Science X-Change

Seminar I

Seminar I

- Building Blocks (polysaccharide, protein, DNA, RNA, lipids)
- ATP-Generation via substrate level phosphorylation, electron transport phosphorylation

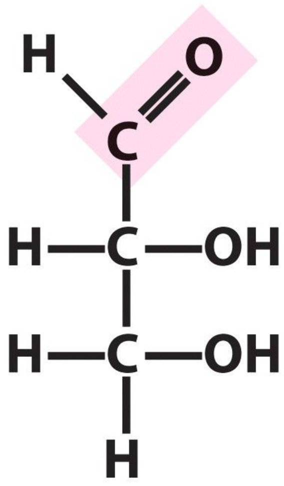
Carbohydrates (Saccharides)

Carbohydrates

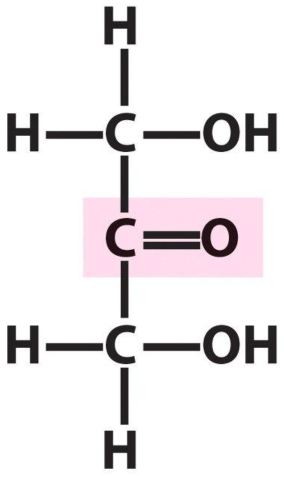
- Name: „hydrated carbon“ = carbohydrates, $(CH_2O)_n$
- Classification according to monomeric units.
- **Monosaccharides** (smallest unit $C_{3\text{-}9}$)
- **Oligosaccharides** (2-20 Monosaccharides) (most abundant disaccharides)
- **Polysaccharides** (>20 Monosaccharides)

Carbohydrates

- Smallest monosaccharides are **trioses.**
- C_1 (e.g. formaldehyde $H_2C{=}O$) or C_2 with the gross fomula $(CH_2O)_n$ are not regarded as sugars, since they miss the typical features (sweet taste, property of crystallisation).
- Glyceraldehyde is an aldehyde: **Aldose** (C_1 highest oxidation level)
- Dihydroxyacetone is a keton: **Ketose** (C_2 highest oxidation level)



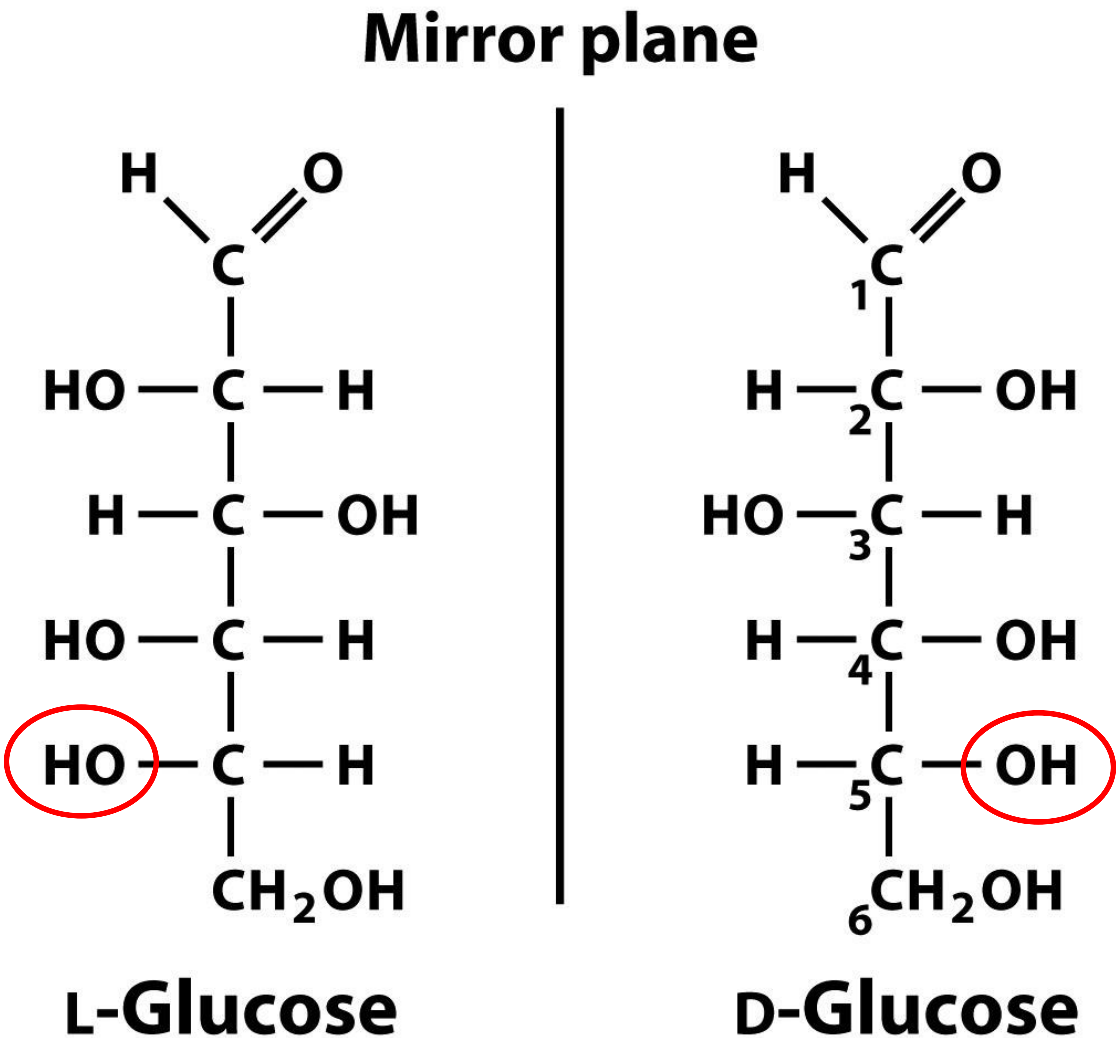
Glyceraldehyde, an aldotriose



Dihydroxyacetone, a ketotriose

Stereoisomers

- In general a molecule with n chiral centers can have 2^n stereoisomers
- Hexoses: $2^4 = 16$ stereoisomers (8D; 8L)
- C-atom of **most distant chiral center from carbonyl C-atom** decides! (OH group in projection formula on the right D-isomer, on the left L-isomer)



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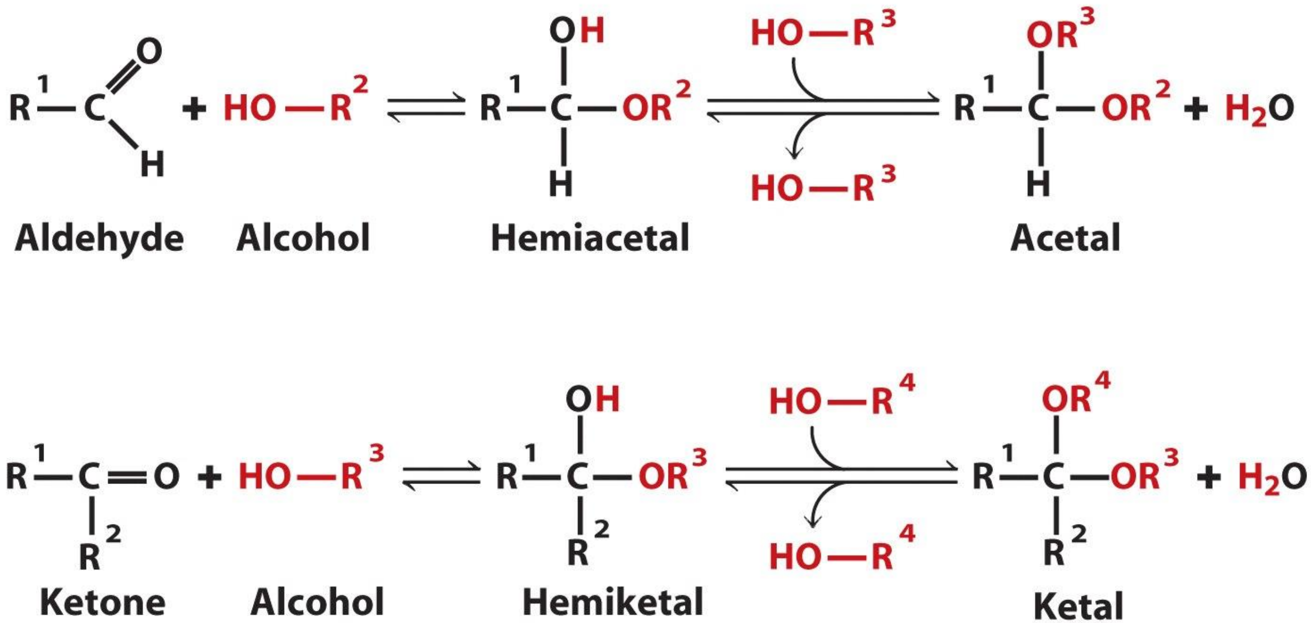
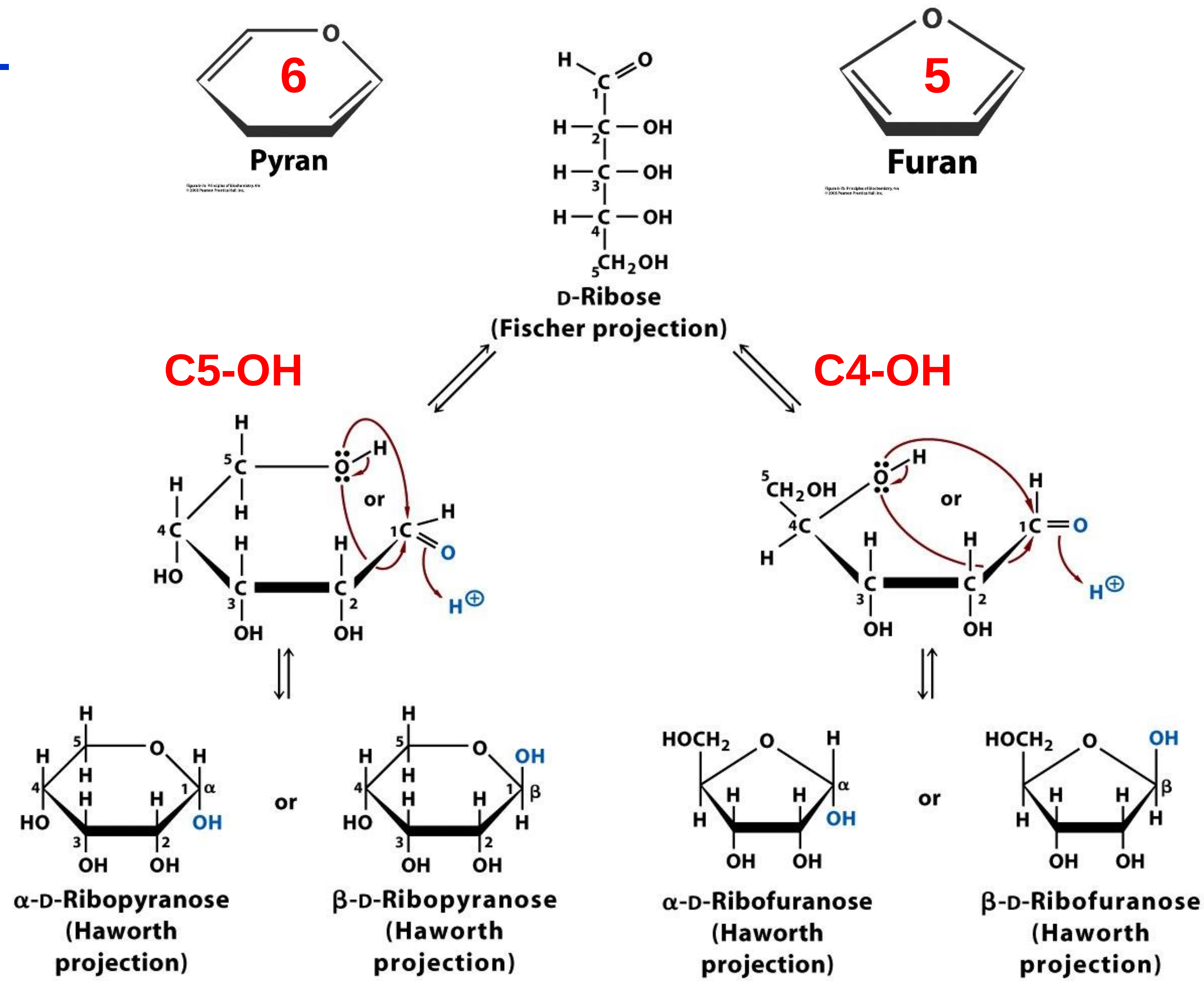
Cyclic structures

- Fromation of **hemiacetals** and **hemiketals**
  - Aldehyde and ketone carbons are electrophilic
  - Alcohol oxygen atom is a nucleophilic
- **Aldehyde or keton reacts with alcohol** to yield an hemiacetal or hemiketal creating a **new chiral center at the carbonyl carbon**.
- Substitution of **a second alcohol molecules** produces an **acetal** or ketal.
- When the **second alcohol is part of another sugar molecule**, the bond produced is a **gycosidic bond**.



Cyclisierung von D-Ribose

- Can form either a **five-membered furanose ring** or a **six-membered pyranose ring**
- Reaction: formation of hemiacetals from the aldehyde group
- In each case, two enantiomeric forms, α or ß are possible



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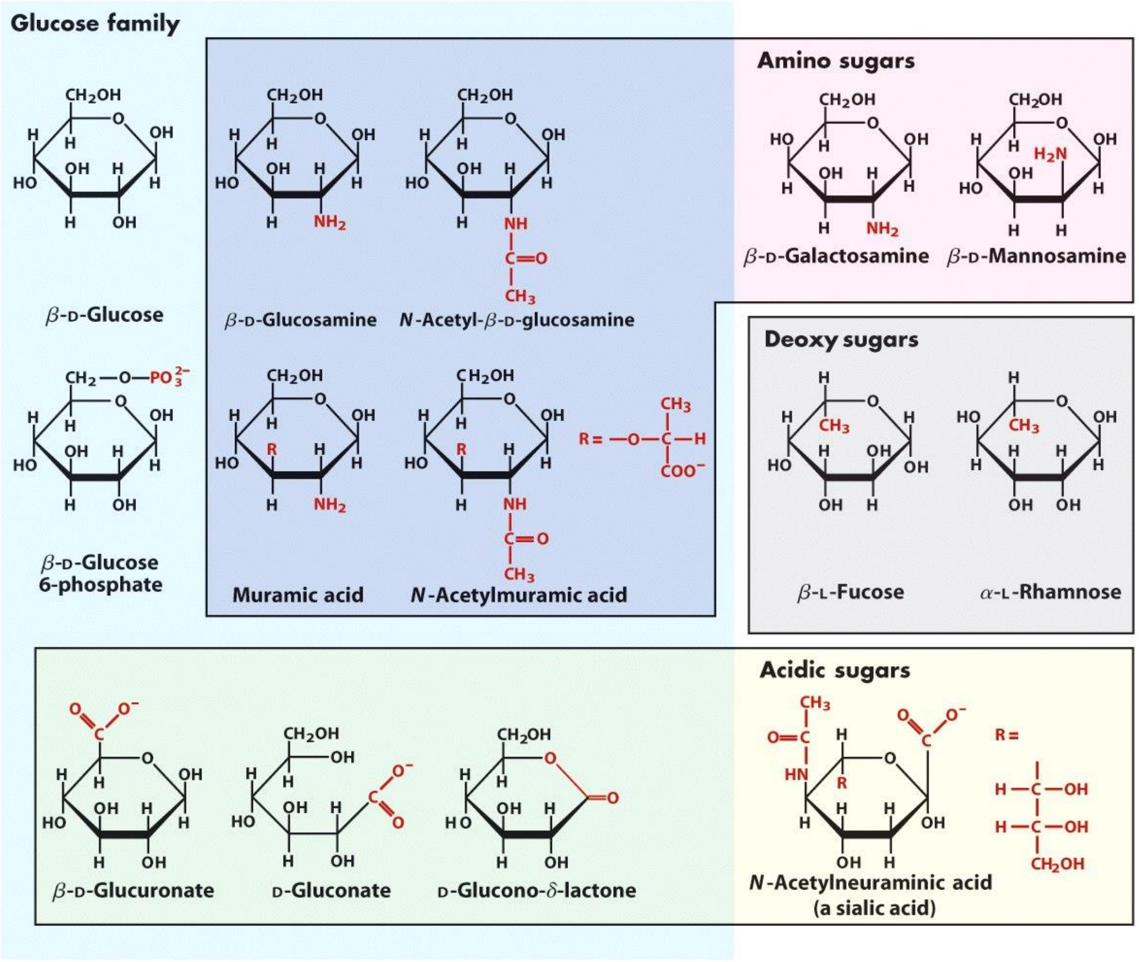
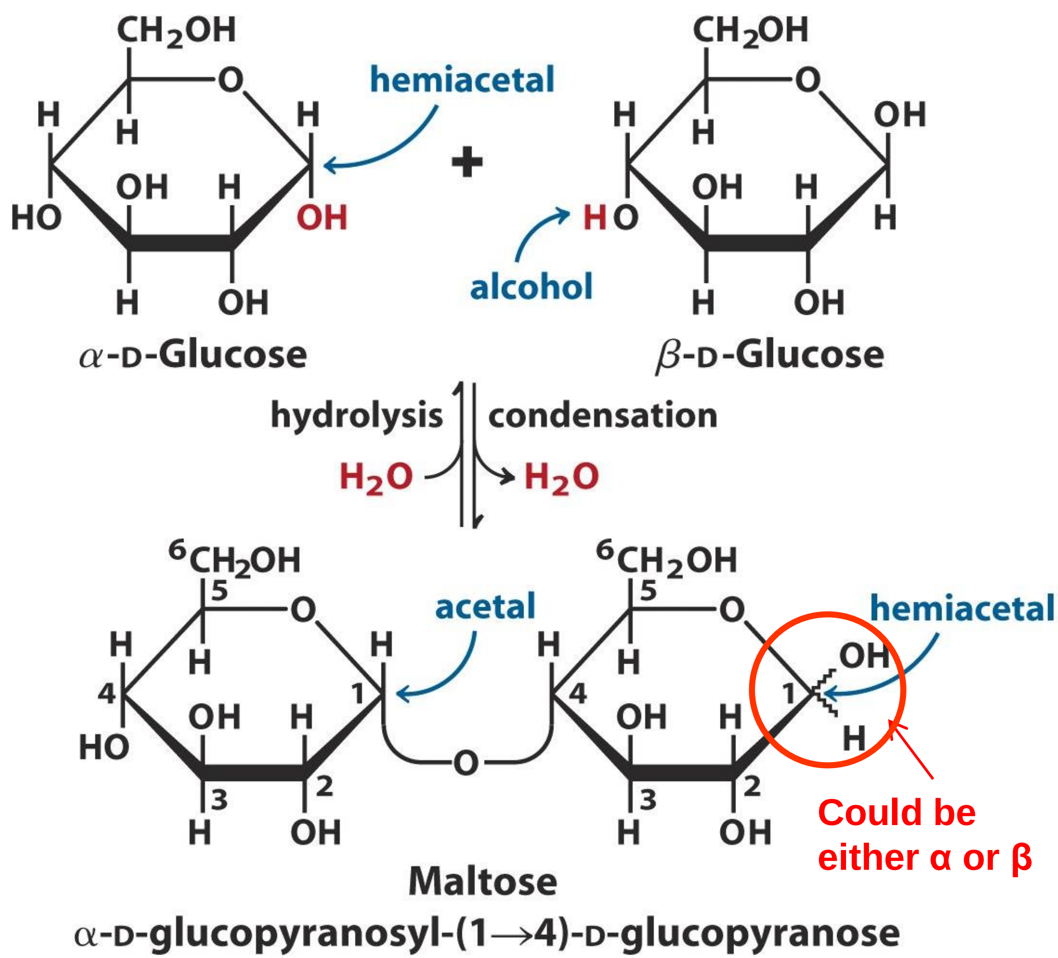
Hexose derivates

- Hydroxyl group in the parent compound is replaced by another substituent.
  - Aminogroup (e.g. glucosamine)
  - Amino group condensed with acetic acid (N-acetylglucosamine)
  - Lactic acid linked to C-4 atom N-acetylmuramic acid
  - Substitution of a hydrogen for hydroxyl group (e.g. fucose)
  - Oxidation of aldehyde group aldonic acids (e.g. gluconic acid)
  - C-6 oxidation uronic acid (e.g. glucuronic acid)
  - Sialic acid C-9 sugar



Glycosidic Bond Formation

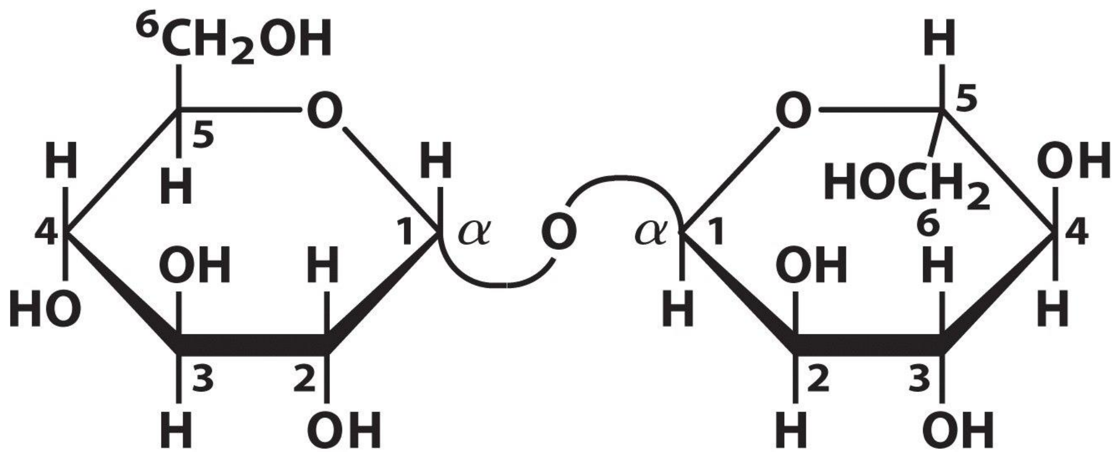
- A **reducing end** of a carbohydrate is a carbon atom which can be in equilibrium with the open-chain aldehyde or keto form.
- If the joining of monomers takes place at such a carbon atom, the free hydroxy group of the pyranose or furanose form is exchanged with an OH-side chain of another sugar, yielding a **full acetal**.
- This prevents opening of the chain to the aldehyde or keto form and renders the modified residue **non-reducing**.



Which is the reducing end?

