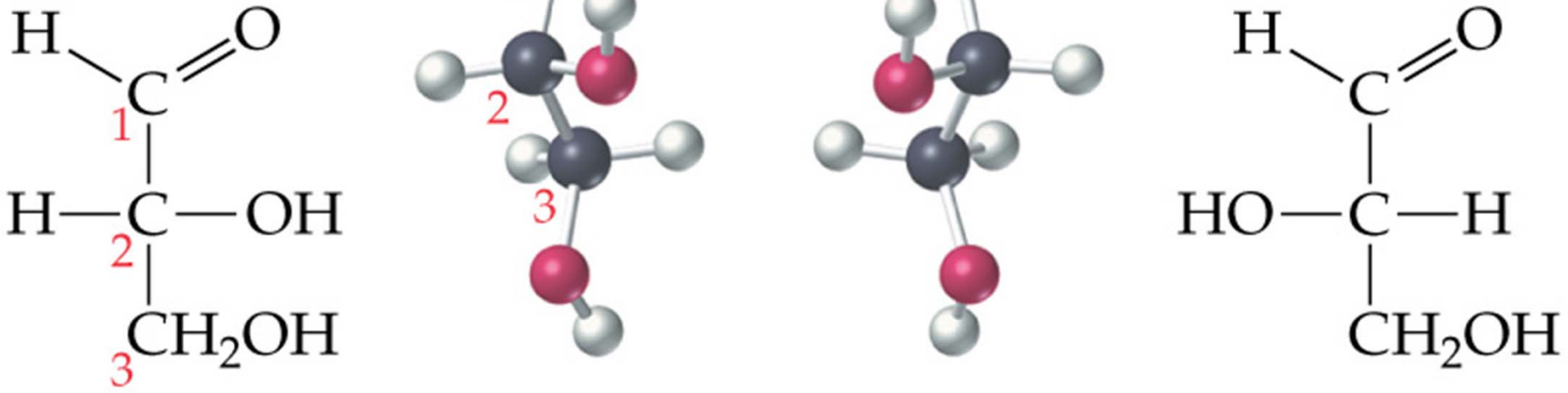
An Introduction to Carbohydrates

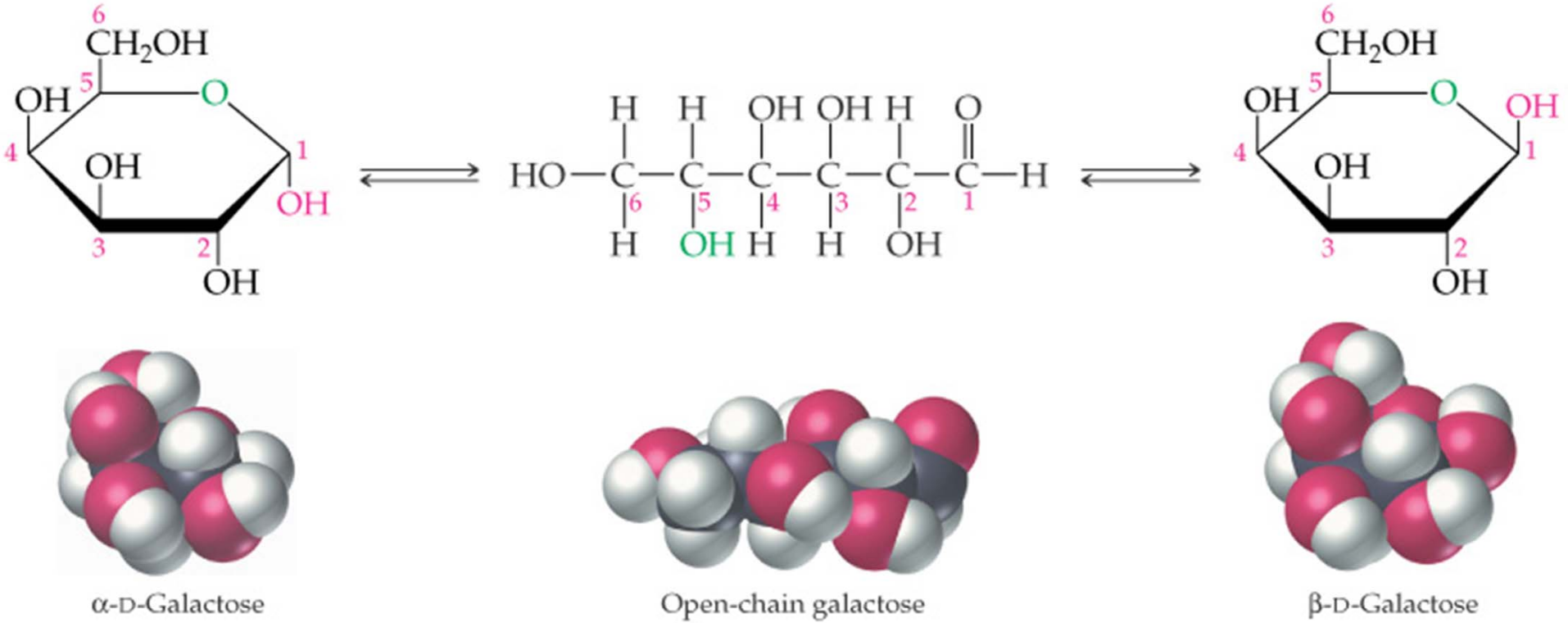
- *Carbohydrates* are a large class of naturally occurring polyhydroxy aldehydes and ketones.
- Monosaccharides also known as simple sugars, are the simplest carbohydrates containing 3-7 carbon atoms.
- sugar containing an aldehydes is known as an aldose.
- sugar containing a ketones is known as a ketose.

- The number of carbon atoms in an aldose or ketose may be specified as by tri, tetr, pent, hex, or hept. For example, glucose is aldohexose and fructose is ketohexose.
- Monosaccharides react with each other to form disaccharides and polysaccharides.
- Monosaccharides are chiral molecules and exist mainly in cyclic forms rather than the straight chain.

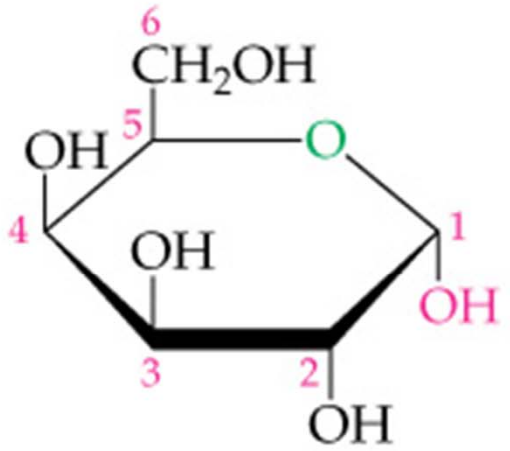


D-Glyceraldehyde
Right-handed

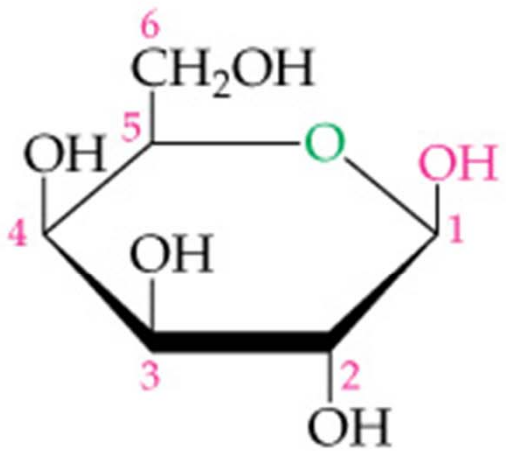
L-Glyceraldehyde
Left-handed


α-D-Galactose
Open-chain galactose
β-D-Galactose

- *Anomers:* Cyclic sugars that differs only in positions of substituents at the hemiacetal carbon; the α-form has the –OH group on the opposite side from the $–CH_2OH$; the β-form the –OH group on the same side as the $–CH_2OH$ group.



