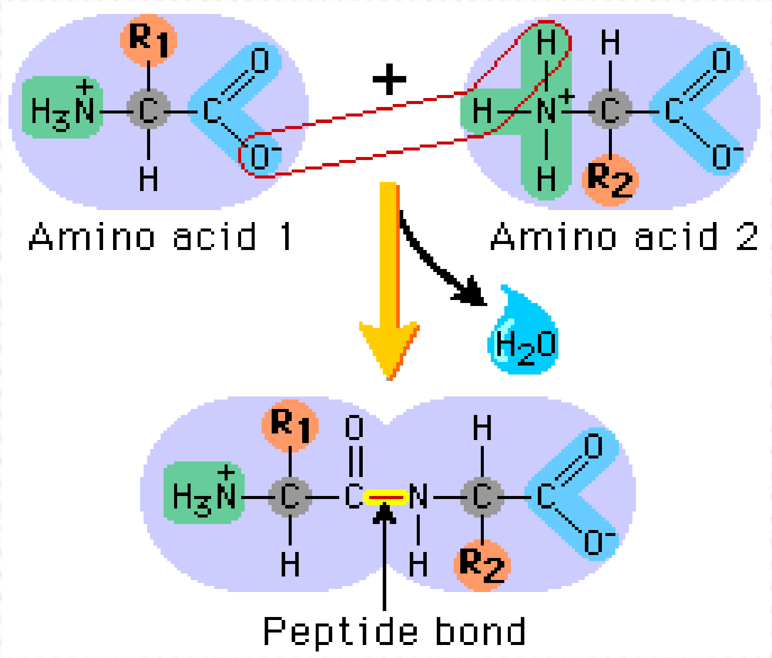
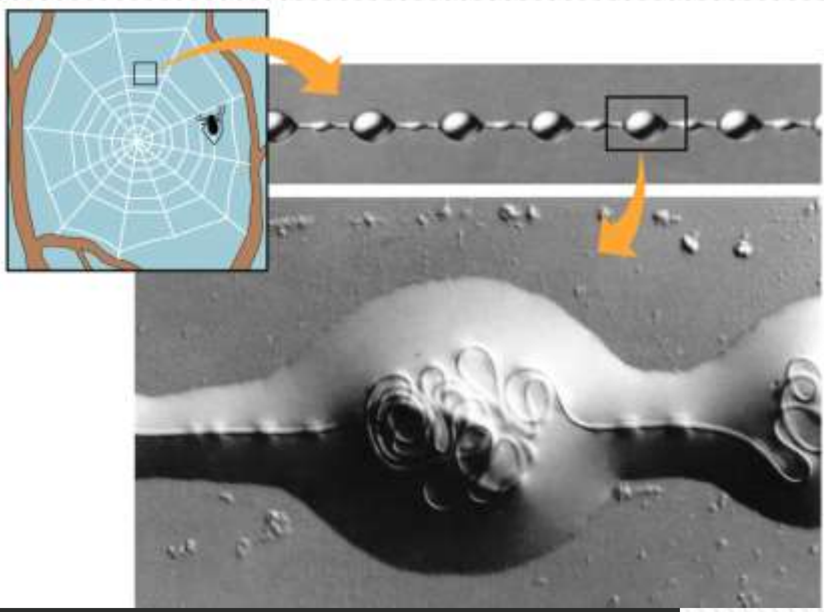




BIOLOGICAL MOLECULES

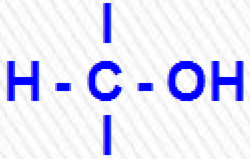
MACROMOLECULES

What is a Macromolecule?

- Organic molecules that weigh more than 100,000 daltons are referred to as macromolecules.
- These macromolecules are constructed of smaller units called polymers. These polymers are subdivided into their basic units called monomers.

CARBOHYDRATES

- Carbo = carbon, hydrate = water;
- Molecular formula $(CH_2O)_n$

$(CH_2O)_n$ or 

- Sugars and associated polymers.
- Monomer is the monosaccharide
- Polymers include starch and cellulose.
- Synthesized by plants using sunlight to convert CO_2 and H_2O to glucose and O_2.

<u>Functions:</u>

- Store energy in chemical bonds
  - Glucose is the most common monosaccharide produced by photosynthetic organisms

Classification of Carbohydrates

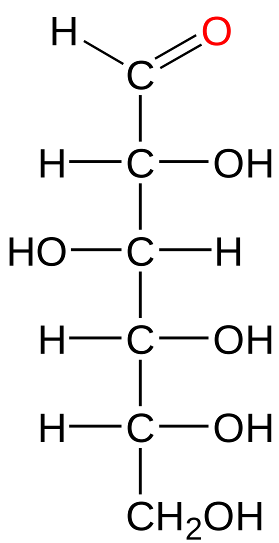
- Monosaccharides - simple sugars with multiple OH groups. Based on number of carbons (3, 4, 5, 6), a monosaccharide is a triose, tetrose, pentose or hexose.
- Disaccharides - 2 monosaccharides covalently linked.
- Oligosaccharides - a few monosaccharides covalently linked.
- Polysaccharides - polymers consisting of chains of monosaccharide or disaccharide units.

Carbohydrates

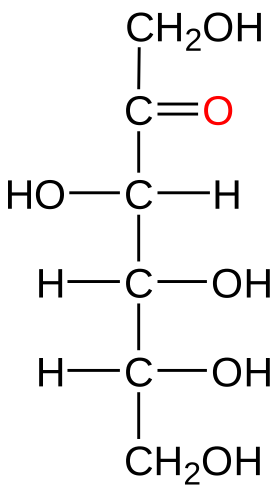
Monosaccharides

Aldoses (e.g., glucose) have an **aldehyde** group at one end.

Ketoses (e.g., fructose) have a **keto** group, usually at C2.



D-glucose

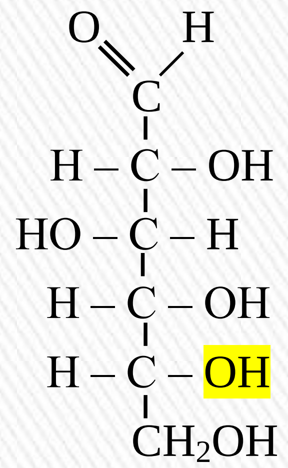


D-fructose

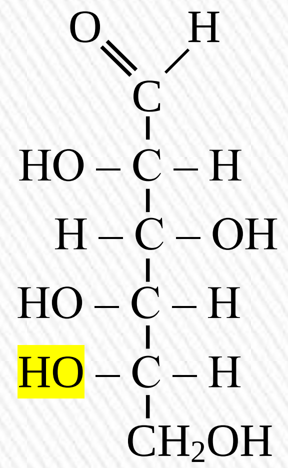
Carbohydrates

For sugars with more than one chiral center, **D** or **L** refers to the asymmetric **C** farthest from the aldehyde or keto group.

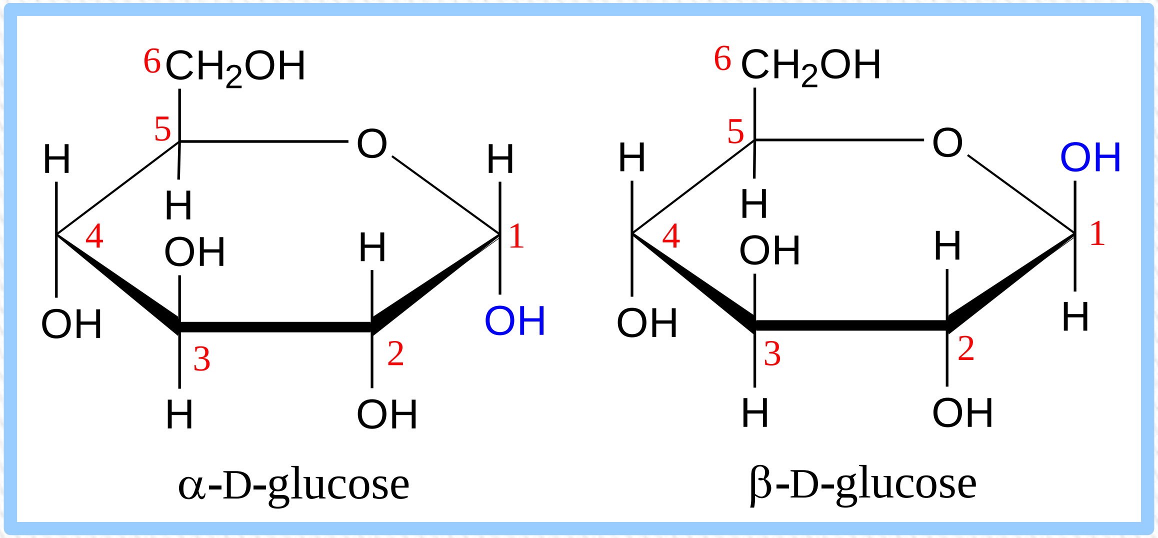
Most naturally occurring sugars are D isomers.



D-glucose



L-glucose



Cyclization of glucose produces a new asymmetric center at C1. The 2 stereoisomers are called anomers, α & β.

Haworth projections represent the cyclic sugars as having essentially planar rings, with the OH at the anomeric C1:

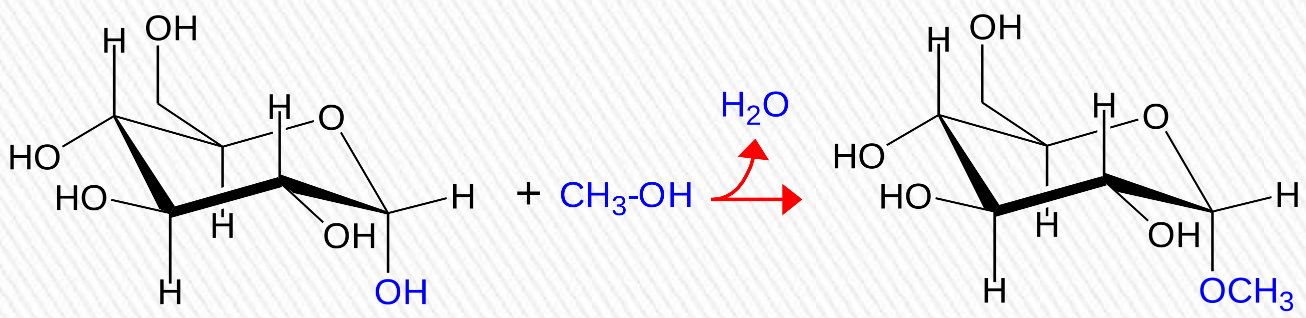
- α (OH below the ring)
- β (OH above the ring).

Glycosidic Bonds

The anomeric hydroxyl and a hydroxyl of another sugar or some other compound can join together, splitting out water to form a **glycosidic bond**:

$$R\text{-}OH + HO\text{-}R' \rightarrow R\text{-}O\text{-}R' + H_2O$$

E.g., methanol reacts with the anomeric OH on glucose to form **methyl glucoside** (methyl-glucopyranose).

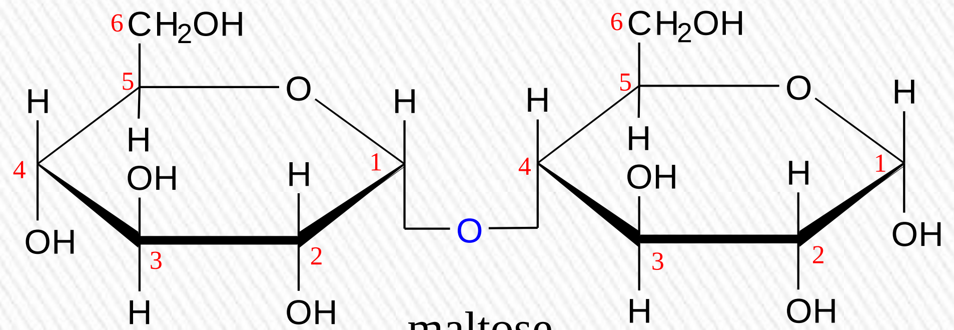


α-D-glucopyranose methanol methyl-α-D-glucopyranose

Disaccharides:

Maltose, a cleavage product of starch (e.g., amylose), is a disaccharide with an a(1® 4) glycosidic link between C1 - C4 OH of 2 glucoses.

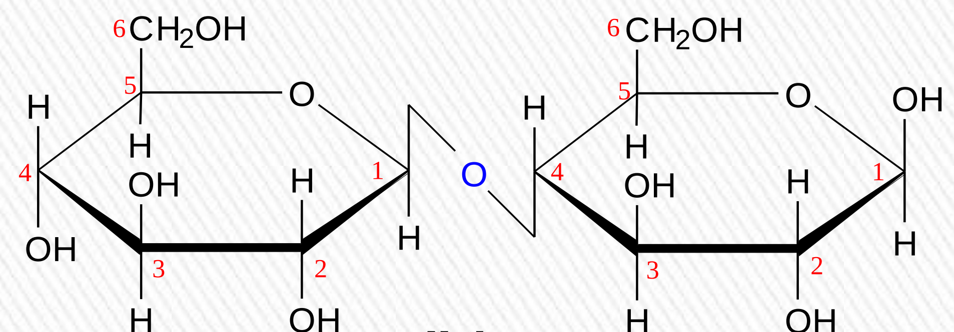
It is the a anomer (C1 O points down).



maltose

Cellobiose, a product of cellulose breakdown, is the otherwise equivalent β anomer (O on C1 points up).