Trehalose

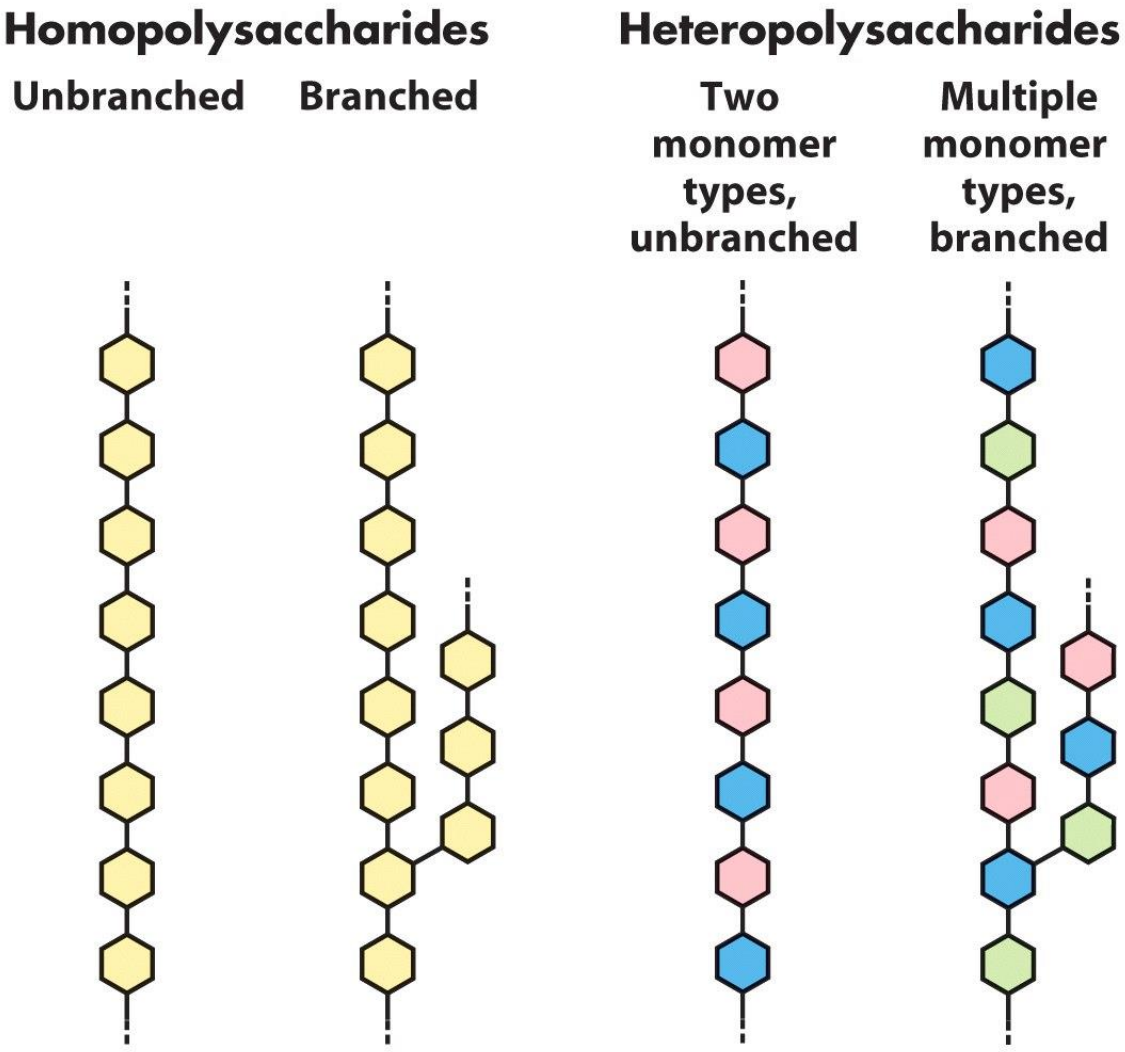
- **Non reducing sugar**
- **Compatible solute „osmolyte“**; accumulated in high concentration th the cell without interfering with cell metabolism
- Stress response/carbon source



Trehalose
α-D-glucopyranosyl α-D-glucopyranoside
Glc(α1↔1α)Glc

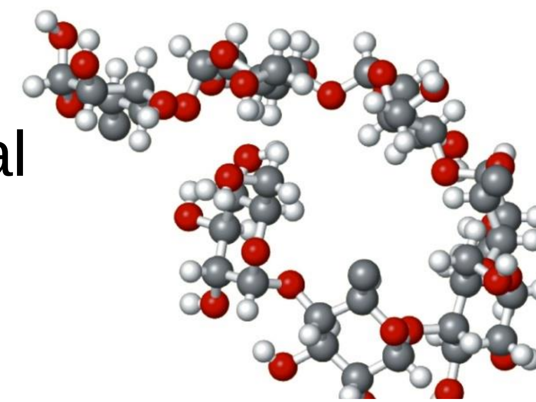
Homo- and Heteropolysaccharides

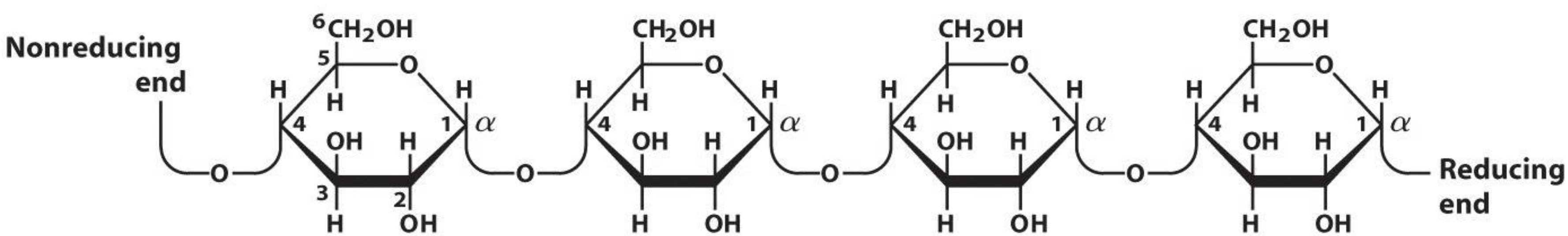
- Polysaccharides or glycans
- Serve as fuels or structural components (e.g. cell wall, animal exo-skeleton)



Starch: Amylose

- Two types of glucose polymers **amylose** & **amylopectin**
- . Amylose is a linear polymer.
  - Glucose residues linked by α(1-->4)-D-glucosidic bonds.
  - Amylose can assume a left-handed helical conformation, which is hydrated on the inside as well as on the outer surface.

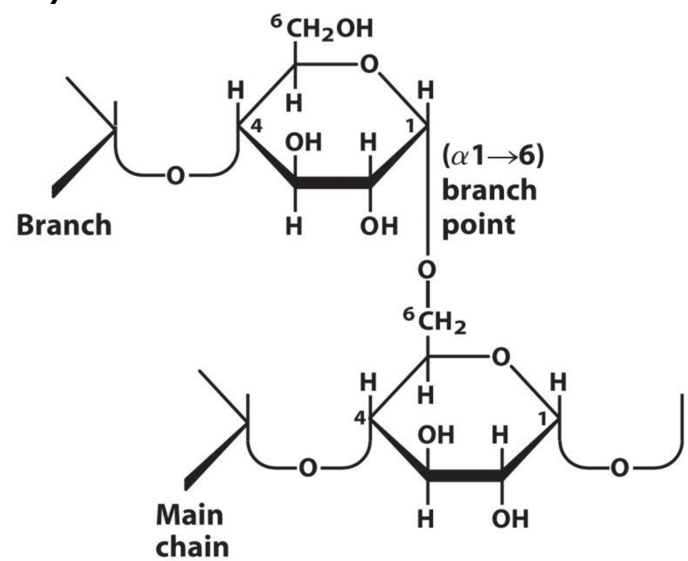


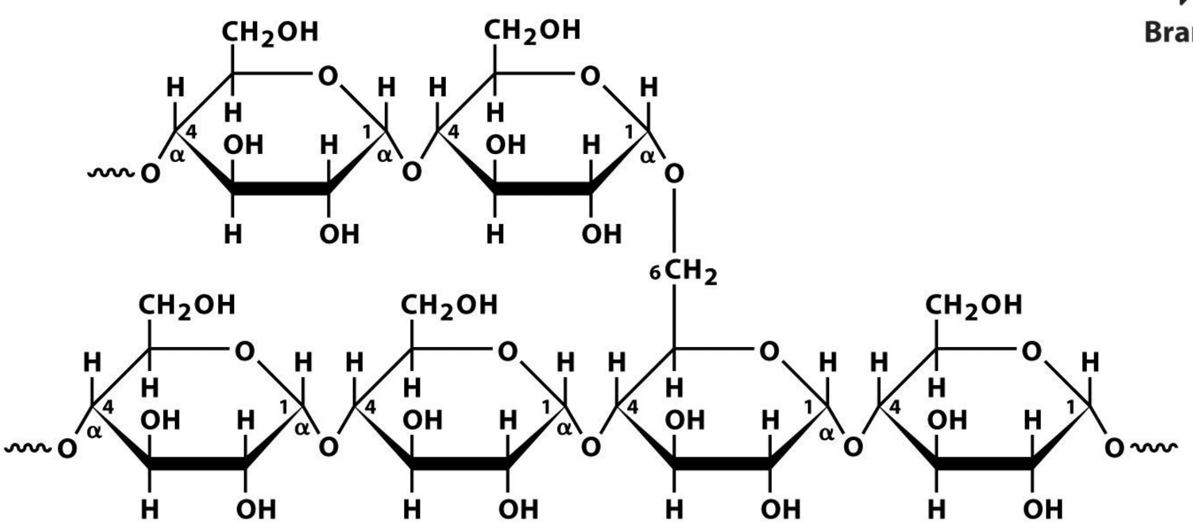


amylose

Starch: Amylopectin

- Amylopectin is a **branched** polymer.
  - The linear glucose residues of the main chain and the side chains of amylopectin are linked by **α(1-->4)-**D-glucosidic bonds
  - **side chains** are linked to the main chain by **α(1-->6)-**D-glucosidic bonds (every 24-30 residues).
  - Size: up to 10^6





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Biomolecules

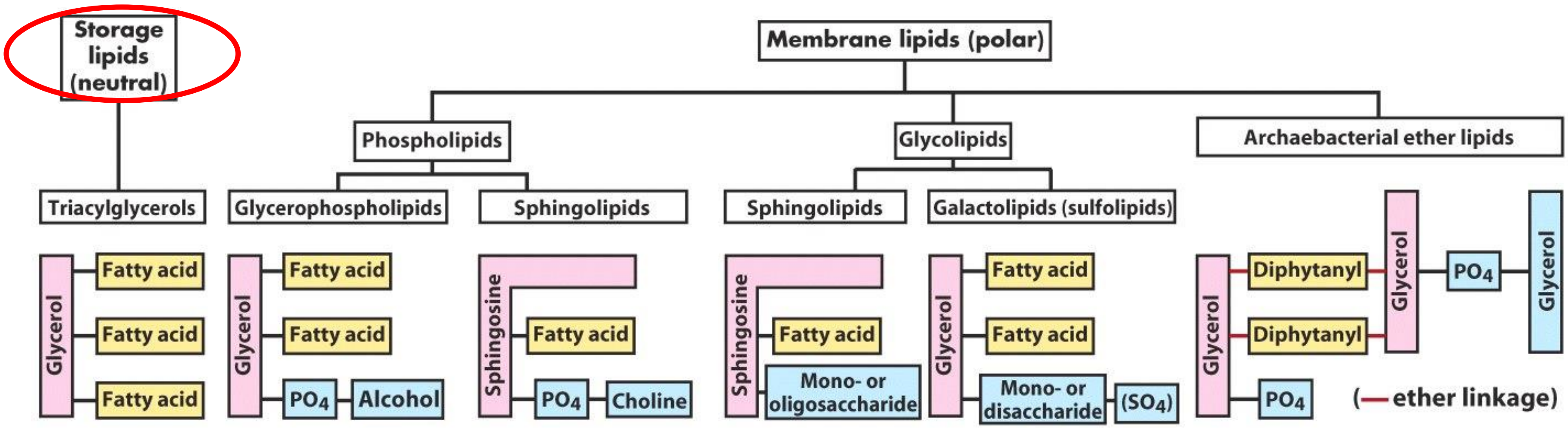
Lipids



Lipids

- **Lipids** are **amphipathic**—they have both hydrophobic (**nonpolar**) and hydrophilic (**polar**) properties.
- Biological lipids are a chemically **diverse** group of compounds
- Common and defining feature - **insolubility in water**
- ***Glycerol bonded to fatty acids and other groups such as phosphate by an ester or ether linkage***

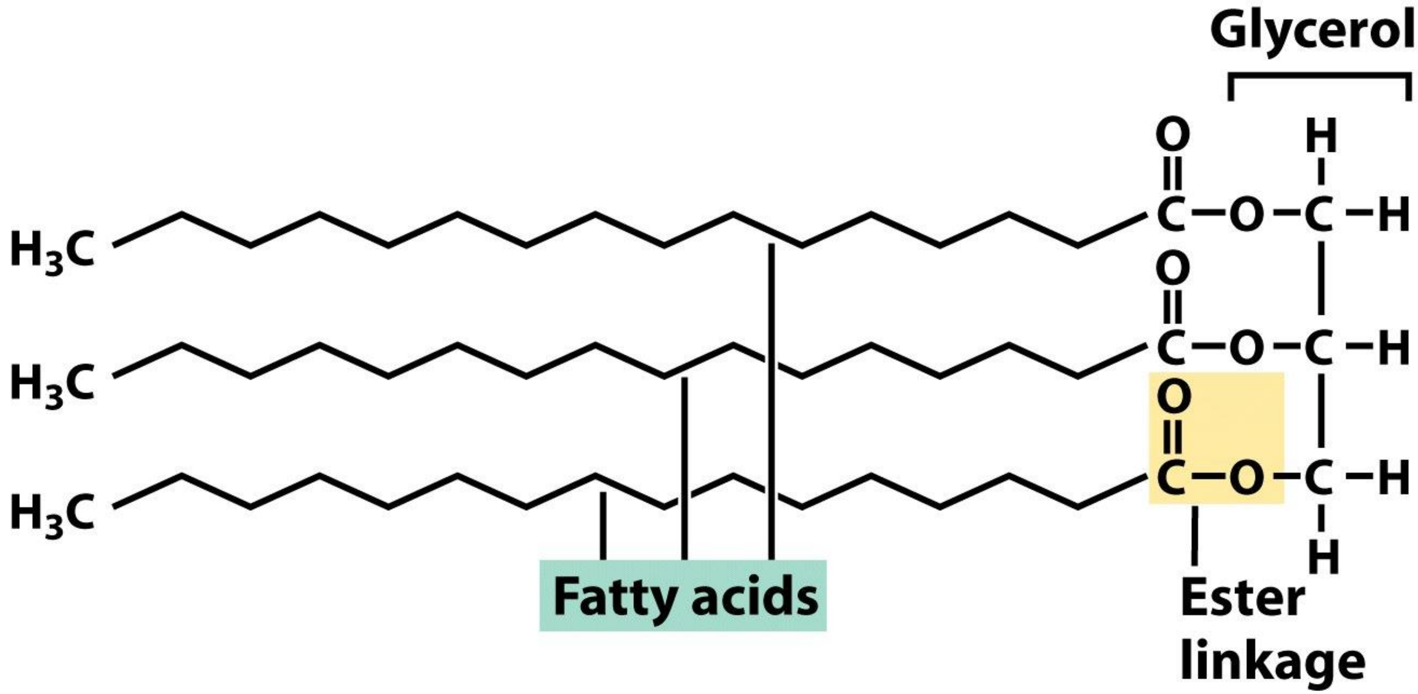
Major Classes of Lipids



Storage Lipids

- Simple lipids (triglycerides)

Simple lipids (triglycerides):
Fatty acids linked to glycerol by ester linkage



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Chemical structures of fatty acids

- Fatty acids consist of a long **hydrocarbon tail** terminating with a **carboxyl group**.
- Since the pKa of the carboxyl group is approximately 4.5 to 5.0, fatty acids are **anionic at physiological pH**.
- In IUPAC nomenclature, carbons are **numbered beginning with the carboxyl carbon**. In common nomenclature, the carbon atom adjacent to the carboxyl carbon is designated α, and the remaining carbons are lettered β, γ, δ, and so on. The carbon atom farthest from the carboxyl carbon is designated the **ω (omega) carbon**, whatever the length of the tail.
- The fatty acid shown, **laurate** (or dodecanoate), has **12 carbon atoms** and contains **no carbon–carbon double bonds**.

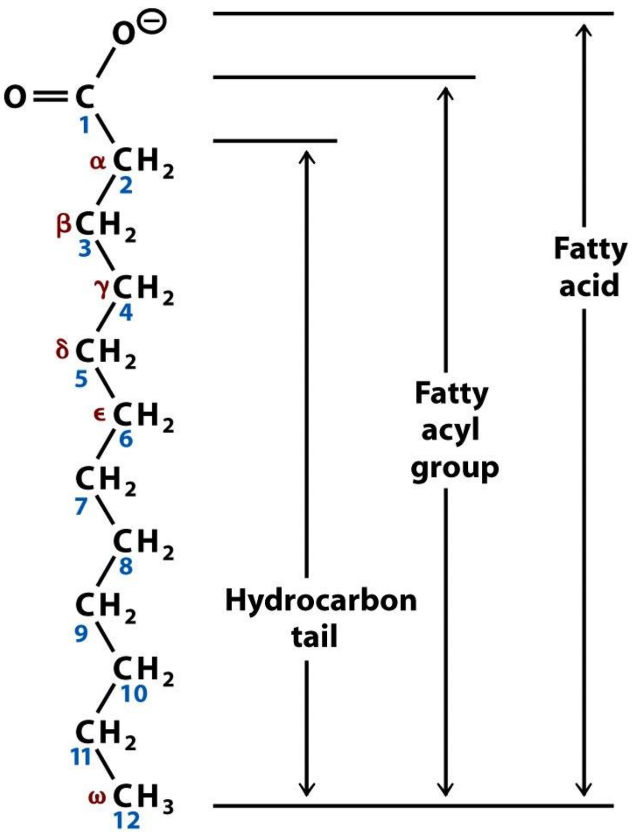

Figure 9-2 Principles of Biochemistry, 4/e

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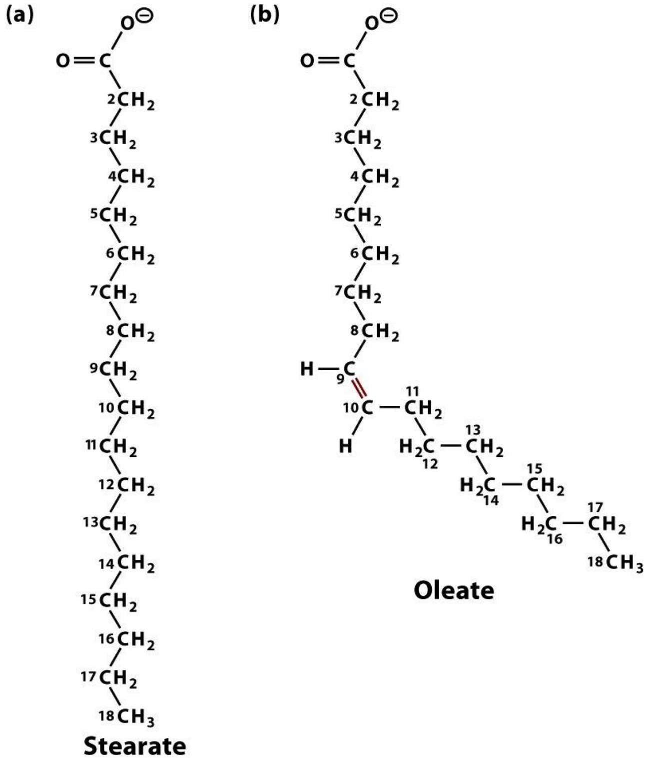
Chemical structures of three C_{18} fatty acids

- (a) **Stearate** (octadecanoate), a **saturated fatty acid**.
- (b) **Oleate** (*cis*-Δ^9-octadecenoate) a **monounsaturated fatty acid**.
- c) **Linolenate** (all-*cis*-$\Delta^{9,12,15}$-octadecatrienoate), a **polyunsaturated fatty acid**. The cis double bonds produce kinks in the tails of the unsaturated fatty acids. Linolenate is a very flexible molecule, and can assume a variety of conformations.

Omega-3-fatty acid can not be synthesized by human must be obtained in the diet.



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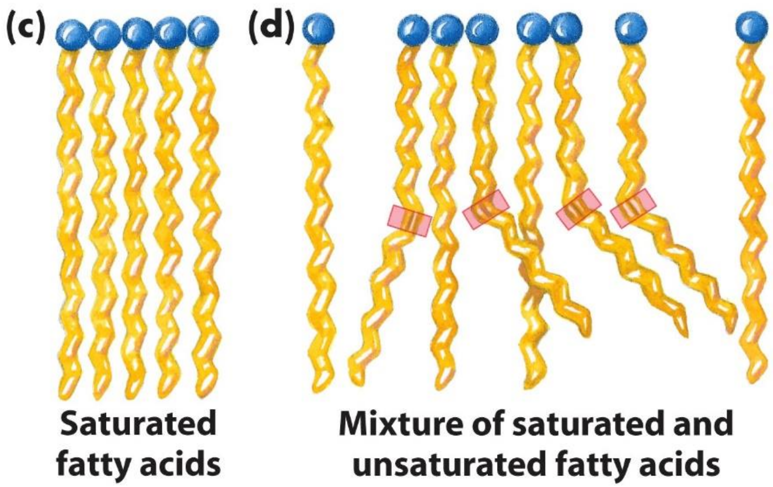
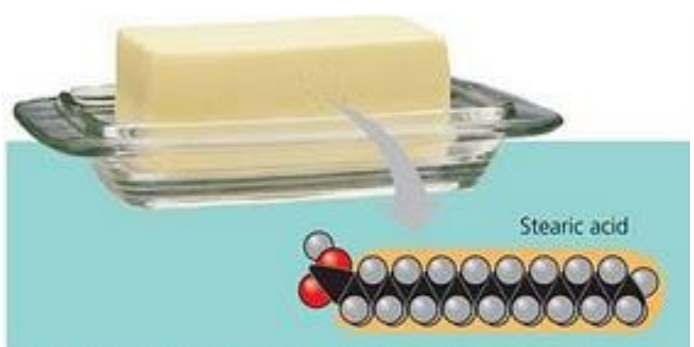
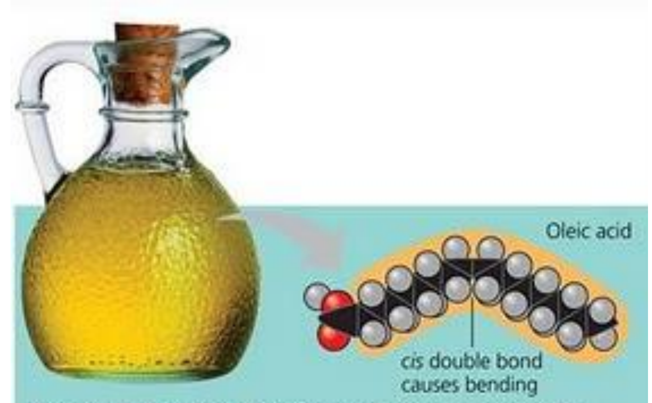
Examples of Fatty Acids



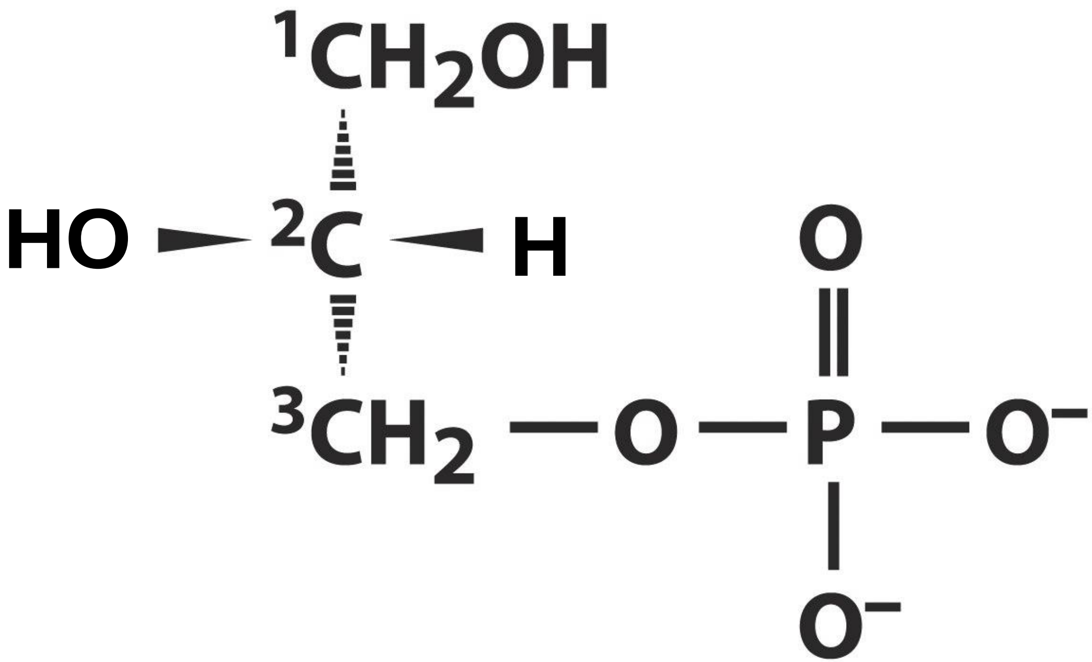


(a) Saturated fat and fatty acid. At room temperature, the molecules of a saturated fat such as this butter are packed closely together, forming a solid.



