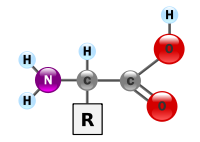
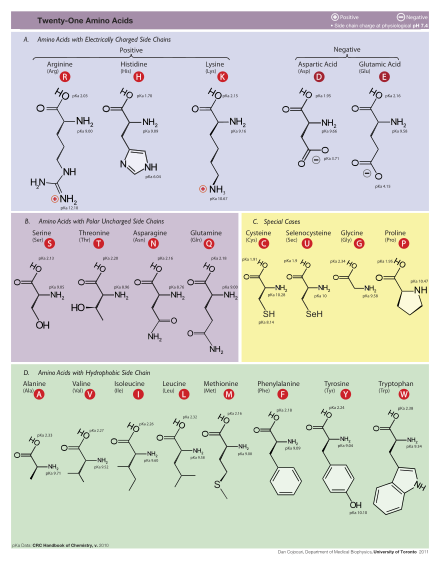
**Amino acid**

From Wikipedia, the free encyclopedia

[](http://en.wikipedia.org/wiki/File:AminoAcidball.svg)

The generic structure of an alpha amino acid in its un-ionized form

[](http://en.wikipedia.org/wiki/File:Amino_Acids.svg)

The 21 amino acids found in [eukaryotes](http://en.wikipedia.org/wiki/Eukaryote), grouped according to their side-chains' [pK](http://en.wikipedia.org/wiki/PKa" \o "PKa)[a](http://en.wikipedia.org/wiki/PKa" \o "PKa) values and charges carried at [physiological pH 7.4](http://en.wikipedia.org/wiki/PH#Living_systems)

**Amino acids** ([/](http://en.wikipedia.org/wiki/Help:IPA_for_English)[əˈmiːnoʊ](http://en.wikipedia.org/wiki/Help:IPA_for_English#Key)[/](http://en.wikipedia.org/wiki/Help:IPA_for_English), [/](http://en.wikipedia.org/wiki/Help:IPA_for_English)[əˈmaɪnoʊ](http://en.wikipedia.org/wiki/Help:IPA_for_English#Key)[/](http://en.wikipedia.org/wiki/Help:IPA_for_English), or [/](http://en.wikipedia.org/wiki/Help:IPA_for_English)[ˈæmɪnoʊ](http://en.wikipedia.org/wiki/Help:IPA_for_English#Key)[/](http://en.wikipedia.org/wiki/Help:IPA_for_English)) are [biologically](http://en.wikipedia.org/wiki/Biology) important [organic compounds](http://en.wikipedia.org/wiki/Organic_compound) composed of [amine](http://en.wikipedia.org/wiki/Amine) (-NH2) and [carboxylic acid](http://en.wikipedia.org/wiki/Carboxylic_acid) (-COOH) [functional groups](http://en.wikipedia.org/wiki/Functional_group), along with a [side-chain](http://en.wikipedia.org/wiki/Substituent) specific to each amino [acid](http://en.wikipedia.org/wiki/Acid). The key elements of an amino acid are [carbon](http://en.wikipedia.org/wiki/Carbon), [hydrogen](http://en.wikipedia.org/wiki/Hydrogen), [oxygen](http://en.wikipedia.org/wiki/Oxygen), and [nitrogen](http://en.wikipedia.org/wiki/Nitrogen), though other elements are found in the side-chains of certain amino acids. About 500 amino acids are known[[1]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes" \l "cite_note-1) and can be classified in many ways. They can be classified according to the core structural functional groups' locations as [alpha- (α-), beta- (β-), gamma- (γ-) or delta- (δ-)](http://en.wikipedia.org/wiki/Alpha_and_beta_carbon) amino acids; other categories relate to [polarity](http://en.wikipedia.org/wiki/Chemical_polarity), [pH](http://en.wikipedia.org/wiki/PH) level, and side-chain group type ([aliphatic](http://en.wikipedia.org/wiki/Aliphatic" \o "Aliphatic),[acyclic](http://en.wikipedia.org/wiki/Open-chain_compound), [aromatic](http://en.wikipedia.org/wiki/Aromatic), containing hydroxyl or [sulfur](http://en.wikipedia.org/wiki/Sulfur), etc.). In the form of [proteins](http://en.wikipedia.org/wiki/Protein), amino acids comprise the second-largest component (water is the largest) of human [muscles](http://en.wikipedia.org/wiki/Muscle), [cells](http://en.wikipedia.org/wiki/Cell_(biology)) and other [tissues](http://en.wikipedia.org/wiki/Tissue_(biology)).[[2]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-2) Outside proteins, amino acids perform critical roles in processes such as [neurotransmitter](http://en.wikipedia.org/wiki/Neurotransmitter) transport and [biosynthesis](http://en.wikipedia.org/wiki/Biosynthesis).

Amino acids having both the amine and the carboxylic acid groups attached to the [first (alpha-) carbon](http://en.wikipedia.org/wiki/Alpha-carbon) atom have particular importance in [biochemistry](http://en.wikipedia.org/wiki/Biochemistry). They are known as **2-, alpha-,** or **α-amino acids** (generic [formula](http://en.wikipedia.org/wiki/Chemical_formula)H2NCHRCOOH in most cases[[3]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-3) where R is an [organic](http://en.wikipedia.org/wiki/Organic_chemistry) [substituent](http://en.wikipedia.org/wiki/Substituent) known as a "[side-chain](http://en.wikipedia.org/wiki/Substituent)");[[4]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-4) often the term "amino acid" is used to refer specifically to these. They include the 23 [proteinogenic](http://en.wikipedia.org/wiki/Proteinogenic_amino_acid" \o "Proteinogenic amino acid) ("protein-building") amino acids,[[5]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-5)[[6]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-6)[[7]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-7) which combine into [peptide](http://en.wikipedia.org/wiki/Peptide) chains ("polypeptides") to form the building-blocks of a vast array of [proteins](http://en.wikipedia.org/wiki/Protein).[[8]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-NIGMS-8) These are all L-[stereoisomers](http://en.wikipedia.org/wiki/Stereoisomerism) ("[left-handed](http://en.wikipedia.org/wiki/Chirality_(chemistry))" [isomers](http://en.wikipedia.org/wiki/Isomer)), although a few D-amino acids ("right-handed") occur in [bacterial envelopes](http://en.wikipedia.org/wiki/Bacterial_envelope) and some [antibiotics](http://en.wikipedia.org/wiki/Antibiotic).[[9]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-9) Twenty of the proteinogenic amino acids are encoded directly by triplet [codons](http://en.wikipedia.org/wiki/Codon) in the [genetic code](http://en.wikipedia.org/wiki/Genetic_code) and are known as "standard" amino acids. The other two ("non-standard" or "non-canonical") are [pyrrolysine](http://en.wikipedia.org/wiki/Pyrrolysine" \o "Pyrrolysine) (found in [methanogenic](http://en.wikipedia.org/wiki/Methanogenic" \o "Methanogenic) organisms and other [eukaryotes](http://en.wikipedia.org/wiki/Eukaryote)) and [selenocysteine](http://en.wikipedia.org/wiki/Selenocysteine" \o "Selenocysteine) (present in many noneukaryotes as well as most eukaryotes). For example, 25 human proteins include selenocysteine (Sec) in their primary structure,[[10]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes" \l "cite_note-10) and the structurally characterized enzymes (selenoenzymes) employ Sec as the catalytic [moiety](http://en.wikipedia.org/wiki/Moiety_(chemistry)) in their active sites.[[11]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-11) Pyrrolysine and selenocysteine are encoded via variant codons; for example, selenocysteine is encoded by [stop codon](http://en.wikipedia.org/wiki/Stop_codon) and [SECIS element](http://en.wikipedia.org/wiki/SECIS_element).[[12]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-12)[[13]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-13)[[14]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-url_The_Genetic_Codes_NCBI-14)Codon–[tRNA](http://en.wikipedia.org/wiki/Transfer_RNA" \o "Transfer RNA) combinations not found in nature can also be used to ["expand" the genetic code](http://en.wikipedia.org/wiki/Expanded_genetic_code) and create novel proteins known as [alloproteins](http://en.wikipedia.org/wiki/Alloprotein" \o "Alloprotein) incorporating non-proteinogenic amino acids.[[15]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-pmid16260173-15)[[16]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-pmid19318213-16)[[17]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-isbn0-387-22046-1-17)

Many important proteinogenic and non-proteinogenic amino acids also play critical non-protein roles within the body. For example, in the [human brain](http://en.wikipedia.org/wiki/Human_brain), glutamate (standard [glutamic acid](http://en.wikipedia.org/wiki/Glutamic_acid)) and[gamma-amino-butyric acid](http://en.wikipedia.org/wiki/Gamma-amino-butyric_acid) ("GABA", non-standard gamma-amino acid) are, respectively, the main [excitatory and inhibitory neurotransmitters](http://en.wikipedia.org/wiki/Neurotransmitter#Excitatory_and_inhibitory);[[18]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-pmid12467378-18) [hydroxyproline](http://en.wikipedia.org/wiki/Hydroxyproline" \o "Hydroxyproline) (a major component of the[connective tissue](http://en.wikipedia.org/wiki/Connective_tissue) [collagen](http://en.wikipedia.org/wiki/Collagen)) is synthesised from [proline](http://en.wikipedia.org/wiki/Proline" \o "Proline); the standard amino acid [glycine](http://en.wikipedia.org/wiki/Glycine) is used to synthesise porphyrins used in [red blood cells](http://en.wikipedia.org/wiki/Red_blood_cell); and the non-standard [carnitine](http://en.wikipedia.org/wiki/Carnitine" \o "Carnitine) is used in [lipid transport](http://en.wikipedia.org/wiki/Lipid).

Nine proteinogenic amino acids are called ["essential"](http://en.wikipedia.org/wiki/Essential_amino_acid) for humans because they cannot be created from other [compounds](http://en.wikipedia.org/wiki/Chemical_compound) by the human body and, so, must be taken in as food. Others may be[conditionally essential](http://en.wikipedia.org/wiki/Essential_amino_acid#Essentiality_vs._conditional_essentiality_in_humans) for certain ages or medical conditions. Essential amino acids may also differ between [species](http://en.wikipedia.org/wiki/Species).[[19]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-19)

Because of their biological significance, amino acids are important in nutrition and are commonly used in [nutritional supplements](http://en.wikipedia.org/wiki/Nutritional_supplement), [fertilizers](http://en.wikipedia.org/wiki/Fertilizer), and [food technology](http://en.wikipedia.org/wiki/Food_technology). Industrial uses include the production of [drugs](http://en.wikipedia.org/wiki/Drugs), [biodegradable plastics](http://en.wikipedia.org/wiki/Biodegradable_plastic), and [chiral catalysts](http://en.wikipedia.org/wiki/Asymmetric_catalysis).

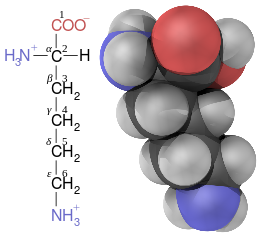
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  + [2.1 Isomerism](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#Isomerism)
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**History**

The first few amino acids were discovered in the early 19th century. In 1806, French chemists [Louis-Nicolas Vauquelin](http://en.wikipedia.org/wiki/Louis-Nicolas_Vauquelin) and [Pierre Jean Robiquet](http://en.wikipedia.org/wiki/Pierre_Jean_Robiquet) isolated a compound in [asparagus](http://en.wikipedia.org/wiki/Asparagus) that was subsequently named [asparagine](http://en.wikipedia.org/wiki/Asparagine), the first amino acid to be discovered.[[20]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-20)[[21]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Anfinsen-21) [Cystine](http://en.wikipedia.org/wiki/Cystine" \o "Cystine) was discovered in 1810,[[22]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-22) although its monomer, [cysteine](http://en.wikipedia.org/wiki/Cysteine), remained undiscovered until 1884.[[21]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Anfinsen-21)[[23]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-23) [Glycine](http://en.wikipedia.org/wiki/Glycine) and [leucine](http://en.wikipedia.org/wiki/Leucine" \o "Leucine) were discovered in 1820.[[24]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-24) Usage of the term *amino acid* in the English language is from 1898.[[25]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-25) Proteins were found to yield amino acids after enzymatic digestion or acid [hydrolysis](http://en.wikipedia.org/wiki/Hydrolysis). In 1902, [Emil Fischer](http://en.wikipedia.org/wiki/Hermann_Emil_Fischer) and [Franz Hofmeister](http://en.wikipedia.org/wiki/Franz_Hofmeister) proposed that proteins are the result of the formation of bonds between the amino group of one amino acid with the carboxyl group of another, in a linear structure that Fischer termed [peptide](http://en.wikipedia.org/wiki/Peptide).[[26]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-26)

**General structure**

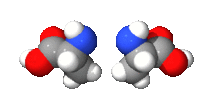
[](http://en.wikipedia.org/wiki/File:Lysine_fisher_structure_and_3d_ball.svg)

[Lysine](http://en.wikipedia.org/wiki/Lysine) with the carbon atoms in the side-chain labeled

In the structure shown at the top of the page, **R** represents a [side-chain](http://en.wikipedia.org/wiki/Substituent) specific to each amino acid. The [carbon](http://en.wikipedia.org/wiki/Carbon) atom next to the [carboxyl group](http://en.wikipedia.org/wiki/Carboxyl_group) is called the [α–carbon](http://en.wikipedia.org/wiki/Alpha_carbon) and amino acids with a side-chain bonded to this carbon are referred to as *alpha amino acids*. These are the most common form found in nature. In the alpha amino acids, the α–carbon is a [chiral](http://en.wikipedia.org/wiki/Chirality_(chemistry)) carbon atom, with the exception of [glycine](http://en.wikipedia.org/wiki/Glycine).[[27]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Creighton-27) In amino acids that have a carbon chain attached to the α–carbon (such as [lysine](http://en.wikipedia.org/wiki/Lysine), shown to the right) the carbons are labeled in order as α, β, γ, δ, and so on.[[28]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-28) In some amino acids, the amine group is attached to the β or γ-carbon, and these are therefore referred to as *beta* or *gamma amino acids*.