The β(1→4) glycosidic linkage is represented as a zig-zag, but one glucose is actually flipped over relative to the other.



cellobiose

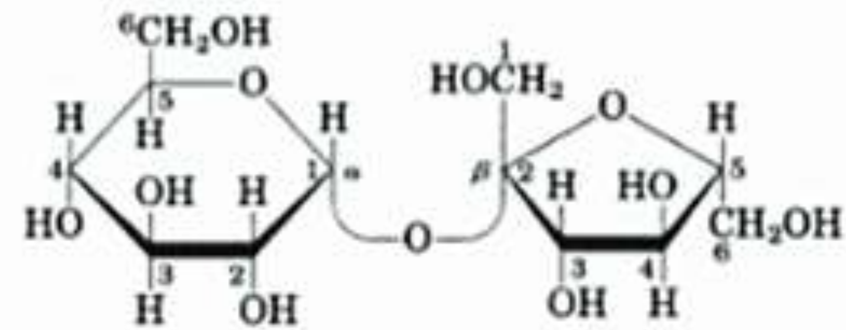
Other disaccharides :

- **Sucrose**, common table sugar, has a glycosidic bond linking the anomeric hydroxyls of glucose & fructose.

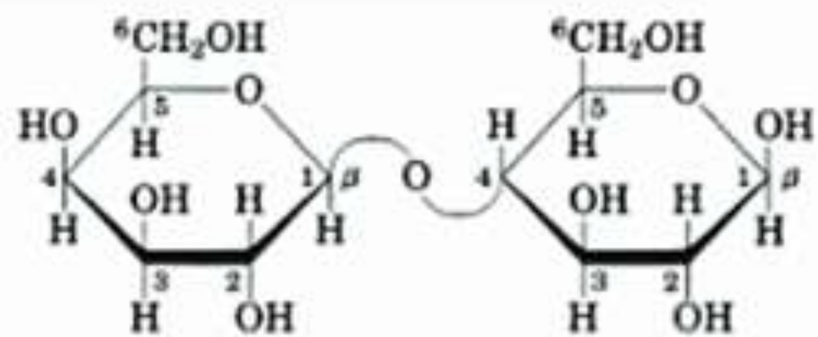
  Because the configuration at the anomeric C of glucose is a (O points down from ring), the linkage is α(1→2).

  The full name of sucrose is a-D-glucopyranosyl-(1→2)-b-D-fructopyranose.)

- **Lactose**, milk sugar, is composed of galactose & glucose, with β(1→4) linkage from the anomeric OH of galactose. Its full name is b-D-galactopyranosyl-(1→ 4)-a-D-glucopyranose



Sucrose

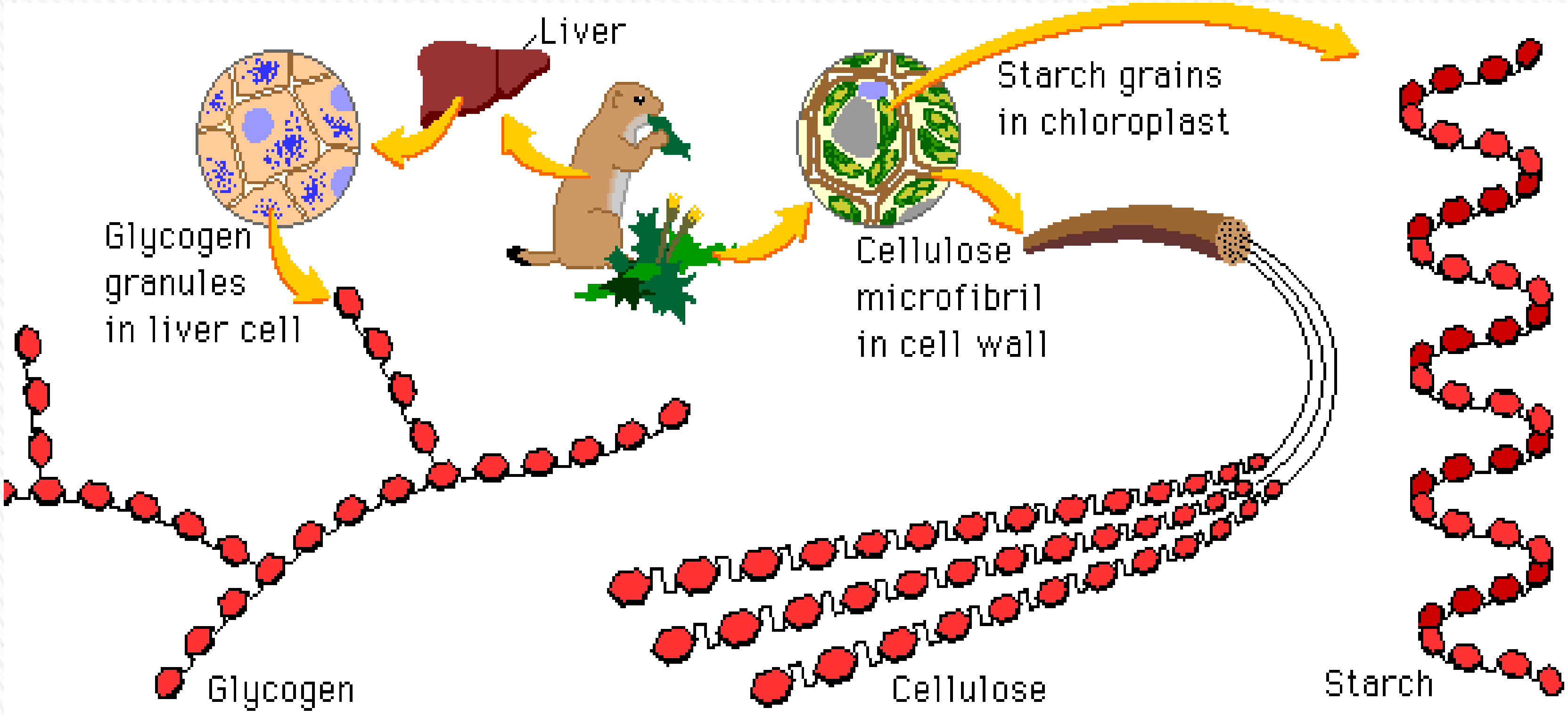


Lactose

Polysaccharides

» Structure: polymers made up from a few hundred to a few thousand monosaccharides.

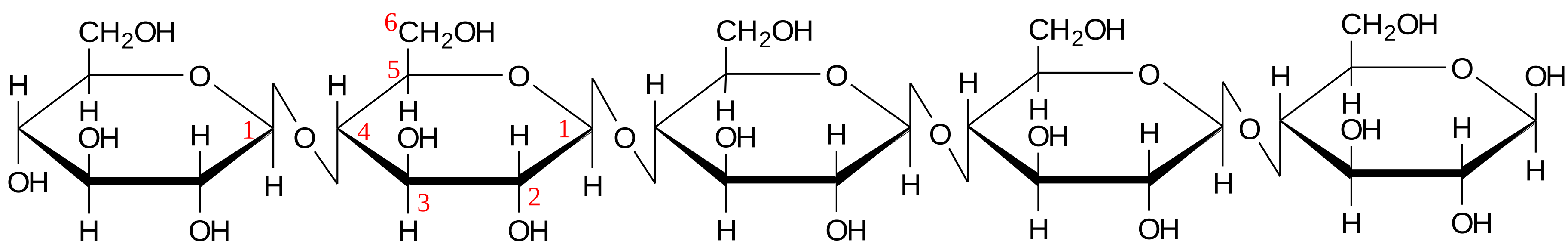
» Functions: energy storage molecules or for structural support:



Polysaccharides – structural molecules

Cellulose, a major constituent of plant cell walls, consists of long linear chains of glucose with β(1→4) linkages.

Every other glucose is flipped over, due to β linkages ➔ promotes intra-chain and inter-chain H-bonds

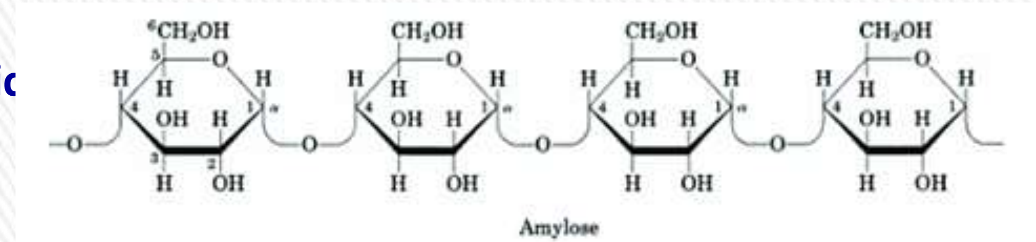


cellulose

Polysaccharides – storage molecules

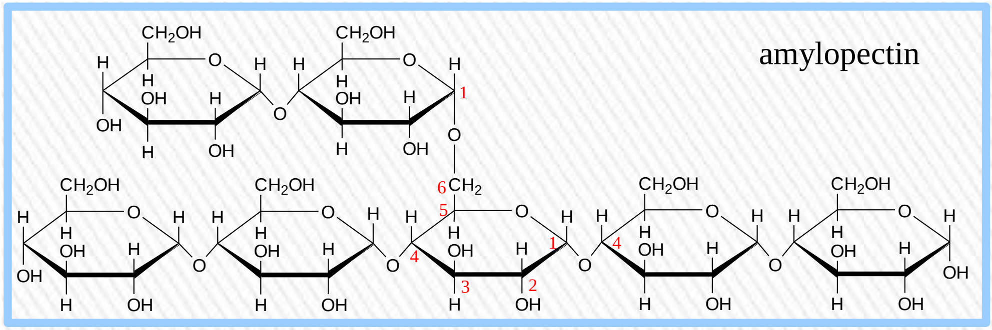
Plants store glucose as **amylose** or **amylopectin** → glucose polymers collectively called starch.

→ **polymeric** form **minimizes osmotic effects**.



a) **Amylose** is a glucose polymer with **α (1→4)** linkages

b) **Amylopectin** → glucose polymer with mainly α(1→ 4) linkages, but it also has **branches** formed by α(1→6) linkages. Branches are generally longer than shown above.



The branches produce a compact structure & provide multiple chain ends at which enzymatic cleavage can occur.

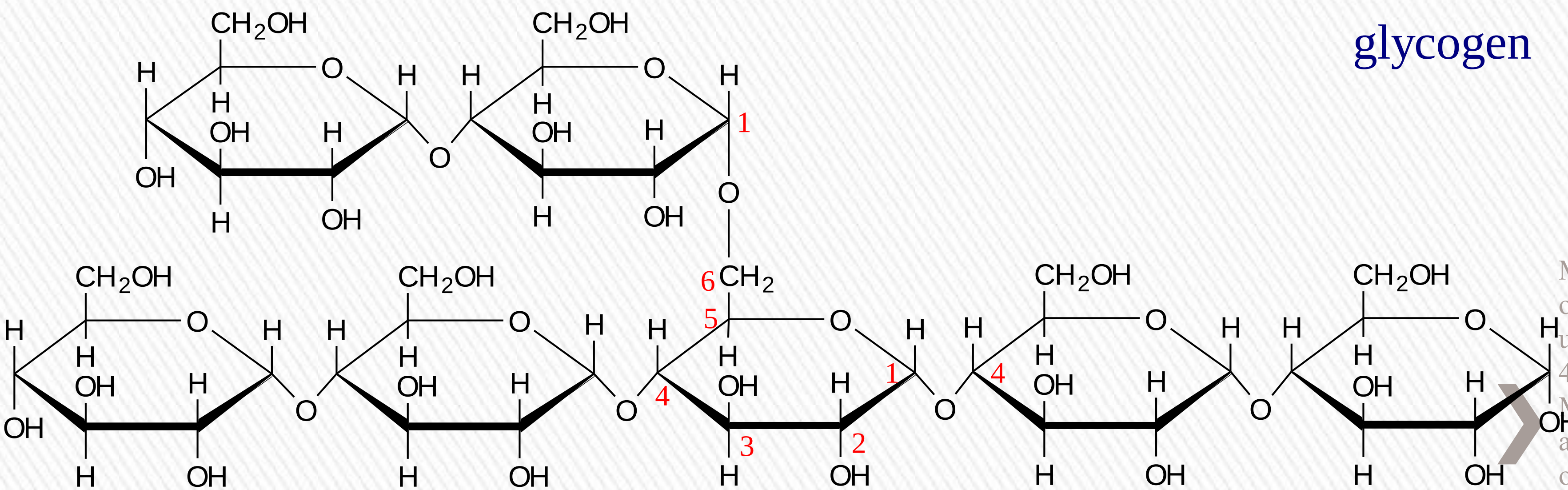
Polysaccharides – storage molecules

Glycogen, the glucose storage polymer in **animals**, is similar in structure to amylopectin.

But glycogen has **more** $\alpha(1\rightarrow6)$ **branches**.

The highly branched structure permits rapid glucose release from glycogen stores, e.g., in muscle during exercise.

The ability to rapidly mobilize glucose is more essential to animals than to plants.



