What is Biochemistry?

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Chemistry of biological molecules
Study of the chemistry of life

Structure of biological molecules
Specificity and molecular interactions
Synthesis and degradation of molecules
Energy transduction and storage
Control of molecular activities
Information, storage and retrieval

What are the properties of a living organism?

Chemical complexity and organization
    (thousands of different molecules)

Extract, transform and use energy from environment
    (we need chemical nutrients, plants need sunlight)
    (need energy to do mechanical, chemical, osmotic work)

Self-replicate and self-assemble
    (keep the population alive)

Sense and respond to environmental changes

Each component has a specific function
    (lungs vs. heart)
    (nucleus of cell vs. membrane)

Evolutionary change
    (changes made to survive)

***Organisms a lot alike at cellular and chemical level

Cellular foundations

Chemical foundations

Physical foundations

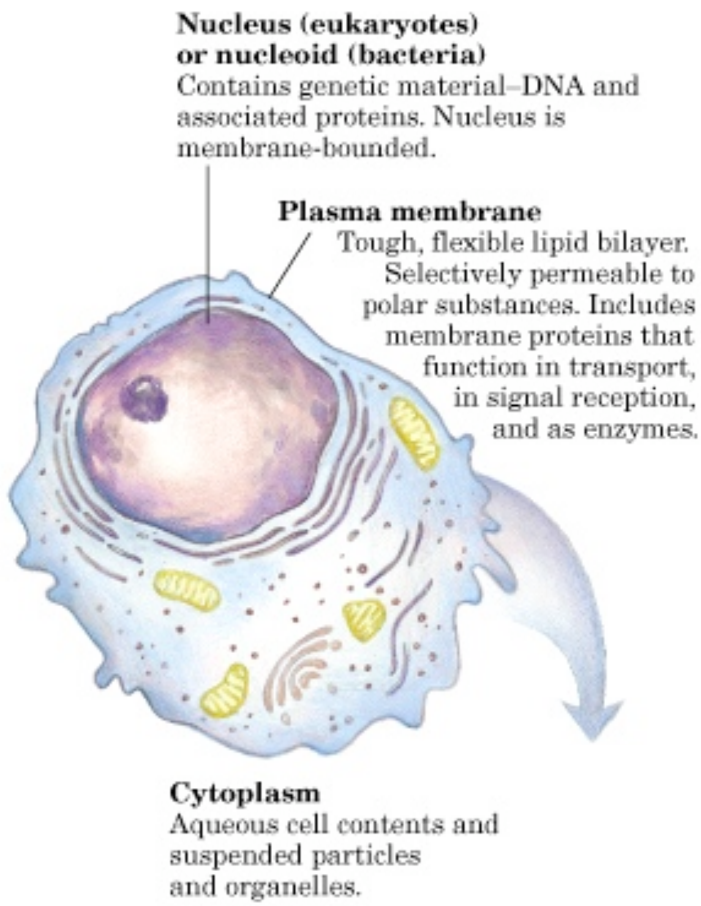
Genetic foundations

Evolutionary foundations

Cellular Foundation

Cells

Structural and functional units of living organisms



Chemical foundations - Macromolecules

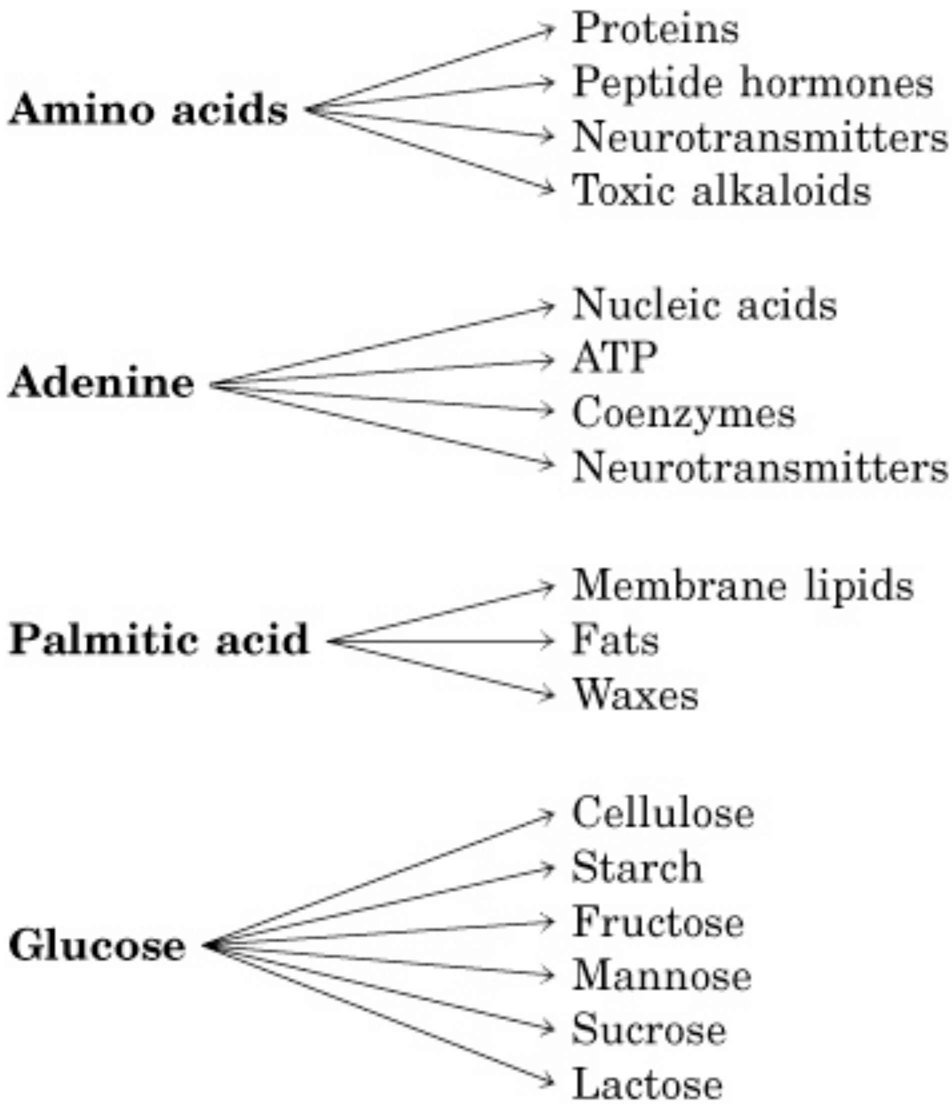
Made of simple monomeric units

Besides water, major macromolecules in cell are:

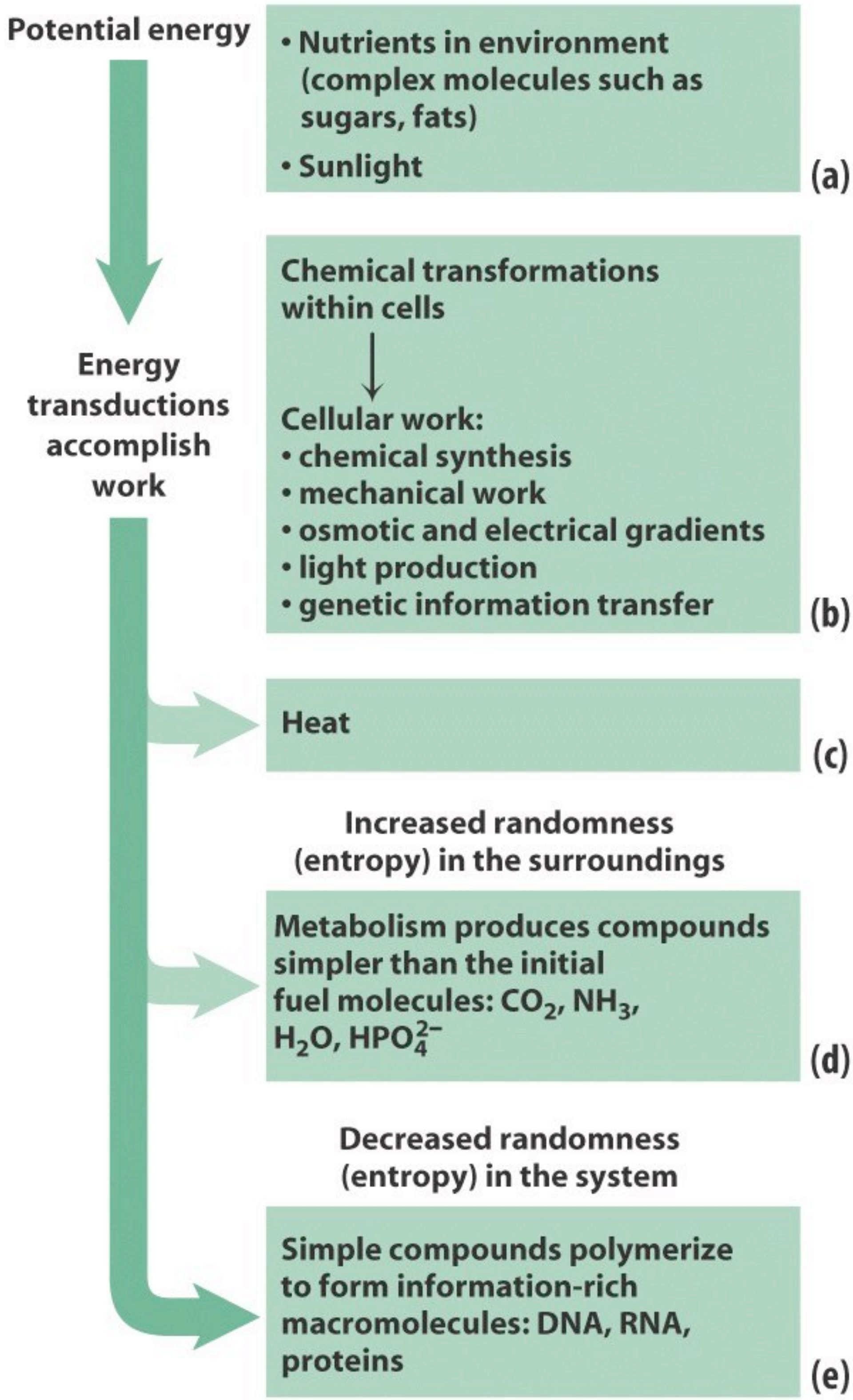
Proteins	long polymers of amino acids catalytic enzymes, structural, signal receptors, transporters size = M.W. 5000 - 1,000,000
Nucleic Acids	polymers of nucleotides to make DNA or RNA store/transmit genetic information size = M.W. up to 1,000,000,000 monomers act as energy source - ATP!!
Polysaccharides	polymers of simple sugars energy-yielding fuel stores extracellular structural elements size = up to 1,000,000 (starch)
Lipids	greasy hydrocarbons structural components of membranes, energy-rich fuel stores, pigments, intracellular signals size = M.W. 750 - 1500 (NOT MACRO)

CARBON CARBON EVERYWHERE!!!!