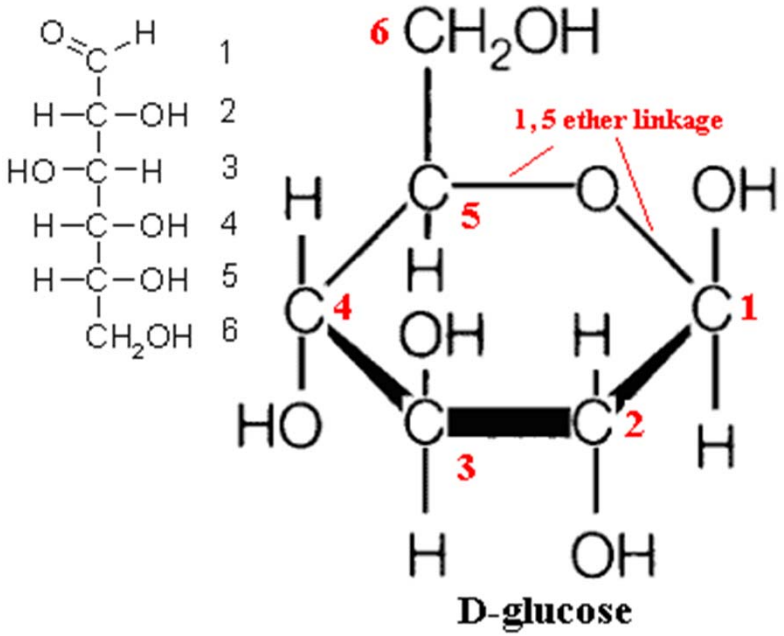
α-D-Galactose

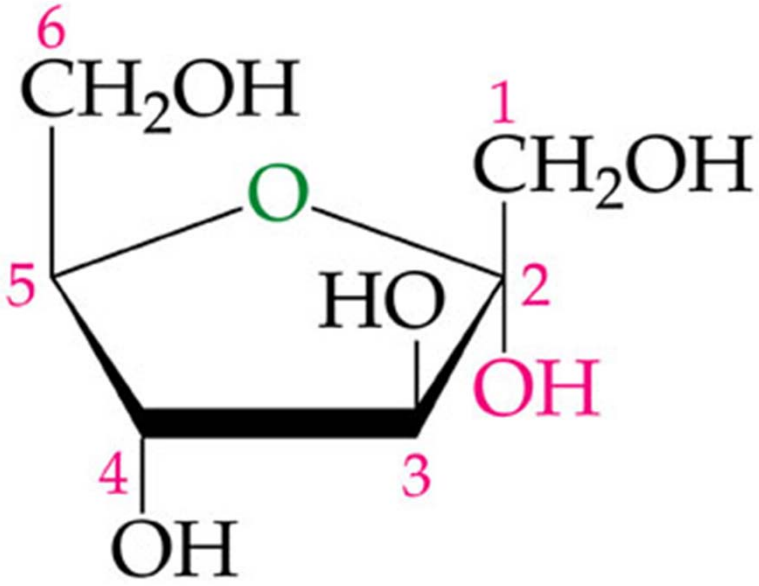


β-D-Galactose

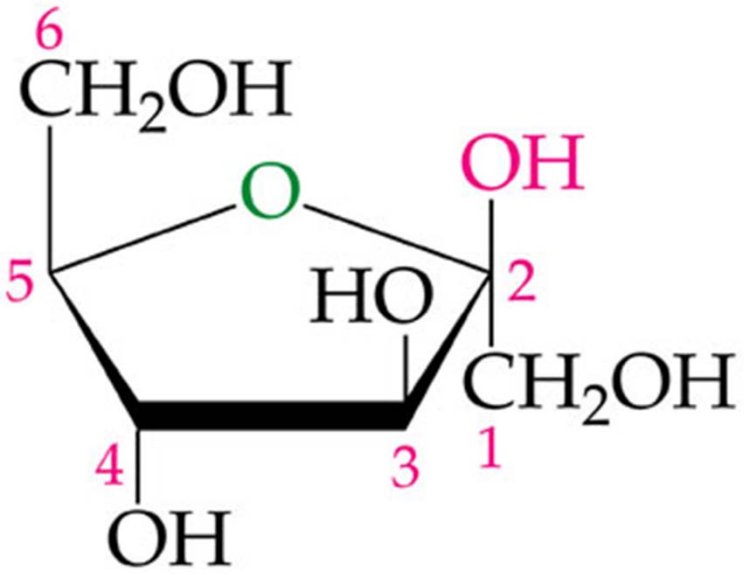
Some Important Monosaccharides

Monosaccharides are generally high-melting, white, crystalline solids that are soluble in water and insoluble in nonpolar solvents. Most monosaccharides are sweet tasting, digestible, and nontoxic.