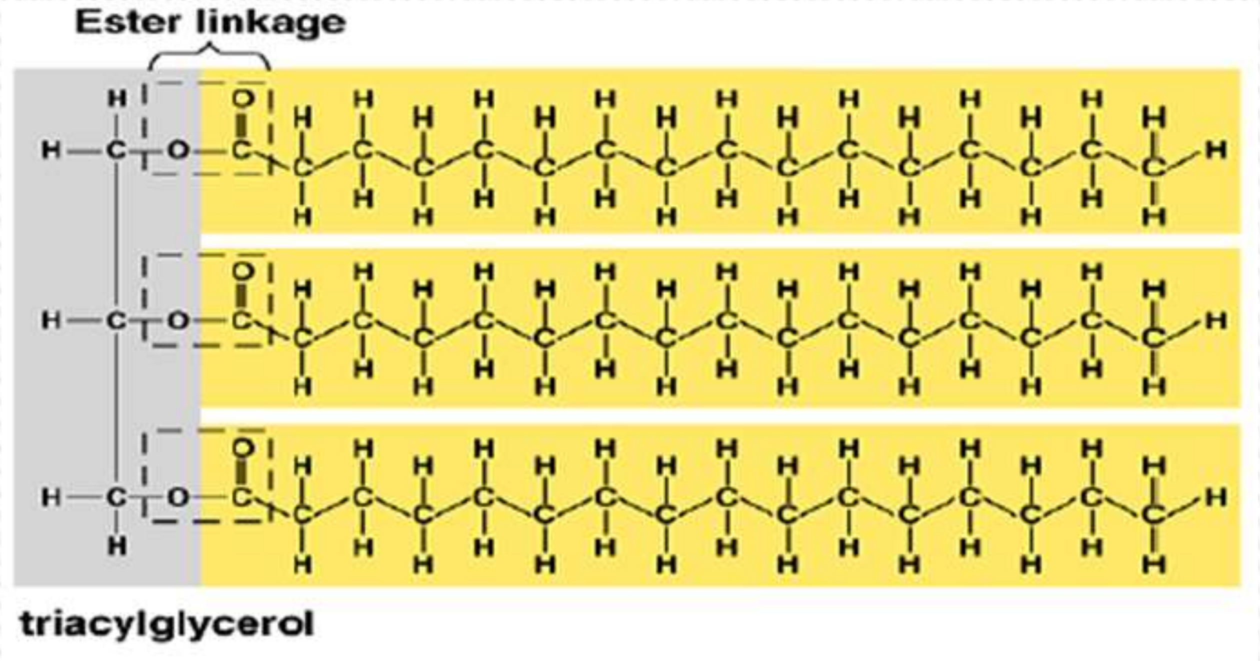
Module 4 - Macromolecules

Lipids

- A group of polymers that have one characteristic in common, they do not mix with water → hydrophobic.
- Structure: Greasy or oily, non-polar compounds
- Functions:
  - Energy storage (per gram = x 2 that of carbo)
  - Membrane structure
  - Protecting against desiccation (drying out).
  - Insulating against cold.
  - Absorbing shocks.
  - Regulating cell activities by hormone actions.
  - Have little to no affinity for water (hydrophobic)
- Some important groups are fats, phospholipids, and steroids.

Fats

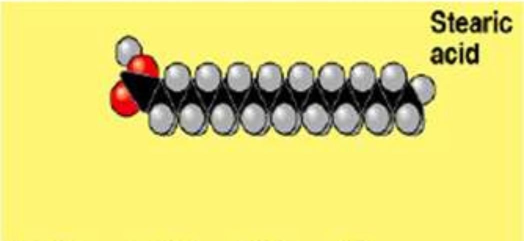
- Fats ➔ large molecules composed of 2 types of monomers, glycerol (an alcohol containing 3 carbons) and 3 fatty acid molecules.
- The bond connecting the glycerol and fatty acids in the fat molecule is called an ester bond.



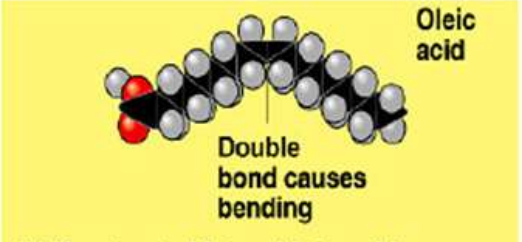
Fats

Two types of fatty acids : saturated and unsaturated.

- **Saturated fats:**
  - single C-C bonds in fatty acid tails
  - solid at room temp
  - most animal fats
- **Unsaturated fats :**
  - one or more double bonds between carbons in the fatty acids allows for "kinks" in the tails
  - liquid at room temp
  - most plant fats



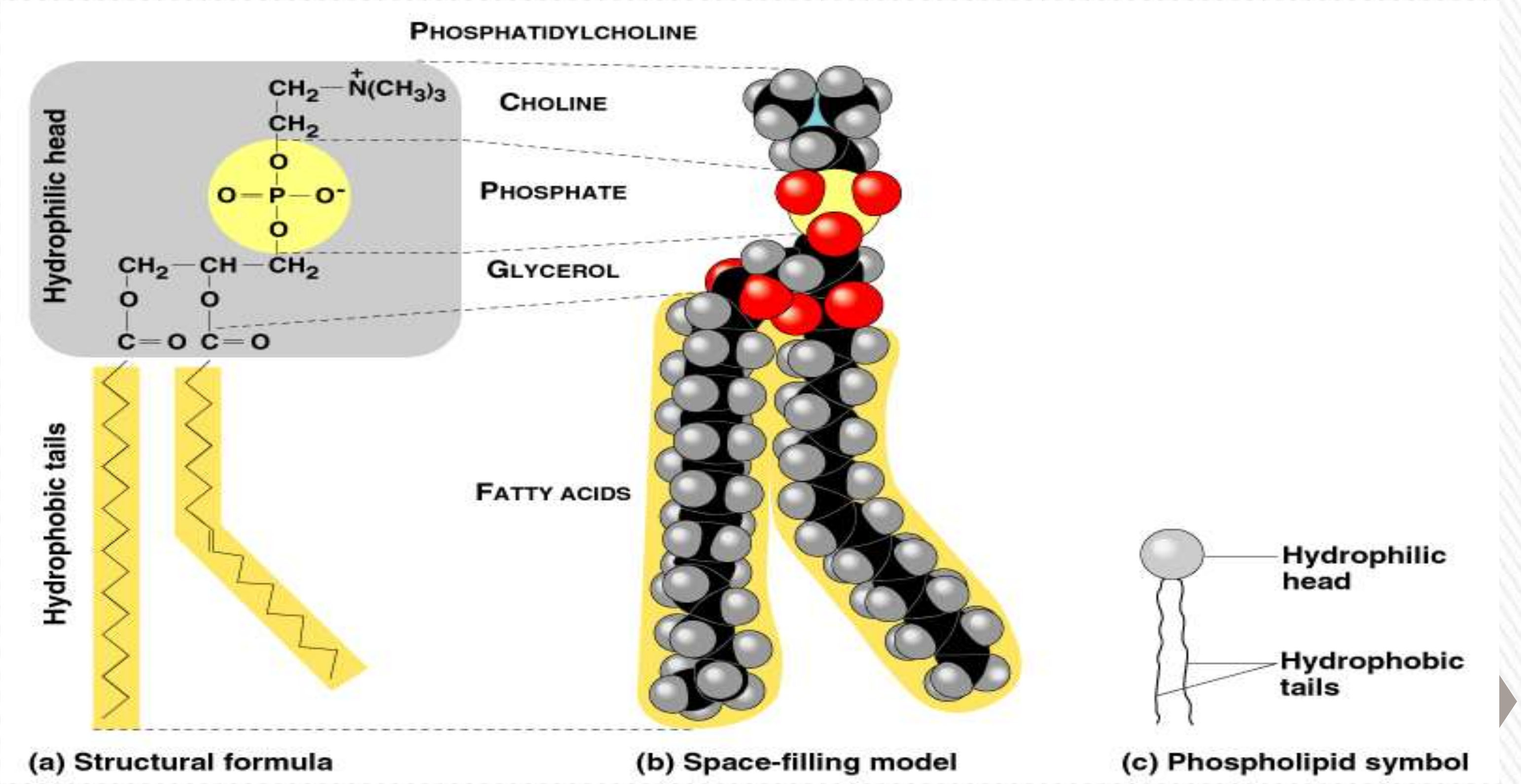
(a) Saturated fat and fatty acid



(b) Unsaturated fat and fatty acid

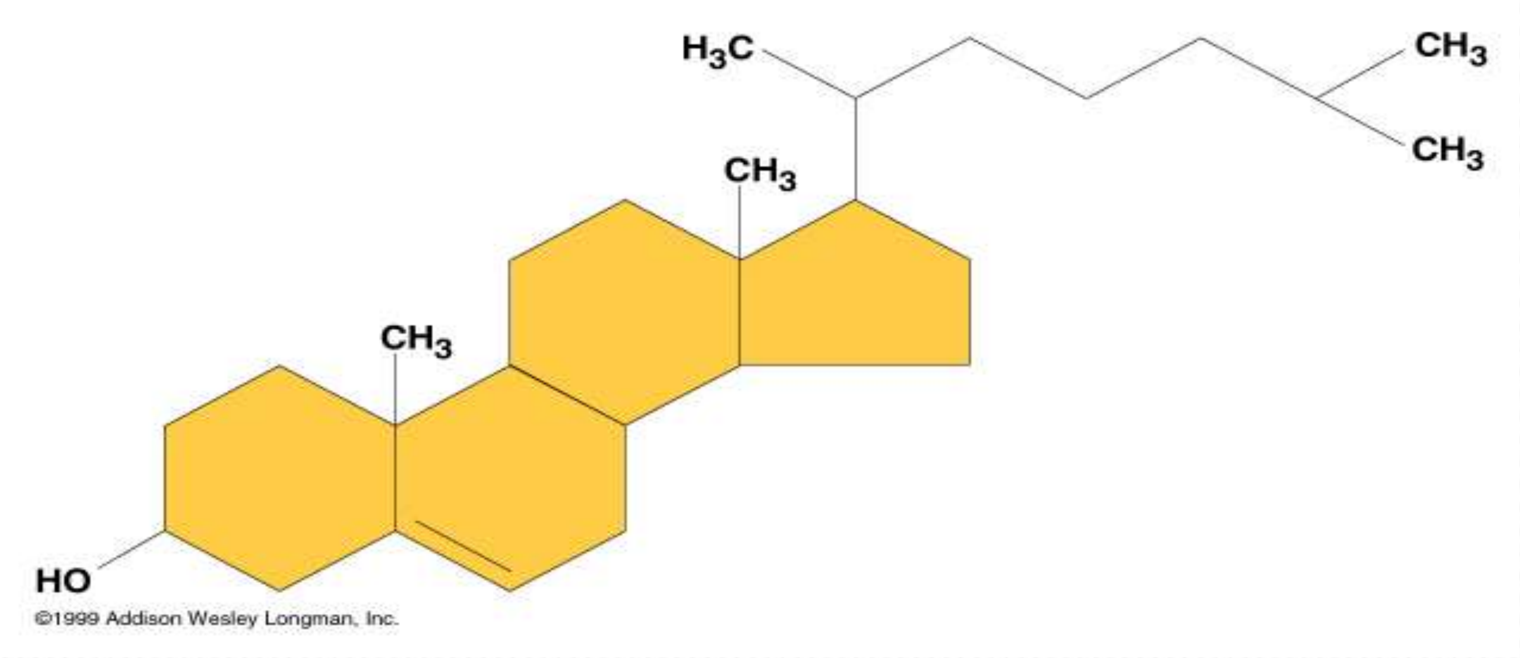
Phospholipids

- Structure: Glycerol + 2 fatty acids + phosphate group.
- Function: Main structural component of cellular membranes, where they arrange in bilayers.



Steroids

- Structure: Four carbon rings with no fatty acid tails
- Functions:
- Component of animal cell membranes (cholesterol)
- Modified to form vertebrate sex hormones



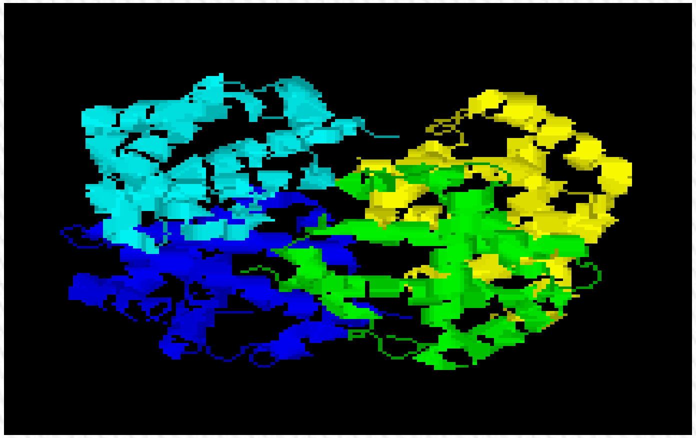
Proteins

Structure:

» Polypeptide chains

» Consist of peptide bonds between 20 possible amino acid monomers

» Have a three-dimensional globular shape



Functions of Proteins

- Enzymes, which can accelerate specific chemical reactions up to 10 billion times faster than they would spontaneously occur.
- Structural materials, including keratin (the protein found in hair and nails) and collagen (the protein found in connective tissue).
- Specific binding areas - such as antibodies that bind specifically to foreign substances to identify them to the body's immune system.
- Specific carriers - including membrane transport proteins that move substances across cell membranes, such as the blood protein hemoglobin which carries oxygen, iron, and other substances through the body.
- Enable contraction - such as actin and myosin fibers that interact in muscle tissue.
- Provide chemical signaling - including hormones such as insulin that regulate sugar levels in blood.

