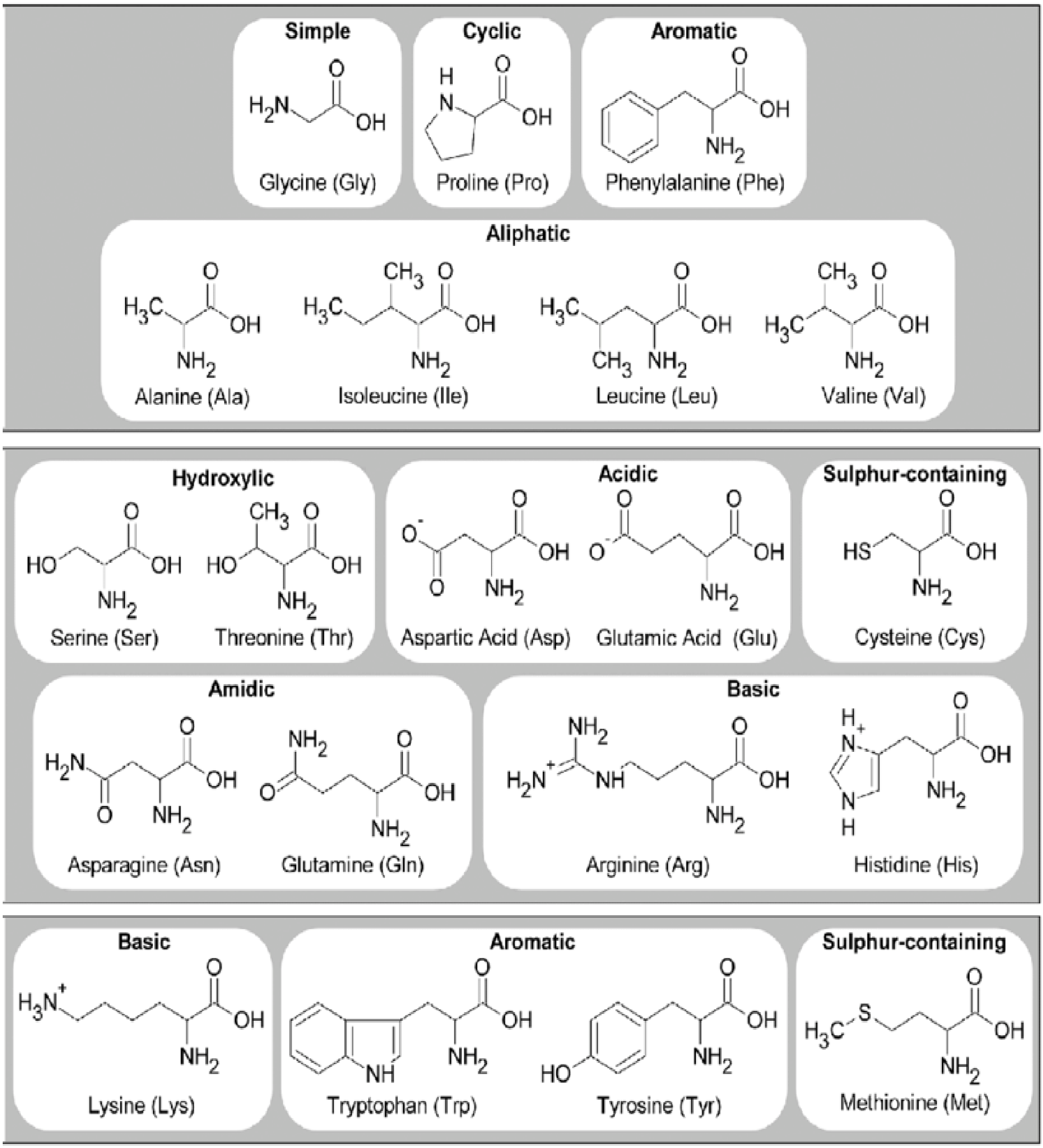


Figure 2. The 20 A.As in Nature.

From a nutritional point of view, A.As are classified into two groups essential and nonessential.

- Essential A.A: are unable to be synthesized and, therefore, they must be provided by diet, such as Val, Leu, ILe, Phe, Trp, Meth, His, Thr, Lys and Arg (semi-essential).
- Nonessential A.As: are as important as the essential ones and cannot be ignored in the physiological processes of humans. Nevertheless, humans can live without taking these A.As in the diet: Gly, Ala, Pro, Ser, Cys, Tyr, Asn, Gln, Asp and Glu.

