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Bioenergitics

Energy & why do we need it?

- **Definition: Capacity to perform work**
- **Types of energy:**
 - ✓ **1- Kinetic: Energy in the process of doing work or Energy of motion**
 - ✓ **2- Potential: Energy content stored in a matter**
- **Why products are more stable than the reactants?**
- **Whether a reaction occurs or not!**



Why Do Chemical Reactions Occur?

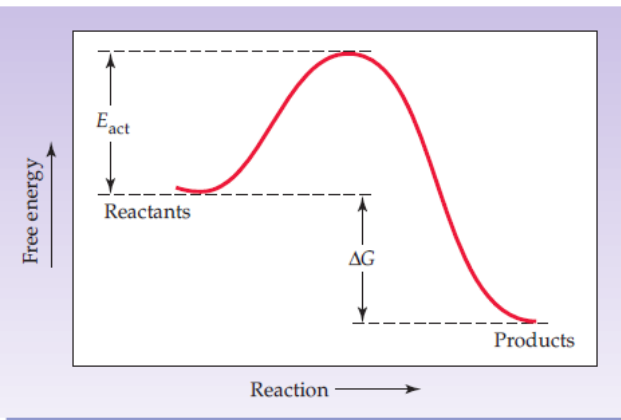
Concept of Free Energy, Gibbs Equation

- Free energy change
- Exergonic vs. endergonic
- The concept of activation energy
- Favorability vs. rates of reactions (thermodynamic vs. kinetic)
- Do all favorable reactions occur at room temperature? “The theory of collision”

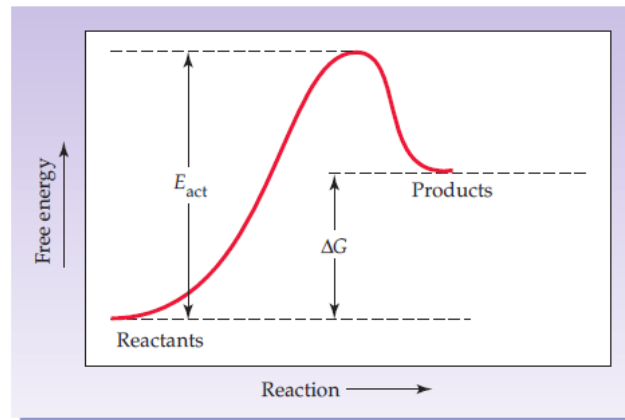
Free-energy change

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

Heat of reaction Temperature (in kelvins) Entropy change



(a) An exergonic reaction

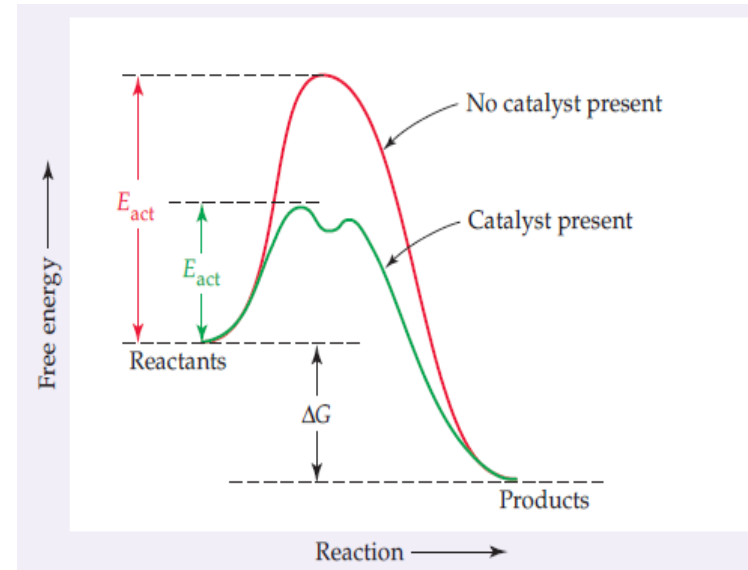
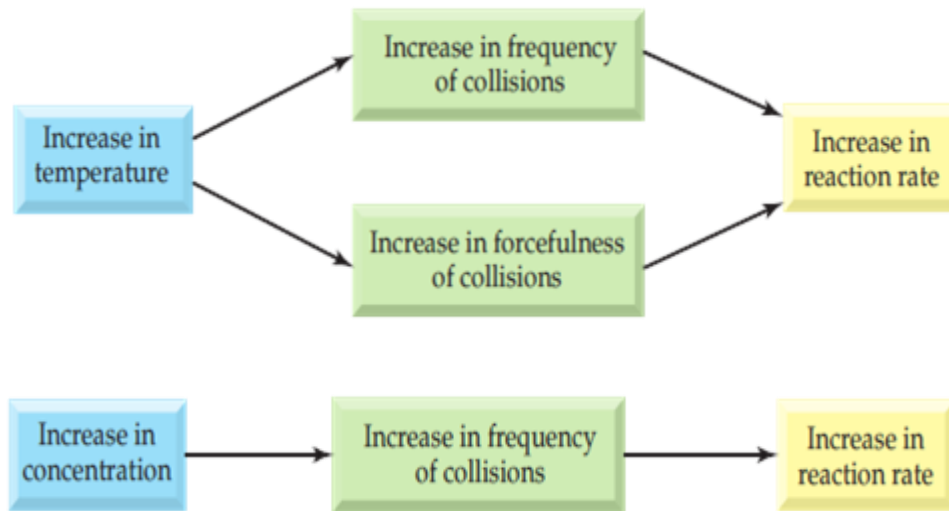