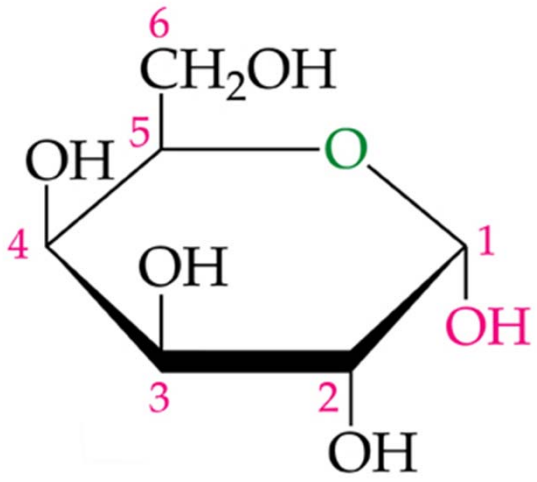




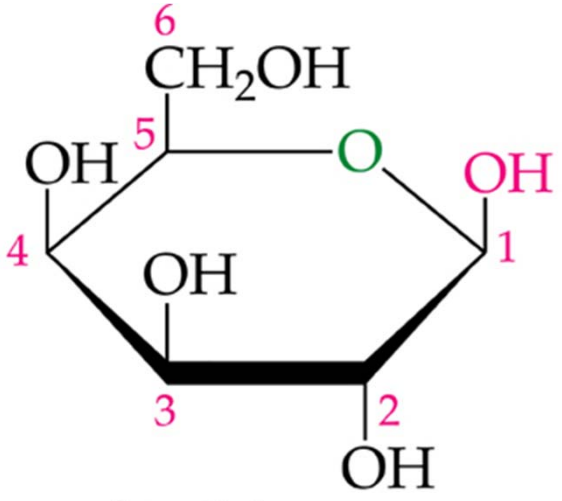
α-D-Fructose



β-D-Fructose

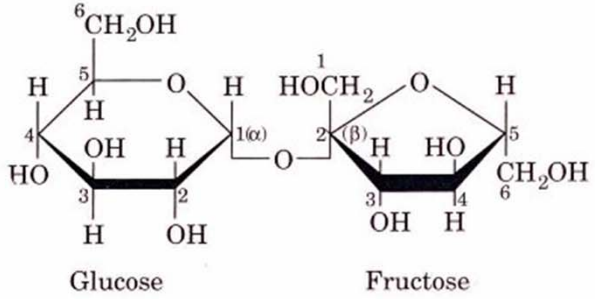


α-D-Galactose

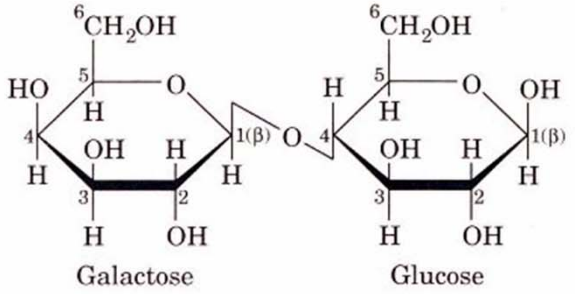


β-D-Galactose

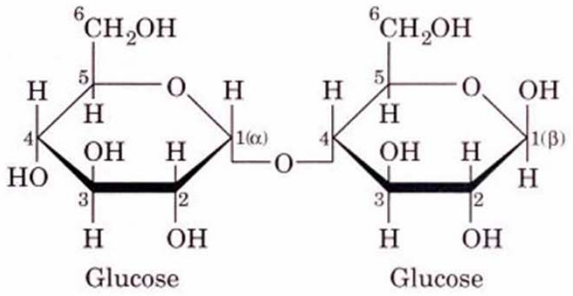
Some Common Disaccharides



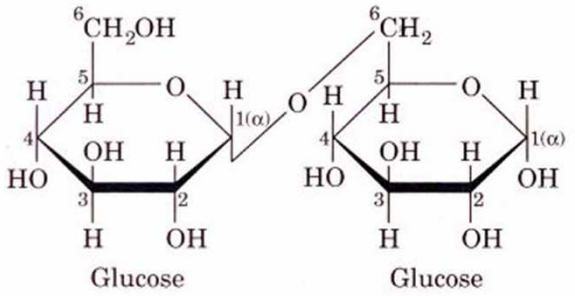
Sucrose



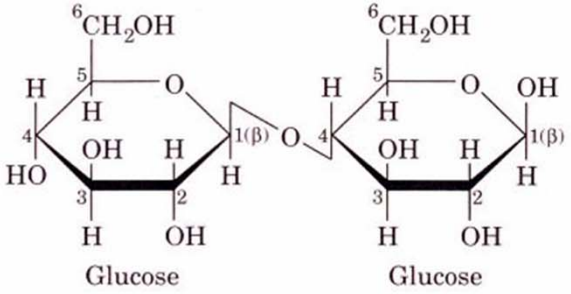
Lactose



Maltose