One of the most useful way to classify the common A.As depends on the polarity of the R group. The polarity refers to the distribution of the electric charge on the molecule surface, therefore, A.As can be classified into:

1. Non polar (Hydrophobic) A.As,
2. Polar (hydrophilic) A.As
3. Acidic (Charged) A.As
4. Basic (Charged) A.A

Group I: Nonpolar amino acids

Amino acid such as Gly (Glycine), Ala (Alanine), Val (Valine), Leu (Leucine), Ile (Isoleucine), Pro (Proline), Phe (Phenylalanine), Meth (Methionine), and Trp (Tryptophan) have R groups, which are either aliphatic or aromatic groups. Therefore, these A.As are hydrophobic or "water dislike", see Figure 3.

In aqueous solutions, the hydrophobic A.As will be buried inside the peptides molecule when it folded into its 3D structure. The chemical structures of group I amino acids are shown in Figure 4.

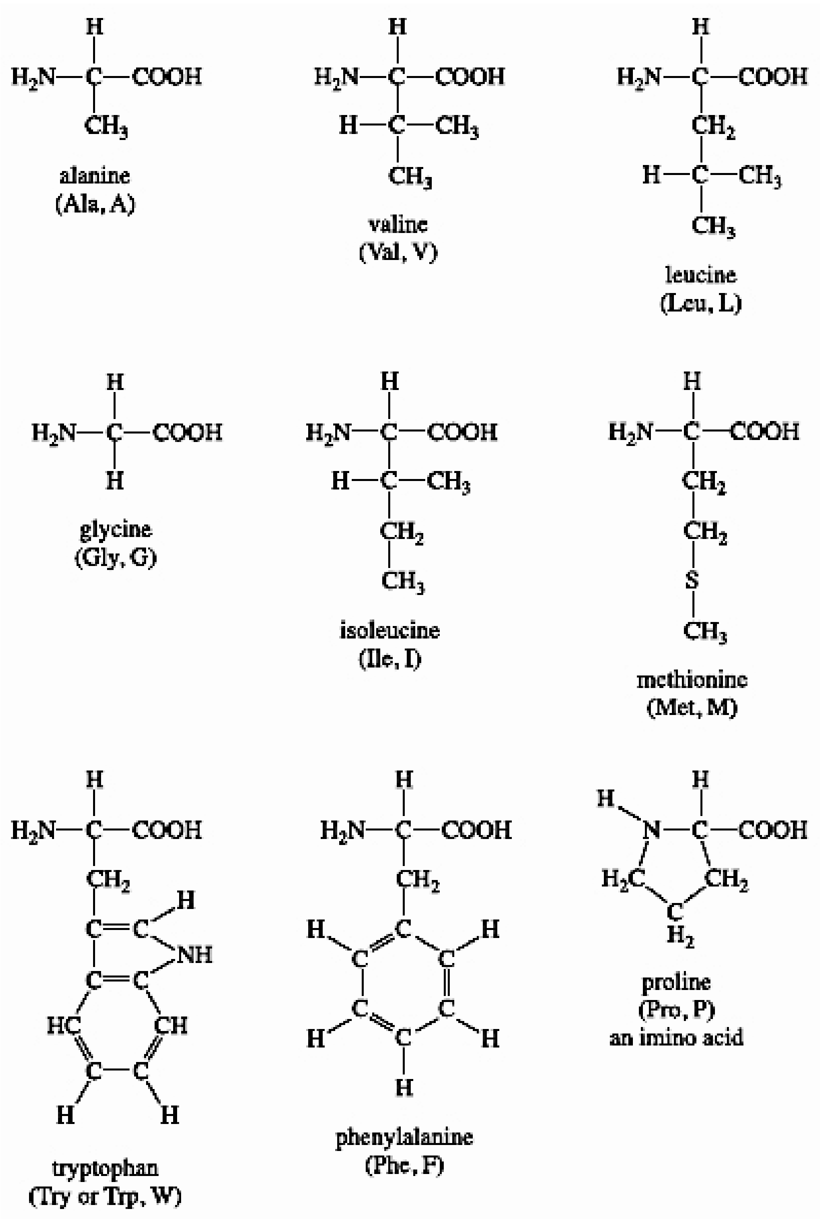


Figure 3. The nonpolar A.As.

