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Bioenergitics

Energy & why do we need it?

- Definition: Capacity to perform work
- Types of energy:
  - -1Kinetic: Energy in the process of doing work or Energy of motion

  - -2Potential: Energy content stored in a matter

- Why products are more stable than the reactants?
- Whether a reaction occurs or not!

Thermodynamics/ Bioenergetics

- Thermodynamics: the study of energy transformations that occur in a collection of matter

- Bioenergetics: studying thermodynamics)energy) in living organisms

- First Law of thermodynamics: Energy cannot be created or destroyed, but only converted to other forms. Energy of universe is constant

- Second Law: All energy transformations are inefficient
  1. systems tend to increase in disorder
  2. systems lose usable energy as heat

Why Do Chemical Reactions Occur? Concept of Free Energy, *Gibbs Equation*

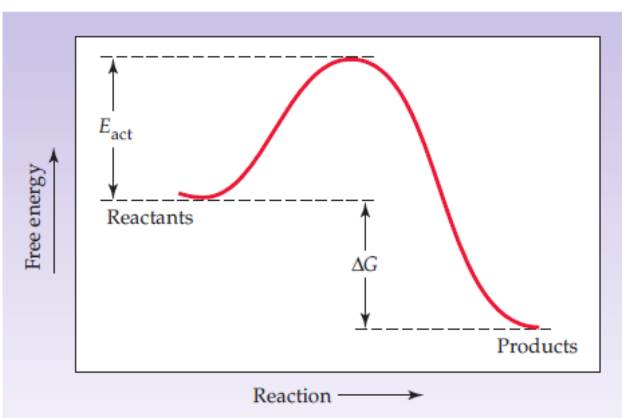
- Free energy change: the total energy change in a system with respect to its temperature

Heat of reaction | Temperature (in kelvins) | Entropy change

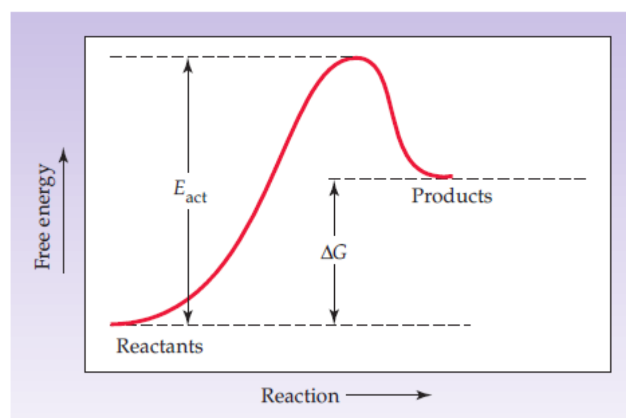
Free-energy change

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

- Exergonic vs. endergonic
- The value of the free-energy change determines spontaneity
- The concept of activation energy



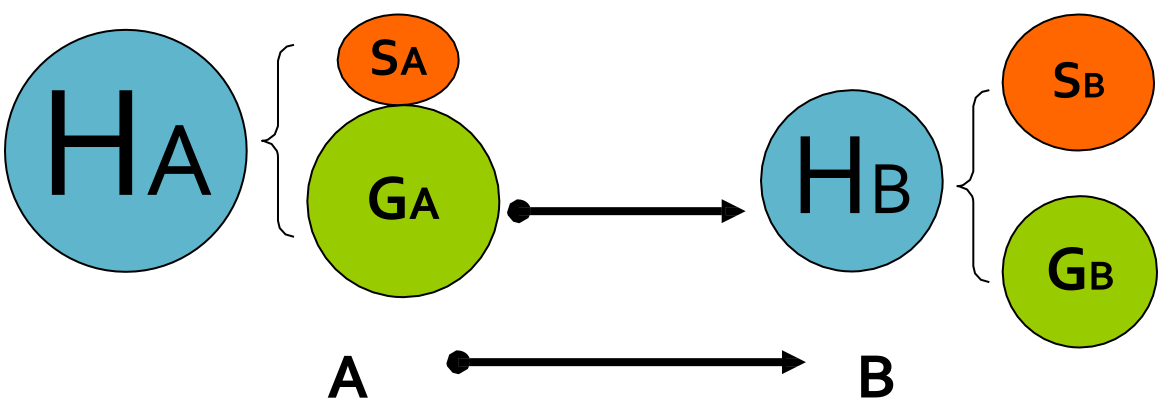
(a) An exergonic reaction



(b) An endergonic reaction

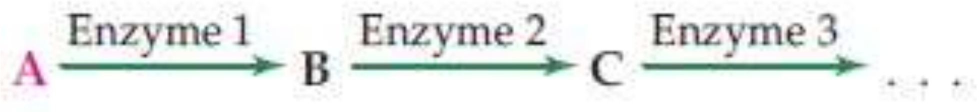
Energy of reactions

- Enthalpy)H &ΔH): A measure of the amount of energy associated with substances involved in a reaction
- Exothermic &endothermic vs. Spontaneous &non-spontaneous –NOT always
- Entropy)S, ΔS): The amount of disorder in a system (solid, liquid &gas(
- Favorable enthalpy &entropy vs. favorable reaction
  - ✓ ΔG= GB-GA
  - ✓ ΔH= HB-HA
  - ✓ ΔS= SB-SA



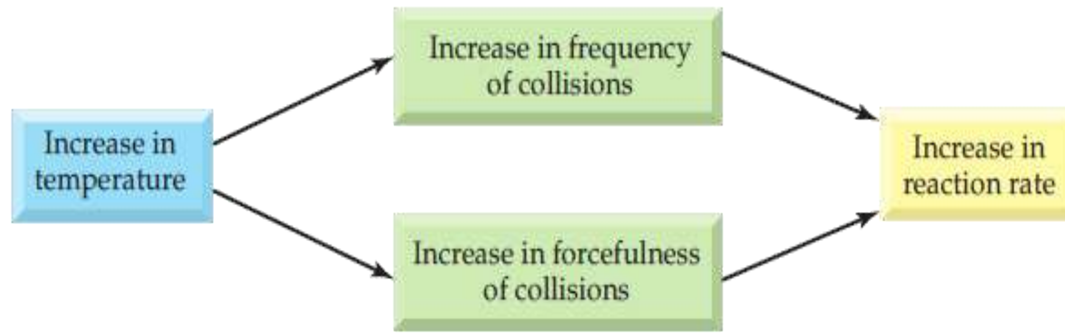
The different free energy terms

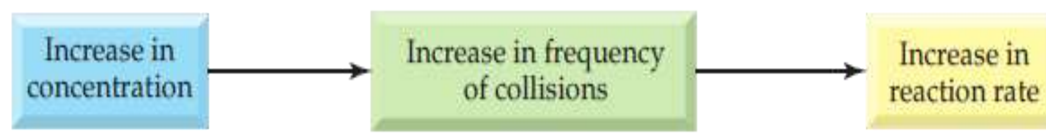
- ΔG =the free energy difference of a system at any condition
- ΔG^{o} =the free energy difference of a system at standard conditions 25)C° 1 &atmospheric pressure, 1M concentration of reactants &products, pH (7 =
- Which one of these terms determine the feasibility the reaction?
- ΔG depends only on initial state and final state of biochemical pathways
- ΔG is not affected by the mechanism of the reaction

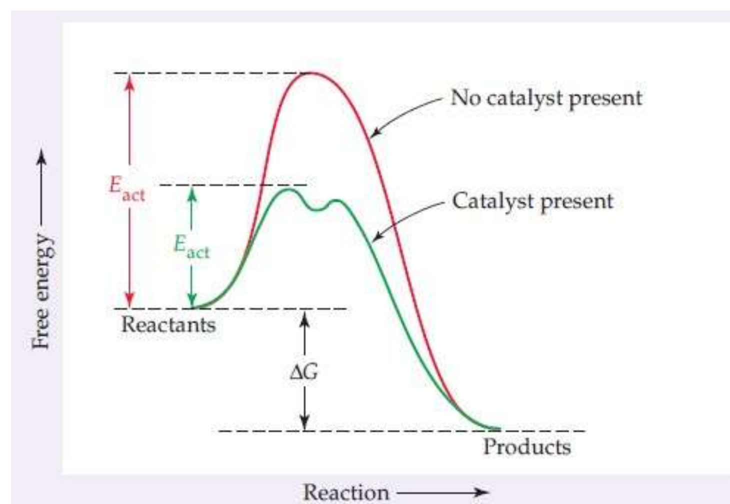


How Do Chemical Reactions Occur?

