Cours Biochimie

Christian Heinis

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Campus: Leçons: PO 01
Exercices: PO 01

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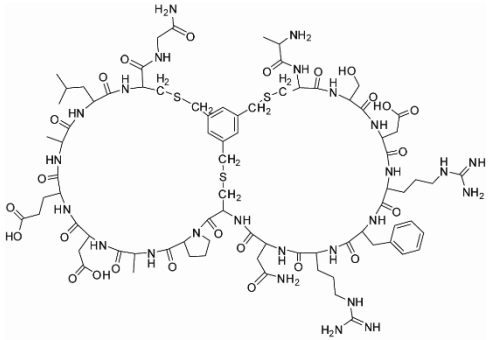
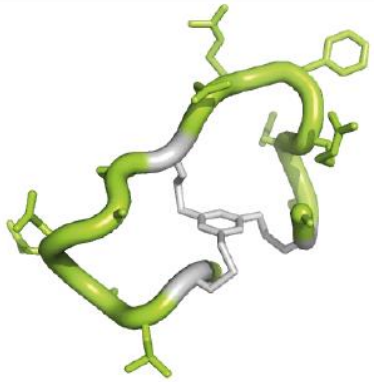
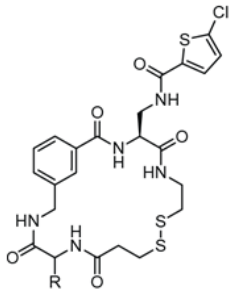
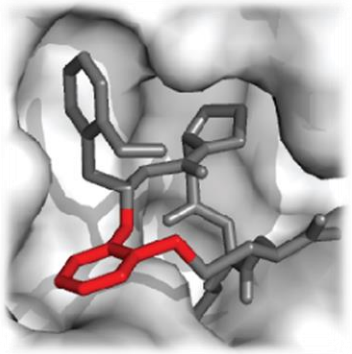
- Professeur en chimie bioorganique
- Laboratoire de Protéines et Peptide Thérapeutiques
- Recherche:









Cours Biochimie

Contenu: - Discuter les classes majeures de biomolécules

- Analyser les fonctions des biomolécules
- Comprendre la relation entre structure et fonction

Protéines	**Acides nucléiques**	**Glucides**
Acides aminés,	DNA, RNA,	**Lipides**
structures, fonctions	les nucléosides	**Molécules du métabolisme**

Comment s'organise le cours?

	Lundi	Mardi	Mercredi	Jeudi	Vendredi
10:15-11:00		Cours magistral			
11:15-12:00		Cours magistral			
12:15-13:00		Exercices			

Exercices

Un exercice per semaine (une feuille, 5-7 questions)

Exercices Biochimie I

Problèmes Leçon 1

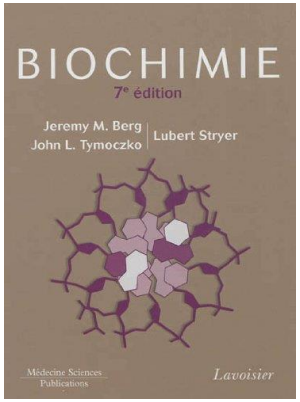
1. A) Calculez le pH d'une solution 0.001 M HCl. B) Calculez la concentration de H^+ présent dans une solution d'acide acétique à pH 4.

2. Un acide avec un pKa de 8.0 est à pH 7.0 en solution. Quel est le rapport des formes protonées et déprotonées de cet acide ? Quelle est le pourcentage de la forme protonée?

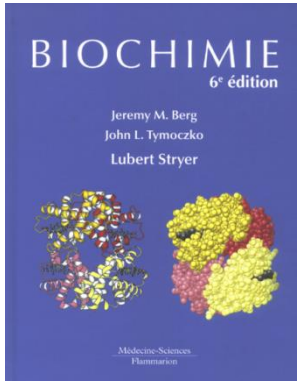
3. Dessinez les structures chimiques des acides aminés suivants au pH 7: alanine, thréonine, glutamate et arginine. Identifiez les donneurs et accepteurs de liaison hydrogène dans chaque molécule.

Contenu du cours accessible sur Moodle (http://moodle.epfl.ch)

Mot de passe: chim10



Livre: « Biochimie »
Berg, Tymoczko,
Stryer (7e édition)



Livre: « Biochimie »
Berg, Tymoczko,
Stryer (6e édition)

Livre: « Biochemistry »
Berg, Tymoczko,
Stryer (9th edition)

Les leçons

Leçon	Subject	Page en Stryer
1	Introduction en biochimie / classes de biomolécules / aminoacides	4-17 (1.2, 1.3), 25-40 (2.1, 2.2)
2	Composition et structure des protéines	40-59 (2.3-2.6)
3	Exploration des protéines et des protéomes	65-90 (3.1-3.3), 93-101 (3.5, 3.6)
4	Structure de la DNA et RNA	107-119 (4.1-4.3)
5	Explorer les gènes et les génomes	134-144 (5.1, 5.2 premières 3 pages)
6	Synthèse des protéines / expression recombinante	117-119 (4.3), 119-127 (4.4), 142-148 (5.2)

Pages indiquées pour la 6^{e} édition de Stryer

7	Exploration de l'Évolution	164-180 (6.1-6.5)
8	Portrait de haemoglobin / des anticorps	183-198 (7.1-7.4), 949-956 (33.1-33.3)
9	Enzymes: concepts de base et cinétique	205-227 (8.1-8.4, 8.5 premières 3 pages)
10	Enzymes: stratégies catalytiques	241-270 (9.1-9.4)
11	Lipides et membranes cellulaires / Les glucides	326-345 (12.1-12.5), 303-315 (11.1, 11.2)
12	Métabolisme	409-429 (15.1-15.4)
13	Modèle de DNA de Watson et Crick	vidéo

Leçon 1

- Introduction en biochimie
  - Les classes de biomolécules
- Interactions moléculaires
  - Forces des interactions
  - Etat de ionisation (pH et pK_a)
- Aminoacides
  - Chimie et structure des aminoacides
  - Les qualités des aminoacides

Les classes de biomolécules

Figure 1-1c
Lehninger Principles of Biochemistry, Fifth Edition

Quels sont les composants des plantes ou des animaux?

Les classes de biomolécules

Figure 1-1c
Lehninger Principles of Biochemistry, Fifth Edition

Quels sont les composants des plantes ou des animaux?

Avec quelles méthodes peut-on analyser les composants?

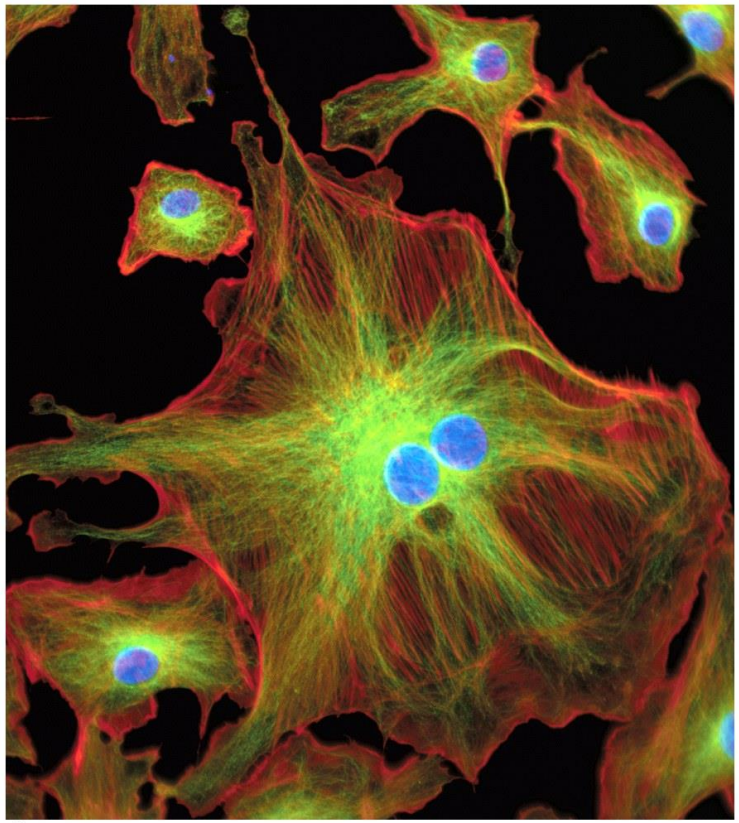


Figure 1-9a
Lehninger Principles of Biochemistry, Fifth Edition

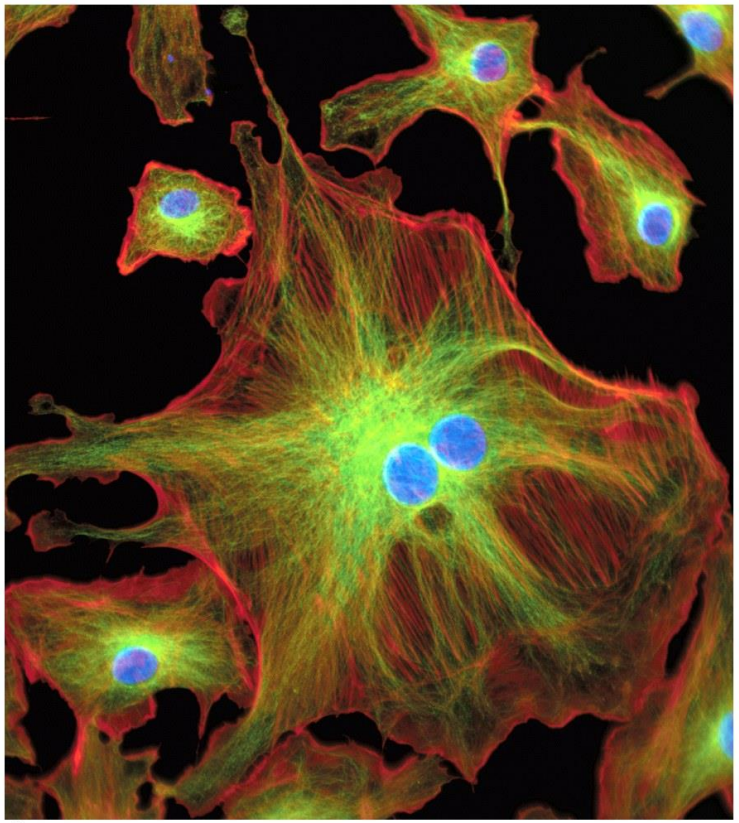


Figure 1-9a
Lehninger Principles of Biochemistry, Fifth Edition

Quels sont les composants des cellules?

Avec quelles méthodes peut-on analyser les composants?

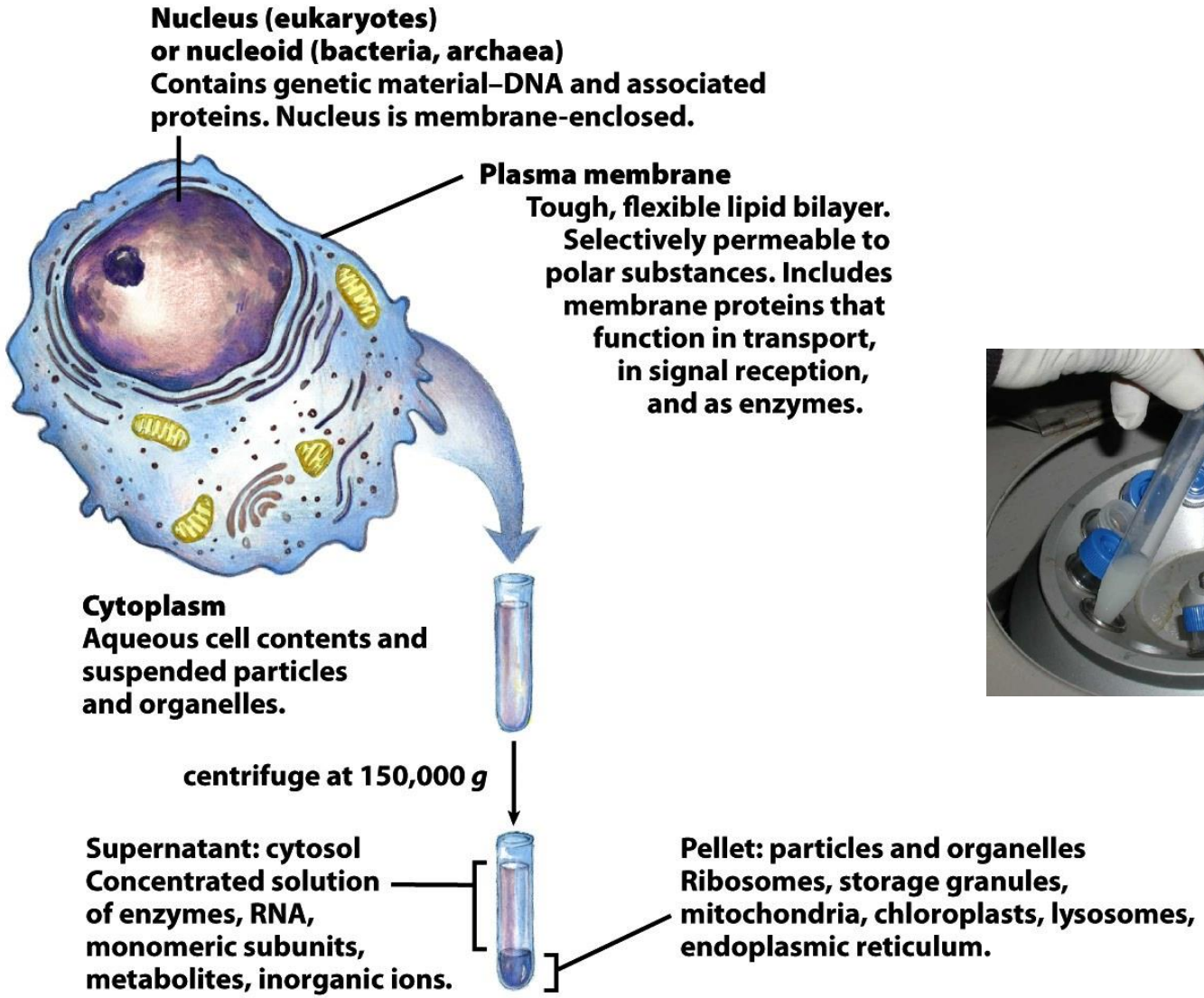
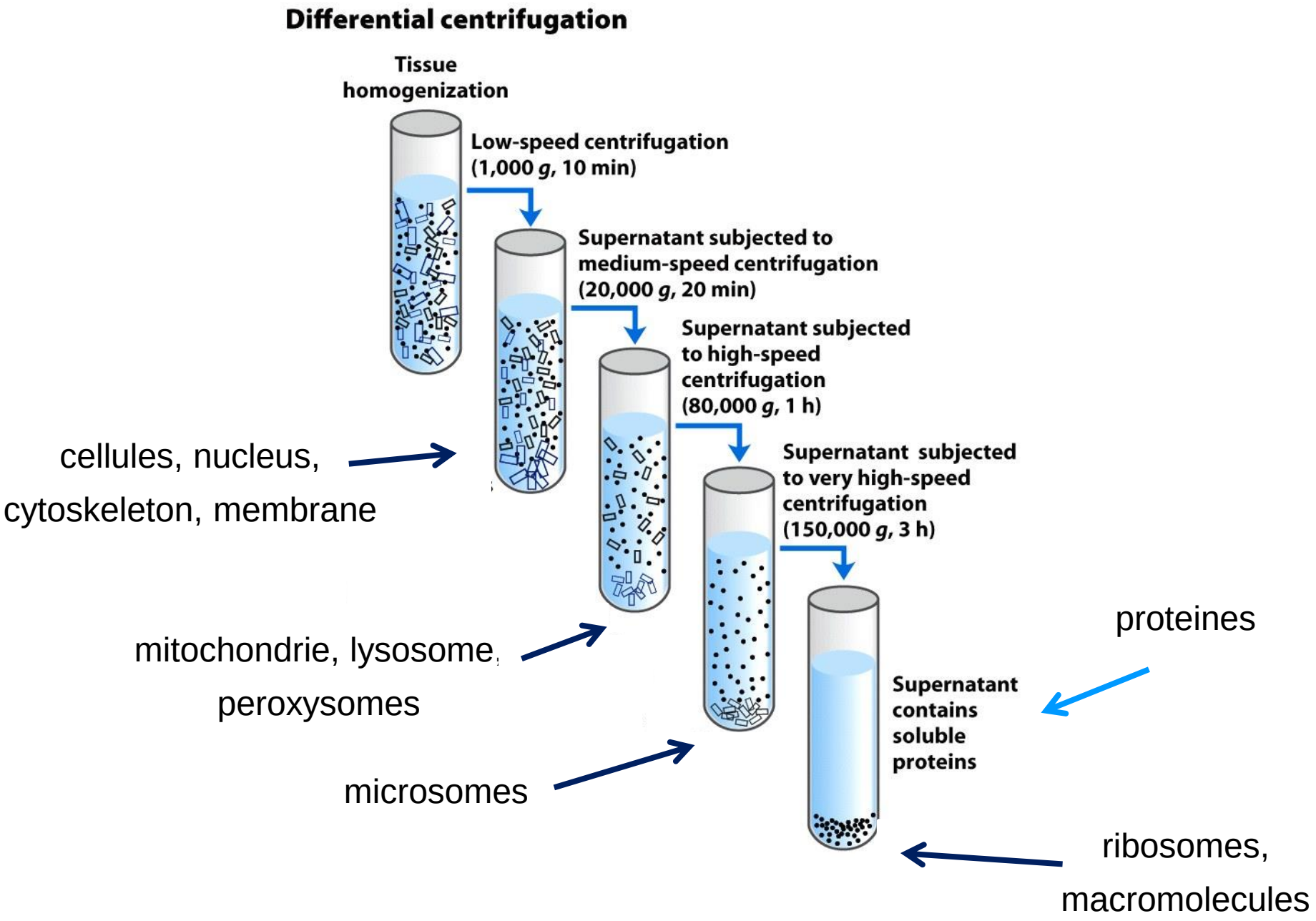


Figure 1-3
Lehninger Principles of Biochemistry, Fifth Edition

sédiment


Differential centrifugation
Tissue homogenization
Low-speed centrifugation (1,000 g, 10 min)
Supernatant subjected to medium-speed centrifugation (20,000 g, 20 min)
Supernatant subjected to high-speed centrifugation (80,000 g, 1 h)
Supernatant subjected to very high-speed centrifugation (150,000 g, 3 h)
Supernatant contains soluble proteins
cellules, nucleus, cytoskeleton, membrane
mitochondrie, lysosome, peroxysomes
microsomes
proteines
ribosomes, macromolecules