(b) Unsaturated fat and fatty acid. At room temperature, the molecules of an unsaturated fat such as this olive oil cannot pack together closely enough to solidify because of the kinks in their fatty acid tails.

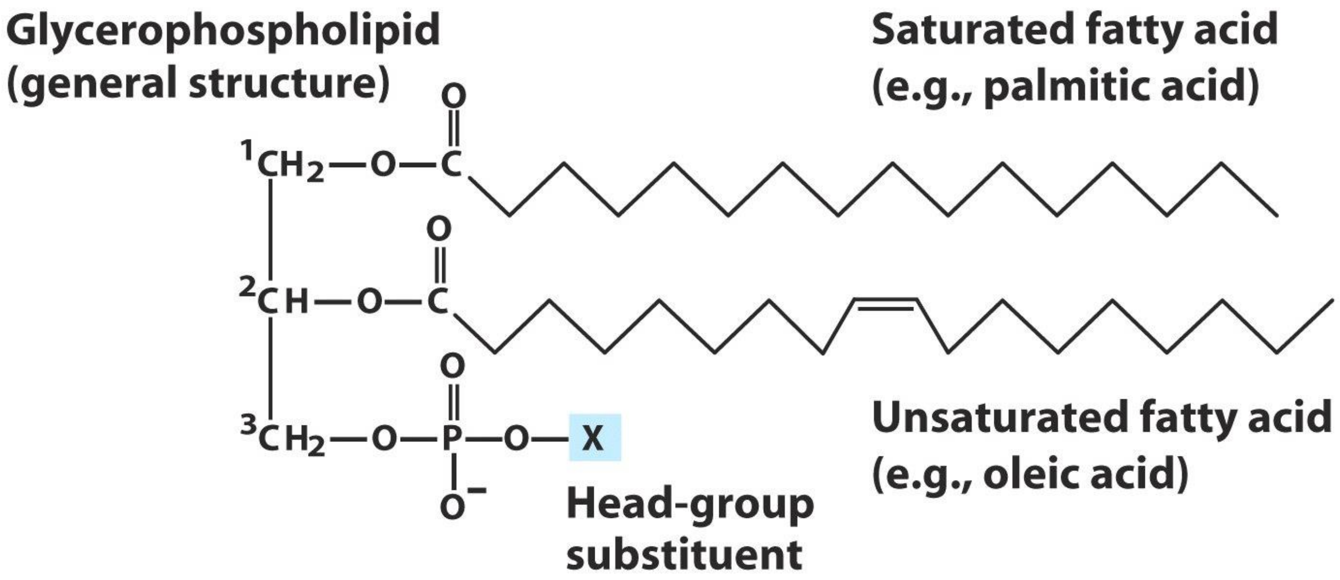
The Backbone of Phospholipids

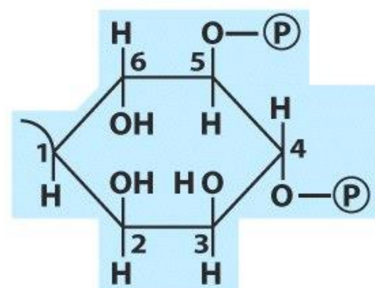
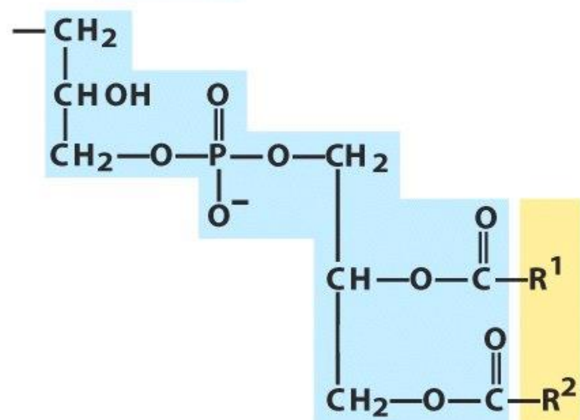


L-Glycerol 3-phosphate
(*sn*-glycerol 3-phosphate)

Glycerophospholipids

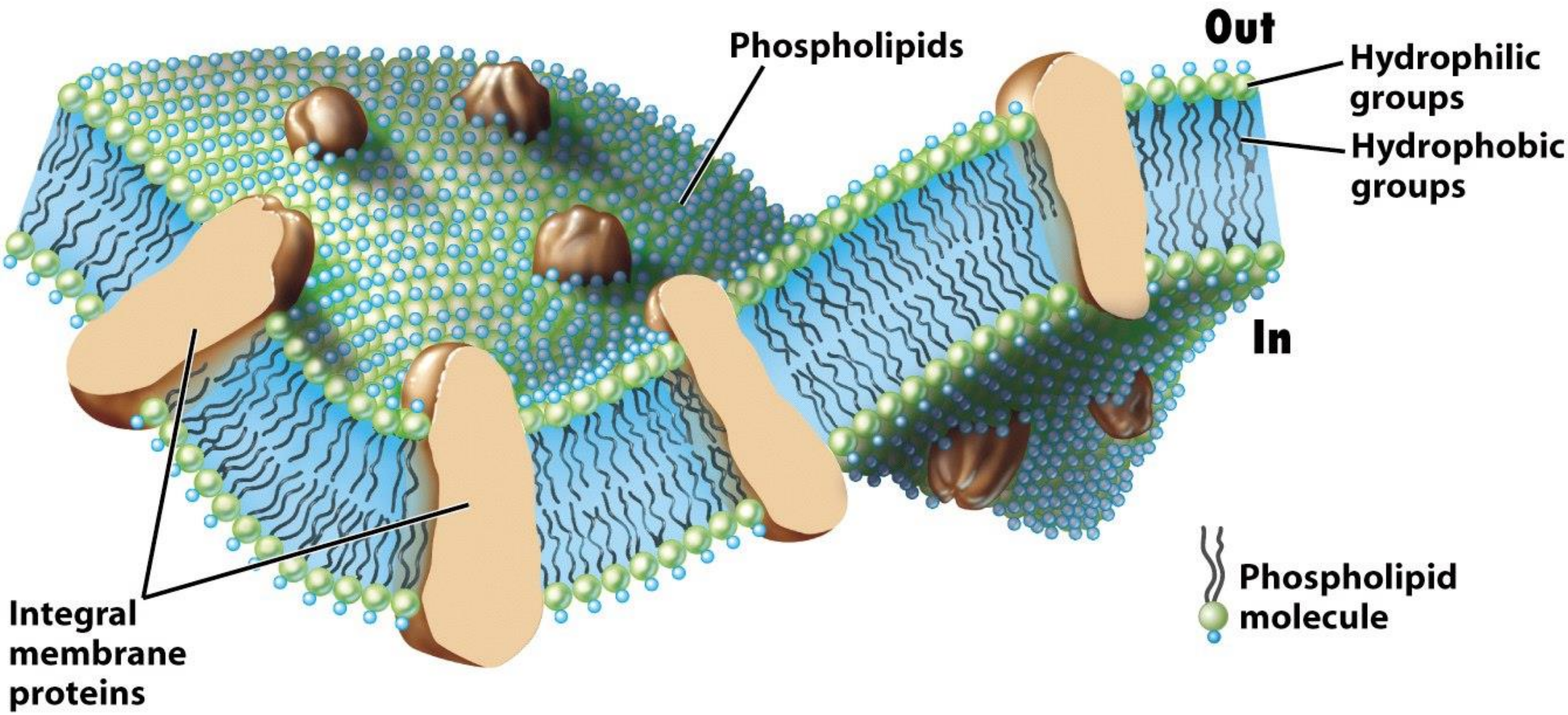
- **Membrane lipids; two fatty acids** are linked to first and second carbon of **glycerol** via **ester linkage;** a **highly polar or charged group** is attached to carbon three via **phosphodiester linkage.**
- **Common glycerophospholipids** are **diacylglycerols** linked to **head-group alcohols** through **a phosphodiester** bond.
- **Phosphatidic acid (X=H)**, a phosphomonoester, is the parent compound.
- Derivatives (x), named for the headgroup alcohol with prefix „phosphatidyl-x“



Name of glycerophospholipid	Name of X	Formula of X	Net charge (at pH 7)
Phosphatidic acid	—	$-H$	− 1
Phosphatidylethanolamine	Ethanolamine	$-CH_2-CH_2-\overset{+}{N}H_3$	0
Phosphatidylcholine	Choline	$-CH_2-CH_2-\overset{+}{N}(CH_3)_3$	0
Phosphatidylserine	Serine	$-CH_2-CH(COO^-)-\overset{+}{N}H_3$	− 1
Phosphatidylglycerol	Glycerol	$-CH_2-CH(OH)-CH_2-OH$	− 1
Phosphatidylinositol 4,5-bisphosphate	*myo*-Inositol 4,5-bisphosphate		− 4
Cardiolipin	Phosphatidyl-glycerol		− 2

Membranes

- *E. coli* phosphatidylethanolamine & phosphatidylcholine



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Nucleotides & Nucleic Acids

Nucleotides

- Three building blocks:
  - Nitrogen-containing base
  - Pentose
  - At least one phosphate

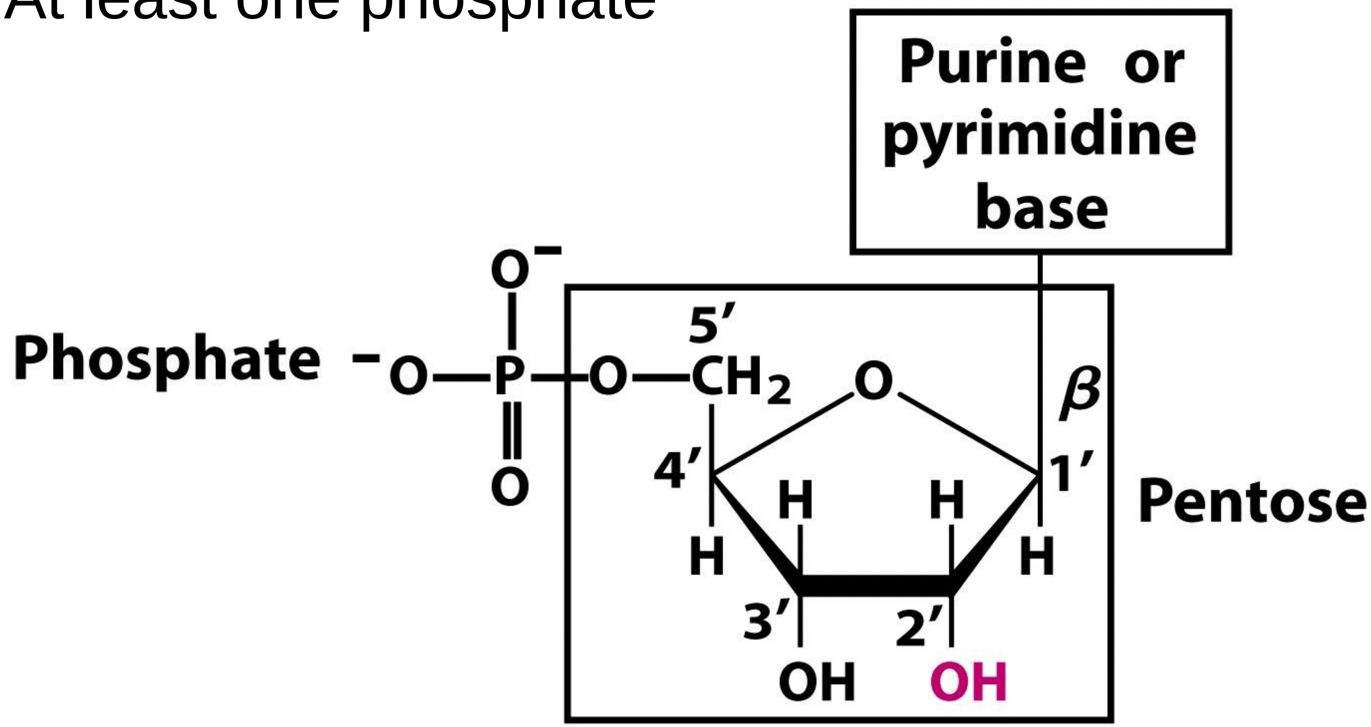

Figure 8-1a
Lehninger Principles of Biochemistry, Fifth Edition
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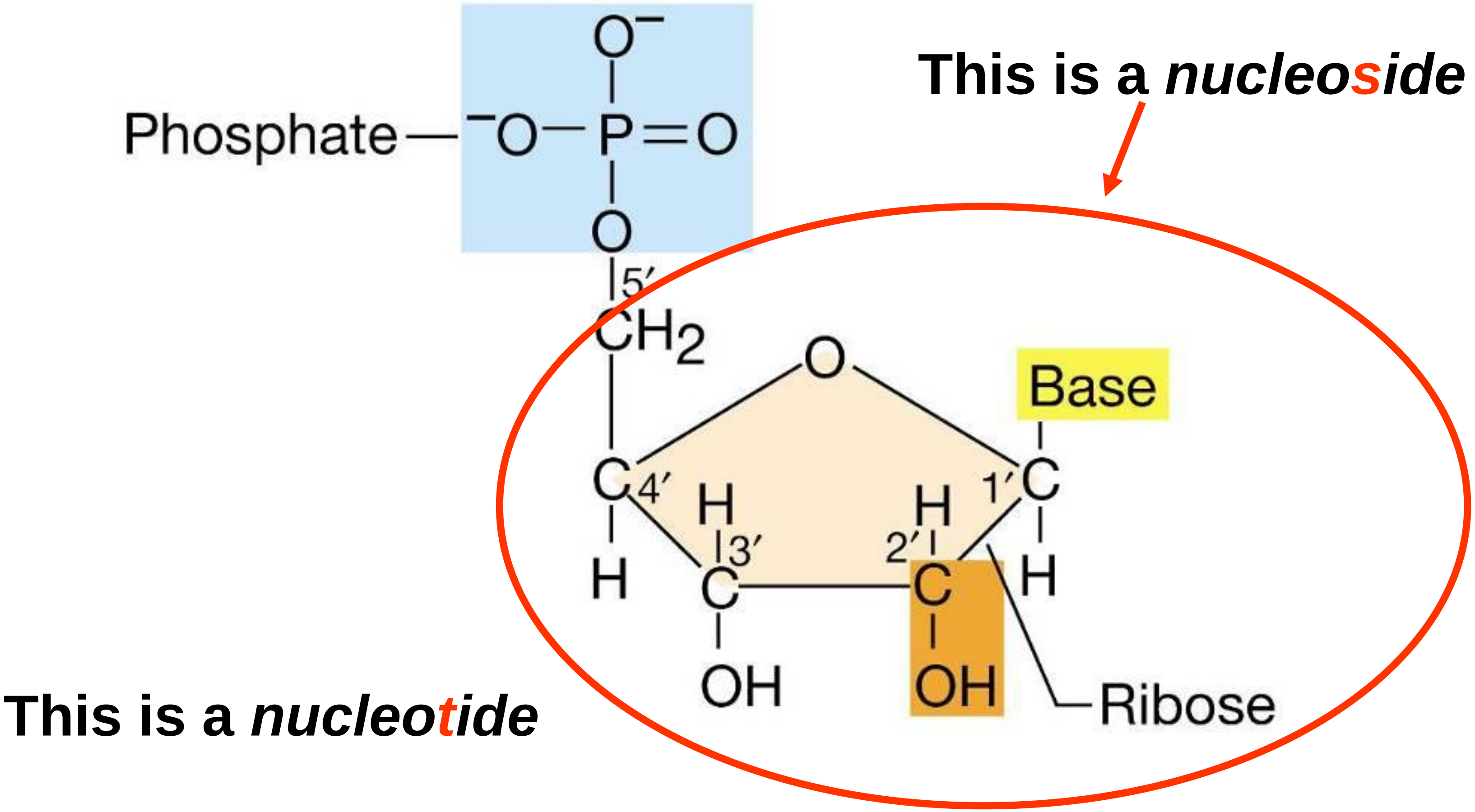
Nucleosides & Nucleotides

- **Nucleotides** (sugar, base and phophate)
- **Nucleoside** (sugar and base, without phosphate)



Pyrimidine and Purine Bases

- The nitrogenous bases are derivatives of two parent compounds:
  - Glycoside linkage between carbon atom (C1) and nitrogen atom (N1, pyrimidine base, N9 purine base)

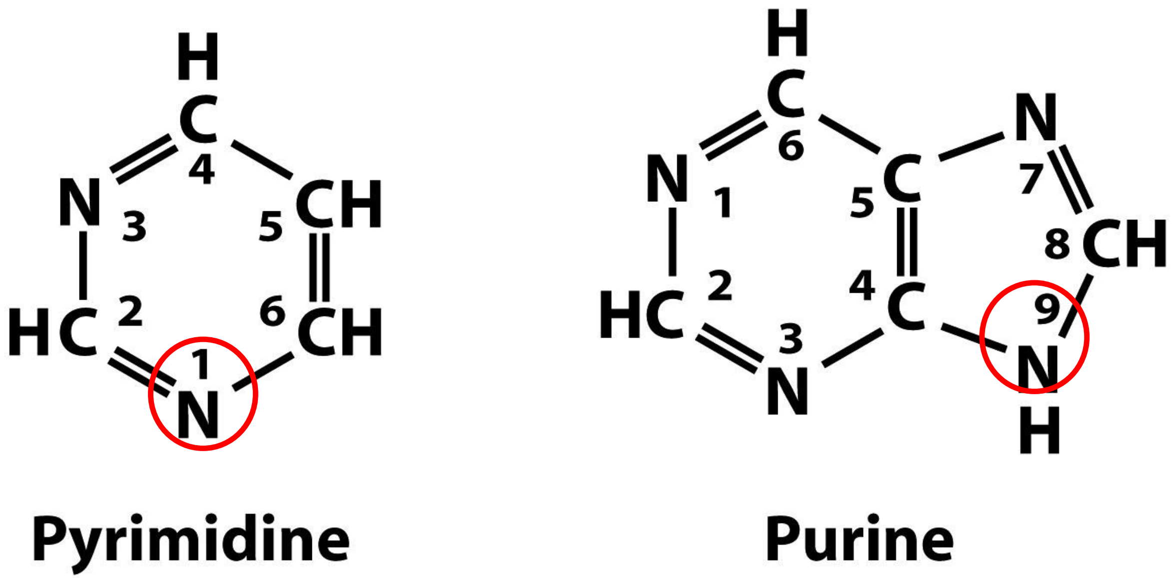


Figure 8-1b
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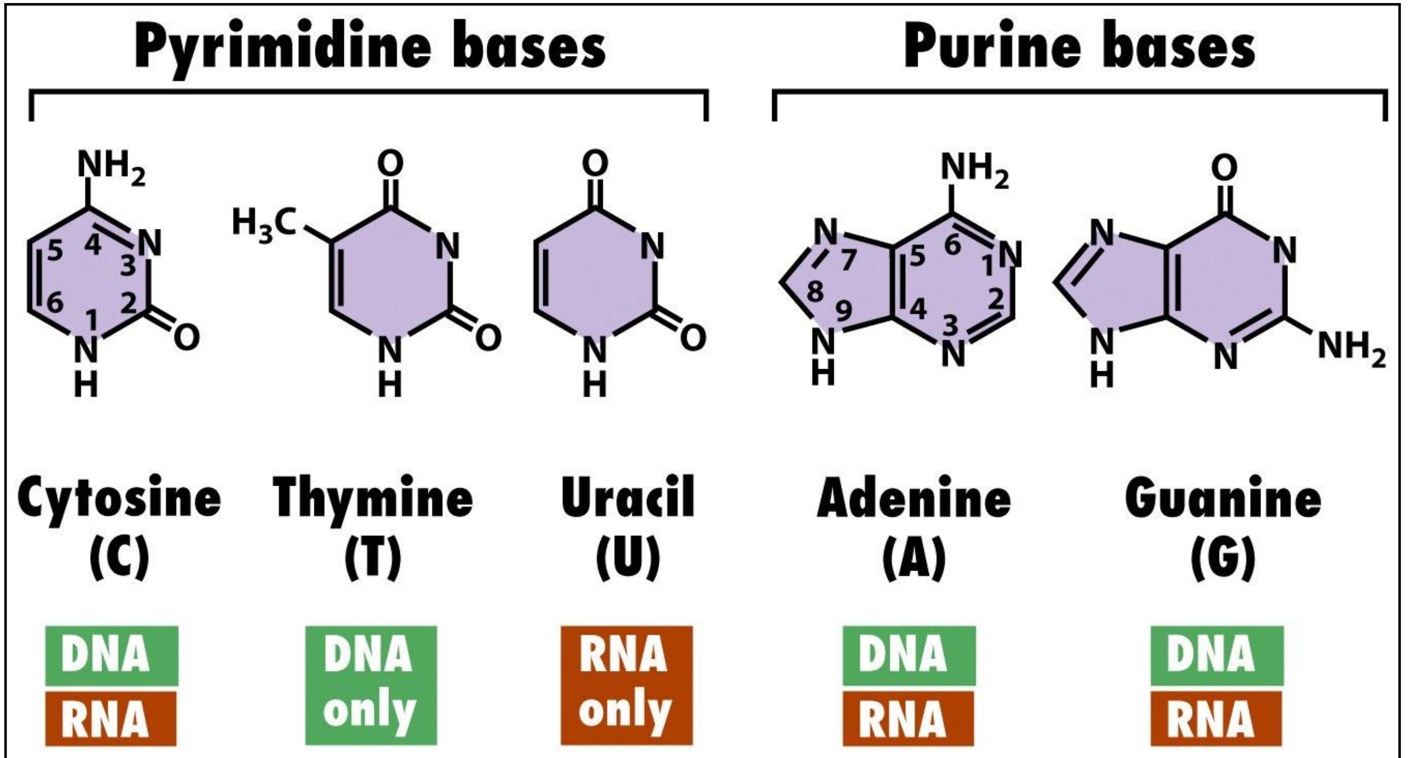
Pyrimidine and Purine Bases

- Major purine and pyrimidine bases of nucleic acids.