- **Favorability vs. rates of reactions (thermodynamic vs. kinetic(**
- **Do all favorable reactions occur at room temperature? "The theory of collision"**
- **Effect of temperature, concentration & catalysts**







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?

$$aA + bB + \cdots \rightleftharpoons mM + nN + \cdots$$

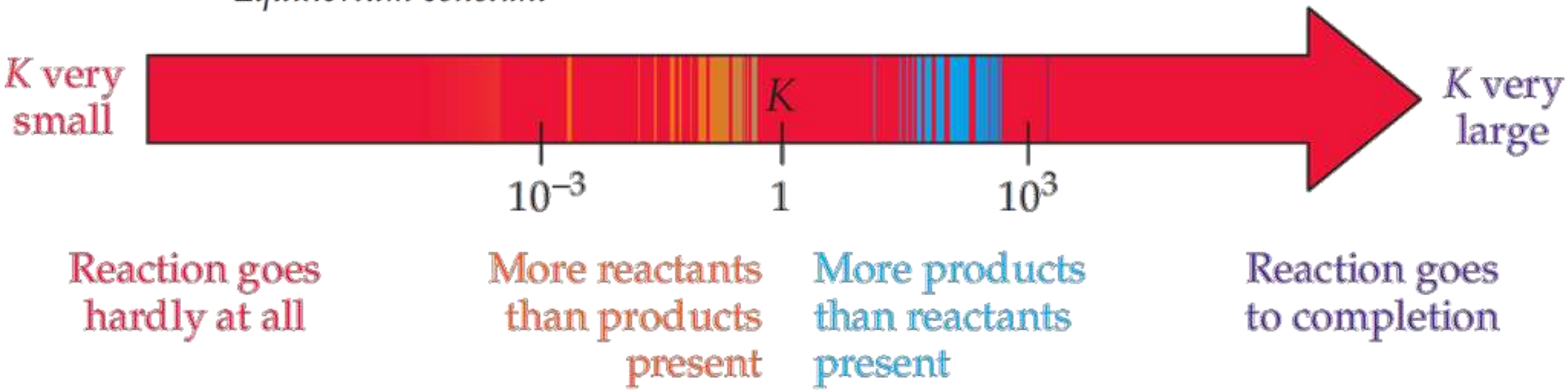
Equilibrium equation

$$K = \frac{[M]^m[N]^n \cdots}{[A]^a[B]^b \cdots}$$

Product concentrations

Reactant concentrations

Equilibrium constant



ΔG & K_{eq}

- At equilibrium, ΔG=o
- Can a reaction has a + ΔGo & still be favorable?

For a reaction **A + B ←→ C + D**

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

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

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

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

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

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

K'_{eq}	$\Delta G^{o\prime}$ kJ/mol	Starting with 1M reactants & products, the reaction:
10^4	23 -	proceeds forward (spontaneous(
10^2	11 -	proceeds forward (spontaneous(
$1 = 10^0$	0	is at **equilibrium**
$^{2-}10$	11 +	reverses to form "reactants"
$^{4-}10$	23 +	reverses to form "reactants"

The Effect of Changing Conditions on Equilibria

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

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

$$aA + bB + \cdots \rightleftharpoons mM + nN + \cdots$$

- 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.

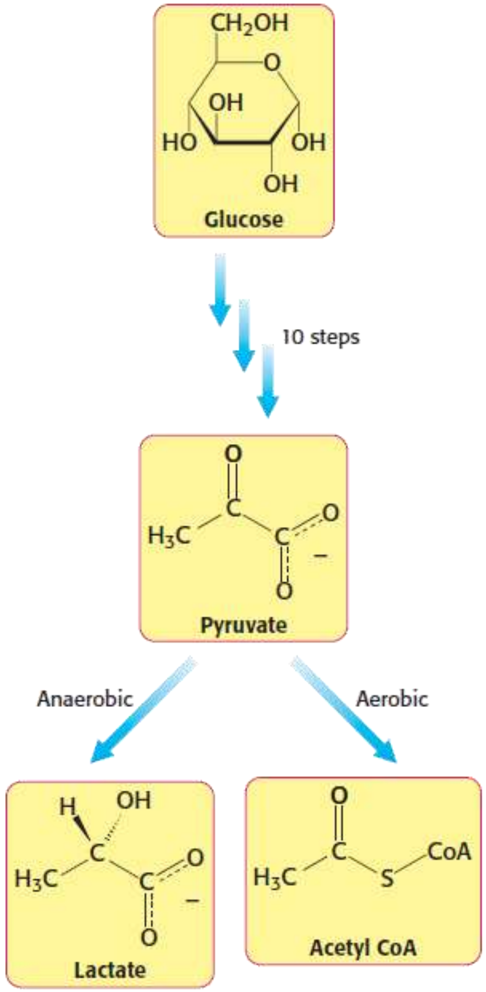
Effect of a catalyst on equilibrium

Metabolism

- What is the source of all energy?)autotrophs vs. heterotrophs(
- Why do we need energy?
  - ✓ (1)the performance of <u>mechanical work</u> in muscle contraction and cellular movements
  - ✓ (2)the <u>active transport</u> of molecules and ions
  - ✓ (3)the <u>synthesis</u> of macromolecules and other biomolecules from simple precursors

- How do we keep the energy in the body?

- Cellular metabolism: the sum of the total biochemical activities of all cells
- Metabolism consists of energy-yielding and energy-requiring reactions

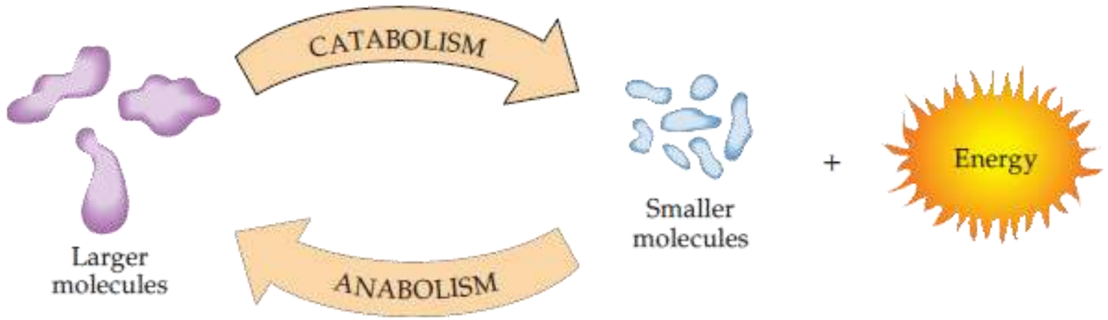


Energy and metabolic pathways

- **Anabolic Pathways)Endergonic reactions:(**
  Those that <u>consume</u> energy to <u>build</u> biomolecules)Protein, Glycogen &lipids(