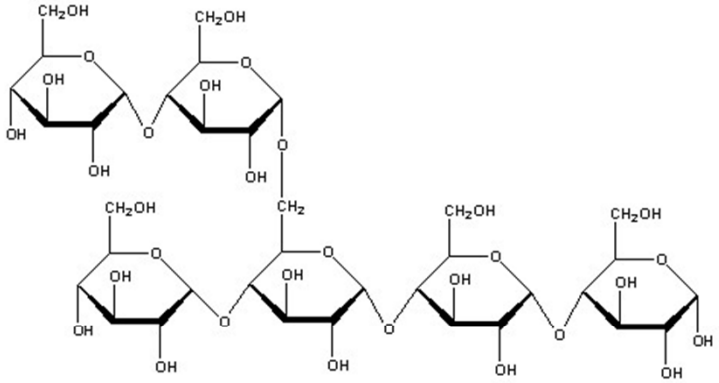


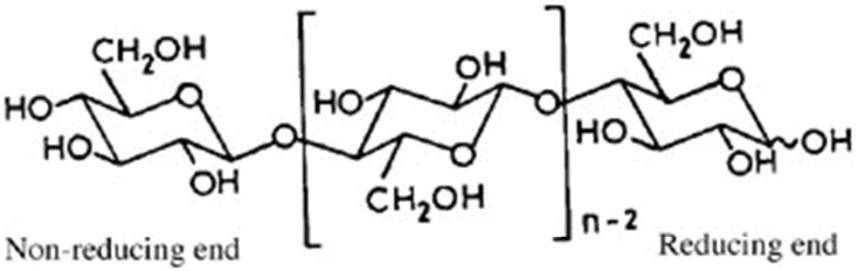
Isomaltose



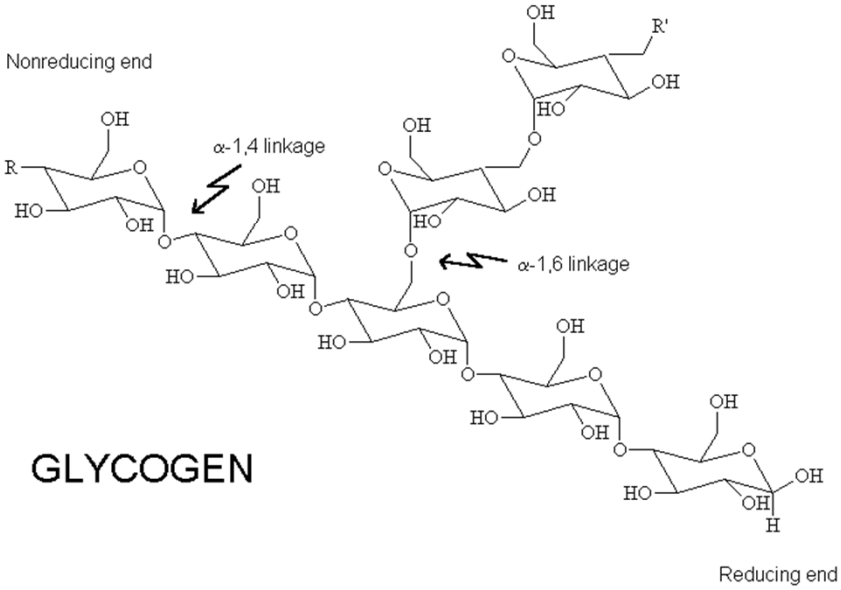
Cellobiose

Polysaccharides

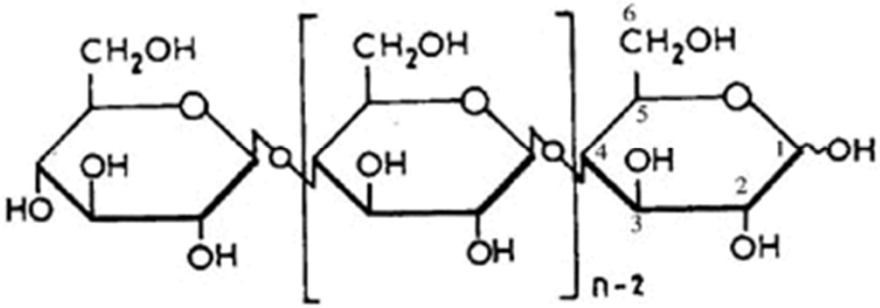




Sometimes shown as

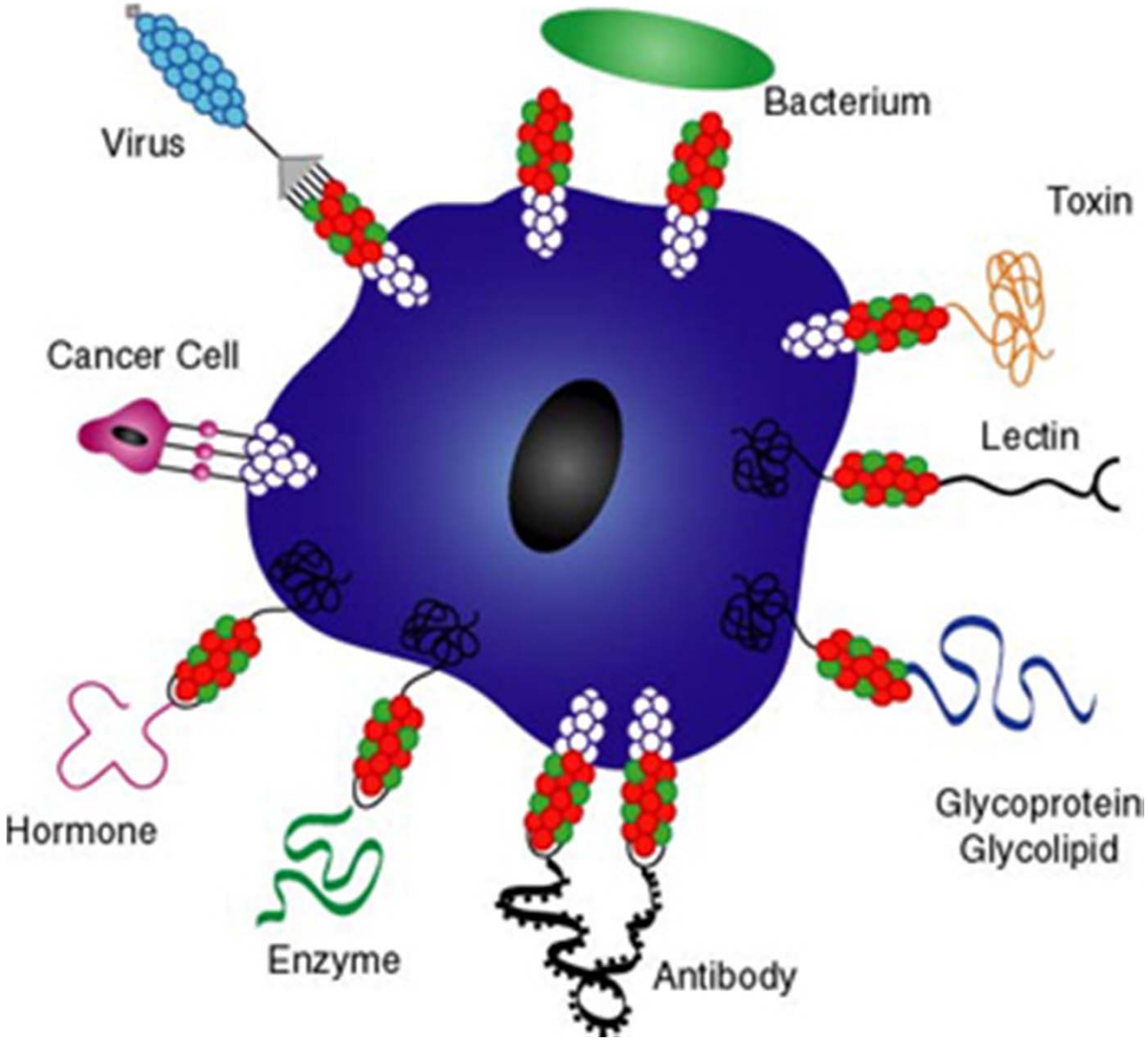


GLYCOGEN



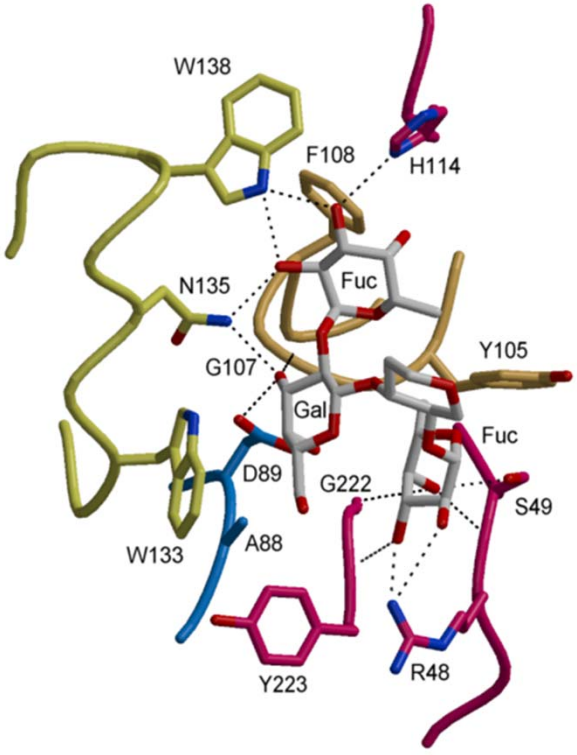
Cellulose

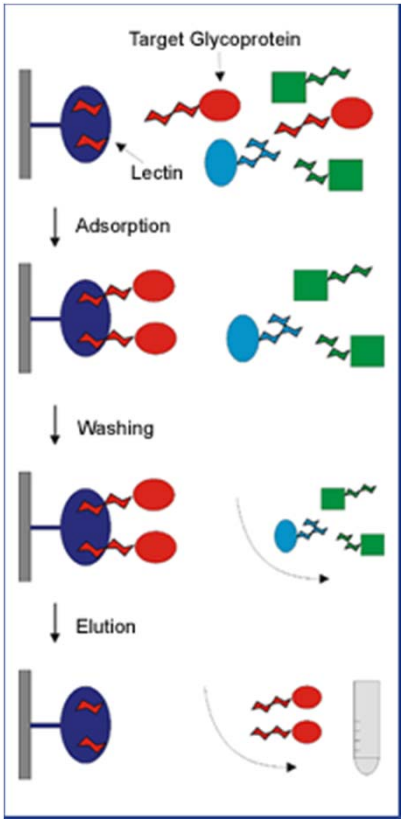
Cell-Surface Carbohydrates Involved in Molecular Recognition