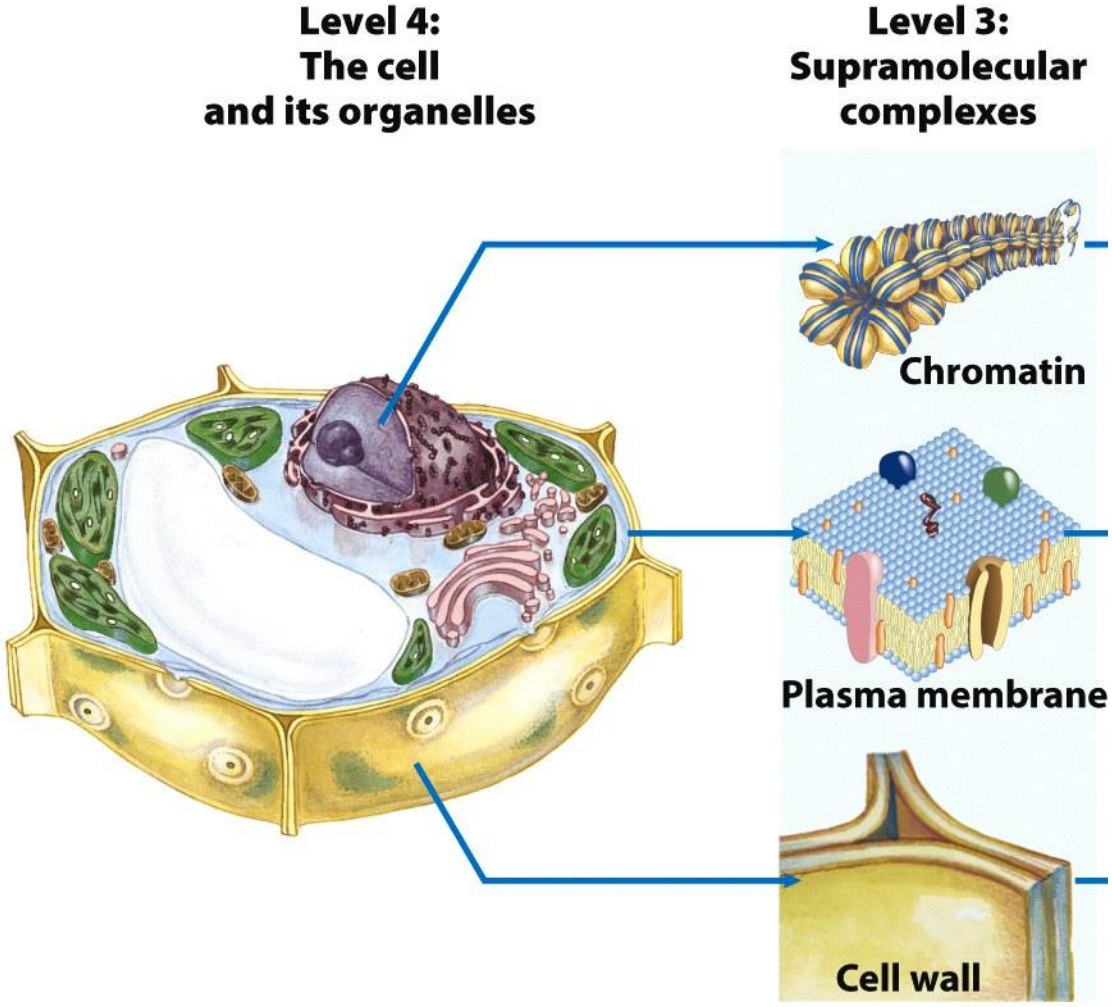


Figure 1-11
Lehninger Principles of Biochemistry, Fifth Edition

paroi cellulaire

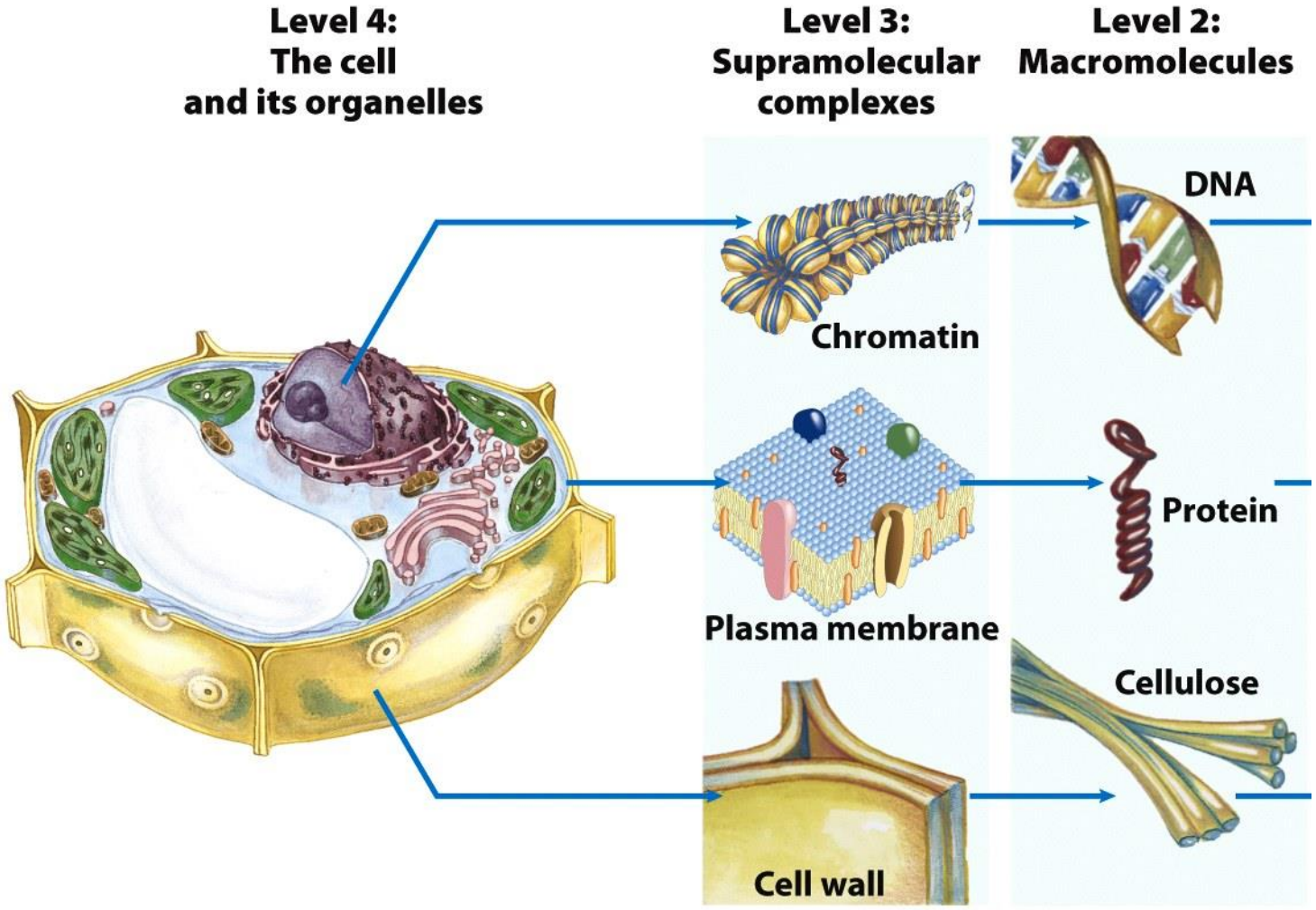
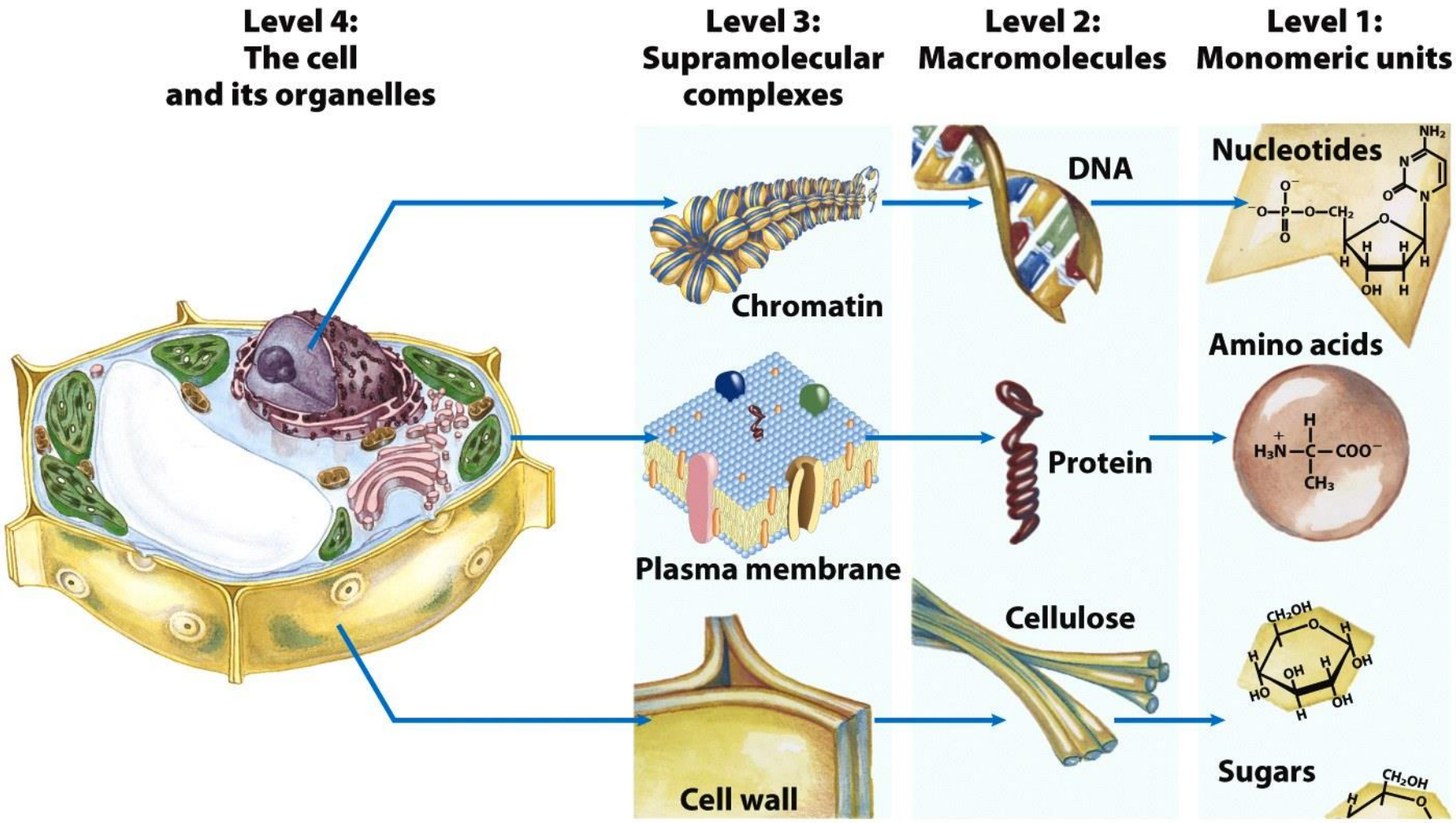
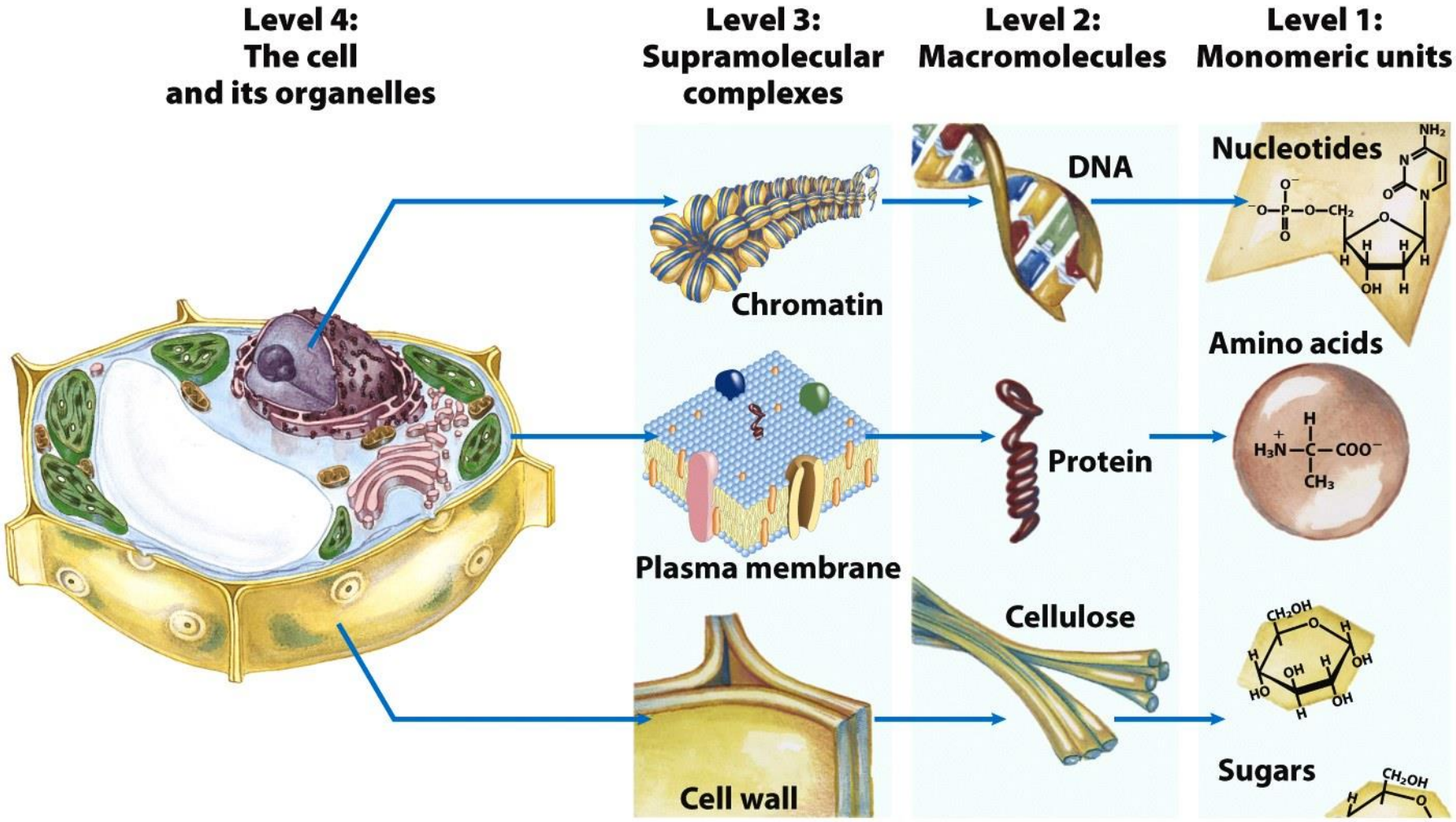


Figure 1-11
Lehninger Principles of Biochemistry, Fifth Edition



La biochimie s'occupe surtout des molécules des niveaux 1 et 2



Quelle <u>part du pois</u> d'une cellule est de H_2O, protéine, DNA, lipide ?

Vue d'ensemble des composants dans une cellule de bactérie (*E.coli*)

TABLE 1–1	Molecular Components of an *E. coli* Cell	
	Percentage of total weight of +1cell	Approximate number of different
Water	70	1
Proteins	15	3,000
Nucleic acids		
DNA	1	1
RNA	6	>3,000
Polysaccharides	3	5
Lipids	2	20
Monomeric subunits and intermediates	2	500
Inorganic ions	1	20

Table 1-1
Lehninger Principles of Biochemistry, Fifth Edition

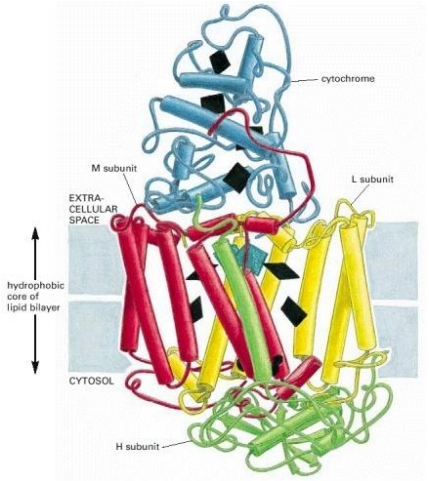
↑

La part du poids d'une cellule (en %)

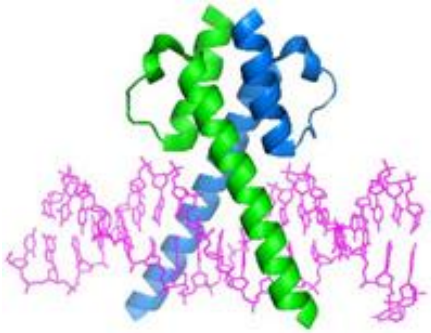
- Introduction en biochimie
  - Les classes de biomolécules
- Interactions moléculaires
  - Forces des interactions
  - Etat de ionisation (pH et pK_a)
- Aminoacides
  - Chimie et structure des aminoacides
  - Les qualités des aminoacides

Interactions moléculaires

Les interactions moléculaires sont nécessaires pour…



…former des structures tridimensionnelles



…les fonctions des biomolécules

Interactions moléculaires

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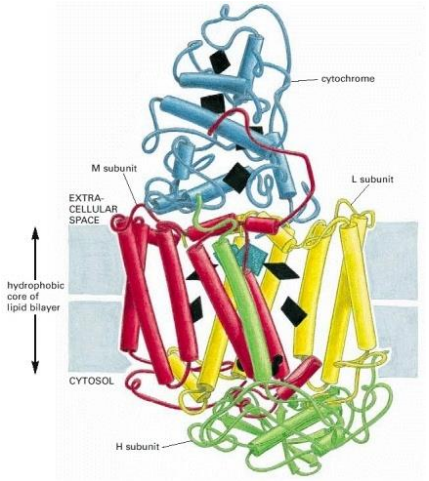

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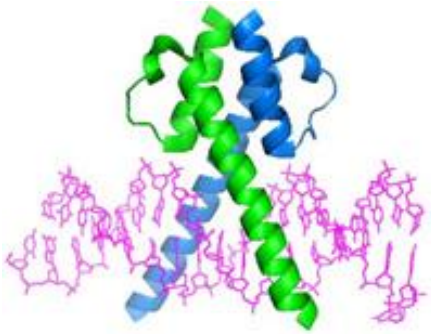


…les fonctions des biomolécules

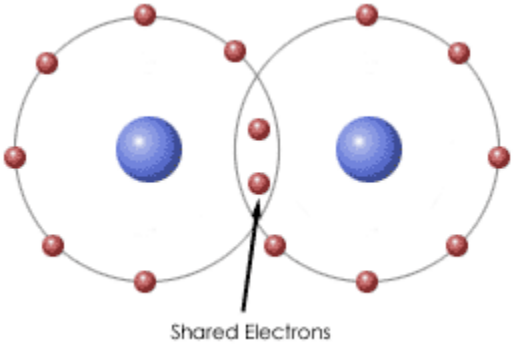
Quels types d'interactions est-ce qu'il y a entre les atomes des biomolécules?

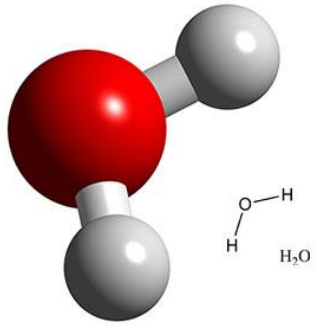
Interactions covalente et non-covalente

Interactions covalente:

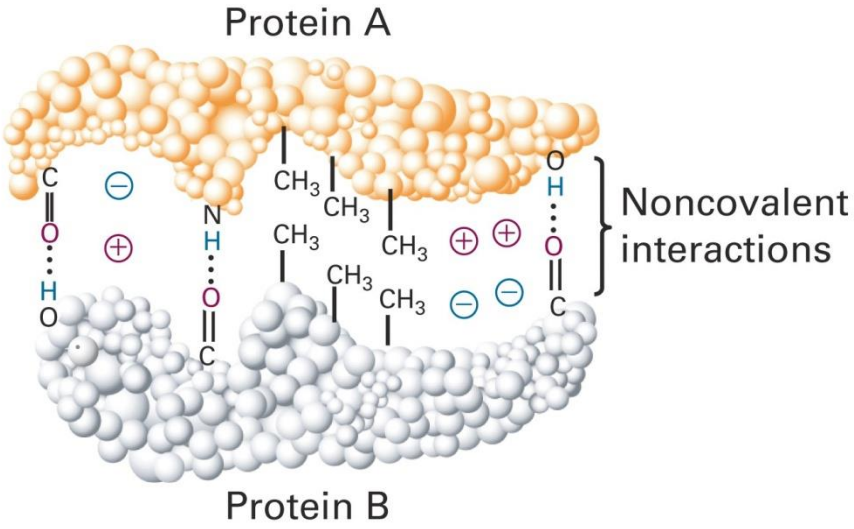
~ 100 kcal/mol

Les atomes partagent un électron





Interactions non-covalentes:

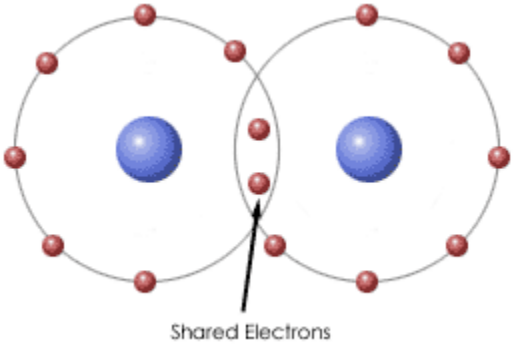


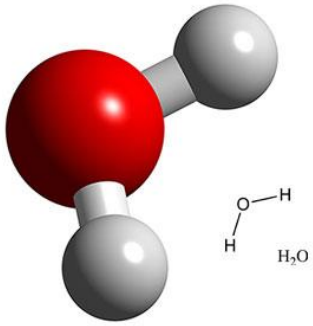
Interactions covalente et non-covalente

Interactions covalente:

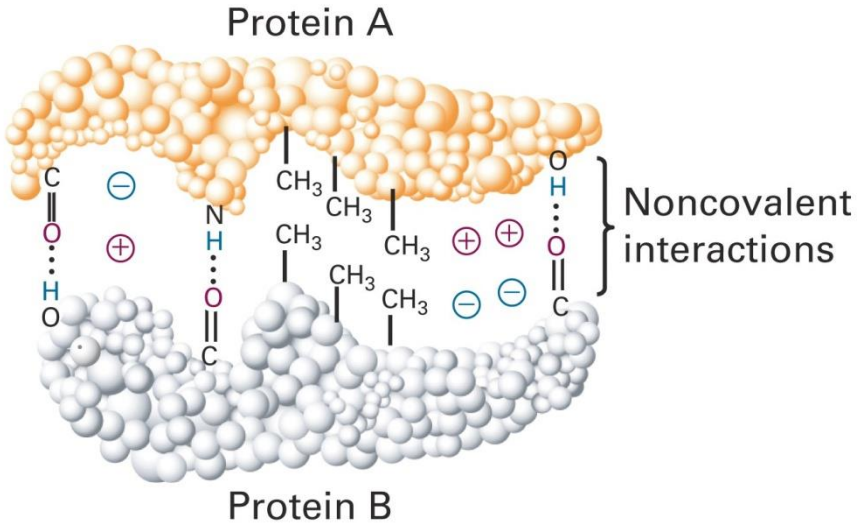
~ 100 kcal/mol

Les atomes partagent un électron





Interactions non-covalentes:



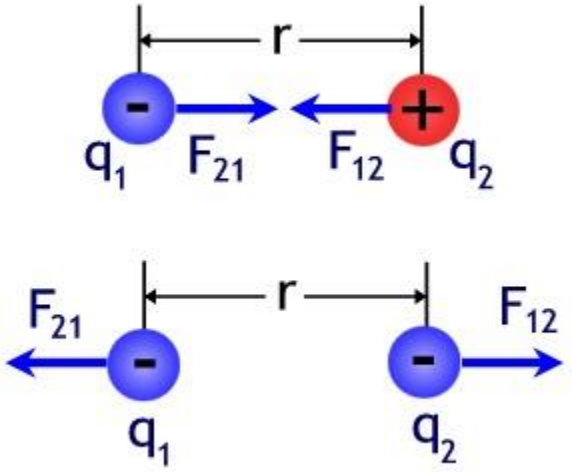
Quels types d'interactions non-covalents existent?

Quatre interactions non-covalentes

- Interactions électrostatiques
- Interactions Van der Waals
- Liaisons hydrogènes
- Effets hydrophobe

1. Interactions électrostatiques

attraction



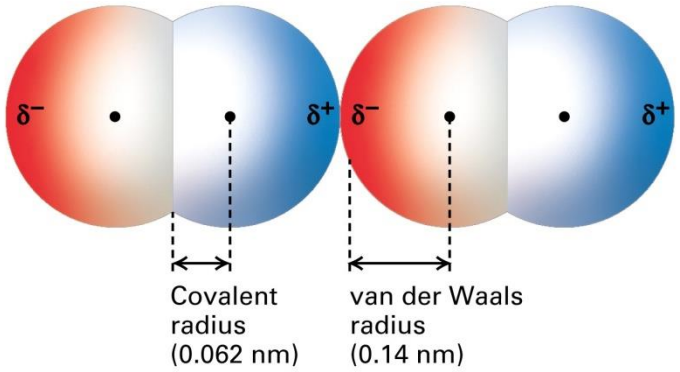
Loi de Coulomb: $E = kq_1q_2/Dr$

D = constante diélectrique, r = distance,

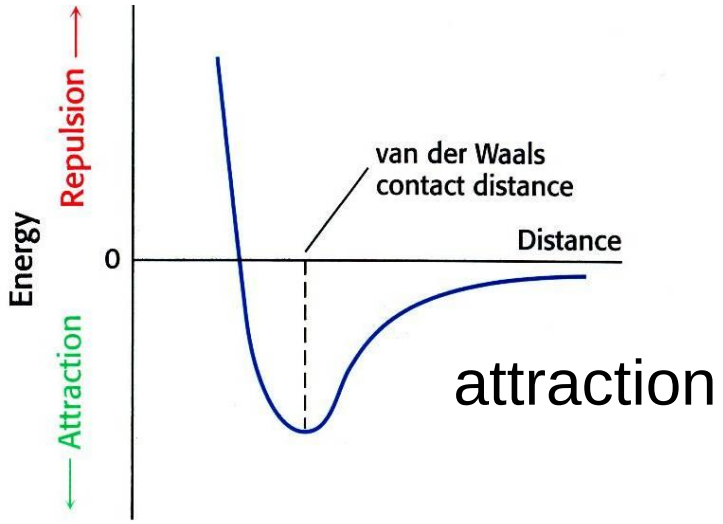
k = constante de proportionnalité

Interaction entre deux charges séparées dans l'eau par 3 Å **= ~ 3 kcal/mol**

2. Interactions de Van der Waals



répulsion

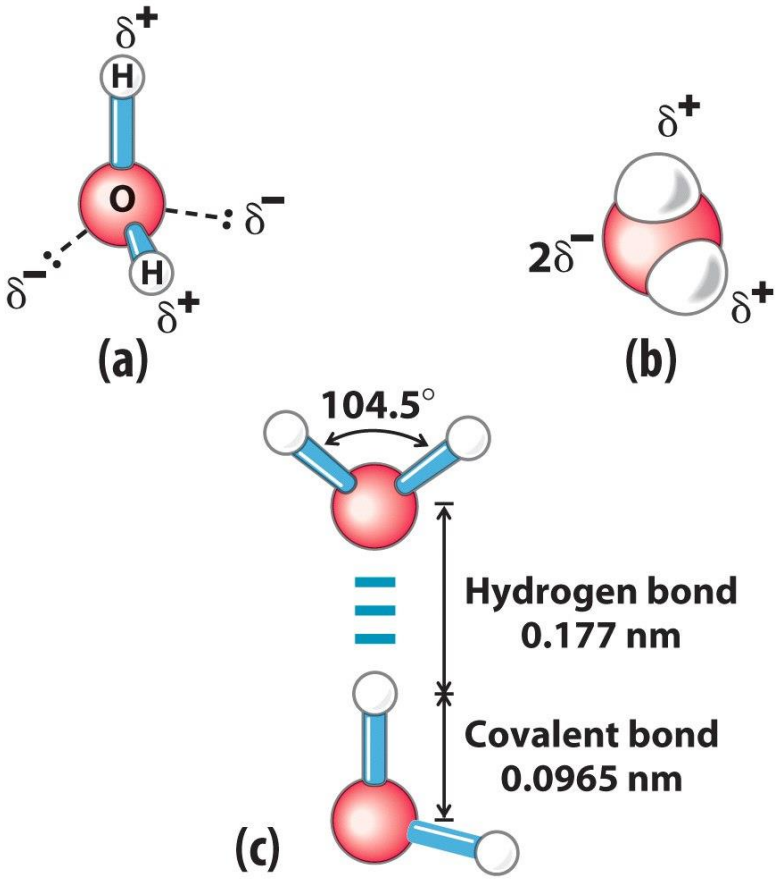


attraction

Résultat d'une asymétrie temporaire de la distribution électronique autour d'un atome/ molécule