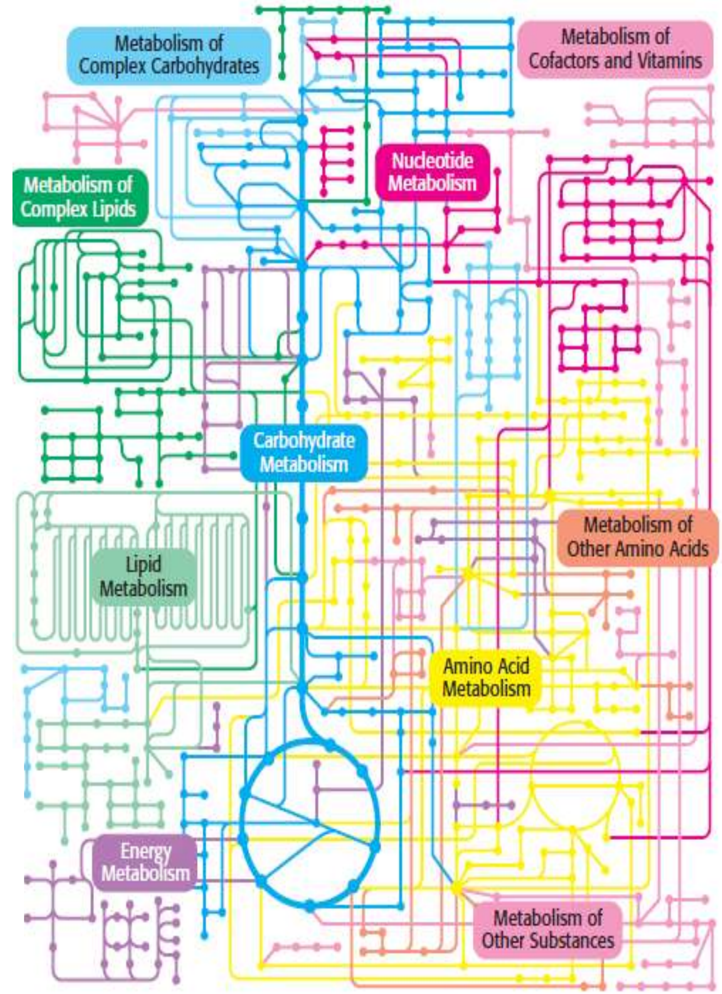
- **Catabolic Pathways)Exergonic reactions:(**
  Those that <u>release</u> energy by <u>breaking down</u> complex molecules into simpler compounds such as glycolysis

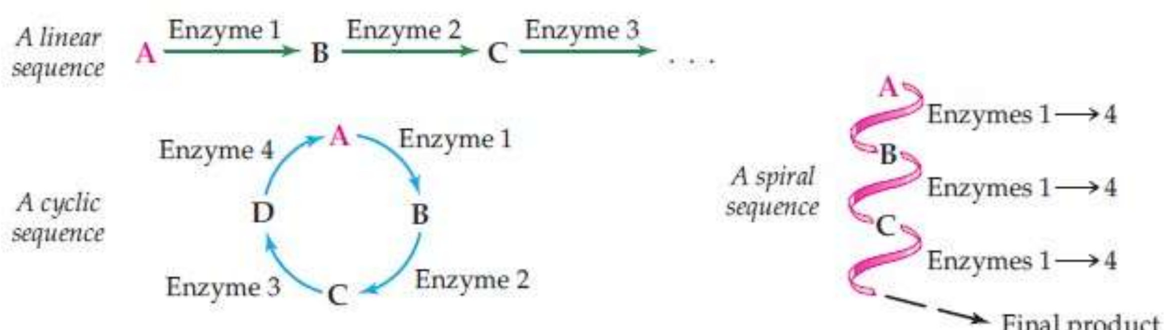
- **Metabolism is essentially a linked series of chemical reactions)biochemical pathways(**



Biochemical (metabolic) pathways

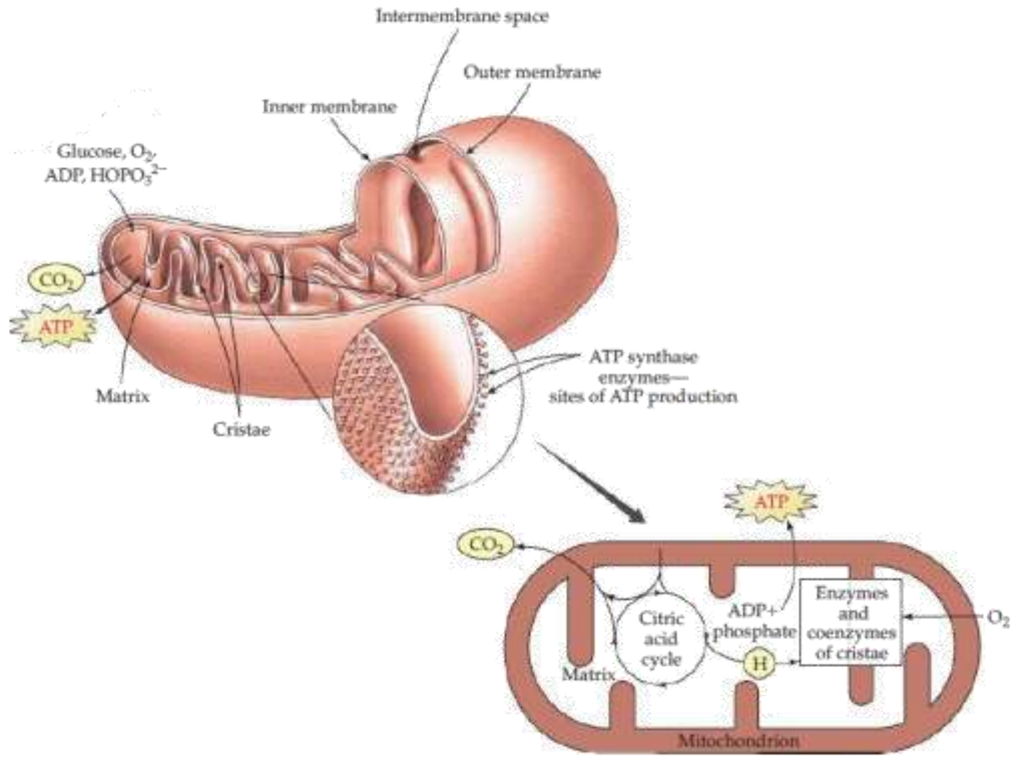
- Are <u>interdependent</u>
- Are subjected to thermodynamics laws
- Their activity is coordinated by sensitive means of communication
- <u>Allosteric enzymes</u> are the predominant regulators
- Biosynthetic &degradative pathways are <u>almost always distinct</u> (regulation(
- Metabolic pathways are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