Monomers of macromolecules

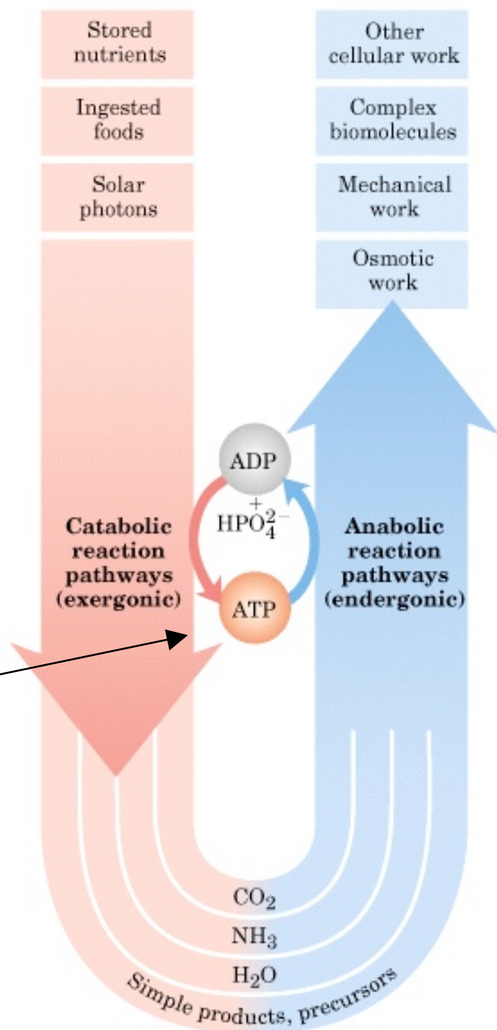


Physical foundations



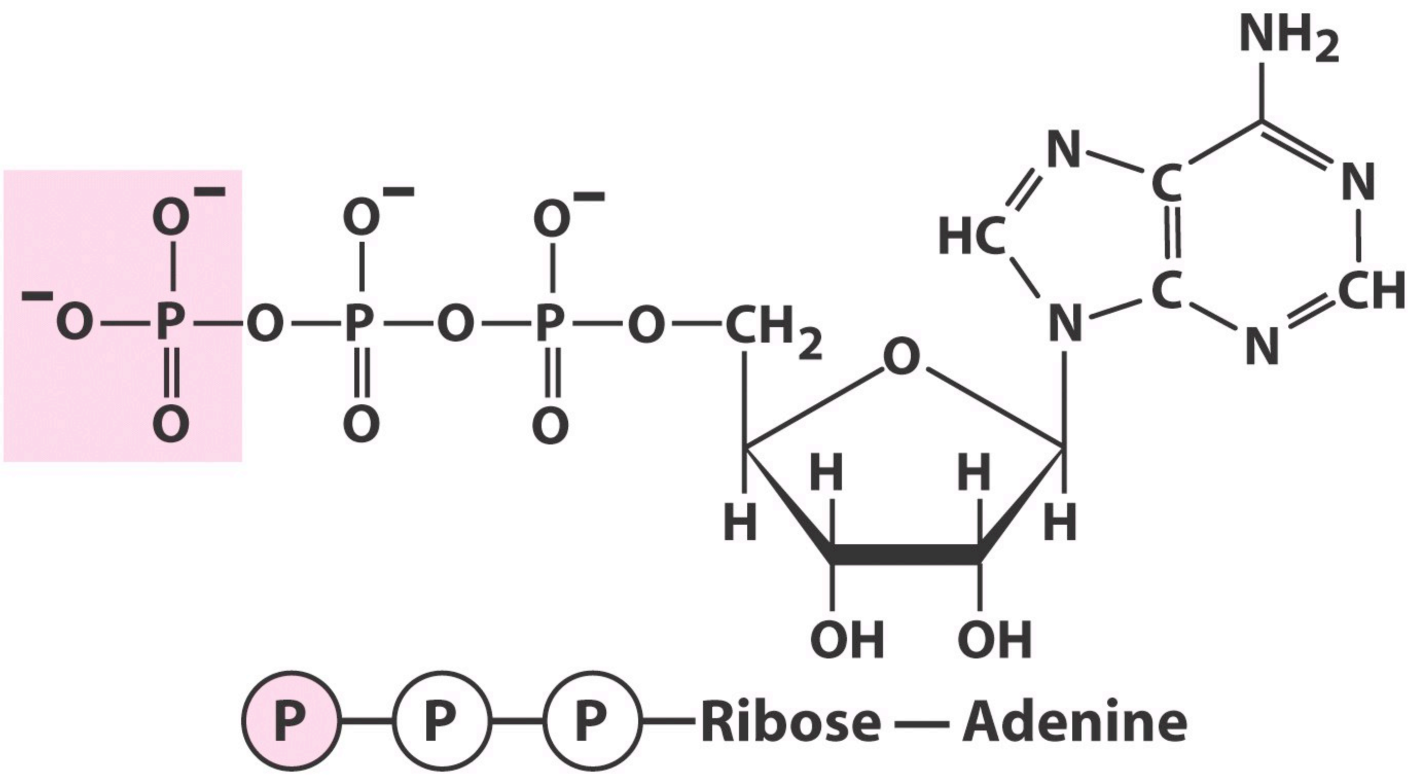
Metabolism

Metabolism = Anabolism + Catabolism

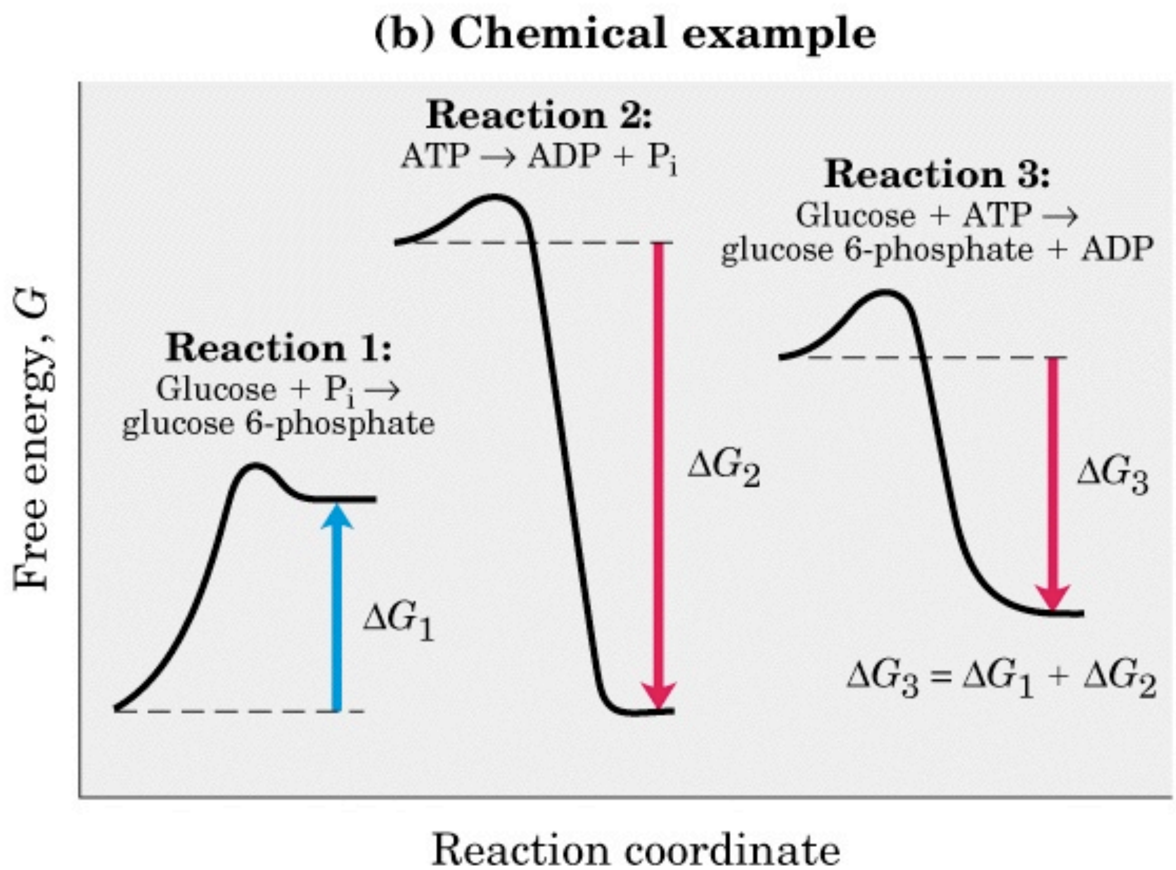


ATP is the carrier of metabolic energy, linking catabolism to anabolism

ATP - adenosine triphosphate



Physical foundations
Energy Coupling in Chemical Reactions



$$\text{Glucose + ATP} \xrightarrow{\text{enzyme}} \text{Glucose 6-phosphate + ADP}$$

Thermodynamics

Life obeys the laws of thermodynamics

System vs. surroundings
Normal cell activities demand energy

1st Law of Thermodynamics
- energy is conserved (cannot be created or destroyed)

2nd Law of Thermodynamics
- spontaneous processes are characterized by conversion of order to disorder

Thermodynamics

Review:

Enthalpy (H)
reflects numbers and kinds of bonds

Entropy (S)
Randomness (measure of disorder) of a system

Free Energy

Spontaneity of process cannot be predicted by entropy alone

True criteria for spontaneity = Gibbs free energy (G)

$\Delta G = \Delta H - T\Delta S$ (constant pressure and temp)

Spontaneous --> $-\Delta G$ (exergonic)
Nonspontaneous --> $+\Delta G$ (endergonic)

Variation of reaction spontaneity (sign of ΔG) with the signs of ΔH and ΔS

ΔH	**ΔS**	**ΔG**
(-)	(+)	Spontaneous at all temperatures
(-)	(-)	Spontaneous at low temperatures
(+)	(+)	Spontaneous at high temperatures
(+)	(-)	Nonspontaneous at all temperatures

