Hogeschool van Arnhem en Nijmegen
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Course bi5b chemistry: Chapter 18
Amino acids and proteins



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Reference

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Fundamentals of General, Organic, and Biological

Chemistry

Seventh Edition

John McMurry
Cornell University

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PEARSON

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CHAPTER GOALS

In this chapter, we will look at the following questions about amino acids and proteins:

1. **What are the structural features of amino acids?**
   THE GOAL: Be able to describe and recognize amino acid structures and illustrate how they are connected in proteins.
2. **What are the properties of amino acids?**
   THE GOAL: Be able to describe how the properties of amino acids depend on their side chains and how their ionic charges vary with pH.
3. **Why do amino acids have "handedness"?**
   THE GOAL: Be able to explain what is responsible for handedness and recognize simple molecules that display this property.
4. **What is the primary structure of a protein and what conventions are used for drawing and naming primary structures?**
   THE GOAL: Be able to define protein primary structure, explain how primary structures are represented, and draw and name a simple protein structure, given its amino acid sequence.
5. **What types of interactions determine the overall shapes of proteins?**
   THE GOAL: Be able to describe and recognize disulfide bonds, hydrogen bonding along the protein backbone, and noncovalent interactions between amino acid side chains in proteins.
6. **What are the secondary and tertiary structures of proteins?**
   THE GOAL: Be able to define these structures and the attractive forces that determine their nature, describe the α-helix and β-sheet, and distinguish between fibrous and globular proteins.
7. **What is quaternary protein structure?**
   THE GOAL: Be able to define quaternary structure, identify the forces responsible for quaternary structure, and give examples of proteins with quaternary structure.
8. **What chemical properties do proteins have?**
   THE GOAL: Be able to describe protein hydrolysis and denaturation, and give some examples of agents that cause denaturation.

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(Reference: Chapter18 from McMurry et al.)

Studiewijzer

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- 18.1
  - je kent de plaats en functie van de *biochemie* in de natuurwetenschappen
  - je (her)kent de functionele groepen van tabel 18.1
- 18.2
  - je weet dat eiwitten polymeren van aminozuren zijn
  - je weet dat aminozuren verschillen in de zijketen op het α-koolstofatoom
  - je kent de 4 structuren van een eiwit
  - je kent de verschillende functies van eiwitten

(Reference: Chapter18 from McMurry et al.)

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Studiewijzer

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- 18.3
  - je weet dat er 20 essentiële aminozuren zijn
  - je kan uitleggen waarom proline een uitzondering vormt
  - je weet dat er zure (2), basische (3) en neutrale aminozuren (15) zijn
  - je weet dat de neutrale aminozuren verdeeld worden in polair (6) en apolair (9)
  - je weet welke intermoleculaire krachten belangrijk zijn

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(Reference: Chapter18 from McMurry et al.)

Studiewijzer

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- 18.4
  - je weet wat zwitter-ionen zijn
  - je kan uitleggen waarom aminozuren zwitter-ionen vormen
  - je weet hoe aminozuren er in zuur en basisch milieu uitzien
  - je weet wat het isoelektrisch punt (pI) is

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(Reference: Chapter18 from McMurry et al.)

Inleiding

- **Biochemie**
  - **de studie van moleculen en hun reacties in levende organismen**
  - **doel: inzicht in de structuur van biomoleculen en de relatie tussen structuur en functie**
  - **eiwitten, koolhydraten, lipiden en nucleïne zuren**

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(Reference: Chapter18 from McMurry et al.)

Inleiding

- **Biochemische reacties**
  - **afbraak van voedingsstoffen**
  - **genereren en opslaan van energie**
  - **synthese biomoleculen**
  - **verwijderen van afvalproducten**

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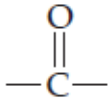
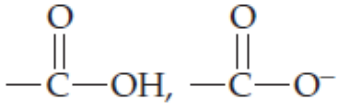
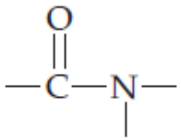
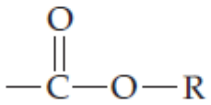
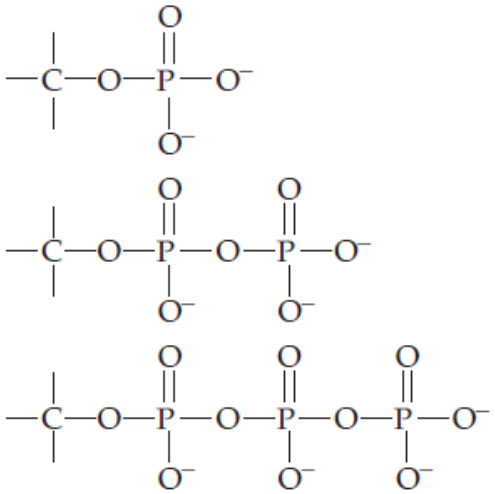
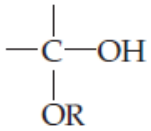
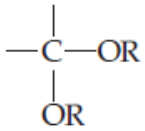
(Reference: Chapter18 from McMurry et al.)

Table 18.1: Important functional groups in biochemistry #1

Amino group	$-NH_3^+$, $-NH_2$	Amino acids and proteins (Sections 18.3, 18.7)
Hydroxyl group	$-OH$	Monosaccharides (carbohydrates) and glycerol: a component of triacylglycerols (lipids) (Sections 21.4, 23.2)
Carbonyl group		Monosaccharides (carbohydrates); in acetyl group (CH_3CO) used to transfer carbon atoms during catabolism (Sections 21.4, 20.4, 20.8)
Carboxyl group		Amino acids, proteins, and fatty acids (lipids) (Sections 18.3, 18.7, 23.2)
Amide group		Links amino acids in proteins; formed by reaction of amino group and carboxyl group (Section 18.7)
Carboxylic acid ester		Triacylglycerols (and other lipids); formed by reaction of carboxyl group and hydroxyl group (Section 23.2)

(Reference: Chapter18 from McMurry et al.)

Table 18.1: Important functional groups in biochemistry #2

Phosphates, mono-, di-, tri-		ATP and many metabolism intermediates (Sections 17.8, 20.5, and throughout metabolism sections)
Hemiacetal group		Cyclic forms of monosaccharides; formed by a reaction of carbonyl group with hydroxyl group (Sections 16.7, 21.4)
Acetal group		Connects monosaccharides in disaccharides and larger carbohydrates; formed by reaction of carbonyl group with hydroxyl group (Sections 16.7, 21.7, 21.9)

(Reference: Chapter18 from McMurry et al.)

18.2: Eiwit structuur

- **Eiwitten:**
  - **polymeren van aminozuren**

- **Aminozuren:**
  - **bevatten een carboxylgroep, een aminogroep en een restgroep**
  - **alfa-aminozuren**

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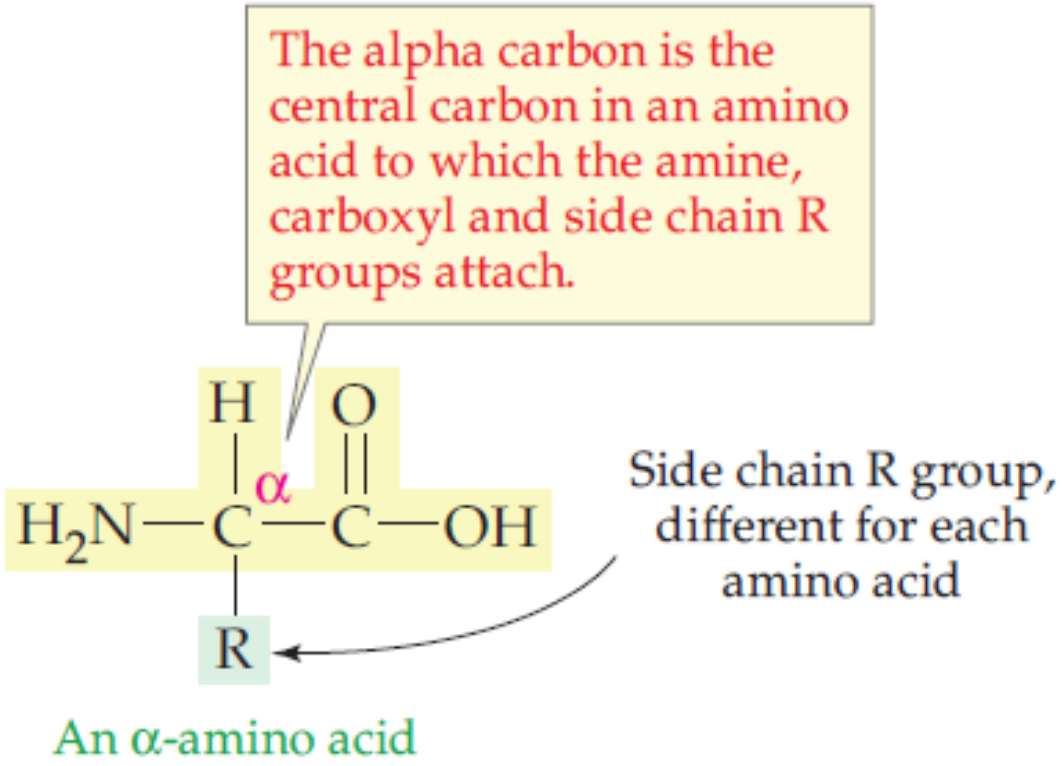
(Reference: Chapter18 from McMurry et al.)

18.2: Protein structure



Protein A large biological molecule made of many amino acids linked together through amide (peptide) bonds.

Amino acid A molecule that contains both an amino group and a carboxylic acid functional group.

Side chain (amino acid) The group bonded to the carbon next to the carboxyl group in an amino acid; different in different amino acids.

Alpha- ($\alpha-$) amino acid An amino acid in which the amino group is bonded to the carbon atom next to the —COOH group.