Amino acids are usually classified by the [properties](http://en.wikipedia.org/wiki/Chemical_property) of their side-chain into four groups. The side-chain can make an amino acid a [weak acid](http://en.wikipedia.org/wiki/Weak_acid) or a [weak](http://en.wikipedia.org/wiki/Weak_base) [base](http://en.wikipedia.org/wiki/Basic_(chemistry)), and a [hydrophile](http://en.wikipedia.org/wiki/Hydrophile" \o "Hydrophile) if the side-chain is [polar](http://en.wikipedia.org/wiki/Polar_molecule) or a [hydrophobe](http://en.wikipedia.org/wiki/Hydrophobe" \o "Hydrophobe) if it is [nonpolar](http://en.wikipedia.org/wiki/Nonpolar).[[27]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Creighton-27) The [chemical structures](http://en.wikipedia.org/wiki/Chemical_structure) of the 22 standard amino acids, along with their chemical properties, are described more fully in the article on these [proteinogenic amino acids](http://en.wikipedia.org/wiki/Proteinogenic_amino_acid" \o "Proteinogenic amino acid).

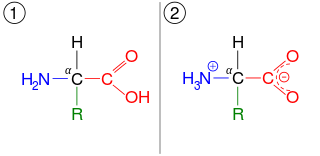
The phrase "[branched-chain amino acids](http://en.wikipedia.org/wiki/Branched-chain_amino_acids)" or BCAA refers to the amino acids having [aliphatic](http://en.wikipedia.org/wiki/Aliphatic) side-chains that are non-linear; these are [leucine](http://en.wikipedia.org/wiki/Leucine" \o "Leucine), [isoleucine](http://en.wikipedia.org/wiki/Isoleucine), and [valine](http://en.wikipedia.org/wiki/Valine" \o "Valine). [Proline](http://en.wikipedia.org/wiki/Proline" \o "Proline) is the only [proteinogenic](http://en.wikipedia.org/wiki/Proteinogenic" \o "Proteinogenic) amino acid whose side-group links to the α-amino group and, thus, is also the only proteinogenic amino acid containing a secondary amine at this position.[[27]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Creighton-27) In chemical terms, proline is, therefore, an [imino acid](http://en.wikipedia.org/wiki/Imino_acid" \o "Imino acid), since it lacks a [primary amino group](http://en.wikipedia.org/wiki/Amine),[[29]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-29) although it is still classed as an amino acid in the current biochemical nomenclature,[[30]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-30) and may also be called an "N-alkylated alpha-amino acid".[[31]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-31)

[](http://en.wikipedia.org/wiki/File:D%2BL-Alanine.gif)

The two enantiomers of alanine, D-Alanine and L-Alanine

**Isomerism**

Of the standard α-amino acids, all but [glycine](http://en.wikipedia.org/wiki/Glycine) can exist in either of two [enantiomers](http://en.wikipedia.org/wiki/Enantiomers), called L or D amino acids, which are mirror images of each other (*see also*[*Chirality*](http://en.wikipedia.org/wiki/Chirality_(chemistry))). While L-amino acids represent all of the amino acids found in [proteins](http://en.wikipedia.org/wiki/Protein) during translation in the ribosome, D-amino acids are found in some proteins produced by enzyme [posttranslational modifications](http://en.wikipedia.org/wiki/Posttranslational_modification) after translation and translocation to the endoplasmic reticulum, as in exotic sea-dwelling organisms such as [cone snails](http://en.wikipedia.org/wiki/Cone_snail).[[32]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-32) They are also abundant components of the [peptidoglycan](http://en.wikipedia.org/wiki/Peptidoglycan) [cell walls](http://en.wikipedia.org/wiki/Cell_wall) of bacteria,[[33]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-33) and D-serine may act as a [neurotransmitter](http://en.wikipedia.org/wiki/Neurotransmitter) in the brain.[[34]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-34) D-amino acids are used in [racemic crystallography](http://en.wikipedia.org/wiki/Racemic_crystallography) to create centrosymmetric crystals, which (depending on the protein) may allow for easier and more robust protein structure determination.[[35]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-35) The L and Dconvention for amino acid configuration refers not to the optical activity of the amino acid itself but rather to the optical activity of the isomer of [glyceraldehyde](http://en.wikipedia.org/wiki/Glyceraldehyde) from which that amino acid can, in theory, be synthesized (D-glyceraldehyde is dextrorotatory; L-glyceraldehyde is levorotatory). In alternative fashion, the [*(S)* and *(R)* designators](http://en.wikipedia.org/wiki/Cahn%E2%80%93Ingold%E2%80%93Prelog_priority_rules) are used to indicate the absolute [stereochemistry](http://en.wikipedia.org/wiki/Stereochemistry). Almost all of the amino acids in proteins are *(S)* at the α carbon, with cysteine being *(R)* and glycine non-chiral.[[36]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-36) Cysteine is unusual since it has a [sulfur](http://en.wikipedia.org/wiki/Sulfur) atom at the second position in its side-chain, which has a larger [atomic mass](http://en.wikipedia.org/wiki/Atomic_mass) than the groups attached to the first carbon, which is attached to the α-carbon in the other standard amino acids, thus the *(R)* instead of *(S)*.

[](http://en.wikipedia.org/wiki/File:Amino_acid_zwitterions.svg)

An amino acid in its (1) un-ionized and (2) zwitterionic forms

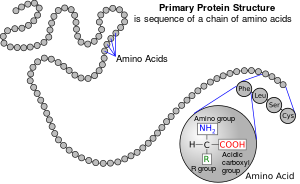
**Zwitterions**

The amine and carboxylic acid functional groups found in amino acids allow them to have [amphiprotic](http://en.wikipedia.org/wiki/Amphoterism" \o "Amphoterism) properties.[[27]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Creighton-27) Carboxylic acid groups (−CO2H) can be deprotonated to become negative carboxylates (−CO2− ), and α-amino groups (NH2−) can be protonated to become positive α-ammonium groups (+NH3−). At pH values greater than the [pKa](http://en.wikipedia.org/wiki/PKa" \o "PKa) of the carboxylic acid group (mean for the 20 common amino acids is about 2.2, see the table of amino acid structures above), the negative carboxylate ion predominates. At pH values lower than the pKa of the α-ammonium group (mean for the 20 common α-amino acids is about 9.4), the nitrogen is predominantly protonated as a positively charged α-ammonium group. Thus, at pH between 2.2 and 9.4, the predominant form adopted by α-amino acids contains a negative carboxylate and a positive α-ammonium group, as shown in structure (2) on the right, so has net zero charge. This molecular state is known as a [zwitterion](http://en.wikipedia.org/wiki/Zwitterion), from the German **Zwitter** meaning *hermaphrodite* or*hybrid*.[[37]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-37) Below pH 2.2, the predominant form will have a neutral carboxylic acid group and a positive α-ammonium ion (net charge +1), and above pH 9.4, a negative carboxylate and neutral α-amino group (net charge −1). The fully neutral form (structure (1) on the right) is a very minor species in aqueous solution throughout the pH range (less than 1 part in 107). Amino acids exist as zwitterions also in the solid phase, and crystallize with salt-like properties unlike typical organic acids or amines.

**Isoelectric point**

At pH values between the two pKa values, the zwitterion predominates, but coexists in [dynamic equilibrium](http://en.wikipedia.org/wiki/Dynamic_equilibrium) with small amounts of net negative and net positive ions. At the exact midpoint between the two pKa values, the trace amount of net negative and trace of net positive ions exactly balance, so that average net charge of all forms present is zero.[[38]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-38) This pH is known as the [isoelectric point](http://en.wikipedia.org/wiki/Isoelectric_point) pI, so pI = ½(pKa1 + pKa2). The individual amino acids all have slightly different pKa values, so have different isoelectric points. For amino acids with charged side-chains, the pKa of the side-chain is involved. Thus for Asp, Glu with negative side-chains, pI = ½(pKa1 + pKaR), where pKaR is the side-chain pKa. Cysteine also has potentially negative side-chain with pKaR = 8.14, so pI should be calculated as for Asp and Glu, even though the side-chain is not significantly charged at neutral pH. For His, Lys, and Arg with positive side-chains, pI = ½(pKaR + pKa2). Amino acids have zero mobility in electrophoresis at their isoelectric point, although this behaviour is more usually exploited for peptides and proteins than single amino acids. Zwitterions have minimum solubility at their isolectric point and some amino acids (in particular, with non-polar side-chains) can be isolated by precipitation from water by adjusting the pH to the required isoelectric point.

**Occurrence and functions in biochemistry**

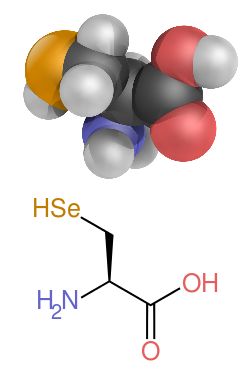
[](http://en.wikipedia.org/wiki/File:Protein_primary_structure.svg)

A [polypeptide](http://en.wikipedia.org/wiki/Polypeptide) is an unbranched chain of amino acids.

**Essential amino acids**

Amino acids are the structural units (monomers) that make up proteins. They join together to form short [polymer](http://en.wikipedia.org/wiki/Polymer) chains called [peptides](http://en.wikipedia.org/wiki/Peptide) or longer chains called either [polypeptides](http://en.wikipedia.org/wiki/Polypeptides) or [proteins](http://en.wikipedia.org/wiki/Protein). These polymers are linear and unbranched, with each amino acid within the chain attached to two neighboring amino acids. The process of making proteins is called [*translation*](http://en.wikipedia.org/wiki/Translation_(biology)) and involves the step-by-step addition of amino acids to a growing protein chain by a [ribozyme](http://en.wikipedia.org/wiki/Ribozyme) that is called a [ribosome](http://en.wikipedia.org/wiki/Ribosome).[[39]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-39) The order in which the amino acids are added is read through the [genetic code](http://en.wikipedia.org/wiki/Genetic_code) from an [mRNA](http://en.wikipedia.org/wiki/Messenger_RNA) template, which is a [RNA](http://en.wikipedia.org/wiki/RNA) copy of one of the organism's [genes](http://en.wikipedia.org/wiki/Gene).

Twenty-two amino acids are naturally incorporated into polypeptides and are called [proteinogenic](http://en.wikipedia.org/wiki/Proteinogenic" \o "Proteinogenic) or natural amino acids.[[27]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Creighton-27) Of these, 20 are encoded by the universal [genetic code](http://en.wikipedia.org/wiki/Genetic_code). The remaining 2, [selenocysteine](http://en.wikipedia.org/wiki/Selenocysteine" \o "Selenocysteine)and [pyrrolysine](http://en.wikipedia.org/wiki/Pyrrolysine" \o "Pyrrolysine), are incorporated into proteins by unique synthetic mechanisms. [Selenocysteine](http://en.wikipedia.org/wiki/Selenocysteine" \o "Selenocysteine) is incorporated when the mRNA being translated includes a [SECIS element](http://en.wikipedia.org/wiki/SECIS_element), which causes the UGA codon to encode selenocysteine instead of a [stop codon](http://en.wikipedia.org/wiki/Stop_codon).[[40]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-40) [Pyrrolysine](http://en.wikipedia.org/wiki/Pyrrolysine" \o "Pyrrolysine) is used by some [methanogenic](http://en.wikipedia.org/wiki/Methanogen" \o "Methanogen) [archaea](http://en.wikipedia.org/wiki/Archaea" \o "Archaea) in enzymes that they use to produce [methane](http://en.wikipedia.org/wiki/Methane). It is coded for with the codon UAG, which is normally a stop codon in other organisms.[[41]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-41) This UAG codon is followed by a [PYLIS downstream sequence](http://en.wikipedia.org/wiki/PYLIS_downstream_sequence).[[42]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-pmid16164991-42)

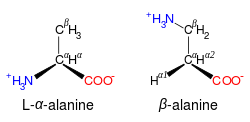
[](http://en.wikipedia.org/wiki/File:Selenocysteine_skeletal_3D.svg)

The amino acid [selenocysteine](http://en.wikipedia.org/wiki/Selenocysteine" \o "Selenocysteine)

**Non-standard amino acids**

Aside from the 23 [proteinogenic amino acids](http://en.wikipedia.org/wiki/Proteinogenic_amino_acid" \o "Proteinogenic amino acid), there are many other amino acids that are called *non-proteinogenic* or *non-standard* (although three of the proteinogenic amino acids are also called *non-standard*, not being encoded simply by the universal [genetic code](http://en.wikipedia.org/wiki/Genetic_code) but requiring additional contextual information). Those either are not found in proteins (for example [carnitine](http://en.wikipedia.org/wiki/Carnitine" \o "Carnitine), [GABA](http://en.wikipedia.org/wiki/Gamma-aminobutyric_acid)) or are not produced directly and in isolation by standard cellular machinery (for example, [hydroxyproline](http://en.wikipedia.org/wiki/Hydroxyproline" \o "Hydroxyproline) and [selenomethionine](http://en.wikipedia.org/wiki/Selenomethionine" \o "Selenomethionine)).