Free Energy and Equilibrium constants

$$A + B + C \Longleftrightarrow D + E + F$$

$$\Delta G = RT \ln Q + \Delta G^\circ$$

$$Q = [D][E][F] / [A][B][C]$$

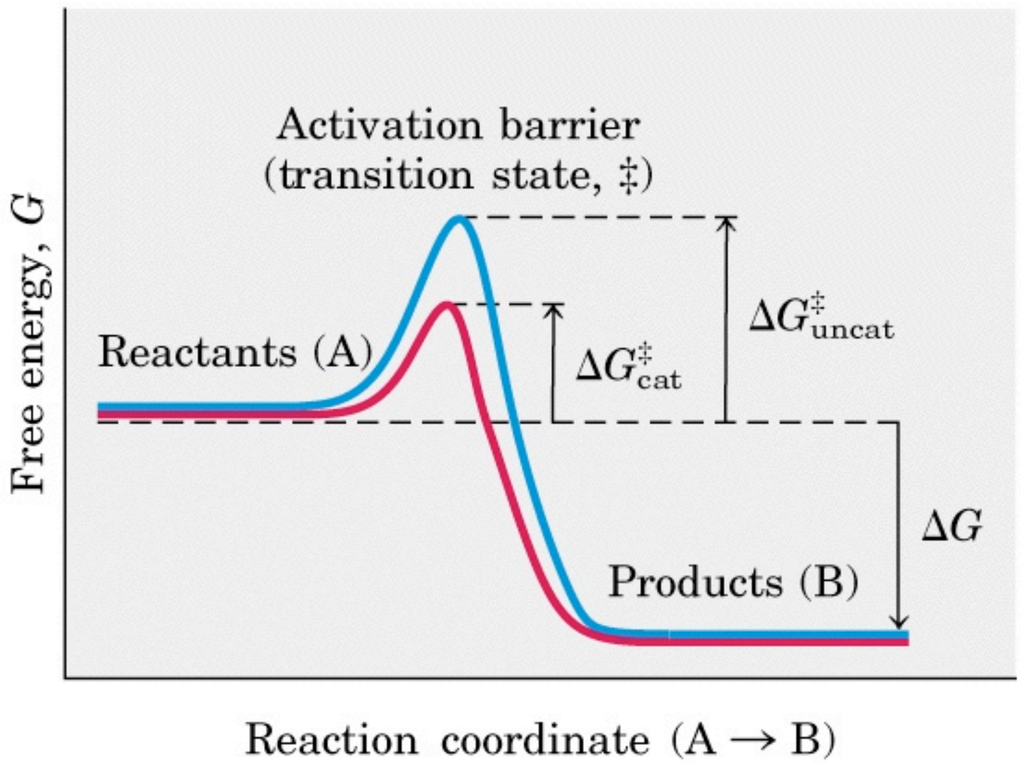
$\Delta G < 0$ reaction goes to products
$\Delta G > 0$ reaction goes to reactants
$\Delta G = 0$ at equilibrium

At equilibrium, $\Delta G = 0$, so

$$0 = RT \ln K + \Delta G^\circ$$

$$\Delta G^\circ = - RT \ln K$$

Enzymes promote chemical reactions

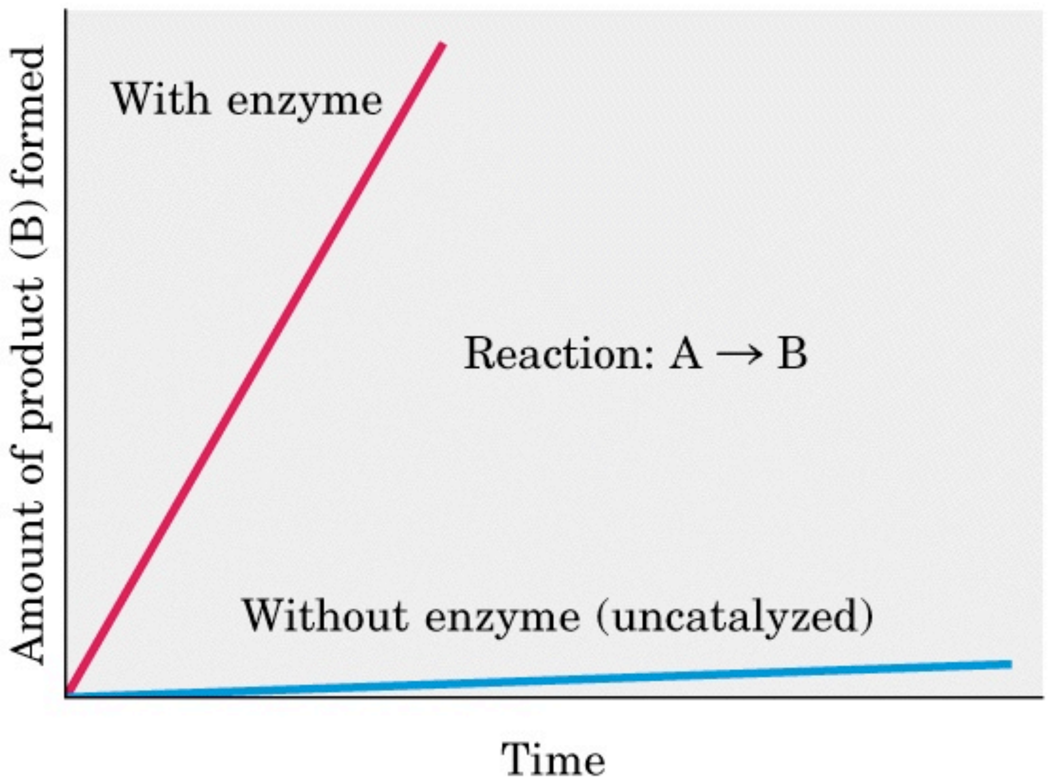


Transition state has a free energy higher than either reactant or product

Cellular chemical reactions occur at a fast enough rate because of enzymes (proteins)