(b) An endergonic reaction

Effect of temperature, concentration & catalysts

$$\Delta G = \Delta G^\circ$$

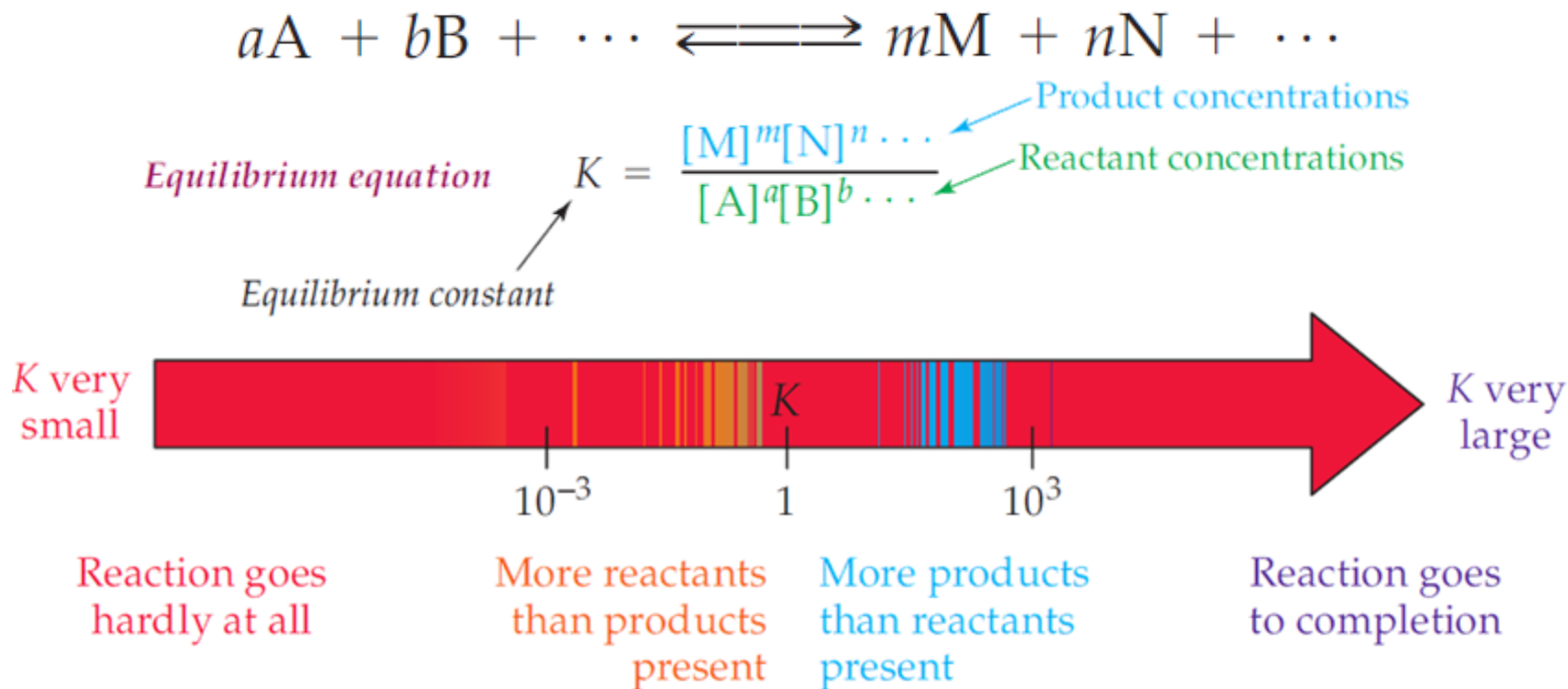
$$\Delta G = \Delta G^\circ + 0$$



- ΔG = the free energy difference of a system at any condition
- ΔG° = the free energy difference of a system at standard conditions (25°C & 1 atmospheric pressure, 1M concentration of reactants & products, pH = 7)
- Which one of these terms determine the feasibility of the reaction?

Reversible Reactions & Chemical Equilibrium

- What is a reversible reaction?
- What is the chemical equilibrium? Chemical equilibrium is an active, dynamic condition
- At equilibrium, are concentrations equal?



ΔG & K_{eq}

- At equilibrium, $\Delta G = 0$
- Can a reaction has a + ΔG° & still be favorable?

For a reaction $A + B \leftrightarrow C + D$

$$\Delta G = \Delta G^\circ + RT \ln \left(\frac{[C][D]}{[A][B]} \right)$$

$$\Delta G = \Delta G^\circ + RT \ln \left(\frac{[C][D]}{[A][B]} \right)$$

$$0 = \Delta G^\circ + RT \ln \left(\frac{[C][D]}{[A][B]} \right)$$

$$\Delta G^\circ = -RT \ln \left(\frac{[C][D]}{[A][B]} \right)$$

$$\text{defining } K'_{eq} = \left(\frac{[C][D]}{[A][B]} \right)$$

$$\Delta G^\circ = -RT \ln K'_{eq}$$

K'_{eq}	ΔG° kJ/mol	Starting with 1 M reactants & products, the reaction:
10^4	- 23	proceeds forward (spontaneous)
10^2	- 11	proceeds forward (spontaneous)
$10^0 = 1$	0	is at equilibrium
10^{-2}	+ 11	reverses to form “reactants”
10^{-4}	+ 23	reverses to form “reactants”