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

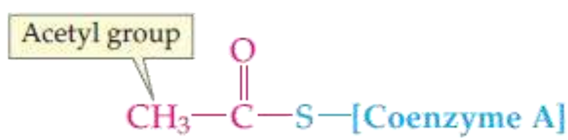


- The ability of mitochondria to reproduce (athletes)
- Maternal inheritance

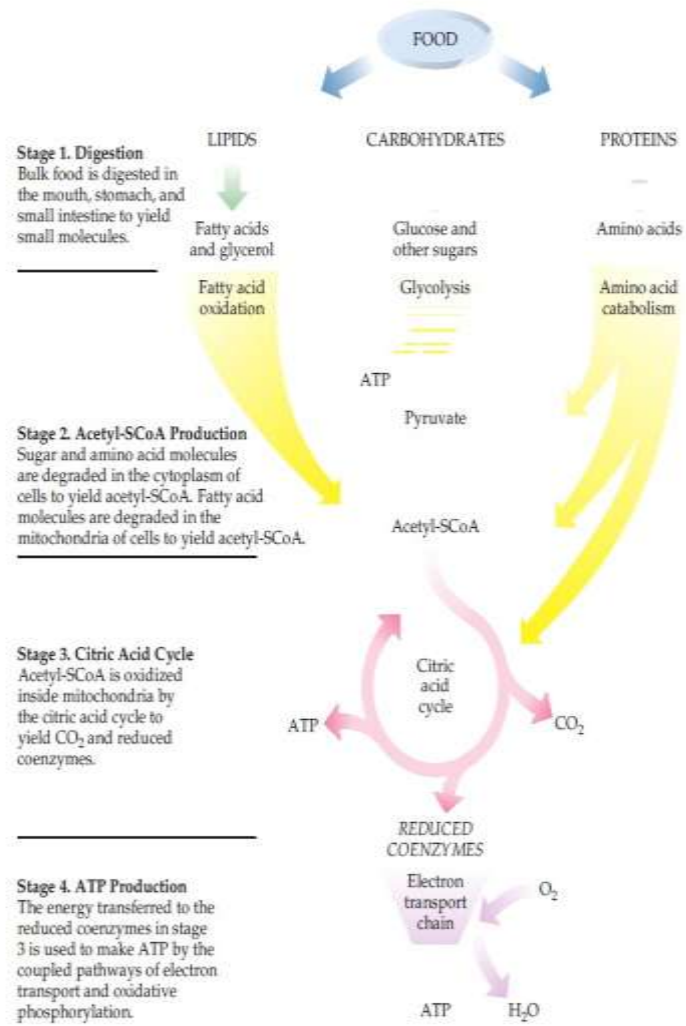
Stages of Energy Production

- Stage) 1Digestion:(
  - ✓Mouth, stomach& , small intestine
  - ✓Carbohydrates to glucose & other sugars
  - ✓Proteins to amino acids
  - ✓Triacylglycerols to glycerol plus fatty acids
  - ✓From there to blood
- Stage) 2Acetyl-coenzyme A(

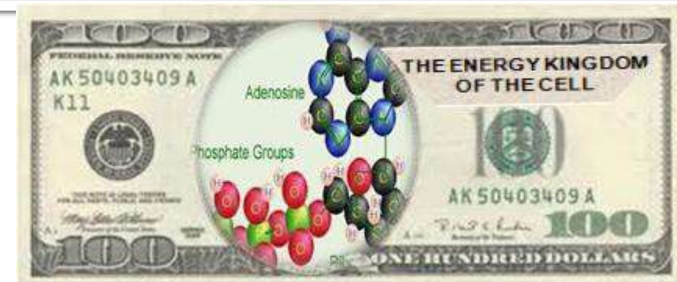
Attachment o facetyl group to coenzyme A



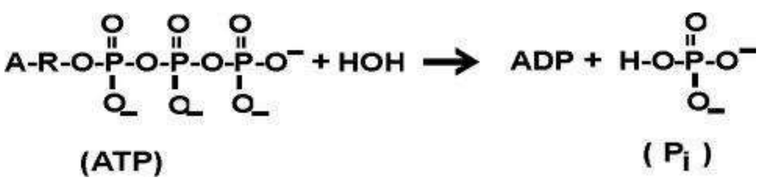
- Stage :3citric acid cycle
- Stage :4electron transfer chain & oxidative phosphorylation