Enzymes lower the energy barrier between reactant and product

Enzymes promote chemical reactions

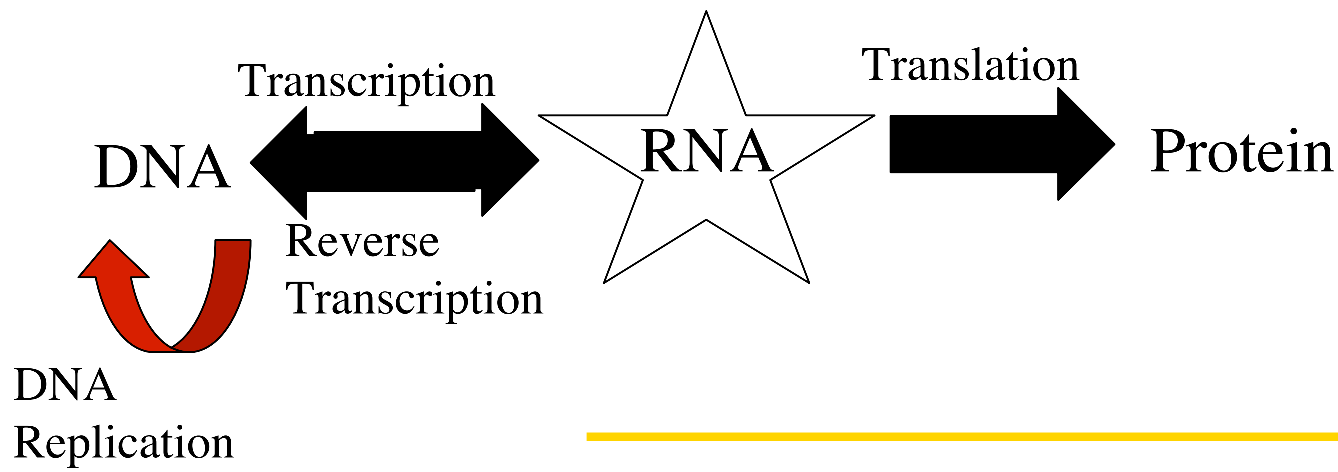


Enzyme-catalyzed reactions proceed at rates up to 10^{10} to 10^{14} times faster than uncatalyzed reactions

