
Proteinogenic amino acid

Proteinogenic amino acids are those amino acids that can be found in proteins and require cellular machinery coded for in the genetic code ^[1] of any organism for their isolated production. There are 22 standard amino acids, but only 21 are found in eukaryotes. Of the 22, 20 are directly encoded by the universal genetic code. Humans can synthesize 11 of these 20 from each other or from other molecules of intermediary metabolism. The other 9 must be consumed in the diet, and so are called *essential amino acids*; those are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The remaining two, selenocysteine and pyrrolysine, are incorporated into proteins by unique synthetic mechanisms.

The word *proteinogenic* means "protein building". Proteinogenic amino acids can be assembled into a polypeptide (the subunit of a protein) through a process called translation (the second stage of protein biosynthesis, part of the overall process of gene expression).

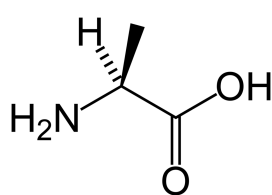
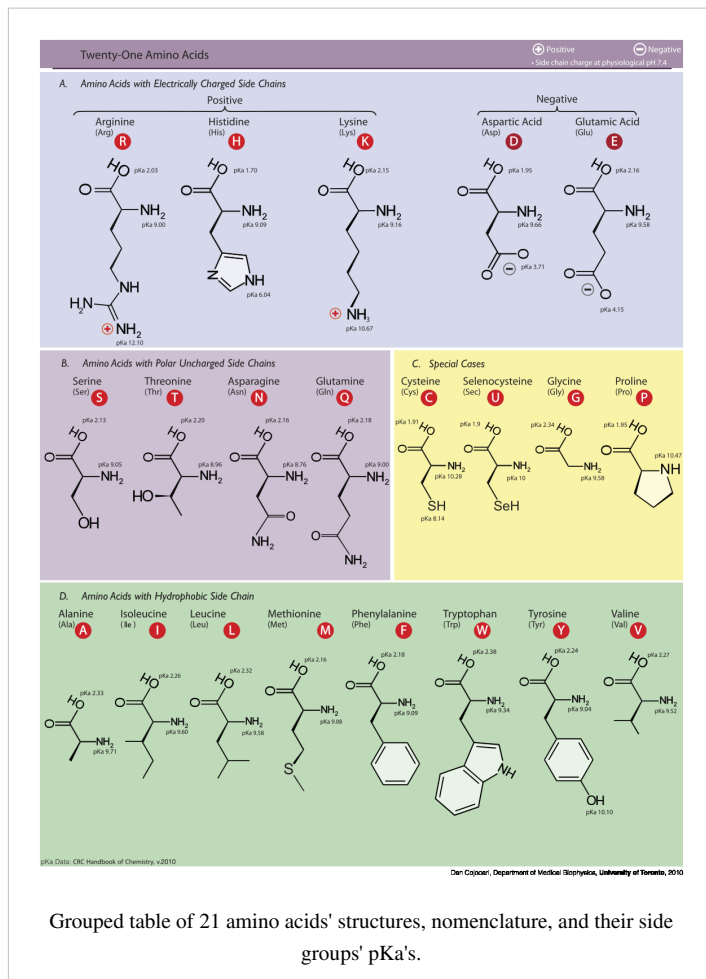
In contrast, **non-proteinogenic** amino acids are either not found in proteins (like carnitine, GABA, or L-DOPA), or are not produced directly and in isolation by standard cellular machinery (like hydroxyproline and selenomethionine). The latter often results from posttranslational modification of proteins.

There are clear reasons why organisms have not evolved to incorporate certain non-proteinogenic amino acids into proteins: for example, ornithine and homoserine cyclize against the peptide backbone and fragment the protein with relatively short half-lives, while others are toxic because they can be mistakenly incorporated into proteins, such as the arginine analog canavanine.