Peptide bond An amide bond that links two amino acids together.

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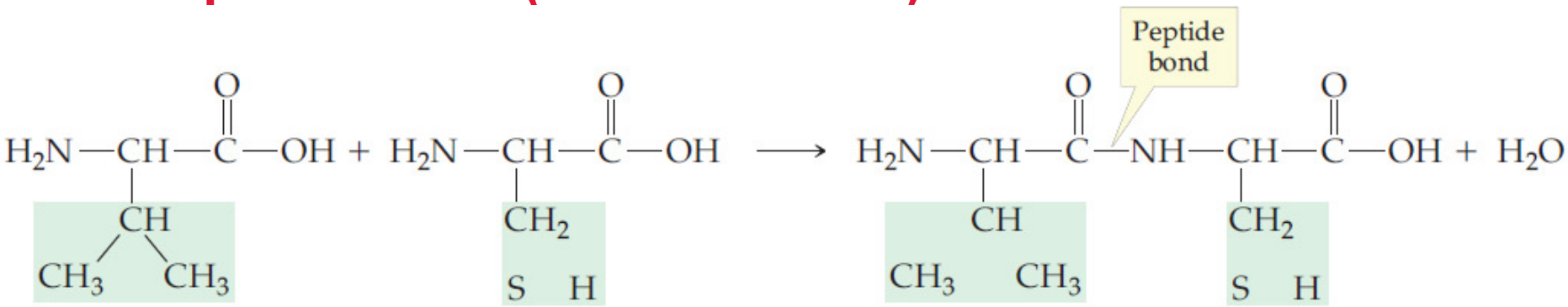
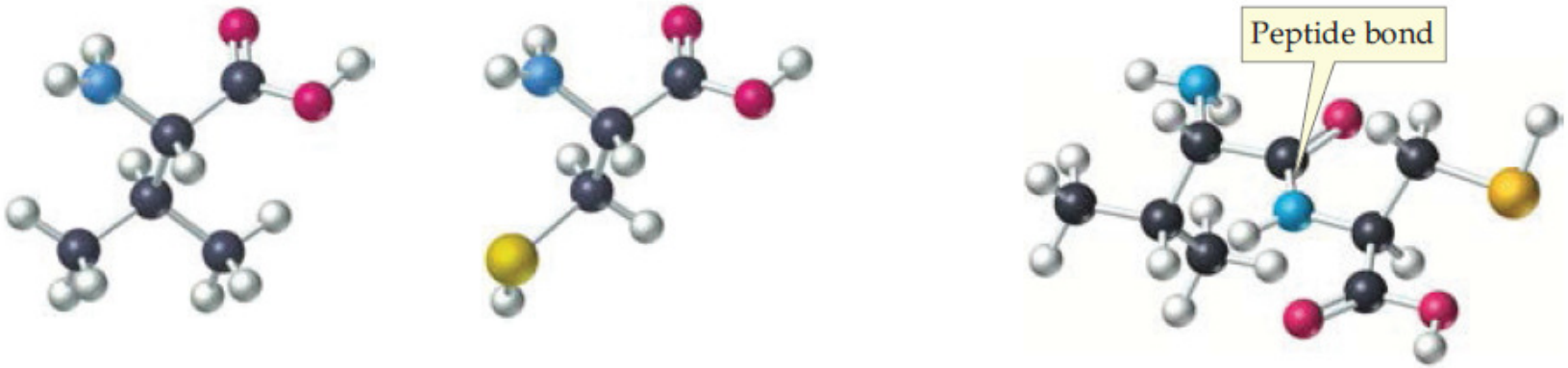
(Reference: Chapter18 from McMurry et al.)

18.2: Peptide bonds (=amide bonds)





(Reference: Chapter18 from McMurry et al.)

18.2: Peptide bonds

Proteins have four levels of structure, each of which is explored later in this chapter.

- *Primary structure* is the sequence of amino acids in a protein chain.
- *Secondary structure* is the regular and repeating spatial organization of neighboring segments of single protein chains.
- *Tertiary structure* is the overall shape of a protein molecule produced by regions of secondary structure combined with the overall bending and folding of the protein chain.
- *Quaternary structure* refers to the overall structure of proteins composed of more than one polypeptide chain.

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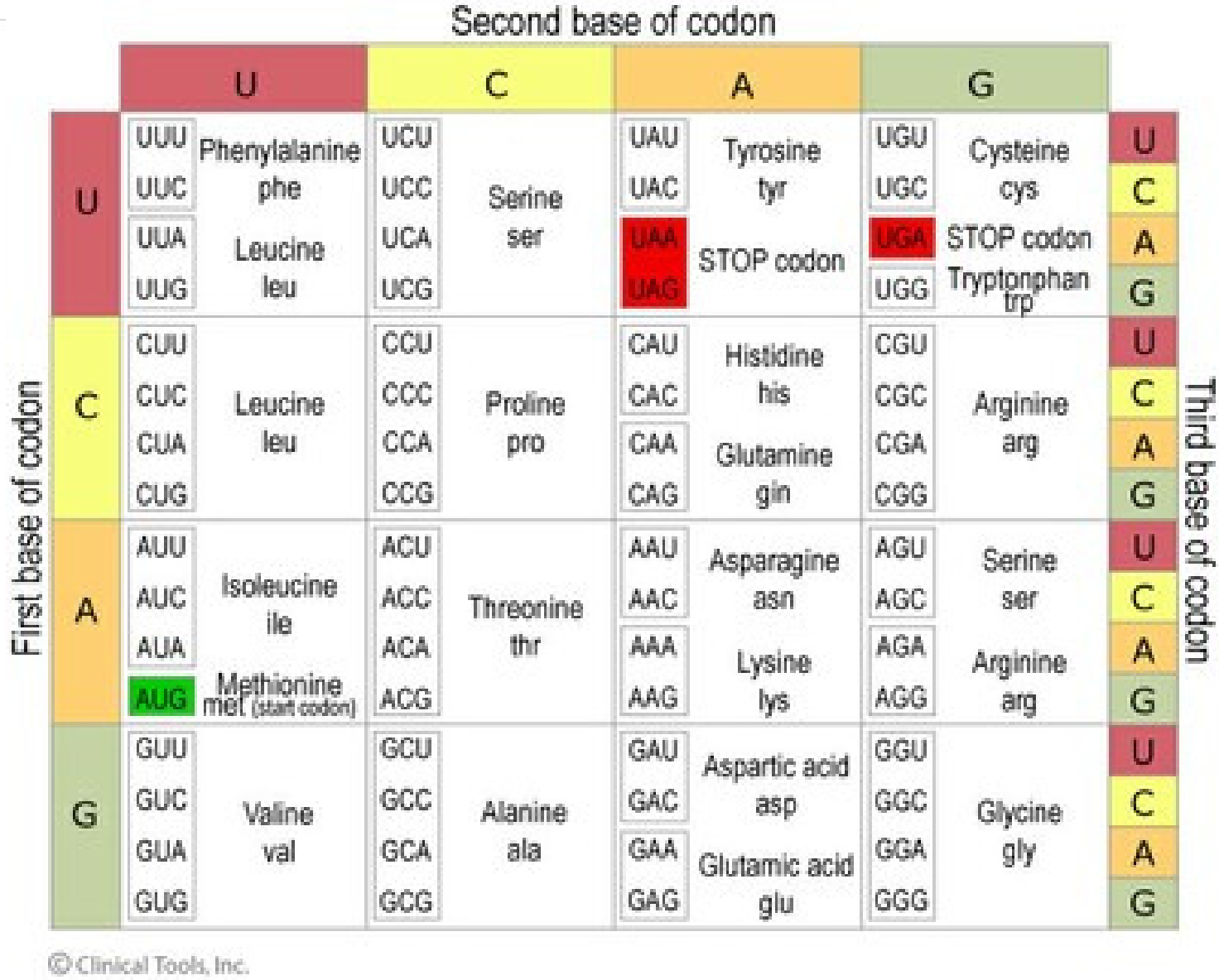
(Reference: Chapter18 from McMurry et al.)



Eigen werk auteur (c) Dr. Ing. P.J. de Groot

De 20 aminozuren

A	Ala	Alanine
C	Cys	Cysteine
D	Asp	Aspartic acid (Aspartate)
E	Glu	Glutamic acid (Glutamate)
F	Phe	Phenylalanine
G	Gly	Glycine
H	His	Histidine
I	Ile	Isoleucine
K	Lys	Lysine
L	Leu	Leucine
M	Met	Methionine
N	Asn	Asparagine
P	Pro	Proline
Q	Gln	Glutamine
R	Arg	Arginine
S	Ser	Serine
T	Thr	Threonine
V	Val	Valine
W	Trp	Tryptophan
Y	Tyr	Tyrosine