Lectin

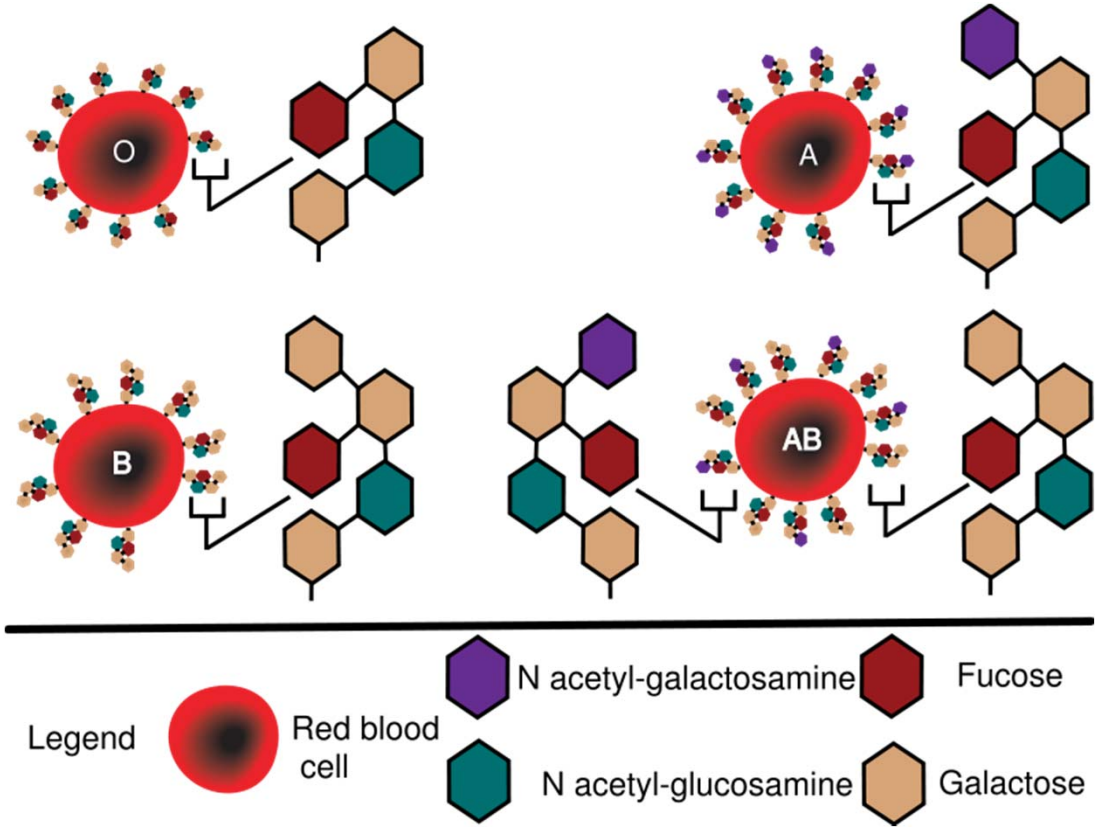
Lectins are sugar-binding proteins which are highly specific for their sugar moieties. They typically play a role in biological recognition phenomena involving cells and proteins. For example, some bacteria use lectins to attach themselves to the cells of the host organism during infection.