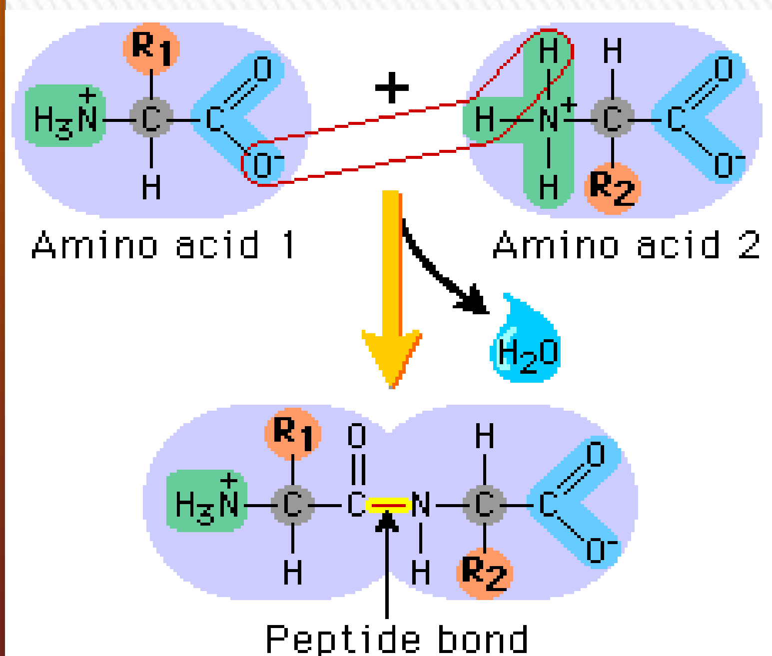
Protein Structures

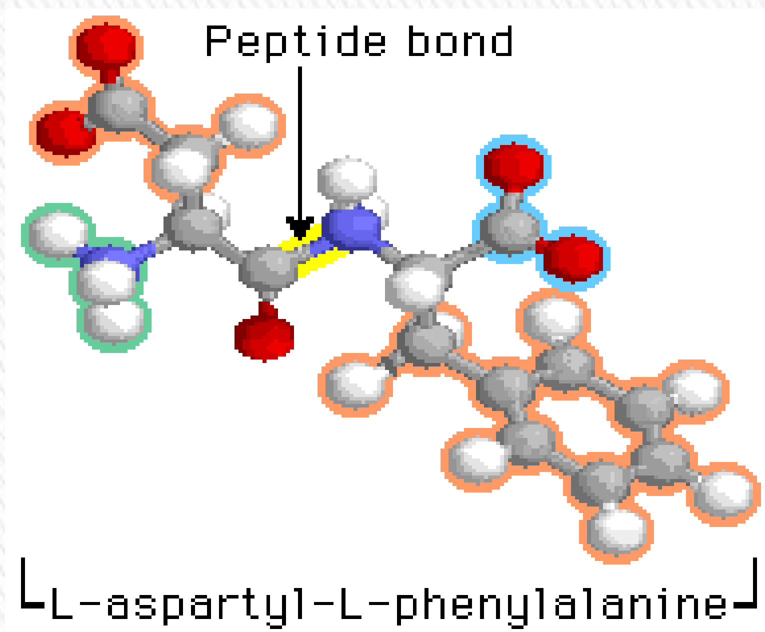
Four levels of protein structures:

- primary (single chain structure)
- secondary (folded due to bonding)
- tertiary (3-D combinations)
- quaternary (combination of 2 or more polypeptides)

Primary Structure

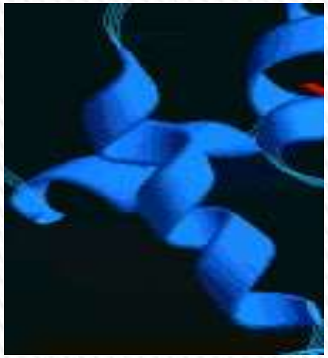
- Unique sequence of amino acids in a protein
- Slight change in primary structure can alter function
- Sequence is determined by genes
- Condensation synthesis reactions form the peptide bonds between amino acids

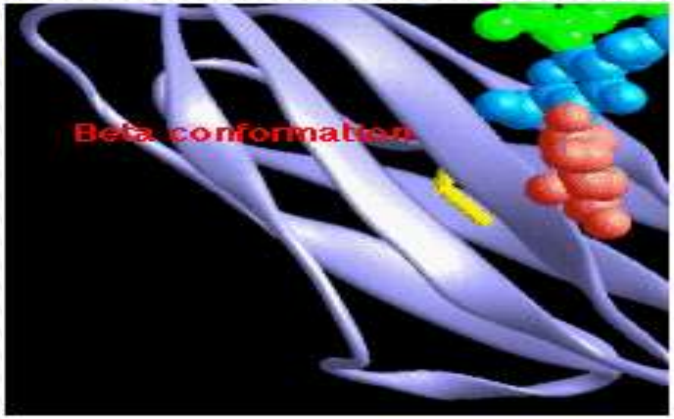




Secondary Structure

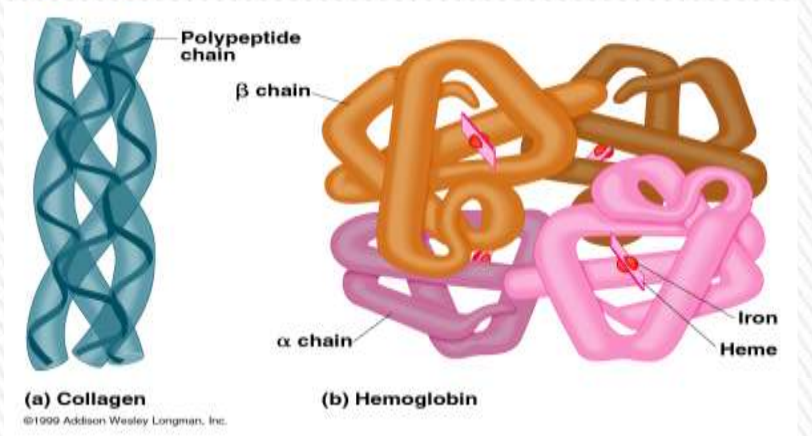
» Repeated folding of protein's polypeptide backbone
» Stabilized by H bonds between peptide linkages in the protein's backbone
» 2 types: alpha helix, beta pleated sheets





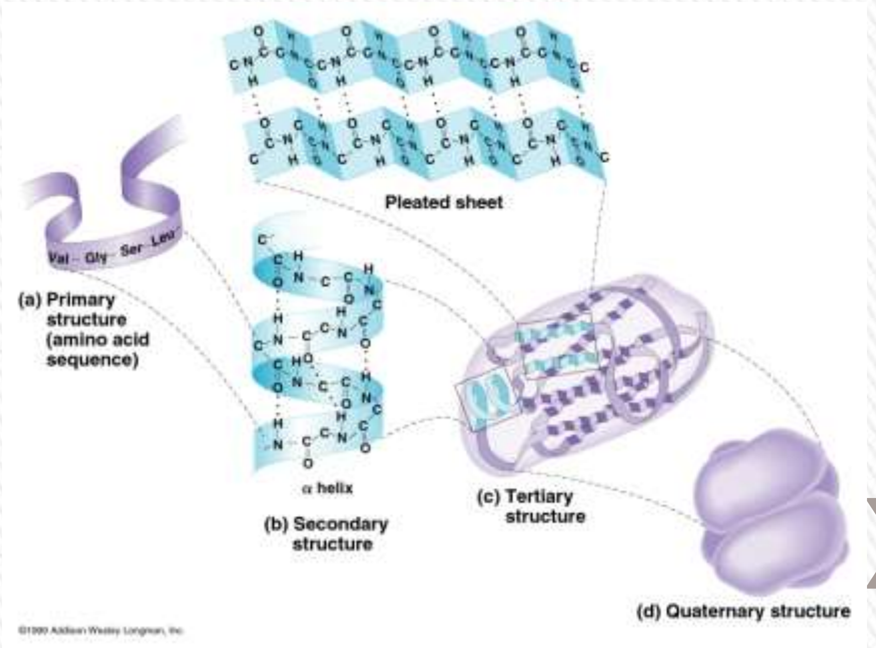
Tertiary Structure

- Irregular contortions of a protein due to bonding between R groups
- Weak bonds:
  - H bonding between polar side chains
  - ionic bonding between charged side chains
  - hydrophobic and van der Waals interactions
- Strong bonds:
  - disulfide bridges form strong covalent linkages

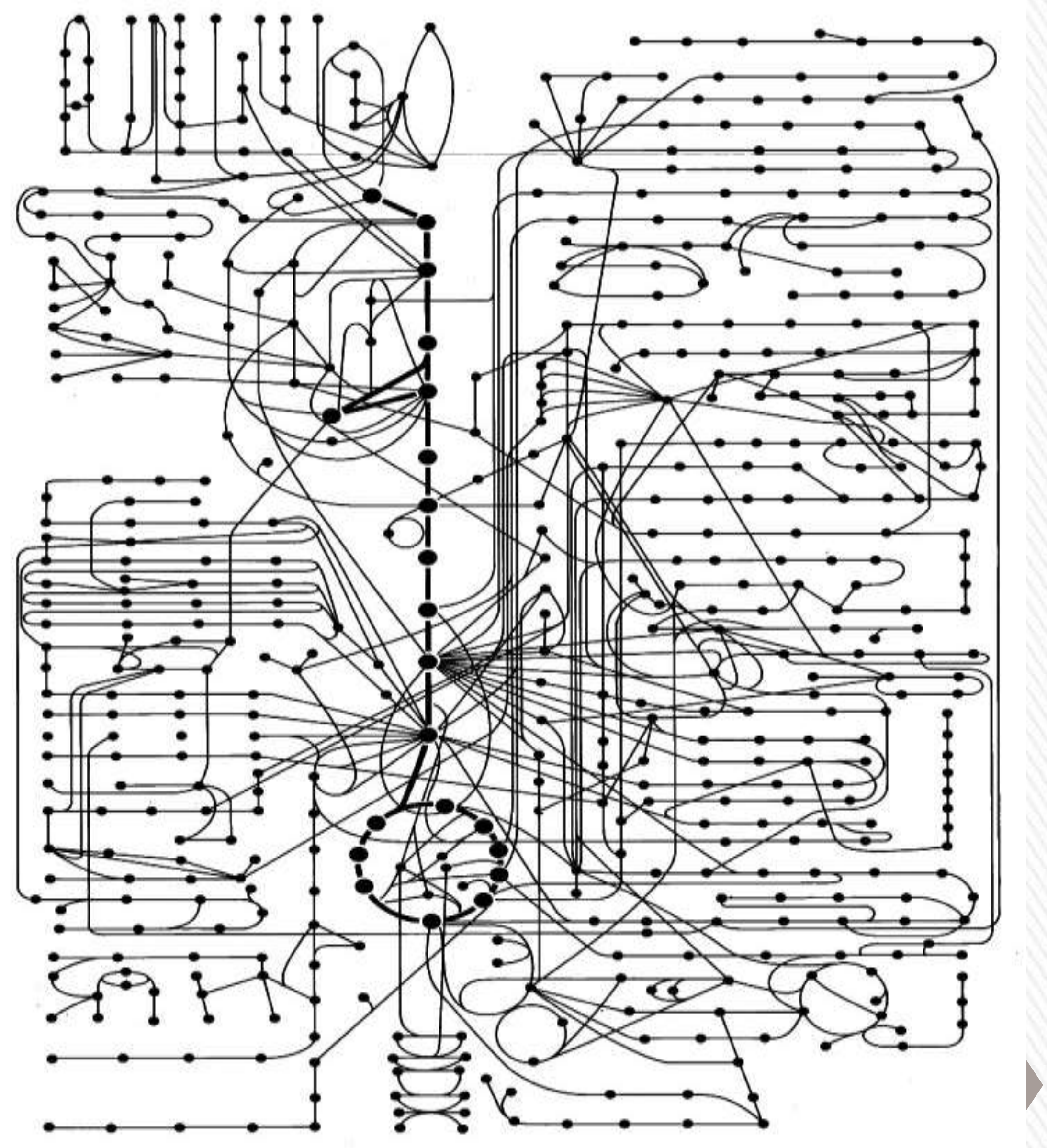


Quaternary Structure

Results from interactions among 2 or more separate polypeptide chains



Bioenergetika, enzim dan metabolisme



Bioenergetika

» Ilmu yang mempelajari energi dalam lingkungan makhluk hidup dan organisma yang menggunakan energi

Energi

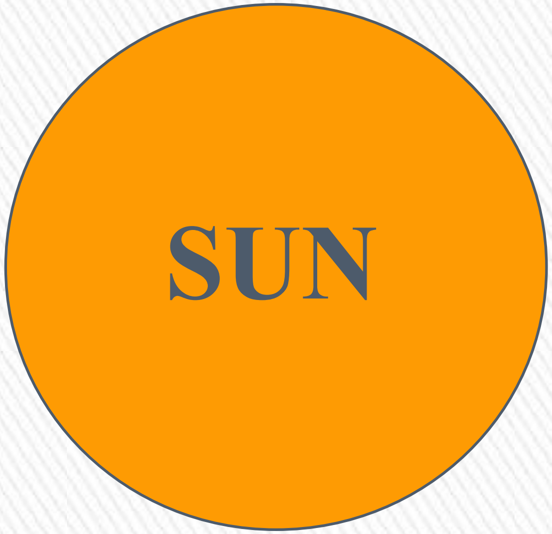
» **Kapasitas untuk melakukan kerja**.