The Effect of Changing Conditions on Equilibria

$$\text{defining } K'_{eq} = \left(\frac{[C][D]}{[A][B]} \right)$$

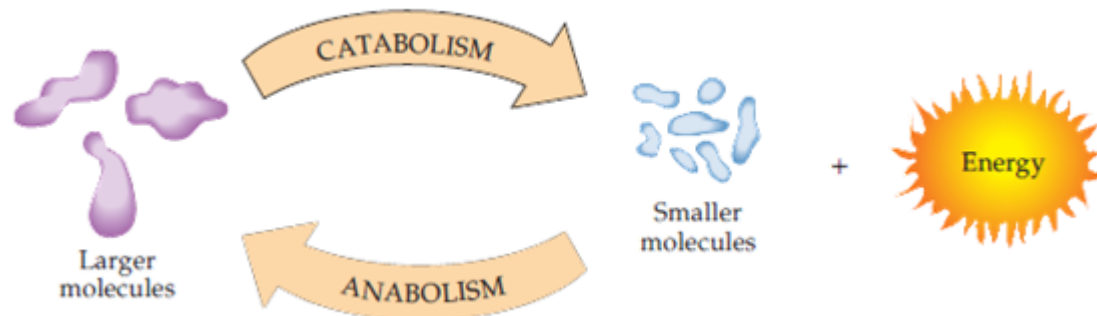
$$\Delta G^{o'} = -RT \ln K'_{eq}$$



- When a stress is applied to a system at equilibrium, the equilibrium shifts to relieve the stress
- Stress: any change that disturbs the original equilibrium
 - Effect of Changes in Concentration
 - ✓ What happens if a reactant/product is continuously supplied/removed?
 - ✓ Metabolic reactions sometimes take advantage of this effect
 - Effect of Changes in Temperature
 - ✓ Endothermic/exothermic are favored by increase/decrease in temperature, respectively.
 - Effect of a catalyst on equilibrium

Energy and metabolic pathways

- **Anabolic Pathways (Endergonic reactions):**
Those that consume energy to build biomolecules
(Protein, Glycogen & lipids)
- **Catabolic Pathways (Exergonic reactions):**
Those that release energy by breaking down complex molecules into simpler compounds such as glycolysis
- **Metabolism is essentially a linked series of chemical reactions (biochemical pathways)**



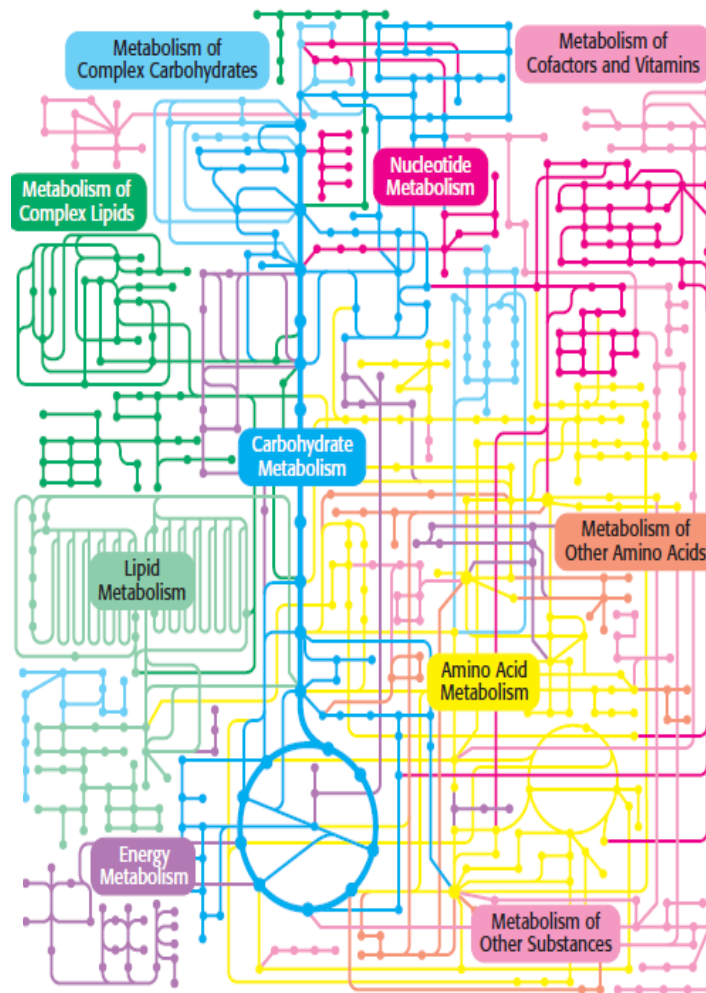
Biochemical (metabolic) pathways

- Are interdependent
- Are subjected to thermodynamics laws
- Their activity is coordinated by sensitive means of communication
- Allosteric enzymes are the predominant regulators
- Biosynthetic & degradative pathways are almost always distinct (regulation)
- Metabolic pathways are linear, cyclic or spiral

A linear sequence
A $\xrightarrow{\text{Enzyme 1}}$ B $\xrightarrow{\text{Enzyme 2}}$ C $\xrightarrow{\text{Enzyme 3}}$...