Non-proteinogenic amino acids that are found in proteins are formed by [post-translational modification](http://en.wikipedia.org/wiki/Post-translational_modification), which is modification after translation during protein synthesis. These modifications are often essential for the function or regulation of a protein; for example, the [carboxylation](http://en.wikipedia.org/wiki/Carboxylation) of [glutamate](http://en.wikipedia.org/wiki/Glutamate) allows for better binding of [calcium cations](http://en.wikipedia.org/wiki/Calcium_in_biology),[[43]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-43) and the [hydroxylation](http://en.wikipedia.org/wiki/Hydroxylation) of [proline](http://en.wikipedia.org/wiki/Proline" \o "Proline) is critical for maintaining [connective tissues](http://en.wikipedia.org/wiki/Collagen).[[44]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-44) Another example is the formation of [hypusine](http://en.wikipedia.org/wiki/Hypusine" \o "Hypusine) in the [translation initiation factor](http://en.wikipedia.org/wiki/Eukaryotic_initiation_factor) [EIF5A](http://en.wikipedia.org/wiki/EIF5A), through modification of a lysine residue.[[45]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-45) Such modifications can also determine the localization of the protein, e.g., the addition of long hydrophobic groups can cause a protein to bind to a [phospholipid](http://en.wikipedia.org/wiki/Phospholipid) membrane.[[46]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-46)

[](http://en.wikipedia.org/wiki/File:Beta_alanine_comparison.svg)

β-alanine and its α-alanine isomer

Some nonstandard amino acids are not found in proteins. Examples include [lanthionine](http://en.wikipedia.org/wiki/Lanthionine" \o "Lanthionine), [2-aminoisobutyric acid](http://en.wikipedia.org/wiki/2-aminoisobutyric_acid), [dehydroalanine](http://en.wikipedia.org/wiki/Dehydroalanine" \o "Dehydroalanine), and the neurotransmitter [gamma-aminobutyric acid](http://en.wikipedia.org/wiki/Gamma-aminobutyric_acid). Nonstandard amino acids often occur as intermediates in the [metabolic pathways](http://en.wikipedia.org/wiki/Metabolic_pathway) for standard amino acids – for example, [ornithine](http://en.wikipedia.org/wiki/Ornithine) and [citrulline](http://en.wikipedia.org/wiki/Citrulline" \o "Citrulline) occur in the [urea cycle](http://en.wikipedia.org/wiki/Urea_cycle), part of amino acid [catabolism](http://en.wikipedia.org/wiki/Catabolism) (see below).[[47]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-47) A rare exception to the dominance of α-amino acids in biology is the β-amino acid [beta alanine](http://en.wikipedia.org/wiki/Beta_alanine) (3-aminopropanoic acid), which is used in plants and microorganisms in the synthesis of [pantothenic acid](http://en.wikipedia.org/wiki/Pantothenic_acid) (vitamin B5), a component of [coenzyme A](http://en.wikipedia.org/wiki/Coenzyme_A).[[48]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-48)

**In human nutrition**

When taken up into the human body from the diet, the 22 standard amino acids either are used to synthesize proteins and other biomolecules or are oxidized to [urea](http://en.wikipedia.org/wiki/Urea) and [carbon dioxide](http://en.wikipedia.org/wiki/Carbon_dioxide) as a source of energy.[[49]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-49) The oxidation pathway starts with the removal of the amino group by a [transaminase](http://en.wikipedia.org/wiki/Transaminase); the amino group is then fed into the [urea cycle](http://en.wikipedia.org/wiki/Urea_cycle). The other product of transamidation is a [keto acid](http://en.wikipedia.org/wiki/Keto_acid" \o "Keto acid) that enters the [citric acid cycle](http://en.wikipedia.org/wiki/Citric_acid_cycle).[[50]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-50) [Glucogenic amino acids](http://en.wikipedia.org/wiki/Glucogenic_amino_acid" \o "Glucogenic amino acid) can also be converted into glucose, through [gluconeogenesis](http://en.wikipedia.org/wiki/Gluconeogenesis).[[51]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-51)

Pyrrolysine trait is restricted to several microbes, and only one organism has both Pyl and Sec. Of the 22 standard amino acids, 9 are called [essential amino acids](http://en.wikipedia.org/wiki/Essential_amino_acid) because the [human body](http://en.wikipedia.org/wiki/Human_body) cannot [synthesize](http://en.wikipedia.org/wiki/Biosynthesis) them from other [compounds](http://en.wikipedia.org/wiki/Chemical_compound) at the level needed for normal growth, so they must be obtained from food.[[52]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-52) In addition, [cysteine](http://en.wikipedia.org/wiki/Cysteine), [taurine](http://en.wikipedia.org/wiki/Taurine" \o "Taurine), [tyrosine](http://en.wikipedia.org/wiki/Tyrosine), and [arginine](http://en.wikipedia.org/wiki/Arginine) are considered semiessential amino-acids in children (though taurine is not technically an amino acid), because the metabolic pathways that synthesize these amino acids are not fully developed.[[53]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-53)[[54]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-54) The amounts required also depend on the age and health of the individual, so it is hard to make general statements about the dietary requirement for some amino acids.

|  |  |
| --- | --- |
| **Essential** | **Nonessential** |
| [Histidine](http://en.wikipedia.org/wiki/Histidine) | [Alanine](http://en.wikipedia.org/wiki/Alanine) |
| [Isoleucine](http://en.wikipedia.org/wiki/Isoleucine) | [Arginine](http://en.wikipedia.org/wiki/Arginine)\* |
| [Leucine](http://en.wikipedia.org/wiki/Leucine) | [Asparagine](http://en.wikipedia.org/wiki/Asparagine) |
| [Lysine](http://en.wikipedia.org/wiki/Lysine) | [Aspartic acid](http://en.wikipedia.org/wiki/Aspartic_acid) |
| [Methionine](http://en.wikipedia.org/wiki/Methionine) | [Cysteine](http://en.wikipedia.org/wiki/Cysteine)\* |
| [Phenylalanine](http://en.wikipedia.org/wiki/Phenylalanine) | [Glutamic acid](http://en.wikipedia.org/wiki/Glutamic_acid) |
| [Threonine](http://en.wikipedia.org/wiki/Threonine) | [Glutamine](http://en.wikipedia.org/wiki/Glutamine)\* |
| [Tryptophan](http://en.wikipedia.org/wiki/Tryptophan) | [Glycine](http://en.wikipedia.org/wiki/Glycine) |
| [Valine](http://en.wikipedia.org/wiki/Valine) | [Ornithine](http://en.wikipedia.org/wiki/Ornithine)\* |
|  | [Proline](http://en.wikipedia.org/wiki/Proline)\* |
|  | [Selenocysteine](http://en.wikipedia.org/wiki/Selenocysteine)\* |
|  | [Serine](http://en.wikipedia.org/wiki/Serine)\* |
|  | [Tyrosine](http://en.wikipedia.org/wiki/Tyrosine)\* |

(\*) Essential only in certain cases.[[55]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes" \l "cite_note-55)[[56]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-56)

**Classification**

Although there are many ways to classify amino acids, these molecules can be assorted into six main groups, on the basis of their structure and the general chemical characteristics of their R groups.

|  |  |
| --- | --- |
| **Class** | **Name of the amino acids** |
| Aliphatic | Glycine, Alanine, Valine, Leucine, Isoleucine |
| Hydroxyl or Sulfur/Selenium-containing | Serine, Cysteine, Selenocysteine, Threonine, Methionine |
| Cyclic | Proline |
| Aromatic | Phenylalanine, Tyrosine, Tryptophan |
| Basic | Histidine, Lysine, Arginine |
| Acidic and their Amide | Aspartate, Glutamate, Asparagine, Glutamine |

**Non-protein functions**

In humans, non-protein amino acids also have important roles as [metabolic intermediates](http://en.wikipedia.org/wiki/Metabolic_intermediate), such as in the biosynthesis of the [neurotransmitter](http://en.wikipedia.org/wiki/Neurotransmitter) [gamma-amino-butyric acid](http://en.wikipedia.org/wiki/Gamma-amino-butyric_acid) (GABA). Many amino acids are used to synthesize other molecules, for example:

* [Tryptophan](http://en.wikipedia.org/wiki/Tryptophan) is a precursor of the neurotransmitter [serotonin](http://en.wikipedia.org/wiki/Serotonin).[[57]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-57)
* [Tyrosine](http://en.wikipedia.org/wiki/Tyrosine) (and its precursor phenylalanine) are precursors of the [catecholamine](http://en.wikipedia.org/wiki/Catecholamine) [neurotransmitters](http://en.wikipedia.org/wiki/Neurotransmitter) [dopamine](http://en.wikipedia.org/wiki/Dopamine), [epinephrine](http://en.wikipedia.org/wiki/Epinephrine) and [norepinephrine](http://en.wikipedia.org/wiki/Norepinephrine).
* [Glycine](http://en.wikipedia.org/wiki/Glycine) is a precursor of [porphyrins](http://en.wikipedia.org/wiki/Porphyrin" \o "Porphyrin) such as [heme](http://en.wikipedia.org/wiki/Heme" \o "Heme).[[58]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-58)
* [Arginine](http://en.wikipedia.org/wiki/Arginine) is a precursor of [nitric oxide](http://en.wikipedia.org/wiki/Nitric_oxide).[[59]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-59)
* [Ornithine](http://en.wikipedia.org/wiki/Ornithine) and [S-adenosylmethionine](http://en.wikipedia.org/wiki/S-Adenosyl_methionine) are precursors of [polyamines](http://en.wikipedia.org/wiki/Polyamine).[[60]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-60)
* [Aspartate](http://en.wikipedia.org/wiki/Aspartate), [glycine](http://en.wikipedia.org/wiki/Glycine), and [glutamine](http://en.wikipedia.org/wiki/Glutamine) are precursors of [nucleotides](http://en.wikipedia.org/wiki/Nucleotide).[[61]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-61)
* [Phenylalanine](http://en.wikipedia.org/wiki/Phenylalanine) is a precursor of various [phenylpropanoids](http://en.wikipedia.org/wiki/Phenylpropanoid" \o "Phenylpropanoid), which are important in plant metabolism.

However, not all of the functions of other abundant non-standard amino acids are known.

Some non-standard amino acids are used as [defenses against herbivores](http://en.wikipedia.org/wiki/Plant_defense_against_herbivory) in plants.[[62]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Hylin1969-62) For example, [canavanine](http://en.wikipedia.org/wiki/Canavanine" \o "Canavanine) is an analogue of [arginine](http://en.wikipedia.org/wiki/Arginine) that is found in many [legumes](http://en.wikipedia.org/wiki/Legume),[[63]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Turner1967-63) and in particularly large amounts in *[Canavalia gladiata](http://en.wikipedia.org/wiki/Canavalia_gladiata" \o "Canavalia gladiata)* (sword bean).[[64]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-64) This amino acid protects the plants from predators such as insects and can cause illness in people if some types of legumes are eaten without processing.[[65]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-65) The non-protein amino acid [mimosine](http://en.wikipedia.org/wiki/Mimosine" \o "Mimosine) is found in other species of legume, in particular *[Leucaena leucocephala](http://en.wikipedia.org/wiki/Leucaena_leucocephala" \o "Leucaena leucocephala)*.[[66]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-66) This compound is an analogue of [tyrosine](http://en.wikipedia.org/wiki/Tyrosine) and can poison animals that graze on these plants.

**Uses in industry**

Amino acids are used for a variety of applications in industry, but their main use is as additives to [animal feed](http://en.wikipedia.org/wiki/Compound_feed). This is necessary, since many of the bulk components of these feeds, such as [soybeans](http://en.wikipedia.org/wiki/Soybean), either have low levels or lack some of the [essential amino acids](http://en.wikipedia.org/wiki/Essential_amino_acid): Lysine, methionine, threonine, and tryptophan are most important in the production of these feeds.[[67]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Leuchtenberger2005-67) In this industry, amino acids are also used to chelate metal cations in order to improve the absorption of minerals from supplements, which may be required to improve the health or production of these animals.[[68]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-68)

The [food industry](http://en.wikipedia.org/wiki/Food_industry) is also a major consumer of amino acids, in particular, [glutamic acid](http://en.wikipedia.org/wiki/Glutamic_acid), which is used as a [flavor enhancer](http://en.wikipedia.org/wiki/Flavor_enhancer),[[69]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Garattini-69) and [Aspartame](http://en.wikipedia.org/wiki/Aspartame) (aspartyl-phenylalanine-1-methyl ester) as a low-calorie [artificial sweetener](http://en.wikipedia.org/wiki/Artificial_sweetener).[[70]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-70) Similar technology to that used for animal nutrition is employed in the human nutrition industry to alleviate symptoms of mineral deficiencies, such as anemia, by improving mineral absorption and reducing negative side effects from inorganic mineral supplementation.[[71]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-71)

The chelating ability of amino acids has been used in fertilizers for agriculture to facilitate the delivery of minerals to plants in order to correct mineral deficiencies, such as iron chlorosis. These fertilizers are also used to prevent deficiencies from occurring and improving the overall health of the plants.[[72]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-72) The remaining production of amino acids is used in the synthesis of [drugs](http://en.wikipedia.org/wiki/Pharmaceutical_drug) and [cosmetics](http://en.wikipedia.org/wiki/Cosmetics).[[67]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Leuchtenberger2005-67)

|  |  |
| --- | --- |
| **Amino acid derivative** | **Pharmaceutical application** |
| [5-HTP](http://en.wikipedia.org/wiki/5-HTP) (5-hydroxytryptophan) | Experimental treatment for depression.[[73]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-73) |
| [L-DOPA](http://en.wikipedia.org/wiki/L-DOPA) (L-dihydroxyphenylalanine) | Treatment for [Parkinsonism](http://en.wikipedia.org/wiki/Parkinsonism).[[74]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-74) |
| [Eflornithine](http://en.wikipedia.org/wiki/Eflornithine) | Drug that inhibits [ornithine decarboxylase](http://en.wikipedia.org/wiki/Ornithine_decarboxylase) and is used in the treatment of [sleeping sickness](http://en.wikipedia.org/wiki/African_trypanosomiasis).[[75]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-75) |