» **Dua contoh:**

1. **energi kinetik**
2. **energi potensial**

Energi kinetik

- **Energi** dalam proses suatu kerja
- **Energi** dari gerakan
- **Contoh**
  1. **aliran sitoplasma**
  2. **energi matahari**

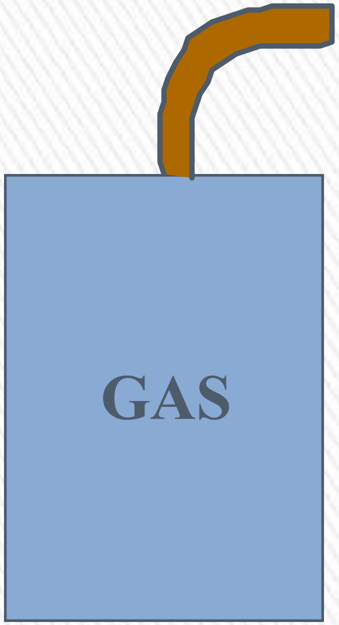


Energi potensial

- **Energy** dari suatu benda pada lokasinya
- **Energi suatu benda** pada posisi tertentu.
- **contoh:**

  1. cairan dalam lisosom

  2. energi kimiawi (gas)



Thermodinamika

» Mempelajari transformasi energi yang terjadi dalam sekelompok materi

» **Dua hukum:**

1. **Hukum termodinamika I**
2. **Hukum termodinamika II**

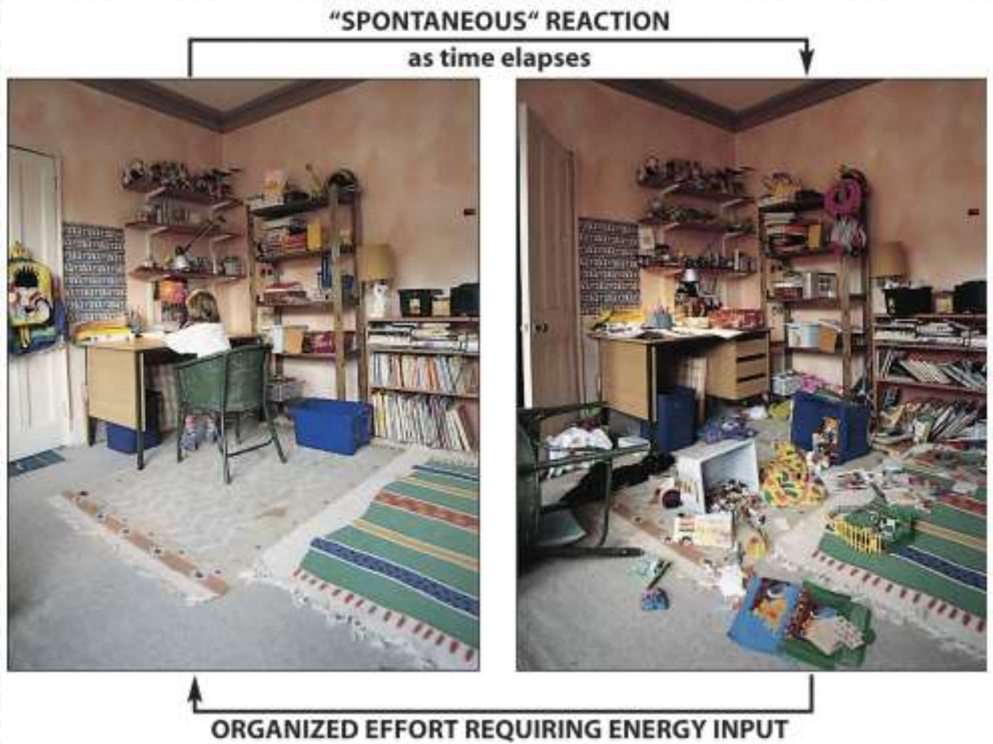
Hukum termodinamika pertama

- **Energi** tidak dapat diciptakan atau dihancurkan, tetapi dapat diubah ke bentuk lain
- Jumlah energi di alam : konstan

Hukum termodinamika II

- Semua **transformasi energi : tidak efisient** karena suatu reaksi menghasilkan **peningkatan entropi** dan hilangnya **energi yang berguna** sebagai **panas**.

- **Entropi**: kekacauan dalam suatu sistem



Endergonik

» **Reaksi kimia** yang **emmerlukan input energi**

Eksogonik

» **Reaksi kimia** yang **melepaskan energi**

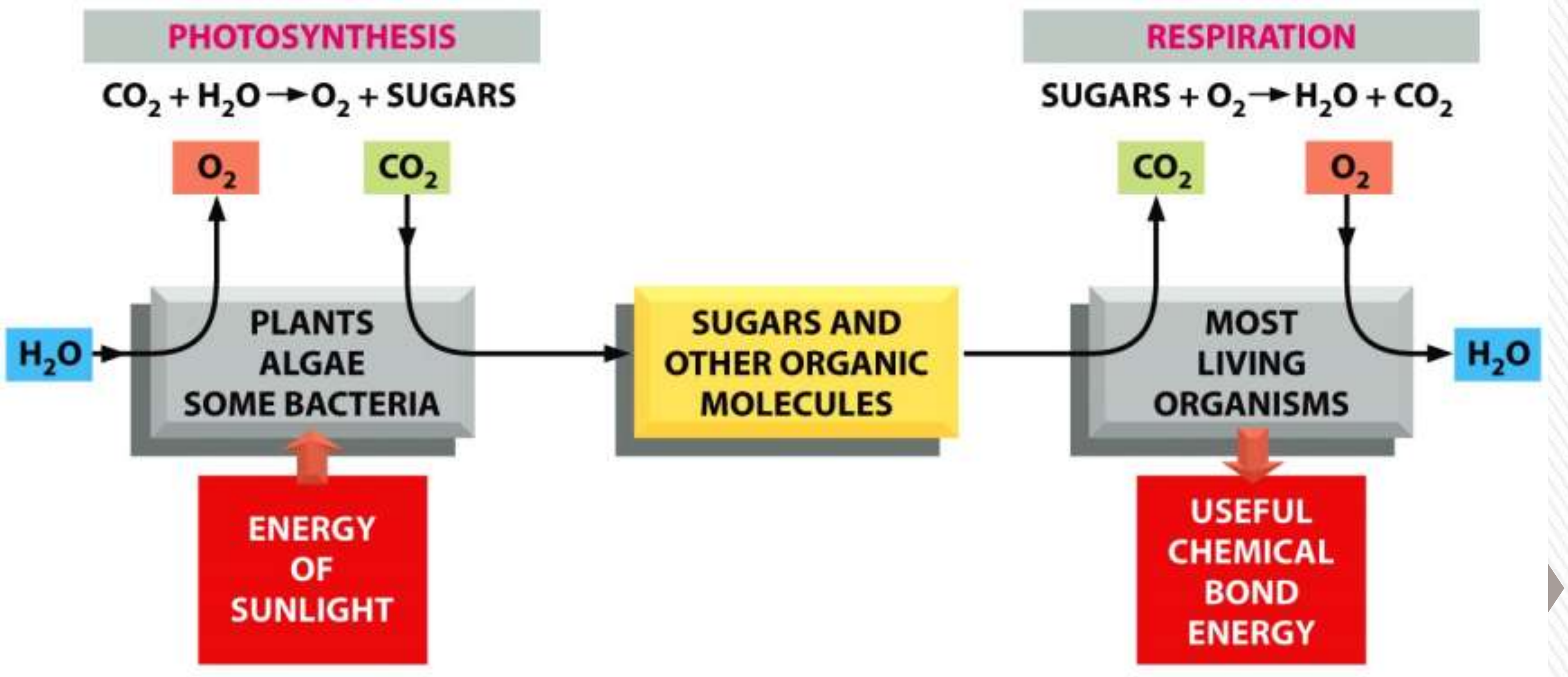


Figure 2-41 *Molecular Biology of the Cell* (© Garland Science 2008)

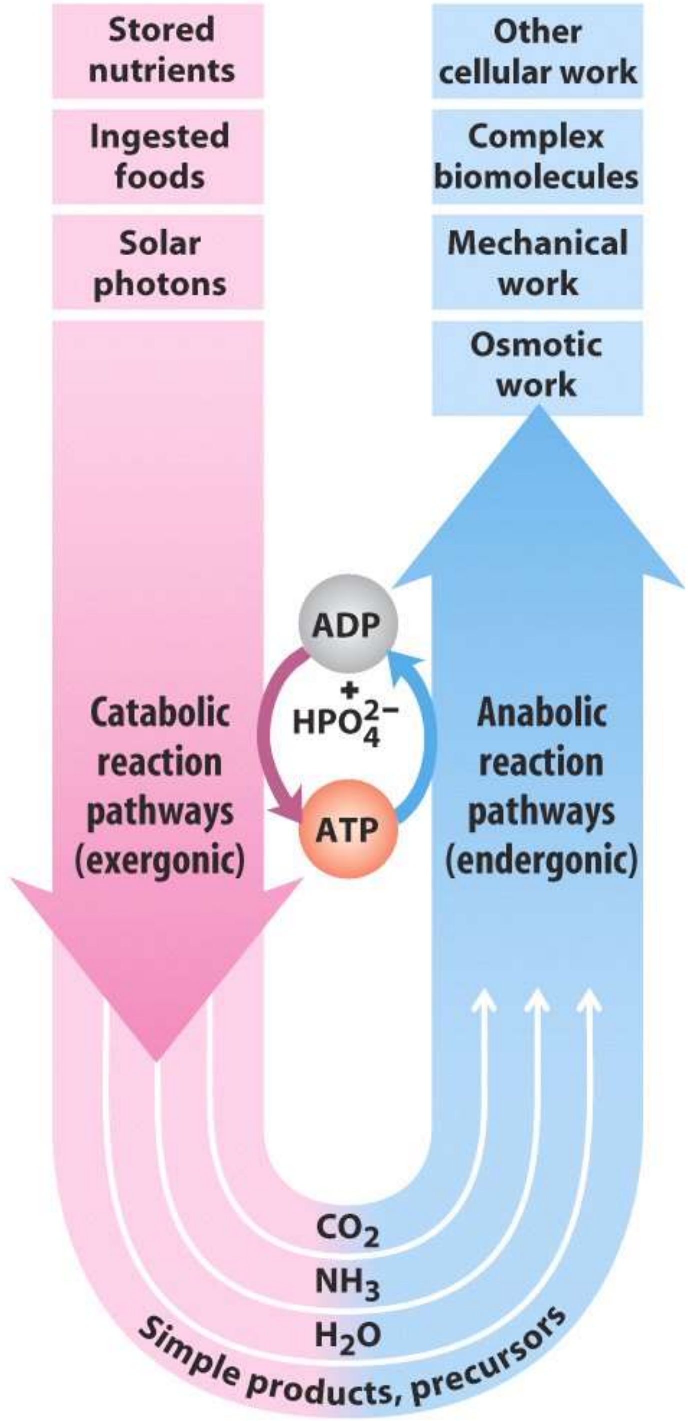
Metabolisme sel

» **Jumlah total** dari **aktivitas kimiawi** dalam semua **sel**.

» Reaksi **endergonik** dan **Eksergonik**

» **2 contoh:**

1. **anabolisme**
2. **katabolisme**



Free Energy

- **Free energy** (*G*)/energi bebas: Jumlah energi yang tersedia untuk melakukan kerja selama reaksi pada temperatur dan tekanan konstan
- **Free energy change (*ΔG*)**/perubahan energi bebas: Perbedaan energi bebas antara produk dan reaktan
- Gibbs : pada temperatur dan tekanan konstan, semua sistem berubah sedemikian rupa agar energi bebas diminimalisasi (*G produk memiliki energi bebas lebih kecil daripada reaktan untuk terjadi secara spontan*)

$$\Delta G = \Delta H - T\Delta S$$

ΔG = perubahan energi bebas

ΔH = perubahan entalpi

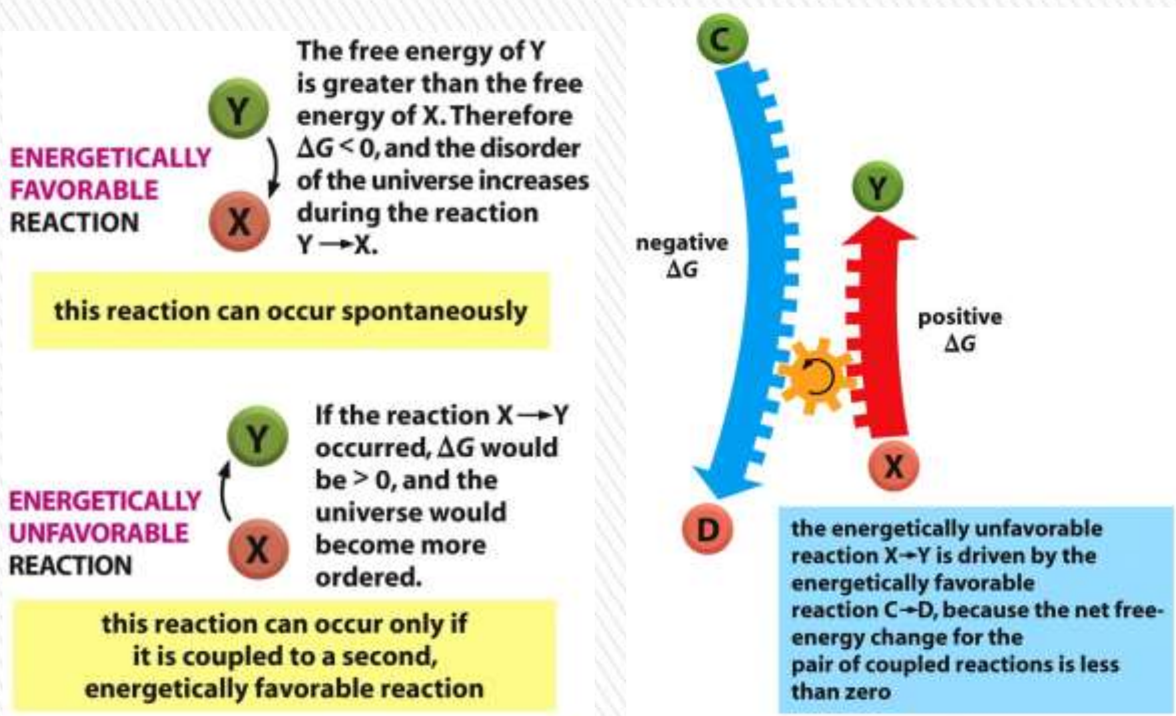
ΔS = perubahan entropi

T = temperatur - Kelvin(K)