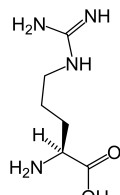
Non-proteinogenic amino acids are found in nonribosomal peptides, which are not produced by the ribosome during translation.

Structures

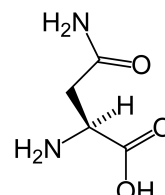
The following illustrates the structures and abbreviations of the 21 amino acids that are directly encoded for protein synthesis by the genetic code of eukaryotes. The structures given below are standard chemical structures, not the typical zwitterion forms that exist in aqueous solutions.



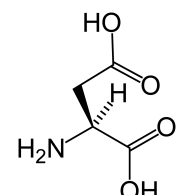
L-Alanine
(Ala / A)



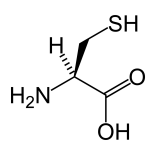
L-Arginine
(Arg / R)



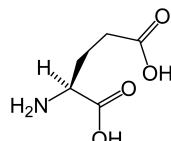
L-Asparagine
(Asn / N)



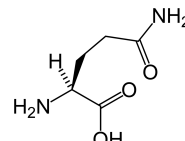
L-Aspartic acid
(Asp / D)



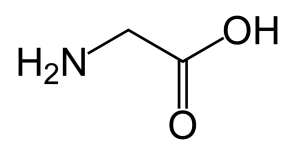
L-Cysteine
(Cys / C)



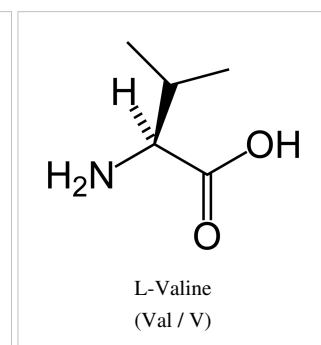
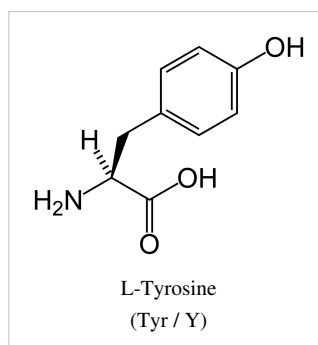
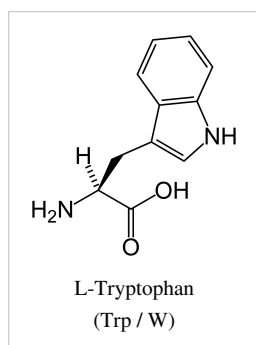
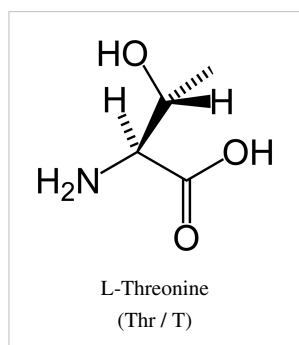
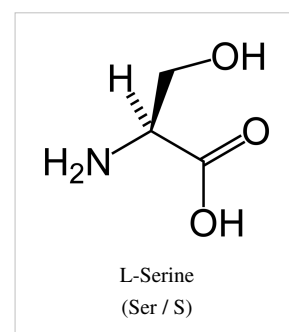
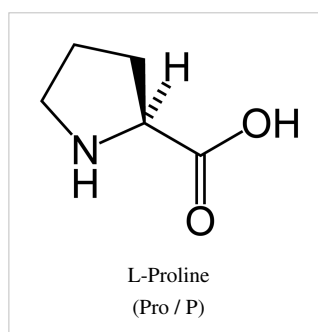
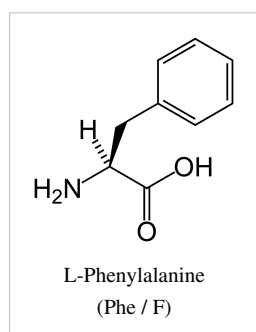
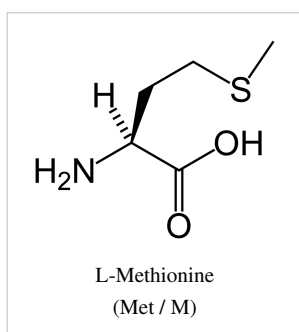
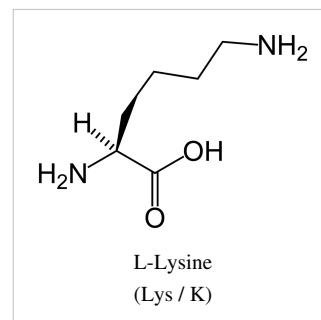
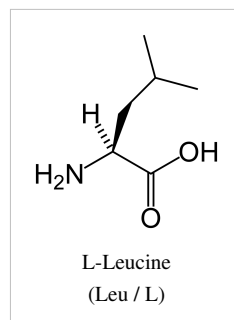
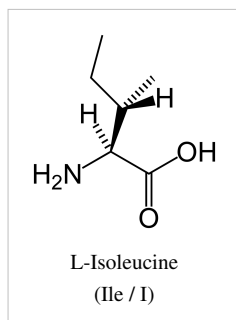
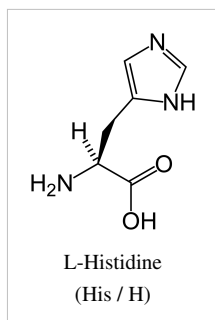
L-Glutamic acid
(Glu / E)