**Expanded genetic code**

Since 2001, 40 non-natural amino acids have been added into protein by creating a unique codon (recoding) and a corresponding transfer-RNA:aminoacyl – tRNA-synthetase pair to encode it with diverse physicochemical and biological properties in order to be used as a tool to exploring [protein structure](http://en.wikipedia.org/wiki/Protein_structure) and function or to create novel or enhanced proteins.[[15]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-pmid16260173-15)[[16]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-pmid19318213-16)

**Nullomers**

Nullomers are codons that in theory code for an amino acid, however in nature there is a selective bias against using this codon in favor of another, for example bacteria prefer to use CGA instead of AGA to code for arginine.[[76]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-76) This creates some sequences that do not appear in the genome. This characteristic can be taken advantage of and used to create new selective cancer-fighting drugs[[77]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes" \l "cite_note-77) and to prevent cross-contamination of DNA samples from crime-scene investigations.[[78]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-78)

**Chemical building blocks**

Amino acids are important as low-cost [feedstocks](http://en.wikipedia.org/wiki/Feedstock" \o "Feedstock). These compounds are used in [chiral pool synthesis](http://en.wikipedia.org/wiki/Chiral_pool_synthesis) as [enantiomerically pure](http://en.wikipedia.org/wiki/Enantiomer" \o "Enantiomer) building-blocks.[[79]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Hanessian1993-79)

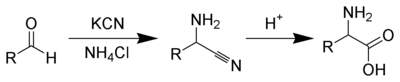
Amino acids have been investigated as precursors [chiral catalysts](http://en.wikipedia.org/wiki/Chiral_catalyst), e.g., for asymmetric [hydrogenation](http://en.wikipedia.org/wiki/Hydrogenation) reactions, although no commercial applications exist.[[80]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Blaser1992-80)

**Biodegradable plastics**

Amino acids are under development as components of a range of biodegradable polymers. These materials have applications as [environmentally friendly](http://en.wikipedia.org/wiki/Environmentally_friendly) packaging and in medicine in [drug delivery](http://en.wikipedia.org/wiki/Drug_delivery) and the construction of [prosthetic implants](http://en.wikipedia.org/wiki/Prosthesis). These polymers include polypeptides, [polyamides](http://en.wikipedia.org/wiki/Polyamide), polyesters, polysulfides, and polyurethanes with amino acids either forming part of their main chains or bonded as side-chains. These modifications alter the physical properties and reactivities of the polymers.[[81]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Sanda1999-81) An interesting example of such materials is [polyaspartate](http://en.wikipedia.org/wiki/Sodium_poly(aspartate)" \o "Sodium poly(aspartate)), a water-soluble biodegradable polymer that may have applications in disposable [diapers](http://en.wikipedia.org/wiki/Diaper) and agriculture.[[82]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Gross2002-82) Due to its solubility and ability to [chelate](http://en.wikipedia.org/wiki/Chelation) metal ions, polyaspartate is also being used as a biodegradeable anti-[scaling](http://en.wikipedia.org/wiki/Fouling) agent and a [corrosion inhibitor](http://en.wikipedia.org/wiki/Corrosion_inhibitor).[[83]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-83)[[84]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Thombre2005-84) In addition, the aromatic amino acid [tyrosine](http://en.wikipedia.org/wiki/Tyrosine) is being developed as a possible replacement for toxic [phenols](http://en.wikipedia.org/wiki/Phenol) such as [bisphenol A](http://en.wikipedia.org/wiki/Bisphenol_A" \o "Bisphenol A) in the manufacture of [polycarbonates](http://en.wikipedia.org/wiki/Polycarbonate).[[85]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Bourke2003-85)

**Reactions**

As amino acids have both a primary [amine](http://en.wikipedia.org/wiki/Amine) group and a primary [carboxyl](http://en.wikipedia.org/wiki/Carboxyl) group, these chemicals can undergo most of the reactions associated with these functional groups. These include [nucleophilic addition](http://en.wikipedia.org/wiki/Nucleophilic_addition), [amide bond](http://en.wikipedia.org/wiki/Amide) formation, and [imine formation](http://en.wikipedia.org/wiki/Alkylimino-de-oxo-bisubstitution) for the amine group, and [esterification](http://en.wikipedia.org/wiki/Esterification), [amide bond](http://en.wikipedia.org/wiki/Amide) formation, and [decarboxylation](http://en.wikipedia.org/wiki/Decarboxylation) for the carboxylic acid group.[[86]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-86) The combination of these functional groups allow amino acids to be effective polydentate ligands for metal-amino acid chelates.[[87]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-87) The multiple side-chains of amino acids can also undergo chemical reactions.[[88]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-88) The types of these reactions are determined by the groups on these side-chains and are, therefore, different between the various types of amino acid.

[](http://en.wikipedia.org/wiki/File:Strecker_Amino_Acid_Synthesis_Scheme.png)

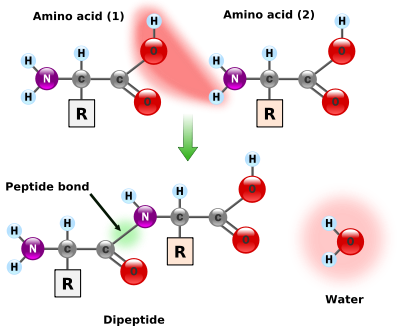
The Strecker amino acid synthesis

**Chemical synthesis**

Several methods exist to synthesize amino acids. One of the oldest methods begins with the [bromination](http://en.wikipedia.org/wiki/Hell-Volhard-Zelinsky_halogenation" \o "Hell-Volhard-Zelinsky halogenation) at the α-carbon of a carboxylic acid. Nucleophilic substitution with [ammonia](http://en.wikipedia.org/wiki/Ammonia) then converts the alkyl bromide to the amino acid.[[89]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-89) In alternative fashion, the [Strecker amino acid synthesis](http://en.wikipedia.org/wiki/Strecker_amino_acid_synthesis" \o "Strecker amino acid synthesis) involves the treatment of an aldehyde with [potassium cyanide](http://en.wikipedia.org/wiki/Potassium_cyanide) and ammonia, this produces an α-amino nitrile as an intermediate. Hydrolysis of the nitrile in acid then yields a α-amino acid.[[90]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-90) Using ammonia or ammonium salts in this reaction gives unsubstituted amino acids, whereas substituting primary and secondary amines will yield substituted amino acids.[[91]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-91) Likewise, using [ketones](http://en.wikipedia.org/wiki/Ketone), instead of aldehydes, gives α,α-disubstituted amino acids.[[92]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-92) The classical synthesis gives[racemic mixtures](http://en.wikipedia.org/wiki/Racemic_mixture) of α-amino acids as products, but several alternative procedures using asymmetric auxiliaries[[93]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-93) or asymmetric catalysts[[94]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-94)[[95]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-95) have been developed.[[96]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-96)

At the current time, the most-adopted method is an [automated](http://en.wikipedia.org/wiki/Automated) synthesis on a solid support (e.g., [polystyrene](http://en.wikipedia.org/wiki/Polystyrene) beads), using [protecting groups](http://en.wikipedia.org/wiki/Protecting_group) (e.g., [Fmoc](http://en.wikipedia.org/wiki/Fmoc_chloride" \o "Fmoc chloride) and [t-Boc](http://en.wikipedia.org/wiki/Tert-butyloxycarbonyl_protecting_group)) and activating groups (e.g., [DCC](http://en.wikipedia.org/wiki/Dicyclohexylcarbodiimide) and [DIC](http://en.wikipedia.org/wiki/Diisopropylcarbodiimide)).

**Peptide bond formation**

[](http://en.wikipedia.org/wiki/File:Peptidformationball.svg)

The condensation of two amino acids to form a [*dipeptide*](http://en.wikipedia.org/wiki/Dipeptide) through a[*peptide bond*](http://en.wikipedia.org/wiki/Peptide_bond)

As both the amine and carboxylic acid groups of amino acids can react to form amide bonds, one amino acid molecule can react with another and become joined through an amide linkage. This[polymerization](http://en.wikipedia.org/wiki/Polymerization) of amino acids is what creates proteins. This [condensation reaction](http://en.wikipedia.org/wiki/Condensation_reaction) yields the newly formed [peptide bond](http://en.wikipedia.org/wiki/Peptide_bond) and a molecule of water. In cells, this reaction does not occur directly; instead, the amino acid is first activated by attachment to a [transfer RNA](http://en.wikipedia.org/wiki/Transfer_RNA) molecule through an [ester](http://en.wikipedia.org/wiki/Ester) bond. This aminoacyl-tRNA is produced in an [ATP](http://en.wikipedia.org/wiki/Adenosine_triphosphate)-dependent reaction carried out by an[aminoacyl tRNA synthetase](http://en.wikipedia.org/wiki/Aminoacyl_tRNA_synthetase).[[97]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-97) This aminoacyl-tRNA is then a substrate for the [ribosome](http://en.wikipedia.org/wiki/Ribosome), which catalyzes the attack of the amino group of the elongating protein chain on the ester bond.[[98]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-98) As a result of this mechanism, all proteins made by ribosomes are synthesized starting at their N-terminus and moving toward their C-terminus.

However, not all peptide bonds are formed in this way. In a few cases, peptides are synthesized by specific enzymes. For example, the tripeptide [glutathione](http://en.wikipedia.org/wiki/Glutathione) is an essential part of the defenses of cells against oxidative stress. This peptide is synthesized in two steps from free amino acids.[[99]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-99) In the first step, [gamma-glutamylcysteine synthetase](http://en.wikipedia.org/wiki/Gamma-glutamylcysteine_synthetase) condenses [cysteine](http://en.wikipedia.org/wiki/Cysteine) and [glutamic acid](http://en.wikipedia.org/wiki/Glutamic_acid) through a peptide bond formed between the side-chain carboxyl of the glutamate (the gamma carbon of this side-chain) and the amino group of the cysteine. This dipeptide is then condensed with [glycine](http://en.wikipedia.org/wiki/Glycine) by[glutathione synthetase](http://en.wikipedia.org/wiki/Glutathione_synthetase) to form glutathione.[[100]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-100)

In chemistry, peptides are synthesized by a variety of reactions. One of the most-used in [solid-phase peptide synthesis](http://en.wikipedia.org/wiki/Peptide_synthesis) uses the aromatic oxime derivatives of amino acids as activated units. These are added in sequence onto the growing peptide chain, which is attached to a solid resin support.[[101]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-101) The ability to easily synthesize vast numbers of different peptides by varying the types and order of amino acids (using [combinatorial chemistry](http://en.wikipedia.org/wiki/Combinatorial_chemistry)) has made peptide synthesis particularly important in creating libraries of peptides for use in drug discovery through [high-throughput screening](http://en.wikipedia.org/wiki/High-throughput_screening).[[102]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-102)

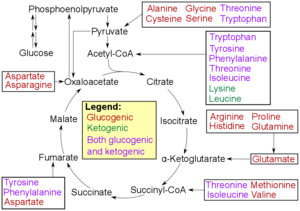
**Biosynthesis**

In plants, nitrogen is first assimilated into organic compounds in the form of [glutamate](http://en.wikipedia.org/wiki/Glutamate), formed from alpha-ketoglutarate and ammonia in the mitochondrion. In order to form other amino acids, the plant uses [transaminases](http://en.wikipedia.org/wiki/Transaminase) to move the amino group to another alpha-keto carboxylic acid. For example, aspartate aminotransferase converts glutamate and oxaloacetate to alpha-ketoglutarate and aspartate.[[103]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-103) Other organisms use transaminases for amino acid synthesis, too.

Nonstandard amino acids are usually formed through modifications to standard amino acids. For example, [homocysteine](http://en.wikipedia.org/wiki/Homocysteine" \o "Homocysteine) is formed through the [transsulfuration pathway](http://en.wikipedia.org/wiki/Transsulfuration_pathway" \o "Transsulfuration pathway) or by the demethylation of methionine via the intermediate metabolite [S-adenosyl methionine](http://en.wikipedia.org/wiki/S-adenosyl_methionine),[[104]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Brosnan-104) while [hydroxyproline](http://en.wikipedia.org/wiki/Hydroxyproline" \o "Hydroxyproline) is made by a [posttranslational modification](http://en.wikipedia.org/wiki/Posttranslational_modification) of [proline](http://en.wikipedia.org/wiki/Proline" \o "Proline).[[105]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-105)

[Microorganisms](http://en.wikipedia.org/wiki/Microorganism) and plants can synthesize many uncommon amino acids. For example, some microbes make [2-aminoisobutyric acid](http://en.wikipedia.org/wiki/2-aminoisobutyric_acid) and [lanthionine](http://en.wikipedia.org/wiki/Lanthionine" \o "Lanthionine), which is a sulfide-bridged derivative of alanine. Both of these amino acids are found in peptidic [lantibiotics](http://en.wikipedia.org/wiki/Lantibiotics" \o "Lantibiotics) such as[alamethicin](http://en.wikipedia.org/wiki/Alamethicin).[[106]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-106) However, in plants, [1-aminocyclopropane-1-carboxylic acid](http://en.wikipedia.org/wiki/1-aminocyclopropane-1-carboxylic_acid) is a small disubstituted cyclic amino acid that is a key intermediate in the production of the plant hormone [ethylene](http://en.wikipedia.org/wiki/Ethylene#Ethylene_as_a_plant_hormone).[[107]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-107)

**Catabolism**

[](http://en.wikipedia.org/wiki/File:Amino_acid_catabolism_revised.png)

Catabolism of proteinogenic amino acids. Amino acids can be classified according to the properties of their main products as either of the following:[[108]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-108)  
\* *Glucogenic*, with the products having the ability to form [glucose](http://en.wikipedia.org/wiki/Glucose) by [gluconeogenesis](http://en.wikipedia.org/wiki/Gluconeogenesis)  
\* *Ketogenic*, with the products not having the ability to form glucose. These products may still be used for[ketogenesis](http://en.wikipedia.org/wiki/Ketogenesis) or [lipid synthesis](http://en.wikipedia.org/wiki/Lipid_synthesis).  
\* Amino acids catabolized into both glucogenic and ketogenic products.