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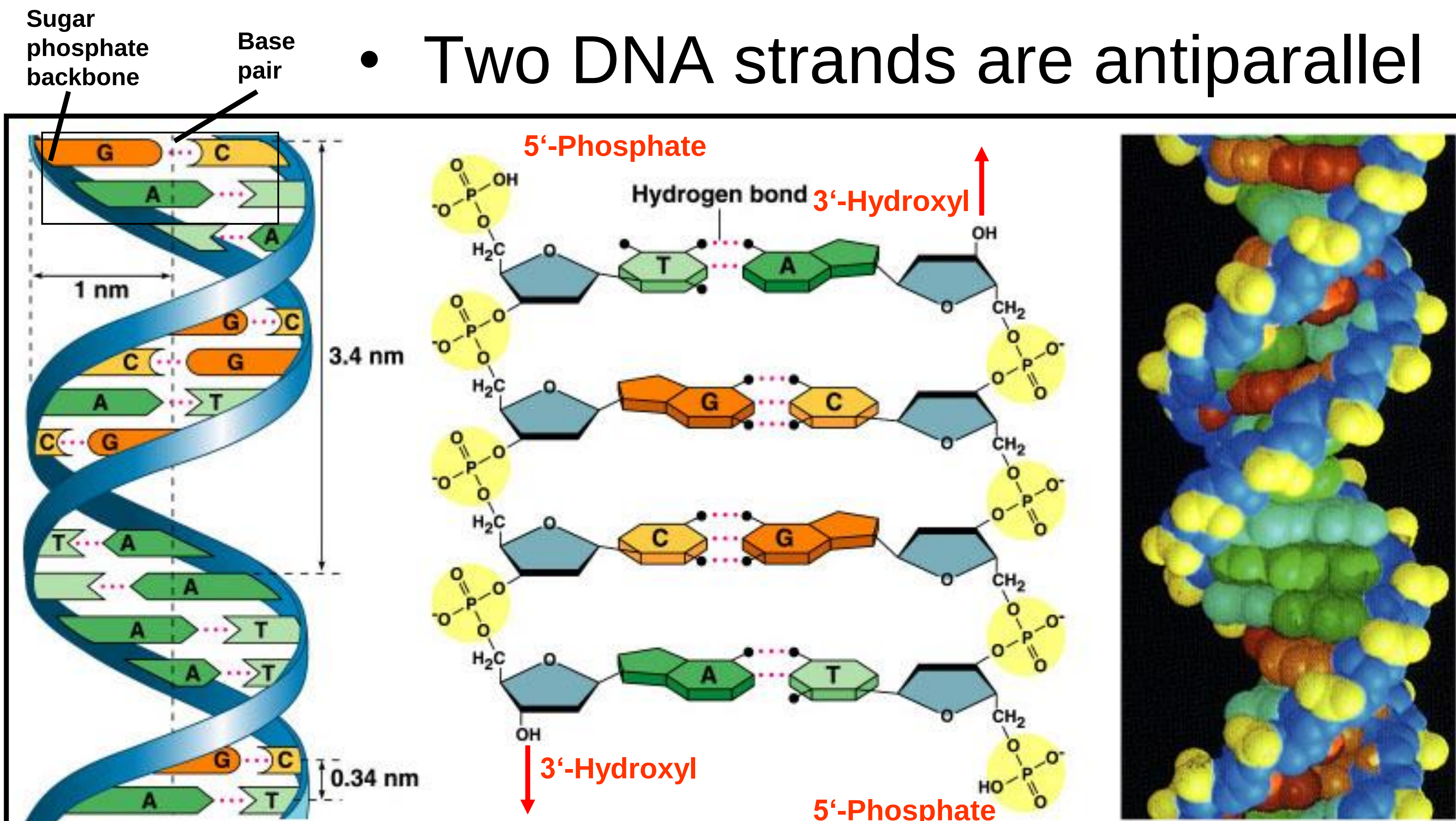
The DNA Double Helix

- Two DNA strands are antiparallel



(a) Key features of DNA structure

(b) Partial chemical structure

(c) Space-filling model

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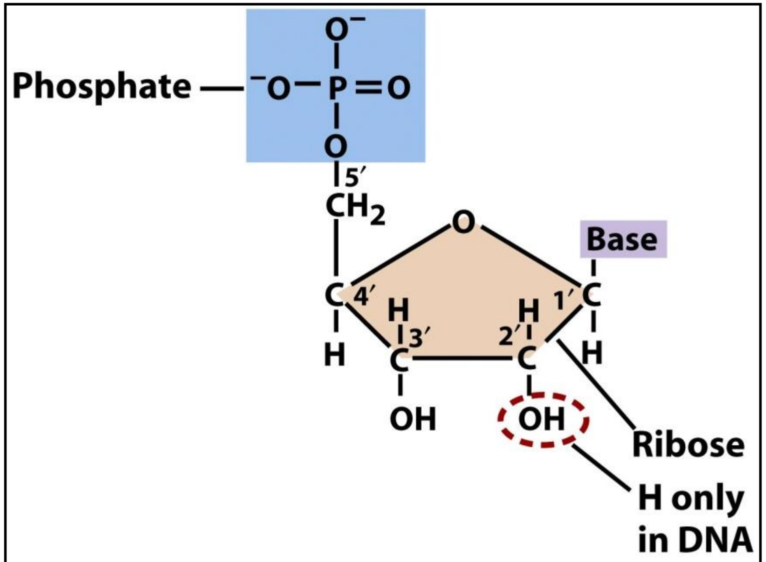
FIGURE 16.5 Biology 6/e

Ribonucleic acid (RNA)

- Ribose
- C, U (no T), A, G,
- Base pairing matches DNA (G=C, A=U)
- mostly single-stranded, secondary structures



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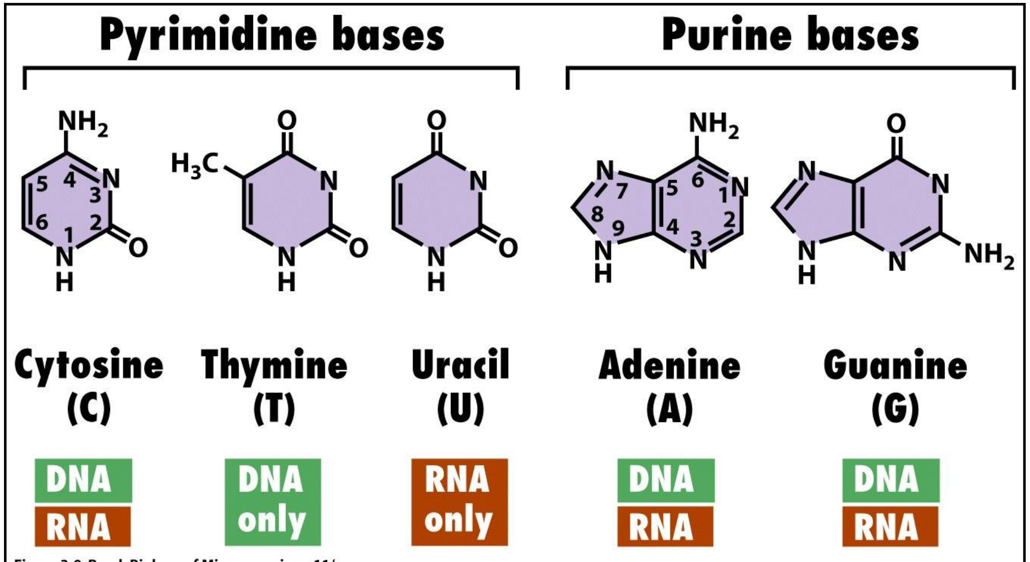

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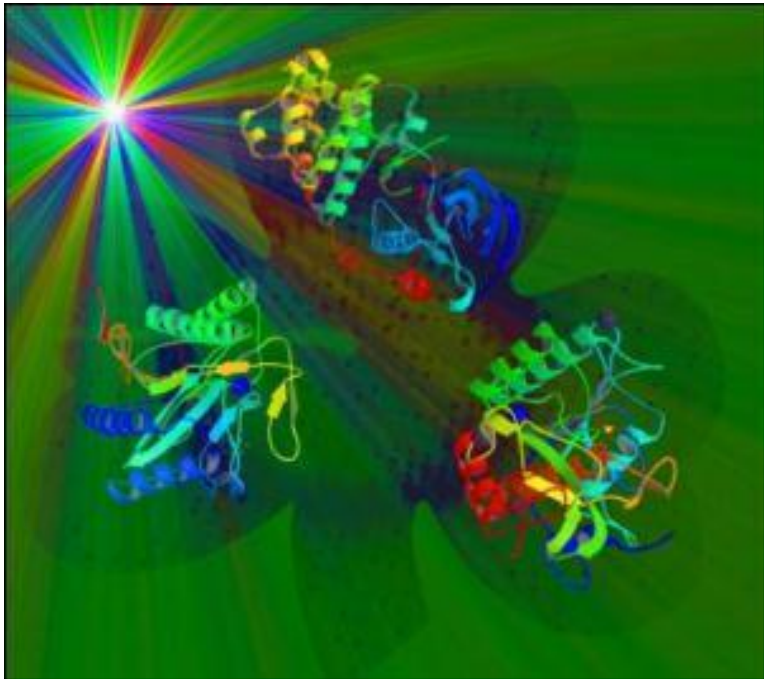
Three major types of RNA

- **messenger RNA (mRNA)**
- **transfer RNA (tRNA)**
- **ribosomal RNA (rRNA)**

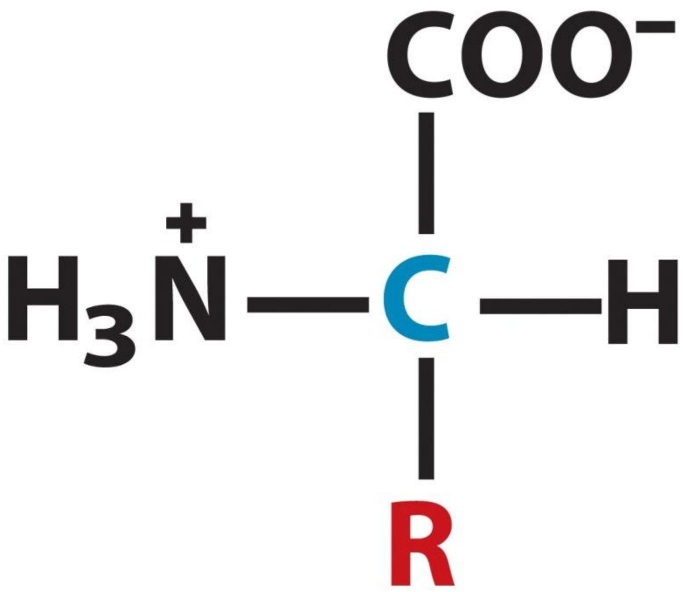
- **Two types of function:**
- **genetic**
  - **carries genetic information of DNA (mRNA)**
- **structural**
  - **e.g. -structural role in ribosome (rRNA),**
  - **amino acid transfer (tRNA),**
  - **catalytic (enzymatic) activity (ribozymes)**

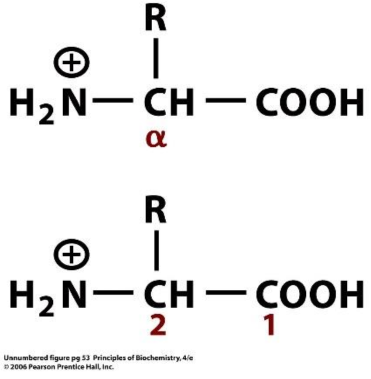
Amino Acids & Proteins



Amino Acid

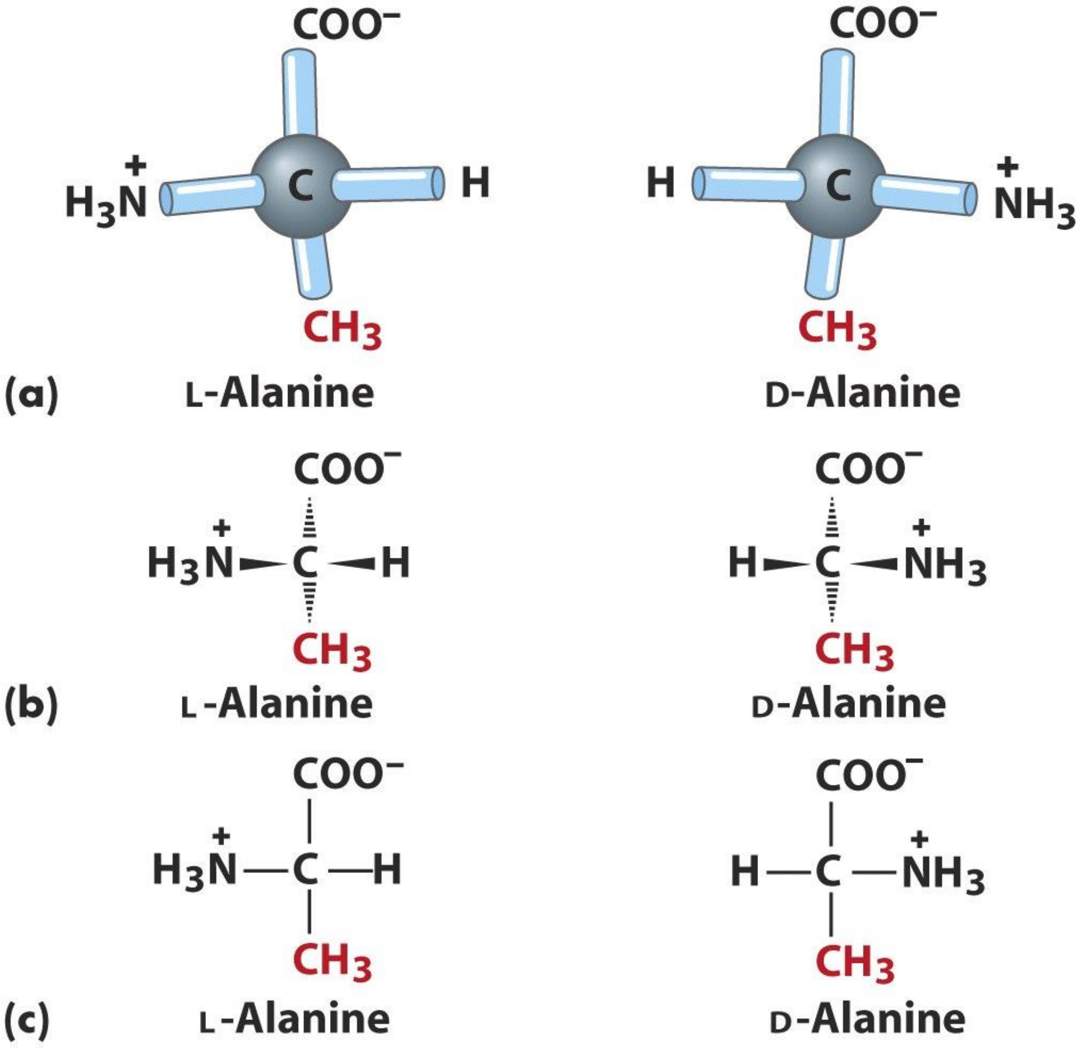
- General Structure of all but one **α-amino acid** (proline, a cyclic amino acid is the excepteion):
- An amino acid has
- a **carboxylate group** (whose carbon atom is designated C-1),
- an **amino group**,
- a **hydrogen atom**, and
- a **side chain** (or **R** group),
- **all attached to C-2** (the **α-carbon**).





Amino Acid Stereoisomers

- Stereoisomers in **α-amino acids**.
- **Mirror images** of each other **(enantiomers).**
- **Except glycine**, all amino acids are **chiral** (L-, D-isomeres; based on convention of the three-carbon sugar glyceraldehyde)
- In living organisms, they usually occur in the **L-form**.
- Some organisms have **racemases**: D ⇨ L-form.



Amino Acids

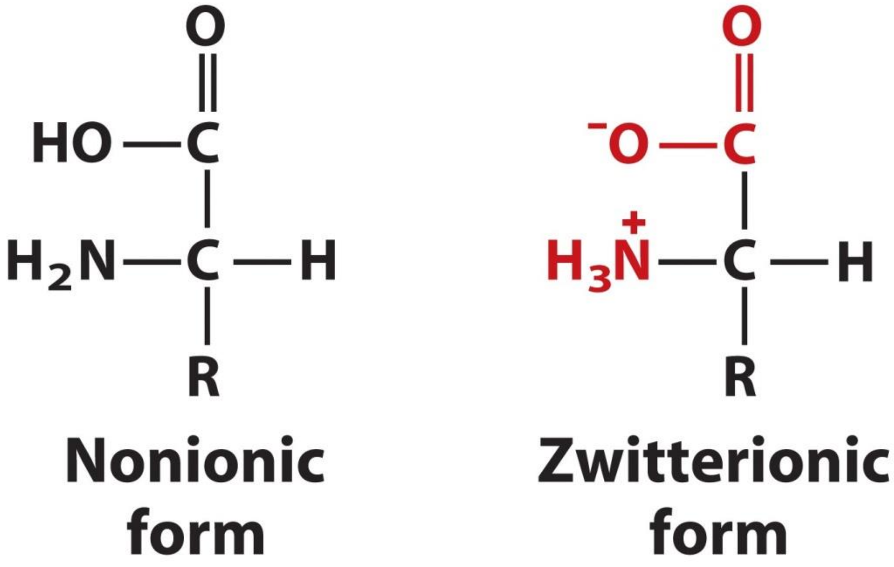
- All common **20 proteinogenic amino aicds** are α-amino acids.
- They **differ in their side chains** (R groups), which vary in structure, size, and electric charge, and which influence the solubility of the amino acid in water.
- In addition to this common ones there are **less common ones**. Some are the result of post-translational modifications, some are amino acids present in living cells but not in proteins.

The 20 Common Amino Acids of Proteins

- 5 groups:
  - Nonpolar, aliphatic R groups
  - Aromatic R groups
  - Polar, uncharged R groups
  - Positively, charged R groups
  - Negatively, charged R goups

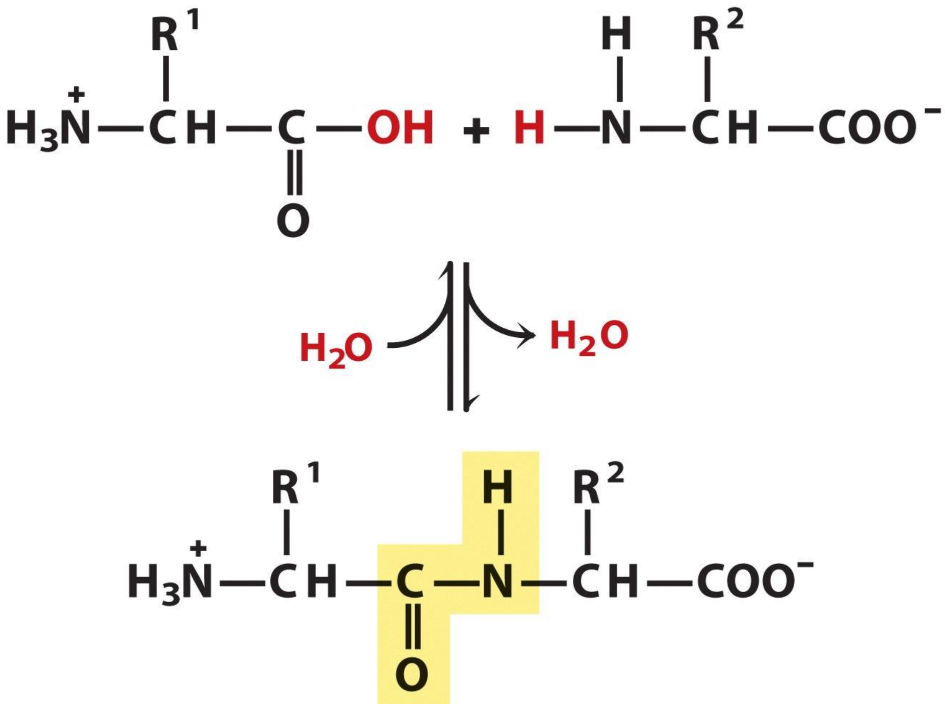
Nonionic and Zwitterionic Forms of Amino Acids

- The **amino and carboxylgroups** of amino acids and the **ionizable R groups** of some amino acids function as **weak acids and bases**.
- When an amino acid (without ionizable R) is dissoved in water at **neutral pH**, it exists in solution as a **dipolar ion „zwitterion“**
- **Ampholytes** are substances that exhibit this **dual (acid/base) nature**. They are amphoteric.