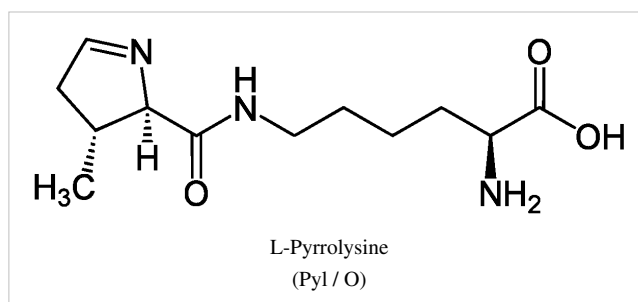
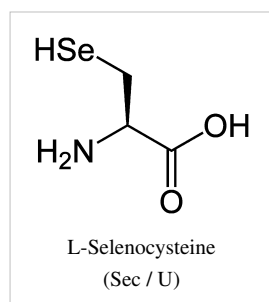
L-Glutamine
(Gln / Q)



Glycine
(Gly / G)



IUPAC/IUBMB now also recommends standard abbreviations for the following two amino acids:



Non-specific abbreviations

Sometimes the specific identity of an amino acid cannot be determined unambiguously. Certain protein sequencing techniques do not distinguish among certain pairs. Thus, the following codes are used:

- *Asx* (*B*) is "asparagine or aspartic acid"
- *Glx* (*Z*) is "glutamic acid or glutamine"
- *Xle* (*J*) is "leucine or isoleucine"

In addition, the symbol *X* is used to indicate an amino acid that is completely unidentified.

Chemical properties

Following is a table listing the one-letter symbols, the three-letter symbols, and the chemical properties of the side-chains of the standard amino acids. The masses listed are based on weighted averages of the elemental isotopes at their natural abundances. Note that forming a peptide bond results in elimination of a molecule of water, so the mass of an amino acid unit within a protein chain is reduced by 18.01524 Da.