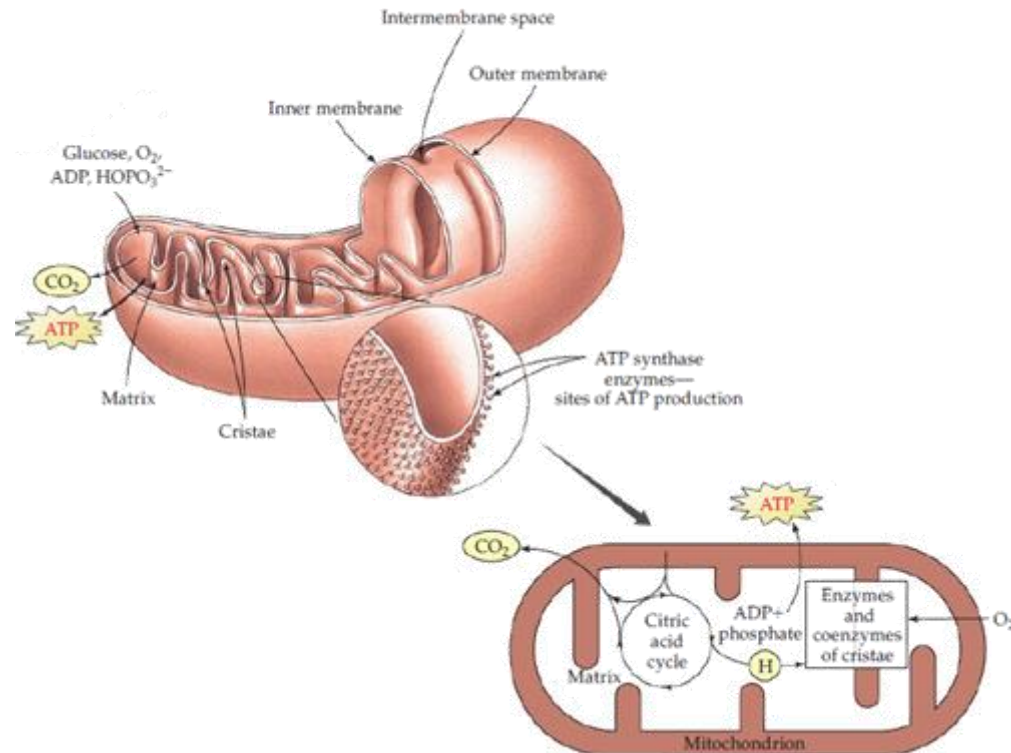
A cyclic sequence
A $\xrightarrow{\text{Enzyme 1}}$ B $\xrightarrow{\text{Enzyme 2}}$ C $\xrightarrow{\text{Enzyme 3}}$ D $\xrightarrow{\text{Enzyme 4}}$ A

A spiral sequence
A $\xrightarrow{\text{Enzymes 1} \rightarrow 4}$ B $\xrightarrow{\text{Enzymes 1} \rightarrow 4}$ C $\xrightarrow{\text{Enzymes 1} \rightarrow 4}$...
Final product



The energy machinery of the cell

- Prokaryotic cells vs. eukaryotic cells
- The mitochondria (singular, mitochondrion) (90% of the body's energy ATP)
- The number of mitochondria is greatest in eye, brain, heart, & muscle, where the need for energy is greatest
- The ability of mitochondria to reproduce (athletes)
- Maternal inheritance



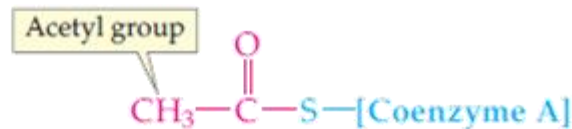
Stages of Energy Production

➤ Stage 1 (Digestion):

- ✓ Mouth, stomach, & small intestine
- ✓ Carbohydrates to glucose & other sugars
- ✓ Proteins to amino acids
- ✓ Triacylglycerols to glycerol plus fatty acids
- ✓ From there to blood

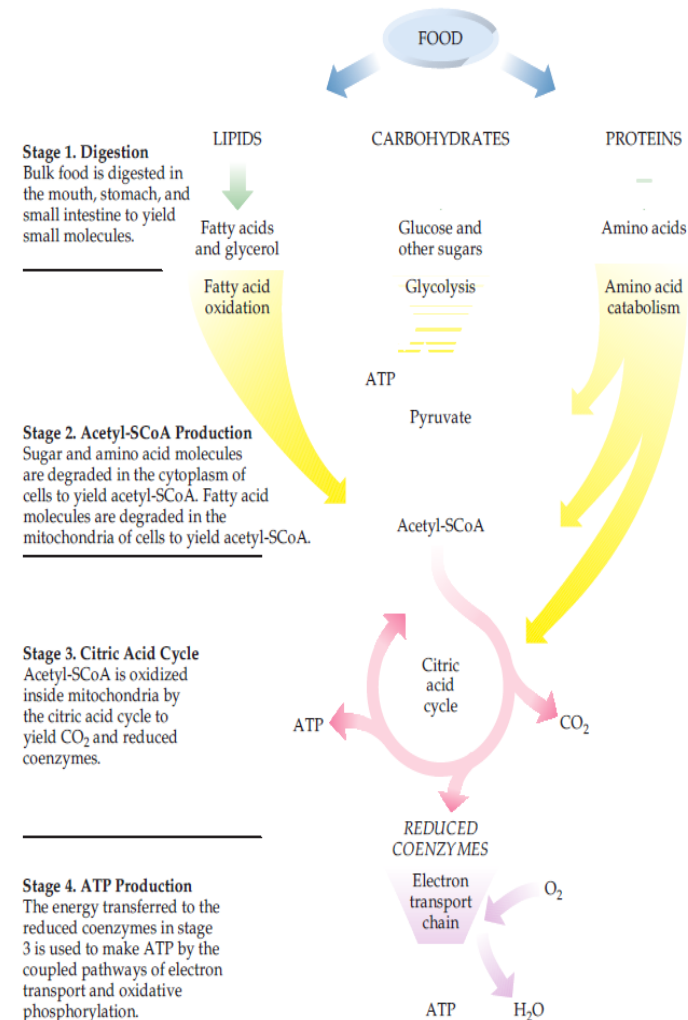
➤ Stage 2 (Acetyl-coenzyme A)