- Ile contains two chiral carbon atoms and it is an isomer of Leu.

- Methionine (Meth) and Cys (Cysteine) are sulphur- containing amino acids. Methionine plays a central role in biosynthesis and metabolism of proteins due to its initiating ability in translation.

Phe consists of a phenyl group attached to Ala (Alanine).

-Trp has an indole ring attached to the alanyl side chain.

-Proline (Pro) does not have neither free α-amino nor free α-carboxyl groups, therefore it is unique among the common amino acids. Instead, its side chain forms a cyclic structure, where the nitrogen atom linkes to two carbon atoms. Strictly speaking, proline is not an α-amino acid but rather an α-imino acid.

Group II: Polar, uncharged amino acids

Amino acids such as Ser (Serine), Cys (Cystien), Thr (Threonine), Tyr (Tyrosine), Asn (Aspargine), and Gln (Glutamine) are classified as polar or "water like" A.As. The side chains of this group have at least one atom (Nitrogen, Oxygen, or Sulphur) which has electron pairs available for hydrogen bonding with water. The chemical structures of this group are shown in Figure 4 below:

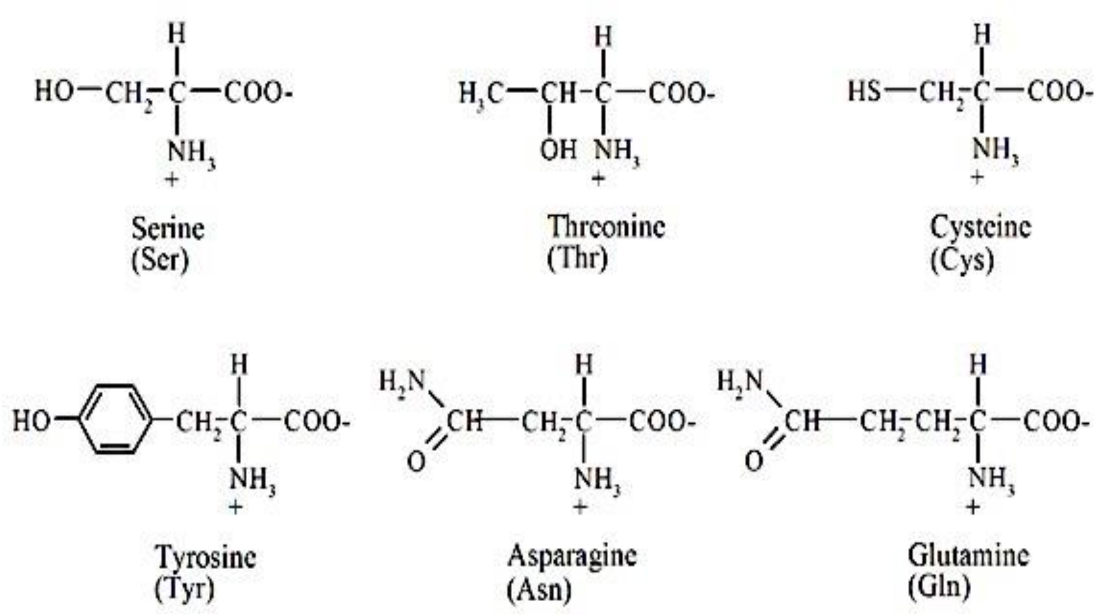


Figure 4. The polar A.As.

- Ser and Thr contain an aliphatic chain bonded to —OH.
- Tyr has an aromatic ring bonded with a hydroxyl group making it a phenol derivative.
- Asn and Gln are both contain amide R groups. The carbonyl group (C=O) could work as a hydrogen bond acceptor, and the amino group (NH_2) could work as a hydrogen bond donor.
- Cys is a sulphur-containing A.A.

Group III: Acidic amino acids

The two acidic A.As in this group are Asp (Aspartic acid) and Glu (Glutamic acid), where both have an additional carboxylic group in the side chain (COO^-), that gives acidic properties (proton donor). They are negatively charged A.As when immerged in an aqueous solution, at physiological pH, where three functional groups on these A.As will be ionized (2 COOH, NH_2), which gives an overall charge of −1.