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De 20 aminozuren

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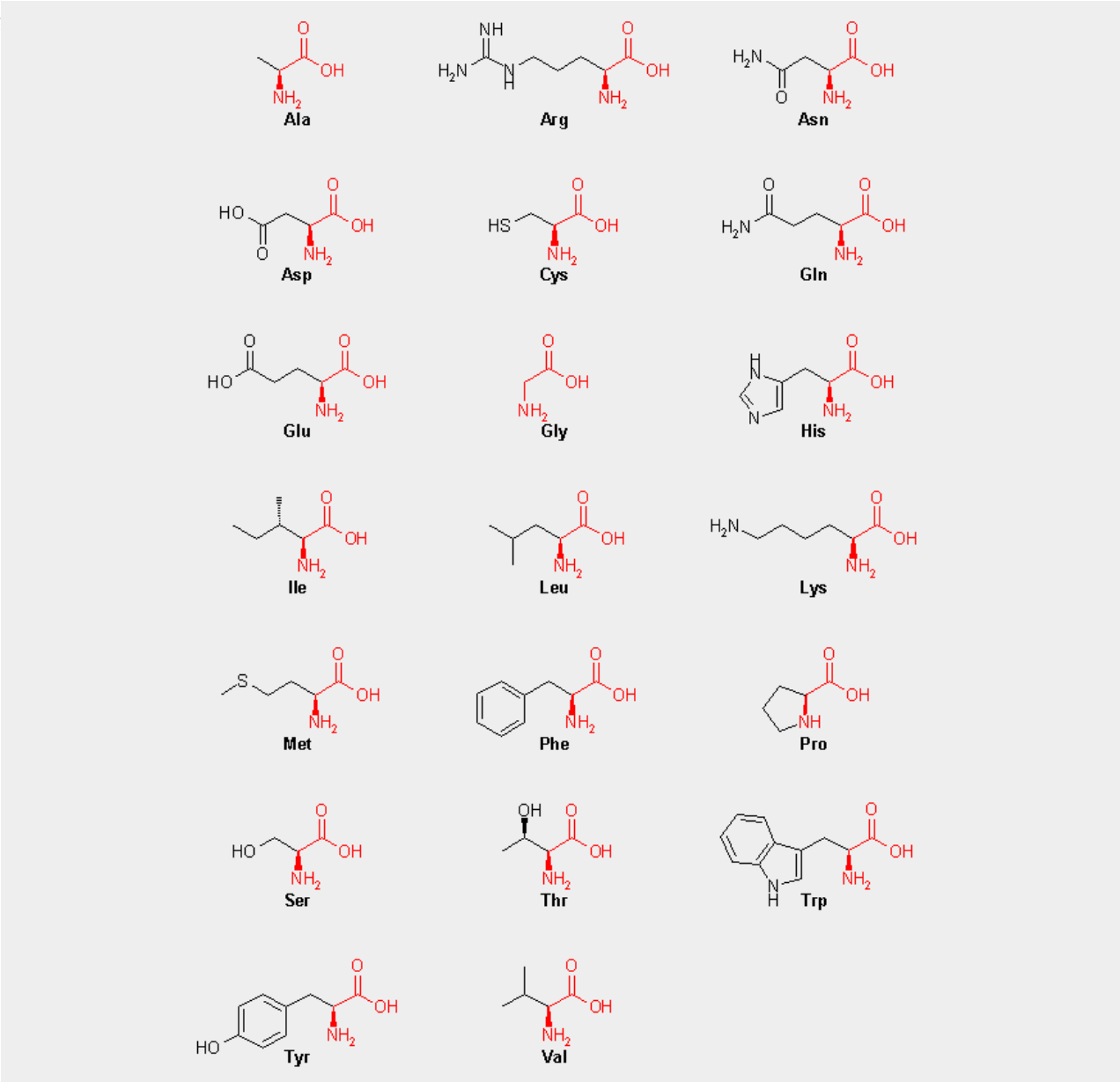

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Functieclassificatie van eiwitten

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TABLE 18.2 Classification of Proteins by Function

Type	Function	Example
Enzymes	Catalyze biochemical reactions	*Amylase*—begins digestion of carbohydrates by hydrolysis
Hormones	Regulate body functions by carrying messages to receptors	*Insulin*—facilitates use of glucose for energy generation
Storage proteins	Make essential substances available when needed	*Myoglobin*—stores oxygen in muscles
Transport proteins	Carry substances through body fluids	*Serum albumin*—carries fatty acids in blood
Structural proteins	Provide mechanical shape and support	*Collagen*—provides structure to tendons and cartilage
Protective proteins	Defend the body against foreign matter	*Immunoglobulin*—aids in destruction of invading bacteria
Contractile proteins	Do mechanical work	*Myosin and actin*—govern muscle movement

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Problems 18.1 & 18.2

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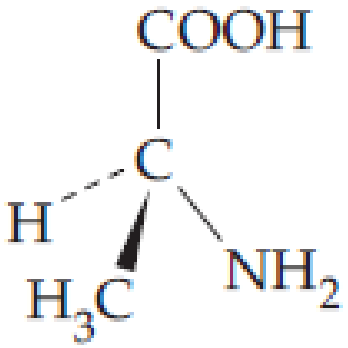
PROBLEM 18.2

Draw alanine showing the tetrahedral geometry of its α carbon.



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(Reference: Chapter18 from McMurry et al.)

Problem 18.3

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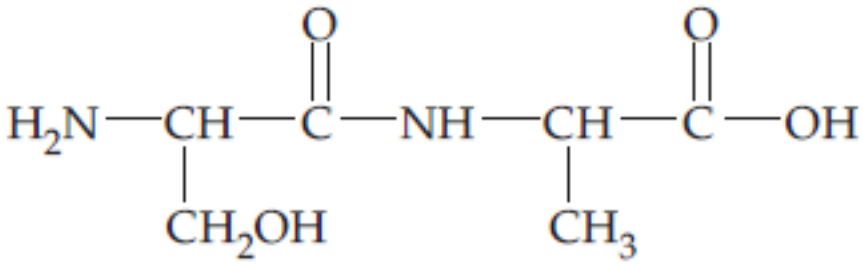
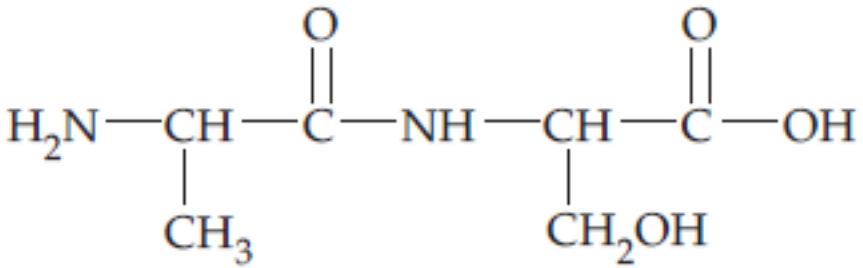
PROBLEM 18.3

Choose one amino acid with a nonpolar side chain and one with a polar side chain; draw the two dipeptides formed by these two amino acids.



Serine Alanine



Alanine Serine

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(Reference: Chapter18 from McMurry et al.)

Problem 18.4

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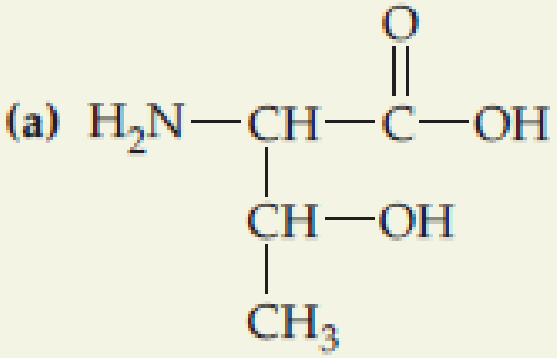
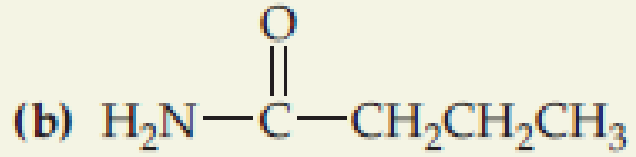
PROBLEM 18.4

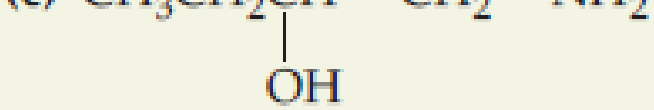
Indicate whether each of the molecules shown below is an α-amino acid or not and explain why.



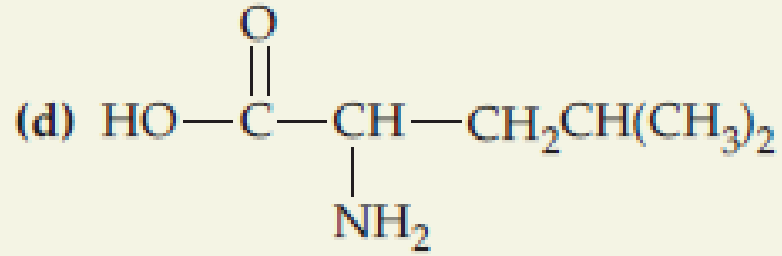
(b)



(c)



(d)



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α–amino acids: **(a), (d)**

(Reference: Chapter18 from McMurry et al.)

Problem 18.5

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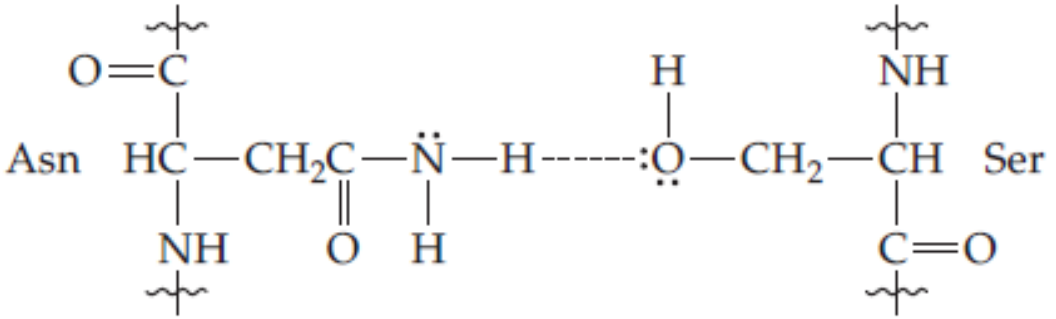
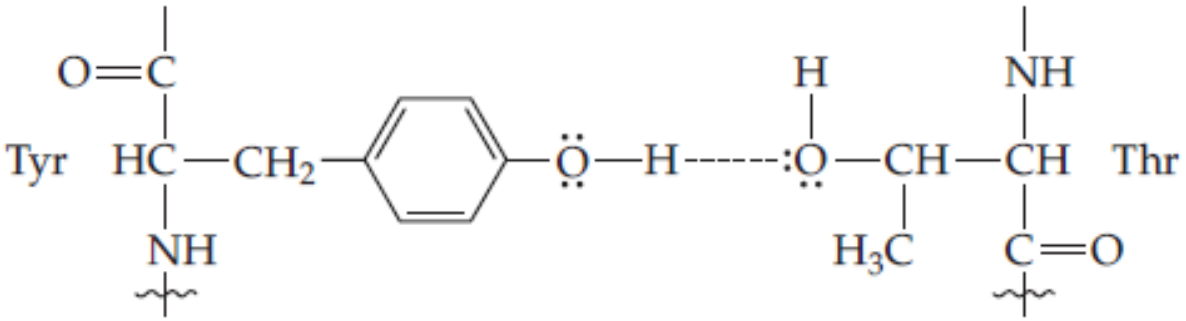
PROBLEM 18.5

Which of the following pairs of amino acids can form hydrogen bonds between their side-chain groups? Draw the pairs that can hydrogen-bond through their side chains and indicate the hydrogen bonds.