~ 0.5 - 1 kcal/mol

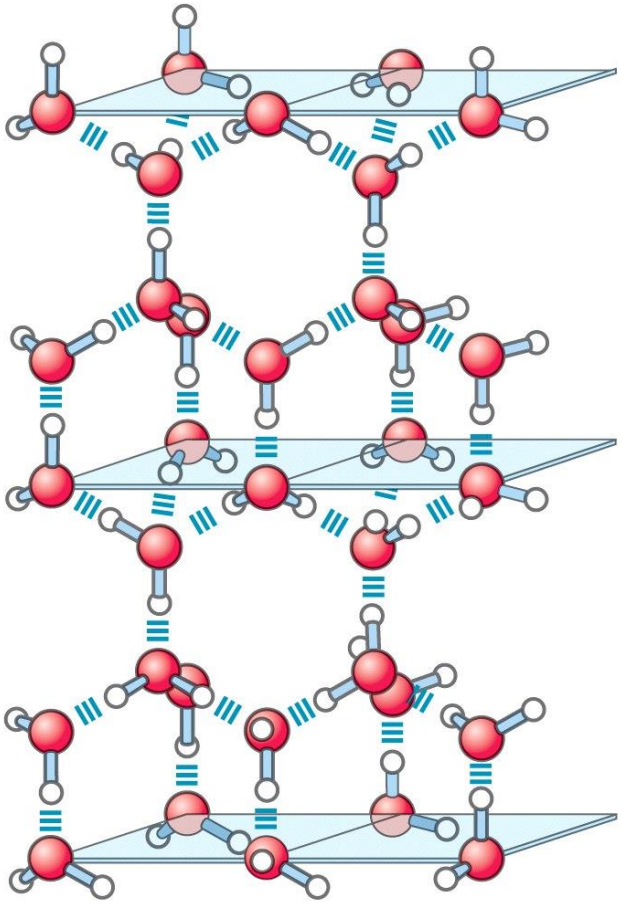
3. Liaisons hydrogènes



- Une liaison hydrogène est formée entre un « hydrogen acceptor » et un « hydrogen donor »
- Interactions électrostatiques, conséquence de la polarisation d'une liaison X-H

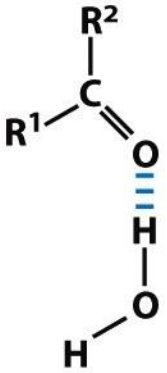
1-5 kcal/mol

Liaisons hydrogènes dans la glace

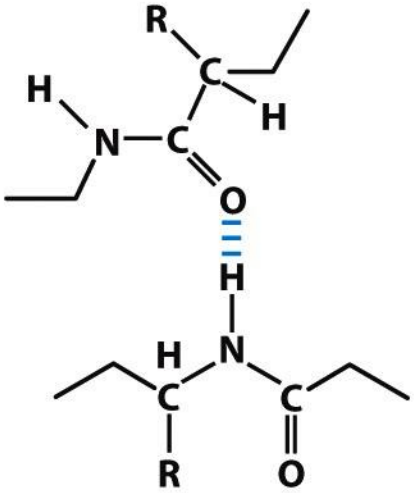


Between the hydroxyl group of an alcohol and water

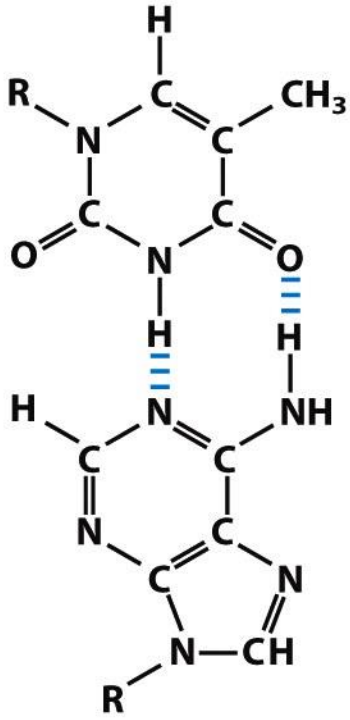
Between the carbonyl group of a ketone and water



Between peptide groups in polypeptides



Between complementary bases of DNA



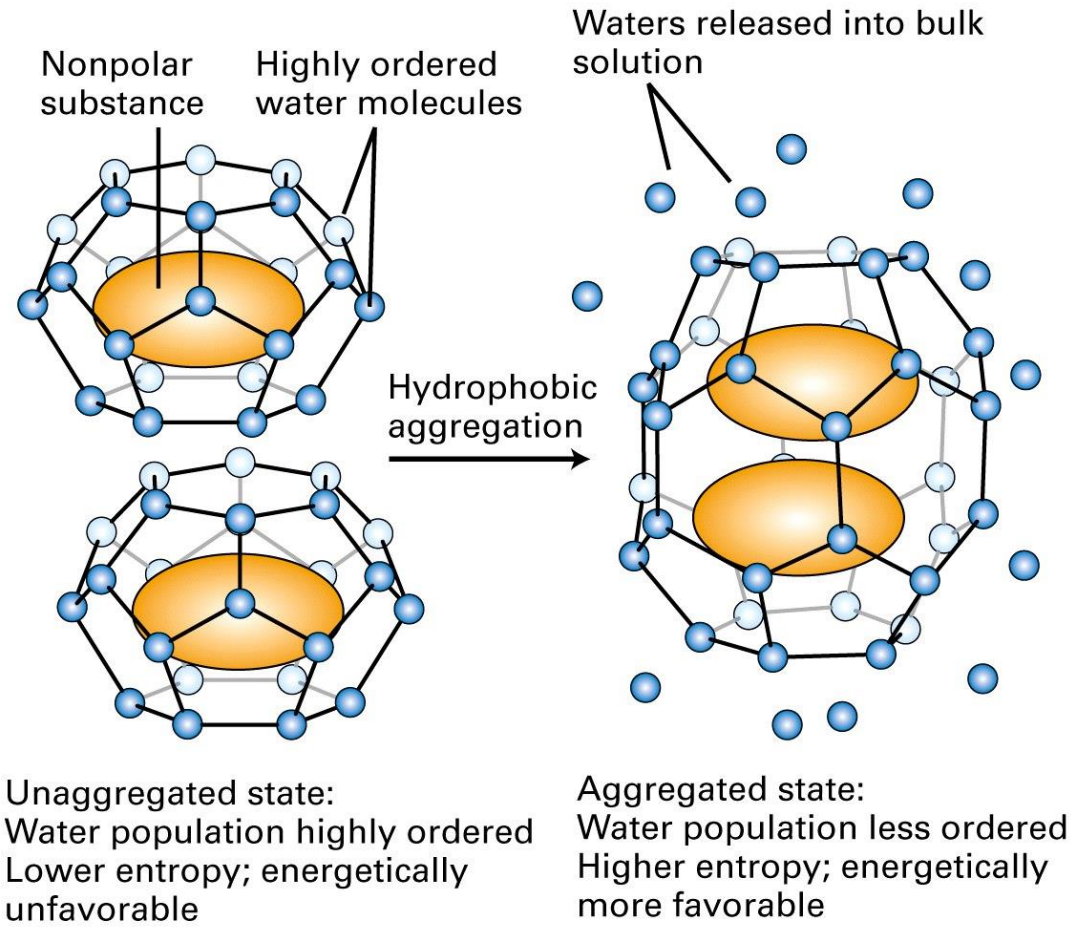
Thymine

Adenine

En général 1-5 kcal/mol, entre 1.5 et 2.6 Å, souvent linéaire.

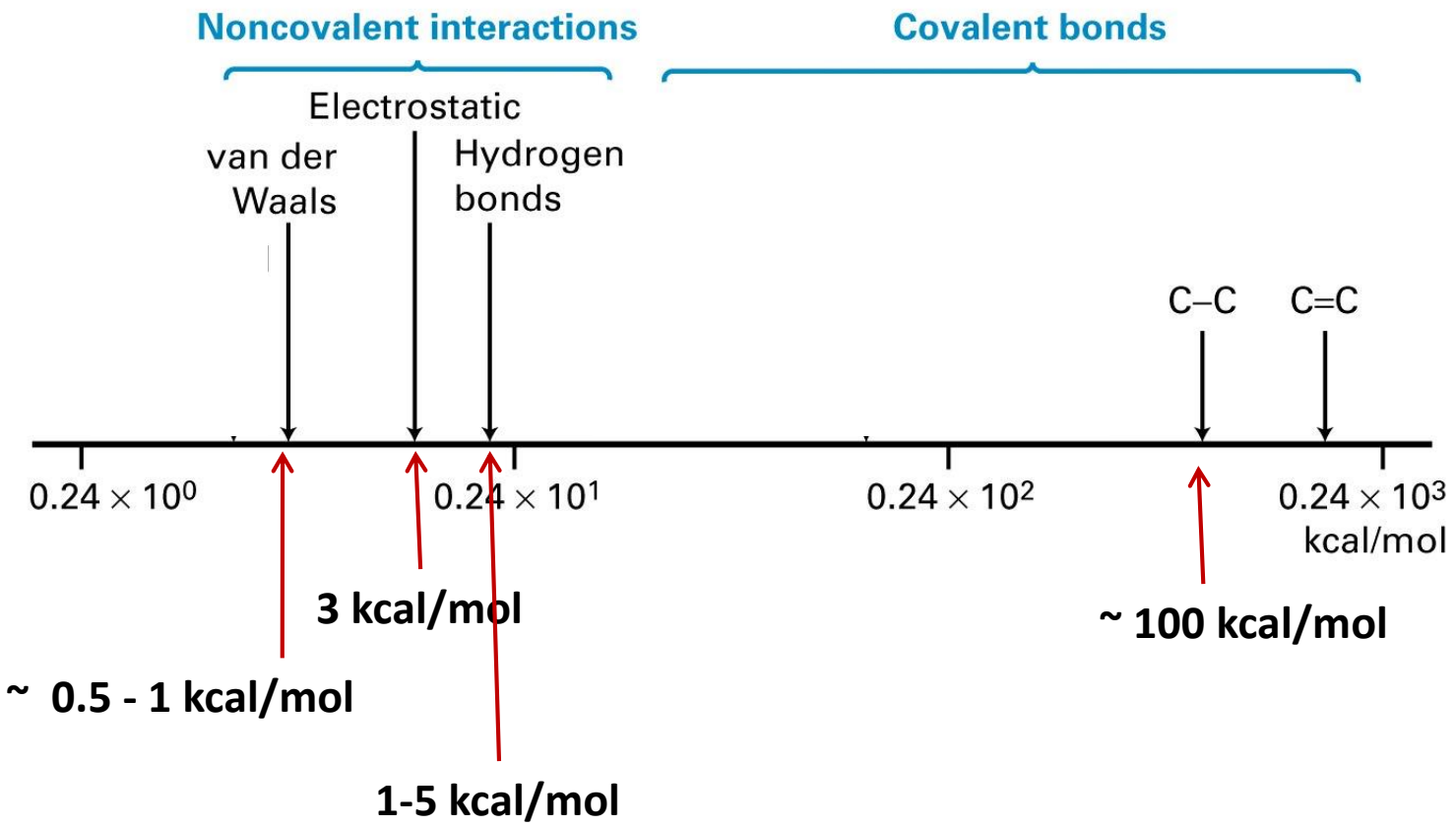
4. L'effet hydrophobe (the hydrophobic effect)

Une cage de molécules d'eau



- Important pour le « protein folding », membranes, DNA double-helix…

Vue d'ensemble des forces des interactions



- Introduction en biochimie
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  - Etat de ionisation (pH et pK_a)
- Aminoacides
  - Chimie et structure des aminoacides
  - Les qualités des aminoacides

pH

Quel est la signification du pH?

pH

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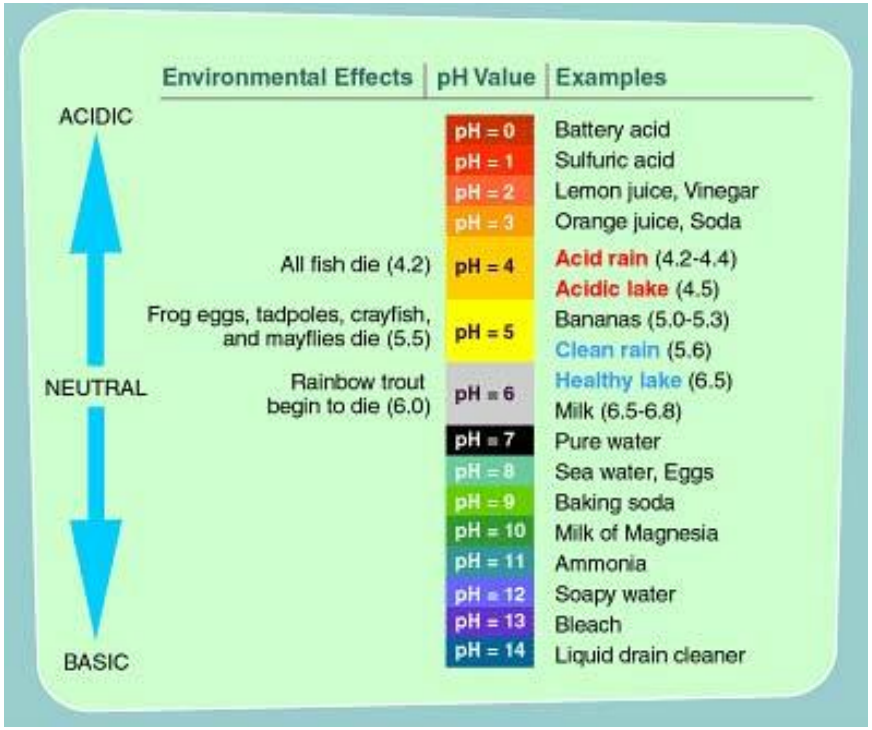


$$pH = - \log_{10} [H^+]$$

Exemple:

Concentration de $H^+ = 10^{-6}$ M

↓

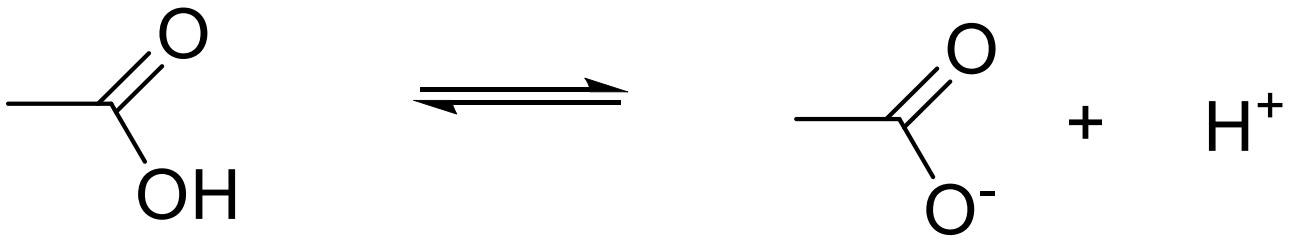
pH = 6

Dans l'eau, le H^+ est toujours lié au H_2O (H_3O^+)

pK_A

Quel est la signification du pK_A?

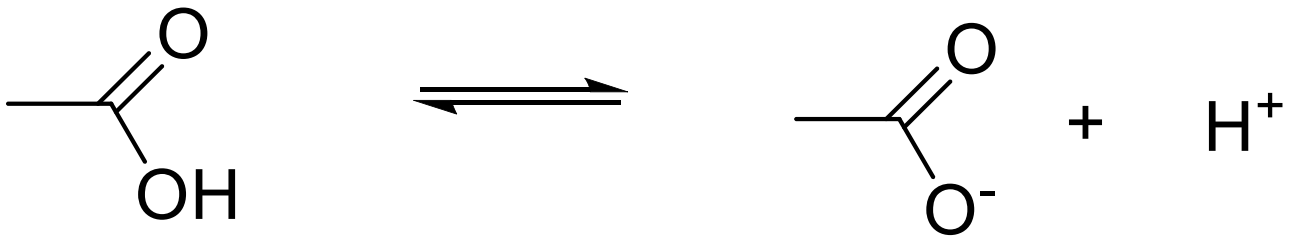
K_A (comme le pK_A) decrit l'état d'ionisation des molécules



acide acétique (HAc)

acétate (Ac^-)

K_A (comme le pK_A) decrit l'état d'ionisation des molécules



acide acétique (HAc)

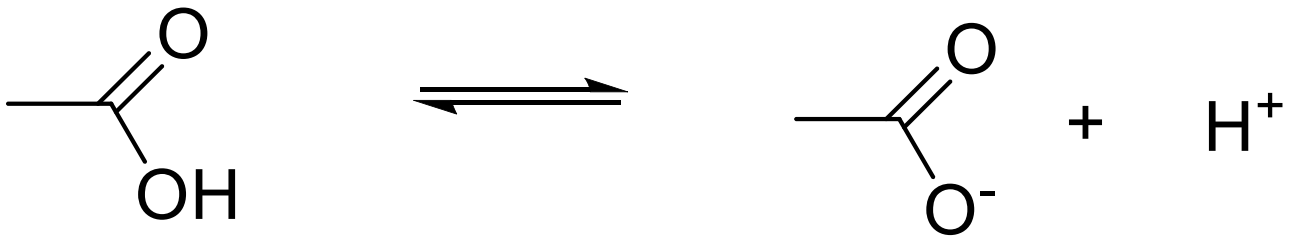
acétate (Ac^-)

Définition de l'équilibre:

$$K_a = \frac{[H^+][Ac^-]}{[HAc]}$$

(Équation 1)

K_A (comme le pK_A) decrit l'état d'ionisation des molécules



acide acétique (HAc)

acétate (Ac^-)

Définition de l'équilibre:

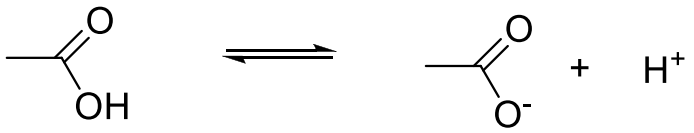
$$K_a = \frac{[H^+][Ac^-]}{[HAc]}$$

(Équation 1)

$$pK_a = -\log_{10}(K_a)$$

(Équation 2)

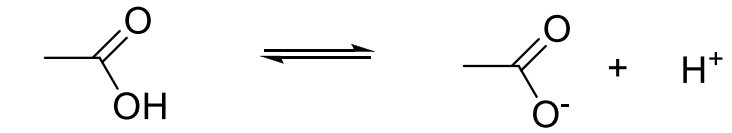
pK_A decrit l'état d'ionisation des molécules



acide acétique (HAc) — acétate (Ac^-)

$$K_a = \frac{[H^+][Ac^-]}{[HAc]}$$

pK_A decrit l'état d'ionisation des molécules



acide acétique (HAc)

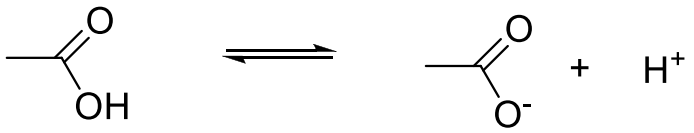
acétate (Ac^-)

$$K_a = \frac{[H^+][Ac^-]}{[HAc]}$$

$$\frac{K_a}{[H^+]} = \frac{[Ac^-]}{[HAc]}$$

Le rapport de $[Ac^-]$ au $[HAc]$

pK_A decrit l'état d'ionisation des molécules



acide acétique (HAc)

acétate (Ac^-)

$$K_a = \frac{[H^+][Ac^-]}{[HAc]}$$

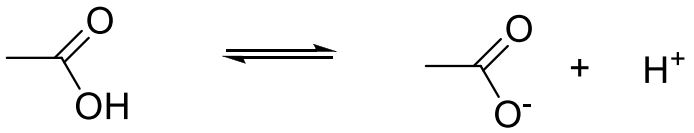
constante de dissociation (fixe)

$$\frac{K_a}{[H^+]} = \frac{[Ac^-]}{[HAc]}$$

concentration de protons

Le rapport de $[Ac^-]$ au $[HAc]$

pK_A decrit l'état d'ionisation des molécules



acide acétique (HAc)

acétate (Ac^-)

$$K_a = \frac{[H^+][Ac^-]}{[HAc]}$$

constante de dissociation (fixe)

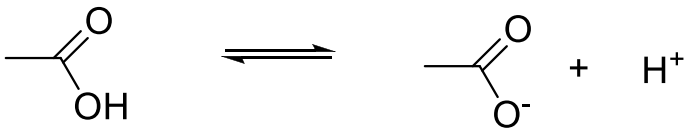
$$\frac{K_a}{[H^+]} = \frac{[Ac^-]}{[HAc]}$$

concentration de protons

Le rapport de $[Ac^-]$ au $[HAc]$

Pourquoi est-ce que c'est intéressant de savoir le rapport de [Ac] au [HAc]?

Quel est le rapport de [Ac^-] avec [HAc] à pH 7?

