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ing factors, neuromodulators, or neurotransmitters. Humans and other higher animals lack the capability to synthesize 10 of the 20 common L- α -amino acids in amounts adequate to support infant growth or to maintain health in adults. Consequently, the human diet must contain adequate quantities of these nutritionally essential amino acids. While human proteins contain only L- α -amino acids, microorganisms make extensive use of D- α -amino acids. *Bacillus subtilis*, for example, secretes a mixture of D-methionine, D-tyrosine, D-leucine, and D-tryptophan to trigger biofilm disassembly, and *Vibrio cholerae* incorporates D-leucine and D-methionine into the peptide component of their peptidoglycan layer. Many bacteria elaborate peptides that contain both D- and L- α -amino acids, several of which possess therapeutic value, including the antibiotics bacitracin and gramicidin.

Essentially all mammals have more than 20 amino acids, several amino acids are specified by multiple codons. Redundant usage limits the available selection to the 20 L- α -amino acids listed in Table 1-1. Their full and three-letter abbreviations for each amino acid can be used to represent the amino acids in proteins and proteins (Table 1-1). Some proteins contain additional amino acids that arise by modification of the amino acid already present in a peptide. Such modifications include conversion of peptidyl methionine and threonine to 3-methoxytyrosine and 3-hydroxytyrosine, and conversion of peptidyl glutamate to 7-carboxyglutamate, and the methylation, formylation, acetylation, n-acylation, and phosphorylation of certain side chains. These modifications extend the biological functions of proteins by altering their solubility, reactivity, and interaction with other proteins.

Table 1-1 L- α -Amino Acids Present in Proteins

Name	Symbol	Structural Formula	pK ₁	pK ₂	pI
With Aliphatic Side Chains			$\alpha\text{-COOH}$	$\alpha\text{-NH}_2$	R Group
Alanine	Ala (A)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_3)-\text{COOH}$	2.4	9.8	5.9
Valine	Val (V)	$\text{H}_2\text{N}-\text{CH}(\text{CH}(\text{CH}_3)_2)-\text{COOH}$	2.3	9.7	5.9
Isoleucine	Ile (I)	$\text{H}_2\text{N}-\text{CH}(\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3)-\text{COOH}$	2.3	9.7	5.9
Leucine	Leu (L)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}(\text{CH}_3)_2)-\text{COOH}$	2.3	9.7	5.9
Proline	Pro (P)	$\text{H}_2\text{N}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{COOH}$	2.3	9.7	5.9
Phenylalanine	Phe (F)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{C}_6\text{H}_5)-\text{COOH}$	2.3	9.7	5.9
Tyrosine	Tyr (Y)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{C}_6\text{H}_4\text{OH})-\text{COOH}$	2.3	9.7	5.9
Threonine	Thr (T)	$\text{H}_2\text{N}-\text{CH}(\text{CH}(\text{CH}_3)\text{OH})-\text{COOH}$	2.3	9.7	5.9
Serine	Ser (S)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{OH})-\text{COOH}$	2.3	9.7	5.9
Methionine	Met (M)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}_2\text{SCH}_3)-\text{COOH}$	2.3	9.7	5.9
Asparagine	Asn (N)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CONH}_2)-\text{COOH}$	2.3	9.7	5.9
Glutamine	Gln (Q)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}_2\text{CONH}_2)-\text{COOH}$	2.3	9.7	5.9
Aspartic acid	Asp (D)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{COOH})-\text{COOH}$	2.3	9.7	5.9
Glutamic acid	Glu (E)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}_2\text{COOH})-\text{COOH}$	2.3	9.7	5.9
Pyrolysine	Pro (P)	$\text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH})-\text{COOH}$	2.3	9.7	5.9