Free Energy Change

$$A \rightleftharpoons B$$

- Tanda ΔG menunjukkan arah reaksi :
- ΔG Negatif : A → B
- ΔG Positif : A ← B
- ΔG = 0 : A ↔ B



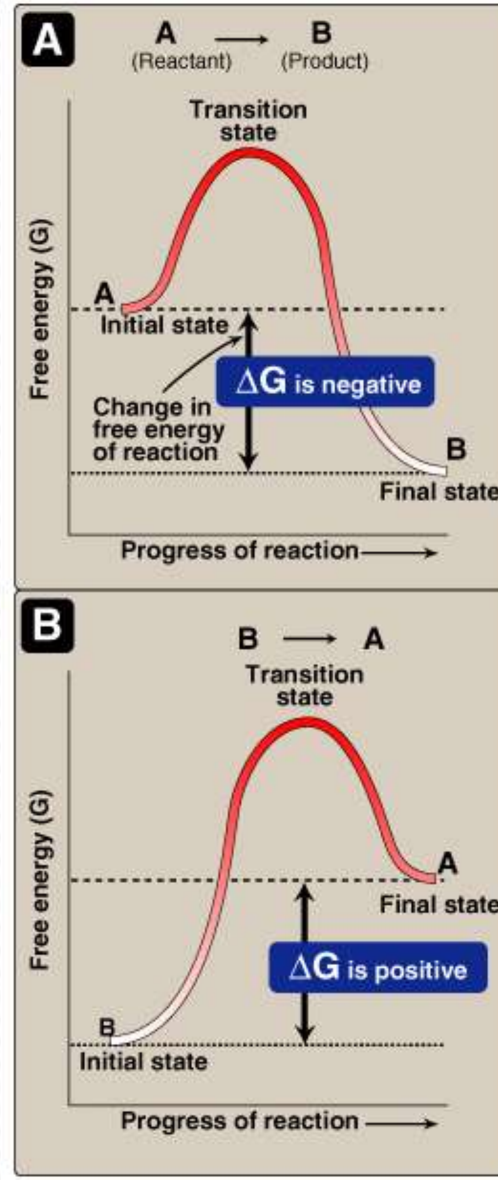


Figure 6.2
Change in free energy (DG) during a reaction. A. The product has a lower free energy (G) than the reactant. B. The product has a higher free energy than the reactant.

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Free Energy Change

ΔG bergantung pada konsentrasi reaktan dan produk

$$\Delta G = \Delta G^{o} + RT \ln \frac{[B]}{[A]}$$

ΔG^{o} = perubahan energi bebas standar

R = konstanta gas

T = temperatur -kelvin

[A] & [B] = konsentrasi reaktan

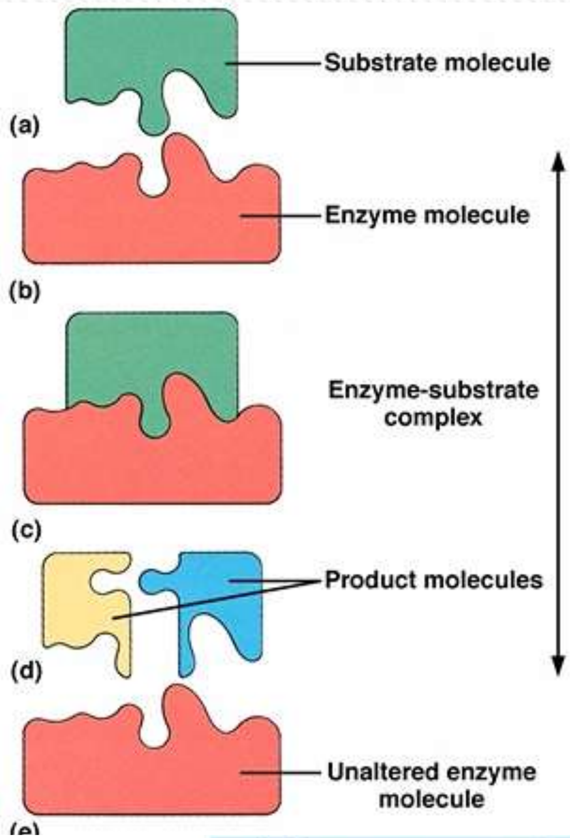
- **Contoh: Hydrolysis kreatin fosfat:**

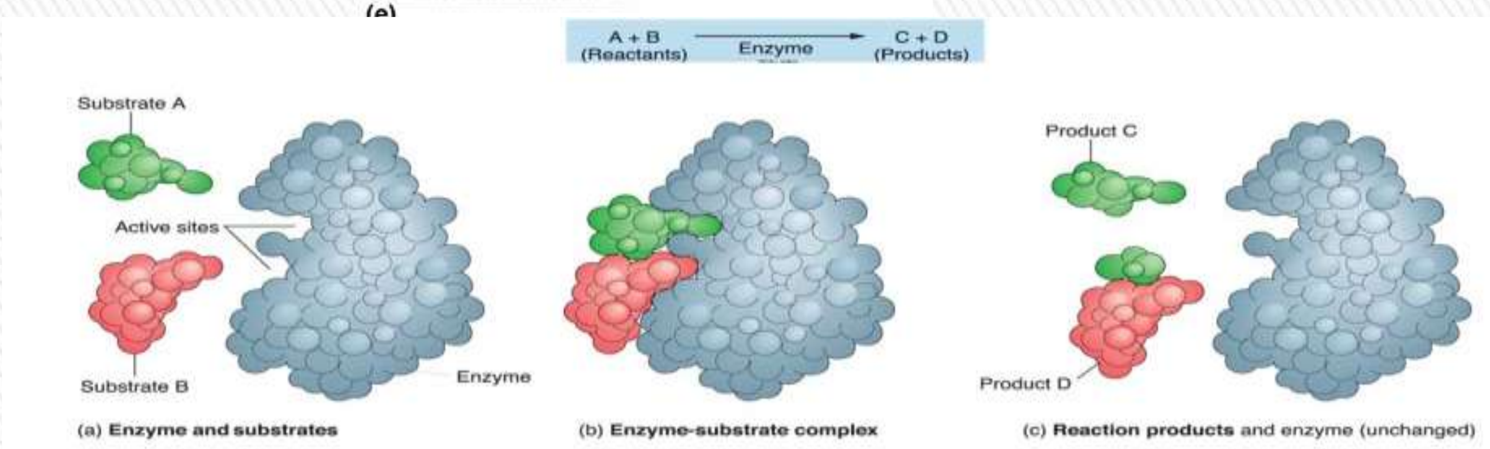
  kreatin fosfat + H_2O ↔ kreatin + fosfat
- Perubahan energi bebas standar = -42.8 kJ/mol
- Dalam sel, perubahan energi bebas = -60.5 kJ/mol

Enzym

- Katalis mengatur kecepatan reaksi
  - Menurunkan energi aktivasi
- Faktor-faktor yang mengatur aktivitas enzim
  - Temperatur
  - pH
- Interaksi dengan substrat spesifik
  - Model kunci dan anak kunci

Interaksi antara Enzym -Substrat





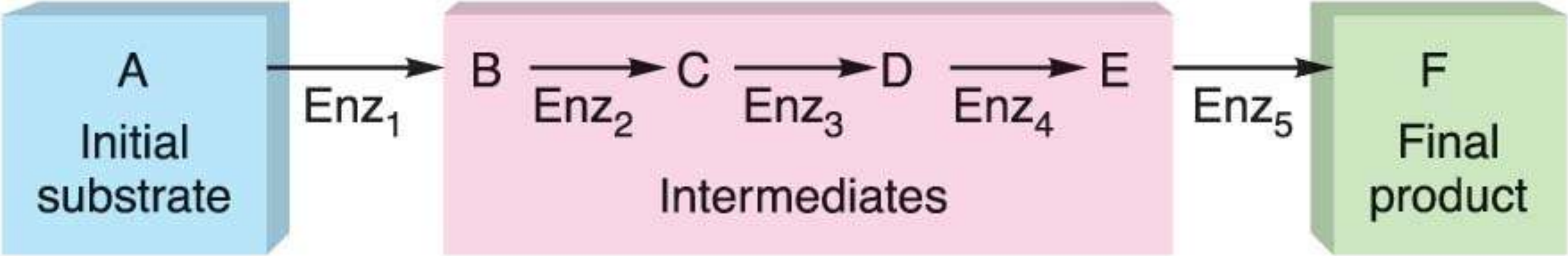


Figure 4.7 **The general pattern of a metabolic pathway.** In metabolic pathways, the product of one enzyme becomes the substrate of the next.

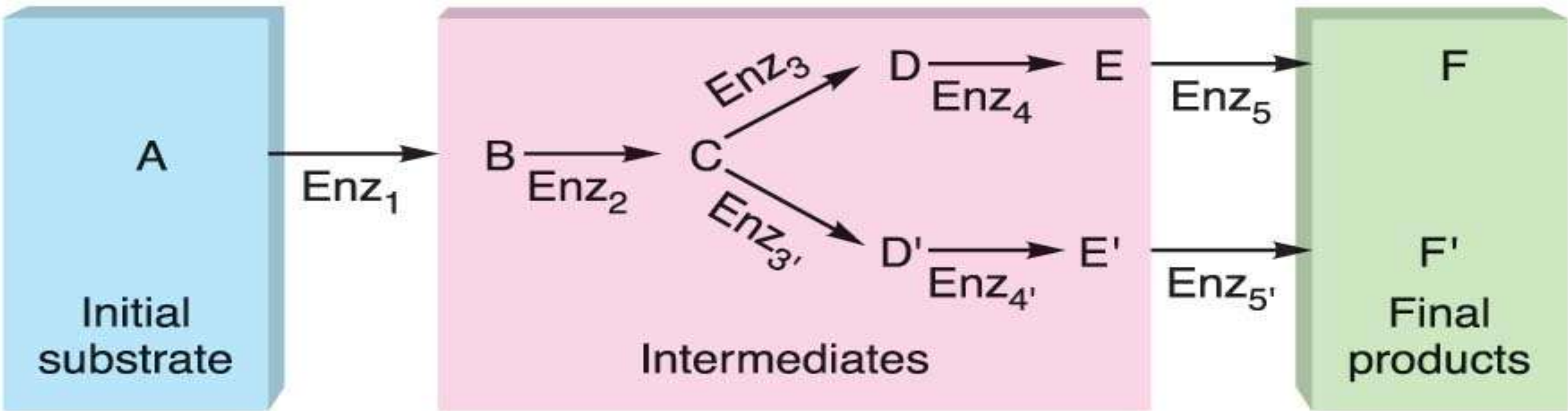
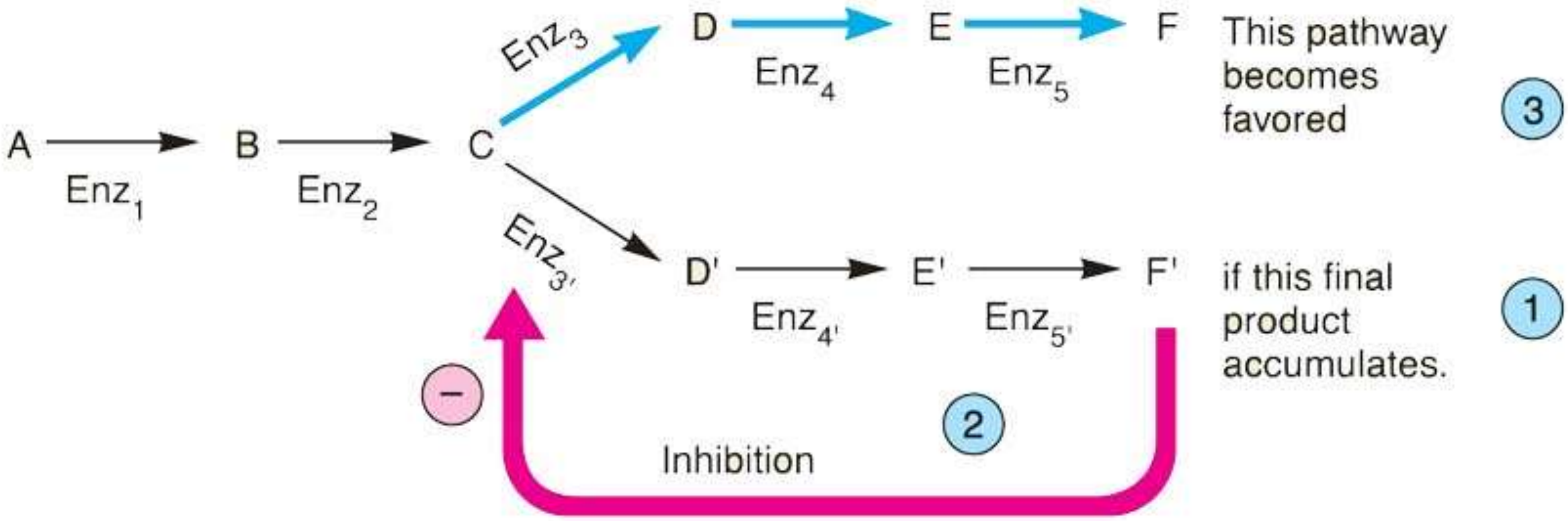


Figure 4.8 **A branched metabolic pathway.** Two or more different enzymes can work on the same substrate at the branch point of the pathway, catalyzing two or more different reactions.