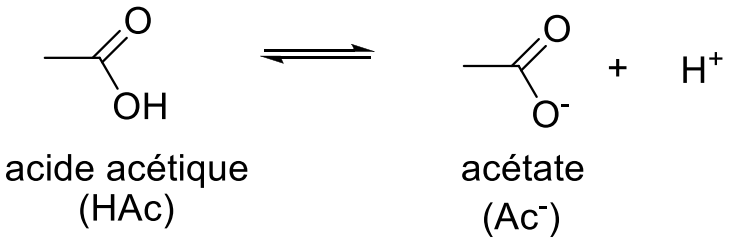


acide acétique (HAc) — acétate (Ac^-)

pK_a (acide acétique) = 4.75 → $pK_a = -\log_{10}(K_a)$

$$\frac{K_a}{[H^+]} = \frac{[Ac^-]}{[HAc]}$$

pK_A decrit l'état d'ionisation des molécules



acide acétique (HAc) — acétate (Ac^-)

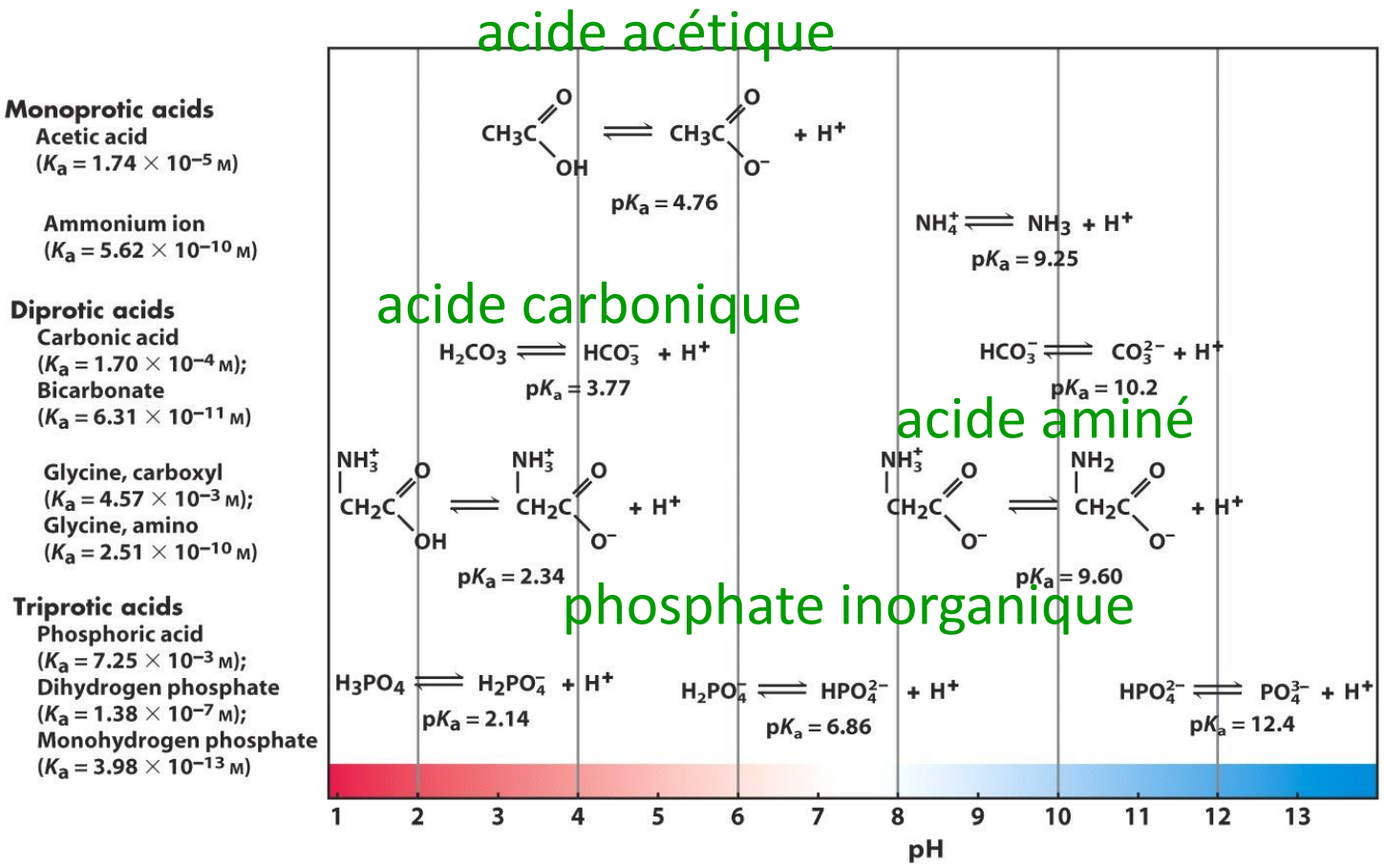
$$\frac{K_a}{[H^+]} = \frac{[Ac^-]}{[HAc]}$$

$pK_a = - \log_{10}(K_a)$ → $K_a = 10^{-4.75} = 0.0000178$

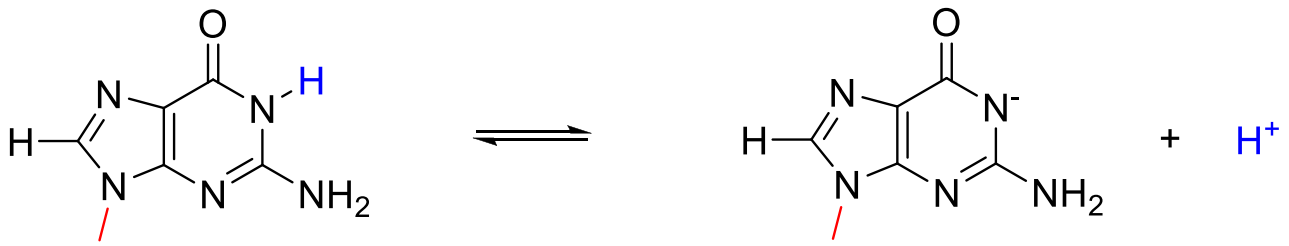
$pH = - \log_{10} [H^+]$ → $[H^+] = 10^{-7} = 0.0000001$

$$\frac{[Ac^-]}{[HAc]} = \frac{0.0000178}{0.0000001} = \mathbf{178}$$

Une connaissance du pK_A d'un groupe fonctionnel est indispensable pour comprendre et prédire ses interactions avec d'autres molécules!!!



Exemple:



guanine protoné
(GH)

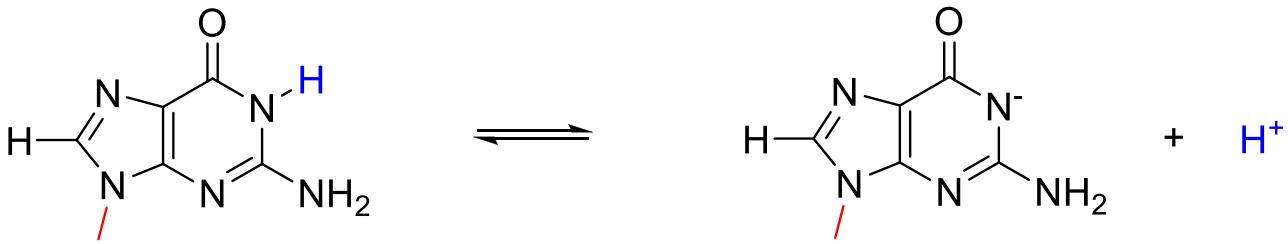
guanine$^-$
(G^-)

$$\frac{K_a}{[H^+]} = \frac{[G^-]}{[GH]}$$

pK_a (guanine) = 9.7

Quel est le rapport de $[G^-]$ au $[GH]$ au cellules (pH 7.4)?

Exemple:



guanine protoné
(GH)

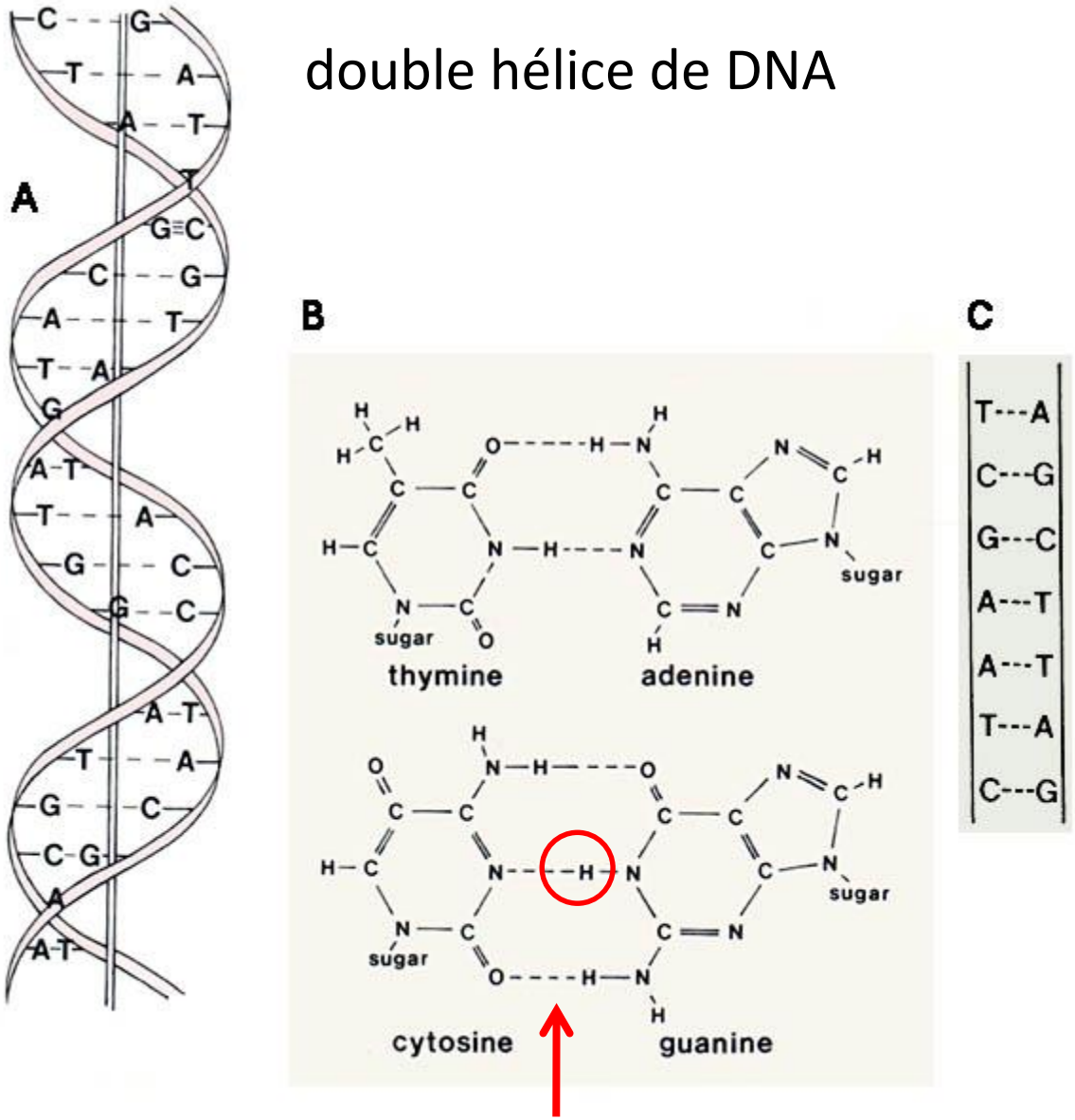
guanine$^-$
(G^-)

$pK_a = - \log_{10}(K_a)$ → $K_a = 10^{-9.7} = 0.0000000002$

$pH = - \log_{10} [H^+]$ → $[H^+] = 10^{-7.4} = 0.00000004$

$$\frac{[G^-]}{[GH]} = \frac{0.0000000002}{0.00000004} = \mathbf{0.005}$$

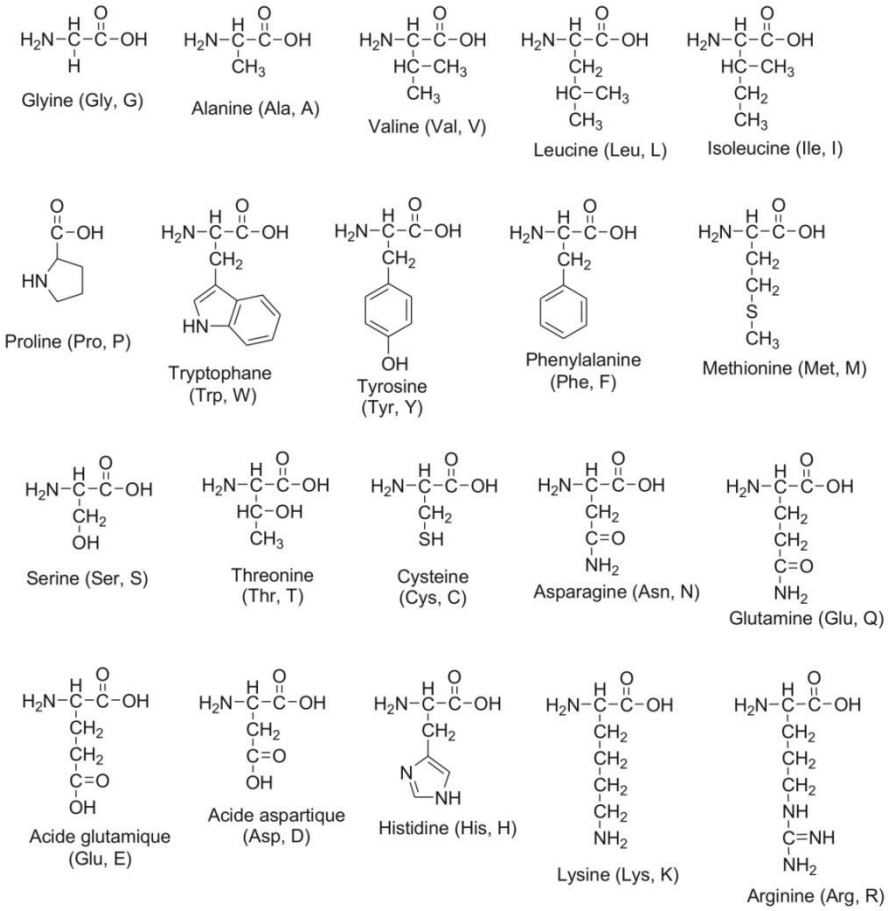
double hélice de DNA

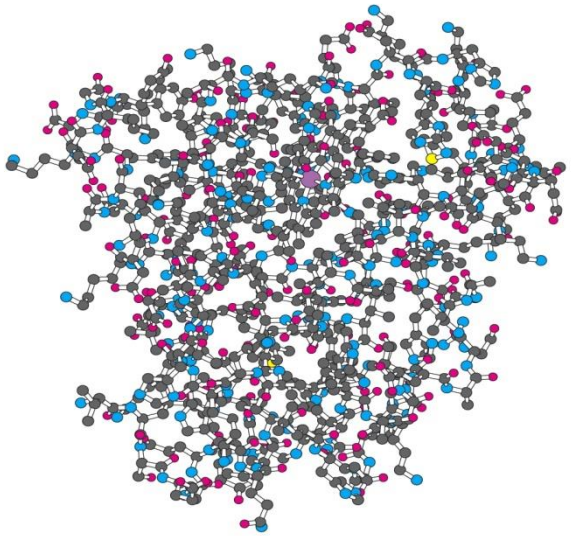


liaison hydrogène

- Introduction en biochimie
  - les classes de biomolécules
- Interactions moléculaires
  - forces des interactions
  - etat de ionisation (pH et pK_a)
- Aminoacides
  - chimie et structure des aminoacides
  - les qualités des aminoacides

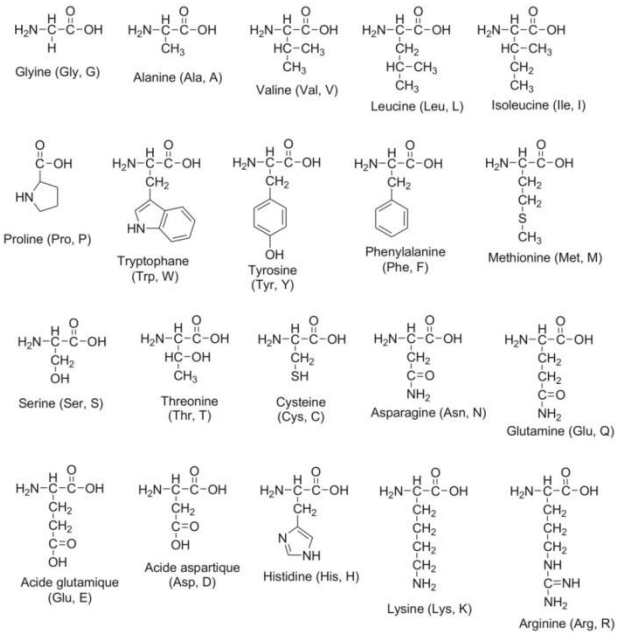
Aminoacides



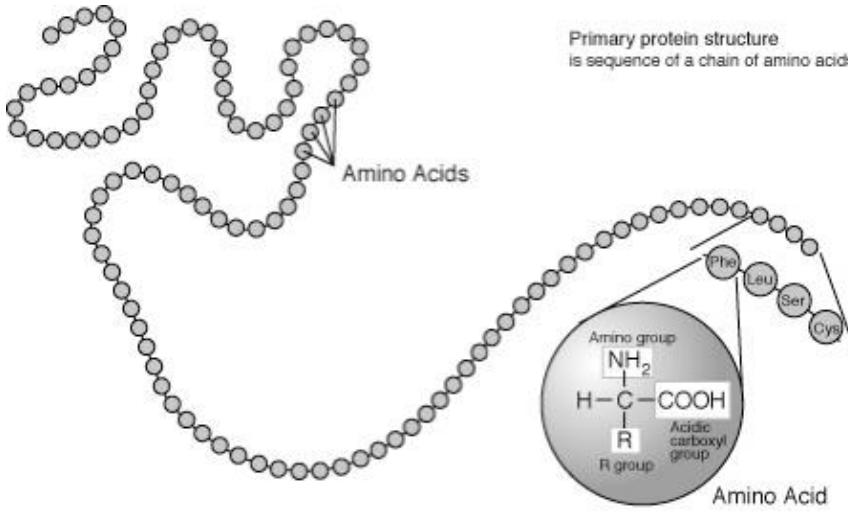


Les 20 aminoacides sont les constituants principaux des protéines.

Aminoacides



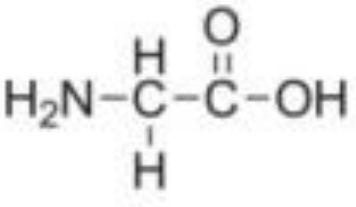
chaîne d'aminoacides



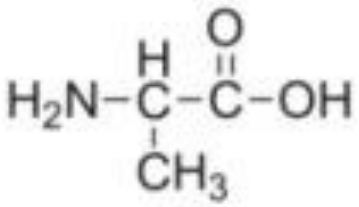
Les 20 aminoacides ont des groupes chimiques en commun. *Lesquels?*

Aminoacides

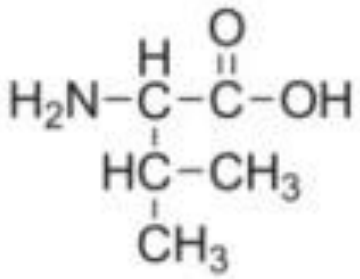
Quelles groupes chimiques sons <u>commun</u> dans les acides aminés?



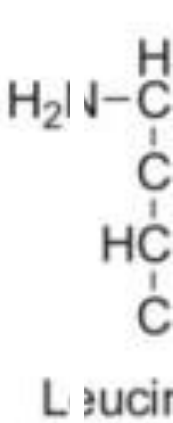
Glyine (Gly, G)



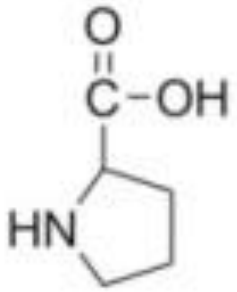
Alanine (Ala, A)



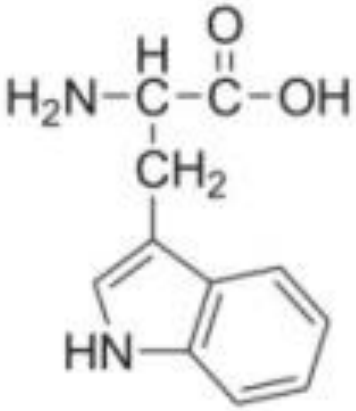
Valine (Val, V)



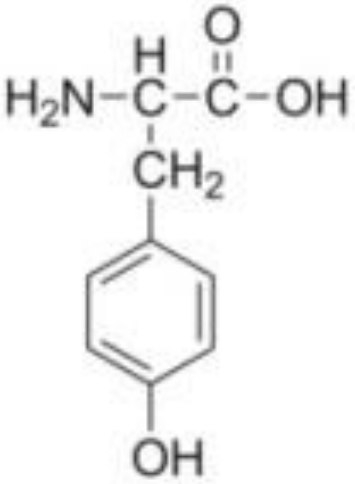
L eucin



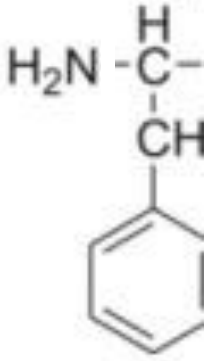
Proline (Pro, P)



Tryptophane (Trp, W)

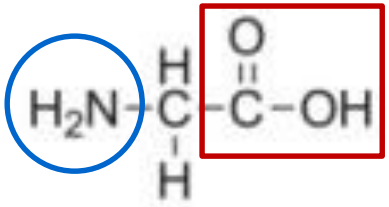


Tyrosine (Tyr, Y)

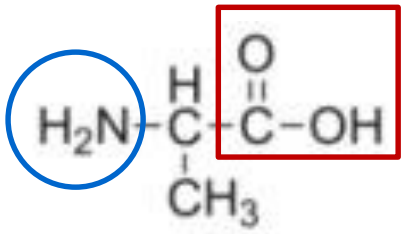


Phenyl (Phe

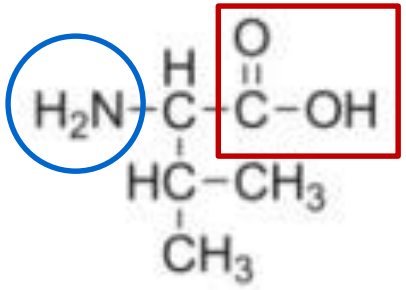
Aminoacides



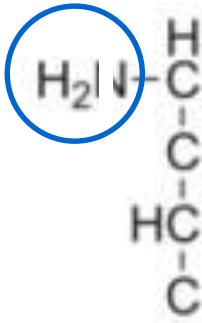
Glyine (Gly, G)

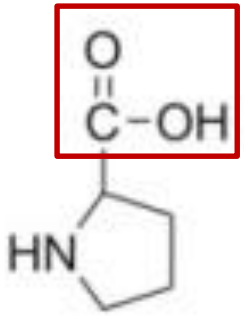


Alanine (Ala, A)

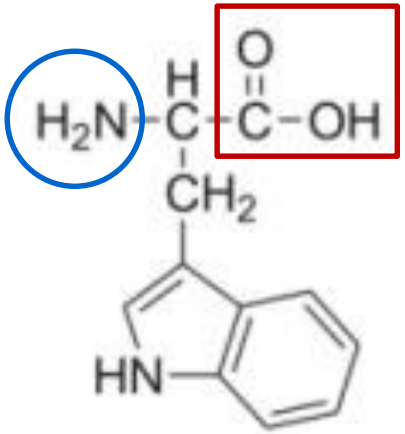


Valine (Val, V)

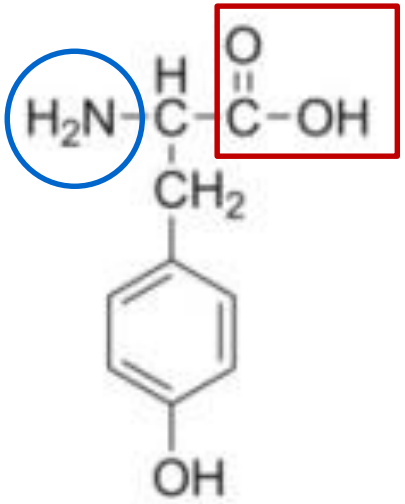




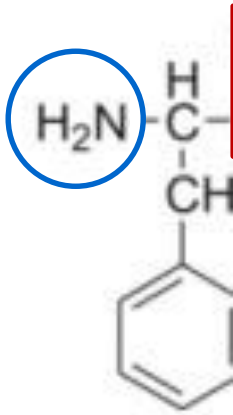
Proline (Pro, P)