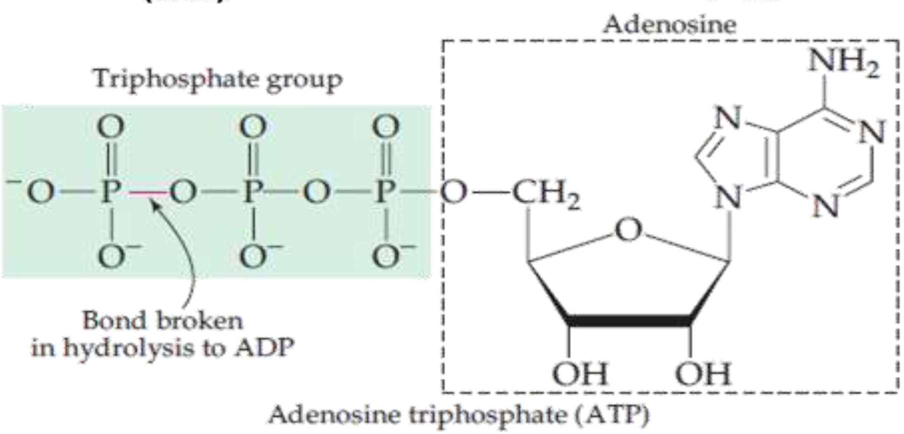
ATP



- 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



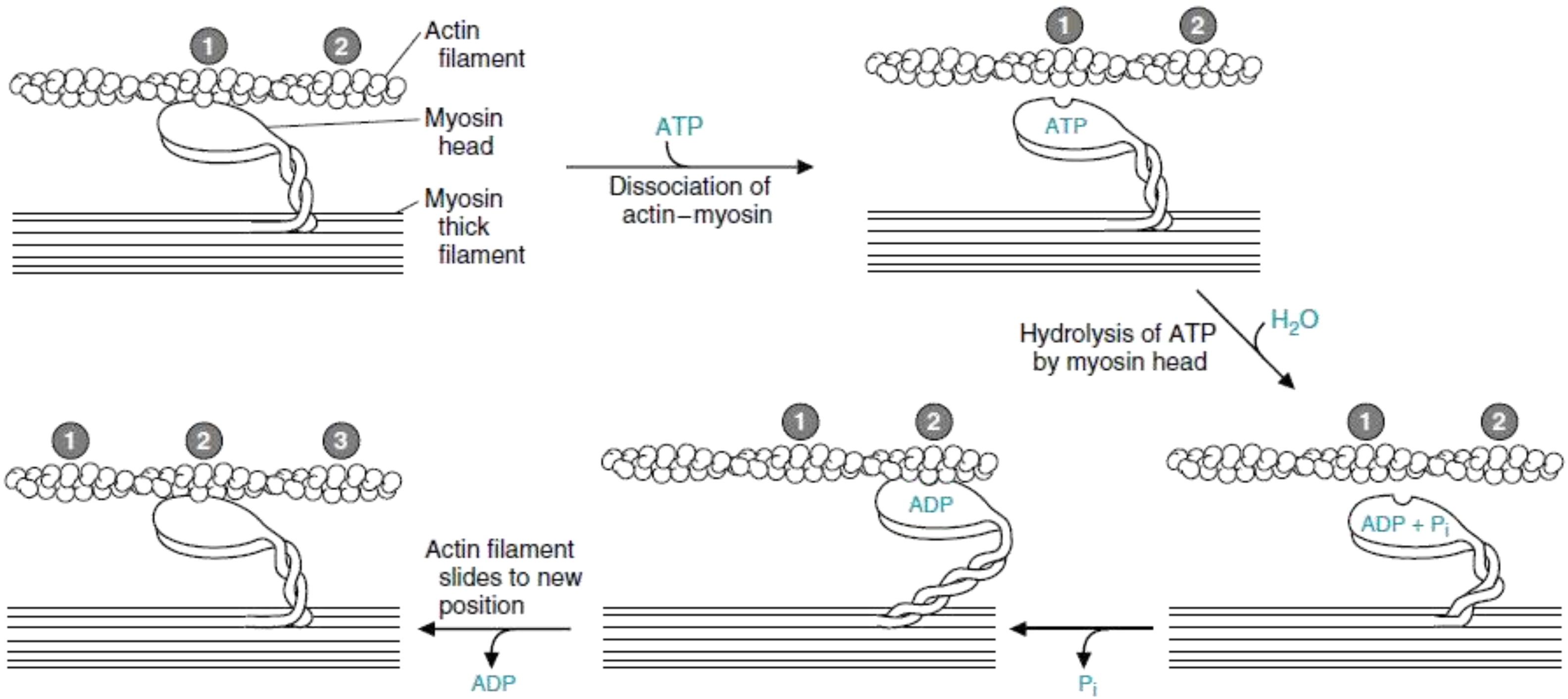
7.3-kcal/mole
3.4-kcal/mole



Compound $+H_2O$	Product + phosphate	ΔG°
Phosphoenol pyruvate	Pyruvate	-14.8
1,3 bisphosphoglycerate	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

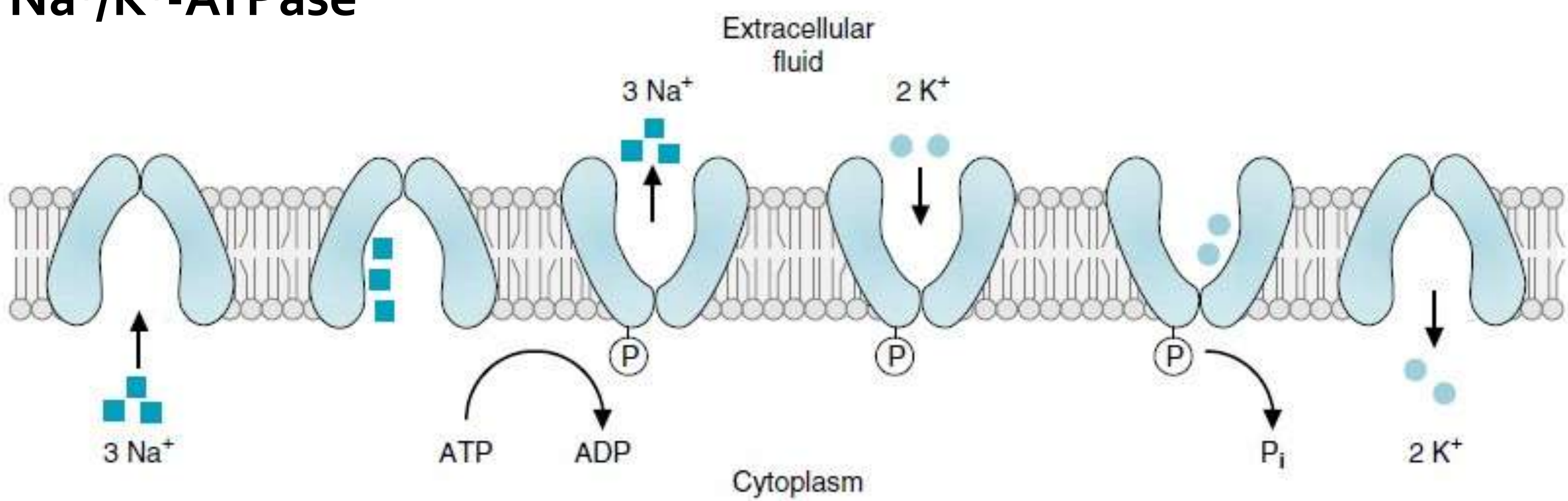
How & where is energy spent?
Energy transformation to do mechanical work

- Exercising muscle fibers have almost a hundred-fold higher rate of ATP utilization and caloric requirements than resting muscle fibers
- The high-energy phosphate bond of ATP is converted into movement by changing the conformation of a protein



How & where is energy spent?
Energy transformation to do transport work

- The expenditure of ATP for Na^+ transport occurs even while we sleep and is estimated to account for 10 to 30% of our BMR
- The high-energy phosphate bond of ATP is used to transport compounds against a concentration gradient
- Na^+ re-enters the cell on co-transport proteins that drive the uptake of amino acids and many other compounds into the cell
- Na^+/K^+-ATPase



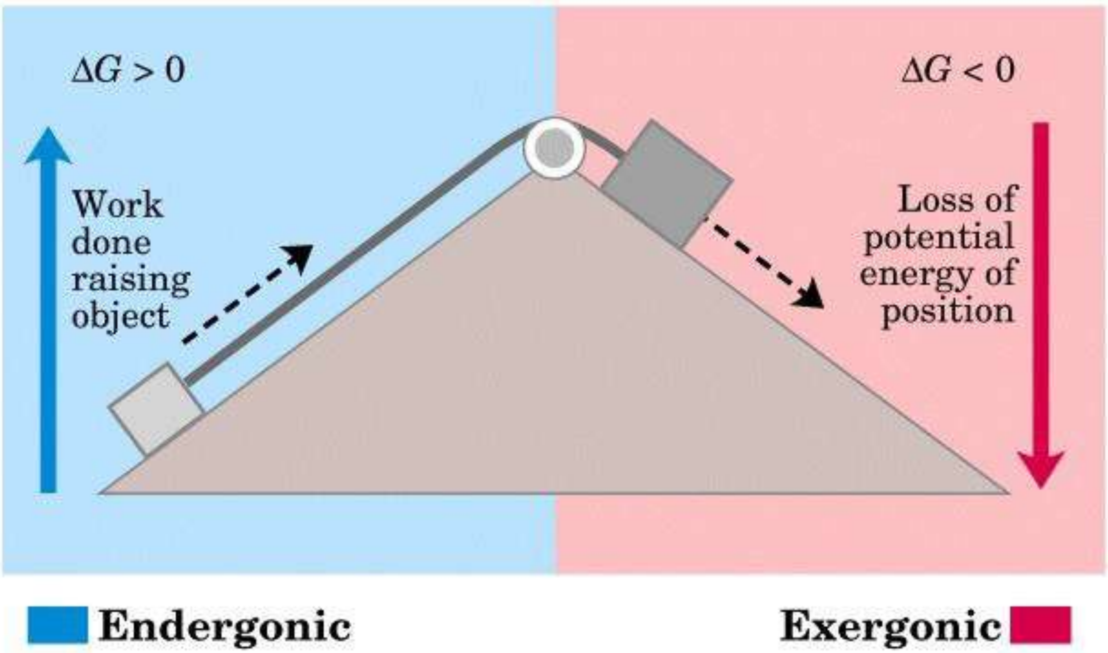
How & where is energy spent? Biochemical work

- %70of our resting daily energy requirement)BMR) arises from work carried out by our largest organs

Estimated daily use of ATP)g ATP/g tissue(	
Heart	16
Brain	6
Kidneys	24
Liver	6
Skeletal muscles (rest(	0.3
Skeletal muscles (running(	23.6

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. ΔGº Values are additive

  i. Through phosphoryl transfer reactions:

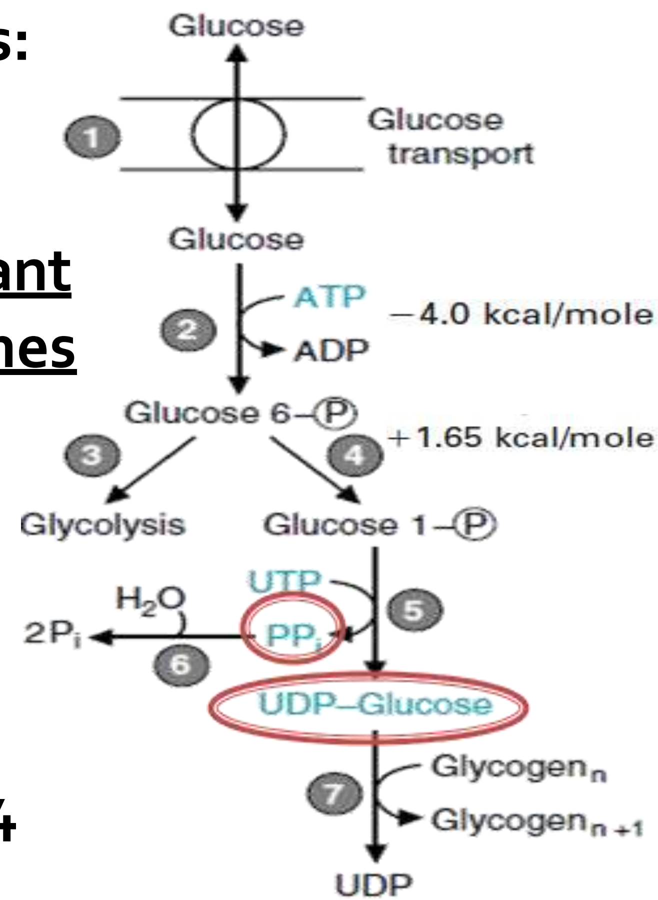
   ✓Step 3.3+) 2vs. 4-kcal/mole(

   ✓Step 2.35- = 4 +2 kcal/mole

   ✓<u>The net value for synthesis is irrelevant to the presence or absence of enzymes</u>

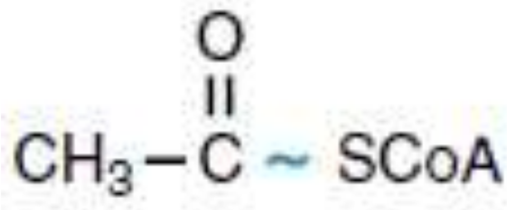
  ii. Activated intermediates)step 4is facilitated by steps 5&(6

II. ΔG Depends on Substrate and Product Concentration)step 4has a ratio of ;6/94 1.65+kcal/mol, if 0.4- ;3/94kcal/mol(

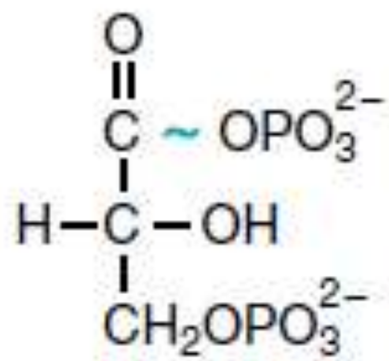


How do our cells get energy for unfavorable biochemical work?

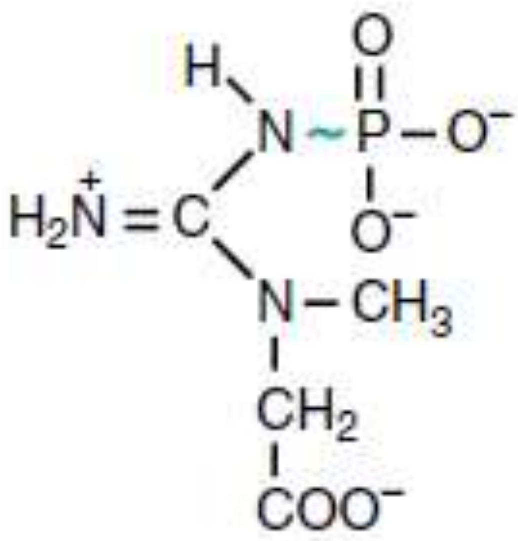
III. **Activated Intermediates other than ATP; UTP is used for combining sugars, CTP in lipid synthesis, and GTP in protein synthesis**