(a) Phe, Thr **(b)** Asn, Ser **(c)** Thr, Tyr **(d)** Gly, Trp

18.5 (b) Asn, Ser **(c)** Thr, Tyr





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(Reference: Chapter18 from McMurry et al.)

Problem 18.6

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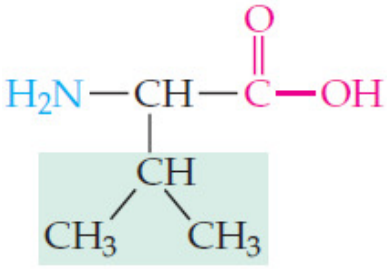
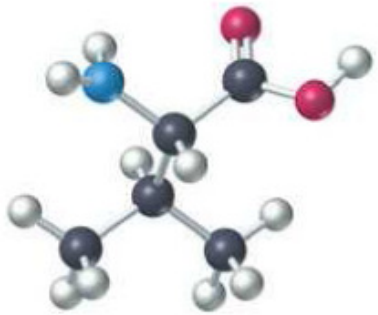
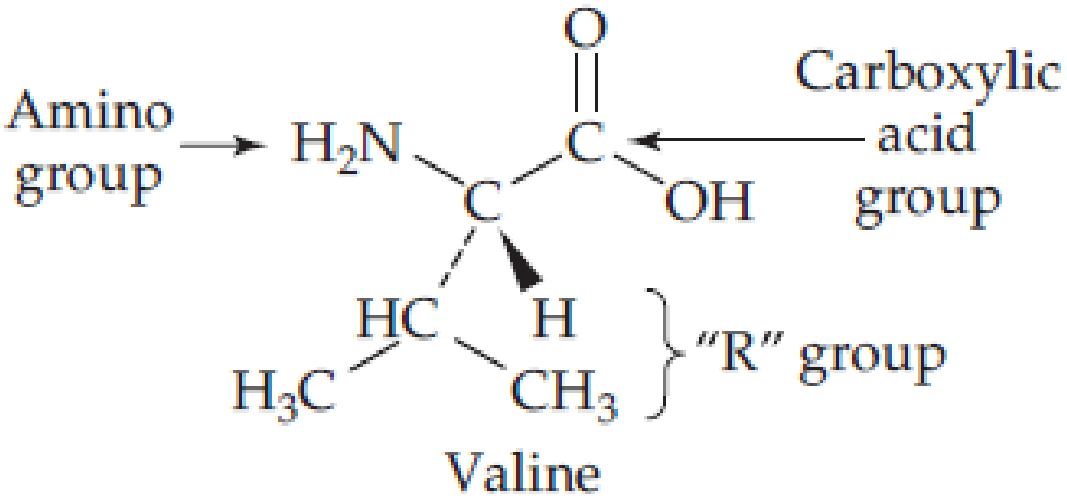
PROBLEM 18.6

In the ball-and-stick model of valine near the beginning of Section 18.2, identify the carboxyl group, the amino group, and the R group.



Valine





Valine

(Reference: Chapter18 from McMurry et al.)

18.3 Aminozuren

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- **Karakteriseren:**
  - hydrofobiciteit
  - grootte
  - lading
  - alcoholiciteit
  - aromaticiteit
- **Speciale karakteristieken**
  - brugvorming (cysteine)
  - starheid (proline)
  - flexibiliteit (glycine)

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18.3 Aminozuur classificatie

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- Aliphatic/hydrophobic
  - Alanine, Leucine, Isoleucine, Valine
- Polar
  - Asparagine, Glutamine
- Alcoholic
  - Serine, Threonine - Thr, (Tyrosine - Tyr)
- Sulfur-containing
  - Methionine, Cysteine
- Aromatic
  - Phenylalanine, Tyrosine - Tyr, Tryptophan - Trp, (Histidine)
- Charged
  - Arginine, Lysine, Asparagine, Glucine, (Histidine)
- Special
  - Glycine (no R), Pro (cyclic, imino-acid)

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- Several amino acids belong in more than one category.

18.3 imino zuur

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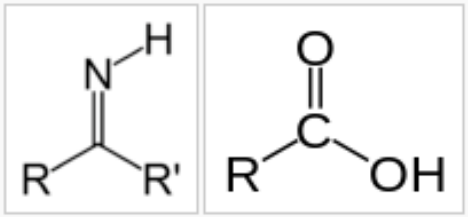
Imino acid

From Wikipedia, the free encyclopedia

In chemistry, an **imino acid** is any molecule that contains both imino (>C=NH) and carboxyl (-C(=O)-OH) functional groups.[1]

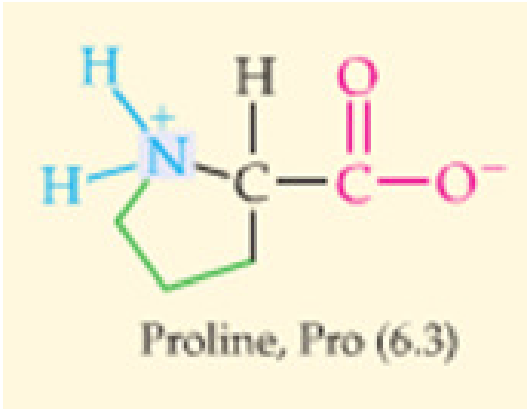


Imino group attached to carbon | Carboxylic acid

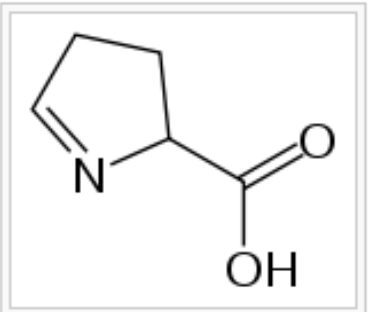
The two functional groups that together define an imino acid

Imino acids are related to amino acids, which contain both amino ($-NH_2$) and carboxyl (-COOH) functional groups, differing in the bonding to the nitrogen.

The D-amino acid oxidase enzymes are able to convert amino acids into imino acids. Also the direct biosynthetic precursor to the amino acid proline is the imino acid (*S*)-Δ^1-pyrroline-5-carboxylate (P5C).



Proline, Pro (6.3)



1-Pyrroline-5-carboxylic acid, an N-substituted imino acid

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Reference: Wikipedia - https://en.wikipedia.org/wiki/Imino_acid

18.3 Apolaire zijketens

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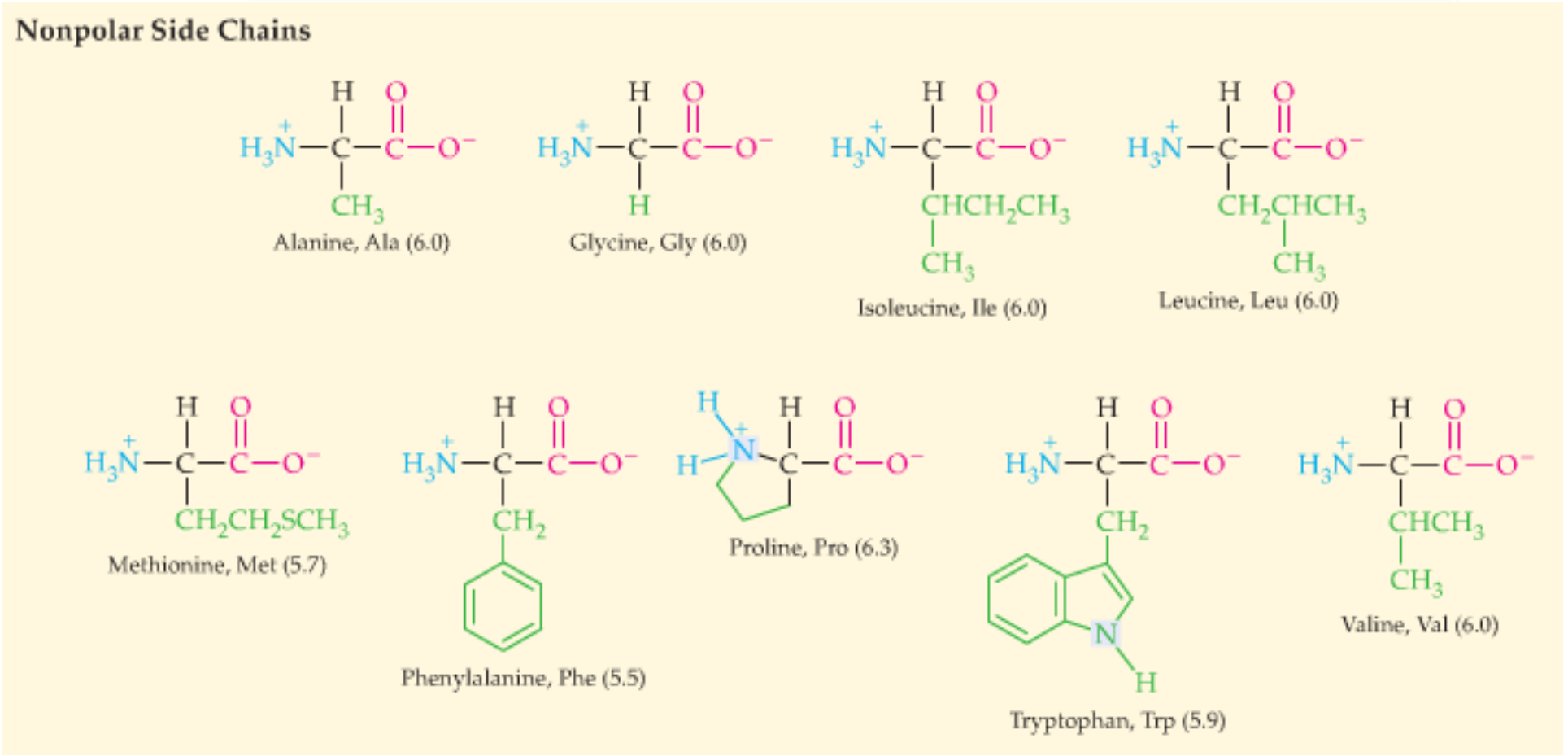

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(Reference: Chapter18 from McMurry et al.)