Attachment of acetyl group to coenzyme A



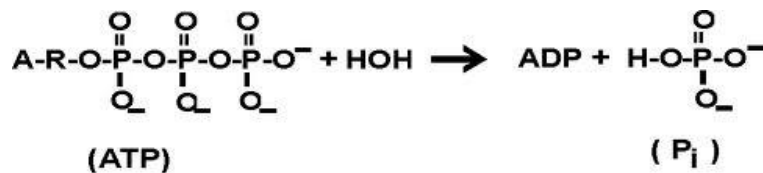
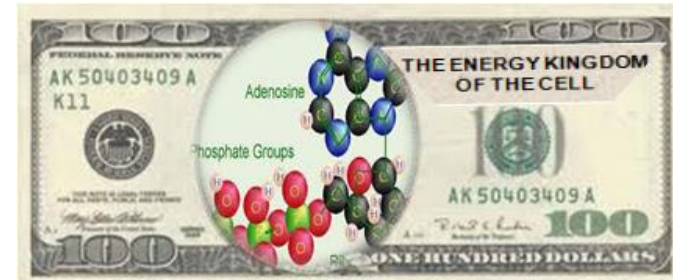
➤ Stage 3: citric acid cycle

➤ Stage 4: electron transfer chain & oxidative phosphorylation

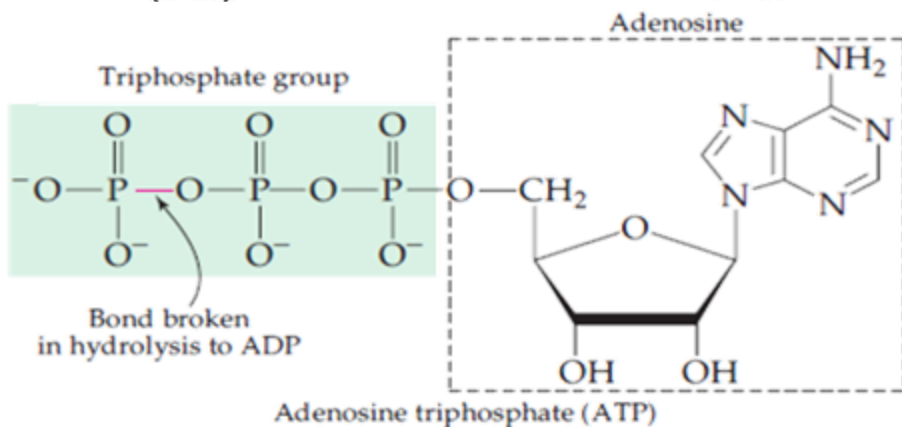


ATP

- ATP is the energy currency of the cell
- What is a high energy molecule?
- Why ATP?
 - Has an intermediate energy value, so can be coupled



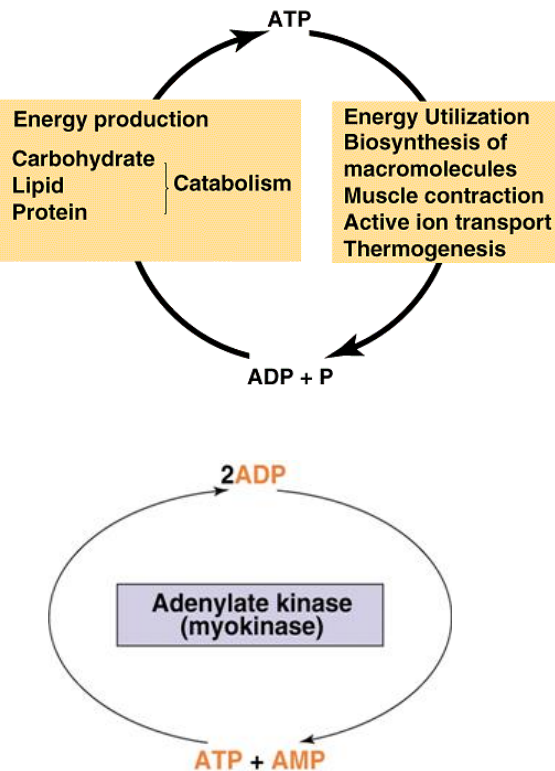
-7.3 kcal/mole
-3.4 kcal/mole



Compound + H ₂ O	Product + phosphate	ΔG°
Phosphoenol pyruvate	Pyruvate	-14.8
1,3 biphosphoglycerate	3 phosphoglycerate	-11.8
Creatine phosphate	Creatine	- 10.3
ATP	ADP	- 7.3
Glucose 1- phosphate	Glucose	-5.0
Glucose 6- phosphate	Glucose	-3.3

Is ATP a good long-term energy storage molecule?

- As food in the cells is gradually oxidized, the released energy is used to re-form the ATP so that the cell always maintains a supply of this essential molecule



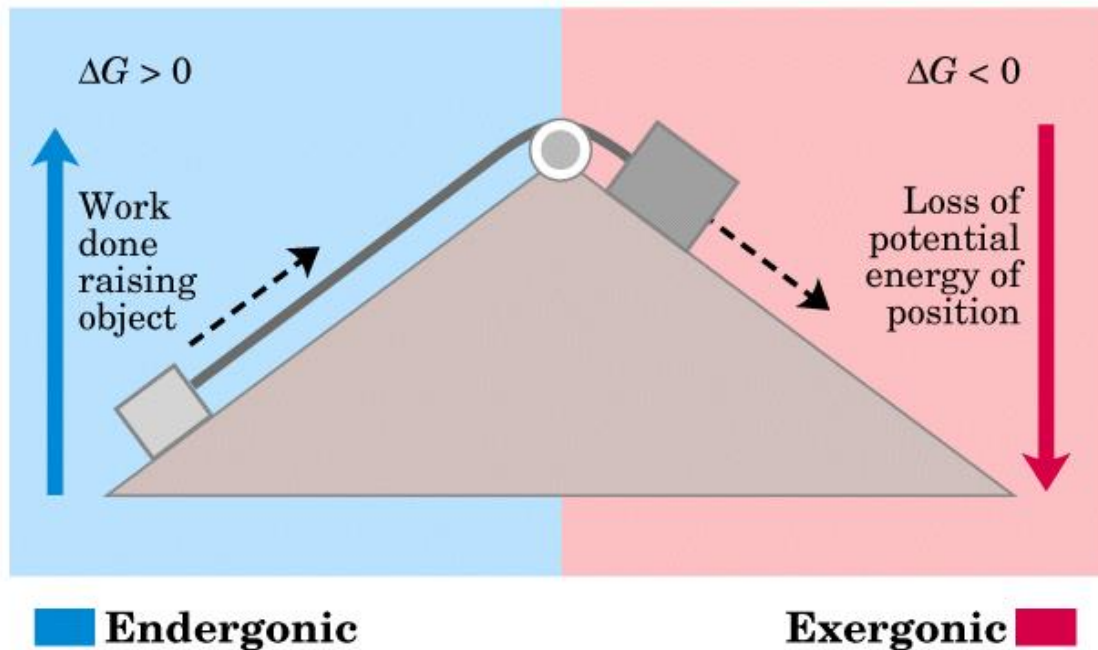
Tissue	ATP turnover (mole/day)
Brain	20.4
Heart	11.4
Kidney	17.4
Liver	21.6
Muscle	19.8
Total	90.6