General chemical properties

Amino Acid	Short	Abbrev.	Avg. Mass (Da)	pI	pK ₁ (α-COOH)	pK ₂ (α- ⁺ NH ₃)
Alanine	A	Ala	89.09404	6.01	2.35	9.87
Cysteine	C	Cys	121.15404	5.05	1.92	10.70
Aspartic acid	D	Asp	133.10384	2.85	1.99	9.90
Glutamic acid	E	Glu	147.13074	3.15	2.10	9.47
Phenylalanine	F	Phe	165.19184	5.49	2.20	9.31
Glycine	G	Gly	75.06714	6.06	2.35	9.78
Histidine	H	His	155.15634	7.60	1.80	9.33
Isoleucine	I	Ile	131.17464	6.05	2.32	9.76
Lysine	K	Lys	146.18934	9.60	2.16	9.06
Leucine	L	Leu	131.17464	6.01	2.33	9.74
Methionine	M	Met	149.20784	5.74	2.13	9.28
Asparagine	N	Asn	132.11904	5.41	2.14	8.72
Pyrrolysine	O	Pyl				
Proline	P	Pro	115.13194	6.30	1.95	10.64
Glutamine	Q	Gln	146.14594	5.65	2.17	9.13
Arginine	R	Arg	174.20274	10.76	1.82	8.99
Serine	S	Ser	105.09344	5.68	2.19	9.21
Threonine	T	Thr	119.12034	5.60	2.09	9.10
Selenocysteine	U	Sec	168.053			
Valine	V	Val	117.14784	6.00	2.39	9.74
Tryptophan	W	Trp	204.22844	5.89	2.46	9.41
Tyrosine	Y	Tyr	181.19124	5.64	2.20	9.21

Side chain properties

Amino Acid	Short	Abbrev.	Side chain	Hydrophobic	pKa	Polar	pH	Small	Tiny	Aromatic or Aliphatic	van der Waals volume
Alanine	A	Ala	-CH ₃	X	-	-	-	X	X	-	67
Cysteine	C	Cys	-CH ₂ SH	X	8.18	-	acidic	X	-	-	86
Aspartic acid	D	Asp	-CH ₂ COOH	-	3.90	X	acidic	X	-	-	91
Glutamic acid	E	Glu	-CH ₂ CH ₂ COOH	-	4.07	X	acidic	-	-	-	109
Phenylalanine	F	Phe	-CH ₂ C ₆ H ₅	X	-	-	-	-	-	Aromatic	135
Glycine	G	Gly	-H	X	-	-	-	X	X	-	48
Histidine	H	His	-CH ₂ -C ₃ H ₃ N ₂	-	6.04	X	weak basic	-	-	Aromatic	118
Isoleucine	I	Ile	-CH(CH ₃)CH ₂ CH ₃	X	-	-	-	-	-	Aliphatic	124
Lysine	K	Lys	-(CH ₂) ₄ NH ₂	-	10.54	X	basic	-	-	-	135
Leucine	L	Leu	-CH ₂ CH(CH ₃) ₂	X	-	-	-	-	-	Aliphatic	124
Methionine	M	Met	-CH ₂ CH ₂ SCH ₃	X	-	-	-	-	-	-	124
Asparagine	N	Asn	-CH ₂ CONH ₂	-	-	X	-	X	-	-	96
Pyrrolysine	O	Pyl									
Proline	P	Pro	-CH ₂ CH ₂ CH ₂ -	X	-	-	-	X	-	-	90
Glutamine	Q	Gln	-CH ₂ CH ₂ CONH ₂	-	-	X	-	-	-	-	114
Arginine	R	Arg	-(CH ₂) ₃ NH-C(NH)NH ₂	-	12.48	X	strongly basic	-	-	-	148
Serine	S	Ser	-CH ₂ OH	-	-	X	-	X	X	-	73
Threonine	T	Thr	-CH(OH)CH ₃	-	-	X	weak acidic	X	-	-	93
Selenocysteine	U	Sec	-CH ₂ SeH	X	5.73	-	-	X	-	-	
Valine	V	Val	-CH(CH ₃) ₂	X	-	-	-	X	-	Aliphatic	105
Tryptophan	W	Trp	-CH ₂ C ₈ H ₆ N	X	-	-	-	-	-	Aromatic	163
Tyrosine	Y	Tyr	-CH ₂ -C ₆ H ₄ OH	-	10.46	X	-	-	-	Aromatic	141

Note: The pKa values of amino acids are typically slightly different when the amino acid is inside a protein. Protein pKa calculations are sometimes used to calculate the change in the pKa value of an amino acid in this situation.