The ionized forms of the acidic A.As are called Asp (Aspartate) and Glu (Glutamate), which have the chemical structures shown in Figure 5.

The ionic side chains of Asp and Glu can form ionic bonds or salt bridges with other complementary positively charged amino acids (Group IV) to strength the protein structure or to increase it functionality. Free Glu and along with its amide Gln (Glutamine) play a central role in amino acid metabolism. In addition, Glutamate is the most abundant excitatory neurotransmitter in the central nervous system CNS.

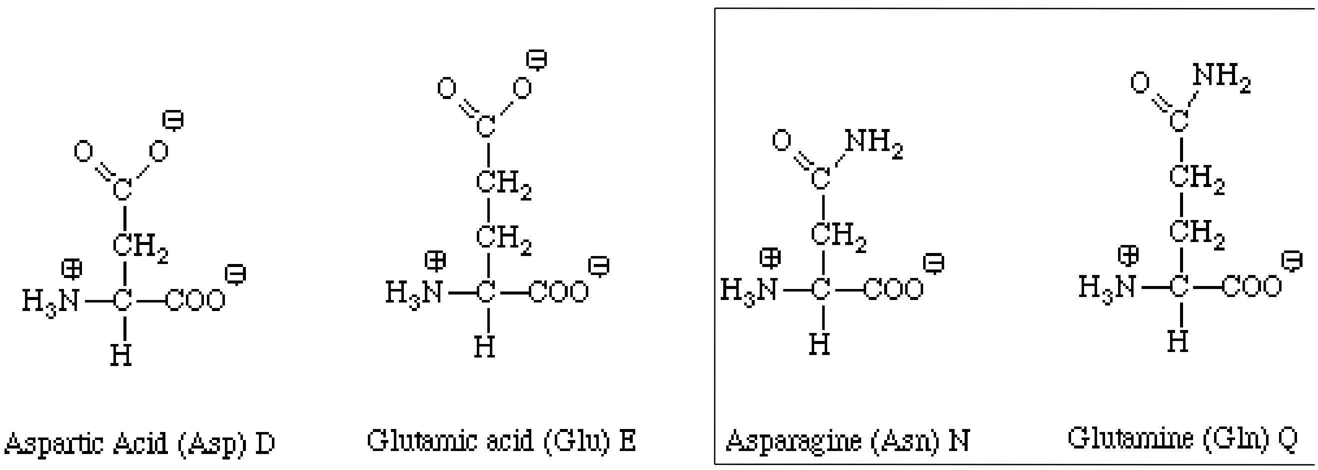


Figure 5. The acidic A.As (to the left-hand side) and their imide configuration (to the right-hand side).

Group IV: Basic amino acids

Arginine (Arg), His (Histidine) and Lys (Lysine) are the common basic A.As (proton acceptor) in this group where both have additional amine group(s) in the side chain (NH_2), that gives basic proprteis. Their chemical structure is shown in Figure 7, where Lys and Arg are existed with an overall charge of +1 at physiological pH=7.

- Arginine is the most basic than others because of its side chain. The R group of Arg contains the guanidino group, which is basic enough to reflect a pKa value of around 12.5.
- As previously mentioned about the acidic A.As Asp and Glu, the side chains of Arg and Lys also could form ionic bonds (salt bridges).
- His has a side chain called imidazole allows to work as acid and base catalysis near the physiological pH value = 7. This propriety is specific for His but not for another A.A. Therefore, His is mostly used to build up active sites of artificial enzymes.

The chemical structures of Group IV amino acids are shown in Figure 6. The majority of A.As in Groups II, III, and IV are hydrophilic "water like", which enable clustering on the surface of globular proteins, in aqueous solutions.