A
B
C
D
E
F
Enz1
Enz2
Enz3
Enz4
Enz5
D'
E'
F'
Enz3'
Enz4'
Enz5'
This pathway becomes favored
3
if this final product accumulates.
1
−
2
Inhibition

Fosfat berenergi tinggi

- Adenosine triphosphate (ATP)
  - Terdiri atas adenin, ribosa dan 3 gugus fosfat
- Pembentukan

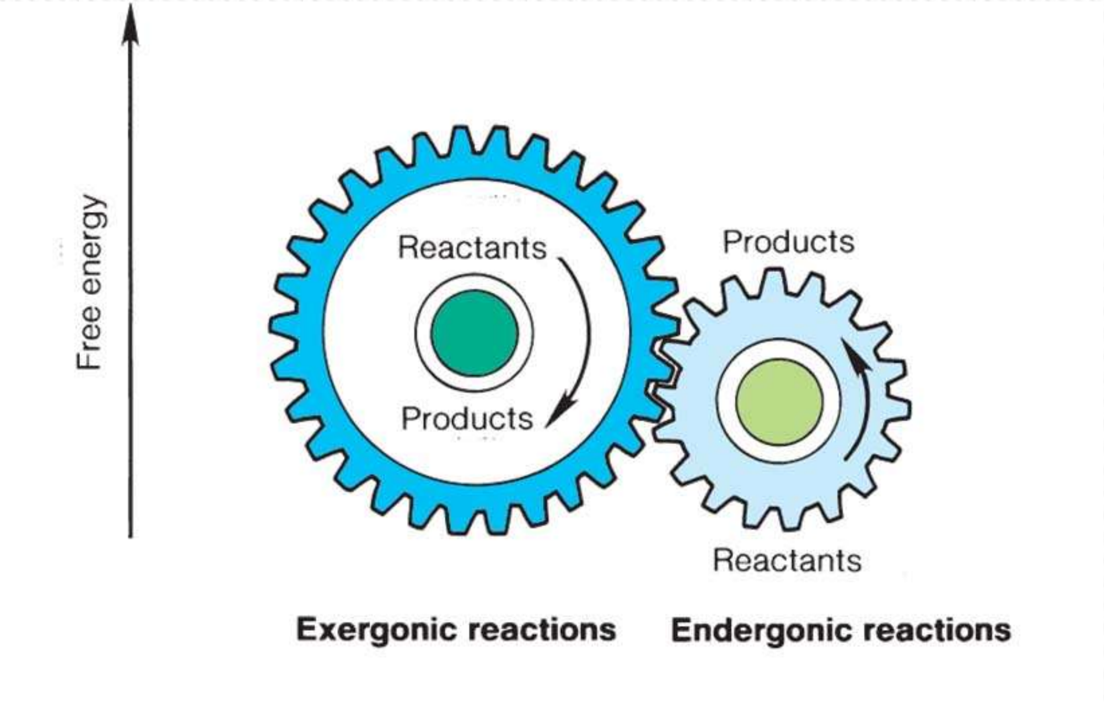
$$ADP + P_i \rightarrow ATP$$

- Pemecahan

$$ATP \xrightarrow[ATPase]{} ADP + P_i + Energy$$

Reaksi *couple*

- Suatu reaksi yang energetically *unfavorable* dapat terjadi jika di-couple dengan reaksi yang energetically *favorable*
- Biasanya tercapai dengan melakukan coupling dengan hidrolisa ATP

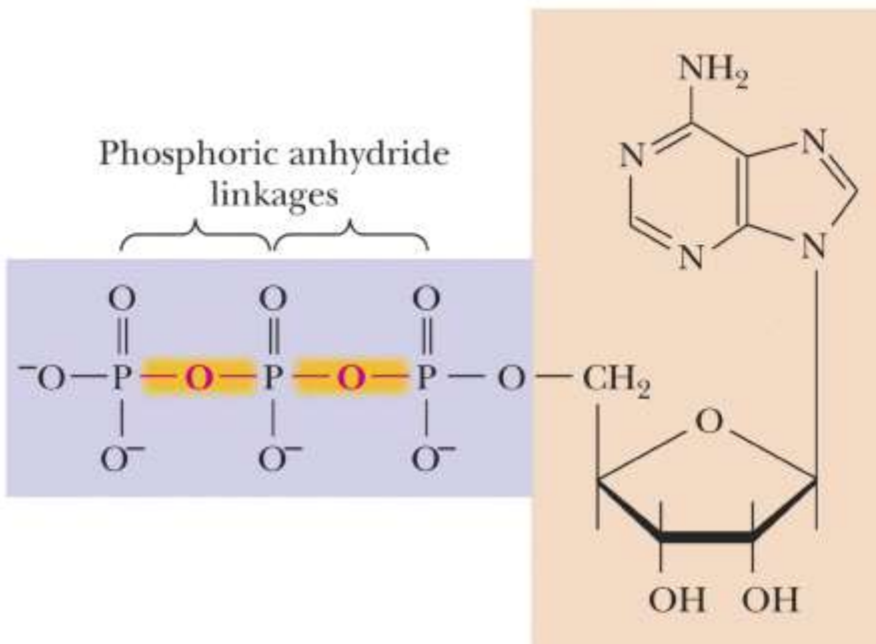


ATP

» ATP memiliki 2 ikatan fosfoanhidrid berenergi tinggi

» ΔG^o untuk hidrolisis ATP menjadi ADP adalah -7.3 kcal/m

Garrett/Grisham, Biochemistry with a Human Focus
Figure 3.9



ATP
(adenosine-5'-triphosphate)

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Electron Carrier

» Oksidasi suatu nutrien dalam sel terjadi melalui reaksi bertahap untuk mendapatkan transduksi energi secara efisien

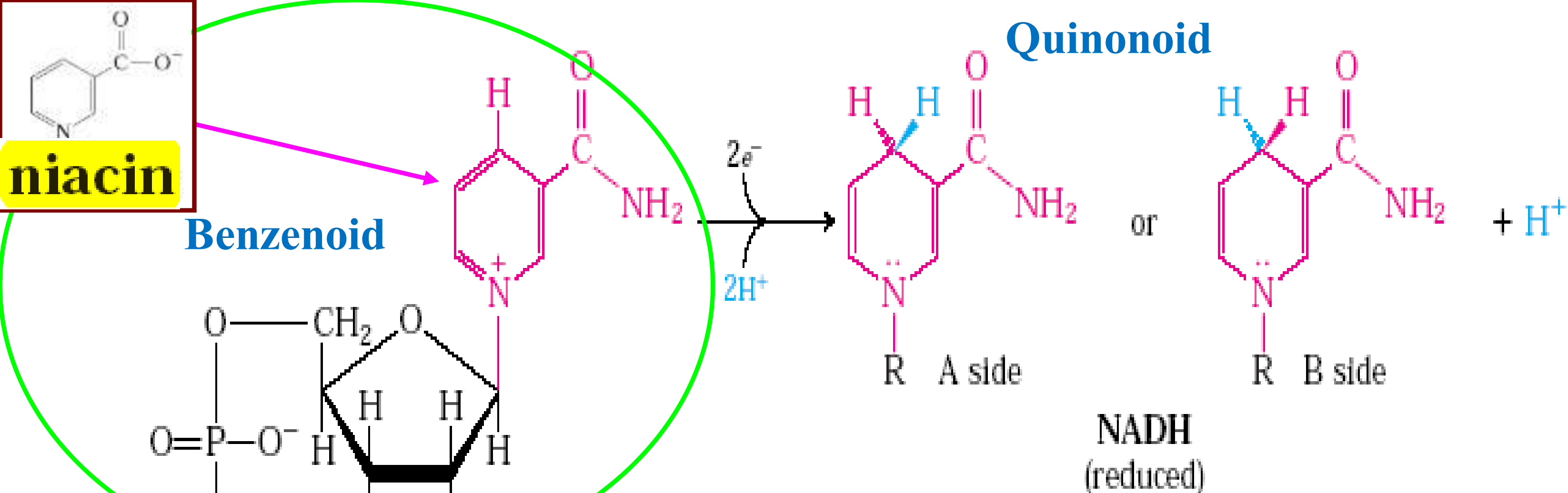
» NAD^+, $NADP^+$, FAD, dan FMN merupakan *electron* carrier universal (coenzim untuk berbagai enzim)

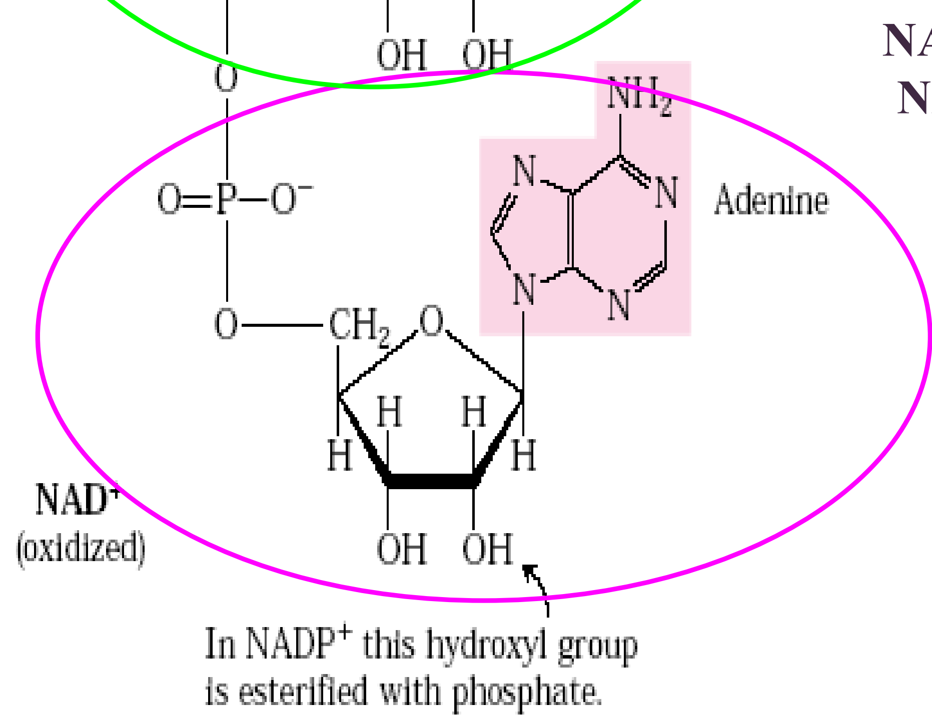
» NAD dan NADP merupakan dinukleotida yang dapat menerima/mendonasikan ion hidrid (dengan 2e) untuk reaksi reduksi/oksidasi

» NAD (atau NAD^+) biasanya berperan dalam oksidasi dan NADP (atau NADPH) dalam reduksi.

» NADH dan $FADH_2$ berperan sebagai kofaktor untuk berbagai enzim yang mengkatalisa oksidasi senyawa nutrien

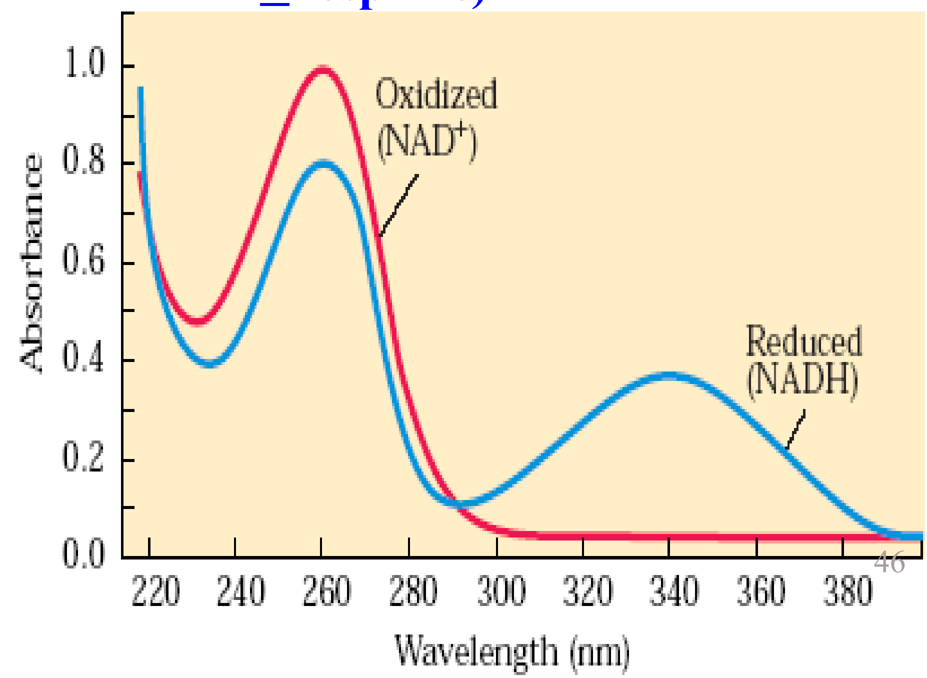
» NADH dan $FADH_2$ akan dioksidasi melalui rantai respirasi dalam membran dalam mitokondria sel eukariot atau membran plasma bakteri untuk menghasilkan energi