Gene expression and biochemistry

Amino Acid	Short	Abbrev.	Codon(s)	Occurrence in human proteins (%)	Essential‡ in humans
Alanine	A	Ala	GCU, GCC, GCA, GCG	7.8	-
Cysteine	C	Cys	UGU, UGC	1.9	Conditionally
Aspartic acid	D	Asp	GAU, GAC	5.3	-
Glutamic acid	E	Glu	GAA, GAG	6.3	Conditionally
Phenylalanine	F	Phe	UUU, UUC	3.9	Yes
Glycine	G	Gly	GGU, GGC, GGA, GGG	7.2	Conditionally
Histidine	H	His	CAU, CAC	2.3	Yes
Isoleucine	I	Ile	AUU, AUC, AUA	5.3	Yes
Lysine	K	Lys	AAA, AAG	5.9	Yes
Leucine	L	Leu	UUA, UUG, CUU, CUC, CUA, CUG	9.1	Yes
Methionine	M	Met	AUG	2.3	Yes
Asparagine	N	Asn	AAU, AAC	4.3	-
Pyrrolysine	O	Pyl	UAG*		-
Proline	P	Pro	CCU, CCC, CCA, CCG	5.2	-
Glutamine	Q	Gln	CAA, CAG	4.2	-
Arginine	R	Arg	CGU, CGC, CGA, CGG, AGA, AGG	5.1	Conditionally
Serine	S	Ser	UCU, UCC, UCA, UCG, AGU, AGC	6.8	-
Threonine	T	Thr	ACU, ACC, ACA, ACG	5.9	Yes
Selenocysteine	U	Sec	UGA**		-
Valine	V	Val	GUU, GUC, GUA, GUG	6.6	Yes
Tryptophan	W	Trp	UGG	1.4	Yes
Tyrosine	Y	Tyr	UAU, UAC	3.2	Conditionally
Stop codon†	-	Term	UAA, UAG, UGA	-	-

* UAG is normally the amber stop codon, but encodes pyrrolysine if a PYLIS element is present.

** UGA is normally the opal (or umber) stop codon, but encodes selenocysteine if a SECIS element is present.

† The stop codon is not an amino acid, but is included for completeness.

‡ An essential amino acid cannot be synthesized in humans and must, therefore, be supplied in the diet. Conditionally essential amino acids are not normally required in the diet, but must be supplied exogenously to specific populations that do not synthesize it in adequate amounts.

Mass spectrometry

In mass spectrometry of peptides and proteins, it is useful to know the masses of the residues. The mass of the peptide or protein is the sum of the residue masses plus the mass of water.^[2]