Genetic foundations

Central Dogma of Biochemistry

informational molecules



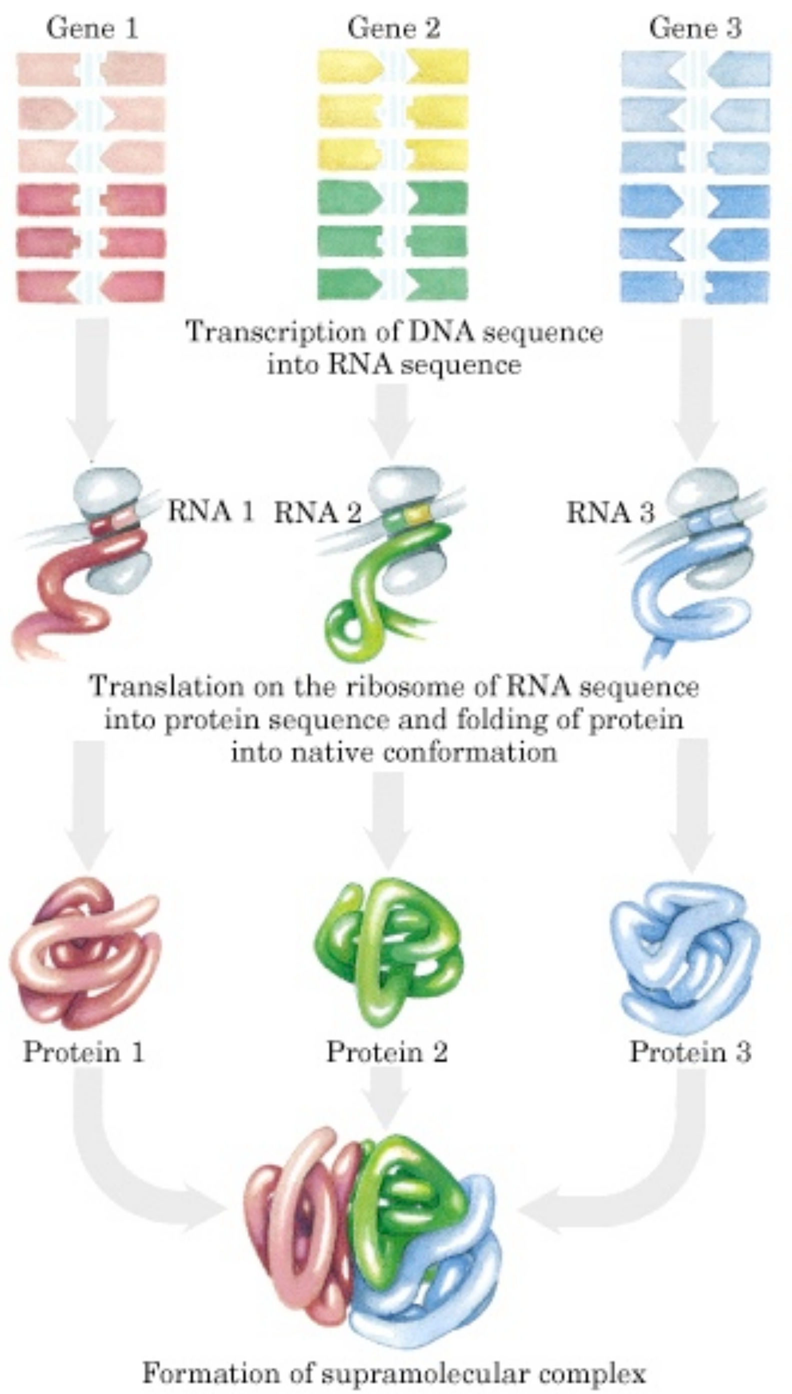
functional molecules

Genetic information

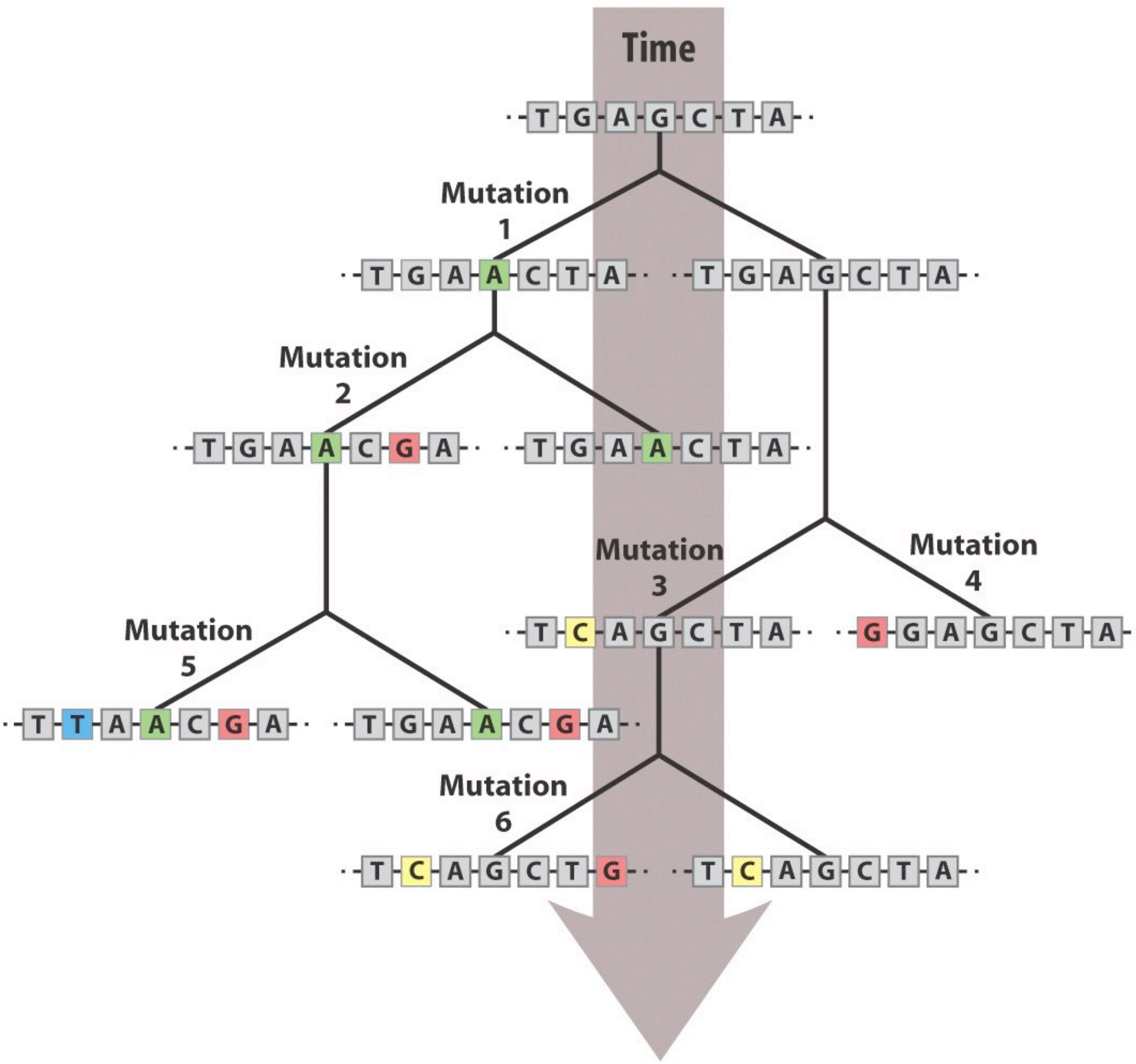
TABLE 1–4 Some Organisms Whose Genomes Have Been Completely Sequenced

Organism	*Genome size (millions of nucleotide pairs)*	*Biological interest*
Mycoplasma pneumoniae	0.8	Causes pneumonia
Treponema pallidum	1.1	Causes syphilis
Borrelia burgdorferi	1.3	Causes Lyme disease
Helicobacter pylori	1.7	Causes gastric ulcers
Methanococcus jannaschii	1.7	Grows at 85 °C!
Haemophilus influenzae	1.8	Causes bacterial influenza
Methanobacterium thermoautotrophicum	1.8	Member of the Archaea
Archaeoglobus fulgidus	2.2	High-temperature methanogen
Synechocystis sp.	3.6	Cyanobacterium
Bacillus subtilis	4.2	Common soil bacterium
Escherichia coli	4.6	Some strains cause toxic shock syndrome
Saccharomyces cerevisiae	12.1	Unicellular eukaryote
Plasmodium falciparum	23	Causes human malaria
Caenorhabditis elegans	97.1	Multicellular roundworm
Anopheles gambiae	278	Malaria vector
Mus musculus domesticus	2.5×10^3	Laboratory mouse
Homo sapiens	2.9×10^3	Human