Peptide bond formation

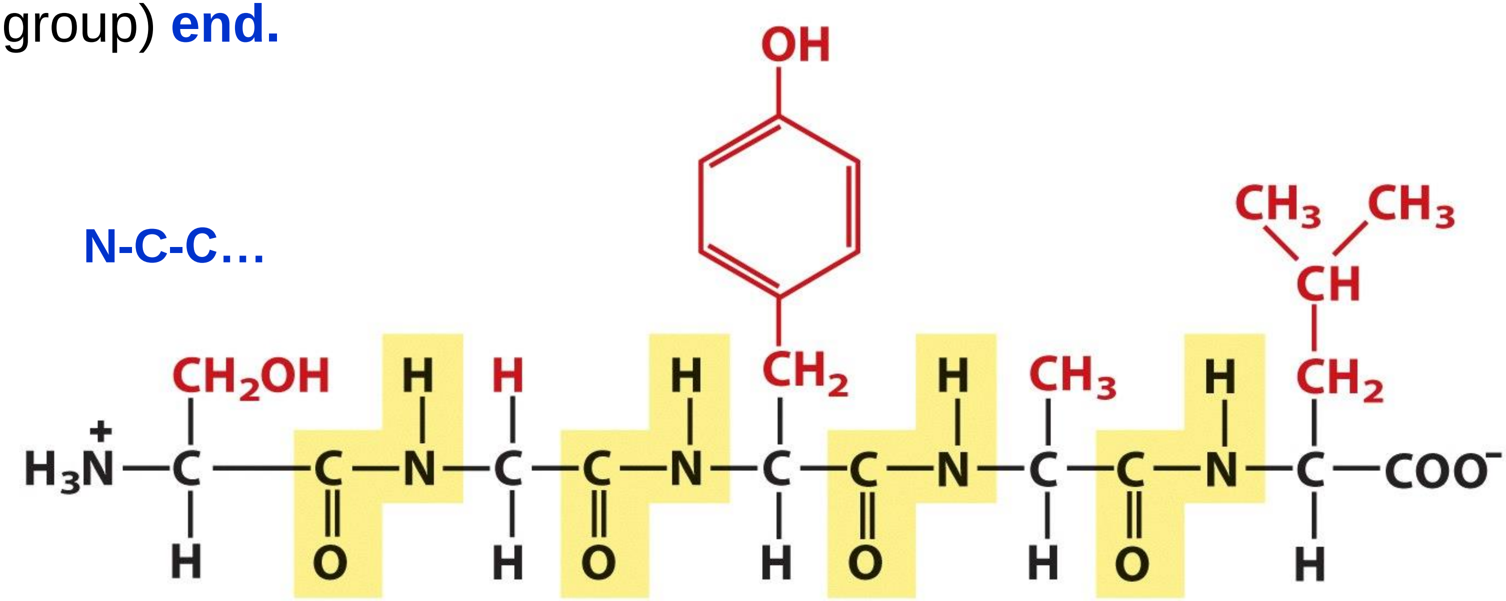
- Aminoacids can be linked through a substituted amide linkage, termed **peptide bond**, to yield a dipeptide.
- The linkage is formed by the **removal of water** (**dehydration**) between the **α-carboxyl** group of one amino acid and the **α-amino** group of a second amino acids in a **condensation** reaction.
- The repeated sequence (**N-C-C**) is the **polypeptide backbone**.
- Dipeptide, tripeptide, oligopeptide, polypeptide
- **Polpeptides** molecular weights <10,000 ; **Proteins** > 10,000



Pentapeptide

- Serylglycyltyrosylalanylleucine (Ser-Gly-Tyr-Ala-Leu)
- Named beginning with the N-terminal residue (by convention placed at the left)
- Every peptide/protein has an **amino-terminal** (or N-terminal, free amino group) and a **carboxy-terminal** (or C-terminal, free carboxyl group) **end.**

N-C-C…

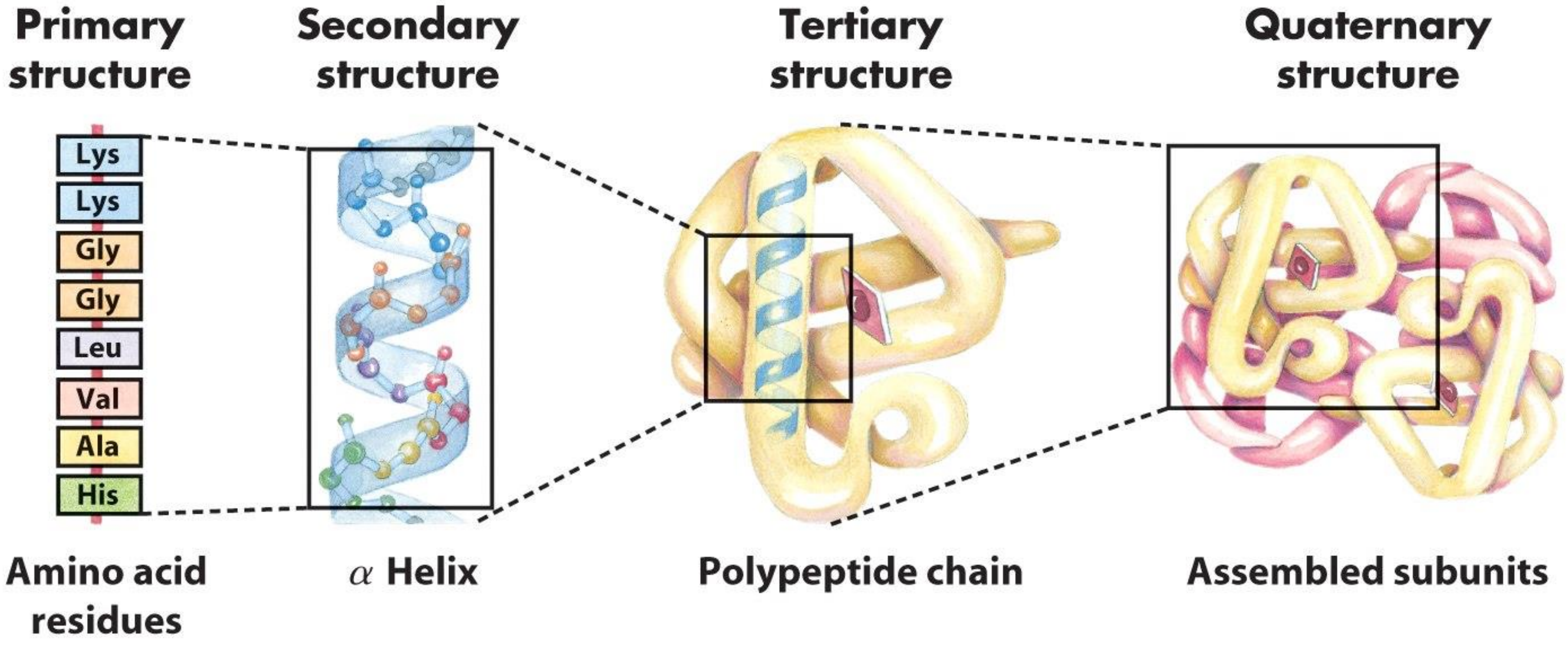


Amino-terminal end

Carboxyl-terminal end

Level of Structures in Proteins

- Primary structure, **sequence** of amino acid residues.
- Secondary structure, particulary stable arrangements of amino acids giving rise to recuring **structural patterns**.
- Tertiary structures describes all aspects of the **three-dimensional folding** of a polypeptide.
- Quarternary structrue, describes the arragement in space of **two or more polypeptides subunits.**



Protein Folding

- Noncovalent interactions

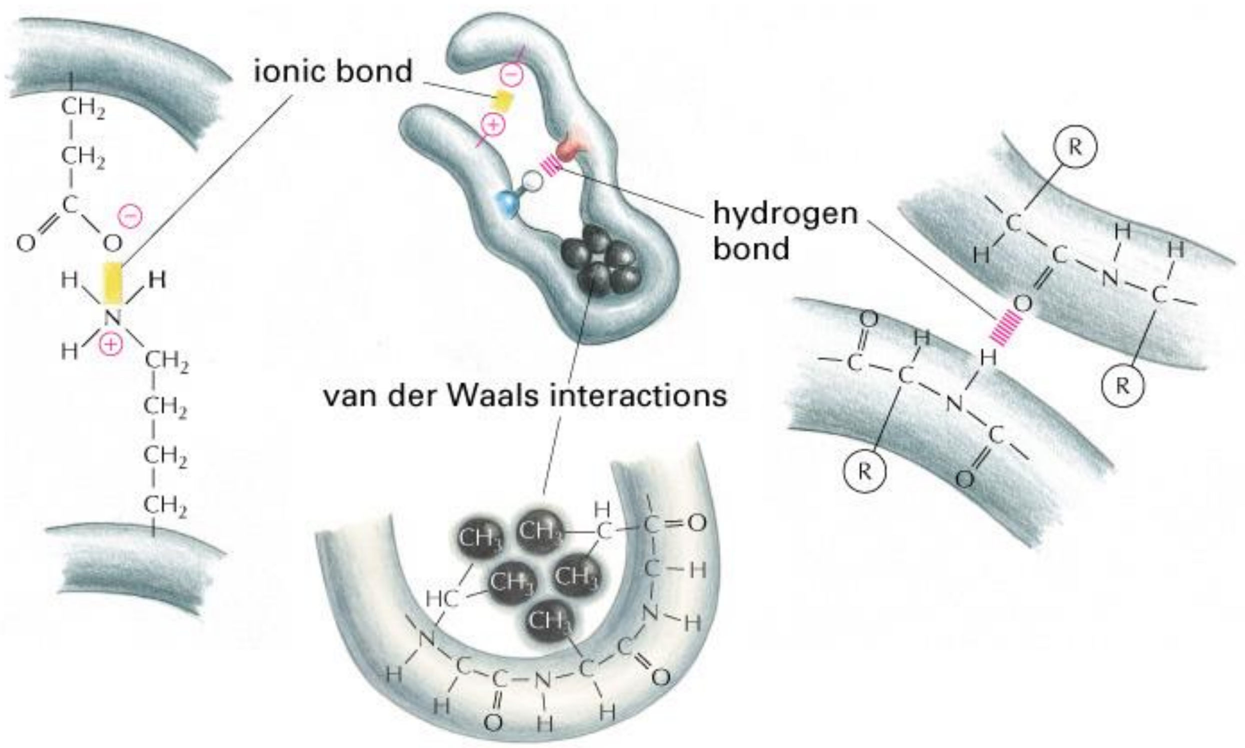
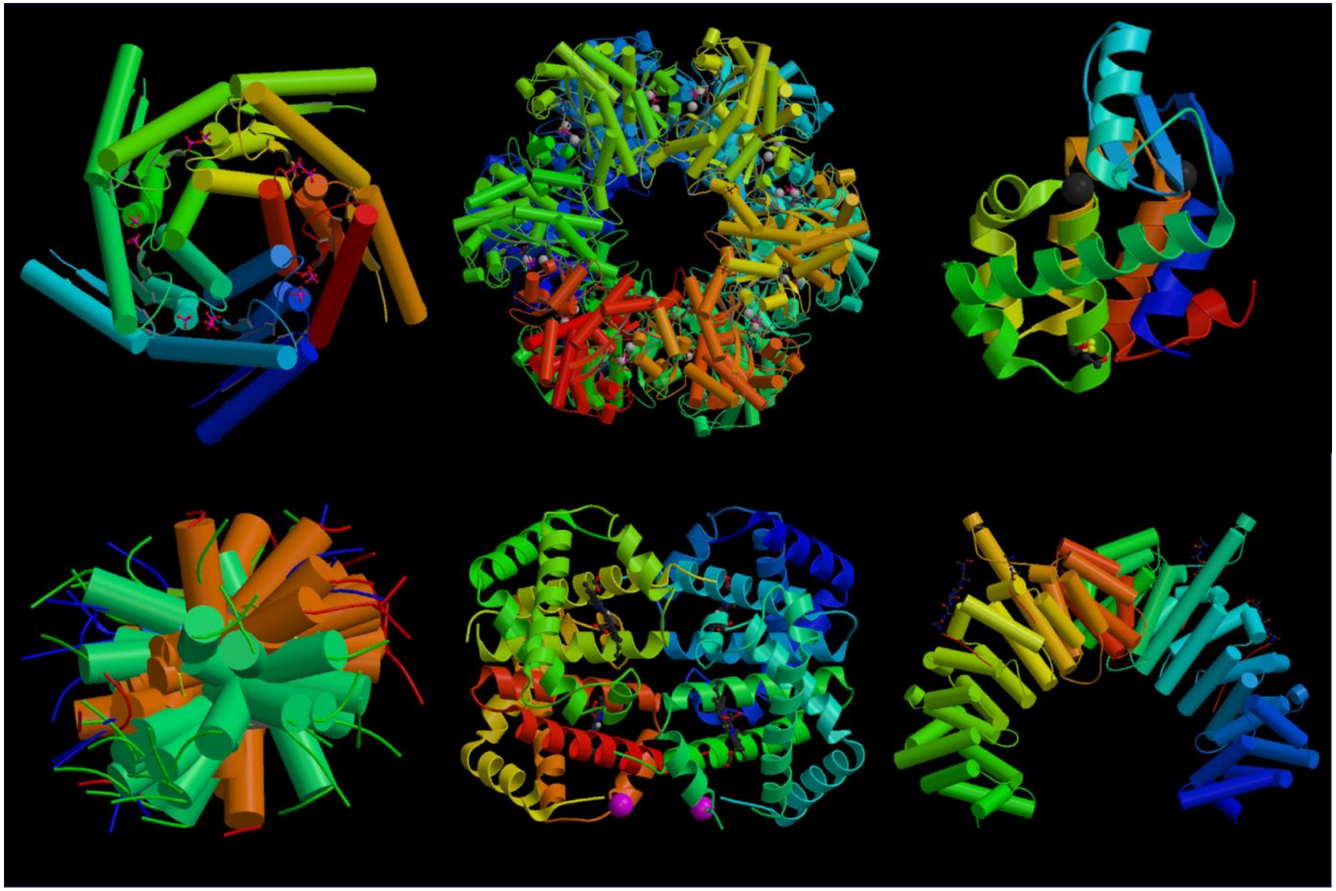


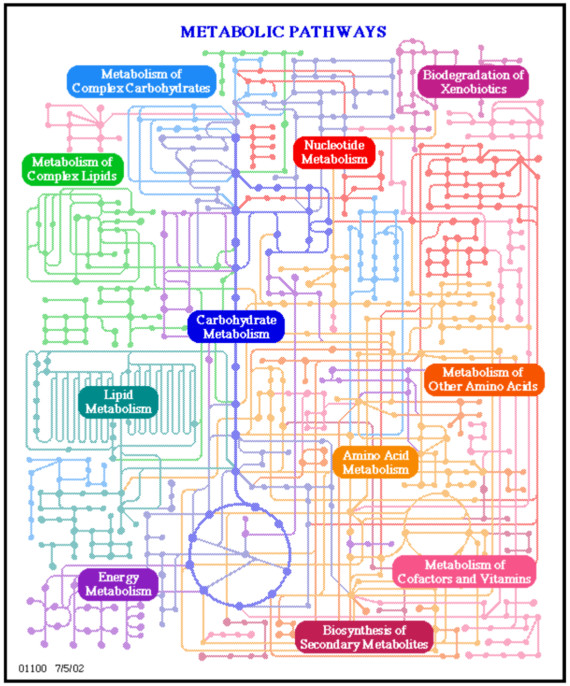
Figure 4-4 **Essential Cell Biology, 2/e. (© 2004 Garland Science)**

Protein Structure and Function

- The multiplicity of functions performed by proteins arises from the huge number of different shapes they adopt.
- **Structure dictates function !**



Principles of Metabolism
-Energy generation-



Energy Change in Exergonic und Endergonic Reactions

- **Change of free energy (ΔG Gibbs free energy (enthalpie)) indicates if a reaction runs spontaneous or not.**
- **$\Delta G^{0\prime}$:** standard conditions, pH 7, 25°C, all reaction compounds at 1M
- Reaction runs spontaneous, **$\Delta G<0$ (exergonic reaction)**
- Reaction can not run spontaneous **$\Delta G>0$ (endergonic reaction)**

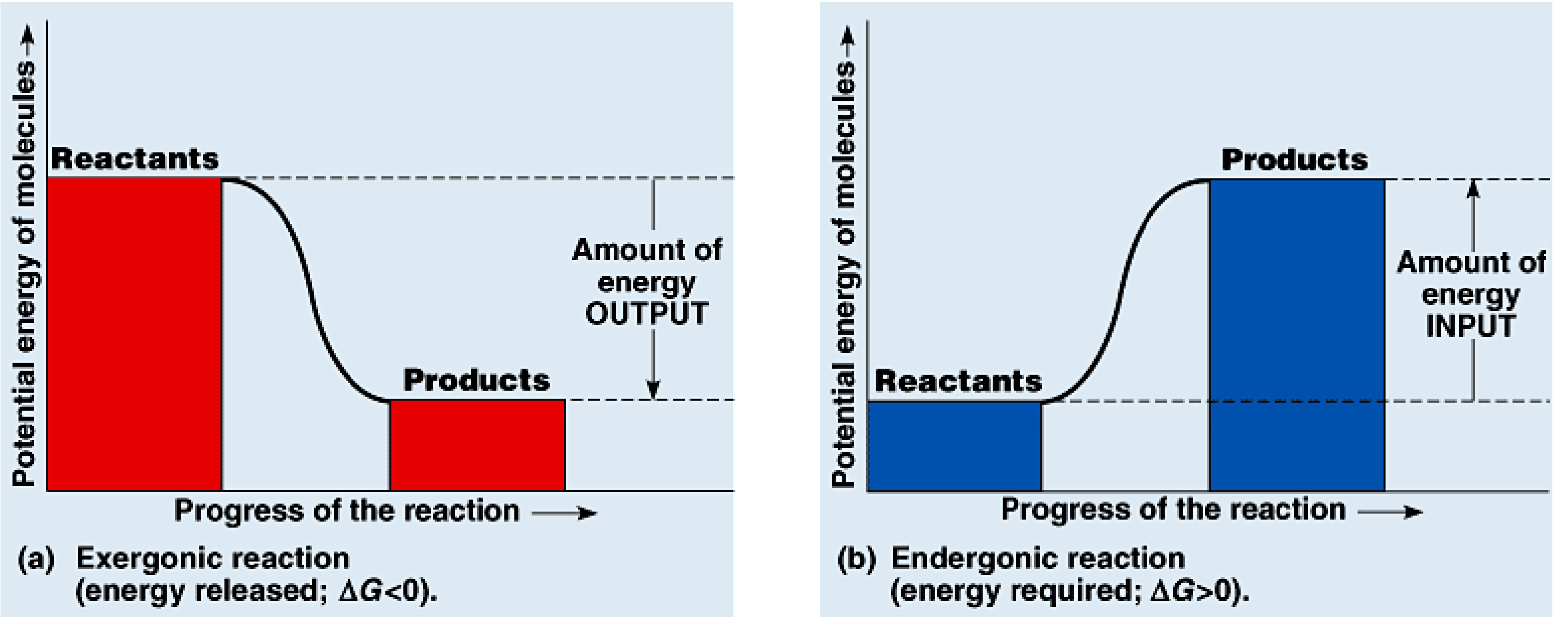


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Fig. 6.5 Biology (6th edition, Campbell & Reece)

Chemical Principles

Example Cellular Respiration

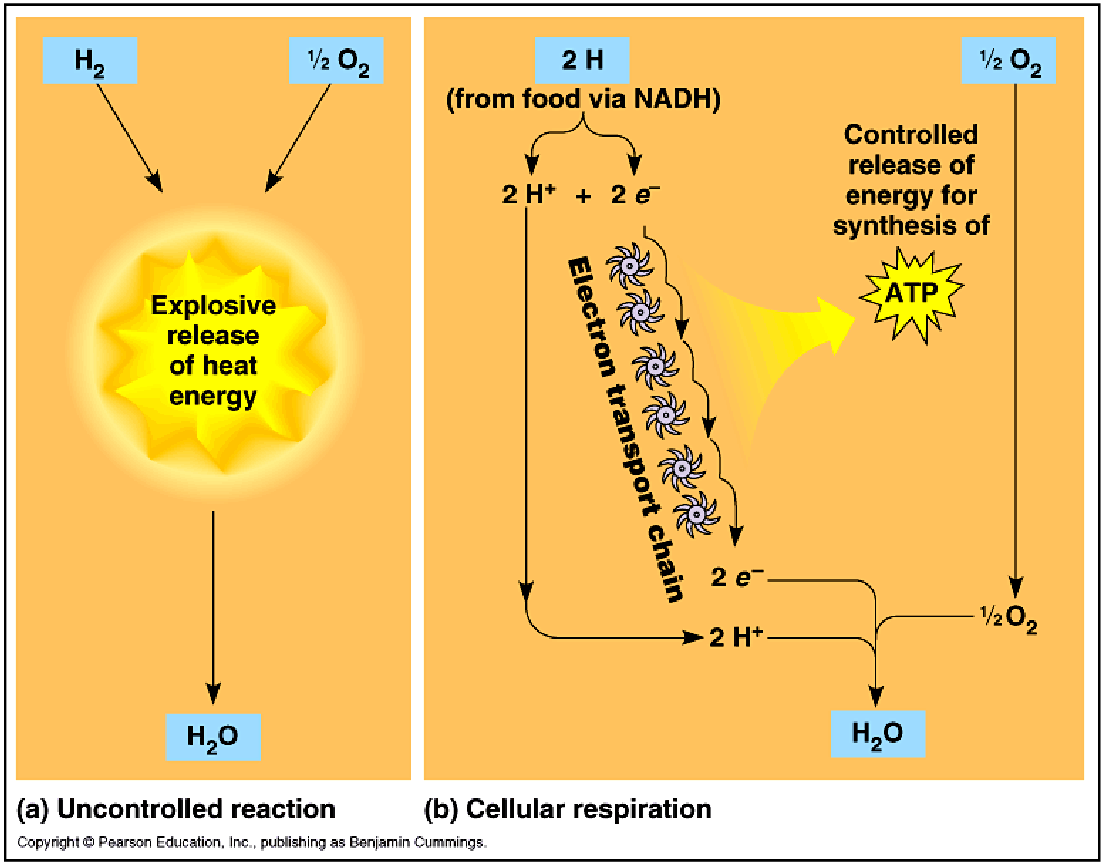

Fig. 9.5 Biology (6th edition, Campbell & Reece)

Electron Transfer in Metabolism

Oxidation-Reduction „Redox“-reactionen
Oxidation: donation/release of electrons
Reduktion: acception/uptake of electrons

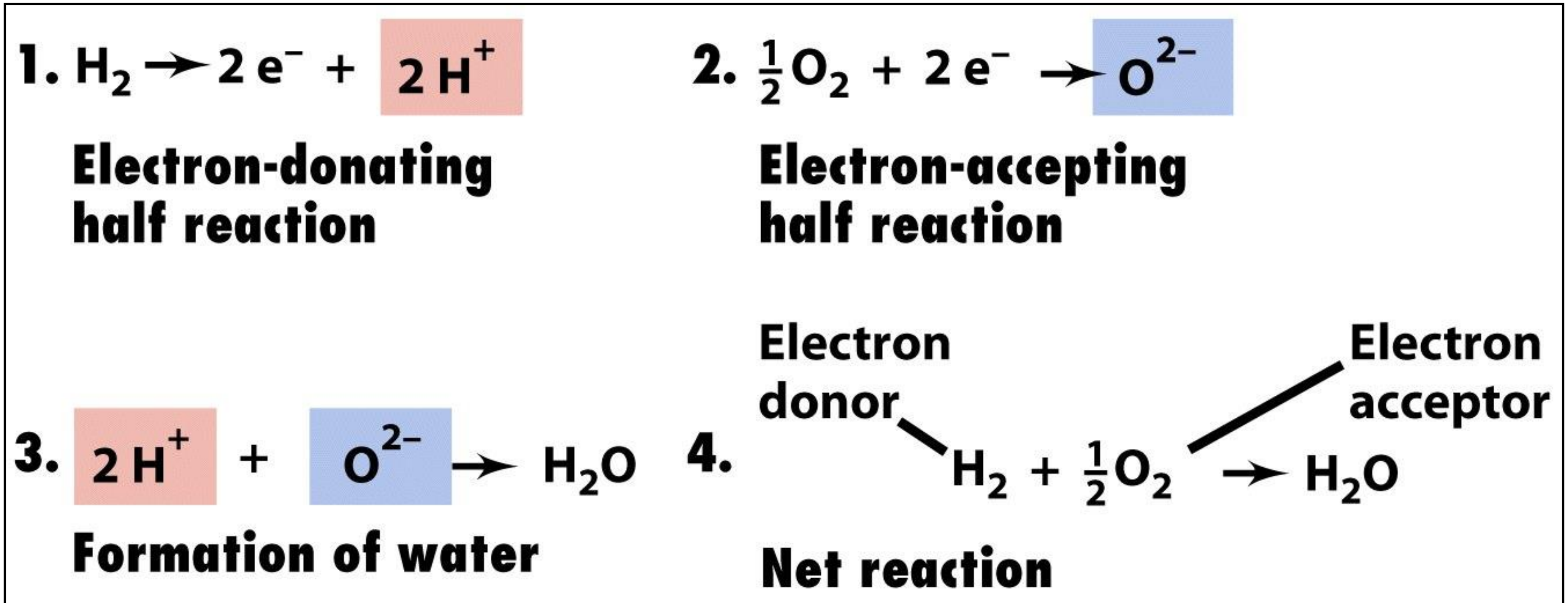

Figure 5-8 Brock Biology of Microorganisms 11/e
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Redoxreaktionen & Redoxpotential

$H_2 + ½\ O_2 \rightarrow H_2O$

$H_2 \rightarrow 2\ e^- + 2\ H^+$
Electron-donor

$½\ O_2 + 2\ e^- \rightarrow O^{2-}$
Electron-acceptor

Reduction (Redox) potential: Substrates vary in their tendency to be oxidized or reduced, wich is expressed as reduction potential (E_0') in volts (V). The free energy ($\Delta G^{0\prime}$) of the redox reaction is proportional to the difference of the reduction potential (E_0‘, standard conditions) of both half reactions.

$$\Delta G^{0\prime} = -n \cdot F \cdot \Delta E_0' = -n \cdot 96{,}5 \cdot \Delta E_0' \text{ (kJ/mol)}$$

n = number of transferred electrons
F = Faraday constant

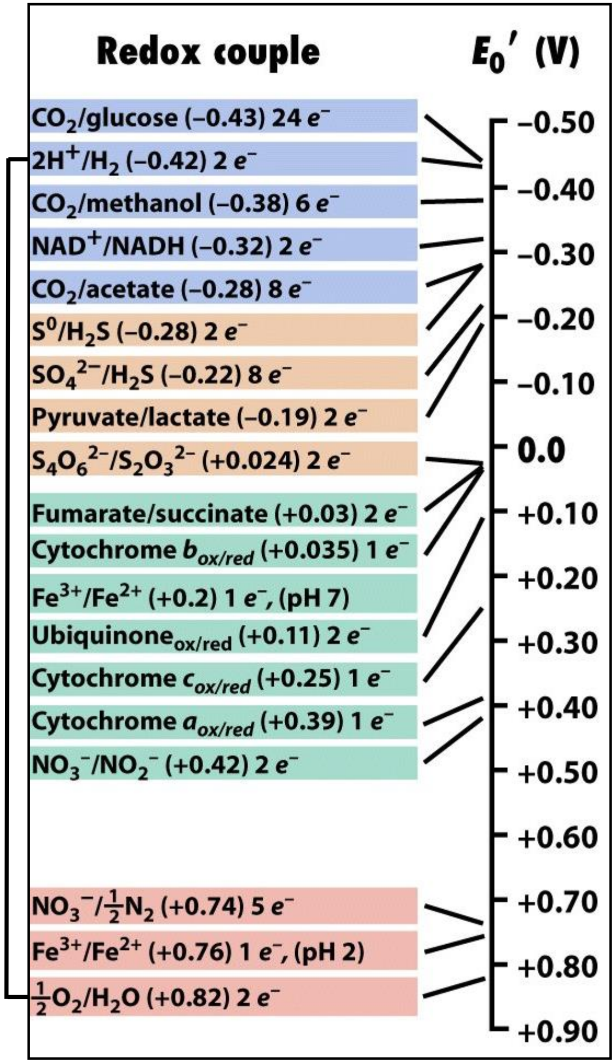

Fig. 5.8, 5.9 Brock Biology of Microorganisms (10th edition) (Madigan et al.)