Amino Acid	Short	Abbrev.	Formula	Mon. Mass§ (Da)	Avg. Mass (Da)
Alanine	A	Ala	C ₃ H ₅ NO	71.03711	71.0788
Cysteine	C	Cys	C ₃ H ₅ NOS	103.00919	103.1388
Aspartic acid	D	Asp	C ₄ H ₅ NO ₃	115.02694	115.0886
Glutamic acid	E	Glu	C ₅ H ₇ NO ₃	129.04259	129.1155
Phenylalanine	F	Phe	C ₉ H ₉ NO	147.06841	147.1766
Glycine	G	Gly	C ₂ H ₃ NO	57.02146	57.0519
Histidine	H	His	C ₆ H ₇ N ₃ O	137.05891	137.1411
Isoleucine	I	Ile	C ₆ H ₁₁ NO	113.08406	113.1594
Lysine	K	Lys	C ₆ H ₁₂ N ₂ O	128.09496	128.1741
Leucine	L	Leu	C ₆ H ₁₁ NO	113.08406	113.1594
Methionine	M	Met	C ₅ H ₉ NOS	131.04049	131.1986
Asparagine	N	Asn	C ₄ H ₆ N ₂ O ₂	114.04293	114.1039
Pyrrolysine	O	Pyl	C ₁₂ H ₂₁ N ₃ O ₃	255.15829	255.3172
Proline	P	Pro	C ₅ H ₇ NO	97.05276	97.1167
Glutamine	Q	Gln	C ₅ H ₈ N ₂ O ₂	128.05858	128.1307
Arginine	R	Arg	C ₆ H ₁₂ N ₄ O	156.10111	156.1875
Serine	S	Ser	C ₃ H ₅ NO ₂	87.03203	87.0782
Threonine	T	Thr	C ₄ H ₇ NO ₂	101.04768	101.1051
Selenocysteine	U	Sec	C ₃ H ₅ NOSe	150.95364	150.0388
Valine	V	Val	C ₅ H ₉ NO	99.06841	99.1326
Tryptophan	W	Trp	C ₁₁ H ₁₀ N ₂ O	186.07931	186.2132
Tyrosine	Y	Tyr	C ₉ H ₉ NO ₂	163.06333	163.1760

§ Monoisotopic mass

Stoichiometry and metabolic cost in cell

Following table lists the abundance of amino acids in E.coli cell and the metabolic cost (ATP) for synthesis the amino acids. Negative numbers indicate the metabolic processes are energy favorable and do not cost net ATP of the cell.^[3] Note that the abundance of amino acids include amino acids in free-form and in polymerization form (proteins).

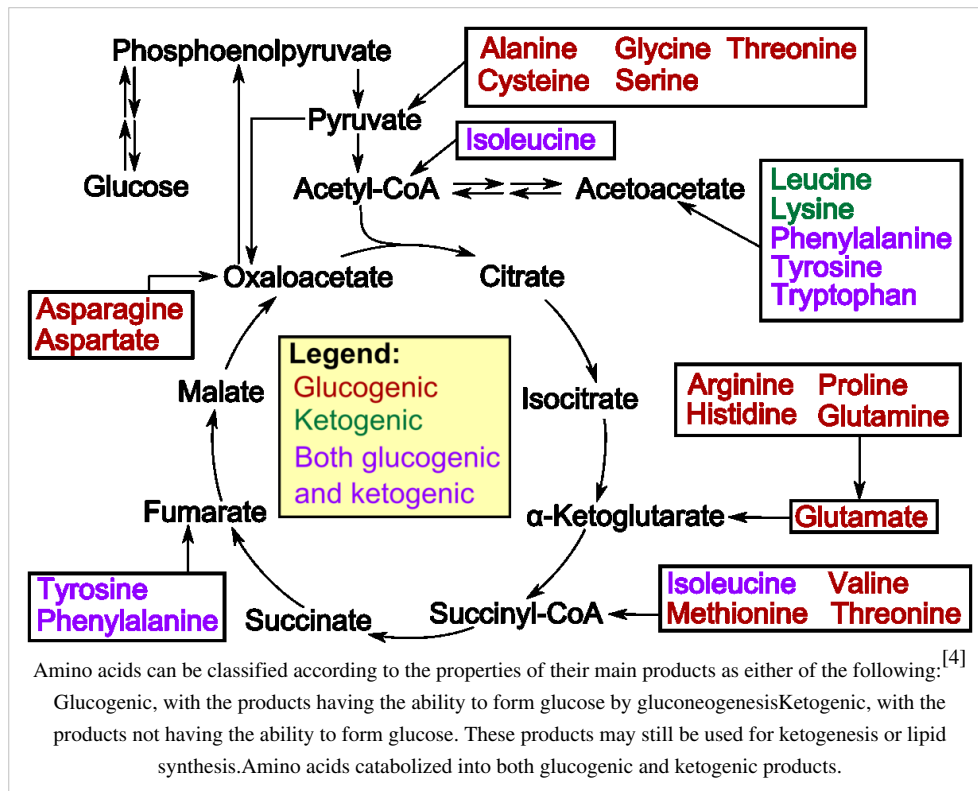
Amino acid	Abundance (# of molecules ($\times 10^8$) per <i>E. coli</i> cell)	ATP cost in synthesis under aerobic condition	ATP cost in synthesis under anaerobic condition
Alanine	2.9	-1	1
Cysteine	0.52	11	15
Aspartic acid	1.4	0	2
Glutamic acid	1.5	-7	-1
Phenylalanine	1.1	-6	2
Glycine	3.5	-2	2
Histidine	0.54	1	7
Isoleucine	1.7	7	11
Lysine	2.0	5	9
Leucine	2.6	-9	1
Methionine	0.88	21	23
Asparagine	1.4	3	5
Proline	1.3	-2	4
Glutamine	1.5	-6	0
Arginine	1.7	5	13
Serine	1.2	-2	2
Threonine	1.5	6	8
Tryptophan	0.33	-7	7
Tyrosine	0.79	-8	2
Valine	2.4	-2	2