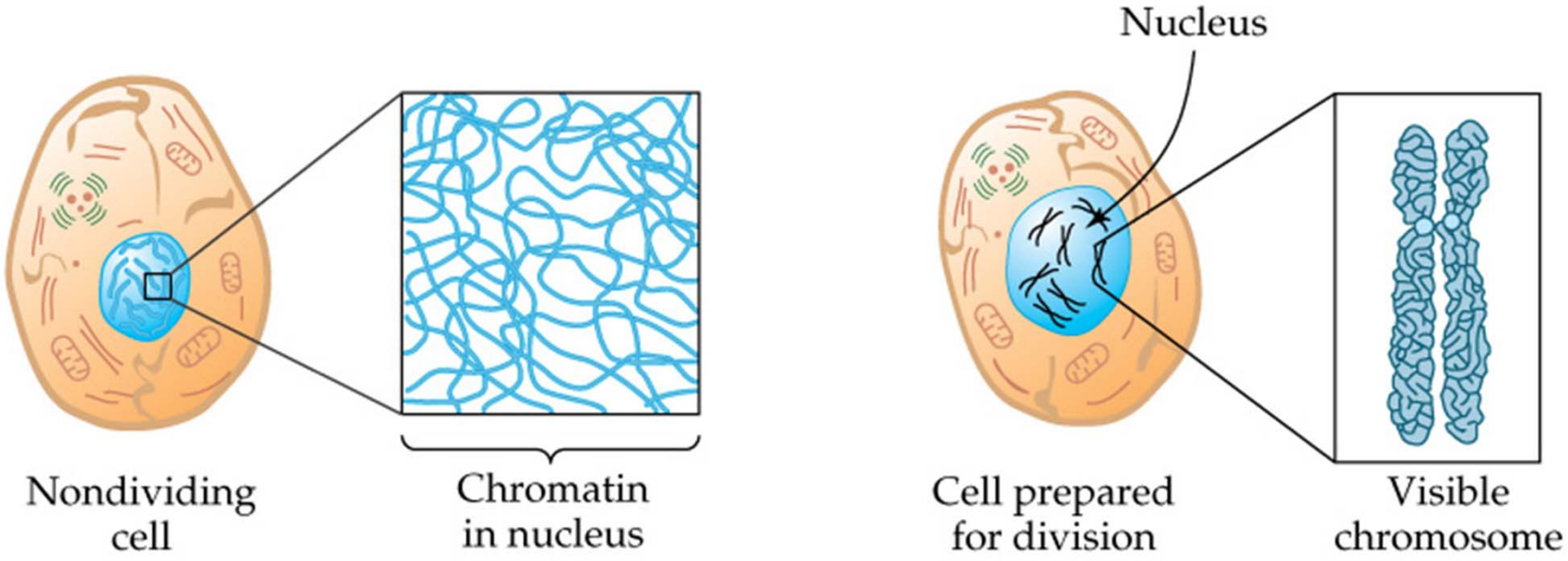


Blood Type

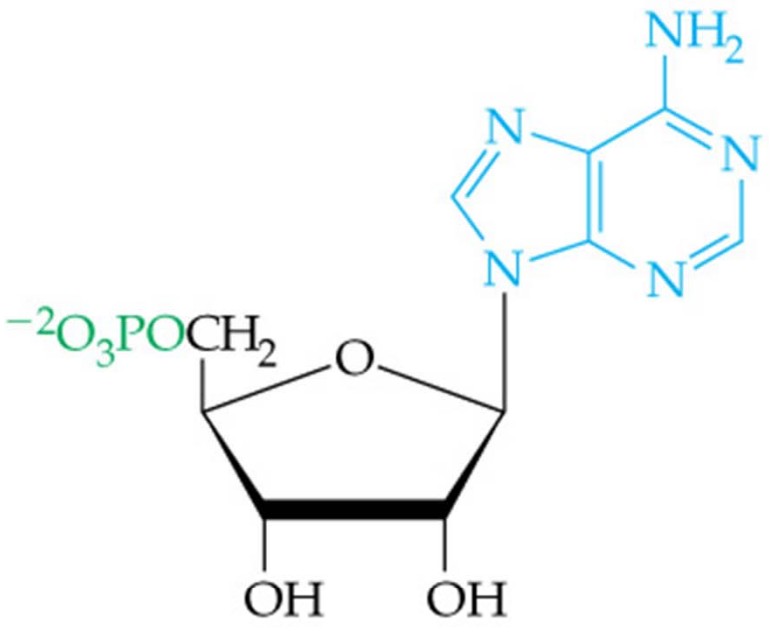
	Group A	Group B	Group AB	Group O
Red blood cell type	A	B	AB	O
Antibodies present	Anti-B	Anti-A	None	Anti-A and Anti-B
Antigens present	A antigen	B antigen	A and B antigens	No antigens



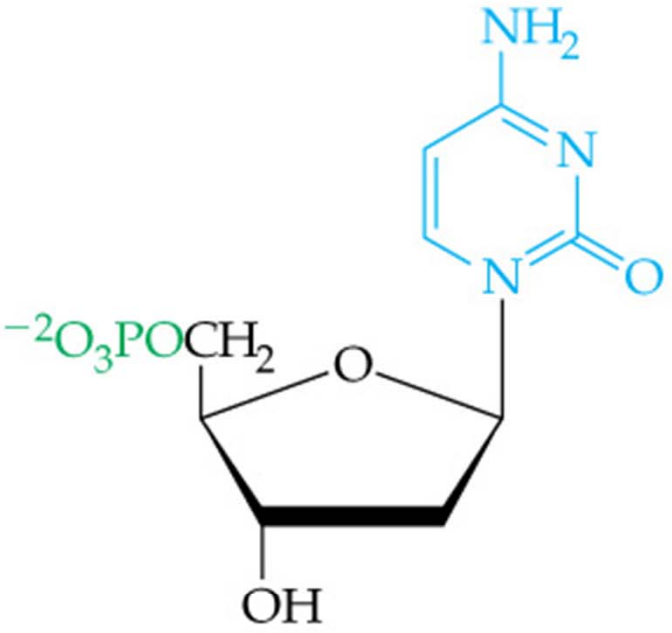
DNA


Nucleus
Nondividing cell
Chromatin in nucleus
Cell prepared for division
Visible chromosome

- In RNA, the sugar is ribose.
- In DNA, the sugar is deoxyribose.



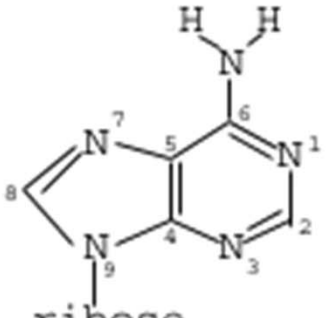
Adenosine 5′-monophosphate (AMP)
(a ribonucleotide)



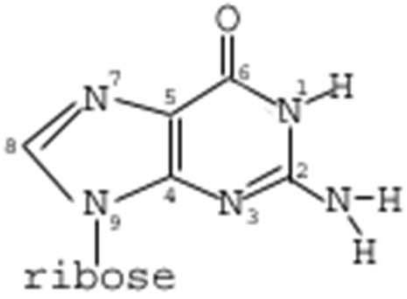
Deoxycytidine 5′-monophosphate (dCMP)
(a deoxyribonucleotide)