The Electronen Tower

$\Delta G^{0'}$ of ATP synthesis or hydrolysis = 32 kJ/mol

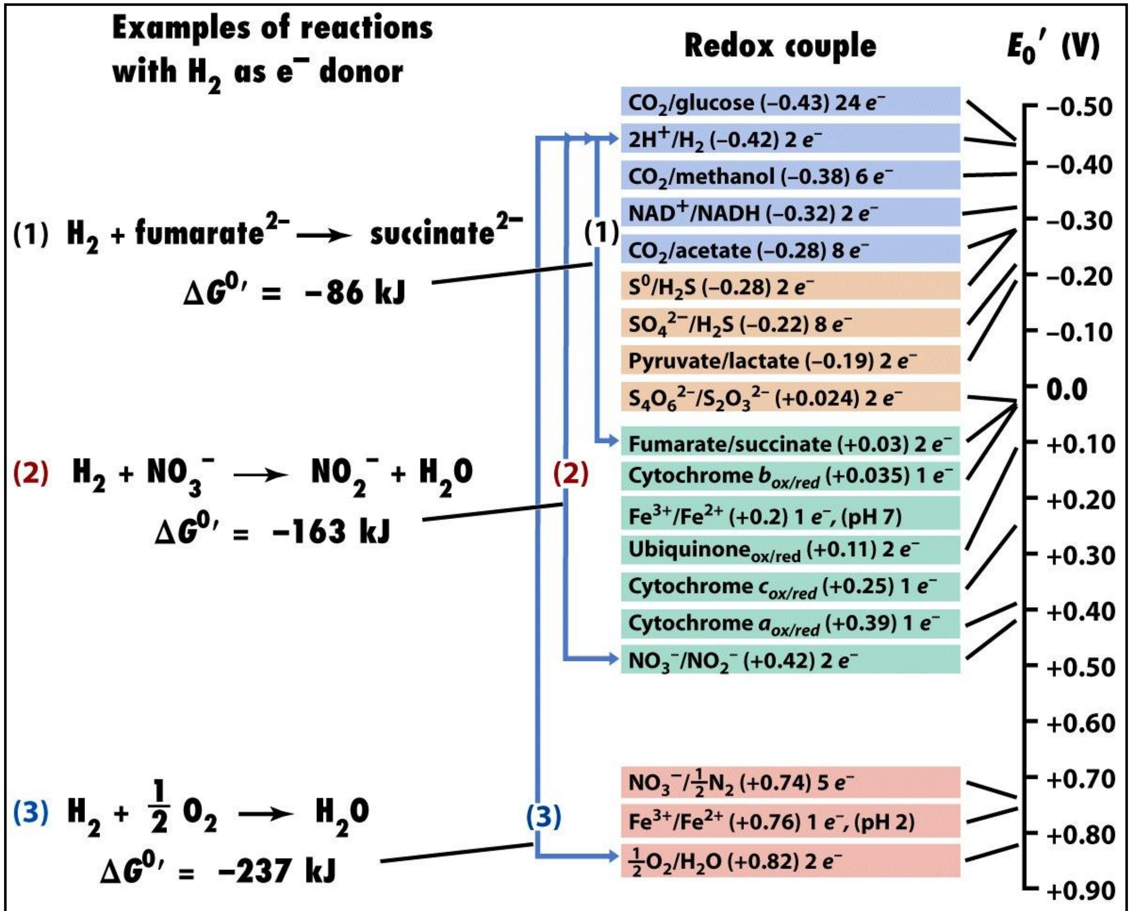

Figure 5-9 Brock Biology of Microorganisms 11/e
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Redoxpairs arranged from the strongest reductants (neg. reduction potential, at the top) to the strongest oxidants (positive reduction potential, at the bottom).

Electronen Carriers

Nicotinamide adenine dinucleotide ($NAD(P)^+$/$NAD(P)H + H^+$)
Free „carrier“ (coenzyme)

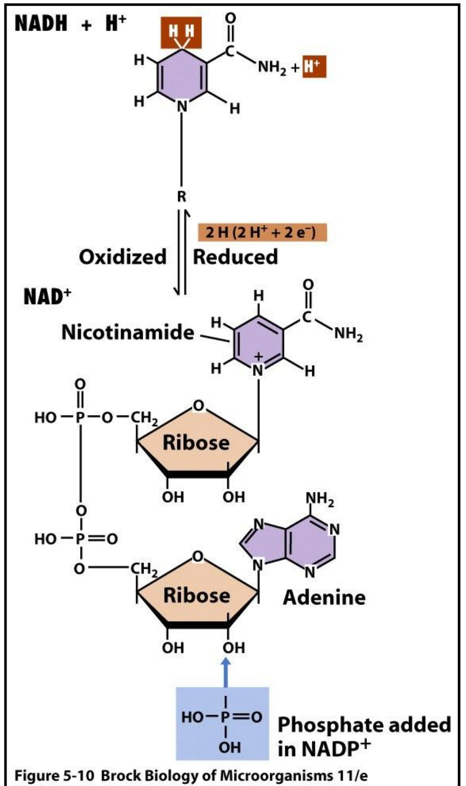

Figure 5-10 Brock Biology of Microorganisms 11/e
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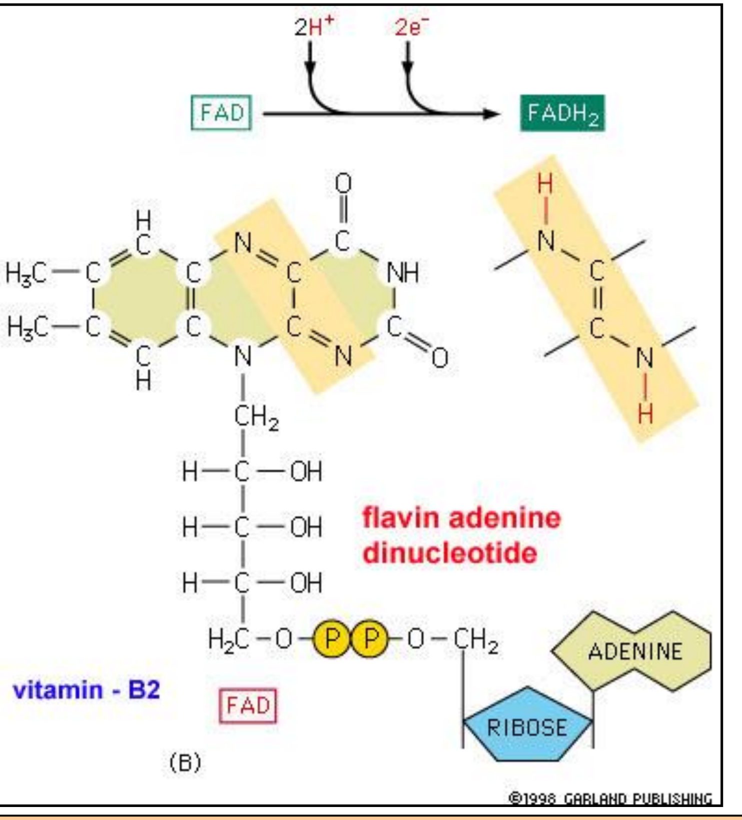
Flavin adenine dinucleotide (FAD) (FAD^+/$FADH_2$)
Bound „Carrier“ (prostethic group, e.g. succinate dehydrogenase)



<u>Glyceraldehyde-3-phosphate dehydrogenase</u>:
Glyceraldehyde-3-phosphate + NAD^+ + P_i ↔1,3-Diphosphoglycerate + NADH + H^+

Energy Currency of all Cells „ATP“

$\Delta G^{0'}$ of ATP synthesis or hydrolysis = 32 kJ/mol

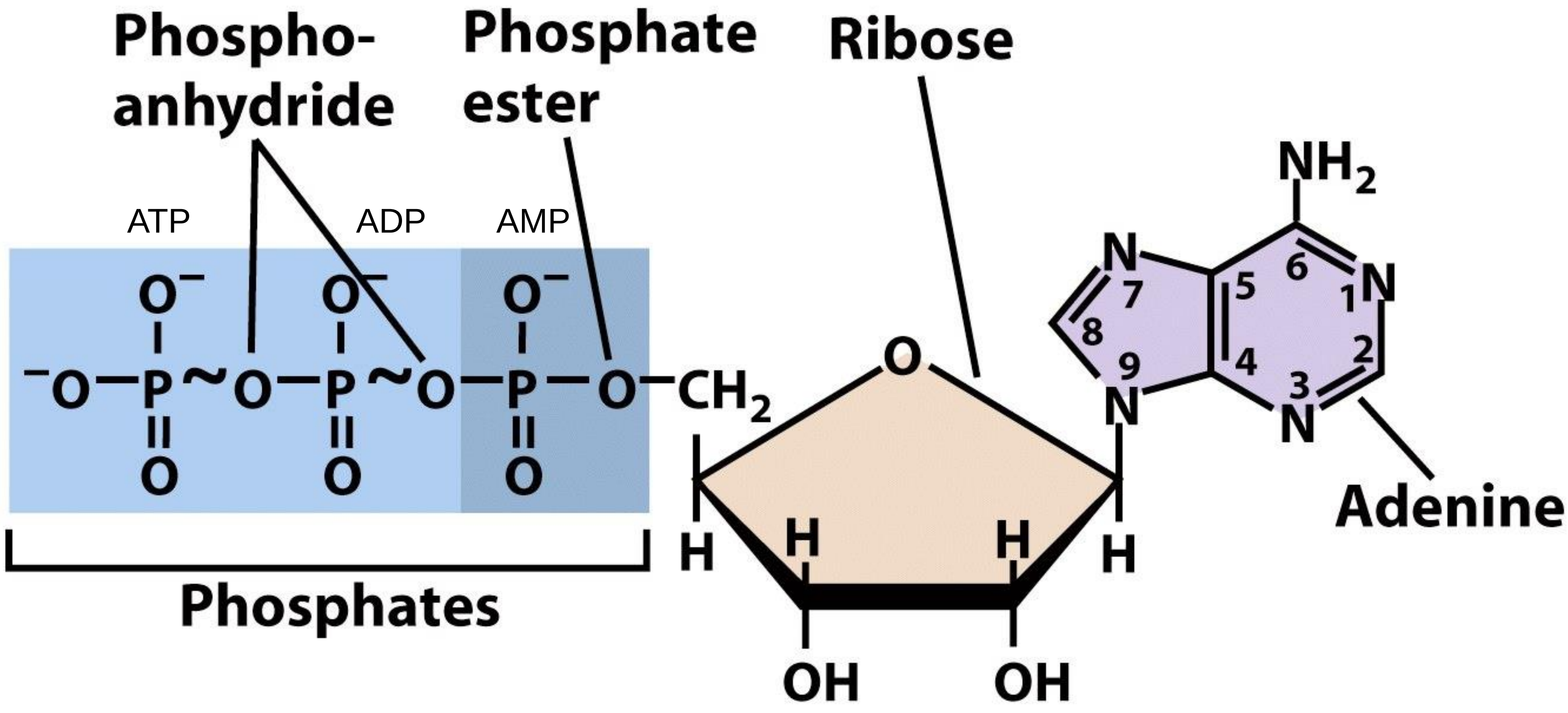


Figure 3-10 Brock Biology of Microorganisms 11/e
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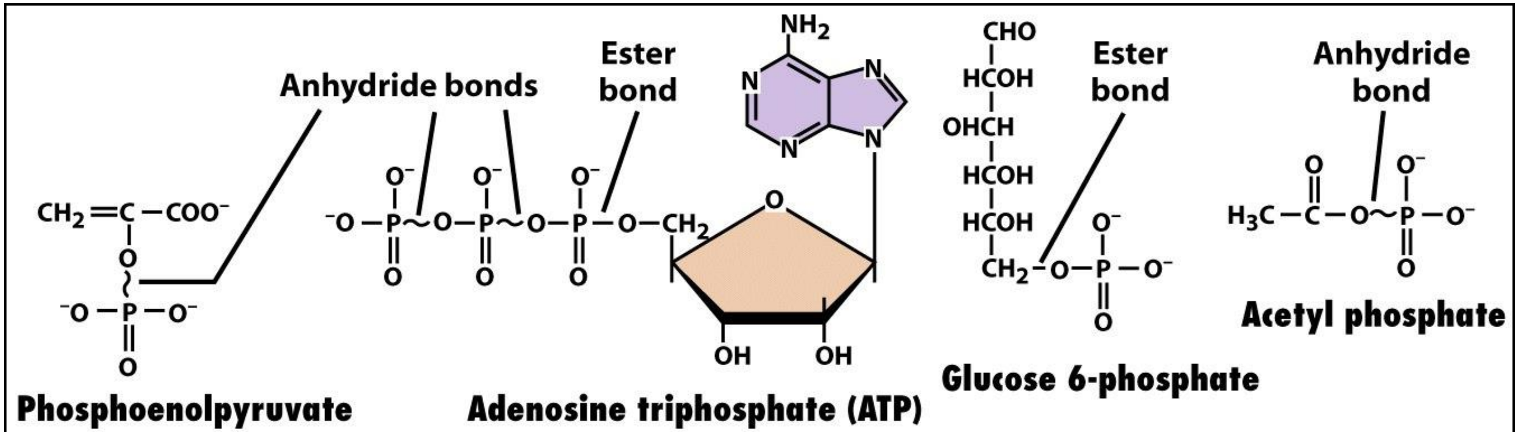
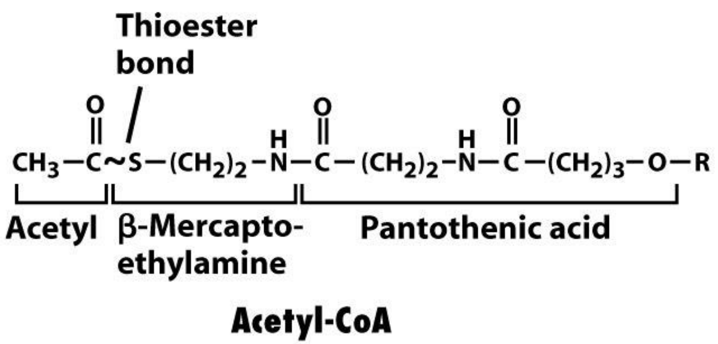
Energy-Rich Compounds





Compound	$G^{0\prime}$ kJ/mol
$\Delta G^{0\prime} > 30$kJ	
Phosphoenolpyruvate	−51.6
1,3-Bisphosphoglycerate	−52.0
Acetyl phosphate	−44.8
ATP	−31.8
ADP	−31.8
Acetyl CoA	−31
$\Delta G^{0\prime} < 30$kJ	
AMP	−14.2
Glucose 6-phosphate	−13.8

Figure 5-12 Brock Biology of Microorganisms 11/e

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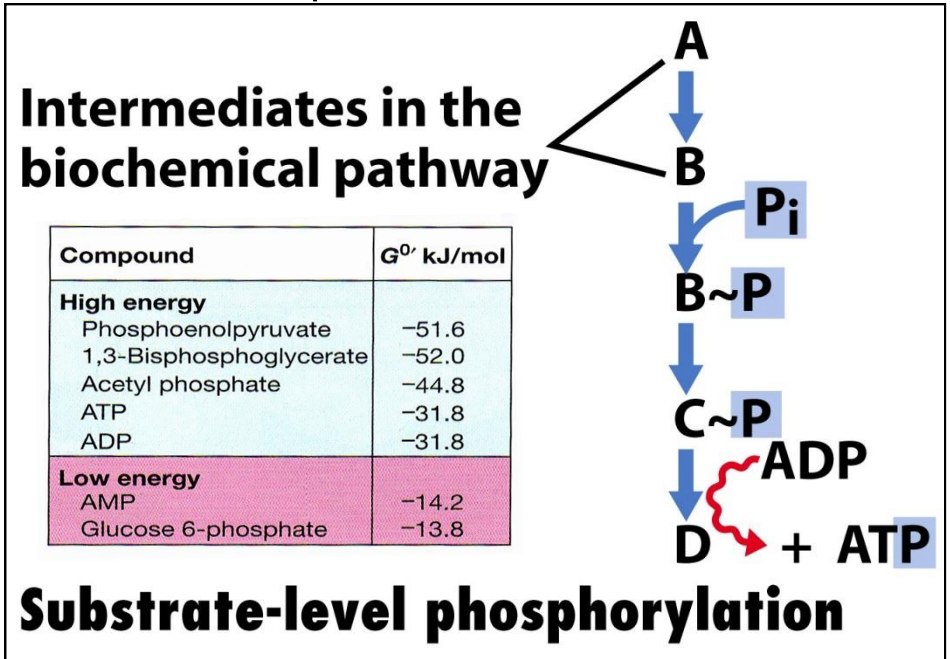
Basic Mechanisms of Energy Conservation

Substrate-level phosphorylation
Formation of energy-rich intermediates produces ATP

Elektron-transport phosphorylation
(Oxidative Phosphorylation)



Compound	$G^{0\prime}$ kJ/mol
High energy	
Phosphoenolpyruvate	−51.6
1,3-Bisphosphoglycerate	−52.0
Acetyl phosphate	−44.8
ATP	−31.8
ADP	−31.8
Low energy	
AMP	−14.2
Glucose 6-phosphate	−13.8

Figure 5-13a Brock Biology of Microorganisms 11/e
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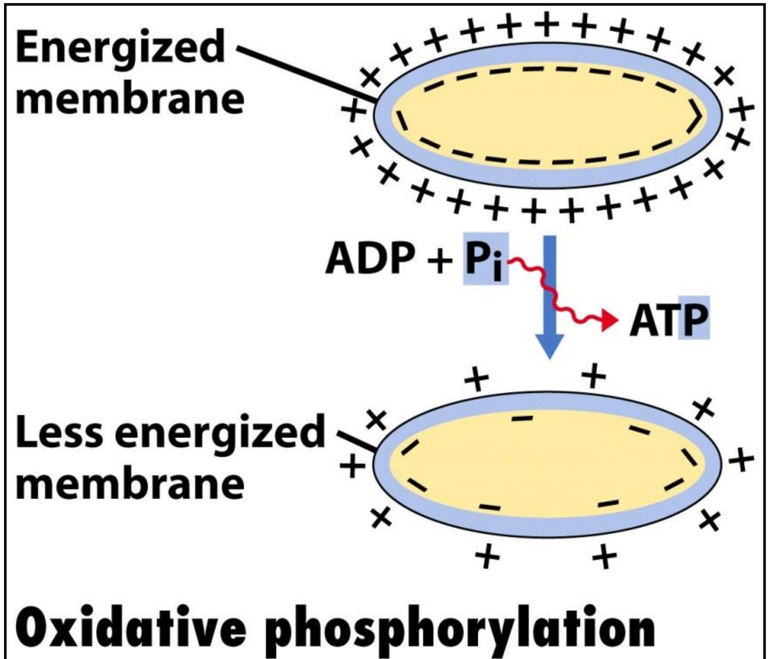

Figure 5-13b Brock Biology of Microorganisms 11/e
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Fig. 5.13 Brock Biology of Microorganisms (11th edition) (Madigan et al.)