Remarks

Amino Acid	Abbrev.		Remarks
Alanine	A	Ala	Very abundant, very versatile. More stiff than glycine, but small enough to pose only small steric limits for the protein conformation. It behaves fairly neutrally, and can be located in both hydrophilic regions on the protein outside and the hydrophobic areas inside.
Asparagine or aspartic acid	B	Asx	A placeholder when either amino acid may occupy a position.
Cysteine	C	Cys	The sulfur atom bonds readily to heavy metal ions. Under oxidizing conditions, two cysteines can join together in a disulfide bond to form the amino acid cystine. When cystines are part of a protein, insulin for example, the tertiary structure is stabilized, which makes the protein more resistant to denaturation; therefore, disulfide bonds are common in proteins that have to function in harsh environments including digestive enzymes (e.g., pepsin and chymotrypsin) and structural proteins (e.g., keratin). Disulfides are also found in peptides too small to hold a stable shape on their own (eg. insulin).
Aspartic acid	D	Asp	Behaves similarly to glutamic acid. Carries a hydrophilic acidic group with strong negative charge. Usually is located on the outer surface of the protein, making it water-soluble. Binds to positively-charged molecules and ions, often used in enzymes to fix the metal ion. When located inside of the protein, aspartate and glutamate are usually paired with arginine and lysine.