Acetyl CoA



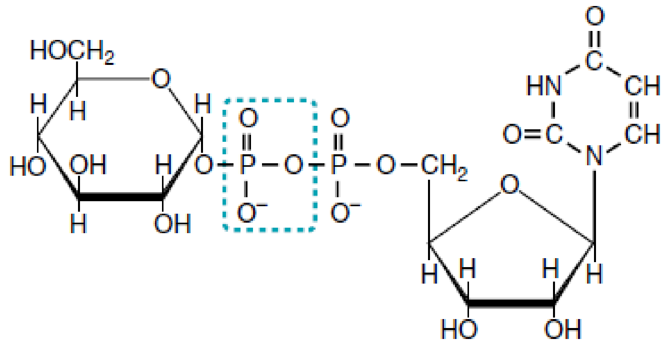
1,3–Bisphosphoglycerate



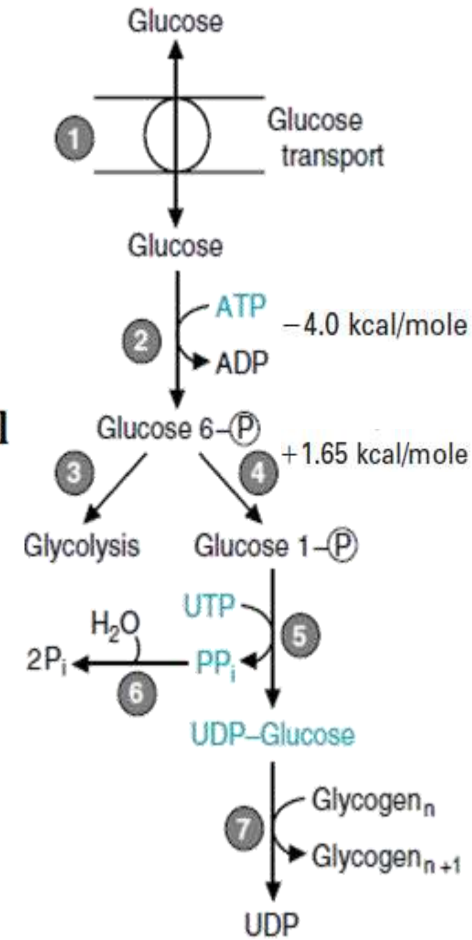
Creatine phosphate

The UDP-glucose as an example

- **UDP Carries the activated sugar**

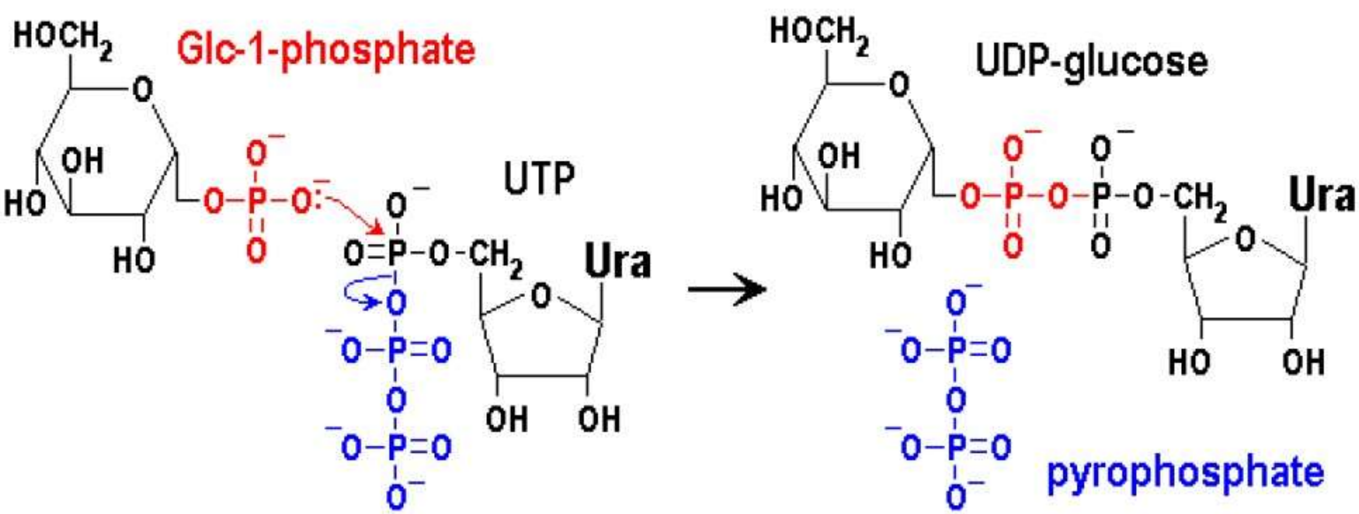


Uridine diphosphate glucose (UDP–glucose)



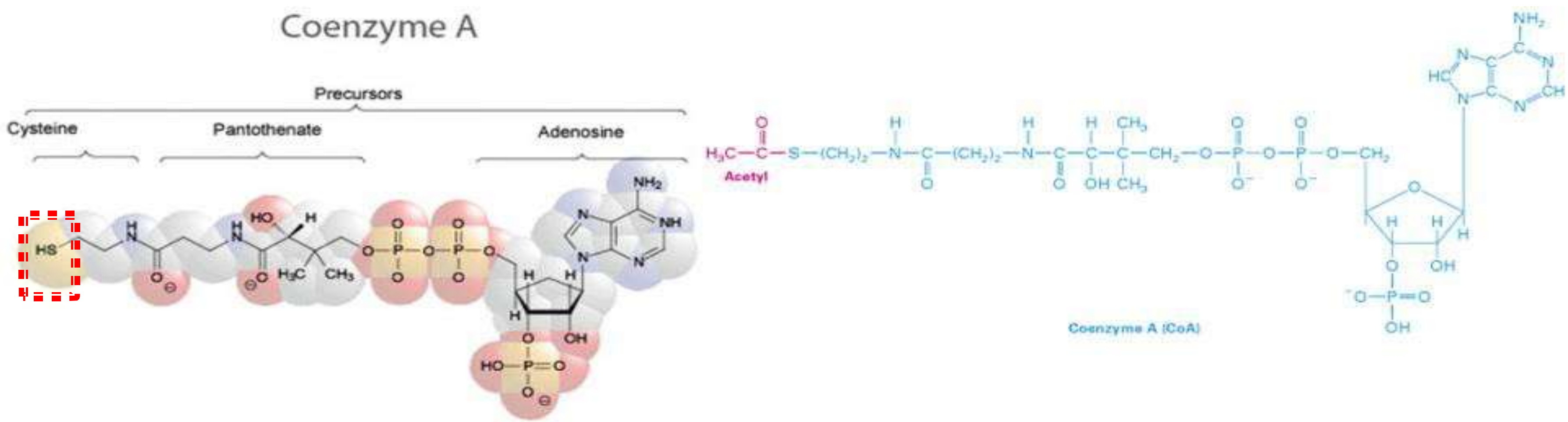
Glycogen synthase

$$[\text{glycogen}]_n + \text{UDP-Glucose} \rightarrow [\text{glycogen}]_{n+1} + \text{UDP} \quad \Delta G^{o\prime} = -33.4 \text{ kJ/mol}$$



The acetyl CoA as an example

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



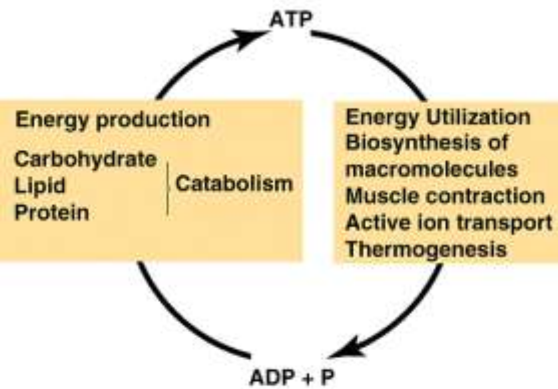
- Acetyl CoA + H_2O ⟶ Acetate + CoA   ΔGº = -7.5kcal
- Acetylcholine + H_2O ⟶ Acetate + Choline ΔGº = -3 kcal

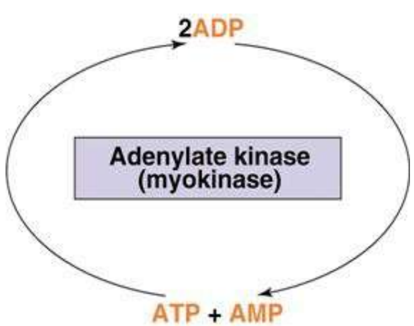
- + Choline ⟶ Acetylcholine +   ΔGº = +3 kcal
- Acetyl CoA + ⟶ + CoA   ΔGº = -7.5 kcal