18.3 Polaire, neutrale zijketens

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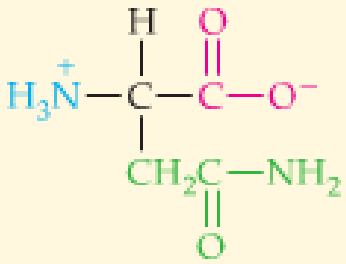
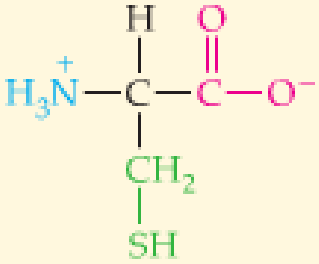
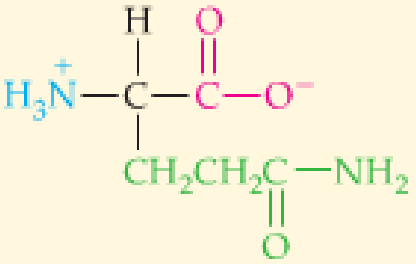
Polar, Neutral Side Chains



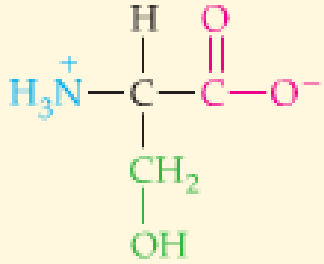
Asparagine, Asn (5.4)



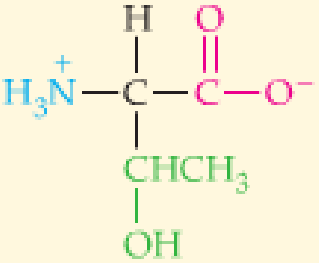
Cysteine, Cys (5.0)



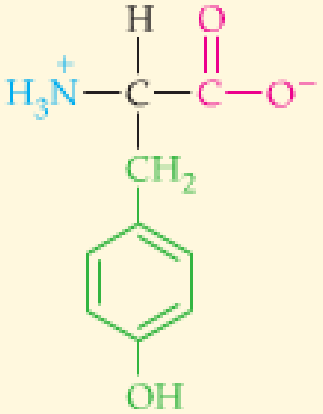
Glutamine, Gln (5.7)



Serine, Ser (5.7)



Threonine, Thr (5.6)



Tyrosine, Tyr (5.7)

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(Reference: Chapter18 from McMurry et al.)

18.3 Zure en basische zijketens

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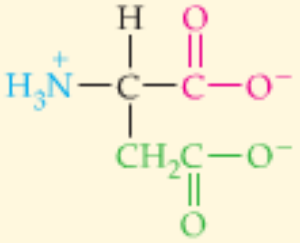
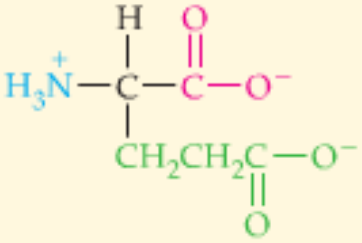
Acidic Side Chains

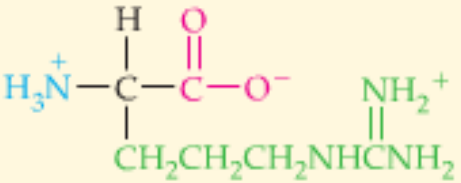


Aspartic acid, Asp (3.0)
(Aspartate)

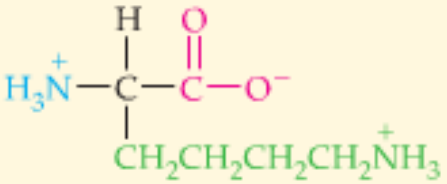


Glutamic acid, Glu (3.2)
(Glutamate)

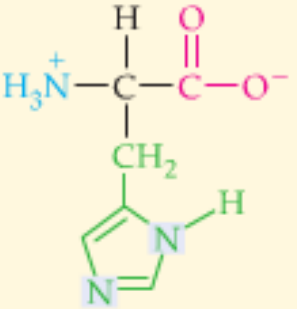
Basic Side Chains



Arginine, Arg (10.8)



Lysine, Lys (9.7)



Histidine, His (7.6)

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(Reference: Chapter18 from McMurry et al.)

18.3 Structuur en functie

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- **Bepalend is:**
  - de volgorde van de aminozuren in het eiwit
  - de chemische aard van de zijketens
- **Intermoleculaire krachten**
  - alle interacties anders dan de covalente (niet-covalente interacties)
- **Hydrofoob en hydrofiel**

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(Reference: Chapter18 from McMurry et al.)

18.4 Zuur-base eigenschappen

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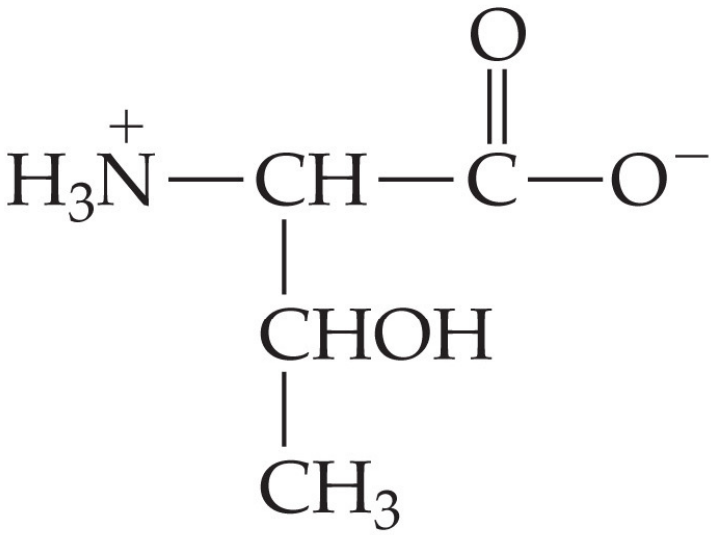
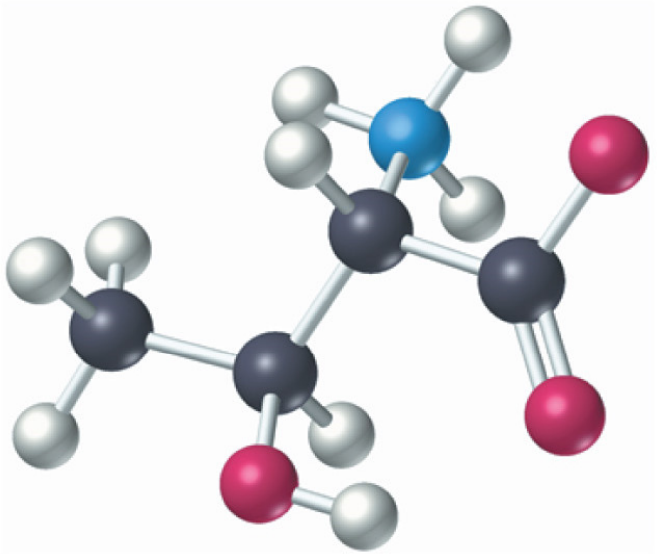
- **Zwitter-ionen**





Threonine—zwitterion

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Lading is afhankelijk van pH