Degradation of an amino acid often involves [deamination](http://en.wikipedia.org/wiki/Deamination) by moving its amino group to alpha-ketoglutarate, forming glutamate. This process involves transaminases, often the same as those used in amination during synthesis. In many vertebrates, the amino group is then removed through the [urea cycle](http://en.wikipedia.org/wiki/Urea_cycle) and is excreted in the form of [urea](http://en.wikipedia.org/wiki/Urea). However, amino acid degradation can produce [uric acid](http://en.wikipedia.org/wiki/Uric_acid) or ammonia instead. For example, [serine dehydratase](http://en.wikipedia.org/wiki/Serine_dehydratase) converts serine to pyruvate and ammonia.[[109]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-109) After removal of one or more amino groups, the remainder of the molecule can sometimes be used to synthesize new amino acids, or it can be used for energy by entering [glycolysis](http://en.wikipedia.org/wiki/Glycolysis) or the [citric acid cycle](http://en.wikipedia.org/wiki/Citric_acid_cycle), as detailed in image at right.

**Physicochemical properties of amino acids**

The 20 amino acids encoded directly by the genetic code can be divided into several groups based on their properties. Important factors are charge, [hydrophilicity](http://en.wikipedia.org/wiki/Hydrophile" \o "Hydrophile) or [hydrophobicity](http://en.wikipedia.org/wiki/Hydrophobe), size, and functional groups.[[27]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Creighton-27)These properties are important for [protein structure](http://en.wikipedia.org/wiki/Protein_structure) and [protein–protein interactions](http://en.wikipedia.org/wiki/Protein%E2%80%93protein_interaction). The water-soluble proteins tend to have their hydrophobic residues (Leu, Ile, Val, Phe, and Trp) buried in the middle of the protein, whereas hydrophilic side-chains are exposed to the aqueous solvent. The [integral membrane proteins](http://en.wikipedia.org/wiki/Integral_membrane_protein) tend to have outer rings of exposed [hydrophobic](http://en.wikipedia.org/wiki/Hydrophobic) amino acids that anchor them into the [lipid bilayer](http://en.wikipedia.org/wiki/Lipid_bilayer). In the case part-way between these two extremes, some [peripheral membrane proteins](http://en.wikipedia.org/wiki/Peripheral_membrane_protein) have a patch of hydrophobic amino acids on their surface that locks onto the membrane. In similar fashion, proteins that have to bind to positively charged molecules have surfaces rich with negatively charged amino acids like [glutamate](http://en.wikipedia.org/wiki/Glutamate) and [aspartate](http://en.wikipedia.org/wiki/Aspartate), while proteins binding to negatively charged molecules have surfaces rich with positively charged chains like [lysine](http://en.wikipedia.org/wiki/Lysine) and [arginine](http://en.wikipedia.org/wiki/Arginine). There are different [hydrophobicity scales](http://en.wikipedia.org/wiki/Hydrophobicity_scale) of amino acid residues.[[110]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-110)

Some amino acids have special properties such as [cysteine](http://en.wikipedia.org/wiki/Cysteine), that can form covalent [disulfide bonds](http://en.wikipedia.org/wiki/Disulfide_bond) to other cysteine residues, [proline](http://en.wikipedia.org/wiki/Proline" \o "Proline) that forms [a cycle](http://en.wikipedia.org/wiki/Cyclic_compound) to the polypeptide backbone, and [glycine](http://en.wikipedia.org/wiki/Glycine) that is more flexible than other amino acids.

Many proteins undergo a range of [posttranslational modifications](http://en.wikipedia.org/wiki/Posttranslational_modification), when additional chemical groups are attached to the amino acids in proteins. Some modifications can produce hydrophobic [lipoproteins](http://en.wikipedia.org/wiki/Lipoprotein),[[111]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes" \l "cite_note-111) or hydrophilic [glycoproteins](http://en.wikipedia.org/wiki/Glycoprotein).[[112]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-112) These type of modification allow the reversible targeting of a protein to a membrane. For example, the addition and removal of the fatty acid [palmitic acid](http://en.wikipedia.org/wiki/Palmitic_acid" \o "Palmitic acid) to cysteine residues in some signaling proteins causes the proteins to attach and then detach from cell membranes.[[113]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-113)

**Table of standard amino acid abbreviations and properties**

| **Amino Acid** | **3-Letter**[[114]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Hausman-114) | **1-Letter**[[114]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Hausman-114) | **Side-chain polarity**[[114]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Hausman-114) | **Side-chain charge (pH 7.4)**[[114]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Hausman-114) | [**Hydropathy index**](http://en.wikipedia.org/wiki/Hydropathy_index)[[115]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-115) | [**Absorbance**](http://en.wikipedia.org/wiki/Absorbance)**λmax(nm)**[[116]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Freifelder-116) | **ε at λmax (x10−3 M−1 cm−1)**[[116]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-Freifelder-116) |
| --- | --- | --- | --- | --- | --- | --- | --- |
| [Alanine](http://en.wikipedia.org/wiki/Alanine) | Ala | A | nonpolar | neutral | 1.8 |  |  |
| [Arginine](http://en.wikipedia.org/wiki/Arginine) | Arg | R | Basic polar | positive | −4.5 |  |  |
| [Asparagine](http://en.wikipedia.org/wiki/Asparagine) | Asn | N | polar | neutral | −3.5 |  |  |
| [Aspartic acid](http://en.wikipedia.org/wiki/Aspartic_acid) | Asp | D | acidic polar | negative | −3.5 |  |  |
| [Cysteine](http://en.wikipedia.org/wiki/Cysteine) | Cys | C | nonpolar | neutral | 2.5 | 250 | 0.3 |
| [Glutamic acid](http://en.wikipedia.org/wiki/Glutamic_acid) | Glu | E | acidic polar | negative | −3.5 |  |  |
| [Glutamine](http://en.wikipedia.org/wiki/Glutamine) | Gln | Q | polar | neutral | −3.5 |  |  |
| [Glycine](http://en.wikipedia.org/wiki/Glycine) | Gly | G | nonpolar | neutral | −0.4 |  |  |
| [Histidine](http://en.wikipedia.org/wiki/Histidine) | His | H | Basic polar | positive(10%)  neutral(90%) | −3.2 | 211 | 5.9 |
| [Isoleucine](http://en.wikipedia.org/wiki/Isoleucine) | Ile | I | nonpolar | neutral | 4.5 |  |  |
| [Leucine](http://en.wikipedia.org/wiki/Leucine) | Leu | L | nonpolar | neutral | 3.8 |  |  |
| [Lysine](http://en.wikipedia.org/wiki/Lysine) | Lys | K | Basic polar | positive | −3.9 |  |  |
| [Methionine](http://en.wikipedia.org/wiki/Methionine) | Met | M | nonpolar | neutral | 1.9 |  |  |
| [Phenylalanine](http://en.wikipedia.org/wiki/Phenylalanine) | Phe | F | nonpolar | neutral | 2.8 | 257, 206, 188 | 0.2, 9.3, 60.0 |
| [Proline](http://en.wikipedia.org/wiki/Proline) | Pro | P | nonpolar | neutral | −1.6 |  |  |
| [Serine](http://en.wikipedia.org/wiki/Serine) | Ser | S | polar | neutral | −0.8 |  |  |
| [Threonine](http://en.wikipedia.org/wiki/Threonine) | Thr | T | polar | neutral | −0.7 |  |  |
| [Tryptophan](http://en.wikipedia.org/wiki/Tryptophan) | Trp | W | nonpolar | neutral | −0.9 | 280, 219 | 5.6, 47.0 |
| [Tyrosine](http://en.wikipedia.org/wiki/Tyrosine) | Tyr | Y | polar | neutral | −1.3 | 274, 222, 193 | 1.4, 8.0, 48.0 |
| [Valine](http://en.wikipedia.org/wiki/Valine) | Val | V | nonpolar | neutral | 4.2 |  |  |

Two additional amino acids are in some species coded for by [codons](http://en.wikipedia.org/wiki/Genetic_code) that are usually interpreted as [stop codons](http://en.wikipedia.org/wiki/Stop_codon):

|  |  |  |
| --- | --- | --- |
| **21st and 22nd amino acids** | **3-Letter** | **1-Letter** |
| [Selenocysteine](http://en.wikipedia.org/wiki/Selenocysteine) | Sec | U |
| [Pyrrolysine](http://en.wikipedia.org/wiki/Pyrrolysine) | Pyl | O |

In addition to the specific amino acid codes, placeholders are used in cases where [chemical](http://en.wikipedia.org/wiki/Protein_sequencing) or [crystallographic](http://en.wikipedia.org/wiki/X-ray_crystallography) analysis of a peptide or protein cannot conclusively determine the identity of a residue.

|  |  |  |
| --- | --- | --- |
| **Ambiguous Amino Acids** | **3-Letter** | **1-Letter** |
| Asparagine or aspartic acid | Asx | B |
| Glutamine or glutamic acid | Glx | Z |
| Leucine or Isoleucine | Xle | J |
| Unspecified or unknown amino acid | Xaa | X |

**Unk** is sometimes used instead of **Xaa**, but is less standard.

In addition, many [non-standard amino acids](http://en.wikipedia.org/wiki/Non-proteinogenic_amino_acids) have a specific code. For example, several peptide drugs, such as [Bortezomib](http://en.wikipedia.org/wiki/Bortezomib" \o "Bortezomib) and [MG132](http://en.wikipedia.org/wiki/MG132), are [artificially synthesized](http://en.wikipedia.org/wiki/Peptide_synthesis) and retain their [protecting groups](http://en.wikipedia.org/wiki/Protecting_group), which have specific codes. Bortezomib is [Pyz](http://en.wikipedia.org/wiki/Pyrazinoic_acid" \o "Pyrazinoic acid)-Phe-boroLeu, and MG132 is [Z](http://en.wikipedia.org/wiki/Carboxybenzyl)-Leu-Leu-Leu-al. To aid in the analysis of protein structure, [photo-reactive amino acid analogs](http://en.wikipedia.org/wiki/Photo-reactive_amino_acid_analog) are available. These include [photoleucine](http://en.wikipedia.org/w/index.php?title=Photoleucine&action=edit&redlink=1" \o "Photoleucine (page does not exist)) (**pLeu**) and [photomethionine](http://en.wikipedia.org/w/index.php?title=Photomethionine&action=edit&redlink=1" \o "Photomethionine (page does not exist)) (**pMet**).[[117]](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_note-117)

**See also**

* [Amino acid dating](http://en.wikipedia.org/wiki/Amino_acid_dating)
* [Beta-peptide](http://en.wikipedia.org/wiki/Beta-peptide)
* [Degron](http://en.wikipedia.org/wiki/Degron)
* [Erepsin](http://en.wikipedia.org/wiki/Erepsin)
* [Homochirality](http://en.wikipedia.org/wiki/Homochirality)
* [Hyperaminoacidemia](http://en.wikipedia.org/wiki/Hyperaminoacidemia)
* [Leucines](http://en.wikipedia.org/wiki/Leucines)
* [Miller–Urey experiment](http://en.wikipedia.org/wiki/Miller%E2%80%93Urey_experiment)
* [Proteinogenic amino acid](http://en.wikipedia.org/wiki/Proteinogenic_amino_acid)
* [Table of codons](http://en.wikipedia.org/wiki/RNA_codon_table), 3-nucleotide sequences that encode each amino acid