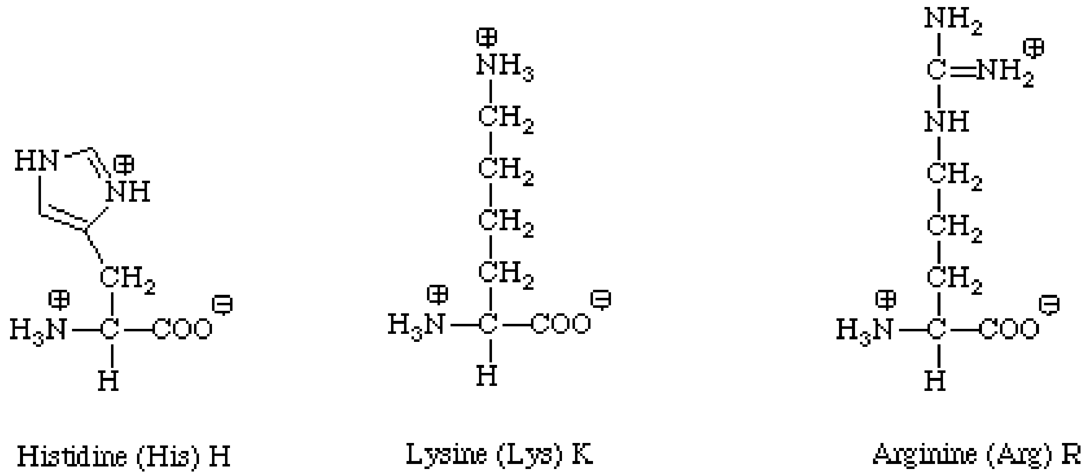
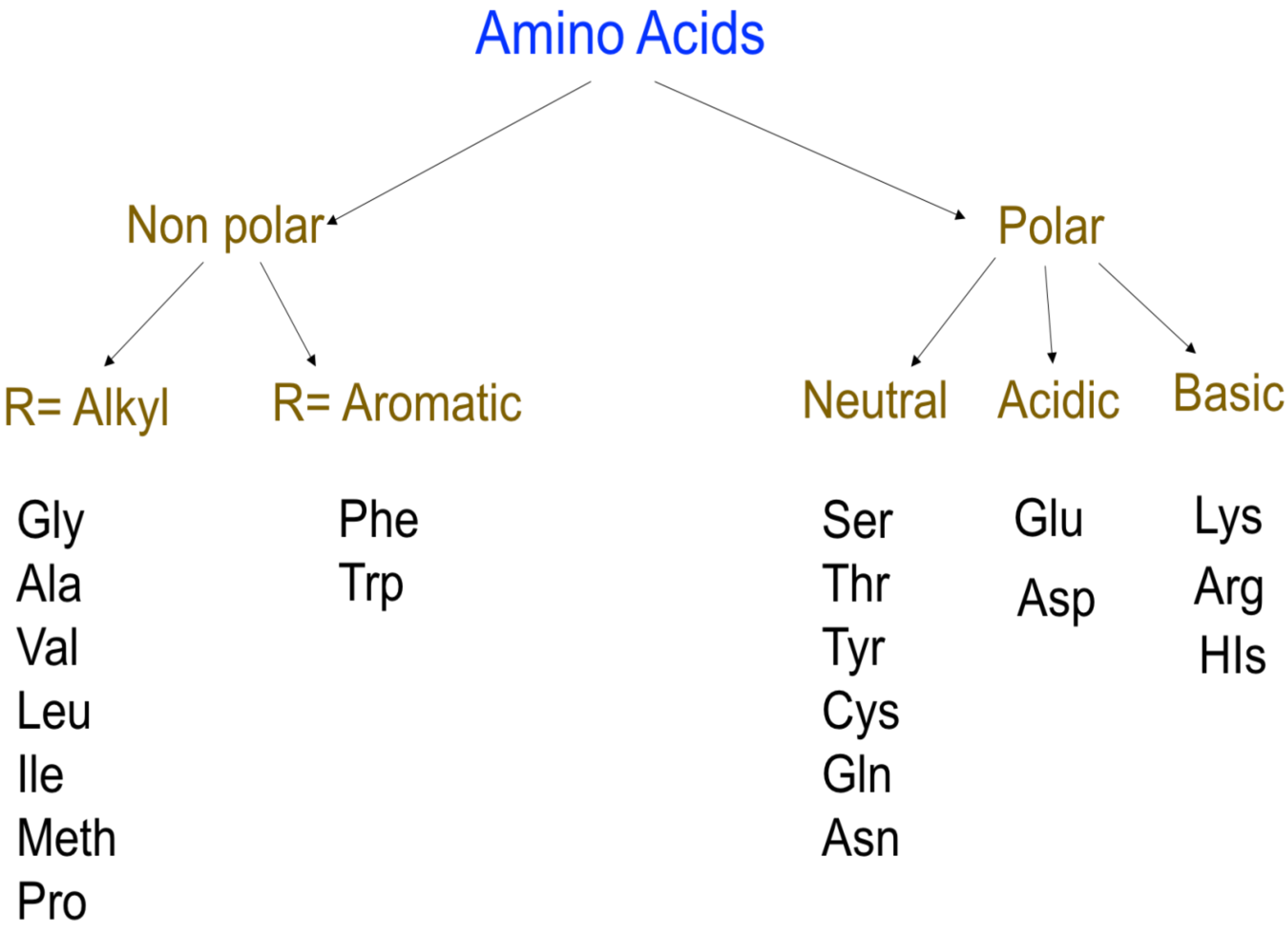