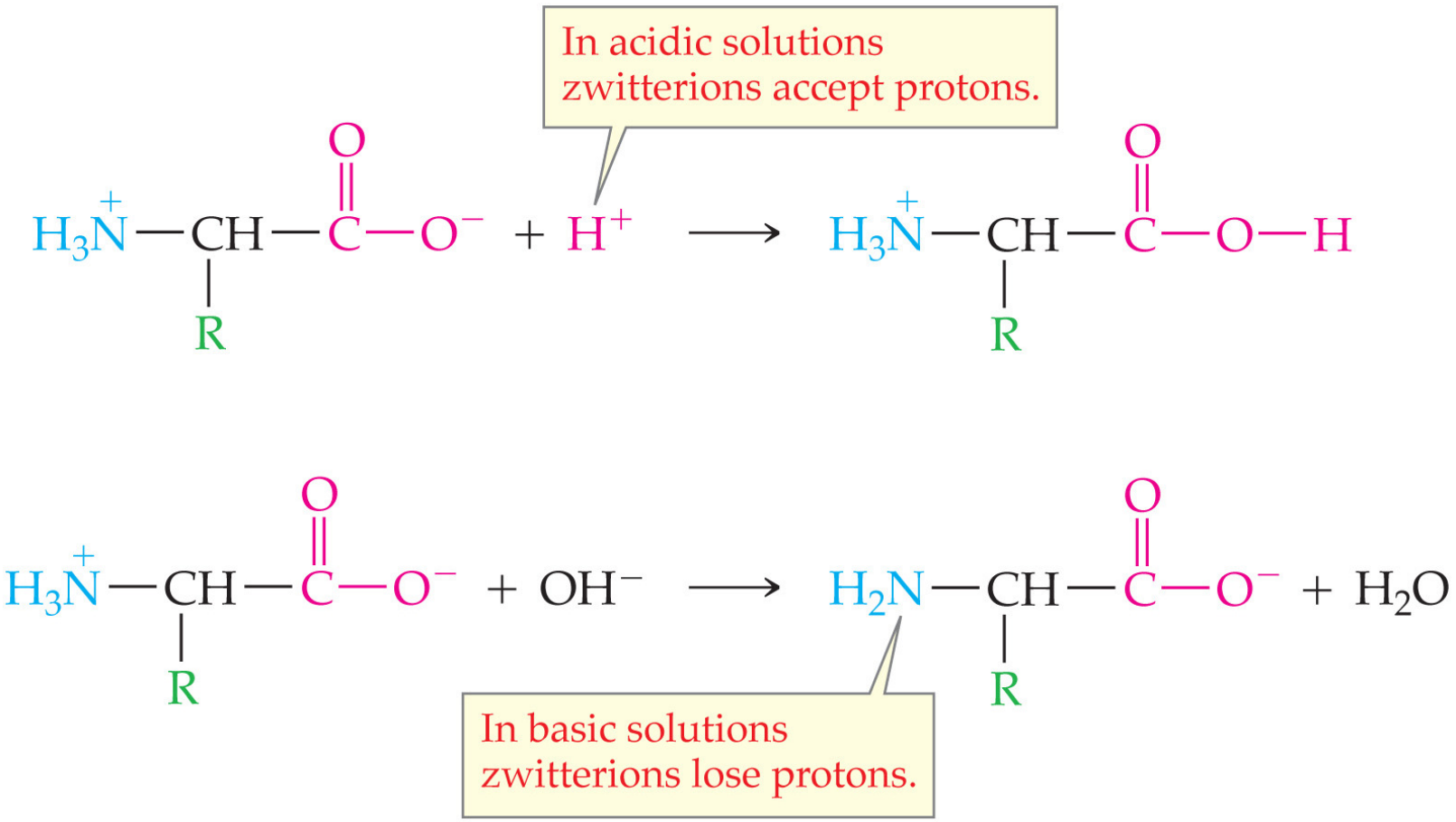


TABLE 3–1 Properties and Conventions Associated with the Common Amino Acids Found in Proteins

Amino acid	Abbreviation/ symbol	M_r*	pK_a values: pK_1 (—COOH)	pK_2 ($—NH_3^+$)	pK_R (R group)	pI	Hydropathy index†	Occurrence in proteins (%)‡
Nonpolar, aliphatic R groups								
Glycine	Gly G	75	2.34	9.60		5.97	−0.4	7.2
Alanine	Ala A	89	2.34	9.69		6.01	1.8	7.8
Proline	Pro P	115	1.99	10.96		6.48	−1.6	5.2
Valine	Val V	117	2.32	9.62		5.97	4.2	6.6
Leucine	Leu L	131	2.36	9.60		5.98	3.8	9.1
Isoleucine	Ile I	131	2.36	9.68		6.02	4.5	5.3
Methionine	Met M	149	2.28	9.21		5.74	1.9	2.3
Aromatic R groups								
Phenylalanine	Phe F	165	1.83	9.13		5.48	2.8	3.9
Tyrosine	Tyr Y	181	2.20	9.11	10.07	5.66	−1.3	3.2
Tryptophan	Trp W	204	2.38	9.39		5.89	−0.9	1.4
Polar, uncharged R groups								
Serine	Ser S	105	2.21	9.15		5.68	−0.8	6.8
Threonine	Thr T	119	2.11	9.62		5.87	−0.7	5.9
Cysteine¶	Cys C	121	1.96	10.28	8.18	5.07	2.5	1.9
Asparagine	Asn N	132	2.02	8.80		5.41	−3.5	4.3
Glutamine	Gln Q	146	2.17	9.13		5.65	−3.5	4.2
Positively charged R groups								
Lysine	Lys K	146	2.18	8.95	10.53	9.74	−3.9	5.9
Histidine	His H	155	1.82	9.17	6.00	7.59	−3.2	2.3
Arginine	Arg R	174	2.17	9.04	12.48	10.76	−4.5	5.1
Negatively charged R groups								
Aspartate	Asp D	133	1.88	9.60	3.65	2.77	−3.5	5.3
Glutamate	Glu E	147	2.19	9.67	4.25	3.22	−3.5	6.3

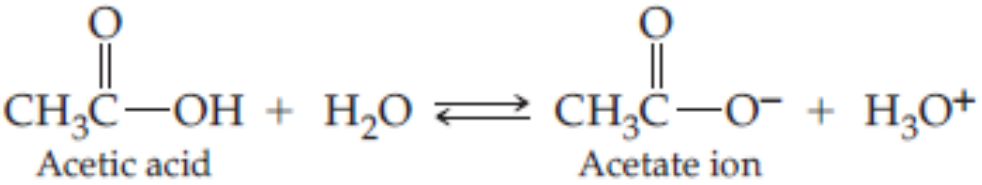
Isoelectrisch punt (pI)

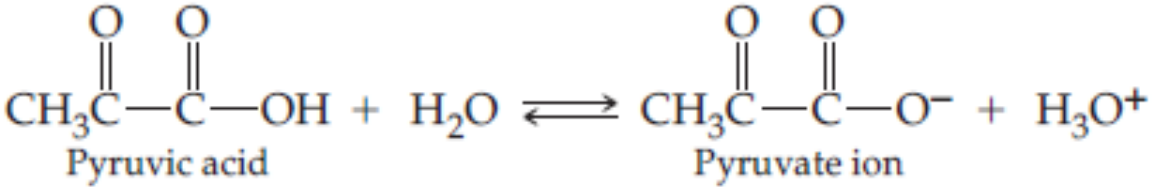
- Het IEP is die pH waarbij het aminozuur (eiwit) een netto lading van 0 heeft
  - dus evenveel plus en min ladingen
  - afhankelijk van de zijketen(s)

Acid-base properties #4

17.3 Acidity of Carboxylic Acids

At pH 7.4 in body fluids, carboxylic acids exist mainly as their carboxylate anions:





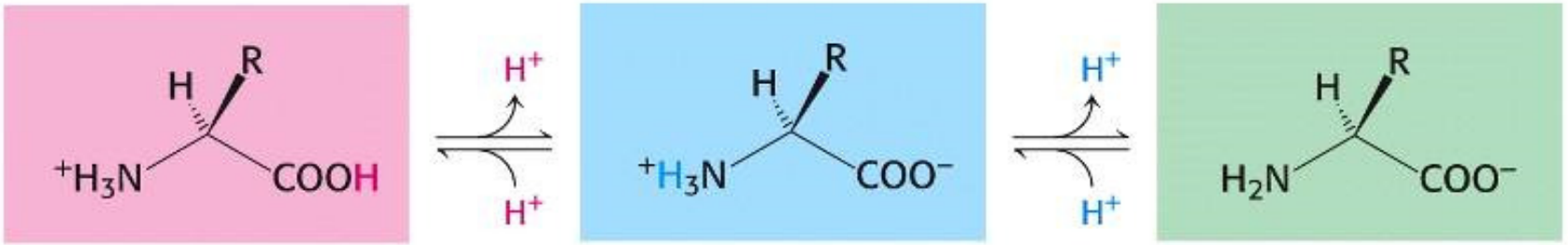
acid dissociation constant K_a :

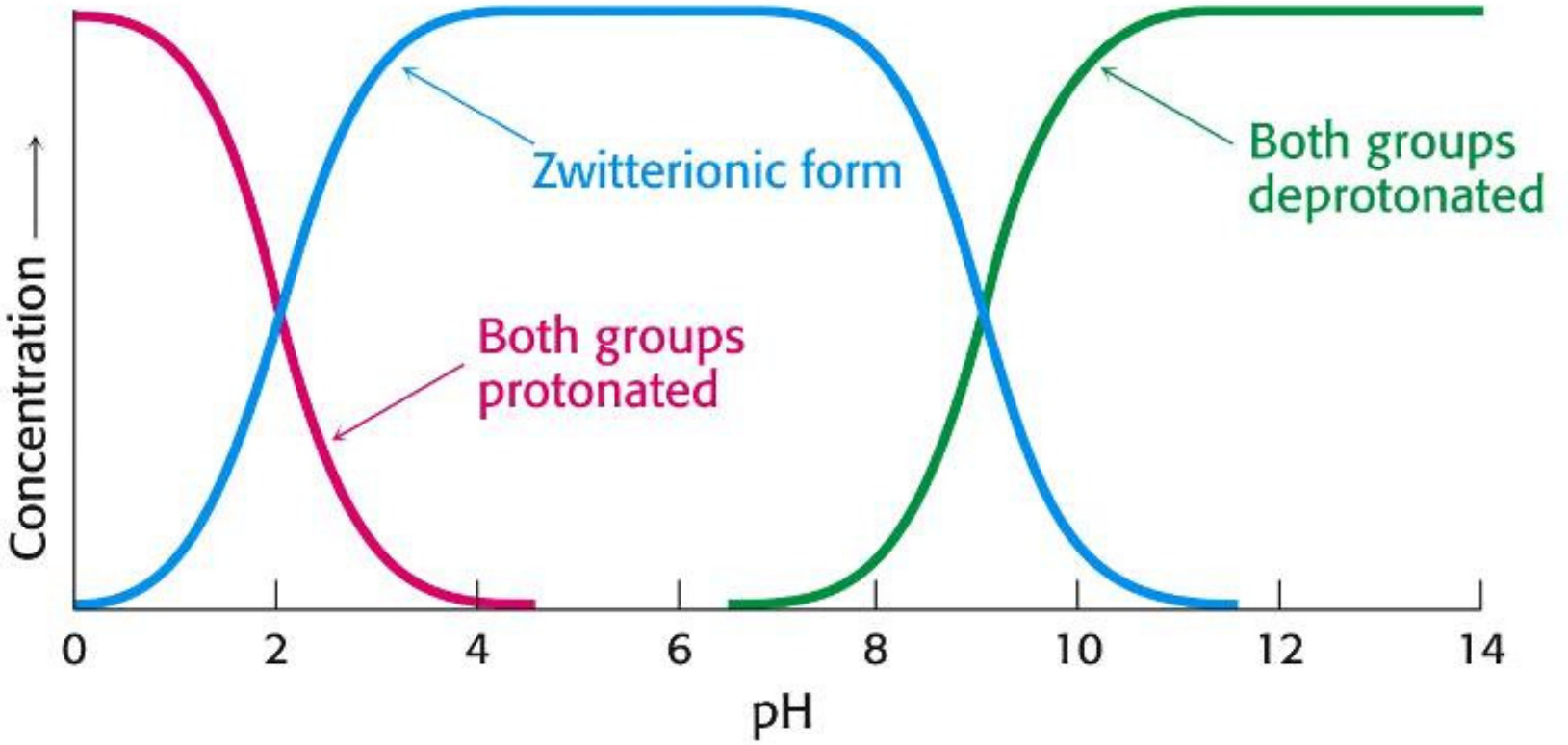
$$\mathrm{pH} = \mathrm{p}K_a + \log \frac{[\mathrm{Z}^-]}{[\mathrm{HZ}]}$$