- Acetyl CoA + Choline ⟶ Acetylcholine + COA

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 (g/mole)
=
94,920 g ATP

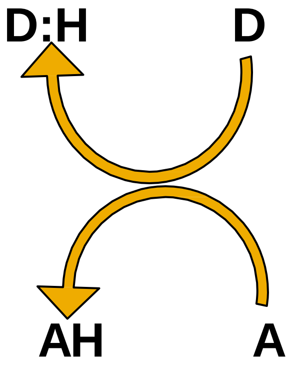
THERMOGENESIS

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

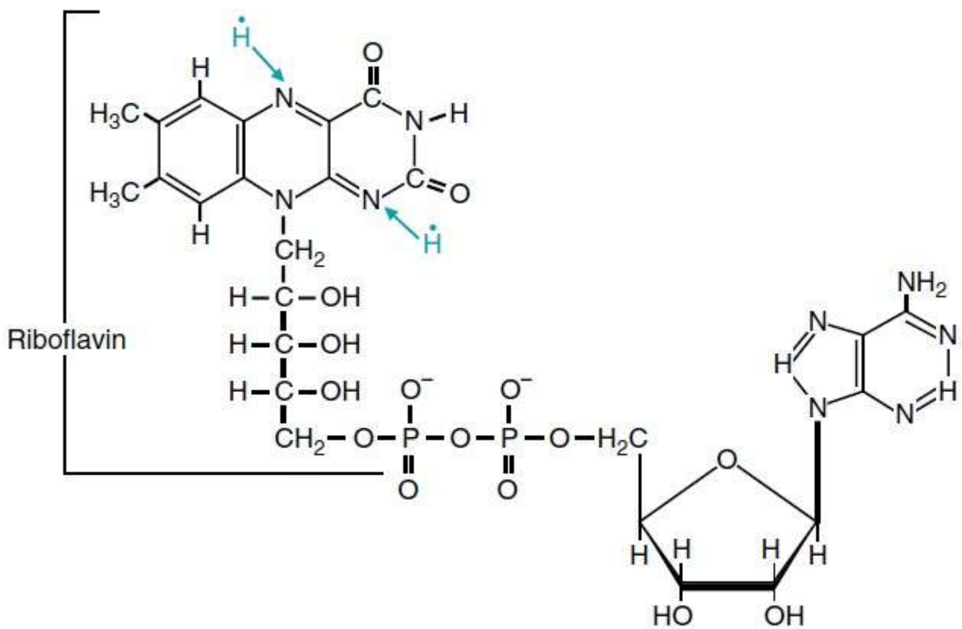
ΔG is related to ΔE

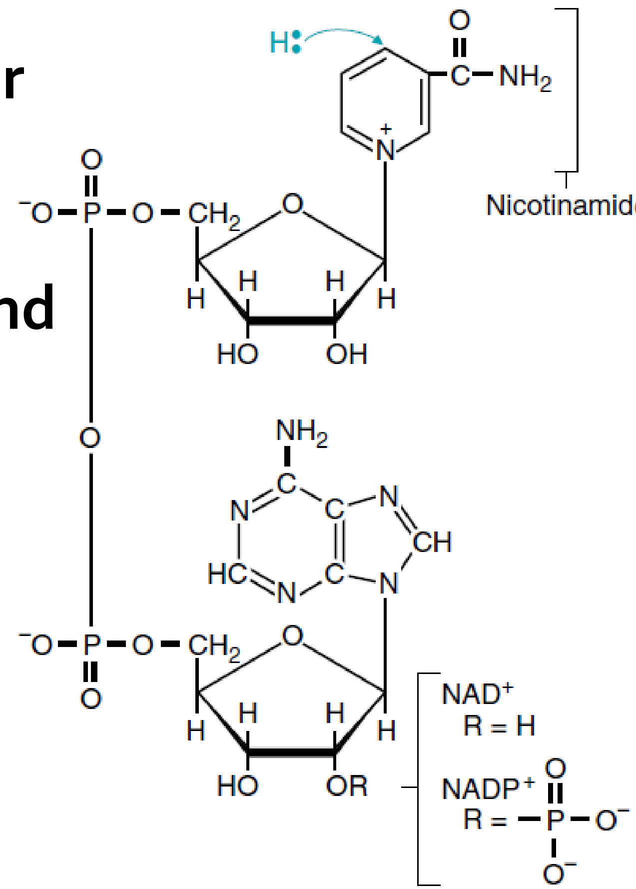
- ΔE is directly proportional to ΔG^o
  - $\Delta G^o = -nf\Delta E^o$
- Where:
- n = the number of transferred electron
- F = the Faraday constant (96.5 kJ/volt) (23.06 kcal/volt)
- *E* = the reduction potential (volts);
- G = the free energy (Kcal or KJ)

  - 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 <u>a pair</u> 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 [illegible] Reduction Potentials of Some Oxidation-Reduction Half-Reactions

Reduction Half-Reactions	$E^{0\prime}$ at pH 7.0
$1/2\ O_2 + 2H^+ + 2\ e^- \rightarrow H_2O$	0.816
Cytochrome a-$Fe^{3+} + 1\ e^- \rightarrow$ cytochrome a-Fe^{2+}	0.290
$CoQ + 2H^+ + 2\ e^- \rightarrow CoQH_2$	0.060
Fumarate $+ 2H^+ + 2\ e^- \rightarrow$ succinate	0.030
Oxalacetate $+ 2H^+ + 2\ e^- \rightarrow$ malate	−0.102
Acetaldehyde $+ 2H^+ + 2\ e^- \rightarrow$ ethanol	−0.163
Pyruvate $+ 2H^+ + 2\ e^- \rightarrow$ lactate	−0.190
Riboflavin $+ 2H^+ + 2\ e^- \rightarrow$ riboflavin-H_2	−0.200
$NAD^+ + 2H^+ + 2\ e^- \rightarrow NADH + H^+$	−0.320
Acetate $+ 2H^+ + 2\ e^- \rightarrow$ acetaldehyde	−0.468

$$NADH + 1/2O_2 \longrightarrow NAD^+ + H_2O$$

$$NADH \longrightarrow NAD^+ + 2e^- \quad \Delta E^o = +0.32$$

$$O + 2e^- \longrightarrow O^{2-} \quad \Delta E^o = +0.82$$

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

$$FADH_2 + 1/2O_2 \longrightarrow FAD + H_2O$$

$$FADH_2 \longrightarrow FAD + 2e^- \quad \Delta E^o = +0.20$$

$$O + 2e^- \longrightarrow O^{2-} \quad \Delta E^o = +0.82$$

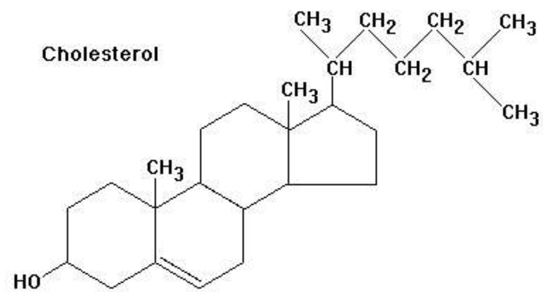
$$\Delta G^o \approx -41\ \text{kcal/mol}$$

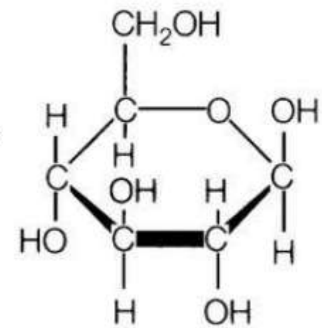
CALORIC VALUES OF FUELS

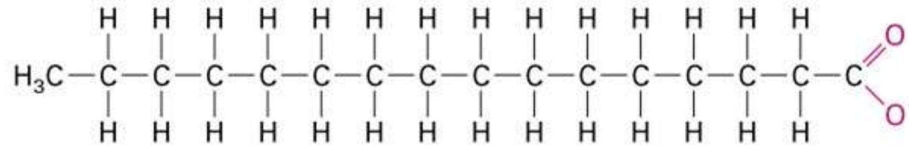
- .1Directly related to its oxidation state)ΔGº)= the transfer of electrons from that fuel)C-H and C-C bonds) to O2

- .2In humans, the enzymes that oxidizes fuels! Burning of wood

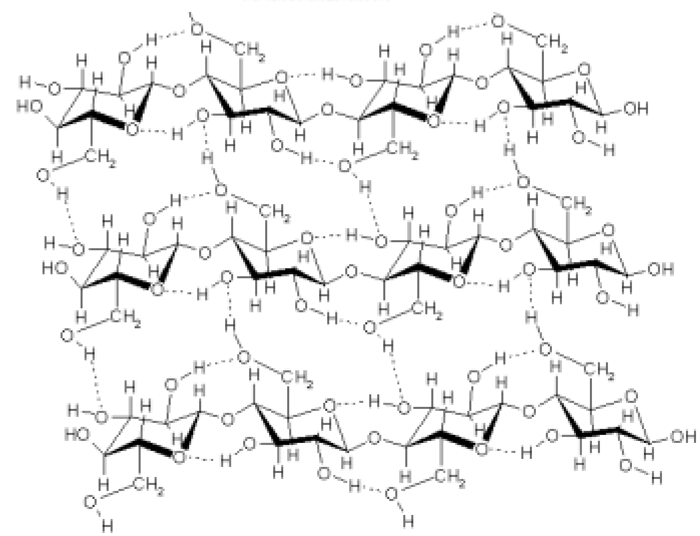
Cholesterol







Palmitate



Compound	ΔGº (kcal/mol)	Molecular weight	Caloric value (kcal/g)
Glucose	686	180	3.8
Palmitate	2380	256	9.3
Glycine	234	75	3.1