Figure 6. The basic A.As.


Amino Acids
Non polar
Polar
R= Alkyl
R= Aromatic
Neutral
Acidic
Basic
Gly
Ala
Val
Leu
Ile
Meth
Pro
Phe
Trp
Ser
Thr
Tyr
Cys
Gln
Asn
Glu
Asp
Lys
Arg
HIs

Chirality and the optical properties

Stereochemistry of amino acids

When the carbon atom of any A.A attached to four different groups, the resulted A.A is called "chiral" and it would be optically active A.A. All A.As are chiral except Glycine (Gly) because it does not have 4 different groups, see Figure 3. The A.A known as optically active molecule only when it rotates an incident light either to the right or to the left-hand side. Therefore, A.A that has asymmetric carbon (chiral atom), exists in Nature in two forms, D (*dextro*, right) and L (*levo*, left), which are mirror images of each other and the called "enantiomers", see Figure 7. All A.As found in proteins almost possess only the L-configuration, although there are some kinds of A.As found in microorganisms (in the cell wall of the bacteria) and in several antibiotics, are D- amino acids.

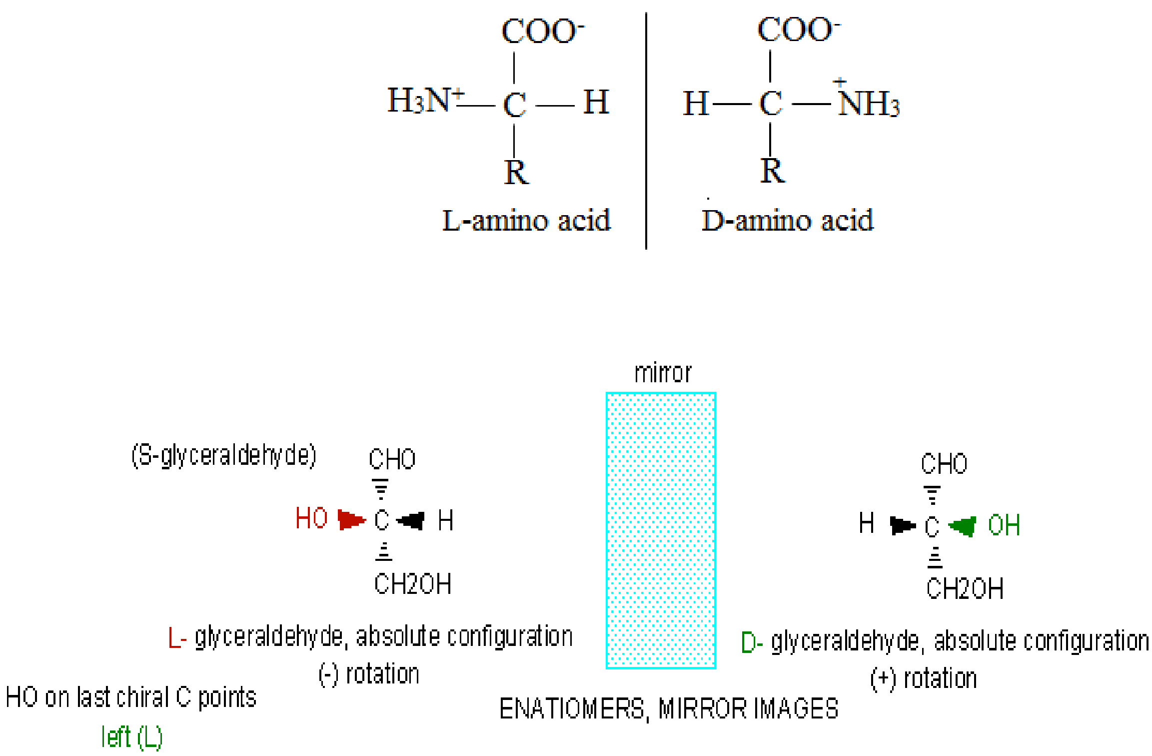


Figure 7. The stereochemistry of A.As . The A.A is chiral when attaches 4 different groups. The D and L configurations of A.A are mirror images of each other.