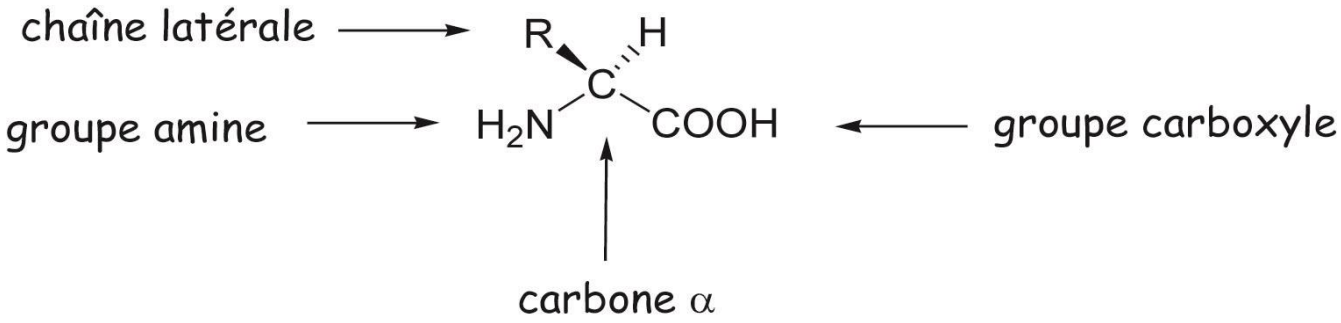


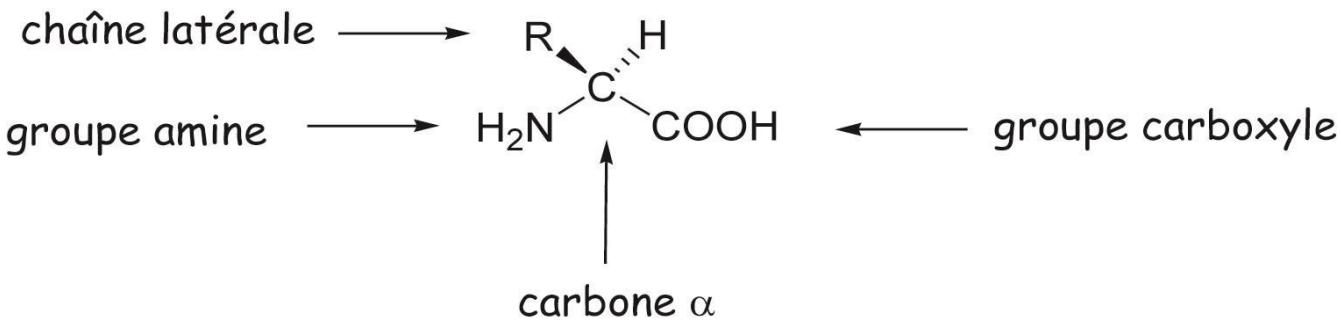
Tryptophane
(Trp, W)



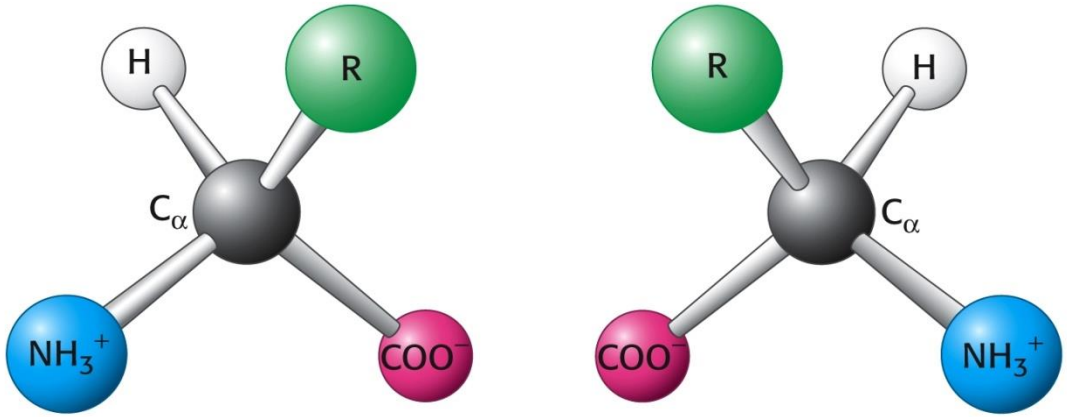
Tyrosine
(Tyr, Y)



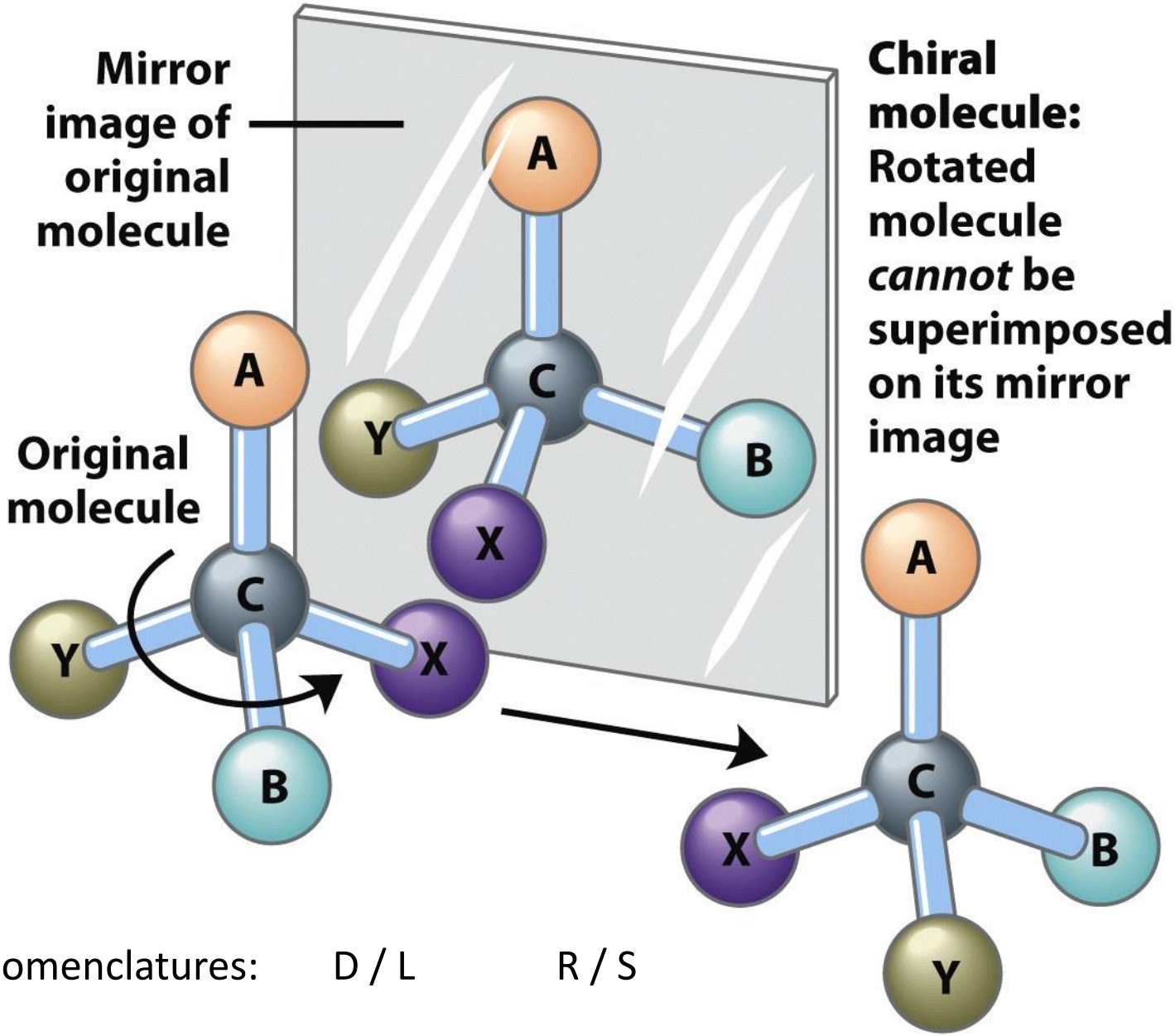

chaîne latérale
groupe amine
groupe carboxyle
carbone α
R
H
C
H2N
COOH



Les α-aminoacides sont chiraux



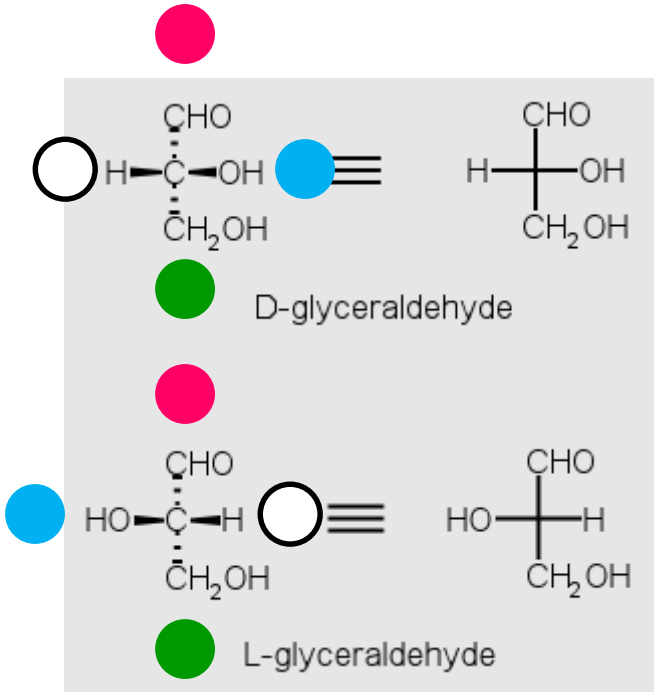
Les isomères sont les <u>images de l'un et l'autre dans un miroir</u>

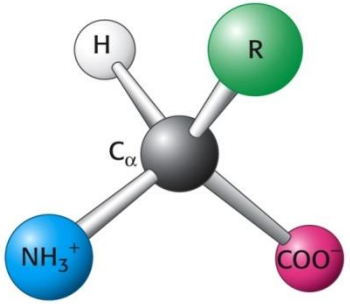


Deux nomenclatures: D / L R / S

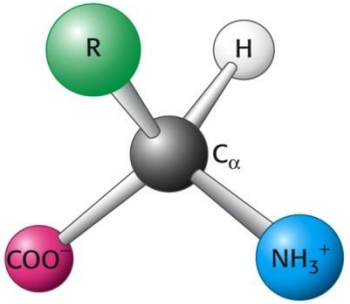
Figure 1-19a
Lehninger Principles of Biochemistry, Fifth Edition

D / L nomenclature





L isomer

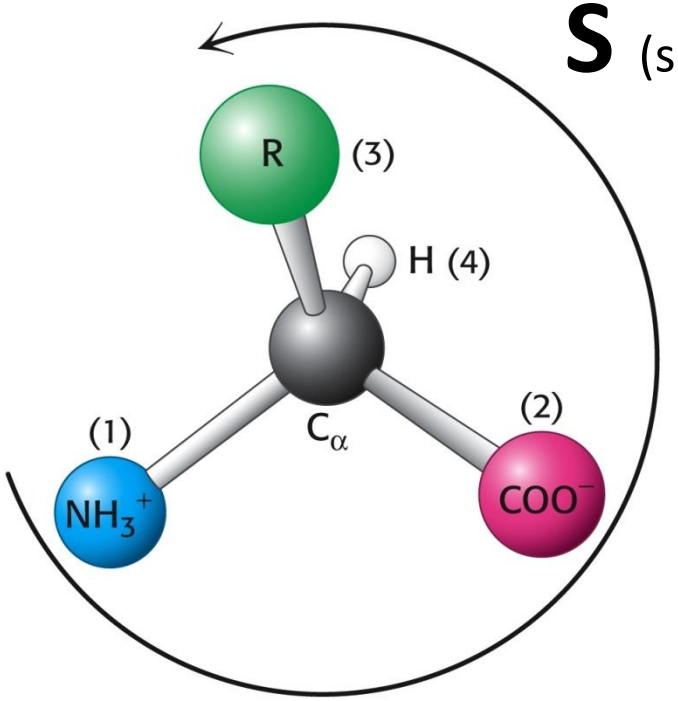


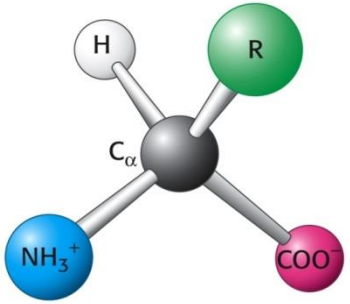
D isomer

Les 20 aminoacides naturels sont tous des isomères L

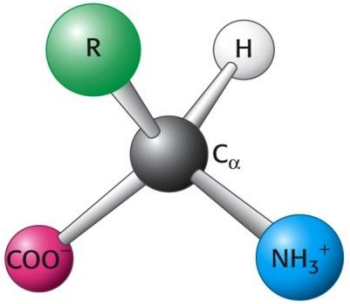
R / S nomenclature

S (sinister = gauche)





S- isomère

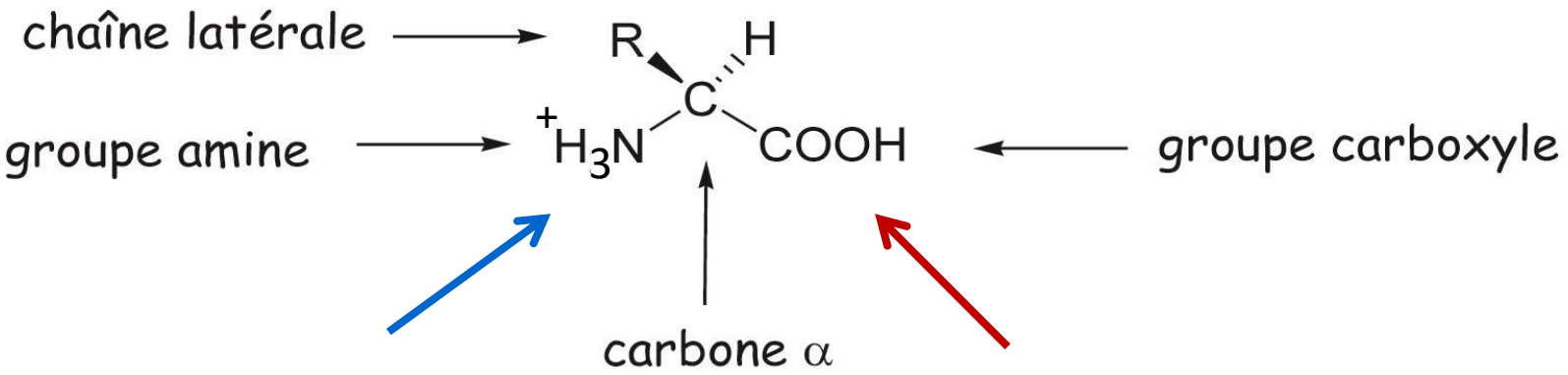


R- isomère

N > CO > C > H

Les 20 aminoacides (avec une exception) naturels sont tous des isomères S

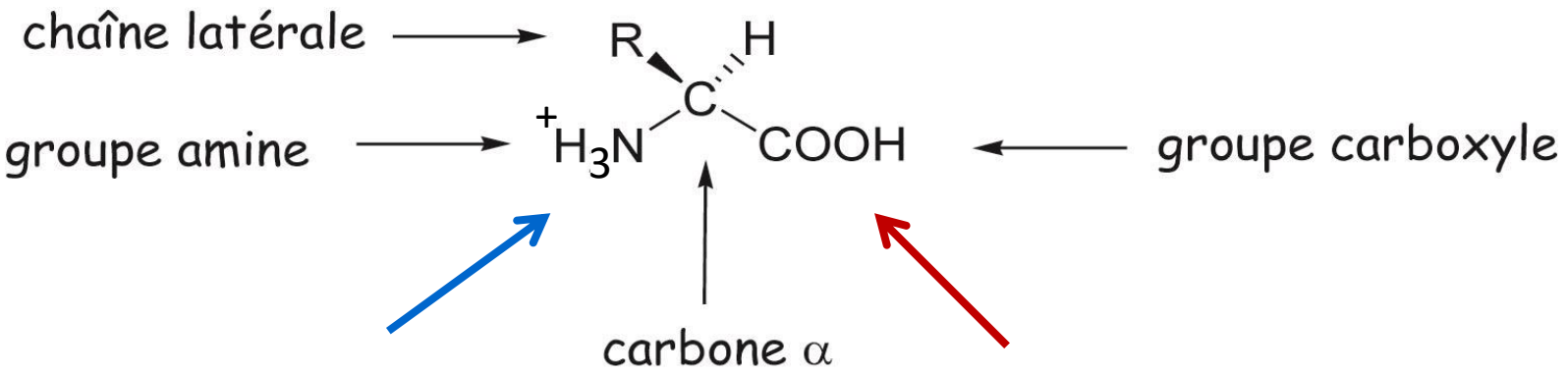
Etat d'ionisation des α-aminoacides



$pK_a = 8$

$pK_a = 3.1$

Etat d'ionisation des α-aminoacides

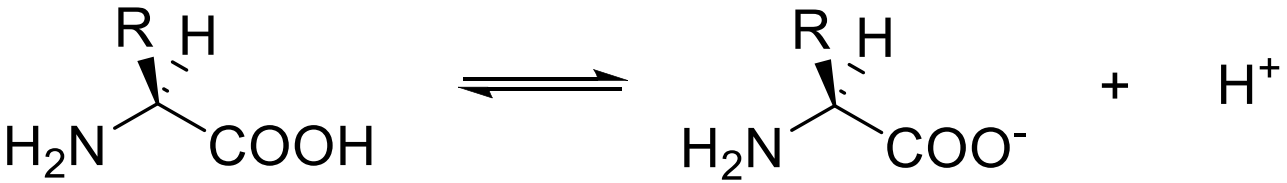


pK_a = 8

pK_a = 3.1

Quel est l'état d'ionisation au pH 7.4?

Etat d'ionisation d'un acide aminé: le group acide carboxylique



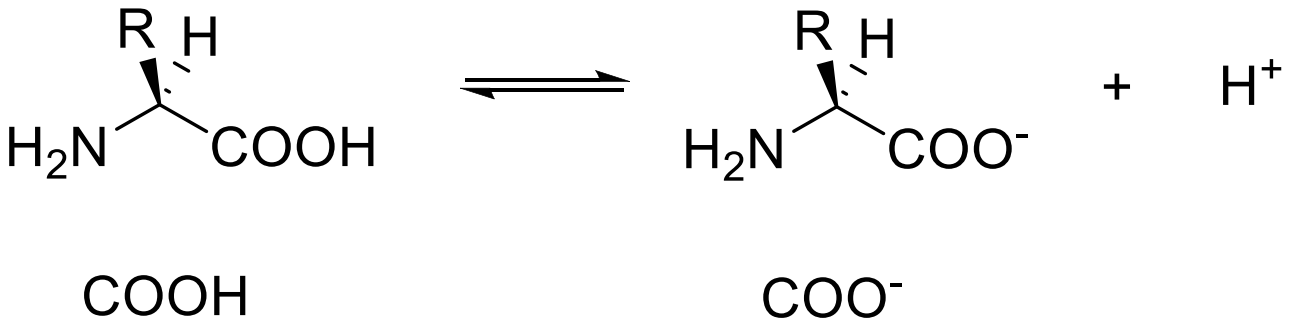
COOH $\rightleftharpoons$ COO^- + H^+

$$\frac{K_a}{[H^+]} = \frac{[COO^-]}{[COOH]}$$

$pK_a = 3.1$

Quel est le rapport de [COO^-] avec [COOH] dans les cellules (pH 7.4)?

Etat d'ionisation d'un acide aminé: le group acide carboxylique

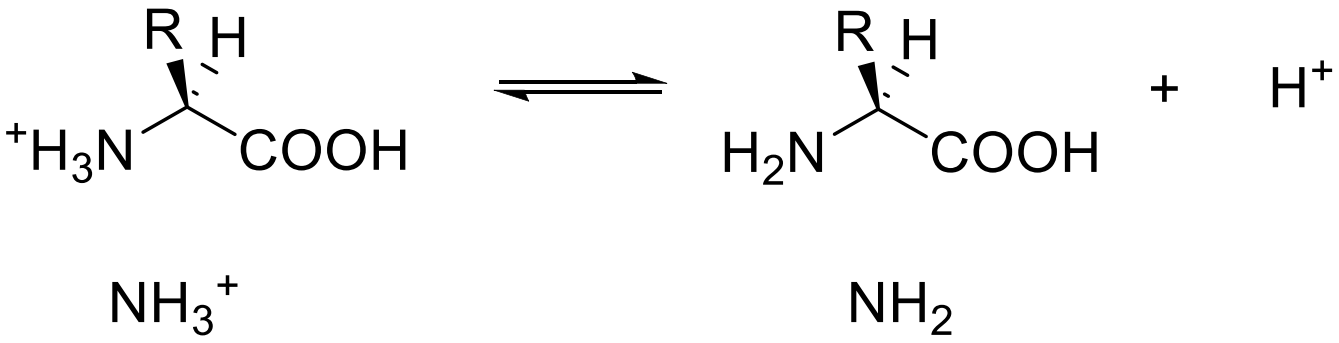


$pK_a = - \log_{10}(K_a)$ → $K_a = 10^{-3.1} = 0.0008$

$pH = - \log_{10} [H^+]$ → $[H^+] = 10^{-7.4} = 0.00000004$

$$\frac{[COO^-]}{[COOH]} = \frac{0.0008}{0.00000004} = \mathbf{20000}$$

Etat d'ionisation d'un acide aminé: le group amine

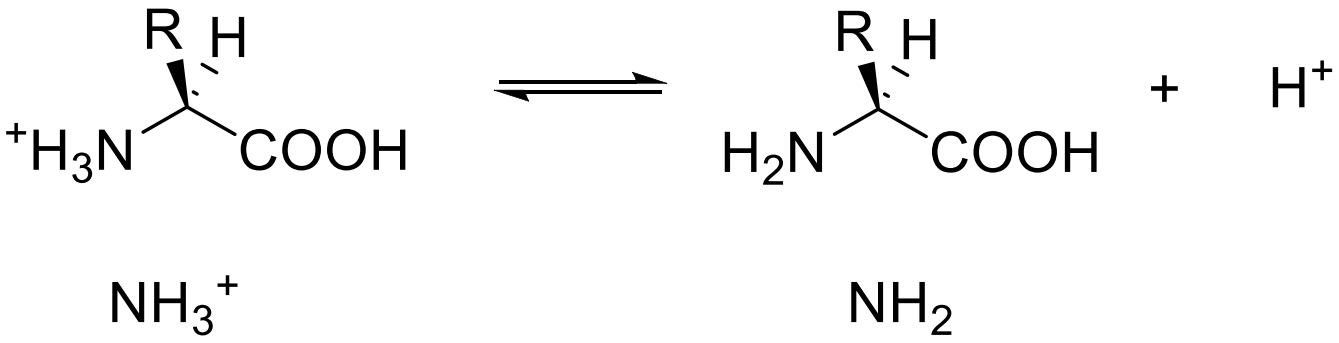


$$\frac{K_a}{[H^+]} = \frac{[NH_2]}{[NH_3^+]}$$

$pK_a = 8$

Quel est le rapport de $[NH_2]$ avec $[NH_3^+]$ dans les cellules (pH 7.4)?