**References and notes**

* 1. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-1) Wagner, Ingrid; Musso, Hans (November 1983). "New Naturally Occurring Amino Acids".*Angew. Chem. Int. Ed. Engl.* **22** (22): 816–828. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1002/anie.198308161](http://dx.doi.org/10.1002%2Fanie.198308161).
  2. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-2) [Human nutrition in the developing world](http://www.fao.org/docrep/W0073E/w0073e04.htm#P1625_217364) – United Nations [Food and Agriculture Organization](http://en.wikipedia.org/wiki/Food_and_Agriculture_Organization), ch.8
  3. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-3) [Proline](http://en.wikipedia.org/wiki/Proline" \o "Proline) is an exception to this general formula. It lacks the NH2 group because of the[cyclization](http://en.wikipedia.org/wiki/Cyclization) of the side-chain and is known as an [imino acid](http://en.wikipedia.org/wiki/Imino_acid" \o "Imino acid); it falls under the category of special structured amino acids.
  4. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-4) [– INTRODUCING AMINO ACIDS](http://www.chemguide.co.uk/organicprops/aminoacids/background.html)
  5. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-5) ["Amino acids"](http://books.google.com/books?id=doe9NwgJTAsC&pg=PA20#v=onepage&q&f=false). *Peptides from A to Z: A Concise Encyclopedia*. John Wiley & Sons. 2008. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [9783527621170](http://en.wikipedia.org/wiki/Special:BookSources/9783527621170).
  6. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-6) Pollegioni, Loredano; Servi, Stefano, eds. (2012). [*Unnatural Amino Acids*](http://www.springer.com/life+sciences/biochemistry+%26+biophysics/book/978-1-61779-330-1). Humana Press. p. v. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-1-61779-331-8](http://en.wikipedia.org/wiki/Special:BookSources/978-1-61779-331-8).
  7. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-7) Hertweck, Christian (2011). "Biosynthesis and Charging of Pyrrolysine, the 22nd Genetically Encoded Amino Acid". *Angew. Chem. Int. Ed.* **50**: 9540–9541. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1002/anie.201103769](http://dx.doi.org/10.1002%2Fanie.201103769).
  8. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-NIGMS_8-0) ["The Structures of Life"](http://publications.nigms.nih.gov/structlife/chapter1.html). National Institute of General Medical Sciences. Retrieved 20 May 2008.
  9. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-9) "Biochemical pathways: an atlas of biochemistry and molecular biology" – Michal, p.5
  10. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-10) Kryukov GV, Castellano S, Novoselov SV, Lobanov AV, Zehtab O, Guigo R, et al. Characterization of mammalian selenoproteomes. *Science*. 2003;300:1439–1443.
  11. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-11) Gromer, S., Urig, S., Becker, K. (2004) The Thioredoxin System – From Science to Clinic. Medicinal Research Reviews. 24(1):40–89.
  12. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-12) [Modeling Electrostatic Contributions to Protein Folding and Binding](http://books.google.com/books?id=BDn-AI_YBlMC&pg=PA1&lpg=PA1&ots=WSsFhHJwDy&sig=jkSLFr7AK8iu6OhdX7KOc10eKRY&hl=en&sa=X&ei=gshLUOWZLIin0AXRm4GoBg) – Tjong, p.1 footnote
  13. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-13) [Frontiers in Drug Design and Discovery](http://books.google.com/books?id=VoJw6fIISSkC&pg=PA299&lpg=PA299&ots=C20L115r05&sig=4cix7yKNlod3xbzy2TWiOzEe6As&hl=en&sa=X&ei=H81LUL6MOfC10QX4wYG4Cw&ved=0CIcBEOgBMA8)ed. Atta-Ur-Rahman & others, p.299
  14. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-url_The_Genetic_Codes_NCBI_14-0) Elzanowski A, Ostell J (7 April 2008). ["The Genetic Codes"](http://www.ncbi.nlm.nih.gov/Taxonomy/Utils/wprintgc.cgi?mode=c). National Center for Biotechnology Information (NCBI). Retrieved 10 March 2010.
  15. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-pmid16260173_15-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-pmid16260173_15-1) Xie J, Schultz PG (December 2005). "Adding amino acids to the genetic repertoire".*Current Opinion in Chemical Biology* **9** (6): 548–54. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.cbpa.2005.10.011](http://dx.doi.org/10.1016%2Fj.cbpa.2005.10.011). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16260173](http://www.ncbi.nlm.nih.gov/pubmed/16260173).
  16. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-pmid19318213_16-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-pmid19318213_16-1) Wang Q, Parrish AR, Wang L (March 2009). ["Expanding the genetic code for biological studies"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2696486). *Chem. Biol.* **16** (3): 323–36. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.chembiol.2009.03.001](http://dx.doi.org/10.1016%2Fj.chembiol.2009.03.001). [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [2696486](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2696486). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [19318213](http://www.ncbi.nlm.nih.gov/pubmed/19318213).
  17. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-isbn0-387-22046-1_17-0) Simon M (2005). *Emergent computation: emphasizing bioinformatics*. New York: AIP Press/Springer Science+Business Media. pp. 105–106. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-387-22046-1](http://en.wikipedia.org/wiki/Special:BookSources/0-387-22046-1).
  18. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-pmid12467378_18-0) Petroff OA (December 2002). ["GABA and glutamate in the human brain"](http://nro.sagepub.com/cgi/pmidlookup?view=long&pmid=12467378). *Neuroscientist* **8** (6): 562–573. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1177/1073858402238515](http://dx.doi.org/10.1177%2F1073858402238515). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12467378](http://www.ncbi.nlm.nih.gov/pubmed/12467378).
  19. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-19) For example, [ruminants](http://en.wikipedia.org/wiki/Ruminant) such as cows obtain a number of amino acids via [microbes](http://en.wikipedia.org/wiki/Microbe) in the [first two stomach chambers](http://en.wikipedia.org/wiki/Reticulorumen).
  20. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-20) Vauquelin LN, Robiquet PJ (1806). "The discovery of a new plant principle in Asparagus sativus". *Annales de Chimie* **57**: 88–93.
  21. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Anfinsen_21-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Anfinsen_21-1) Anfinsen CB, Edsall JT, Richards FM (1972). *Advances in Protein Chemistry*. New York: Academic Press. pp. 99, 103. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-0-12-034226-6](http://en.wikipedia.org/wiki/Special:BookSources/978-0-12-034226-6).
  22. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-22) Wollaston WH (1810). "On cystic oxide, a new species of urinary calculus". *Philosophical Transactions of the Royal Society* **100** (0): 223–30. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1098/rstl.1810.0015](http://dx.doi.org/10.1098%2Frstl.1810.0015).
  23. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-23) Baumann E (1884). ["Über cystin und cystein"](http://vlp.mpiwg-berlin.mpg.de/library/data/lit16533). *Z Physiol Chemie* **8** (4): 299–305. [Archived](http://web.archive.org/web/20110314075450/http:/vlp.mpiwg-berlin.mpg.de/library/data/lit16533) from the original on 14 March 2011. Retrieved 28 March 2011.
  24. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-24) Braconnot HM (1820). "Sur la conversion des matières animales en nouvelles substances par le moyen de l'acide sulfurique". *Annales de Chimie et Physique*. Série 2 **13**: 113–25.
  25. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-25) ["etymonline.com entry for *amino*"](http://www.etymonline.com/index.php?term=amino). www.etymonline.com. Retrieved 19 July 2010.
  26. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-26) Joseph S. Fruton (1990). "Chapter 5- Emil Fischer and Franz Hofmeister". *Contrasts in Scientific Style: Research Groups in the Chemical and Biochemical Sciences,* **191**. American Philosophical Society. pp. 163–165. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-87169-191-4](http://en.wikipedia.org/wiki/Special:BookSources/0-87169-191-4).
  27. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Creighton_27-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Creighton_27-1) [***c***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Creighton_27-2) [***d***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Creighton_27-3) [***e***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Creighton_27-4) [***f***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Creighton_27-5) Creighton, Thomas H. (1993). "Chapter 1". *Proteins: structures and molecular properties*. San Francisco: W. H. Freeman. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-0-7167-7030-5](http://en.wikipedia.org/wiki/Special:BookSources/978-0-7167-7030-5).
  28. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-28) ["Nomenclature and Symbolism for Amino Acids and Peptides"](http://www.chem.qmul.ac.uk/iupac/AminoAcid/AA1n2.html). IUPAC-IUB Joint Commission on Biochemical Nomenclature. 1983. [Archived](http://web.archive.org/web/20081009023202/http:/www.chem.qmul.ac.uk/iupac/AminoAcid/AA1n2.html) from the original on 9 October 2008. Retrieved 17 November 2008.
  29. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-29) Jodidi, S. L. (1 March 1926). "The Formol Titration of Certain Amino Acids". *Journal of the American Chemical Society* **48** (3): 751–753. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/ja01414a033](http://dx.doi.org/10.1021%2Fja01414a033).
  30. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-30) Liebecq, Claude, ed. (1992). *Biochemical Nomenclature and Related Documents* (2nd ed.). Portland Press. pp. 39–69. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-1-85578-005-7](http://en.wikipedia.org/wiki/Special:BookSources/978-1-85578-005-7).
  31. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-31) Smith, Anthony D. (1997). *Oxford dictionary of biochemistry and molecular biology*. Oxford: Oxford University Press. p. 535. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-0-19-854768-6](http://en.wikipedia.org/wiki/Special:BookSources/978-0-19-854768-6). [OCLC](http://en.wikipedia.org/wiki/OCLC) [37616711](http://www.worldcat.org/oclc/37616711).
  32. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-32) Pisarewicz K, Mora D, Pflueger FC, Fields GB, Marí F (May 2005). "Polypeptide chains containing D-gamma-hydroxyvaline". *Journal of the American Chemical Society* **127** (17): 6207–15. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/ja050088m](http://dx.doi.org/10.1021%2Fja050088m).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15853325](http://www.ncbi.nlm.nih.gov/pubmed/15853325).
  33. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-33) van Heijenoort J (March 2001). "Formation of the glycan chains in the synthesis of bacterial peptidoglycan". *Glycobiology* **11** (3): 25R–36R. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1093/glycob/11.3.25R](http://dx.doi.org/10.1093%2Fglycob%2F11.3.25R). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [11320055](http://www.ncbi.nlm.nih.gov/pubmed/11320055).
  34. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-34) Wolosker H, Dumin E, Balan L, Foltyn VN (July 2008). "D-amino acids in the brain: D-serine in neurotransmission and neurodegeneration". *The FEBS Journal* **275** (14): 3514–26.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1111/j.1742-4658.2008.06515.x](http://dx.doi.org/10.1111%2Fj.1742-4658.2008.06515.x). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [18564180](http://www.ncbi.nlm.nih.gov/pubmed/18564180).
  35. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-35) Matthews, B.W. (2009). ["Racemic crystallography—easy crystals and easy structures: What's not to like?"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2774423). *Protein Science* **18** (6): 1135–1138. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1002/pro.125](http://dx.doi.org/10.1002%2Fpro.125).[PMC](http://en.wikipedia.org/wiki/PubMed_Central) [2774423](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2774423). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [19472321](http://www.ncbi.nlm.nih.gov/pubmed/19472321).
  36. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-36) Hatem, Salama Mohamed Ali (2006). ["Gas chromatographic determination of Amino Acid Enantiomers in tobacco and bottled wines"](http://geb.uni-giessen.de/geb/volltexte/2006/3038/index.html). University of Giessen. Retrieved 17 November 2008.
  37. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-37) Simmons, William J.; Gerhard Meisenberg (2006). *Principles of medical biochemistry*. Mosby Elsevier. p. 19. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-323-02942-6](http://en.wikipedia.org/wiki/Special:BookSources/0-323-02942-6).
  38. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-38) Fennema OR. *Food Chemistry 3rd Ed*. CRC Press. pp. 327–8. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-8247-9691-8](http://en.wikipedia.org/wiki/Special:BookSources/0-8247-9691-8).
  39. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-39) Rodnina MV, Beringer M, Wintermeyer W (January 2007). "How ribosomes make peptide bonds". *Trends in Biochemical Sciences* **32** (1): 20–6. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.tibs.2006.11.007](http://dx.doi.org/10.1016%2Fj.tibs.2006.11.007). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [17157507](http://www.ncbi.nlm.nih.gov/pubmed/17157507).
  40. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-40) Driscoll DM, Copeland PR (2003). "Mechanism and regulation of selenoprotein synthesis".*Annual Review of Nutrition* **23** (1): 17–40. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1146/annurev.nutr.23.011702.073318](http://dx.doi.org/10.1146%2Fannurev.nutr.23.011702.073318). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12524431](http://www.ncbi.nlm.nih.gov/pubmed/12524431).
  41. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-41) Krzycki JA (December 2005). "The direct genetic encoding of pyrrolysine". *Current Opinion in Microbiology* **8** (6): 706–12. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.mib.2005.10.009](http://dx.doi.org/10.1016%2Fj.mib.2005.10.009). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16256420](http://www.ncbi.nlm.nih.gov/pubmed/16256420).
  42. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-pmid16164991_42-0) Théobald-Dietrich A, Giegé R, Rudinger-Thirion J (2005). "Evidence for the existence in mRNAs of a hairpin element responsible for ribosome dependent pyrrolysine insertion into proteins". *Biochimie* **87** (9–10): 813–7. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.biochi.2005.03.006](http://dx.doi.org/10.1016%2Fj.biochi.2005.03.006). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16164991](http://www.ncbi.nlm.nih.gov/pubmed/16164991).
  43. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-43) Vermeer C (March 1990). ["Gamma-carboxyglutamate-containing proteins and the vitamin K-dependent carboxylase"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1131186). *The Biochemical Journal* **266** (3): 625–36. [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [1131186](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1131186). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [2183788](http://www.ncbi.nlm.nih.gov/pubmed/2183788).
  44. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-44) Bhattacharjee A, Bansal M (March 2005). "Collagen structure: the Madras triple helix and the current scenario". *IUBMB Life* **57** (3): 161–72. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1080/15216540500090710](http://dx.doi.org/10.1080%2F15216540500090710). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16036578](http://www.ncbi.nlm.nih.gov/pubmed/16036578).
  45. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-45) Park MH (February 2006). ["The post-translational synthesis of a polyamine-derived amino acid, hypusine, in the eukaryotic translation initiation factor 5A (eIF5A)"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2494880). *Journal of Biochemistry* **139** (2): 161–9. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1093/jb/mvj034](http://dx.doi.org/10.1093%2Fjb%2Fmvj034). [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [2494880](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2494880). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16452303](http://www.ncbi.nlm.nih.gov/pubmed/16452303).
  46. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-46) Blenis J, Resh MD (December 1993). "Subcellular localization specified by protein acylation and phosphorylation". *Current Opinion in Cell Biology* **5** (6): 984–9. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/0955-0674(93)90081-Z](http://dx.doi.org/10.1016%2F0955-0674%2893%2990081-Z).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [8129952](http://www.ncbi.nlm.nih.gov/pubmed/8129952).
  47. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-47) Curis E, Nicolis I, Moinard C et al. (November 2005). "Almost all about citrulline in mammals". *Amino Acids* **29** (3): 177–205. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1007/s00726-005-0235-4](http://dx.doi.org/10.1007%2Fs00726-005-0235-4). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16082501](http://www.ncbi.nlm.nih.gov/pubmed/16082501).
  48. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-48) Coxon KM, Chakauya E, Ottenhof HH et al. (August 2005). "Pantothenate biosynthesis in higher plants". *Biochemical Society Transactions* **33** (Pt 4): 743–6. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1042/BST0330743](http://dx.doi.org/10.1042%2FBST0330743). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16042590](http://www.ncbi.nlm.nih.gov/pubmed/16042590).
  49. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-49) Sakami W, Harrington H (1963). "Amino acid metabolism". *Annual Review of Biochemistry***32** (1): 355–98. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1146/annurev.bi.32.070163.002035](http://dx.doi.org/10.1146%2Fannurev.bi.32.070163.002035). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [14144484](http://www.ncbi.nlm.nih.gov/pubmed/14144484).
  50. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-50) Brosnan JT (April 2000). ["Glutamate, at the interface between amino acid and carbohydrate metabolism"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=10736367). *The Journal of Nutrition* **130** (4S Suppl): 988S–90S. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [10736367](http://www.ncbi.nlm.nih.gov/pubmed/10736367).
  51. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-51) Young VR, Ajami AM (September 2001). ["Glutamine: the emperor or his clothes?"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=11533293). *The Journal of Nutrition***131** (9 Suppl): 2449S–59S; discussion 2486S–7S. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [11533293](http://www.ncbi.nlm.nih.gov/pubmed/11533293).
  52. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-52) Young VR (August 1994). ["Adult amino acid requirements: the case for a major revision in current recommendations"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=8064412).*The Journal of Nutrition* **124** (8 Suppl): 1517S–1523S. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [8064412](http://www.ncbi.nlm.nih.gov/pubmed/8064412).
  53. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-53) Imura K, Okada A (January 1998). "Amino acid metabolism in pediatric patients". *Nutrition***14** (1): 143–8. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/S0899-9007(97)00230-X](http://dx.doi.org/10.1016%2FS0899-9007%2897%2900230-X). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [9437700](http://www.ncbi.nlm.nih.gov/pubmed/9437700).
  54. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-54) Lourenço R, Camilo ME (2002). "Taurine: a conditionally essential amino acid in humans? An overview in health and disease". *Nutrición Hospitalaria* **17** (6): 262–70. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12514918](http://www.ncbi.nlm.nih.gov/pubmed/12514918).
  55. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-55) Fürst P, Stehle P (June 2004). ["What are the essential elements needed for the determination of amino acid requirements in humans?"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=15173430). *The Journal of Nutrition* **134** (6 Suppl): 1558S–1565S.[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15173430](http://www.ncbi.nlm.nih.gov/pubmed/15173430).
  56. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-56) Reeds PJ (July 2000). ["Dispensable and indispensable amino acids for humans"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=10867060). *The Journal of Nutrition***130** (7): 1835S–40S. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [10867060](http://www.ncbi.nlm.nih.gov/pubmed/10867060).
  57. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-57) Savelieva KV, Zhao S, Pogorelov VM et al. (2008). ["Genetic disruption of both tryptophan hydroxylase genes dramatically reduces serotonin and affects behavior in models sensitive to antidepressants"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2565062). In Bartolomucci, Alessandro. *PloS ONE* **3** (10): e3301. [Bibcode](http://en.wikipedia.org/wiki/Bibcode):[2008PLoSO...3.3301S](http://adsabs.harvard.edu/abs/2008PLoSO...3.3301S). [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1371/journal.pone.0003301](http://dx.doi.org/10.1371%2Fjournal.pone.0003301). [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [2565062](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2565062). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [18923670](http://www.ncbi.nlm.nih.gov/pubmed/18923670).
  58. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-58) Shemin D, Rittenberg D (1 December 1946). ["The biological utilization of glycine for the synthesis of the protoporphyrin of hemoglobin"](http://www.jbc.org/cgi/reprint/166/2/621).*Journal of Biological Chemistry* **166** (2): 621–5. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [20276176](http://www.ncbi.nlm.nih.gov/pubmed/20276176).
  59. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-59) Tejero J, Biswas A, Wang ZQ et al. (November 2008). ["Stabilization and characterization of a heme-oxy reaction intermediate in inducible nitric-oxide synthase"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2586280). *The Journal of Biological Chemistry* **283** (48): 33498–507. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1074/jbc.M806122200](http://dx.doi.org/10.1074%2Fjbc.M806122200). [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [2586280](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2586280). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [18815130](http://www.ncbi.nlm.nih.gov/pubmed/18815130).