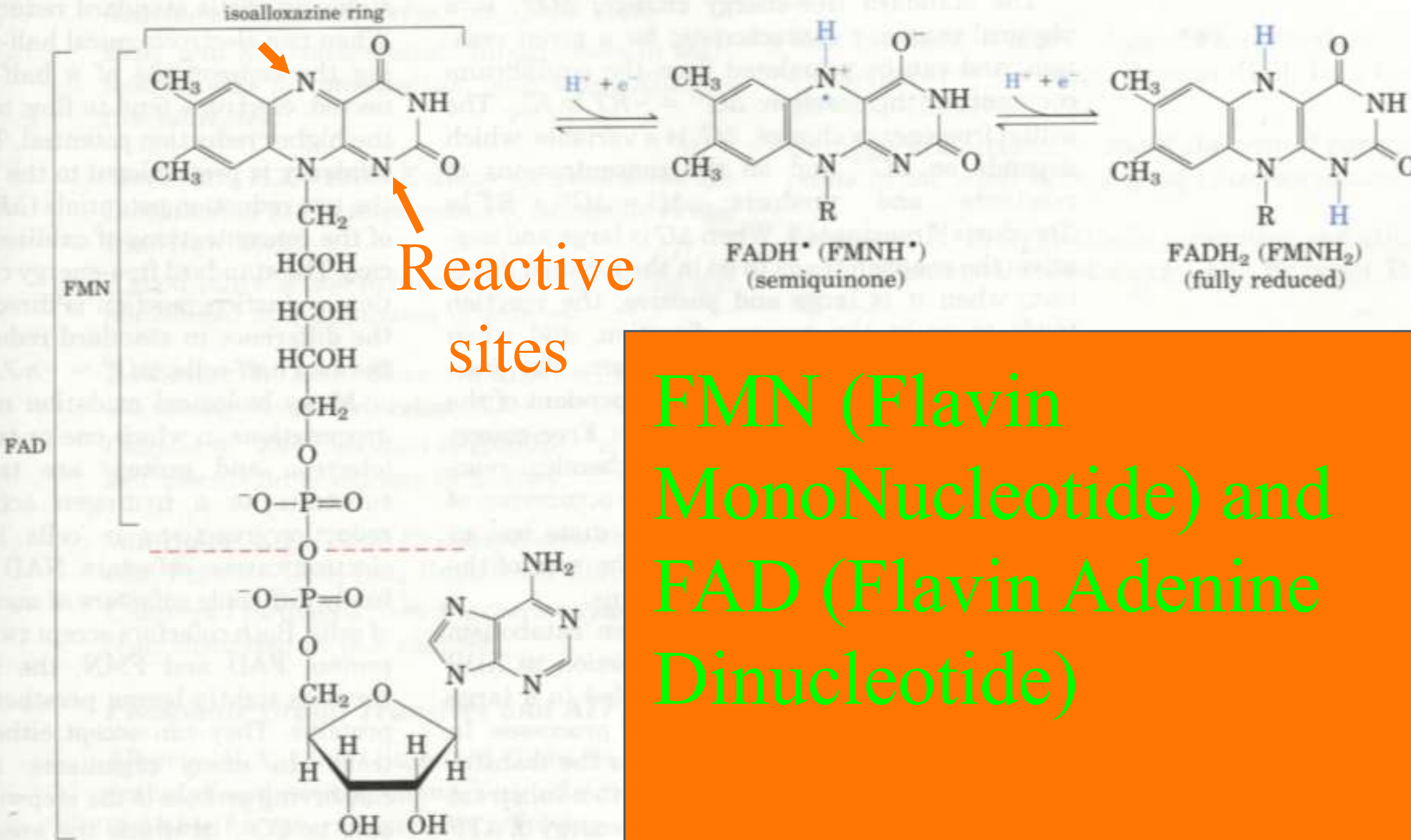


(a)

NAD (N̲icotinamide A̲denine D̲inucleotide) & NADP (N̲icotinamide A̲denine D̲inucleotide P̲hosphate)



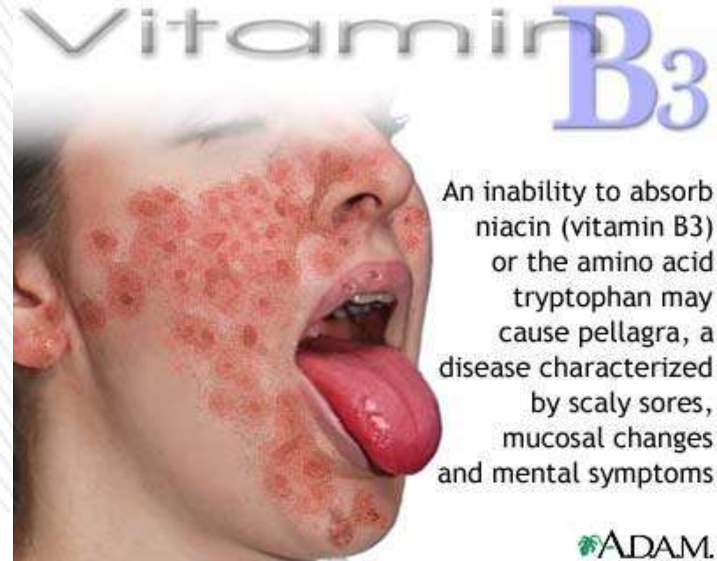
(b)



Flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN)

FMN (Flavin MonoNucleotide) and FAD (Flavin Adenine Dinucleotide)

Kekurangan vitamin niacin menyebabkan penyakit pellagra ("rough skin" disease)



Frank Strong,
1908–1993

D. Wayne Woolley,
1914–1966

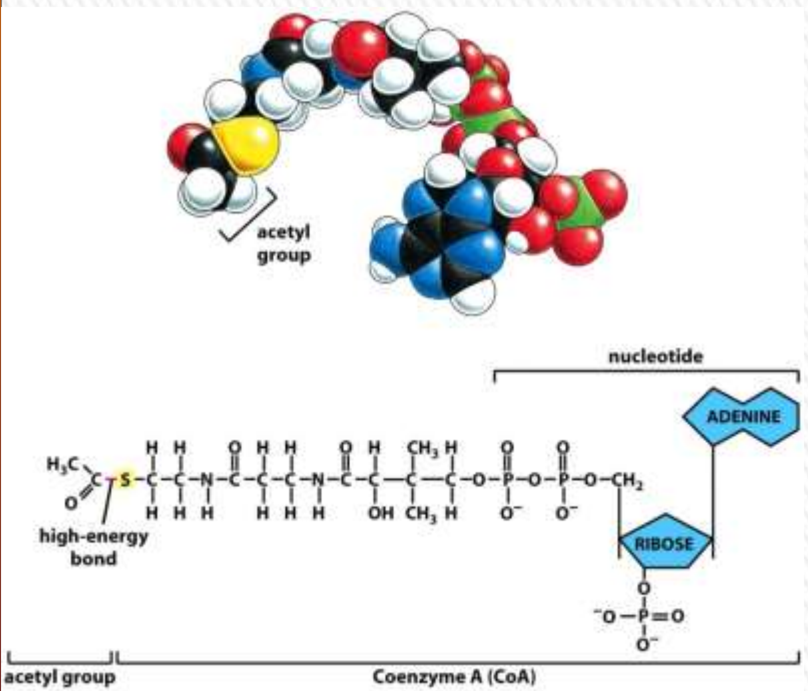
Conrad Elvehjem,
1901–1962

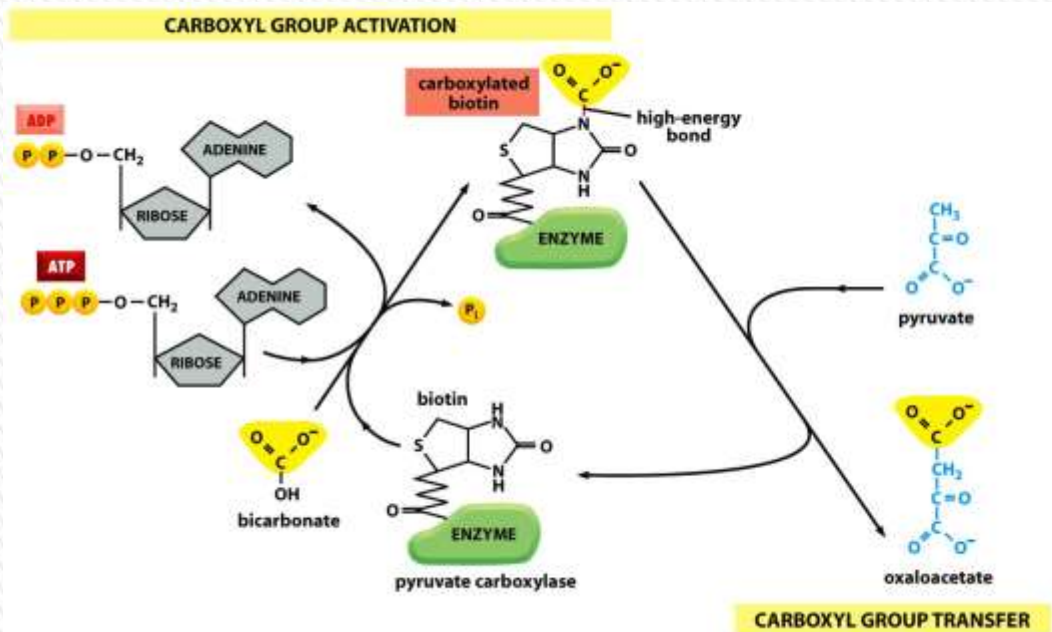
They identified in 1937 that niacin is the curative agent For pellagra ("blacktongue" in dogs) .

Molekul carrier lainnya

Table 2–5 Some Activated Carrier Molecules Widely Used in Metabolism

ACTIVATED CARRIER	GROUP CARRIED IN HIGH-ENERGY LINKAGE
ATP	phosphate
NADH, NADPH, $FADH_2$	electrons and hydrogens
Acetyl CoA	acetyl group
Carboxylated biotin	carboxyl group
S-Adenosylmethionine	methyl group
Uridine diphosphate glucose	glucose





Energi untuk bekerja

- Karbohidrat
  - Glukosa
    - Disimpan sebagai glikogen
- Lemak
  - Terutama berupa asam lemak
    - Disimpan sebagai trigliserida
- Protein
  - Bukan merupakan sumber energi utama

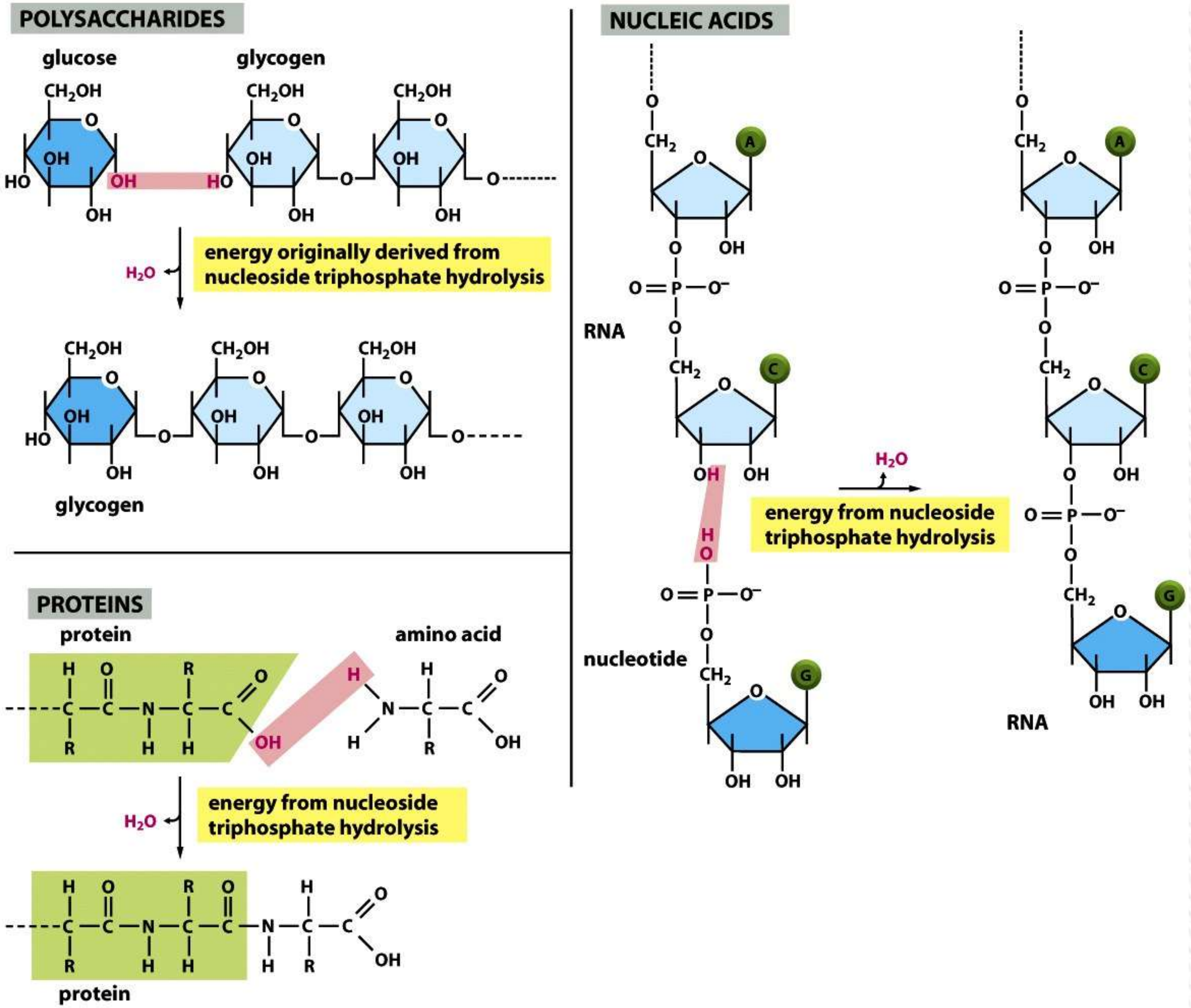


Figure 2-65 *Molecular Biology of the Cell* (© Garland Science 2008)

Pembentukan energi sel

- Sumber energi utama : gula
  - Sel tumbuhan → dapat membuat sumber energinya sendiri dari hasil fotosintesis
  - Sel hewan → memperoleh dari makanan
- Oksidasi gula/sumber energi → proses di sel hewan = sel tumbuhan:
  - Energi yang terikat pada gula → oksidasi → CO_2 dan H_2O → dengan sistem kerja yang sangat efektif dan efisien
  - Energi tersimpan dalam molekul ATP dan NADH