Etat d'ionisation d'un acide aminé: le group amine

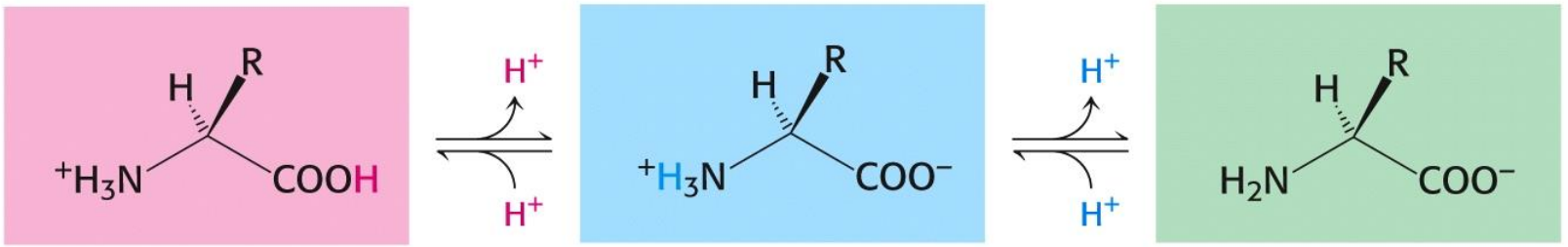


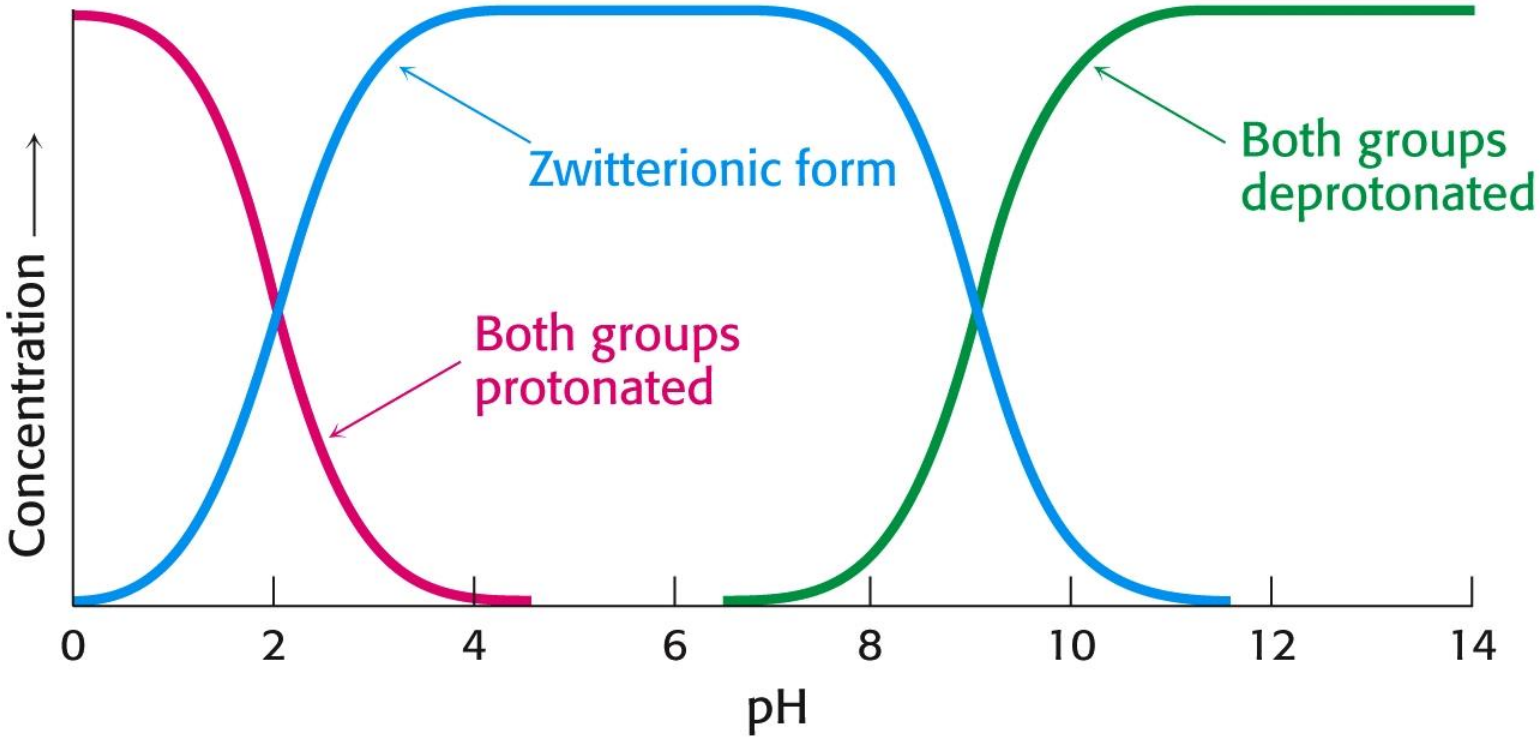
$pK_a = - \log_{10}(K_a)$ → $K_a = 10^{-8} = 0.00000001$

$pH = - \log_{10} [H^+]$ → $[H^+] = 10^{-7.4} = 0.00000004$

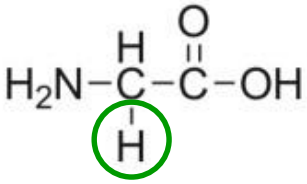
$$\frac{[NH_2]}{[NH_3^+]} = \frac{0.00000001}{0.00000004} = \mathbf{0.25}$$

A pH neutre, les α-aminoacides se trouvent sous forme d'ions dipolaires

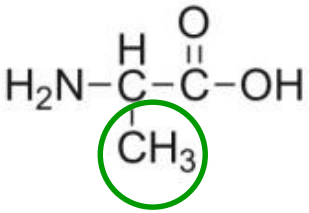




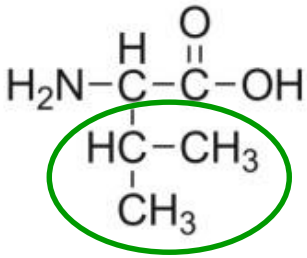
Les chaînes latérales



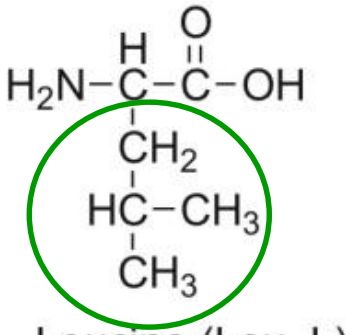
Glyine (Gly, G)



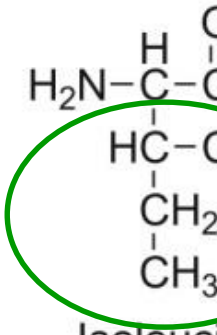
Alanine (Ala, A)



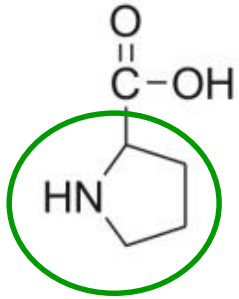
Valine (Val, V)



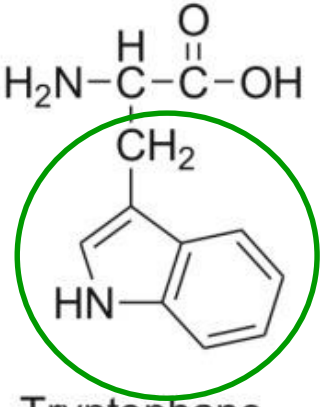
Leucine (Leu, L)



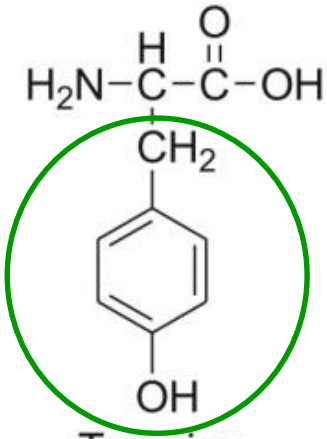
Isoleuci



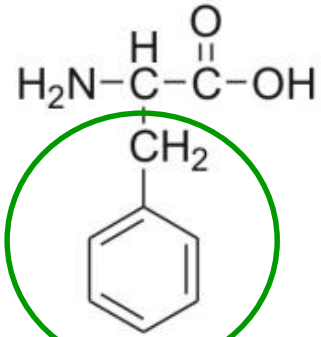
Proline (Pro, P)



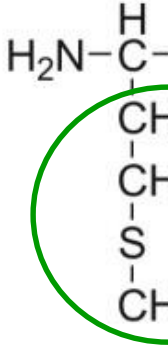
Tryptophane
(Trp, W)



Tyrosine
(Tyr, Y)



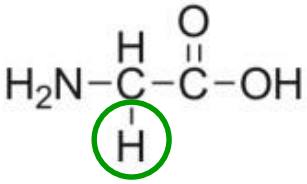
Phenylalanine
(Phe, F)



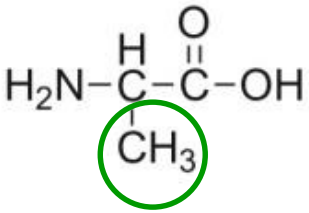
Methion

Les chaînes latérales

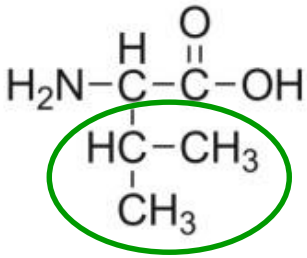
Pourquoi est-ce les acides aminés ont des chaînes latérales variables?



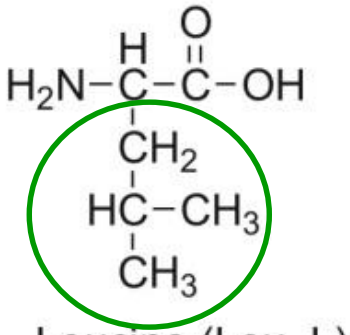
Glyine (Gly, G)



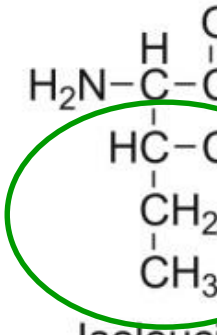
Alanine (Ala, A)



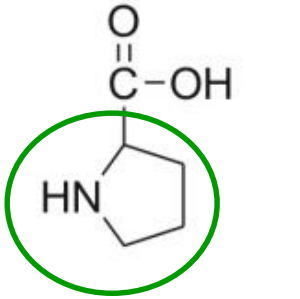
Valine (Val, V)



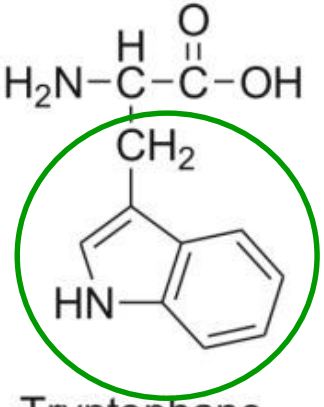
Leucine (Leu, L)



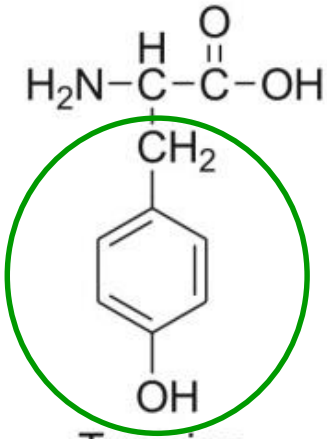
Isoleuci



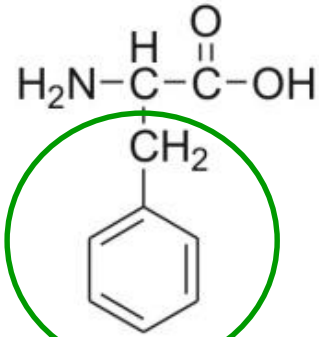
Proline (Pro, P)



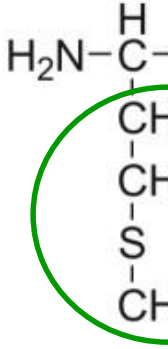
Tryptophane
(Trp, W)



Tyrosine
(Tyr, Y)



Phenylalanine
(Phe, F)



Methion

Fonctions des chaînes latérales

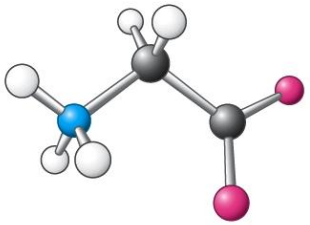
1. Les chaînes latérales influencent la structure tridimensionnelle d'une protéine

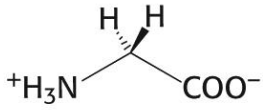
2. Les chaînes latérales influencent les interactions d'une protéine avec des autres molécules

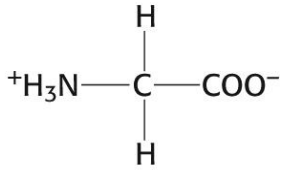
3. Dans les protéines, quelques chaînes latérales ont des fonctions particulières (par exemples elles aident à catalyser des réactions chimiques)

La glycine et l'alanine sont les aminoacides les plus petits

Glycine
(Gly, G)

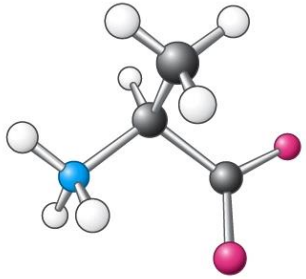


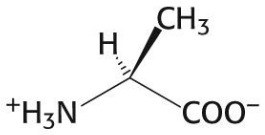


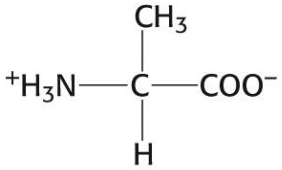


Glycine
(Gly, G)

Alanine
(Ala, A)



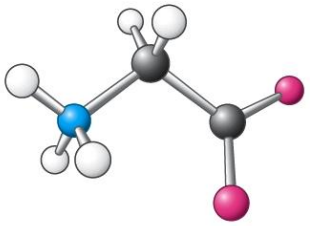




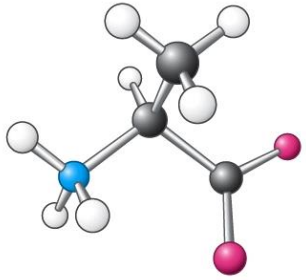
Alanine
(Ala, A)

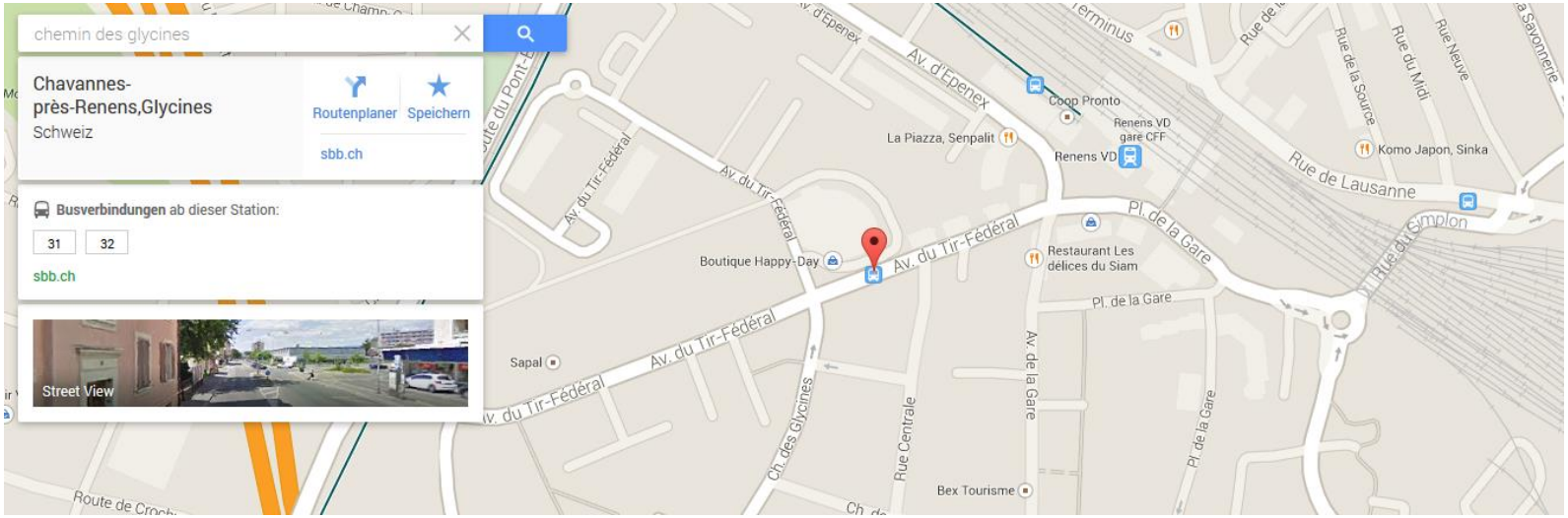
La glycine et l'alanine sont les aminoacides les plus petits

Glycine
(Gly, G)



Alanine
(Ala, A)

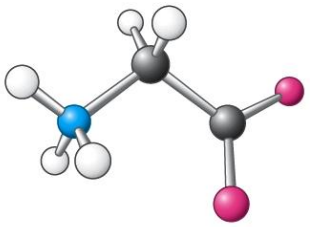


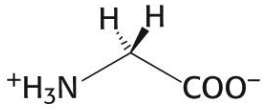


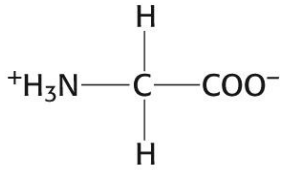
La glycine et l'alanine sont les aminoacides les plus petits

Quelle est la chaîne latérale de glycine?

Glycine (Gly, G)

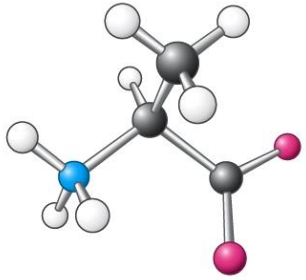


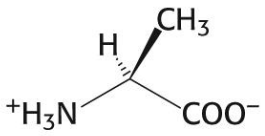


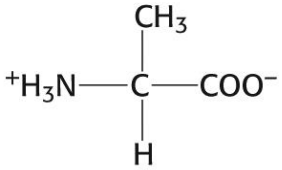


Glycine (Gly, G)

Alanine (Ala, A)

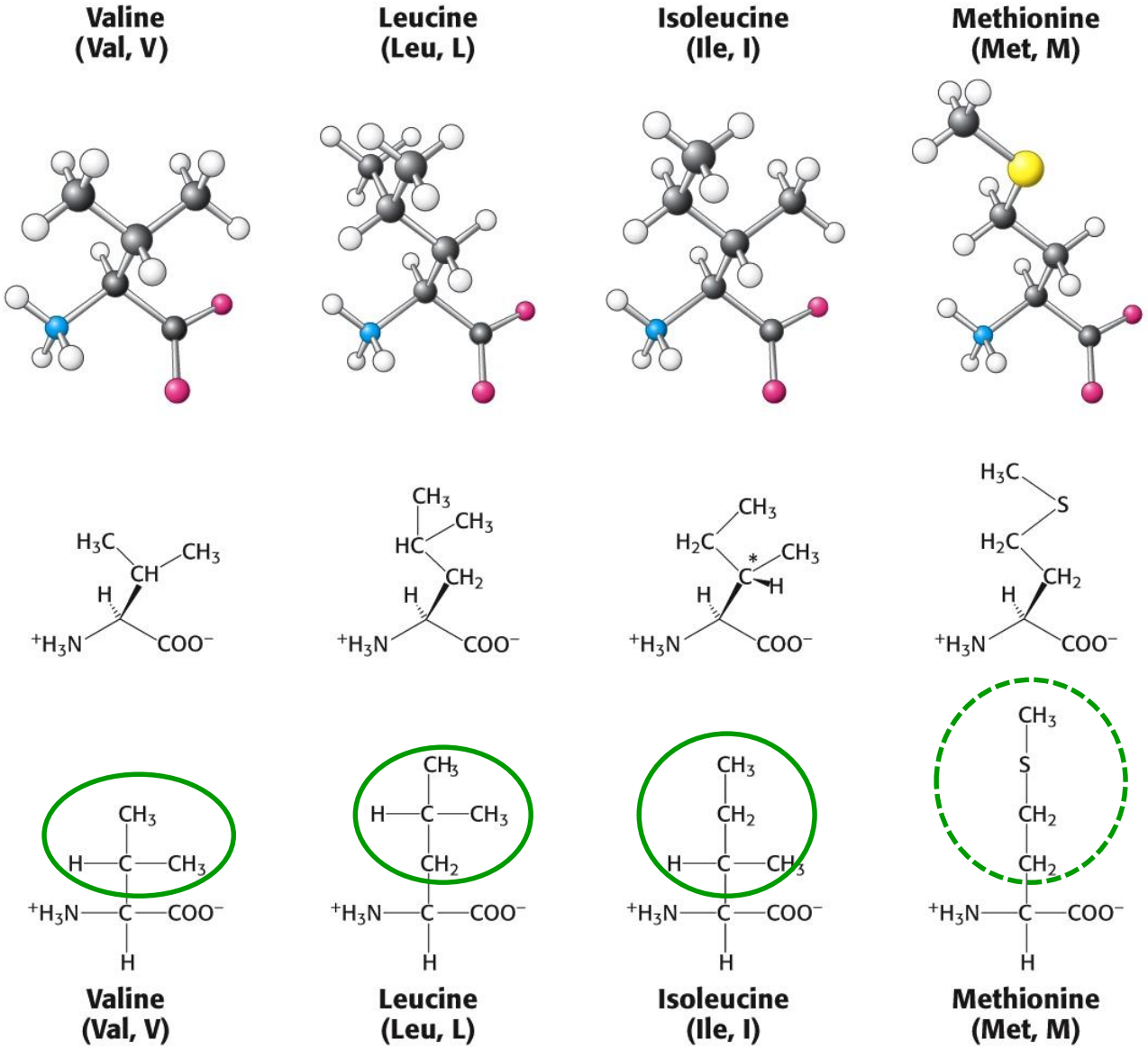




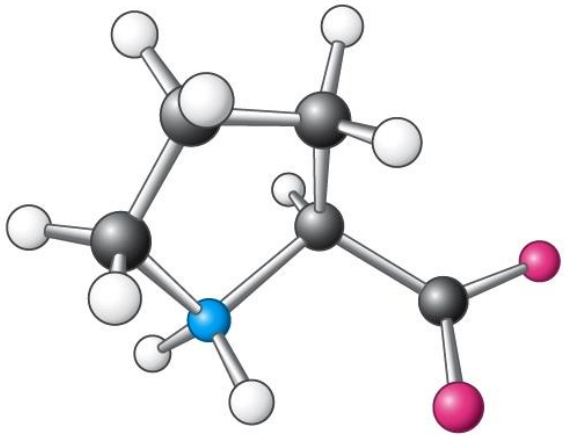


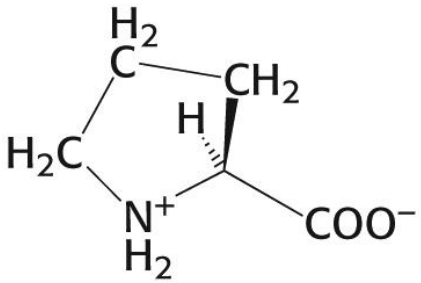
Alanine (Ala, A)

Chaînes latérales hydrocarbonée plus long

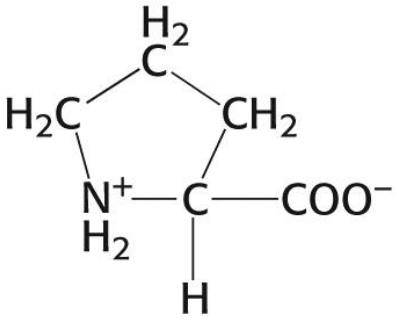


La proline



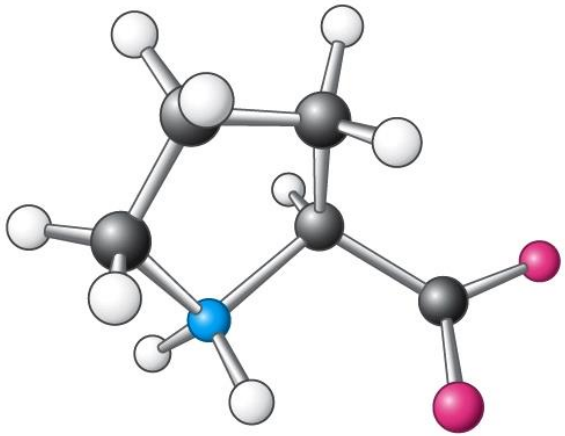


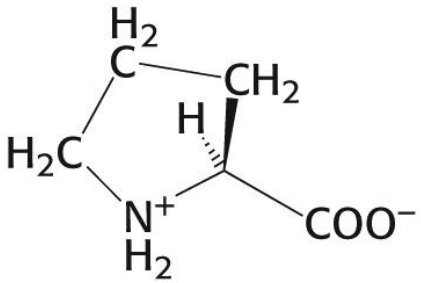
Proline
(Pro, P)



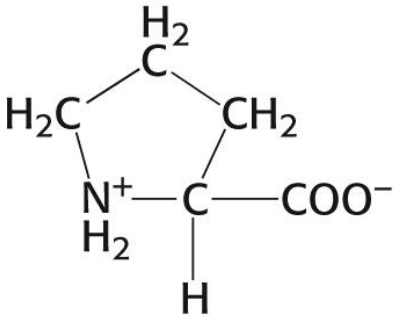
Quelle est la chaîne latérale de proline?