  60. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-60) Rodríguez-Caso C, Montañez R, Cascante M, Sánchez-Jiménez F, Medina MA (August 2006). "Mathematical modeling of polyamine metabolism in mammals". *The Journal of Biological Chemistry* **281** (31): 21799–812. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1074/jbc.M602756200](http://dx.doi.org/10.1074%2Fjbc.M602756200). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16709566](http://www.ncbi.nlm.nih.gov/pubmed/16709566).
  61. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-61) Stryer, Lubert; Berg, Jeremy Mark; Tymoczko, John L. (2002). *Biochemistry*. San Francisco: W.H. Freeman. pp. 693–8. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-7167-4684-0](http://en.wikipedia.org/wiki/Special:BookSources/0-7167-4684-0).
  62. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Hylin1969_62-0) Hylin, John W. (1969). "Toxic peptides and amino acids in foods and feeds". *Journal of Agricultural and Food Chemistry* **17** (3): 492–6. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/jf60163a003](http://dx.doi.org/10.1021%2Fjf60163a003).
  63. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Turner1967_63-0) Turner, B. L.; Harborne, J. B. (1967). "Distribution of canavanine in the plant kingdom".*Phytochemistry* **6** (6): 863–66. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/S0031-9422(00)86033-1](http://dx.doi.org/10.1016%2FS0031-9422%2800%2986033-1).
  64. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-64) Ekanayake S, Skog K, Asp NG (May 2007). "Canavanine content in sword beans (Canavalia gladiata): analysis and effect of processing". [*Food and Chemical Toxicology*](http://en.wikipedia.org/wiki/Food_and_Chemical_Toxicology) **45** (5): 797–803. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.fct.2006.10.030](http://dx.doi.org/10.1016%2Fj.fct.2006.10.030).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [17187914](http://www.ncbi.nlm.nih.gov/pubmed/17187914).
  65. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-65) Rosenthal GA (2001). "L-Canavanine: a higher plant insecticidal allelochemical". *Amino Acids***21** (3): 319–30. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1007/s007260170017](http://dx.doi.org/10.1007%2Fs007260170017). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [11764412](http://www.ncbi.nlm.nih.gov/pubmed/11764412).
  66. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-66) Hammond AC (May 1995). ["Leucaena toxicosis and its control in ruminants"](http://jas.fass.org/cgi/pmidlookup?view=long&pmid=7665380). *Journal of Animal Science***73** (5): 1487–92. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [7665380](http://www.ncbi.nlm.nih.gov/pubmed/7665380).
  67. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Leuchtenberger2005_67-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Leuchtenberger2005_67-1) Leuchtenberger W, Huthmacher K, Drauz K (November 2005). "Biotechnological production of amino acids and derivatives: current status and prospects". *Applied Microbiology and Biotechnology* **69** (1): 1–8. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1007/s00253-005-0155-y](http://dx.doi.org/10.1007%2Fs00253-005-0155-y). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16195792](http://www.ncbi.nlm.nih.gov/pubmed/16195792).
  68. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-68) Ashmead, H. DeWayne (1993). *The Role of Amino Acid Chelates in Animal Nutrition*. Westwood: Noyes Publications.
  69. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Garattini_69-0) Garattini S (April 2000). ["Glutamic acid, twenty years later"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=10736350). *The Journal of Nutrition***130** (4S Suppl): 901S–9S. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [10736350](http://www.ncbi.nlm.nih.gov/pubmed/10736350).
  70. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-70) Stegink LD (July 1987). ["The aspartame story: a model for the clinical testing of a food additive"](http://www.ajcn.org/cgi/pmidlookup?view=long&pmid=3300262). *The American Journal of Clinical Nutrition* **46** (1 Suppl): 204–15. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [3300262](http://www.ncbi.nlm.nih.gov/pubmed/3300262).
  71. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-71) Albion Laboratories, Inc. ["Albion Ferrochel Website"](http://www.albionferrochel.com/). Retrieved 12 July 2011.
  72. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-72) Ashmead, H. DeWayne (1986). *Foliar Feeding of Plants with Amino Acid Chelates*. Park Ridge: Noyes Publications.
  73. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-73) Turner EH, Loftis JM, Blackwell AD (March 2006). "Serotonin a la carte: supplementation with the serotonin precursor 5-hydroxytryptophan". *Pharmacology & Therapeutics* **109** (3): 325–38. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.pharmthera.2005.06.004](http://dx.doi.org/10.1016%2Fj.pharmthera.2005.06.004). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16023217](http://www.ncbi.nlm.nih.gov/pubmed/16023217).
  74. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-74) Kostrzewa RM, Nowak P, Kostrzewa JP, Kostrzewa RA, Brus R (March 2005). "Peculiarities of L: -DOPA treatment of Parkinson's disease". *Amino Acids* **28** (2): 157–64.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1007/s00726-005-0162-4](http://dx.doi.org/10.1007%2Fs00726-005-0162-4).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15750845](http://www.ncbi.nlm.nih.gov/pubmed/15750845).
  75. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-75) Heby O, Persson L, Rentala M (August 2007). "Targeting the polyamine biosynthetic enzymes: a promising approach to therapy of African sleeping sickness, Chagas' disease, and leishmaniasis". *Amino Acids* **33** (2): 359–66. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1007/s00726-007-0537-9](http://dx.doi.org/10.1007%2Fs00726-007-0537-9). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [17610127](http://www.ncbi.nlm.nih.gov/pubmed/17610127).
  76. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-76) Cruz-Vera, LR (2004). ["Ribosome stalling and peptidyl-tRNA drop-off during translational delay at AGA codons"](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC516057). *Nucleic Acid Research*. 32 **18** (15): 4462–8. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1093/nar/gkh784](http://dx.doi.org/10.1093%2Fnar%2Fgkh784). [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [516057](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC516057). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15317870](http://www.ncbi.nlm.nih.gov/pubmed/15317870).
  77. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-77) ["Molecules 'too dangerous for nature' kill cancer cells"](http://www.newscientist.com/article/dn22424-molecules-too-dangerous-for-nature-kill-cancer-cells.html). Retrieved 28 October 2012.
  78. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-78) ["Lethal DNA tags could keep innocent people out of jail"](http://www.newscientist.com/article/mg21829155.900-lethal-dna-tags-could-keep-innocent-people-out-of-jail.html). New Scientist. Retrieved 27 May 2013.
  79. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Hanessian1993_79-0) Hanessian, S. (1993). "Reflections on the total synthesis of natural products: Art, craft, logic, and the chiron approach". *Pure and Applied Chemistry* **65** (6): 1189–204.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1351/pac199365061189](http://dx.doi.org/10.1351%2Fpac199365061189).
  80. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Blaser1992_80-0) Blaser, Hans Ulrich (1992). "The chiral pool as a source of enantioselective catalysts and auxiliaries". *Chemical Reviews* **92** (5): 935–52. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/cr00013a009](http://dx.doi.org/10.1021%2Fcr00013a009).
  81. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Sanda1999_81-0) Sanda, Fumio; Endo, Takeshi (1999). "Feature Article Syntheses and functions of polymers based on amino acids". *Macromolecular Chemistry and Physics* **200** (12): 2651–61.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1002/(SICI)1521-3935(19991201)200:12<2651::AID-MACP2651>3.0.CO;2-P](http://dx.doi.org/10.1002%2F%28SICI%291521-3935%2819991201%29200%3A12%3C2651%3A%3AAID-MACP2651%3E3.0.CO%3B2-P).
  82. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Gross2002_82-0) Gross, R. A.; Kalra, B. (2002). ["Biodegradable Polymers for the Environment"](http://www.sciencemag.org/cgi/content/abstract/297/5582/803). *Science* **297** (5582): 803–807. [Bibcode](http://en.wikipedia.org/wiki/Bibcode):[2002Sci...297..803G](http://adsabs.harvard.edu/abs/2002Sci...297..803G).[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1126/science.297.5582.803](http://dx.doi.org/10.1126%2Fscience.297.5582.803).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12161646](http://www.ncbi.nlm.nih.gov/pubmed/12161646).
  83. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-83) Low, K. C.; Wheeler, A. P.; Koskan, L. P. (1996). *Commercial poly(aspartic acid) and Its Uses*. Advances in Chemistry Series **248**. Washington, D.C.: [American Chemical Society](http://en.wikipedia.org/wiki/American_Chemical_Society).
  84. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Thombre2005_84-0) Thombre, S.M.; Sarwade, B.D. (2005). ["Synthesis and Biodegradability of Polyaspartic Acid: A Critical Review"](http://www.informaworld.com/index/718581646.pdf). *Journal of Macromolecular Science, Part A* **42** (9): 1299–1315. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1080/10601320500189604](http://dx.doi.org/10.1080%2F10601320500189604).
  85. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Bourke2003_85-0) Bourke, S. L.; Kohn, J. (2003). ["Polymers derived from the amino acid l-tyrosine: polycarbonates, polyarylates and copolymers with poly(ethylene glycol)"](http://linkinghub.elsevier.com/retrieve/pii/S0169409X03000383). *Advanced Drug Delivery Reviews* **55** (4): 447–466. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/S0169-409X(03)00038-3](http://dx.doi.org/10.1016%2FS0169-409X%2803%2900038-3). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12706045](http://www.ncbi.nlm.nih.gov/pubmed/12706045).
  86. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-86) Elmore, Donald Trevor; Barrett, G. C. (1998). *Amino acids and peptides*. Cambridge, UK: Cambridge University Press. pp. 48–60. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-521-46827-2](http://en.wikipedia.org/wiki/Special:BookSources/0-521-46827-2).
  87. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-87) Konar, Sanjit; et al. (2010). "Structural determination and characterization of copper and zinc bis-glycinates with X-ray crystallography and mass spectrometry". *Journal of Coordination Chemistry* **63** (19): 3335. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1080/00958972.2010.514336](http://dx.doi.org/10.1080%2F00958972.2010.514336).
  88. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-88) Gutteridge A, Thornton JM (November 2005). "Understanding nature's catalytic toolkit".*Trends in Biochemical Sciences* **30** (11): 622–9. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.tibs.2005.09.006](http://dx.doi.org/10.1016%2Fj.tibs.2005.09.006). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16214343](http://www.ncbi.nlm.nih.gov/pubmed/16214343).
  89. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-89) McMurry, John (1996). *Organic chemistry*. Pacific Grove, CA, USA: Brooks/Cole. p. 1064. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-534-23832-7](http://en.wikipedia.org/wiki/Special:BookSources/0-534-23832-7).
  90. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-90) [Strecker, Adolph](http://en.wikipedia.org/wiki/Adolph_Strecker" \o "Adolph Strecker) (1850). "Ueber die künstliche Bildung der Milchsäure und einen neuen, dem Glycocoll homologen Körper". *Justus Liebigs Annalen der Chemie* **75** (1): 27–45.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1002/jlac.18500750103](http://dx.doi.org/10.1002%2Fjlac.18500750103).
  91. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-91) [Strecker, Adolph](http://en.wikipedia.org/wiki/Adolph_Strecker" \o "Adolph Strecker) (1854). "Ueber einen neuen aus Aldehyd – Ammoniak und Blausäure entstehenden Körper". *Justus Liebigs Annalen der Chemie* **91** (3): 349–51.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1002/jlac.18540910309](http://dx.doi.org/10.1002%2Fjlac.18540910309).
  92. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-92) Masumoto S, Usuda H, Suzuki M, Kanai M, Shibasaki M (May 2003). "Catalytic enantioselective Strecker reaction of ketoimines". *Journal of the American Chemical Society***125** (19): 5634–5. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/ja034980](http://dx.doi.org/10.1021%2Fja034980).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12733893](http://www.ncbi.nlm.nih.gov/pubmed/12733893).
  93. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-93) Davis, F. A.; Reddy, Rajarathnam E.; Portonovo, Padma S. (1994). "Asymmetric strecker synthesis using enantiopure sulfinimines: A convenient synthesis of α-amino acids". [*Tetrahedron Letters*](http://en.wikipedia.org/wiki/Tetrahedron_Letters) **35** (50): 9351. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/S0040-4039(00)78540-6](http://dx.doi.org/10.1016%2FS0040-4039%2800%2978540-6).
  94. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-94) Ishitani, Haruro; Komiyama, Susumu; Hasegawa, Yoshiki; Kobayashi, Shū (2000). "Catalytic Asymmetric Strecker Synthesis. Preparation of Enantiomerically Pure α-Amino Acid Derivatives from Aldimines and Tributyltin Cyanide or Achiral Aldehydes, Amines, and Hydrogen Cyanide Using a Chiral Zirconium Catalyst". *Journal of the American Chemical Society* **122** (5): 762–6. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/ja9935207](http://dx.doi.org/10.1021%2Fja9935207).
  95. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-95) Huang, Jinkun; Corey, E. J. (2004). "A New Chiral Catalyst for the Enantioselective Strecker Synthesis of α-Amino Acids". *Orgic Letters* **62** (6): 5027–9. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/ol047698w](http://dx.doi.org/10.1021%2Fol047698w). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15606127](http://www.ncbi.nlm.nih.gov/pubmed/15606127).
  96. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-96) Duthaler, Rudolf O. (1994). "Recent developments in the stereoselective synthesis of α-aminoacids". *Tetrahedron* **50** (6): 1539–1650. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/S0040-4020(01)80840-1](http://dx.doi.org/10.1016%2FS0040-4020%2801%2980840-1).
  97. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-97) Ibba M, Söll D (May 2001). ["The renaissance of aminoacyl-tRNA synthesis"](http://www.nature.com/embor/journal/v2/n5/full/embor420.html). *EMBO Reports* **2** (5): 382–7. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):10.1093/embo-reports/kve095 (inactive 18 February 2010). [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [1083889](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1083889). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [11375928](http://www.ncbi.nlm.nih.gov/pubmed/11375928).
  98. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-98) Lengyel P, Söll D (June 1969). ["Mechanism of protein biosynthesis"](http://mmbr.asm.org/cgi/pmidlookup?view=long&pmid=4896351). *Bacteriological Reviews***33** (2): 264–301. [PMC](http://en.wikipedia.org/wiki/PubMed_Central) [378322](http://www.ncbi.nlm.nih.gov/pmc/articles/PMC378322).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [4896351](http://www.ncbi.nlm.nih.gov/pubmed/4896351).
  99. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-99) Wu G, Fang YZ, Yang S, Lupton JR, Turner ND (March 2004). ["Glutathione metabolism and its implications for health"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=14988435). *The Journal of Nutrition* **134** (3): 489–92. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [14988435](http://www.ncbi.nlm.nih.gov/pubmed/14988435).
  100. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-100) Meister A (November 1988). ["Glutathione metabolism and its selective modification"](http://www.jbc.org/cgi/pmidlookup?view=long&pmid=3053703). *The Journal of Biological Chemistry* **263** (33): 17205–8. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [3053703](http://www.ncbi.nlm.nih.gov/pubmed/3053703).
  101. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-101) Carpino, Louis A. (1992). "1-Hydroxy-7-azabenzotriazole. An efficient peptide coupling additive". *Journal of the American Chemical Society* **115** (10): 4397–8.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1021/ja00063a082](http://dx.doi.org/10.1021%2Fja00063a082).
  102. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-102) Marasco D, Perretta G, Sabatella M, Ruvo M (October 2008). "Past and future perspectives of synthetic peptide libraries". *Current Protein & Peptide Science* **9** (5): 447–67.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.2174/138920308785915209](http://dx.doi.org/10.2174%2F138920308785915209).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [18855697](http://www.ncbi.nlm.nih.gov/pubmed/18855697).
  103. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-103) Jones, Russell Celyn; Buchanan, Bob B.; Gruissem, Wilhelm (2000). *Biochemistry & molecular biology of plants*. Rockville, Md: American Society of Plant Physiologists. pp. 371–2. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-943088-39-9](http://en.wikipedia.org/wiki/Special:BookSources/0-943088-39-9).
  104. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Brosnan_104-0) Brosnan JT, Brosnan ME (June 2006). ["The sulfur-containing amino acids: an overview"](http://jn.nutrition.org/cgi/pmidlookup?view=long&pmid=16702333). *The Journal of Nutrition***136** (6 Suppl): 1636S–1640S. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [16702333](http://www.ncbi.nlm.nih.gov/pubmed/16702333).
  105. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-105) Kivirikko KI, Pihlajaniemi T (1998). "Collagen hydroxylases and the protein disulfide isomerase subunit of prolyl 4-hydroxylases". *Advances in Enzymology and Related Areas of Molecular Biology* **72**: 325–98. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [9559057](http://www.ncbi.nlm.nih.gov/pubmed/9559057).
  106. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-106) Whitmore L, Wallace BA (May 2004). "Analysis of peptaibol sequence composition: implications for in vivo synthesis and channel formation". *European Biophysics Journal* **33** (3): 233–7. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1007/s00249-003-0348-1](http://dx.doi.org/10.1007%2Fs00249-003-0348-1). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [14534753](http://www.ncbi.nlm.nih.gov/pubmed/14534753).
  107. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-107) Alexander L, Grierson D (October 2002). "Ethylene biosynthesis and action in tomato: a model for climacteric fruit ripening". *Journal of Experimental Botany* **53** (377): 2039–55.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1093/jxb/erf072](http://dx.doi.org/10.1093%2Fjxb%2Ferf072). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [12324528](http://www.ncbi.nlm.nih.gov/pubmed/12324528).
  108. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-108) Stipanuk, M. H. (2006). Biochemical, physiological, & molecular aspects of human nutrition (2 ed.): Saunders Elsevier.
  109. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-109) Stryer, Lubert; Berg, Jeremy Mark; Tymoczko, John L. (2002). *Biochemistry*. San Francisco: W.H. Freeman. pp. 639–49. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-7167-4684-0](http://en.wikipedia.org/wiki/Special:BookSources/0-7167-4684-0).
  110. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-110) Urry, Dan W. (2004). "The change in Gibbs free energy for hydrophobic association: Derivation and evaluation by means of inverse temperature transitions". *Chemical Physics Letters* **399** (1–3): 177–83. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/S0009-2614(04)01565-9](http://dx.doi.org/10.1016%2FS0009-2614%2804%2901565-9).
  111. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-111) Magee T, Seabra MC (April 2005). "Fatty acylation and prenylation of proteins: what's hot in fat". *Current Opinion in Cell Biology* **17** (2): 190–6. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.ceb.2005.02.003](http://dx.doi.org/10.1016%2Fj.ceb.2005.02.003). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15780596](http://www.ncbi.nlm.nih.gov/pubmed/15780596).
  112. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-112) Pilobello KT, Mahal LK (June 2007). "Deciphering the glycocode: the complexity and analytical challenge of glycomics". *Current Opinion in Chemical Biology* **11** (3): 300–5.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/j.cbpa.2007.05.002](http://dx.doi.org/10.1016%2Fj.cbpa.2007.05.002).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [17500024](http://www.ncbi.nlm.nih.gov/pubmed/17500024).
  113. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-113) Smotrys JE, Linder ME (2004). "Palmitoylation of intracellular signaling proteins: regulation and function". *Annual Review of Biochemistry* **73** (1): 559–87.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1146/annurev.biochem.73.011303.073954](http://dx.doi.org/10.1146%2Fannurev.biochem.73.011303.073954). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15189153](http://www.ncbi.nlm.nih.gov/pubmed/15189153).
  114. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Hausman_114-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Hausman_114-1) [***c***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Hausman_114-2) [***d***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Hausman_114-3) Hausman, Robert E.; Cooper, Geoffrey M. (2004). *The cell: a molecular approach*. Washington, D.C: ASM Press. p. 51. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-87893-214-3](http://en.wikipedia.org/wiki/Special:BookSources/0-87893-214-3).
  115. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-115) Kyte J, Doolittle RF (May 1982). "A simple method for displaying the hydropathic character of a protein". *Journal of Molecular Biology* **157** (1): 105–32. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1016/0022-2836(82)90515-0](http://dx.doi.org/10.1016%2F0022-2836%2882%2990515-0).[PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [7108955](http://www.ncbi.nlm.nih.gov/pubmed/7108955).
  116. ^ [Jump up to:***a***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Freifelder_116-0) [***b***](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-Freifelder_116-1) Freifelder, D. (1983). *Physical Biochemistry* (2nd ed.). W. H. Freeman and Company.[ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [0-7167-1315-2](http://en.wikipedia.org/wiki/Special:BookSources/0-7167-1315-2).
  117. [**Jump up^**](http://en.wikipedia.org/w/index.php?title=Amino_acid&printable=yes#cite_ref-117) Suchanek M, Radzikowska A, Thiele C (April 2005). "Photo-leucine and photo-methionine allow identification of protein-protein interactions in living cells". *Nature Methods* **2** (4): 261–7.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1038/nmeth752](http://dx.doi.org/10.1038%2Fnmeth752). [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [15782218](http://www.ncbi.nlm.nih.gov/pubmed/15782218).