EMP-Weg (Glycolysis)

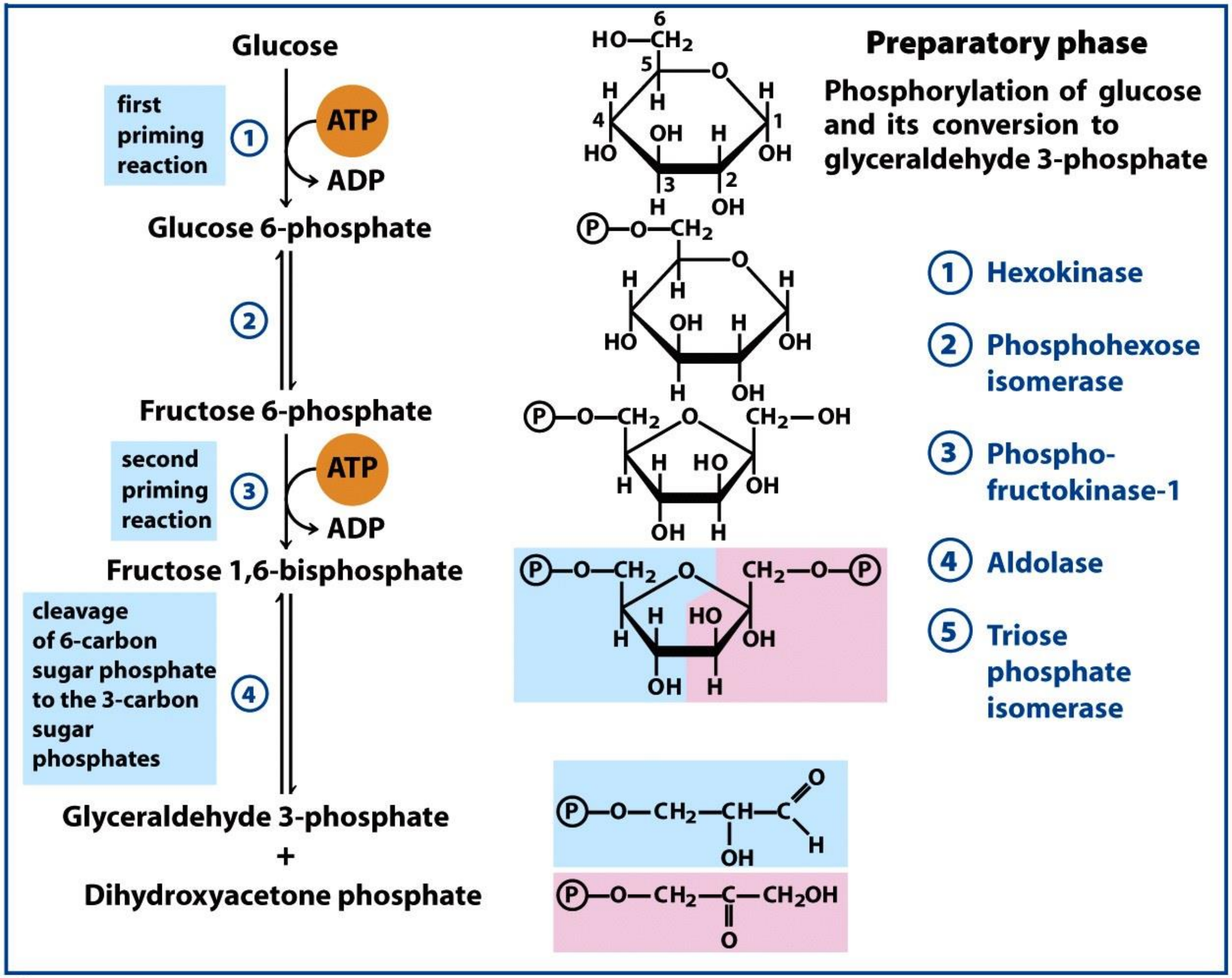

Figure 14-2a
Lehninger Principles of Biochemistry, Fifth Edition
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EMP-Weg (Glycolysis)

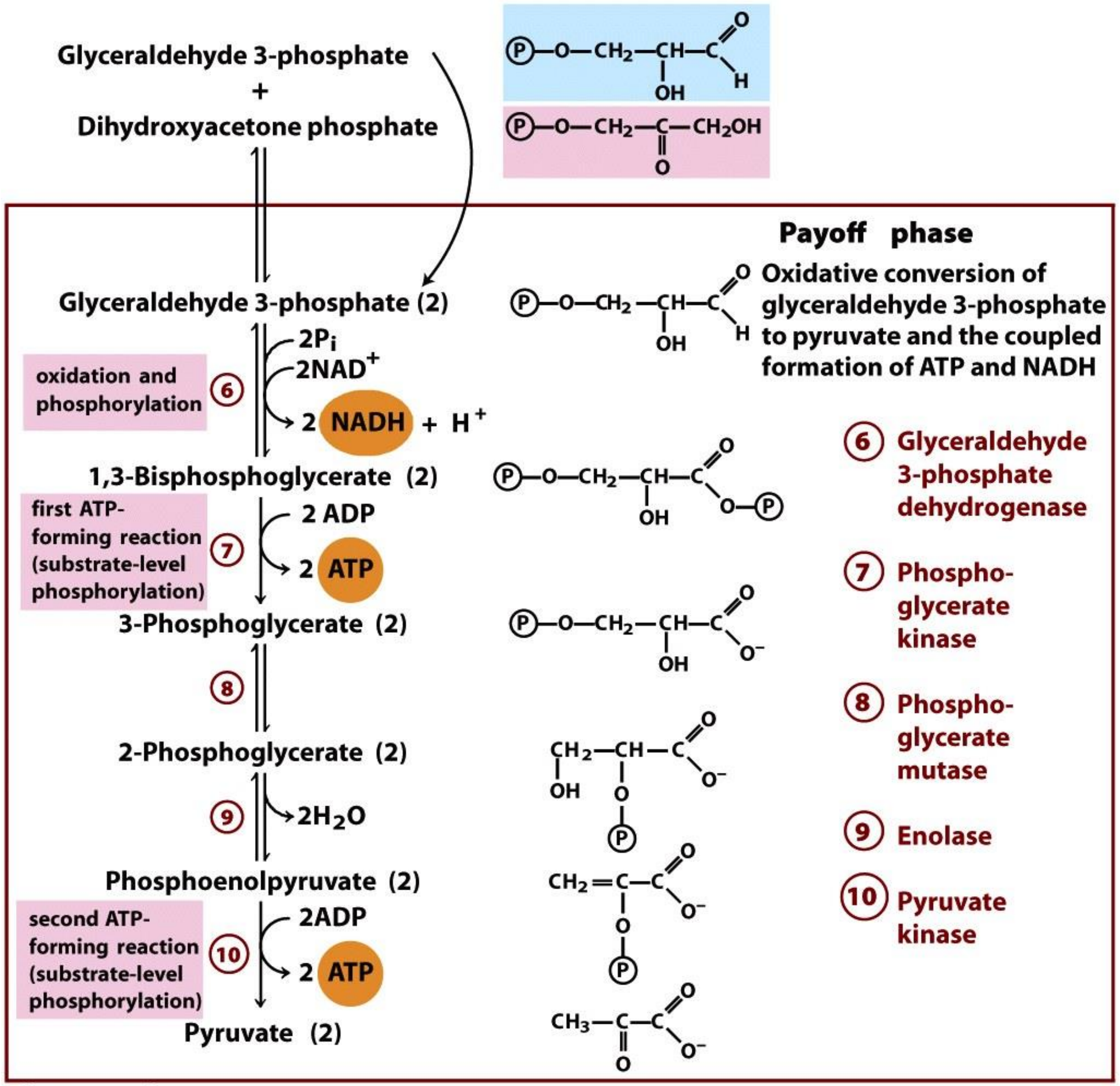

Figure 14-2b

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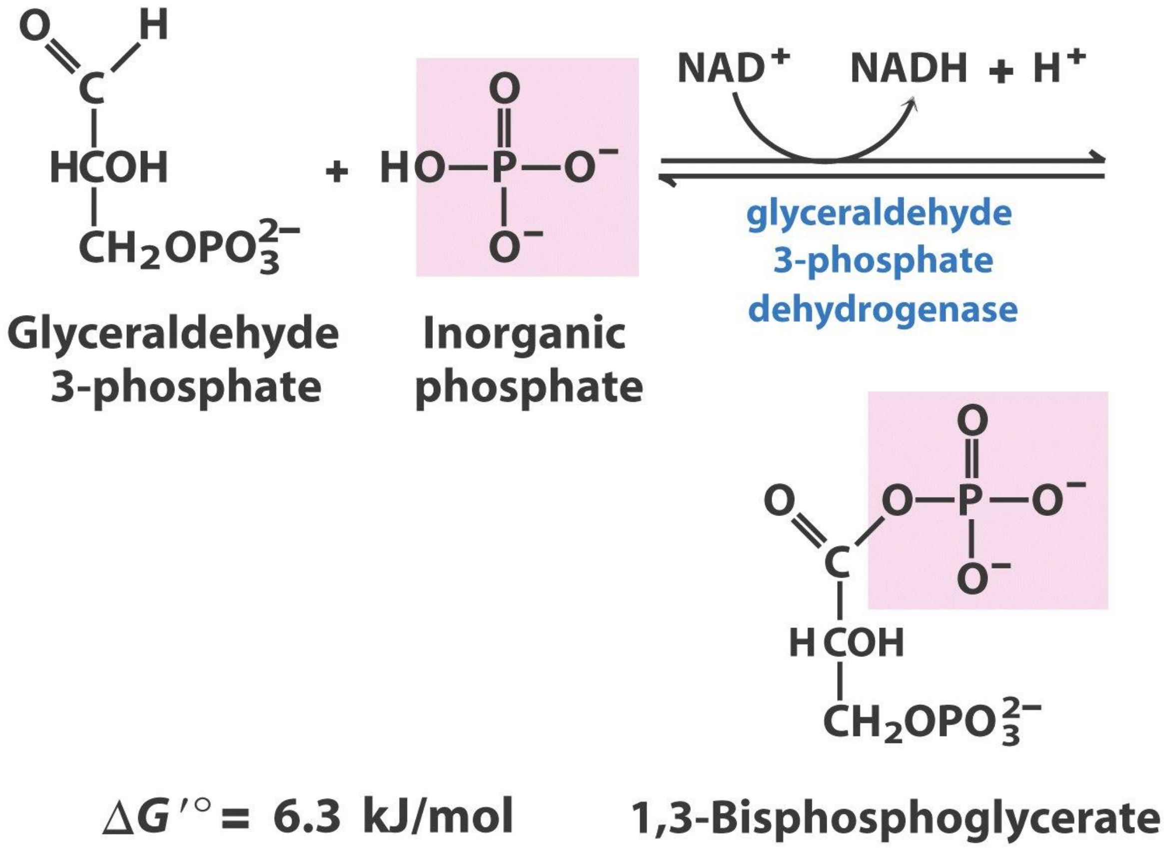
Glyceraldehyde-3-phosphate dehydrogenase

- Which compound is oxidized/reduced?



Energetics of Glycolysis

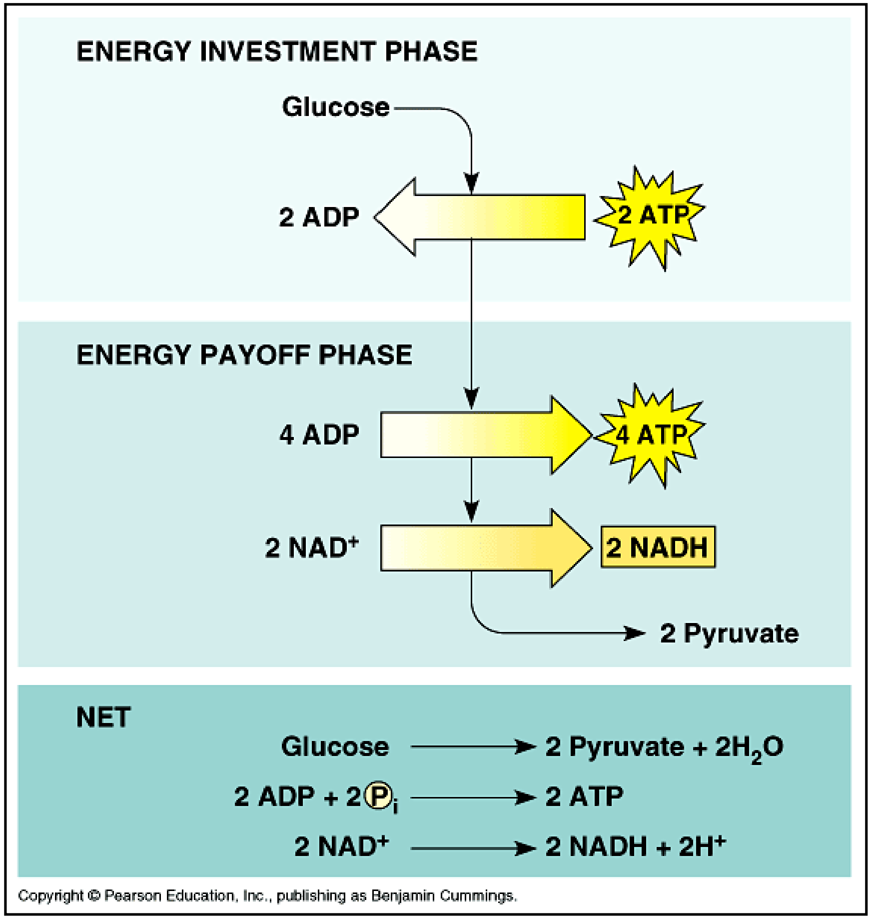


Fig. 9.8 **Die Glycolyse im Überblick.**
Biology (6th edition, Campbell & Reece)

Pyruvat Dehydrogenase and Citric Acid Cycle

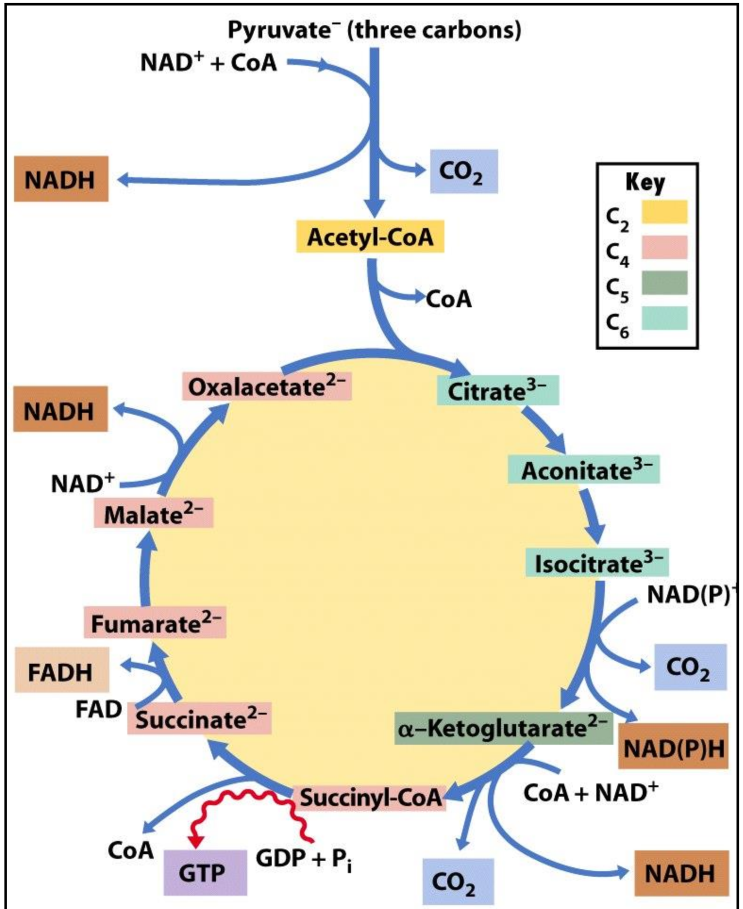


Figure 5-22a Brock Biology of Microorganisms 11/e

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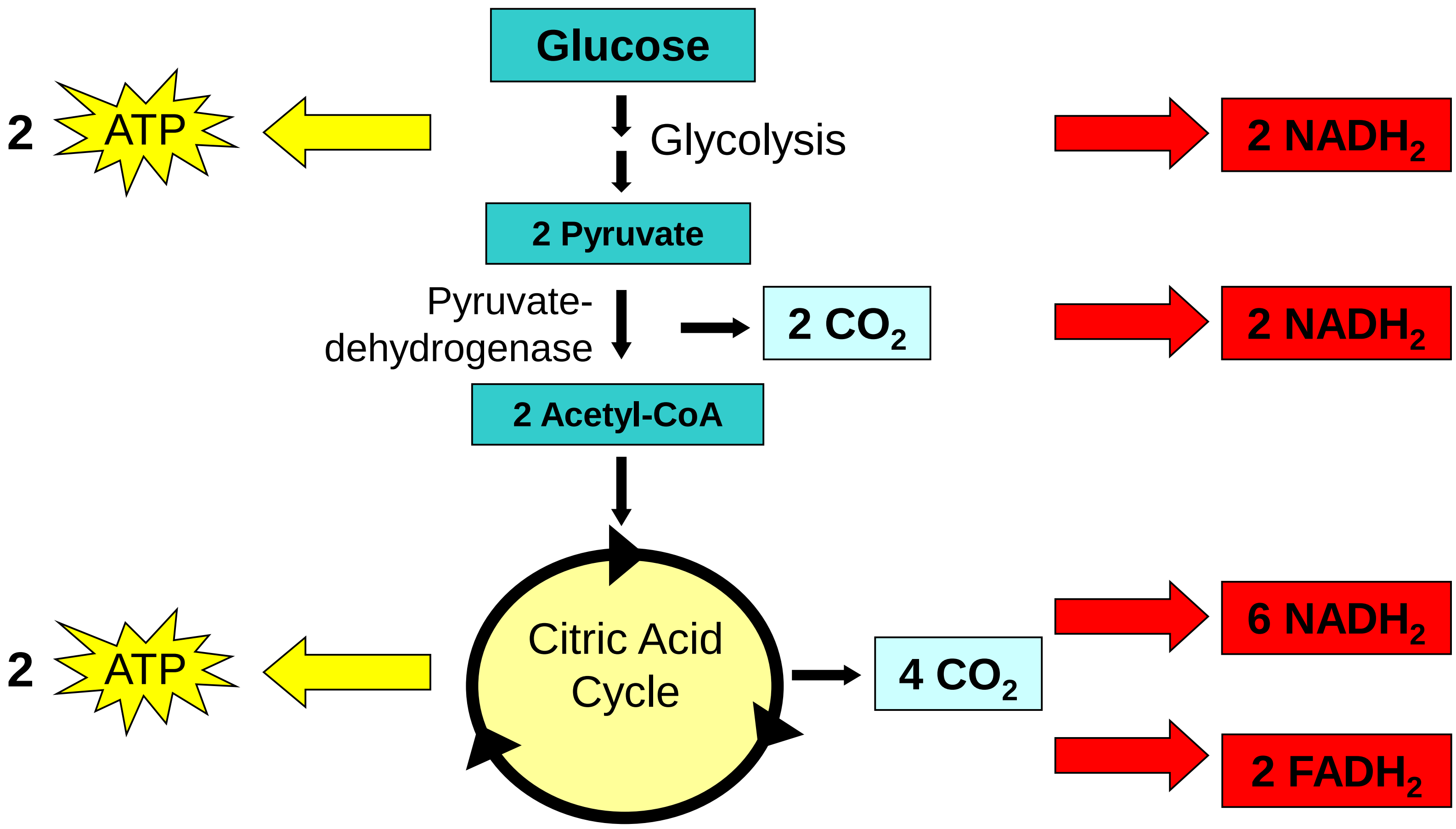
Energetics of Carbohydrate Metabolism



$$C_6H_{12}O_6 + 6\ H_2O + 4\ ADP + 4\ P_i \rightarrow 6\ CO_2 + 24\ [H] + 4\ ATP$$

Electron Transport Chain

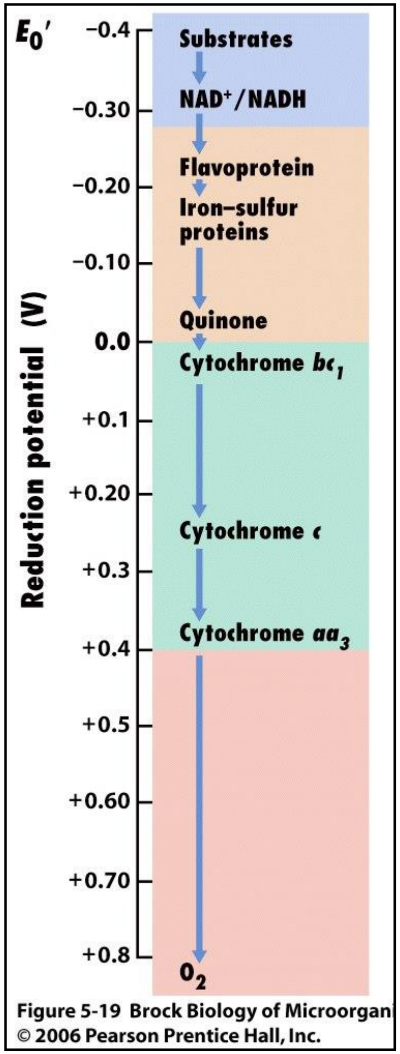


Fig. 5.19 Brock Biology of Microorganisms (10th edition) (Madigan et al.)

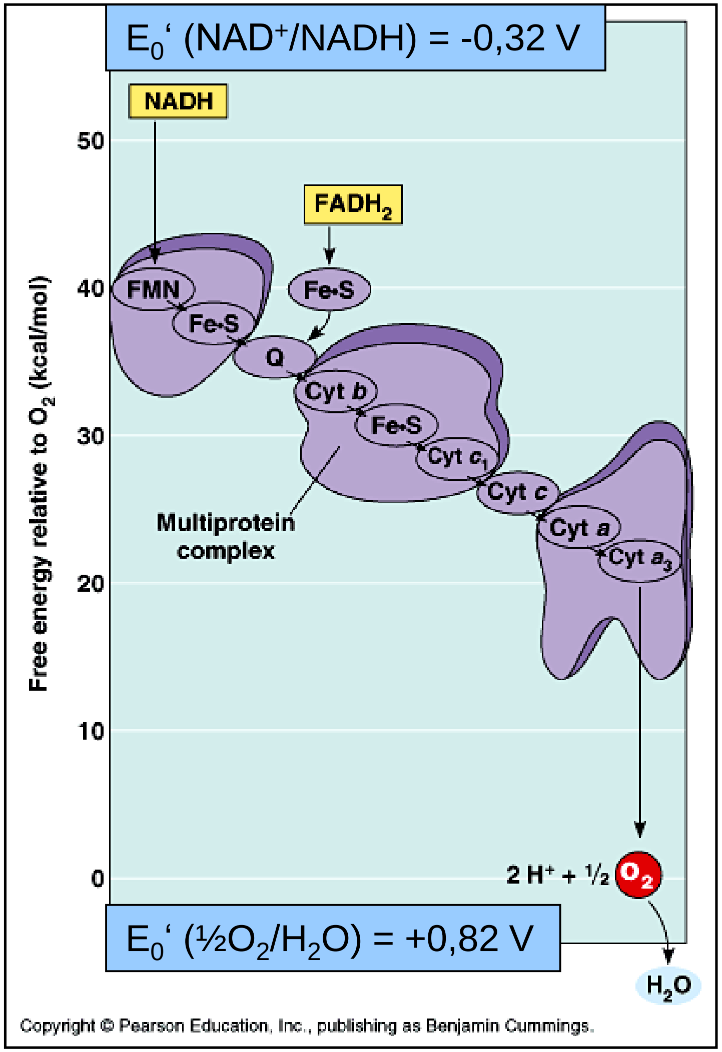


Fig. 9.13 Biology (6th edition, Campbell & Reece)

- The mitochondrial or bacterial electron transport chain (ETC) = a series of e^- carriers, operating together to transfer e^- from NADH and $FADH_2$ to a terminal e^- acceptor, O_2
- E^- flow from carriers with more negative reduction potentials (E_0) to carriers with more positive E_0

Elektron Transport Chain

- In eukaryotes the e$^-$ transport chain carriers are in the inner mitochondrial membrane, connected by coenzyme Q and cytochrome c
- E$^-$ transfer accompanied by proton movement across inner mitochondrial membrane (**proton pumps**)