La proline a aussi une chaîne latérale aliphatique mais est aussi le seul aminoacide cyclique





Proline
(Pro, P)

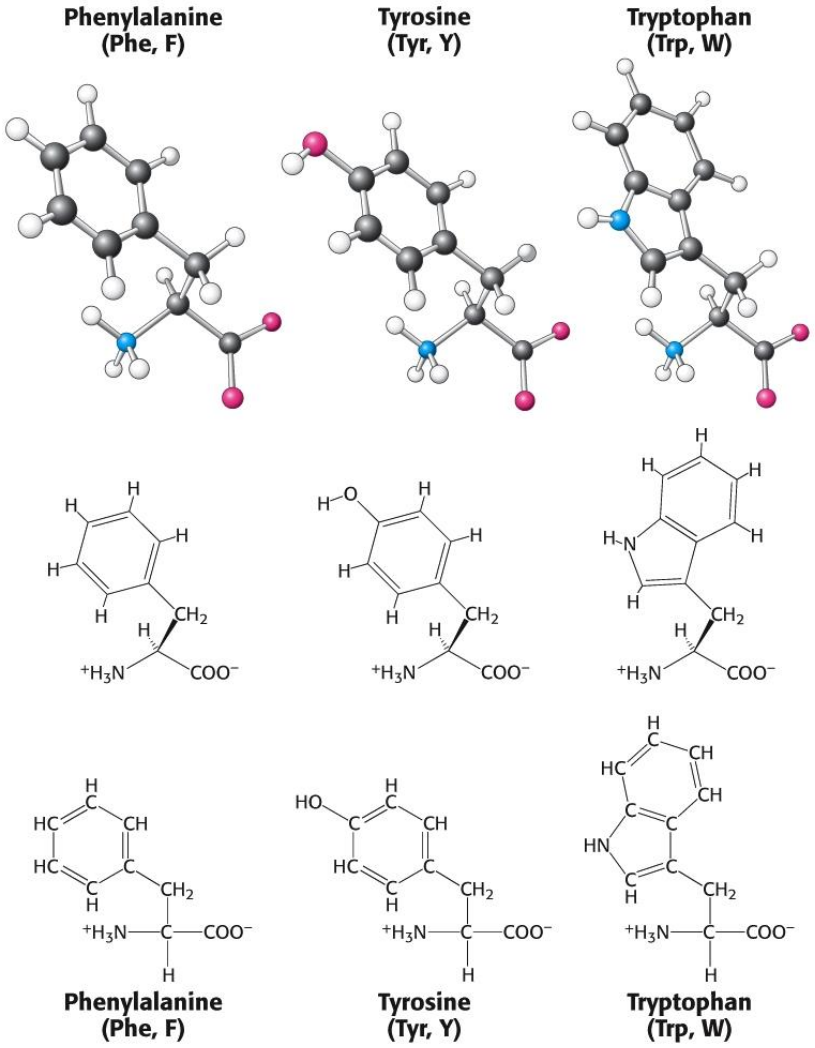


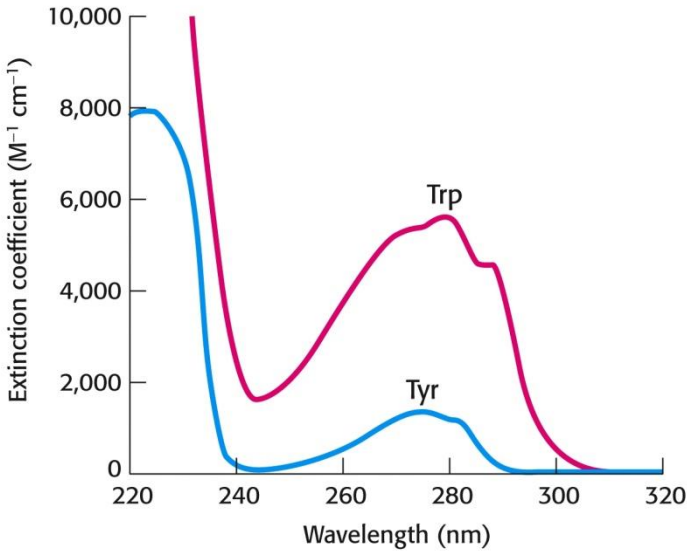
La proline joue souvent un rôle structurel important.

Prolin

Village en Valais

Chaînes latérales aromatiques

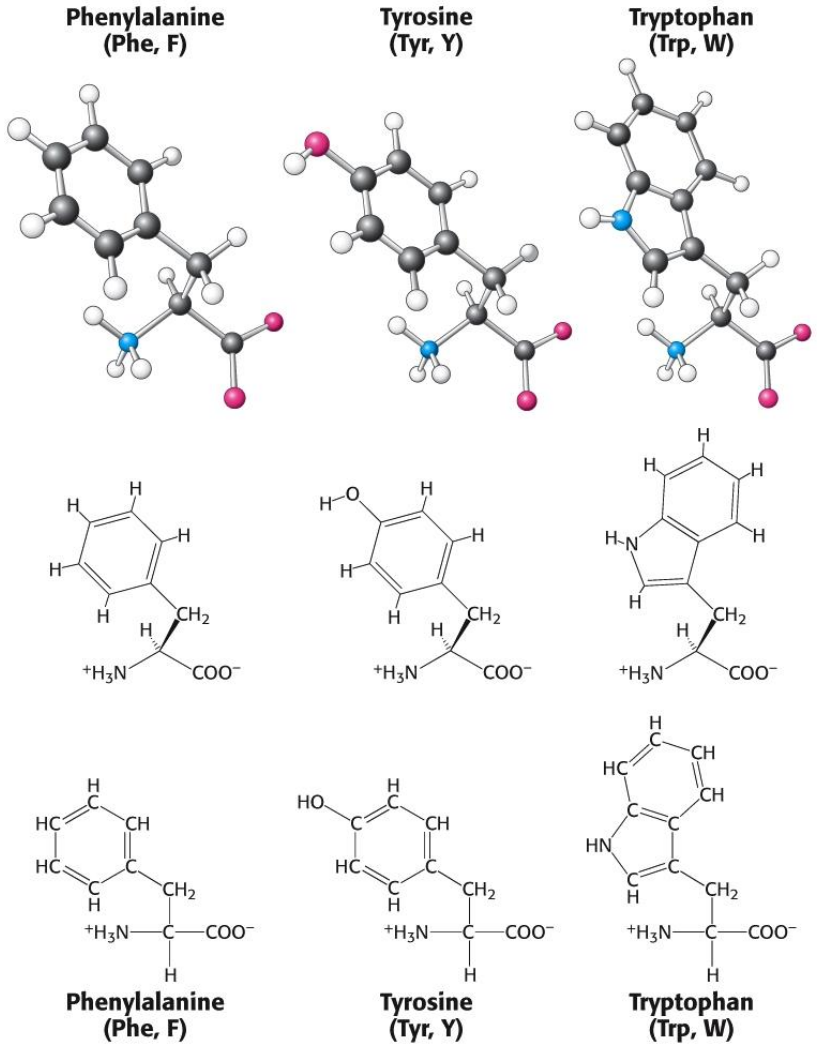




Tyr et Trp déterminent les spectres UV des protéines

pK_a = 10.9

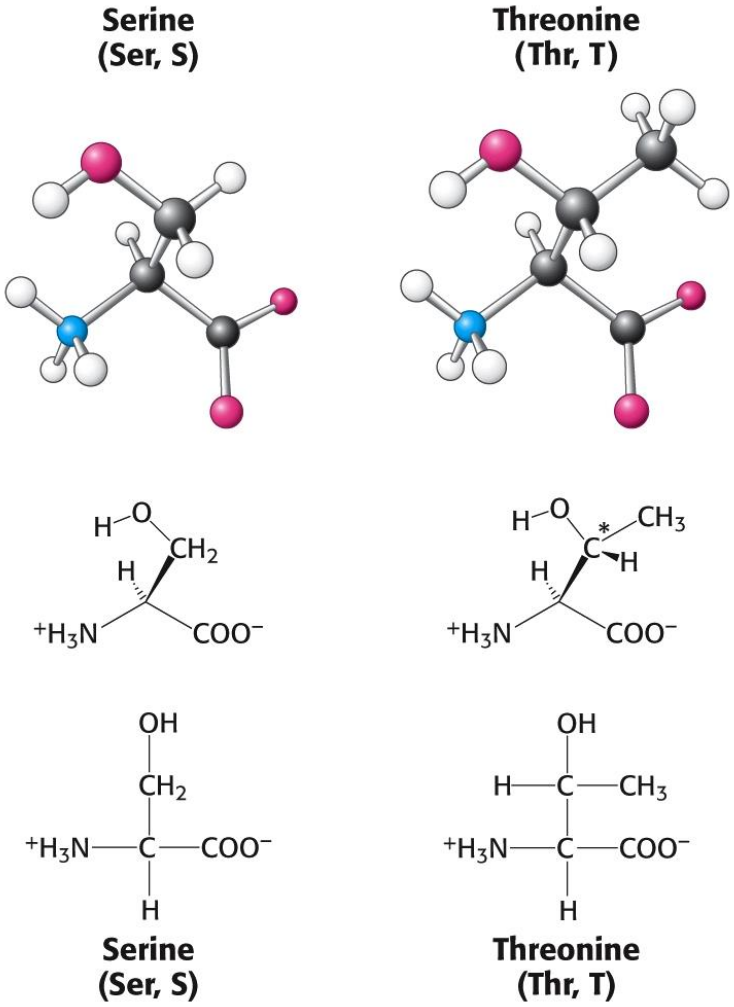
Chaînes latérales aromatiques



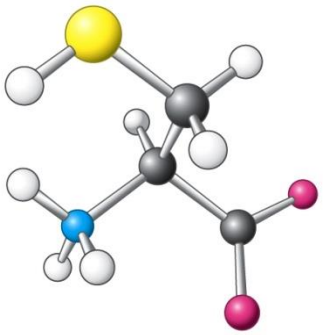
Quel est l'état de ionisation dans la chaîne latérale de tyrosine?

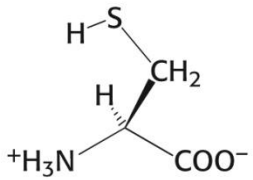
pK_a = 10.9

Chaînes latérales avec des groupes hydroxyles

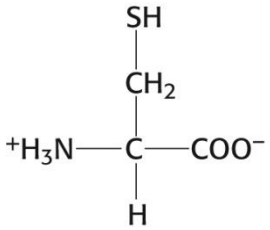


Chaînes latérales avec des groupes thiols





Cysteine
(Cys, C)



$pK_a = 8.3$

Un pont disulfure (= lien covalent) peut être formé par oxidation (réversible)

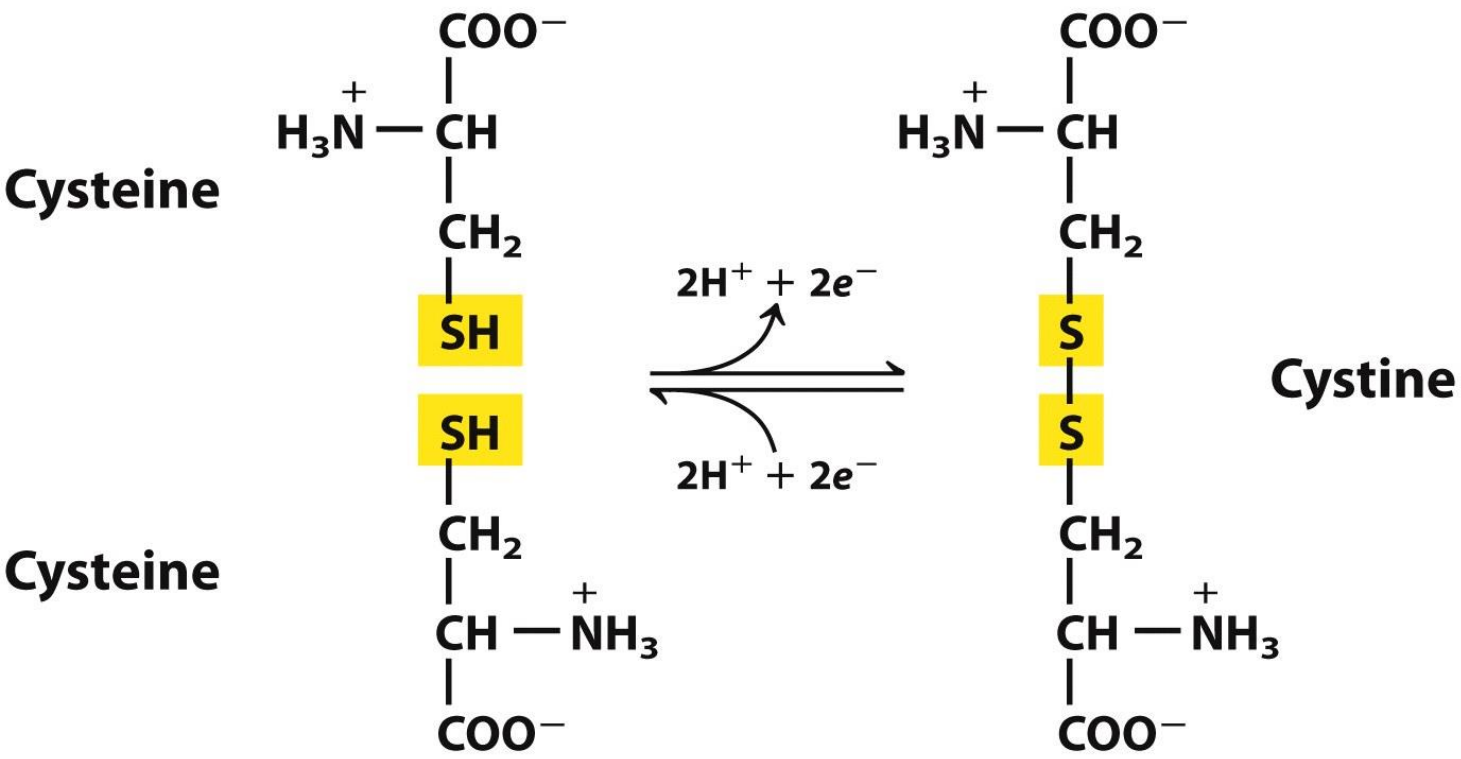
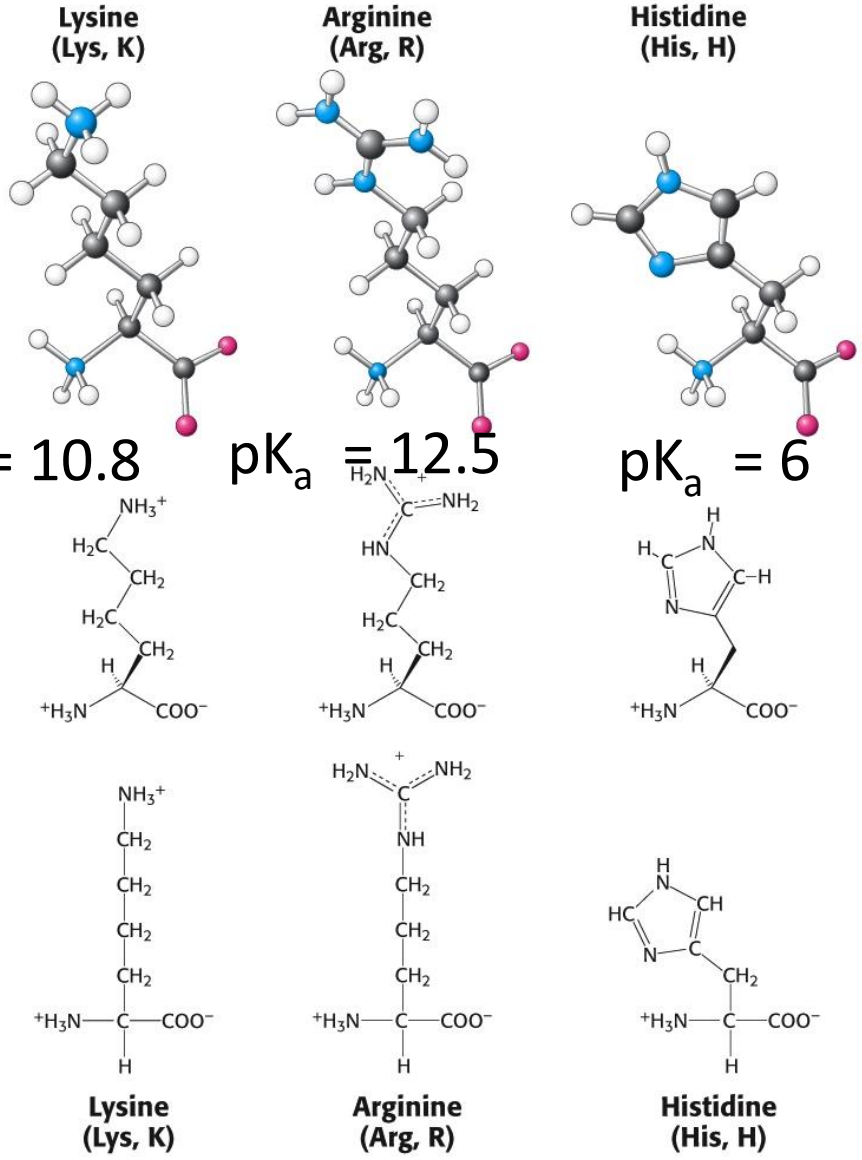


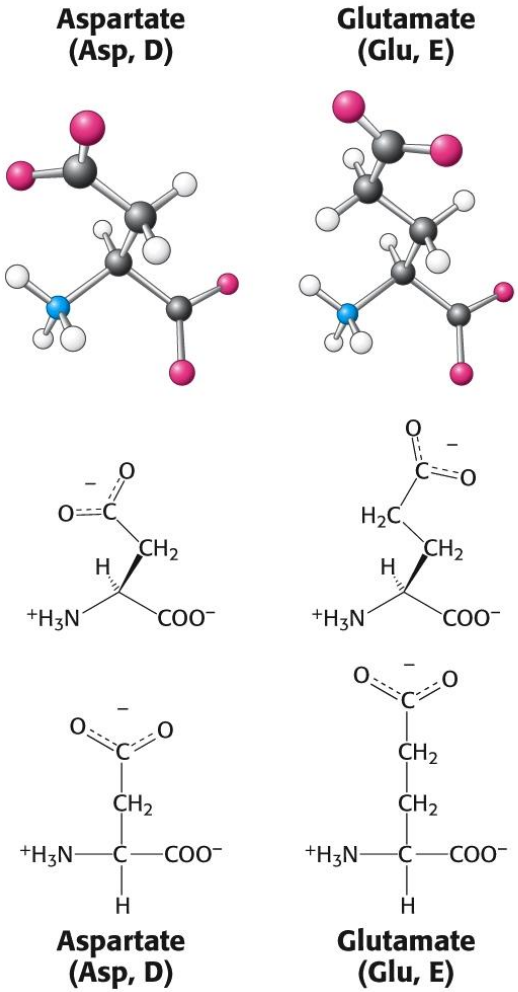
Figure 3-7
Lehninger Principles of Biochemistry, Fifth Edition

Chaînes latérales avec des groupes basiques

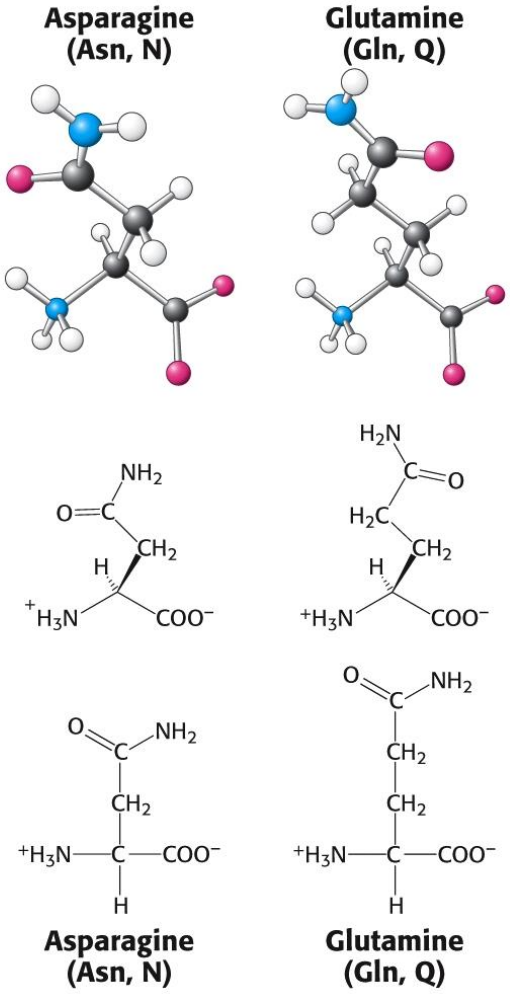


Chaînes latérales avec des groupes carboxylates

pK_a = 4.1

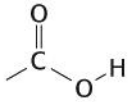
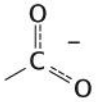
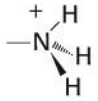


Chaînes latérales avec des groupes carboxamides



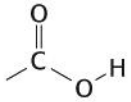
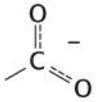
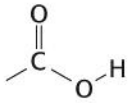
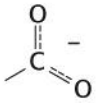
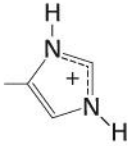
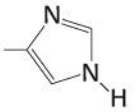
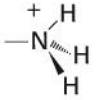
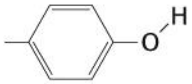
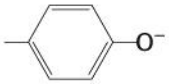
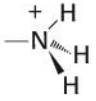
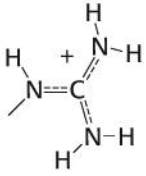
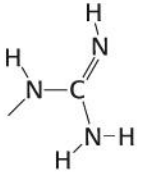
Liste des groupes fonctionnels ionisables des 20 aminoacides

TABLE 3.1 Typical pK_a values of ionizable groups in proteins

Group	Acid	⇌	Base	Typical pK_a*
Terminal α-carboxyl group		⇌		3.1
Terminal α-amino group		⇌		8.0

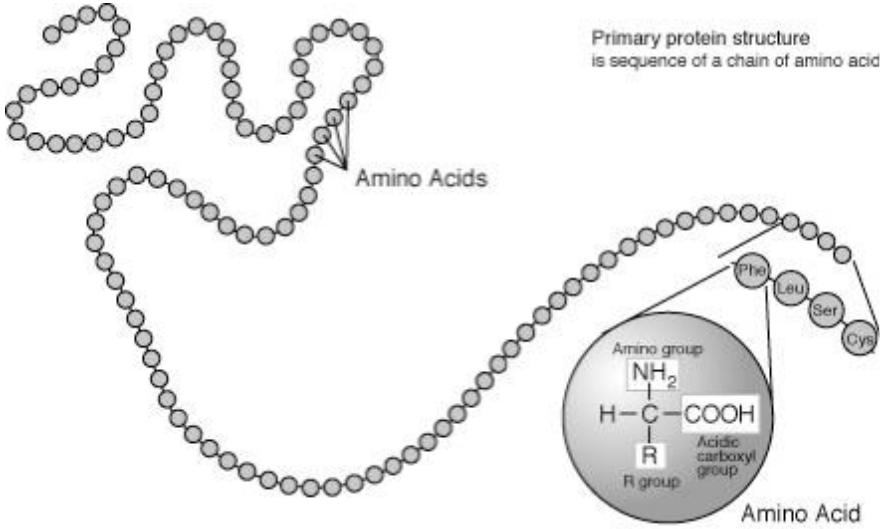
Liste des groupes fonctionnels ionisables des 20 aminoacides

TABLE 3.1 Typical pK_a values of ionizable groups in proteins

Group	Acid		Base	Typical pK_a*
Terminal α-carboxyl group		⇌		3.1
Aspartic acid Glutamic acid		⇌		4.1
Histidine		⇌		6.0
Terminal α-amino group		⇌		8.0
Cysteine		⇌		8.3
Tyrosine		⇌		10.9
Lysine		⇌		10.8
Arginine		⇌		12.5

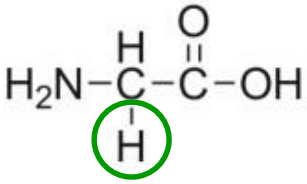
*pK_a values depend on temperature, ionic strength, and the microenvironment of the ionizable group.