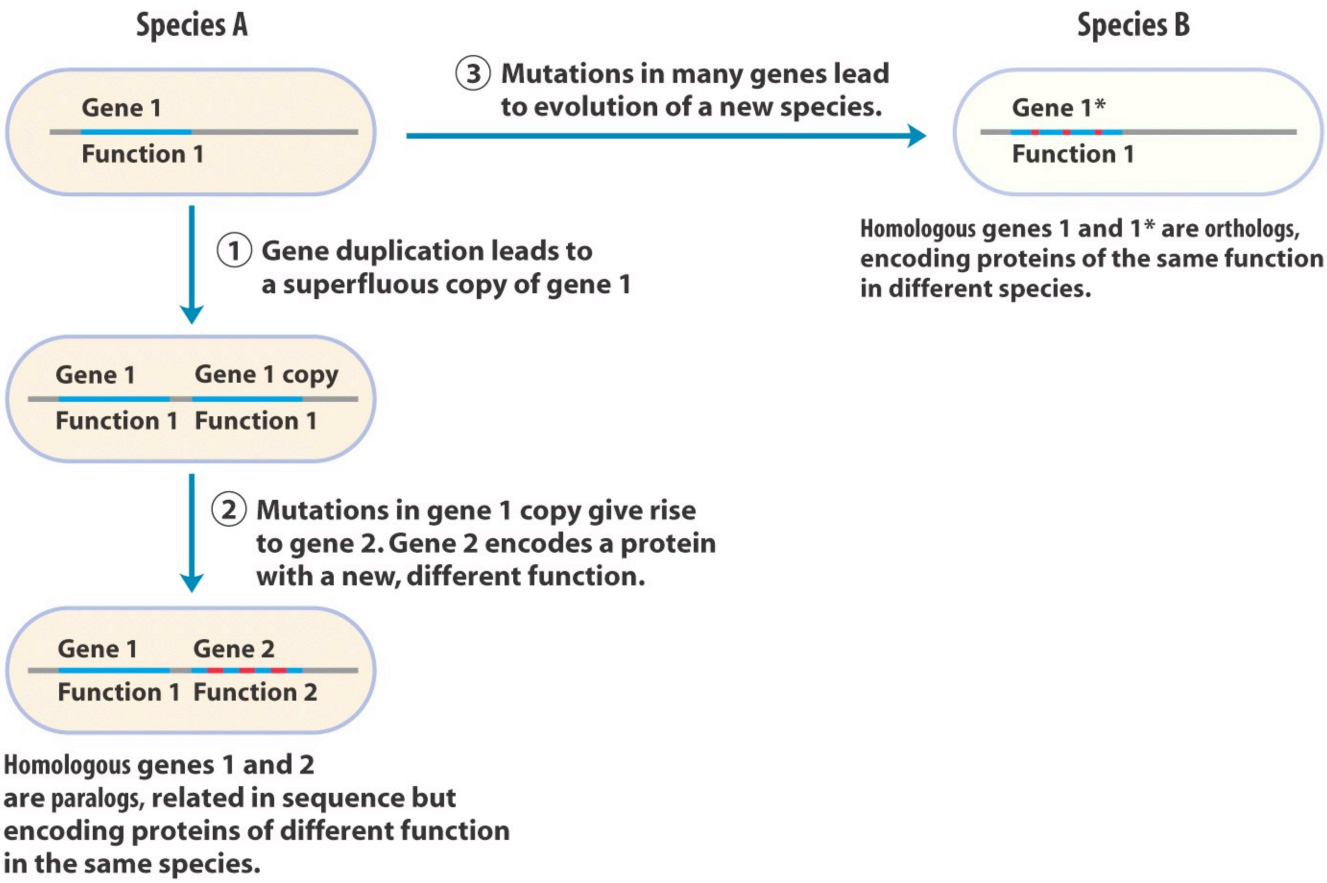
Linear DNA encodes proteins with complex 3D structures



Evolutionary foundations
Changes in genetic information - evolution

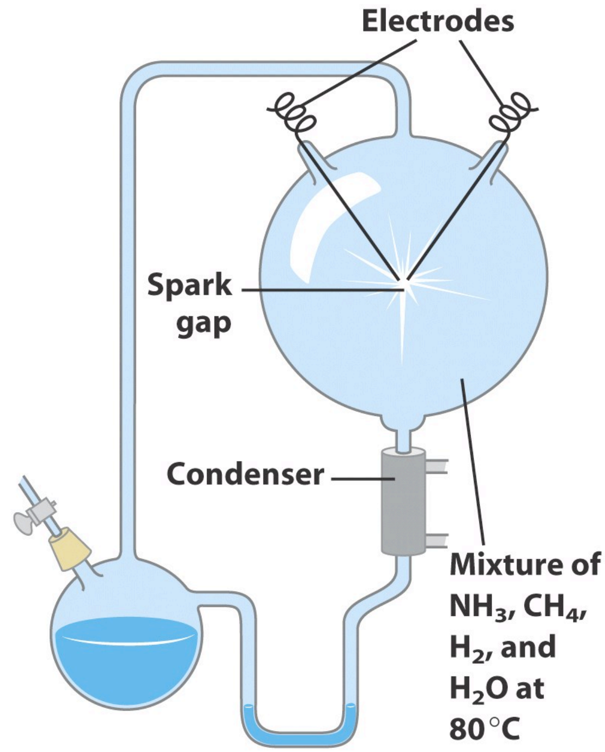


Changes in genetic information - evolution



<u>Chemical evolution simulated in the lab</u>

Yields from Sparking a Mixture of CH_4, NH_3, H_2O, and H_2



Compound	Yield (%)
Formic Acid	**4.0**
Glycine (Amino acid)	**2.1**
Glycolic acid	**1.9**
Alanine (Amino acid)	**1.7**
Lactic acid	**1.6**
β-alanine	**0.76**
Propionic acid	**0.66**
Acetic acid	**0.51**
Iminodiacetic acid	**0.37**
α-Amino-*n*-butyric acid	**0.34**
α-Hydroxybutyric acid	**0.34**
Succinic acid	**0.27**
Sarcosine	**0.25**
Iminoaceticpropionic acid	**0.13**
***N*-Methylalanine**	**0.07**
Glutamic acid (Amino acid)	**0.051**
***N*-Methylurea**	**0.051**
Urea	**0.034**
Aspartic acid (Amino acid)	**0.024**
α-Aminoisobutyric acid	**0.007**

Source: Miller, S.J. and Orgel, L.E., *The Origins of Life on Earth*, p. 85, Prentice-Hall (1974).

RNA WORLD

Creation of prebiotic soup, including nucleotides, from components of Earth's primitive atmosphere

↓

Production of short RNA molecules with random sequences

↓

Selective replication of self-duplicating catalytic RNA segments

↓

Synthesis of specific peptides, catalyzed by RNA

↓

Increasing role of peptides in RNA replication; coevolution of RNA and protein

↓

Primitive translation system develops, with RNA genome and RNA-protein catalysts

↓

Genomic RNA begins to be copied into DNA

↓

DNA genome, translated on RNA-protein complex (ribosome) with protein catalysts

Crick

Orgel

Rich!!

Watson

RNA tie club - 1955