$$90.6 * 551 \text{ (g/mole)} = 49,920 \text{ g ATP}$$

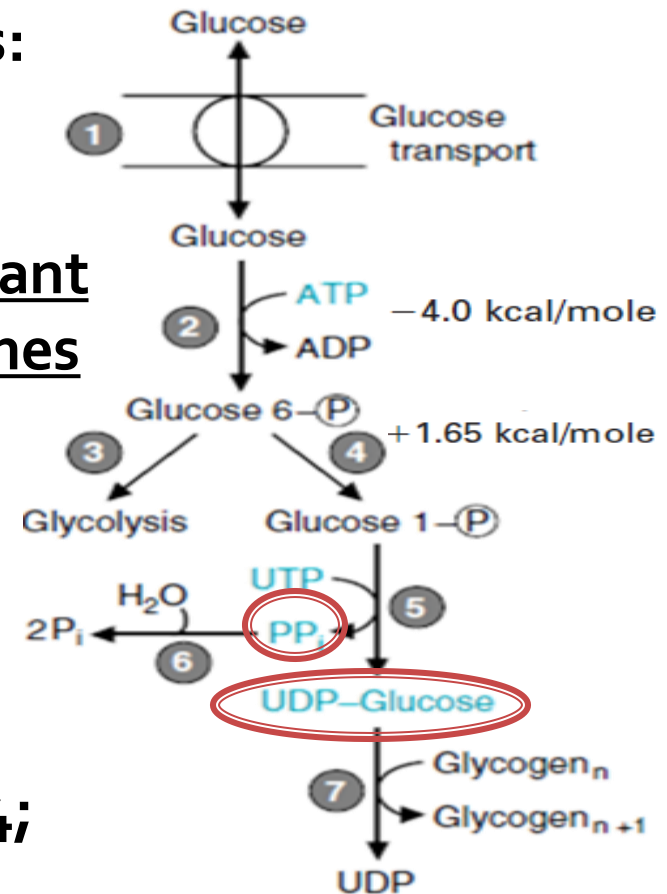
How do our cells get energy for unfavorable biochemical work?

➤ The concept of coupling



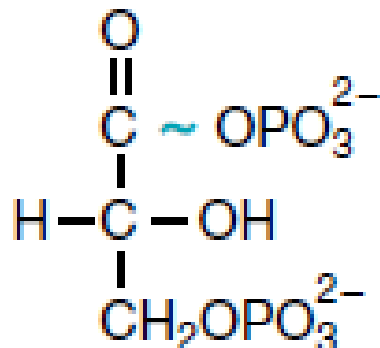
How do our cells get energy for unfavorable biochemical work?

- I. ΔG° Values are additive
 - i. Through phosphoryl transfer reactions:
 - ✓ Step 2 (+3.3 vs. -4 kcal/mole)
 - ✓ Step 2 + 4 = -2.35 kcal/mole
 - ✓ The net value for synthesis is irrelevant to the presence or absence of enzymes
 - ii. Activated intermediates (step 4 is facilitated by steps 5&6)
- II. ΔG Depends on Substrate and Product Concentration (step 4 has a ratio of 6/94; +1.65 kcal/mol, if 3/94; -0.4 kcal/mol)

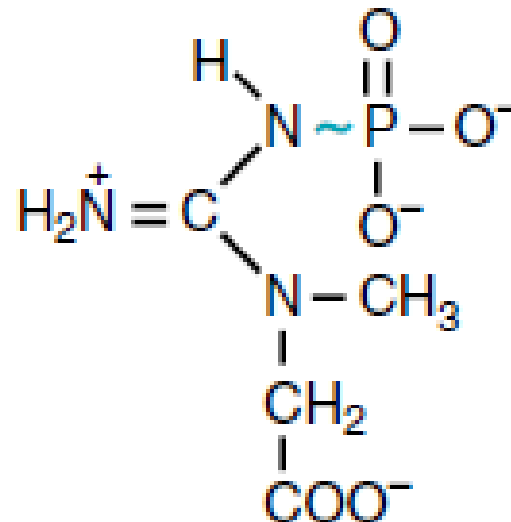
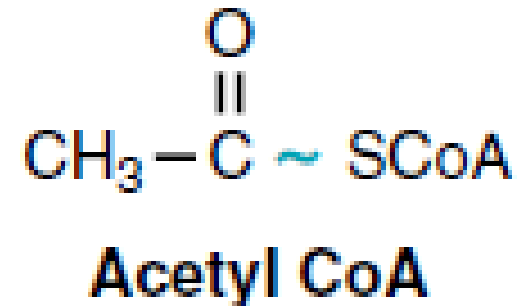


How do our cells get energy for unfavorable biochemical work?