**Further reading**

* Tymoczko, John L. (2012). "Protein Composition and Structure". *Biochemistry*. New York: W. H. Freeman and company. pp. 28–31. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [9781429229364](http://en.wikipedia.org/wiki/Special:BookSources/9781429229364).
* [Doolittle, Russell F.](http://en.wikipedia.org/wiki/Russell_Doolittle) (1989). "Redundancies in protein sequences". In [Fasman, G.D.](http://en.wikipedia.org/w/index.php?title=Gerald_David_Fasman&action=edit&redlink=1" \o "Gerald David Fasman (page does not exist)). *Predictions of Protein Structure and the Principles of Protein Conformation*. New York: [Plenum Press](http://en.wikipedia.org/wiki/Plenum_Press). pp. 599–623. [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-0-306-43131-9](http://en.wikipedia.org/wiki/Special:BookSources/978-0-306-43131-9). [LCCN](http://en.wikipedia.org/wiki/Library_of_Congress_Control_Number) [89008555](http://lccn.loc.gov/89008555).
* Nelson, David L.; Cox, Michael M. (2000). *Lehninger Principles of Biochemistry* (3rd ed.). [Worth Publishers](http://en.wikipedia.org/wiki/Worth_Publishers). [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-1-57259-153-0](http://en.wikipedia.org/wiki/Special:BookSources/978-1-57259-153-0). [LCCN](http://en.wikipedia.org/wiki/Library_of_Congress_Control_Number) [99049137](http://lccn.loc.gov/99049137).
* [Meierhenrich, Uwe](http://en.wikipedia.org/wiki/Uwe_Meierhenrich) (2008). [*Amino acids and the asymmetry of life*](http://rogov.zwz.ru/Macroevolution/amino.pdf) (PDF, 11.2 MB). Berlin: [Springer Verlag](http://en.wikipedia.org/wiki/Springer_Verlag). [ISBN](http://en.wikipedia.org/wiki/International_Standard_Book_Number) [978-3-540-76885-2](http://en.wikipedia.org/wiki/Special:BookSources/978-3-540-76885-2). [LCCN](http://en.wikipedia.org/wiki/Library_of_Congress_Control_Number) [2008930865](http://lccn.loc.gov/2008930865).
* Morelli, Robert J. (1952). *Studies of amino acid absorption from the small intestine*. San Francisco.

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