$$\mathrm{RCOOH} + \mathrm{H_2O} \rightleftharpoons \mathrm{RCOO^-} + \mathrm{H_3O^+} \qquad K_a = \frac{[\mathrm{RCOO^-}][\mathrm{H_3O^+}]}{[\mathrm{RCOOH}]}$$

(Reference: Chapter 17.3 from McMurry et al.)

Existentiediagram





(Reference: Chapter18 from McMurry et al.)

Hoe bereken je een existentiediagram

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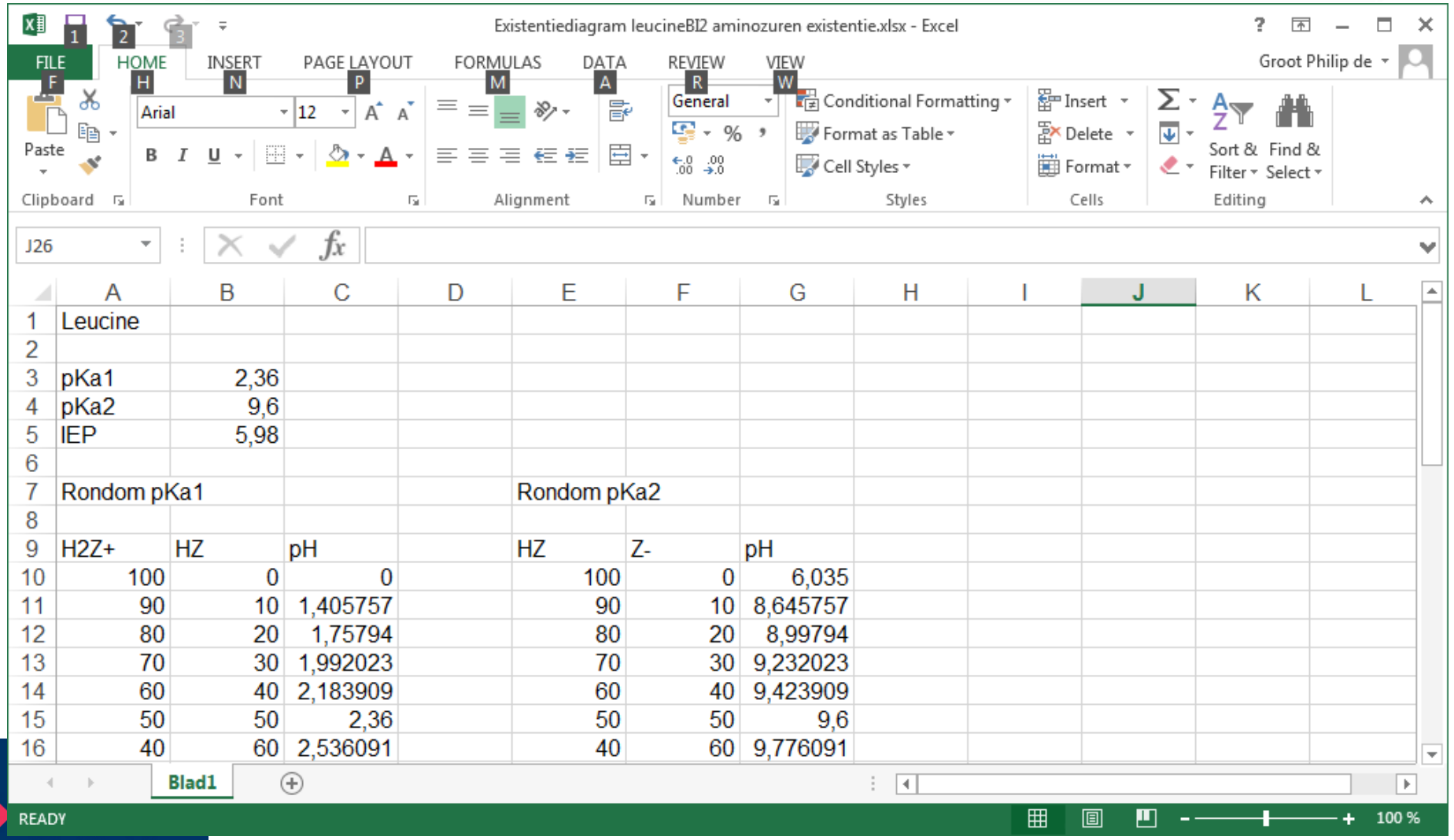
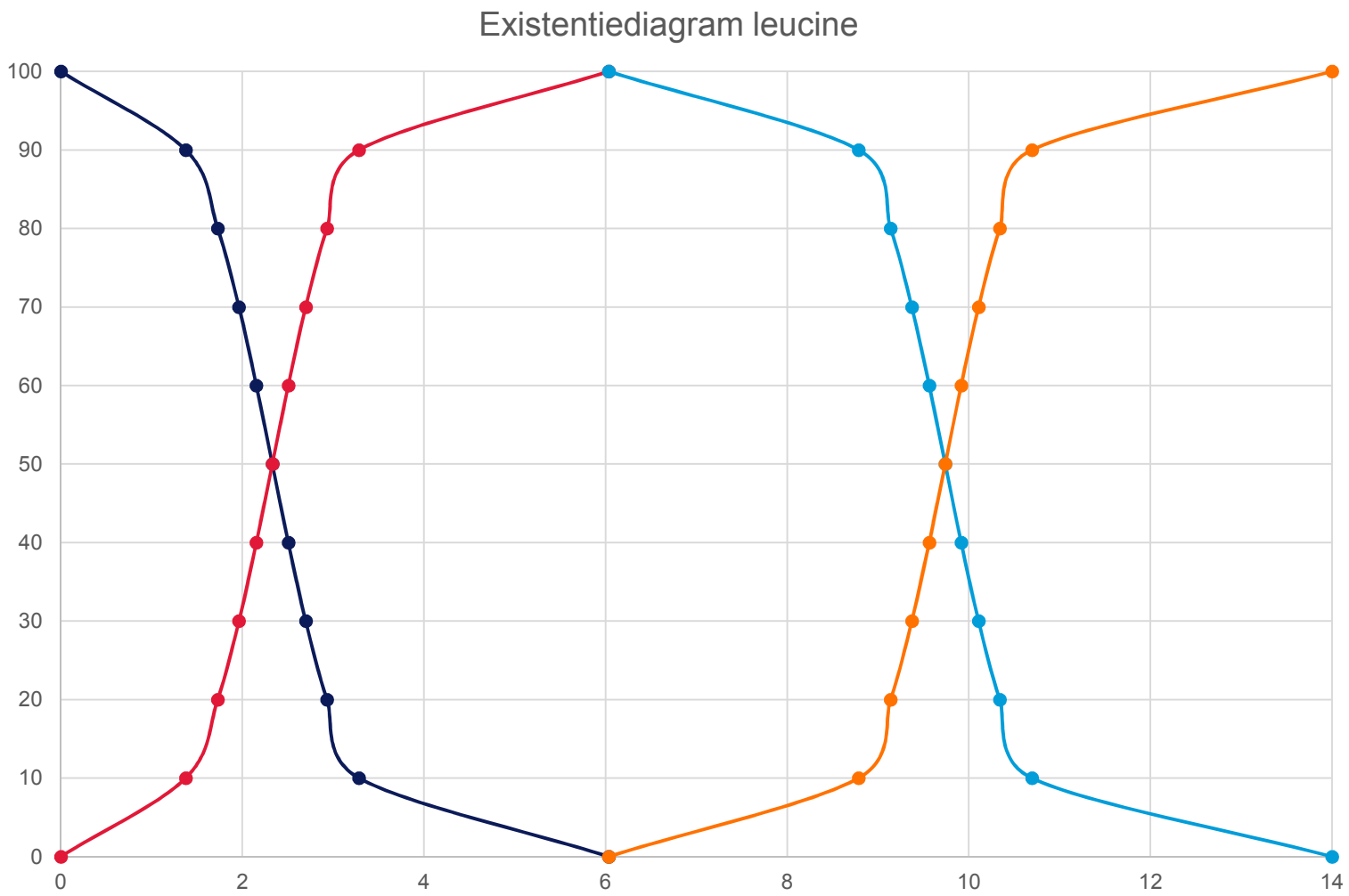


