Learning Objectives

- To recognize amino acids and classify them based on the characteristics of their side chains.

The proteins in all living species, from bacteria to humans, are constructed from the same set of 20 amino acids, so called because each contains an amino group attached to a carboxylic acid. The amino acids in proteins are α-amino acids, which means the amino group is attached to the α-carbon of the carboxylic acid. Humans can synthesize only about half of the needed amino acids; the remainder must be obtained from the diet and are known as essential amino acids. However, two additional amino acids have been found in limited quantities in proteins: Selenocysteine was discovered in 1986, while pyrrolysine was discovered in 2002.

The amino acids are colorless, nonvolatile, crystalline solids, melting and decomposing at temperatures above 200°C. These melting temperatures are more like those of inorganic salts than those of amines or organic acids and indicate that the structures of the amino acids in the solid state and in neutral solution are best represented as having both a negatively charged group and a positively charged group. Such a species is known as a zwitterion.

Classification

In addition to the amino and carboxyl groups, amino acids have a side chain or R group attached to the α-carbon. Each amino acid has unique characteristics arising from the size, shape, solubility, and ionization properties of its R group. As a result, the side chains of amino acids exert a profound effect on the structure and biological activity of proteins. Although amino acids can be classified in various ways, one common approach is to classify them according to whether the functional group on the side chain at neutral pH is nonpolar, polar but uncharged, negatively charged, or positively charged. The structures and names of the 20 amino acids, their one- and three-letter abbreviations, and some of their distinctive features are given in Table 1.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Abbreviation</th>
<th>Structural Formula (at pH 6)</th>
<th>Molar Mass</th>
<th>Distinctive Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amino acids with a nonpolar R group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>glycine</td>
<td>gly (G)</td>
<td>H₃N⁺―CH―CO⁻</td>
<td>75</td>
<td>the only amino acid lacking a chiral carbon</td>
</tr>
<tr>
<td>Common Name</td>
<td>Abbreviation</td>
<td>Structural Formula (at pH 6)</td>
<td>Molar Mass</td>
<td>Distinctive Feature</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
<td>------------------------------</td>
<td>------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>alanine</td>
<td>ala (A)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>89</td>
<td>—</td>
</tr>
<tr>
<td>valine</td>
<td>val (V)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>117</td>
<td>a branched-chain amino acid</td>
</tr>
<tr>
<td>leucine</td>
<td>leu (L)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>131</td>
<td>a branched-chain amino acid</td>
</tr>
<tr>
<td>isoleucine</td>
<td>ile (I)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>131</td>
<td>an essential amino acid because most animals cannot synthesize branched-chain amino acids</td>
</tr>
<tr>
<td>phenylalanine</td>
<td>phe (F)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>165</td>
<td>also classified as an aromatic amino acid</td>
</tr>
<tr>
<td>tryptophan</td>
<td>trp (W)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>204</td>
<td>also classified as an aromatic amino acid</td>
</tr>
<tr>
<td>methionine</td>
<td>met (M)</td>
<td><img src="image" alt="Structural Formula" /></td>
<td>149</td>
<td>side chain functions as a methyl group donor</td>
</tr>
<tr>
<td>Common Name</td>
<td>Abbreviation</td>
<td>Structural Formula (at pH 6)</td>
<td>Molar Mass</td>
<td>Distinctive Feature</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
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<td>------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>proline</td>
<td>pro (P)</td>
<td><img src="image" alt="Proline Structural Formula" /></td>
<td>115</td>
<td>contains a secondary amine group; referred to as an (\alpha)-imino acid</td>
</tr>
<tr>
<td>serine</td>
<td>ser (S)</td>
<td><img src="image" alt="Serine Structural Formula" /></td>
<td>105</td>
<td>found at the active site of many enzymes</td>
</tr>
<tr>
<td>threonine</td>
<td>thr (T)</td>
<td><img src="image" alt="Threonine Structural Formula" /></td>
<td>119</td>
<td>named for its similarity to the sugar threose</td>
</tr>
<tr>
<td>cysteine</td>
<td>cys (C)</td>
<td><img src="image" alt="Cysteine Structural Formula" /></td>
<td>121</td>
<td>oxidation of two cysteine molecules yields cystine</td>
</tr>
<tr>
<td>tyrosine</td>
<td>tyr (Y)</td>
<td><img src="image" alt="Tyrosine Structural Formula" /></td>
<td>181</td>
<td>also classified as an aromatic amino acid</td>
</tr>
<tr>
<td>asparagine</td>
<td>asn (N)</td>
<td><img src="image" alt="Asparagine Structural Formula" /></td>
<td>132</td>
<td>the amide of aspartic acid</td>
</tr>
<tr>
<td>glutamine</td>
<td>gln (Q)</td>
<td><img src="image" alt="Glutamine Structural Formula" /></td>
<td>146</td>
<td>the amide of glutamic acid</td>
</tr>
</tbody>
</table>