- III. Activated Intermediates
other than ATP; UTP is used
for combining sugars, CTP in
lipid synthesis, and GTP in
protein synthesis



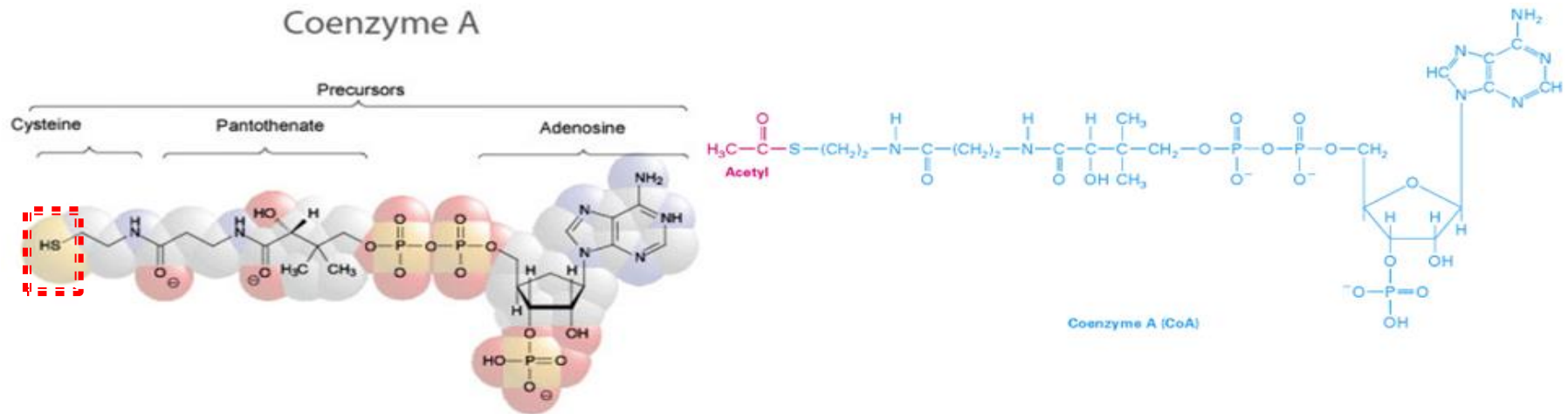
1,3-Bisphosphoglycerate



Creatine phosphate

The acetyl CoA as an example

- Coenzyme A is a universal carrier (donor) of Acyl groups
- Forms a thio-ester bond with carboxyl group



- Acetyl CoA + H₂O \longrightarrow Acetate + CoA $\Delta G^\circ = -7.5 \text{ kcal}$
 - Acetylcholine + H₂O \longrightarrow Acetate + Choline $\Delta G^\circ = -3 \text{ kcal}$
 - $\quad \quad \quad$ + Choline \longrightarrow Acetylcholine + $\Delta G^\circ = +3 \text{ kcal}$
 - Acetyl CoA + \longrightarrow $\quad \quad \quad$ + CoA $\Delta G^\circ = -7.5 \text{ kcal}$
-
- Acetyl CoA + Choline \longrightarrow Acetylcholine + COA

THERMOGENESIS

- The first law of thermodynamics
- Heat production is a natural consequence of “burning fuels”
- Thermogenesis refers to energy expended for generating heat (37°C) in addition to that expended for ATP production
- Shivering thermogenesis (ATP utilization): responding to sudden cold with asynchronous muscle contractions
- Non-shivering thermogenesis (ATP production efficiency)



Oxidation-Reduction reactions (Redox)

➤ Oxidation:

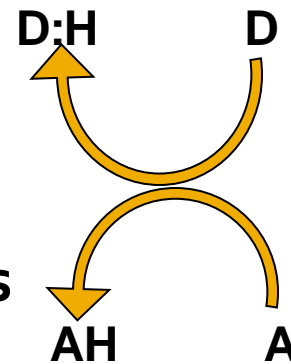
- ✓ Gain of Oxygen
- ✓ Loss of Hydrogen
- ✓ Loss of electrons

➤ Reduction:

- ✓ Gain of Hydrogen
- ✓ Gain of electron
- ✓ Loss of Oxygen

- **E = redox Potential:** it is a **POTENTIAL ENERGY** that measures the tendency of oxidant/reductant to gain/lose electrons, to become reduced/oxidized

- Electrons move from compounds with lower reduction potential (more negative) to compounds with higher reduction potential (more positive)



- Oxidation and reduction must occur simultaneously

Oxidation-Reduction reactions (Redox)

- $\Delta E = E_A - E_D$
- ΔE = Redox difference of a system in any condition
- ΔE° = Redox difference of a system in standard condition (25C° and 1 atmosphere pressure, pH = 7)
 - Does ΔE determine the feasibility of a reaction?
 - $\Delta G^\circ = -nf\Delta E^\circ$

ΔG is related to ΔE

➤ ΔE is directly proportional to ΔG°

➤ $\Delta G^\circ = -nf\Delta E^\circ$

➤ Where:

➤ n = the number of transferred electron

➤ F = the Faraday constant (96.5 kJ/volt) (23.06 kcal/volt)

➤ E = the reduction potential (volts);

➤ G = the free energy (Kcal or KJ)