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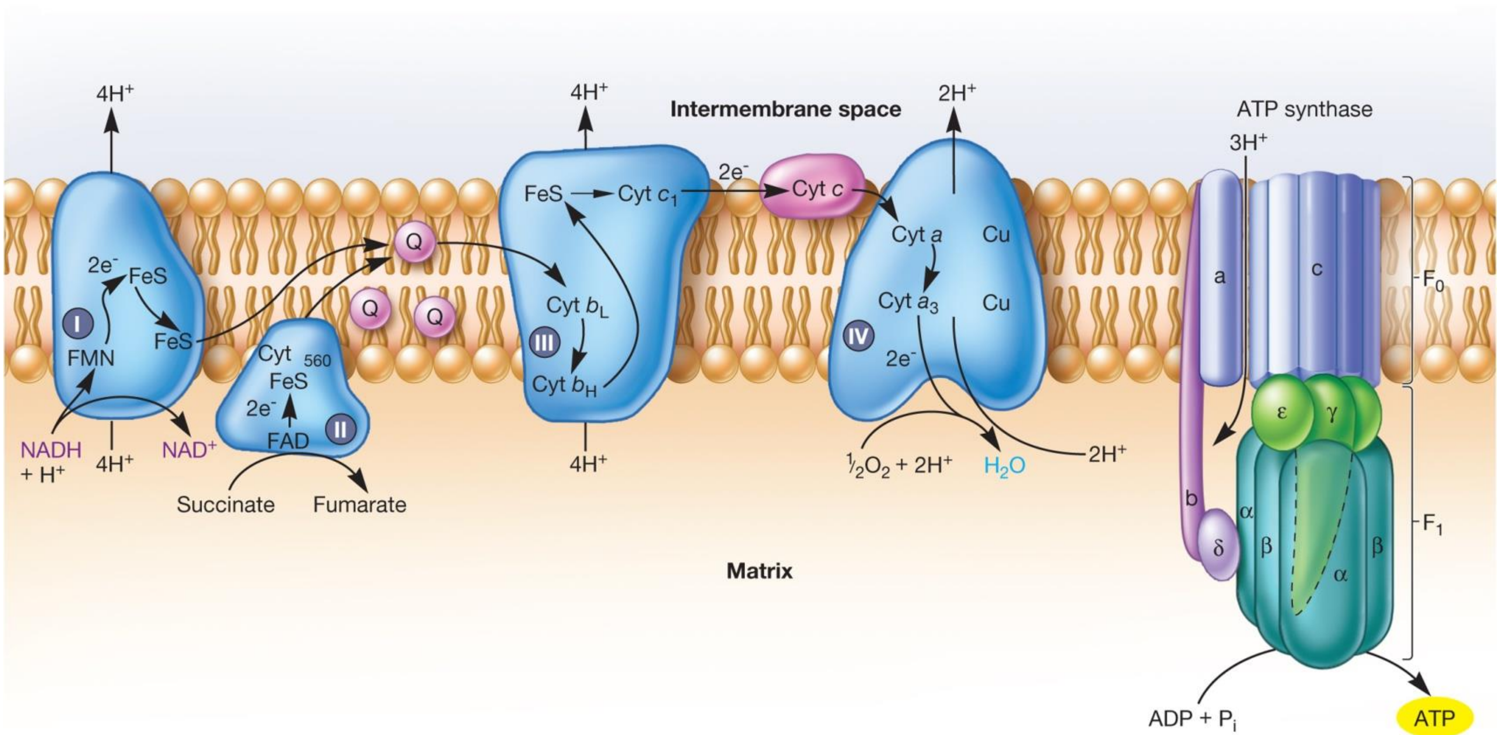

Chemiosmotic Model

- In this simple representation of the chemiosmotic theory applied to mitochondria, electrons from NADH and other oxidizable substrates pass through a chain of carriers arranged asymmetrically in the inner membrane.
- Electron flow is accompanied by proton transfer across the membrane, producing both a chemical gradient (ΔpH) and an electrical gradient (Δψ).
- The inner mitochondrial membrane is impermeable to protons; protons can reenter the matrix only through proton-specific channels (F_o). The **proton-motive force (PMF)** that drives protons back into the matrix provides the energy for ATP synthesis, catalyzed by the F_1 complex associated with F

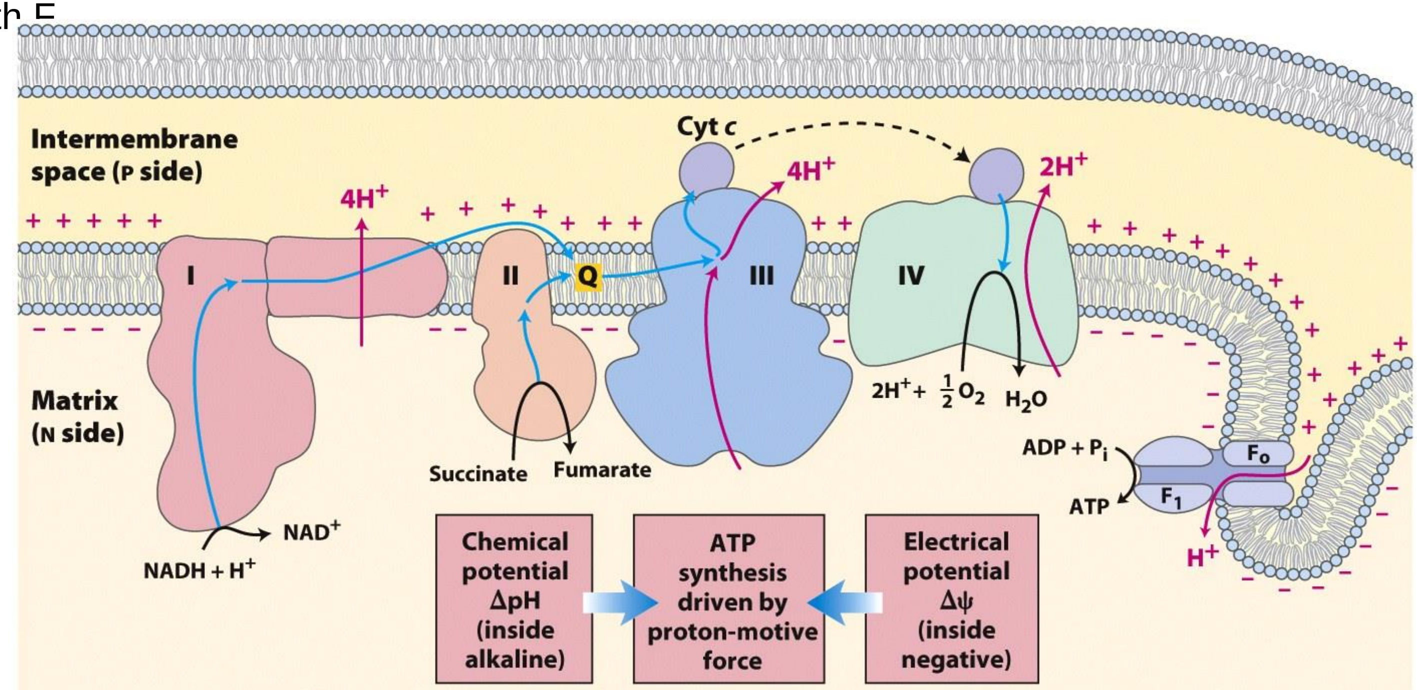

Figure 19-19
Lehninger Principles of Biochemistry, Fifth Edition
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ATP-Synthase/ATPase

-reversibel

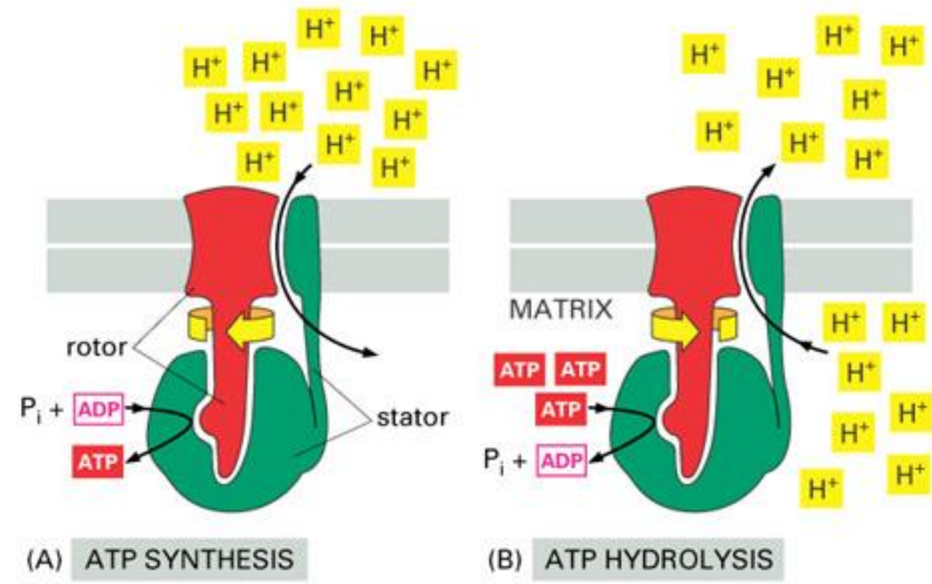
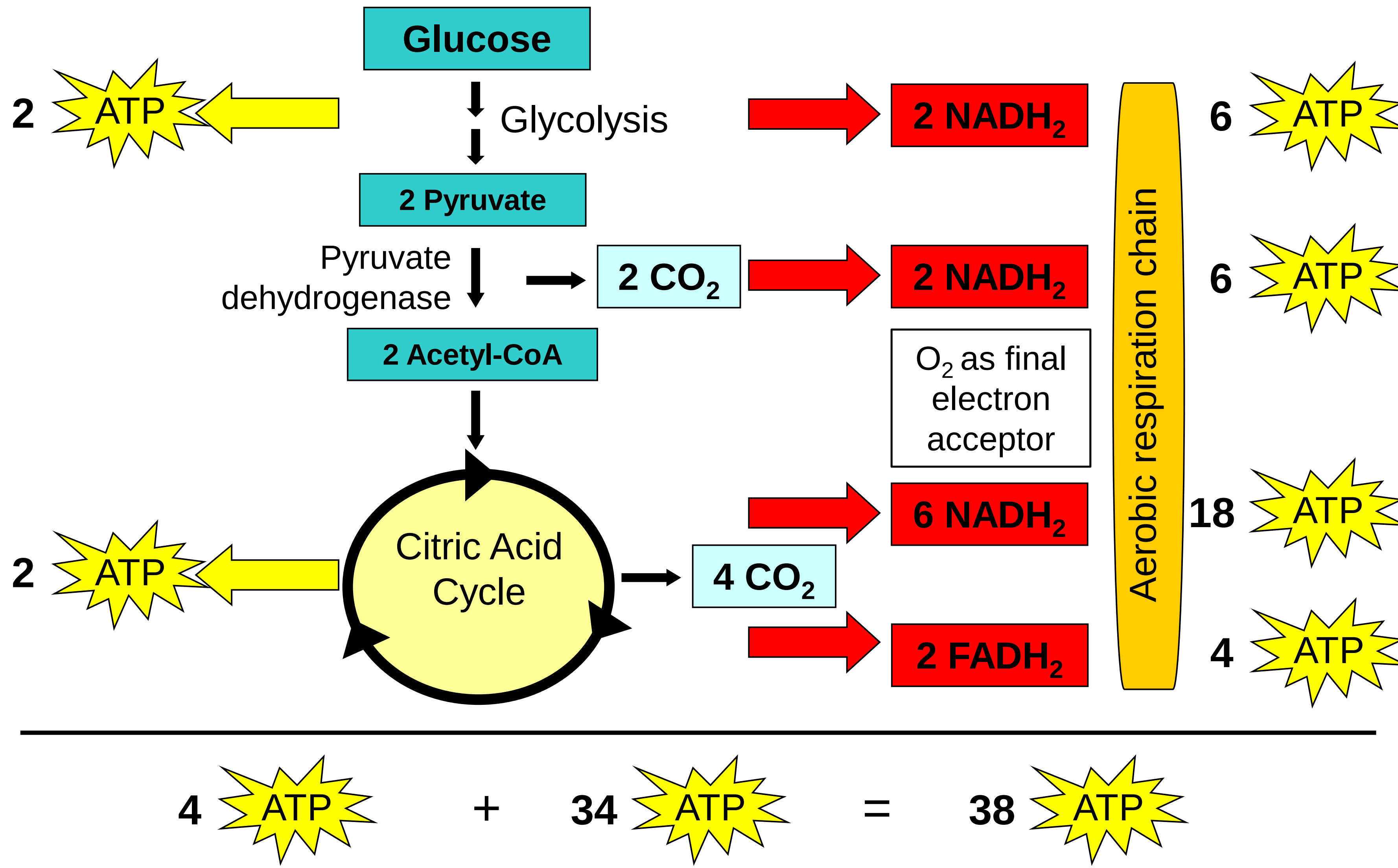


Figure 14-15 Essential Cell Biology, 2/e. (© 2004 Garland Science)

Fig. 14.15 Essential Cell Biology (2nd edition, Alberts, Bray et al.)

Energetics of Carbohydrate Metabolism (Aerobic Respiration)



Chemical Principles

Example Cellular Respiration

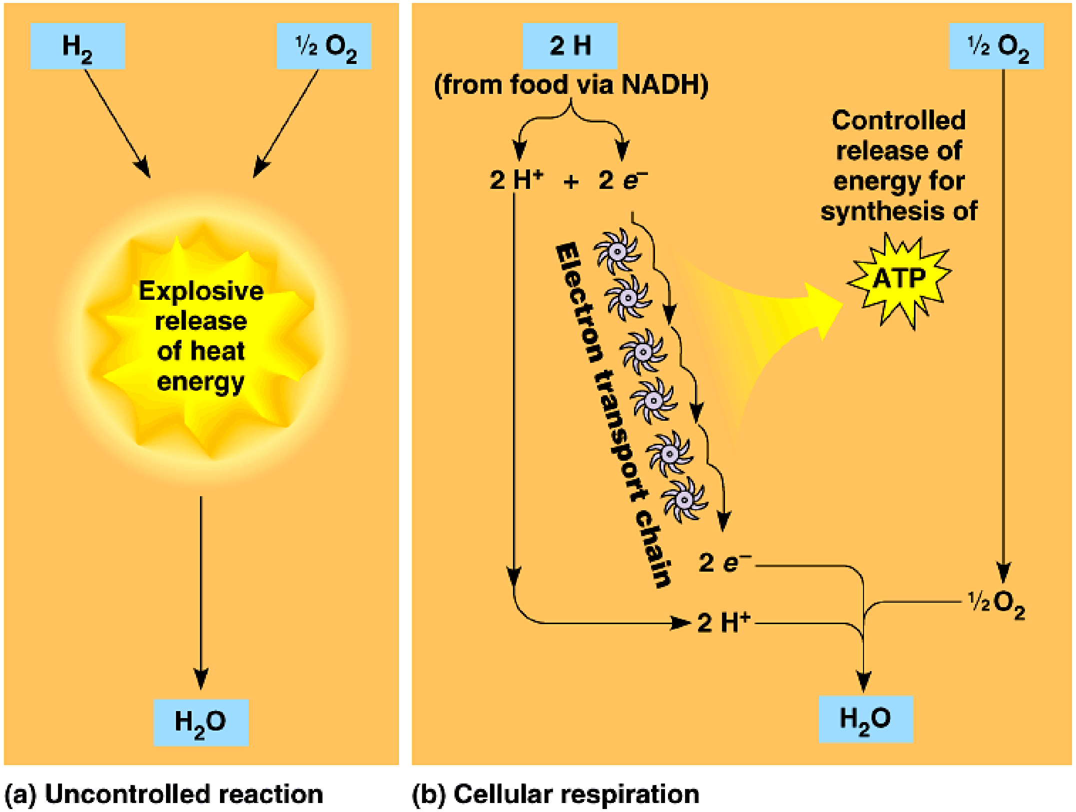


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Fig. 9.5 Biology (6th edition, Campbell & Reece)

PMF Energized Membrane

Proton-motive force (PMF)

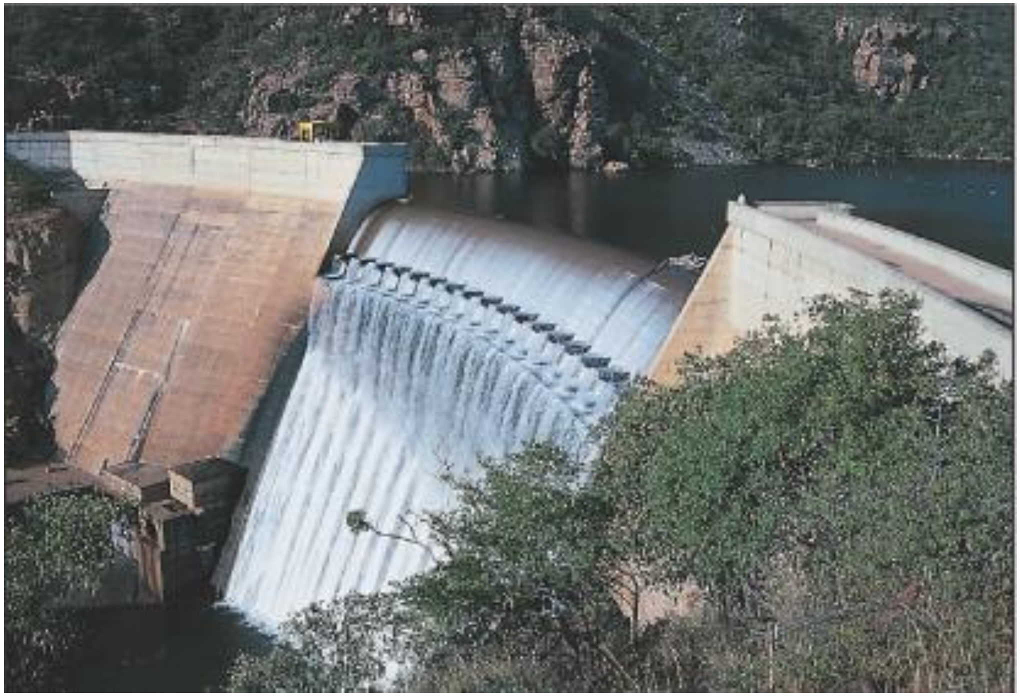


Figure 12-11 Essential Cell Biology, 2/e. (© 2004 Garland Science)

Fermentation

Atmung/Fermentation

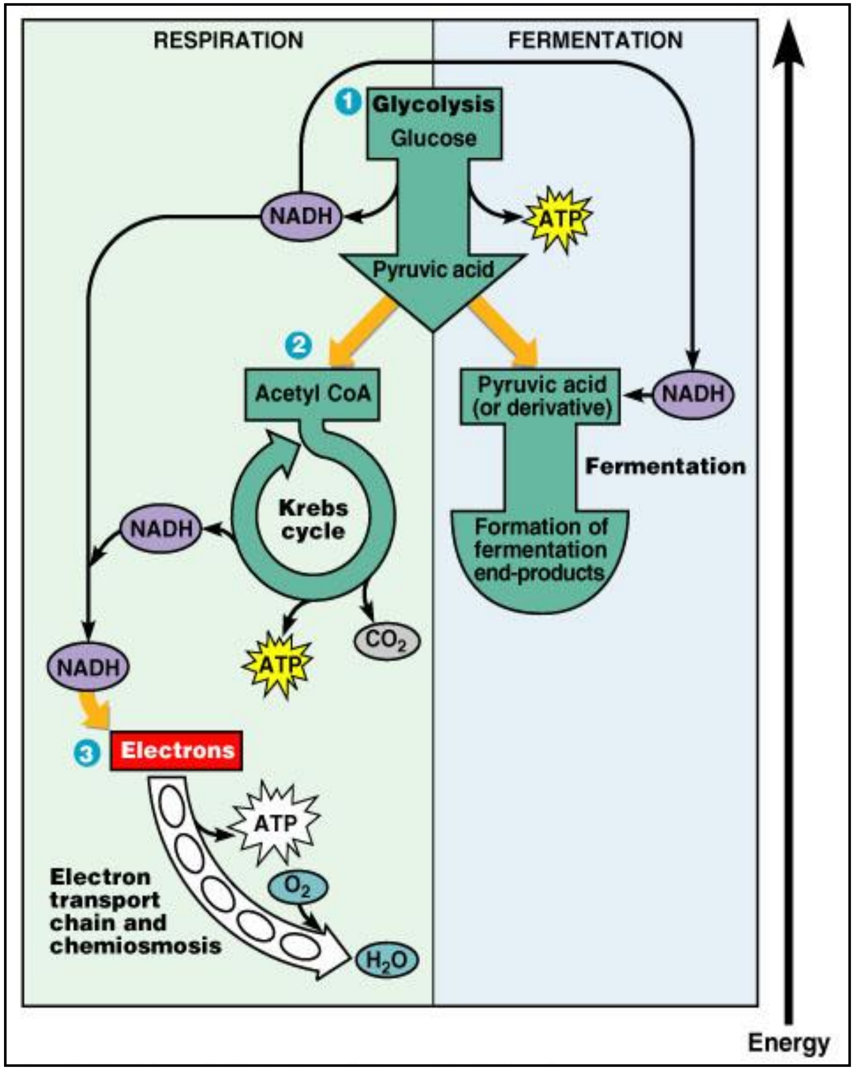
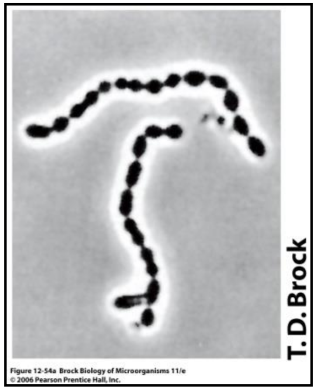
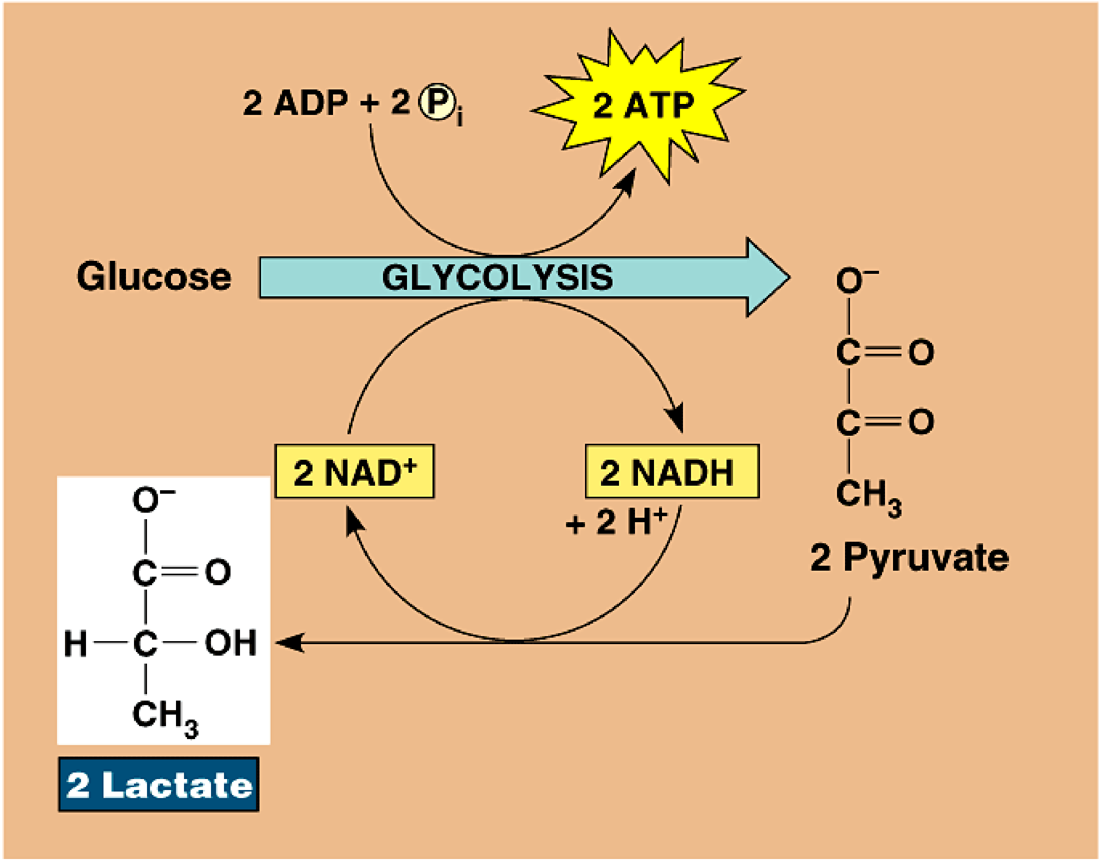


Fig. 5.14 Microbiology: An Introduction (Tortora, Funke, Case)

Lacitc Acid Fermentation



Lactococcus lactis



(b) Lactic acid fermentation

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