	A	B	C	D	E	F	G	H	I	J	K	L
1	Leucine											
2												
3	pKa1	2,36										
4	pKa2	9,6										
5	IEP	5,98										
6												
7	Rondom pKa1				Rondom pKa2							
8												
9	H2Z+	HZ	pH		HZ	Z-	pH					
10	100	0	0		100	0	6,035					
11	90	10	1,405757		90	10	8,645757					
12	80	20	1,75794		80	20	8,99794					
13	70	30	1,992023		70	30	9,232023					
14	60	40	2,183909		60	40	9,423909					
15	50	50	2,36		50	50	9,6					
16	40	60	2,536091		40	60	9,776091					

Hoe bereken je een existentiediagram



Worked example 18.1

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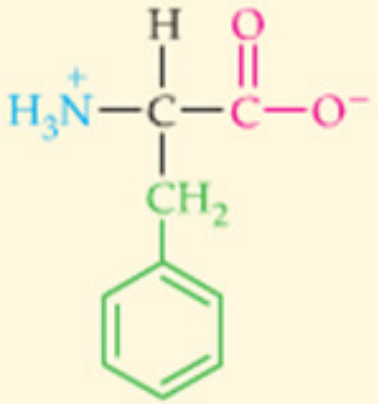
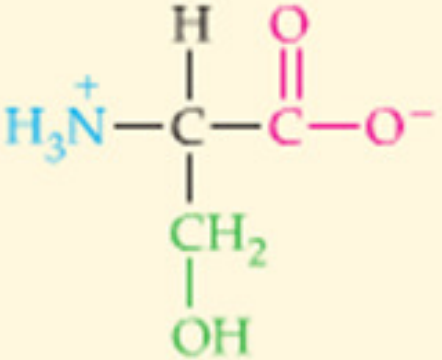
Determining Side-Chain Hydrophobicity/Hydrophilicity

Consider the structures of phenylalanine and serine in Table 18.3. Which of these two amino acids has a hydrophobic side chain and which has a hydrophilic side chain?



Phenylalanine, Phe (5.5)



Serine, Ser (5.7)

ANALYSIS Identify the side chains. The side chain in phenylalanine is an alkane. The side chain in serine contains a hydroxyl group.

SOLUTION

The hydrocarbon side chain in phenylalanine is an alkane, which is nonpolar and hydrophobic. The hydroxyl group in the side chain of serine is polar and is therefore hydrophilic.

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(Reference: Chapter18 from McMurry et al.)

Worked example 18.2

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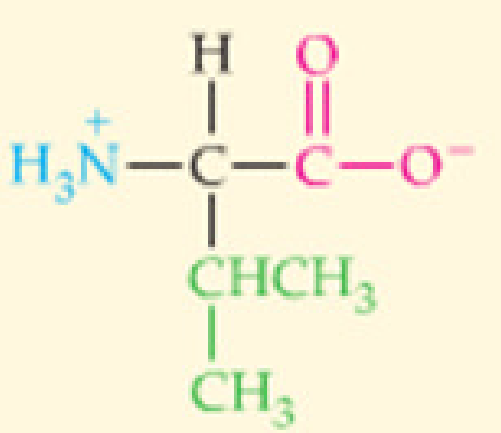
Drawing Zwitterion Forms

Look up the zwitterion structure of valine in Table 18.3. Draw valine as it would be found (a) at low pH and (b) at high pH.



Valine, Val (6.0)

ANALYSIS At low pH, which is acidic, basic groups may gain H^+ and at high pH, which is basic, acidic groups may lose H^+. In the zwitterion form of an amino acid, the $—COO^-$ group is basic and the $—NH_3^+$ is acidic.

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Worked example 18.2

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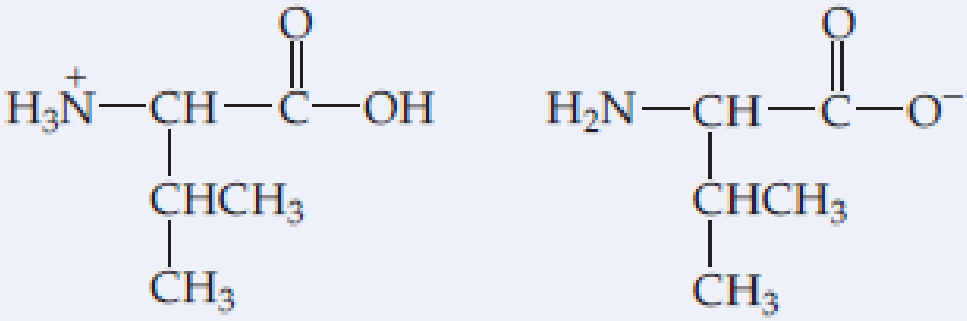
Drawing Zwitterion Forms

SOLUTION

Valine has an alkyl-group side chain that is unaffected by pH. At low pH, which is acidic, valine adds a hydrogen ion to its carboxyl group to give the structure on the left below. At high pH, which is basic, valine loses a hydrogen ion from its acidic $-NH_3^+$ group to give the structure on the right below.



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(Reference: Chapter18 from McMurry et al.)

Problem 18.7

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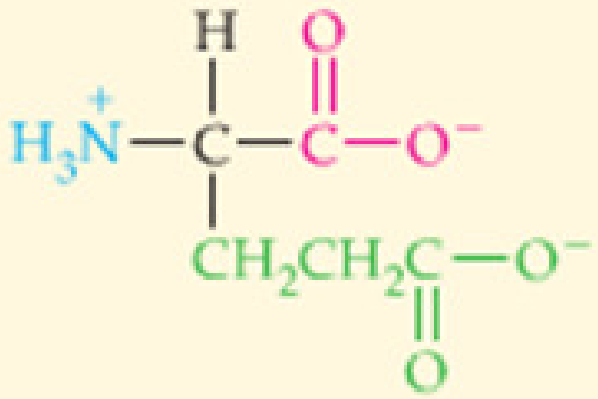
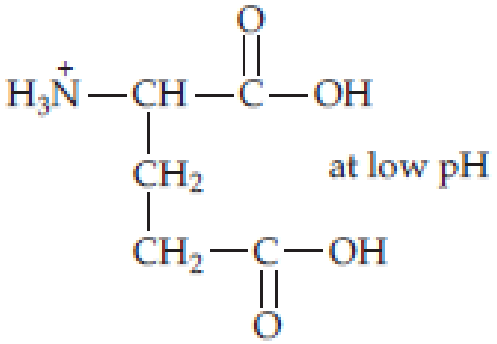
PROBLEM 18.7

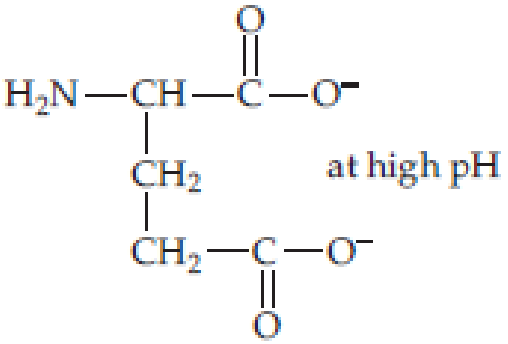
Draw the structure of glutamic acid at low pH and at high pH.



Glutamic acid, Glu (3.2)
(Glutamate)



at low pH



at high pH

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(Reference: Chapter18 from McMurry et al.)

Problem 18.7

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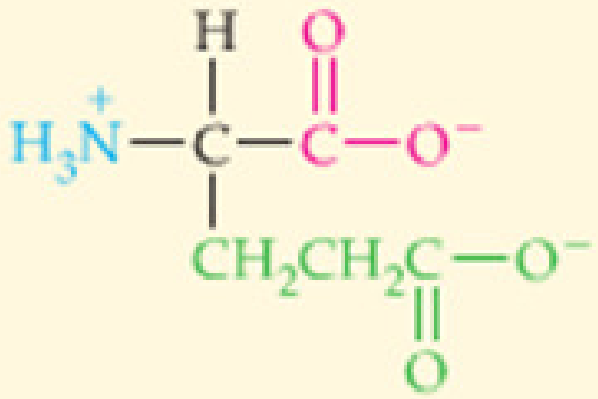
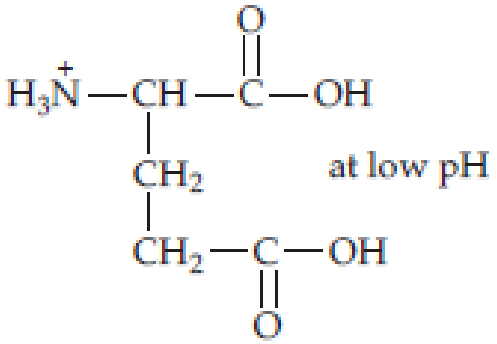
PROBLEM 18.7

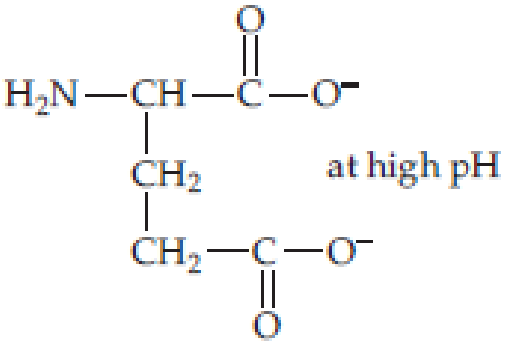
Draw the structure of glutamic acid at low pH and at high pH.



Glutamic acid, Glu (3.2)
(Glutamate)



at low pH



at high pH

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(Reference: Chapter18 from McMurry et al.)