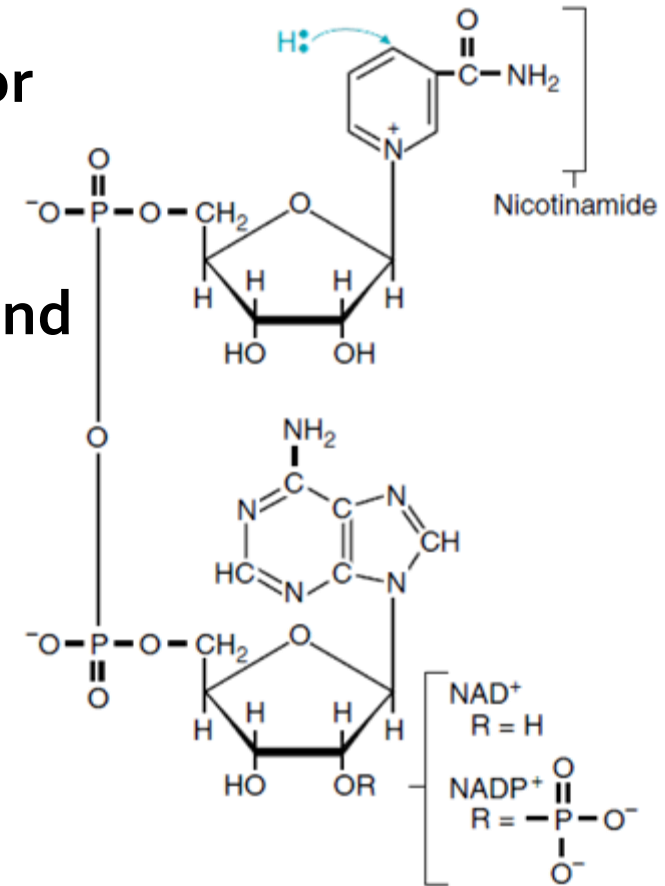
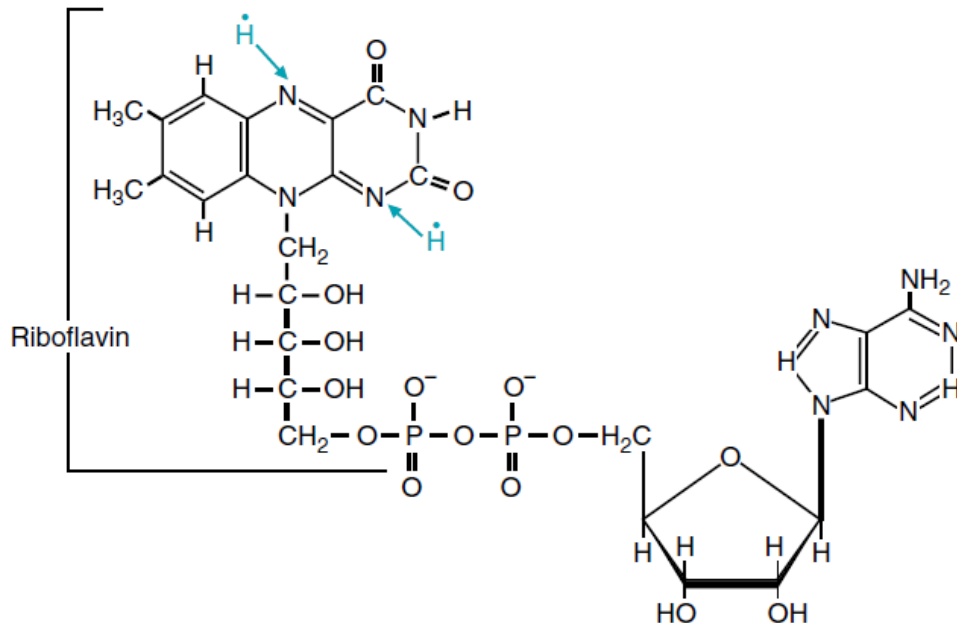
➤ In other words; energy (work) can be derived from the transfer of electrons

➤ Or

➤ Oxidation of foods can be used to synthesize ATP

Oxidation-Reduction reactions (Redox)

- Always involve a pair of chemicals: an electron donor and an electron acceptor (Food vs. NAD^+)
- NAD^+ vs. FAD
- NAD^+ vs. NADP^+ (fatty acid synthesis and detoxification reactions)

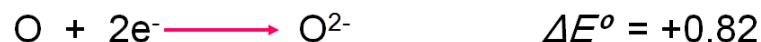


Oxidation-Reduction reactions (Redox)

- The more negative the reduction potential, the greater is the energy available for ATP generation

Table 19.4. Reduction Potentials of Some Oxidation-Reduction Half-Reactions

Reduction Half-Reactions	$E^{\circ'}$ at pH 7.0
$1/2 \text{ O}_2 + 2\text{H}^+ + 2 \text{e}^- \rightarrow \text{H}_2\text{O}$	0.816
Cytochrome a- $\text{Fe}^{3+} + 1 \text{e}^- \rightarrow$ cytochrome a- Fe^{2+}	0.290
$\text{CoQ} + 2\text{H}^+ + 2 \text{e}^- \rightarrow \text{CoQH}_2$	0.060
Fumarate + $2\text{H}^+ + 2 \text{e}^- \rightarrow$ succinate	0.030
Oxalacetate + $2\text{H}^+ + 2 \text{e}^- \rightarrow$ malate	-0.102
Acetaldehyde + $2\text{H}^+ + 2 \text{e}^- \rightarrow$ ethanol	-0.163
Pyruvate + $2\text{H}^+ + 2 \text{e}^- \rightarrow$ lactate	-0.190
Riboflavin + $2\text{H}^+ + 2 \text{e}^- \rightarrow$ riboflavin- H_2	-0.200
$\text{NAD}^+ + 2\text{H}^+ + 2 \text{e}^- \rightarrow \text{NADH} + \text{H}^+$	-0.320
Acetate + $2\text{H}^+ + 2 \text{e}^- \rightarrow$ acetaldehyde	-0.468



$$\Delta G^{\circ} \approx - 53 \text{ kcal/mol}$$

$$\Delta G^{\circ} \approx - 41 \text{ kcal/mol}$$