Base

Purines

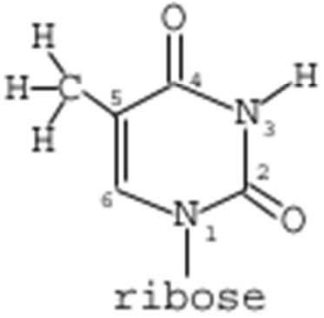


adenosine

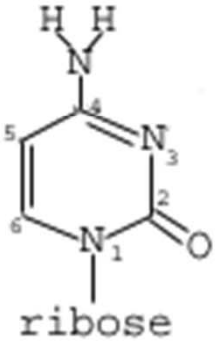


guanine

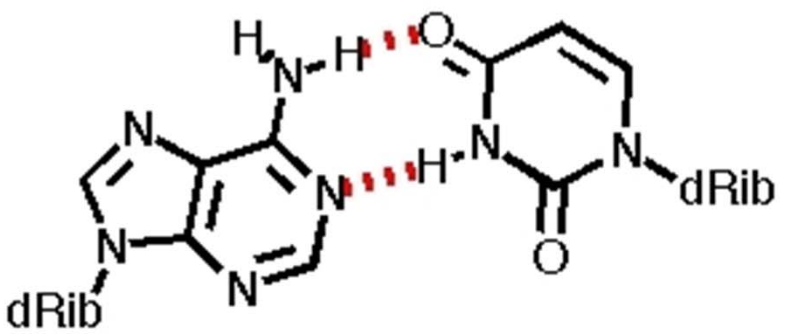
Pyrimidines



thymine



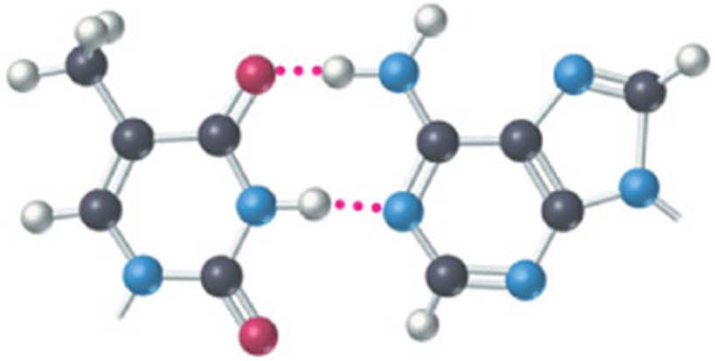
cytosine

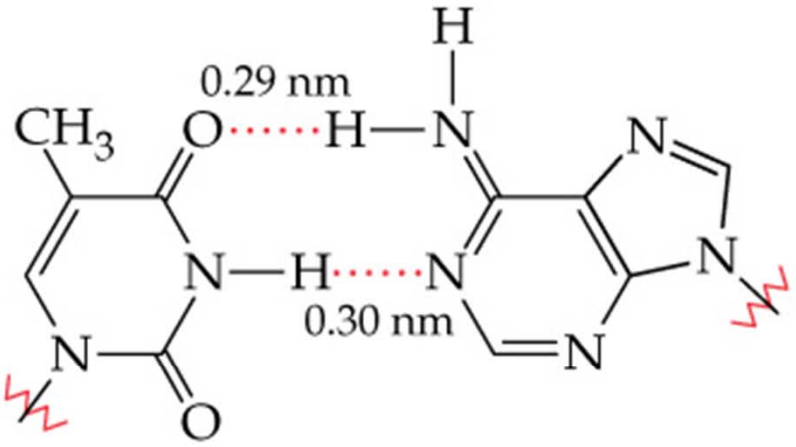


Adenine

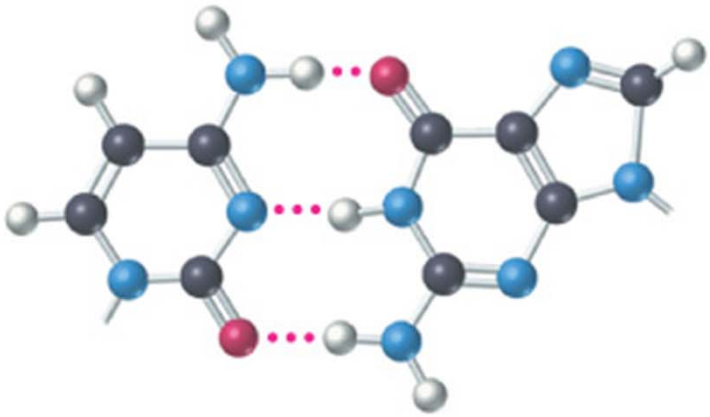
Uracil