Glutamic acid	E	Glu	Behaves similar to aspartic acid. Has longer, slightly more flexible side chain.
Phenylalanine	F	Phe	Essential for humans. Phenylalanine, tyrosine, and tryptophan contain large rigid aromatic group on the side-chain. These are the biggest amino acids. Like isoleucine, leucine and valine, these are hydrophobic and tend to orient towards the interior of the folded protein molecule. Phenylalanine can be converted into Tyrosine.
Glycine	G	Gly	Because of the two hydrogen atoms at the α carbon, glycine is not optically active. It is the smallest amino acid, rotates easily, adds flexibility to the protein chain. It is able to fit into the tightest spaces, e.g., the triple helix of collagen. As too much flexibility is usually not desired, as a structural component it is less common than alanine.
Histidine	H	His	In even slightly acidic conditions protonation of the nitrogen occurs, changing the properties of histidine and the polypeptide as a whole. It is used by many proteins as a regulatory mechanism, changing the conformation and behavior of the polypeptide in acidic regions such as the late endosome or lysosome, enforcing conformation change in enzymes. However only a few histidines are needed for this, so it is comparatively scarce.
Isoleucine	I	Ile	Essential for humans. Isoleucine, leucine and valine have large aliphatic hydrophobic side chains. Their molecules are rigid, and their mutual hydrophobic interactions are important for the correct folding of proteins, as these chains tend to be located inside of the protein molecule.
Leucine or isoleucine	J	Xle	A placeholder when either amino acid may occupy a position
Lysine	K	Lys	Essential for humans. Behaves similarly to arginine. Contains a long flexible side-chain with a positively-charged end. The flexibility of the chain makes lysine and arginine suitable for binding to molecules with many negative charges on their surfaces. E.g., DNA-binding proteins have their active regions rich with arginine and lysine. The strong charge makes these two amino acids prone to be located on the outer hydrophilic surfaces of the proteins; when they are found inside, they are usually paired with a corresponding negatively-charged amino acid, e.g., aspartate or glutamate.
Leucine	L	Leu	Essential for humans. Behaves similar to isoleucine and valine. See isoleucine.
Methionine	M	Met	Essential for humans. Always the first amino acid to be incorporated into a protein; sometimes removed after translation. Like cysteine, contains sulfur, but with a methyl group instead of hydrogen. This methyl group can be activated, and is used in many reactions where a new carbon atom is being added to another molecule.
Asparagine	N	Asn	Similar to aspartic acid. Asn contains an amide group where Asp has a carboxyl.
Pyrrolysine	O	Pyl	Similar to lysine, with a pyrroline ring attached.
Proline	P	Pro	Contains an unusual ring to the N-end amine group, which forces the CO-NH amide sequence into a fixed conformation. Can disrupt protein folding structures like α helix or β sheet, forcing the desired kink in the protein chain. Common in collagen, where it often undergoes a posttranslational modification to hydroxyproline.
Glutamine	Q	Gln	Similar to glutamic acid. Gln contains an amide group where Glu has a carboxyl. Used in proteins and as a storage for ammonia. The most abundant Amino Acid in the body.
Arginine	R	Arg	Functionally similar to lysine.
Serine	S	Ser	Serine and threonine have a short group ended with a hydroxyl group. Its hydrogen is easy to remove, so serine and threonine often act as hydrogen donors in enzymes. Both are very hydrophilic, therefore the outer regions of soluble proteins tend to be rich with them.
Threonine	T	Thr	Essential for humans. Behaves similarly to serine.
Selenocysteine	U	Sec	Selenated form of cysteine, which replaces sulfur.
Valine	V	Val	Essential for humans. Behaves similarly to isoleucine and leucine. See isoleucine.
Tryptophan	W	Trp	Essential for humans. Behaves similarly to phenylalanine and tyrosine (see phenylalanine). Precursor of serotonin. Naturally fluorescent.
Unknown	X	Xaa	Placeholder when the amino acid is unknown or unimportant.
Tyrosine	Y	Tyr	Behaves similarly to phenylalanine (precursor to Tyrosine) and tryptophan (see phenylalanine). Precursor of melanin, epinephrine, and thyroid hormones. Naturally fluorescent, although fluorescence is usually quenched by energy transfer to tryptophans.
Glutamic acid or glutamine	Z	Glx	A placeholder when either amino acid may occupy a position.

Catabolism



References

- [1] Ambrogelly A, Palioura S, Söll D (Jan 2007). "Natural expansion of the genetic code" (<http://www.nature.com/nchembio/journal/v3/n1/abs/nchembio847.html>). *Nat Chem Biol* **3** (1): 29–35. doi:10.1038/nchembio847. PMID 17173027. .
 - [2] "The amino acid masses" (http://education.expasy.org/student_projects/isotopident/htdocs/aa-list.html). ExpASy. . Retrieved 2009-01-06.
 - [3] *Physical Biology of the Cell* (Garland Science) p. 178
 - [4] Chapter 20 (Amino Acid Degradation and Synthesis) in: Denise R., PhD. Ferrier. *Lippincott's Illustrated Reviews: Biochemistry (Lippincott's Illustrated Reviews)*. Hagerstwon, MD: Lippincott Williams & Wilkins. ISBN 0-7817-2265-9.
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