**Amino acids with a polar but neutral R group**
<table>
<thead>
<tr>
<th>Common Name</th>
<th>Abbreviation</th>
<th>Structural Formula (at pH 6)</th>
<th>Molar Mass</th>
<th>Distinctive Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>aspartic acid</td>
<td>asp (D)</td>
<td><img src="image1" alt="aspartic acid structural formula" /></td>
<td>132</td>
<td>carboxyl groups are ionized at physiological pH; also known as aspartate</td>
</tr>
<tr>
<td>glutamic acid</td>
<td>glu (E)</td>
<td><img src="image2" alt="glutamic acid structural formula" /></td>
<td>146</td>
<td>carboxyl groups are ionized at physiological pH; also known as glutamate</td>
</tr>
<tr>
<td>histidine</td>
<td>his (H)</td>
<td><img src="image3" alt="histidine structural formula" /></td>
<td>155</td>
<td>the only amino acid whose R group has a pKₐ (6.0) near physiological pH</td>
</tr>
<tr>
<td>lysine</td>
<td>lys (K)</td>
<td><img src="image4" alt="lysine structural formula" /></td>
<td>147</td>
<td>—</td>
</tr>
<tr>
<td>arginine</td>
<td>arg (R)</td>
<td><img src="image5" alt="arginine structural formula" /></td>
<td>175</td>
<td>almost as strong a base as sodium hydroxide</td>
</tr>
</tbody>
</table>

The first amino acid to be isolated was asparagine in 1806. It was obtained from protein found in asparagus juice (hence the name). Glycine, the major amino acid found in gelatin, was named for its sweet taste (Greek ῥυκυς, meaning “sweet”). In some cases an amino acid found in a protein is actually a derivative of one of the common 20 amino acids (one such derivative is hydroxyproline). The modification occurs after the amino acid has been assembled into a protein.
Configuration

Notice in Table \( \PageIndex{1} \) that glycine is the only amino acid whose \( \alpha \)-carbon is not chiral. Therefore, with the exception of glycine, the amino acids could theoretically exist in either the D- or the L-enantiomeric form and rotate plane-polarized light. As with sugars, chemists use glyceraldehyde as the reference compound for the assignment of configuration to amino acids. Its structure closely resembles an amino acid structure except that in the latter, an amino group takes the place of the OH group on the chiral carbon of the sugar.

We learned that all naturally occurring sugars belong to the D series. It is interesting, therefore, that nearly all known plant and animal proteins are composed entirely of L-amino acids. However, certain bacteria contain D-amino acids in their cell walls, and several antibiotics (e.g., actinomycin D and the gramicidins) contain varying amounts of D-leucine, D-phenylalanine, and D-valine.

Summary

Amino acids can be classified based on the characteristics of their distinctive side chains as nonpolar, polar but uncharged, negatively charged, or positively charged. The amino acids found in proteins are L-amino acids.

Concept Review Exercises

1. What is the general structure of an \( \alpha \)-amino acid?

2. Identify the amino acid that fits each description.
   a. also known as aspartate
   b. almost as strong a base as sodium hydroxide
   c. does not have a chiral carbon
Answers

1. 

![Amino Acid Structure](image)

2. 
   a. aspartic acid  
   b. arginine  
   c. glycine

Exercises

1. Write the side chain of each amino acid.
   a. serine  
   b. arginine  
   c. phenylalanine

2. Write the side chain of each amino acid.
   a. aspartic acid  
   b. methionine  
   c. valine

3. Draw the structure for each amino acid.
   a. alanine  
   b. cysteine  
   c. histidine

4. Draw the structure for each amino acid.
   a. threonine  
   b. glutamic acid  
   c. leucine

5. Identify an amino acid whose side chain contains a(n)
   a. amide functional group.  
   b. aromatic ring.  
   c. carboxyl group.

6. Identify an amino acid whose side chain contains a(n)
   a. OH group
b. branched chain

c. amino group

Answers

1. a. $\text{CH}_2\text{OH}^-$

\[
\begin{align*}
\text{--(CH}_2\text{)}_3\text{--NH--C}^+\text{NH}_2 \\
\text{NH}_2
\end{align*}
\]

b. 

\[
\begin{align*}
\text{--CH}_2
\end{align*}
\]

c. 

2. 

3. a. 

\[
\begin{align*}
\text{H}_3\text{N}^+\text{--CH--C}^\text{--O} \\
\text{CH}_3
\end{align*}
\]

b. 

\[
\begin{align*}
\text{H}_3\text{N}^+\text{--CH--C}^\text{--O} \\
\text{CH}_2\text{SH}
\end{align*}
\]

c. 

\[
\begin{align*}
\text{H}_3\text{N}^+\text{--CH--C}^\text{--O} \\
\text{CH}_2\text{SH}
\end{align*}
\]
4.

5.  a. asparagine or glutamine  
    b. phenylalanine, tyrosine, or tryptophan  
    c. aspartic acid or glutamic acid