The zwitterion

Because the structure of A.As has both the basic (NH_2) and the acidic (COOH) group attached at the α-carbon, it can act as either an acid or a base and here the A.As will called "an amphoteric molecule". Thus, at the physiological pH (about 7–7.4), the free A.As are always existing as dipolar ion or " a zwitterion" form, and dose not really exist as unionized form (NH_2-RCH-COOH).

A zwitterion carries an equal number of positively and negatively charged groups, and therefore, the net charge of such A.A molecule will be zero, see Figure 8.

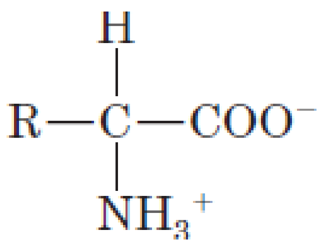


Figure 8. The zwitterion, where the ionic form of the A.As is neutral (no net charge) and the number of positive and negative charges = zero.

The zwitterion could act either as an acid or a base, see Figure 9.

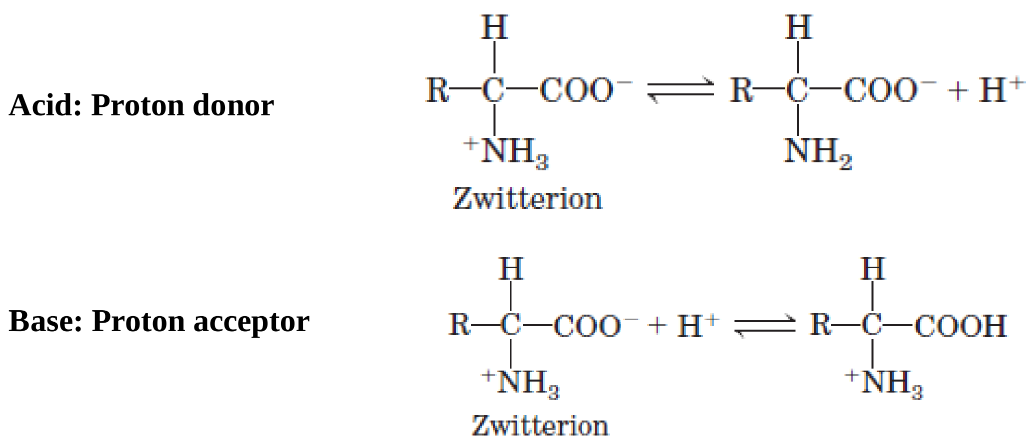


Figure 9. The zwitterion behaves as acid and base.

All A.As and proteins solutions pass through a transition state when subjected to changes in the pH. This transition state has an equal number of the positive and negative charges (zwitterion). For example, when Ala is fully protonated, its groups will be NH_3 and COOH, which then dissociated to produce protons, see Figure 10.

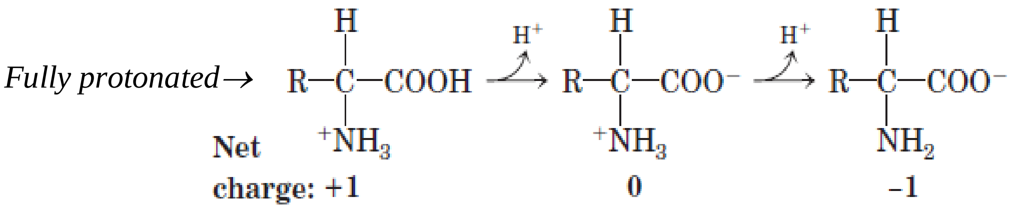


Figure 10. Dissociation of the fully protonated Ala.

The pH at zwitterion occurs is known as the isoelectric point (or isoelectric pH) and is denoted as pI. However, there is no pH at which the A.A has zero charge, therefore, all A.As and proteins are always carrying charged groups and be ionized.