Chaîne d'aminoacides

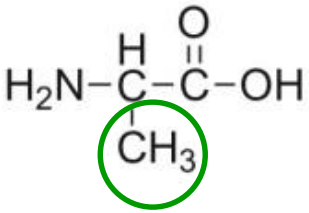


Comment est-ce que les acides aminés peuvent être connectés?

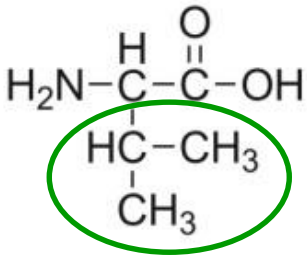
Les chaînes latérales



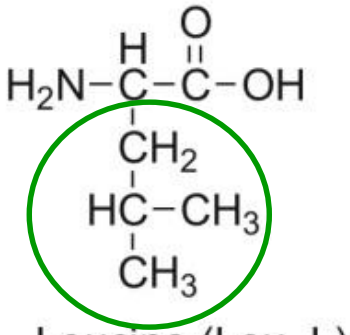
Glyine (Gly, G)



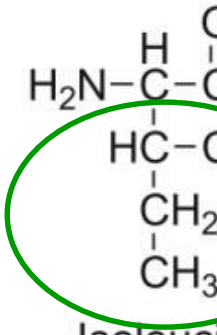
Alanine (Ala, A)



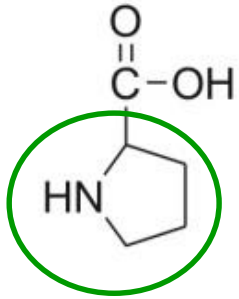
Valine (Val, V)



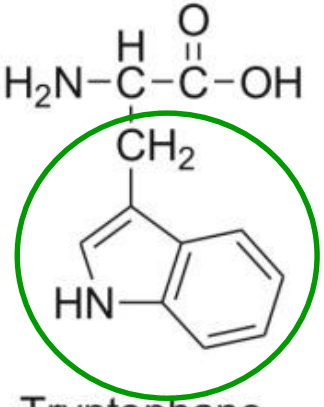
Leucine (Leu, L)



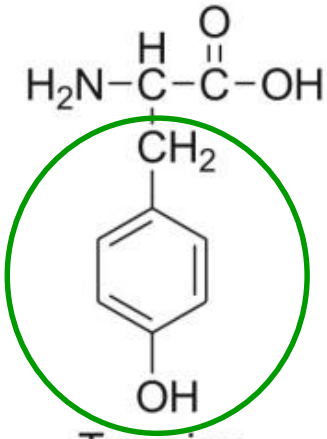
Isoleuci



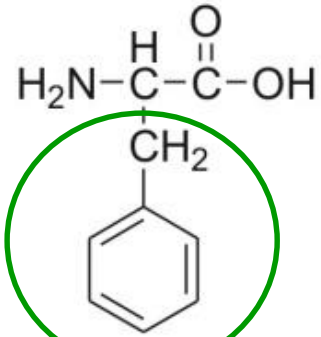
Proline (Pro, P)



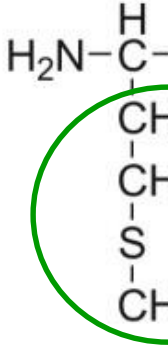
Tryptophane
(Trp, W)



Tyrosine
(Tyr, Y)

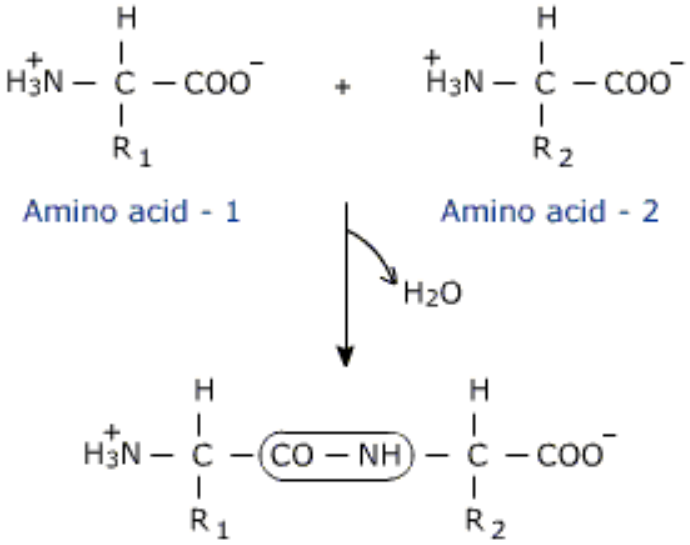


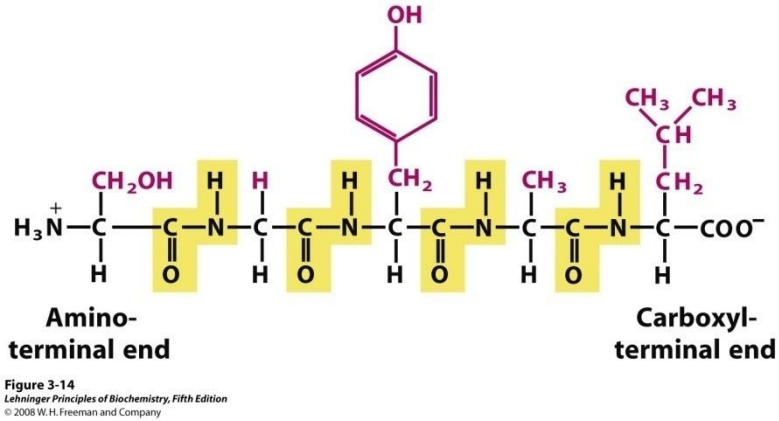
Phenylalanine
(Phe, F)

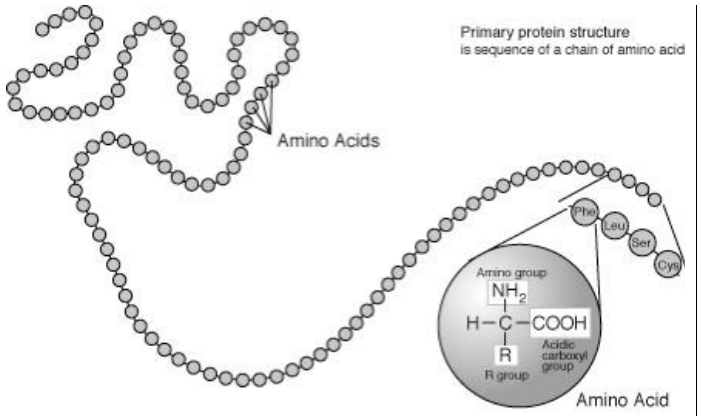


Methion

Chaîne d'aminoacides







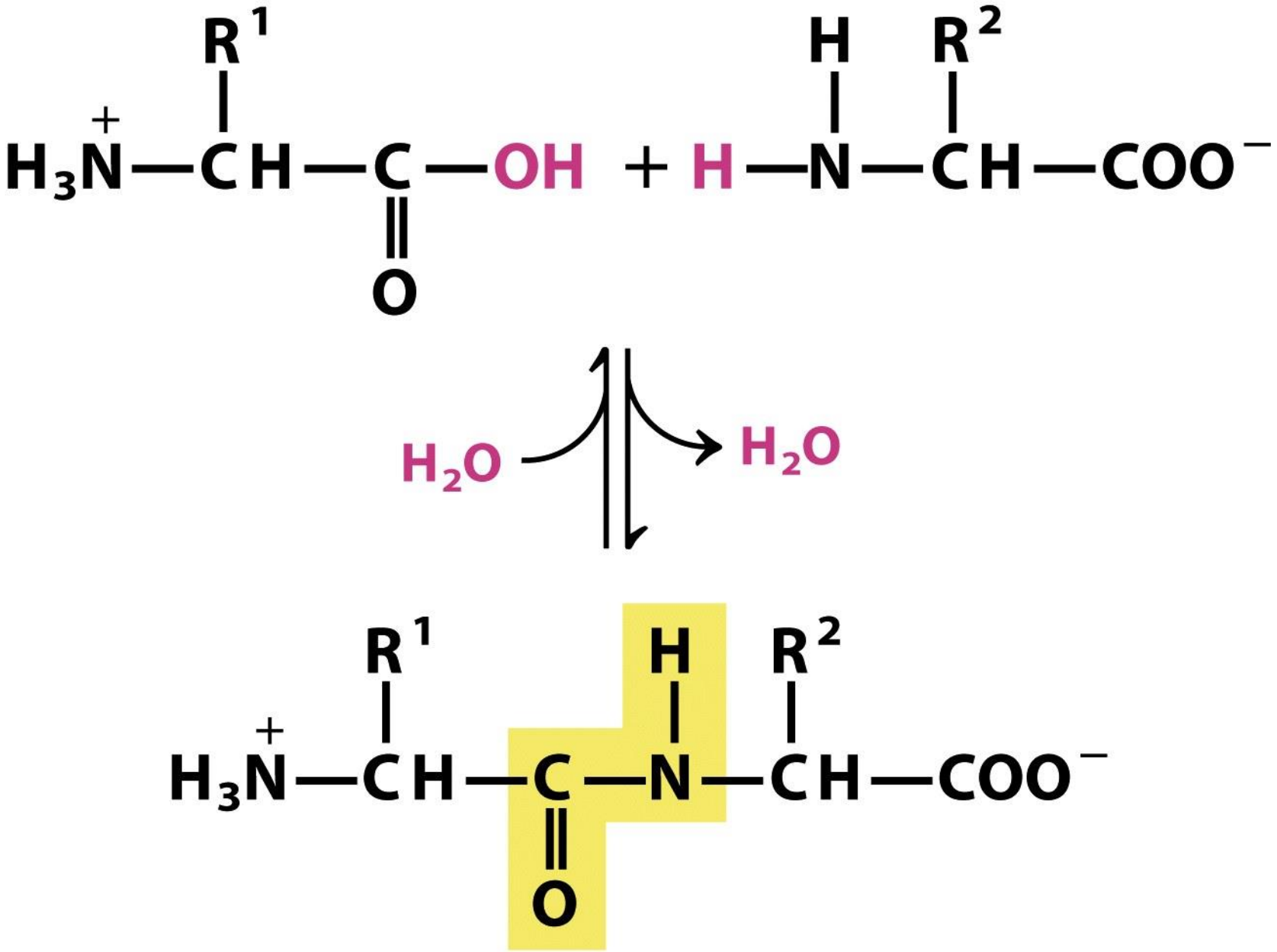


Figure 3-13
Lehninger Principles of Biochemistry, Fifth Edition

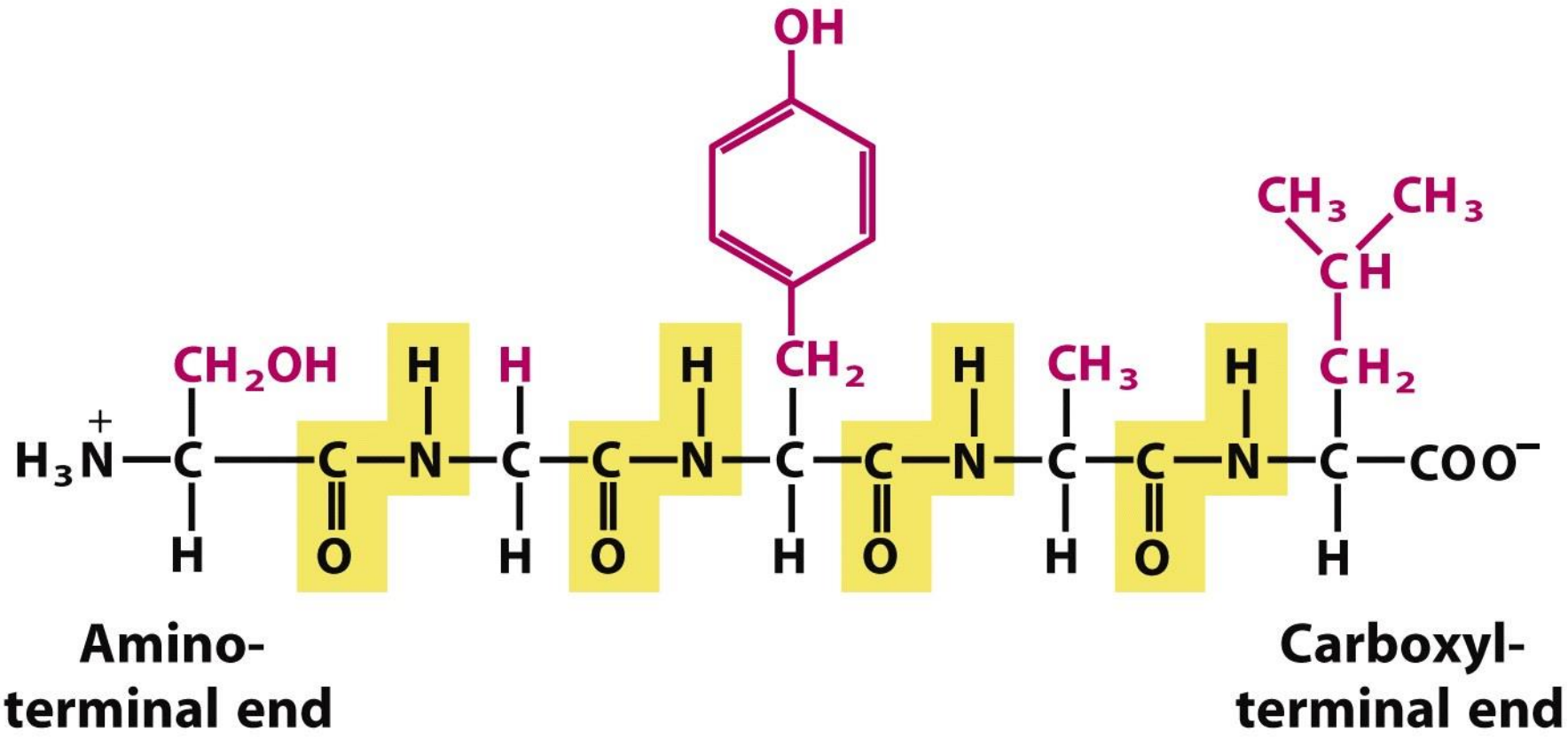


Figure 3-14
Lehninger Principles of Biochemistry, Fifth Edition

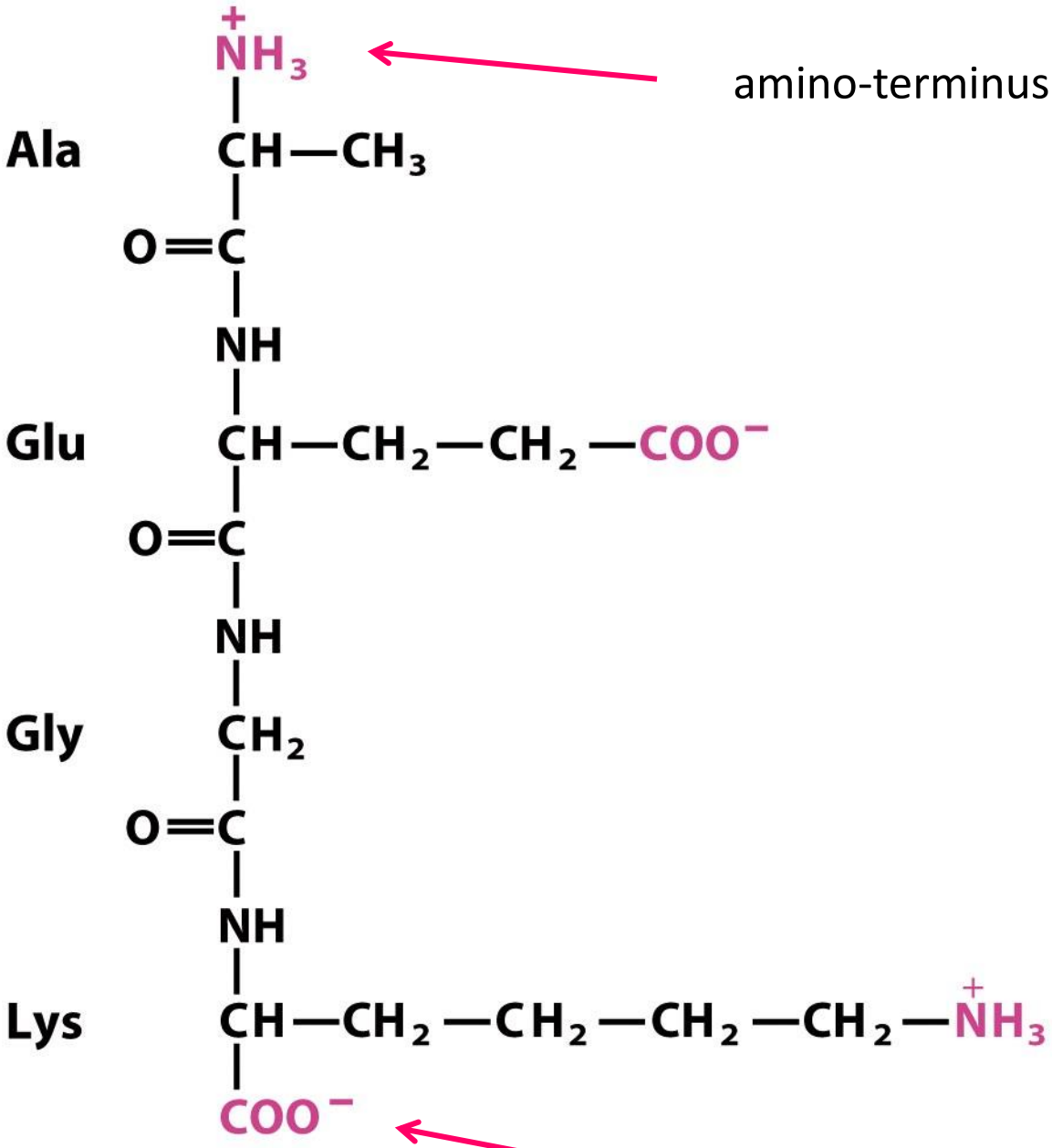


Figure 3-15
Lehninger Principles of Biochemistry, Fifth Edition

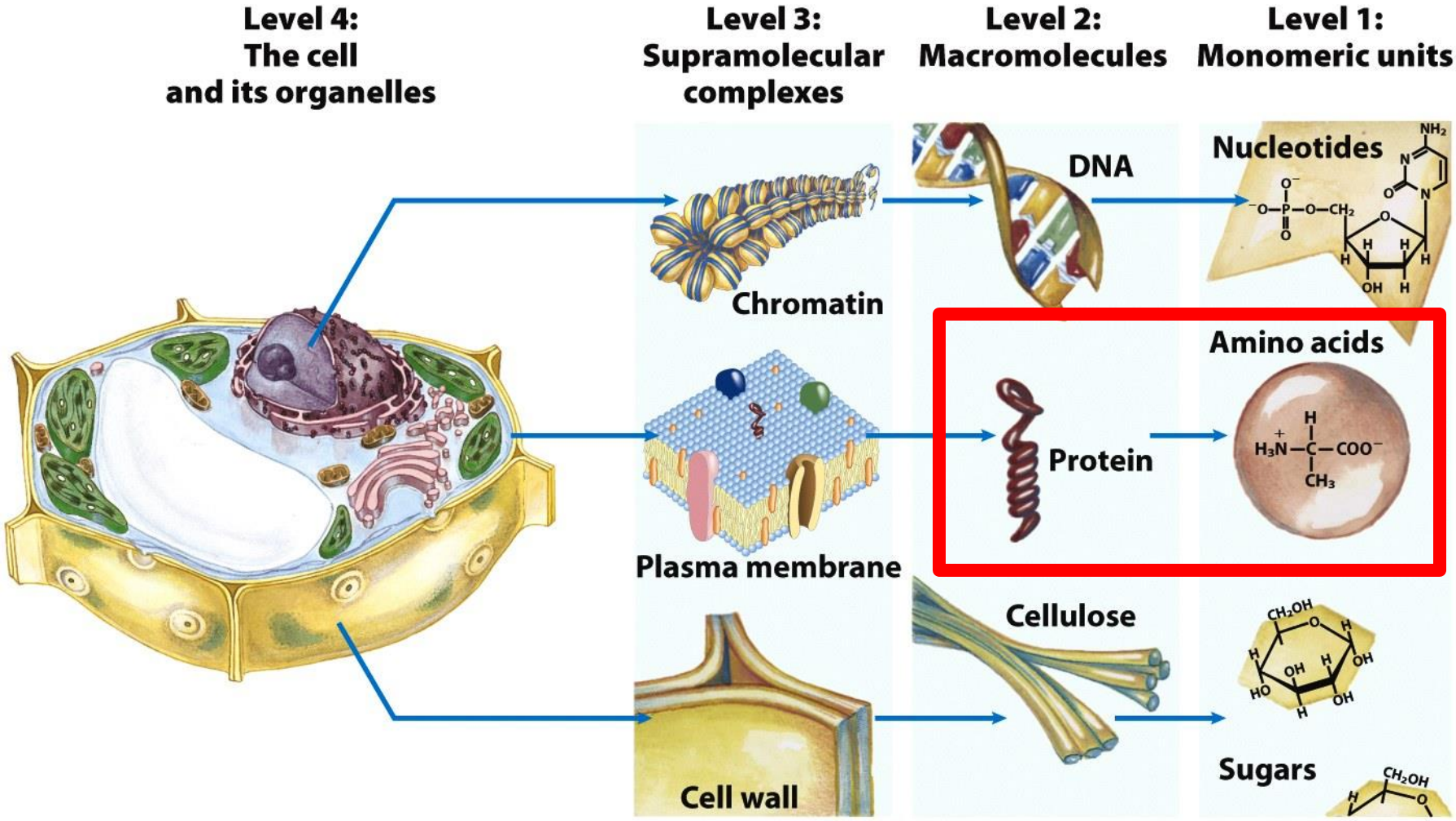


Figure 1-11
Lehninger Principles of Biochemistry, Fifth Edition