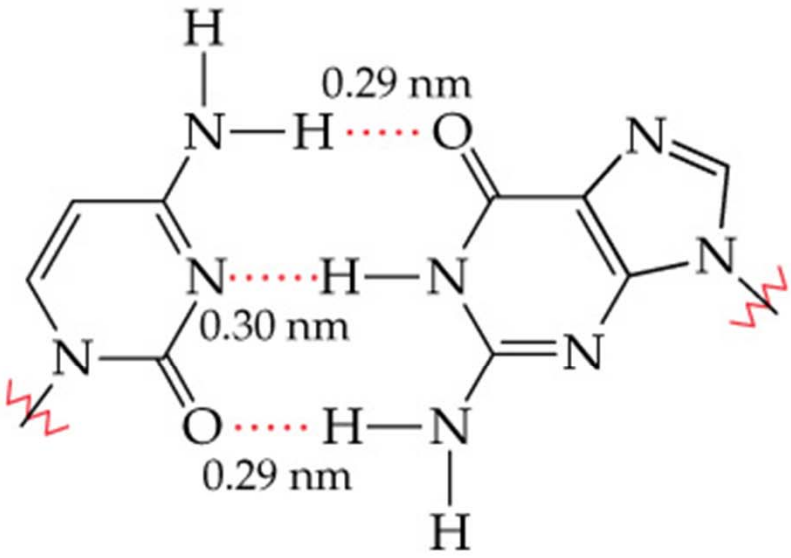
Thymine–Adenine

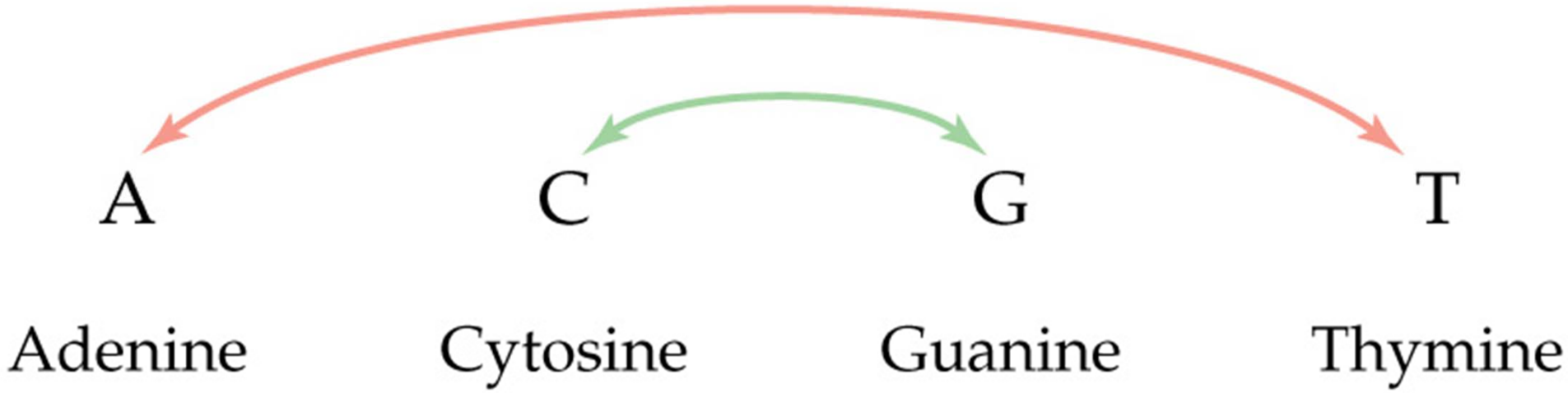


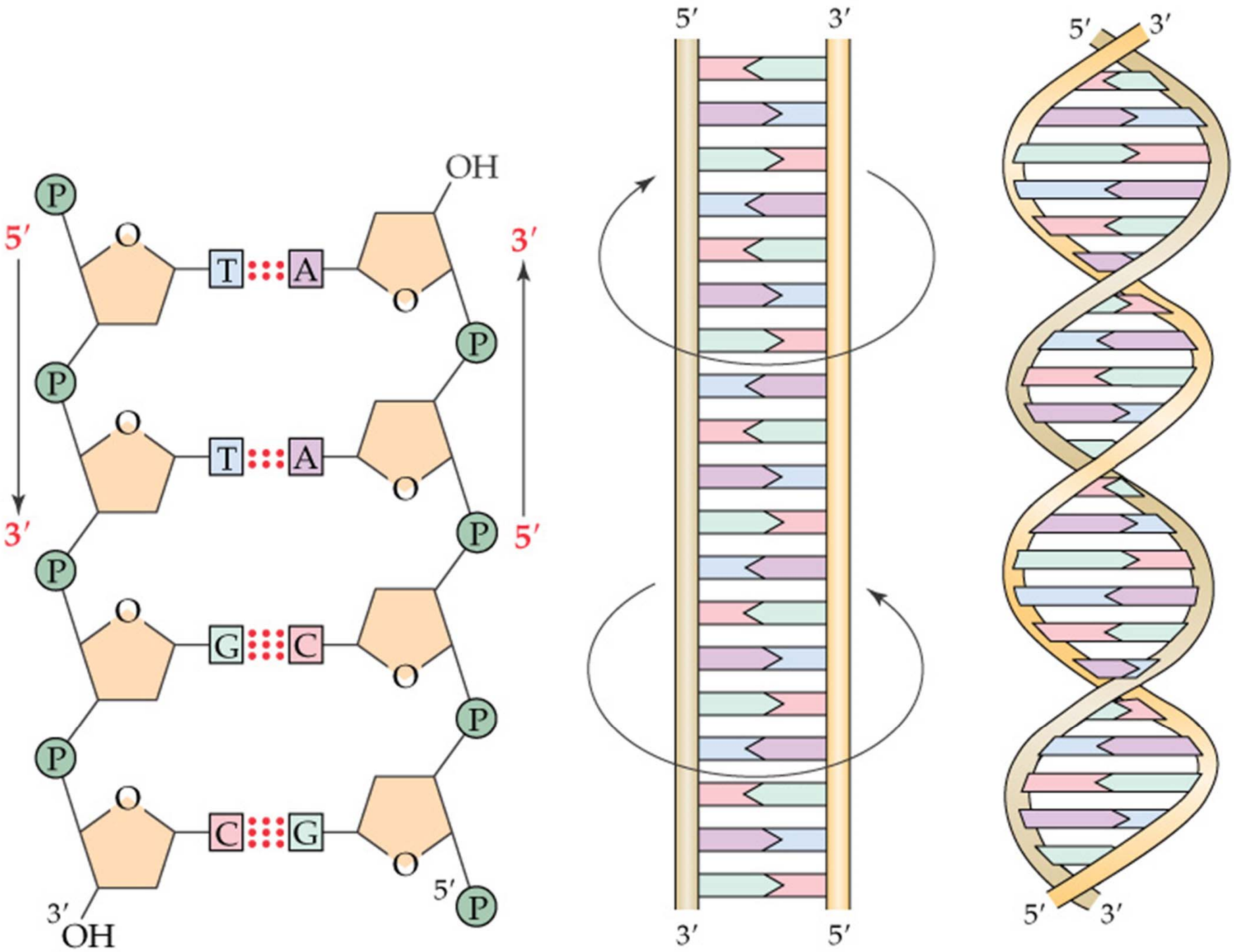


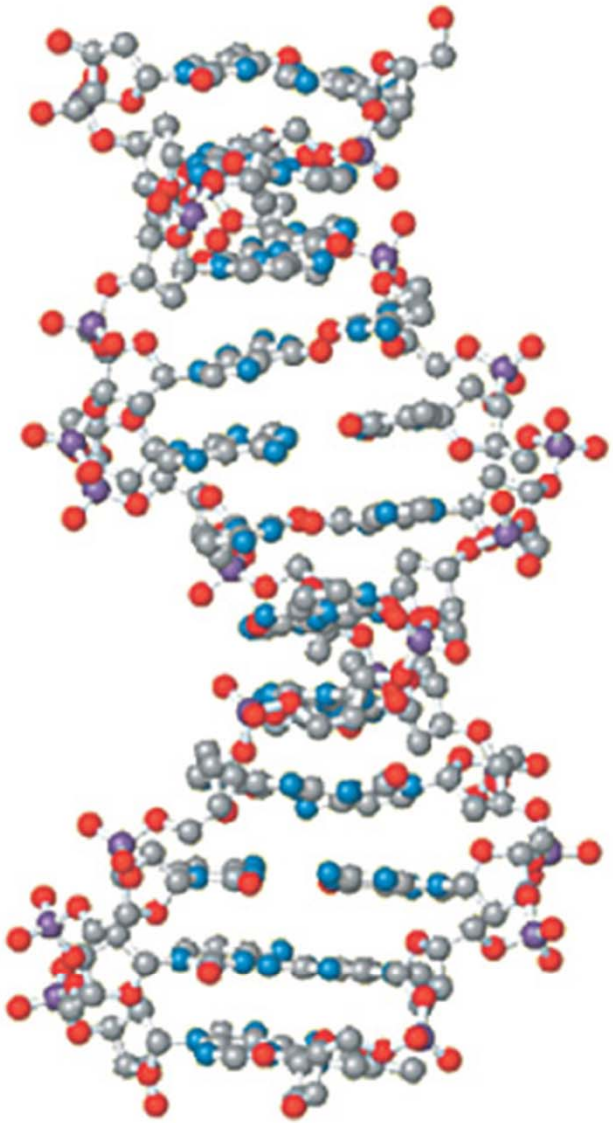
Cytosine–Guanine



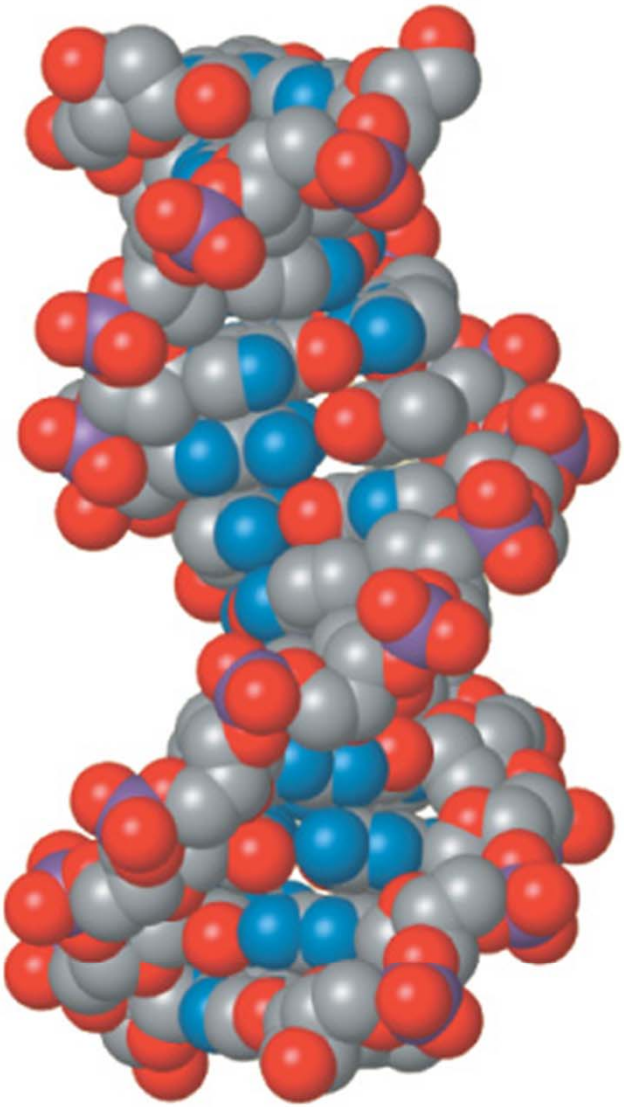



A
C
G
T
Adenine
Cytosine
Guanine
Thymine


5′
3′
OH
P
O
T
A
G
C
3′
OH
5′
P
5′
3′
3′
5′
5′
3′
5′
3′



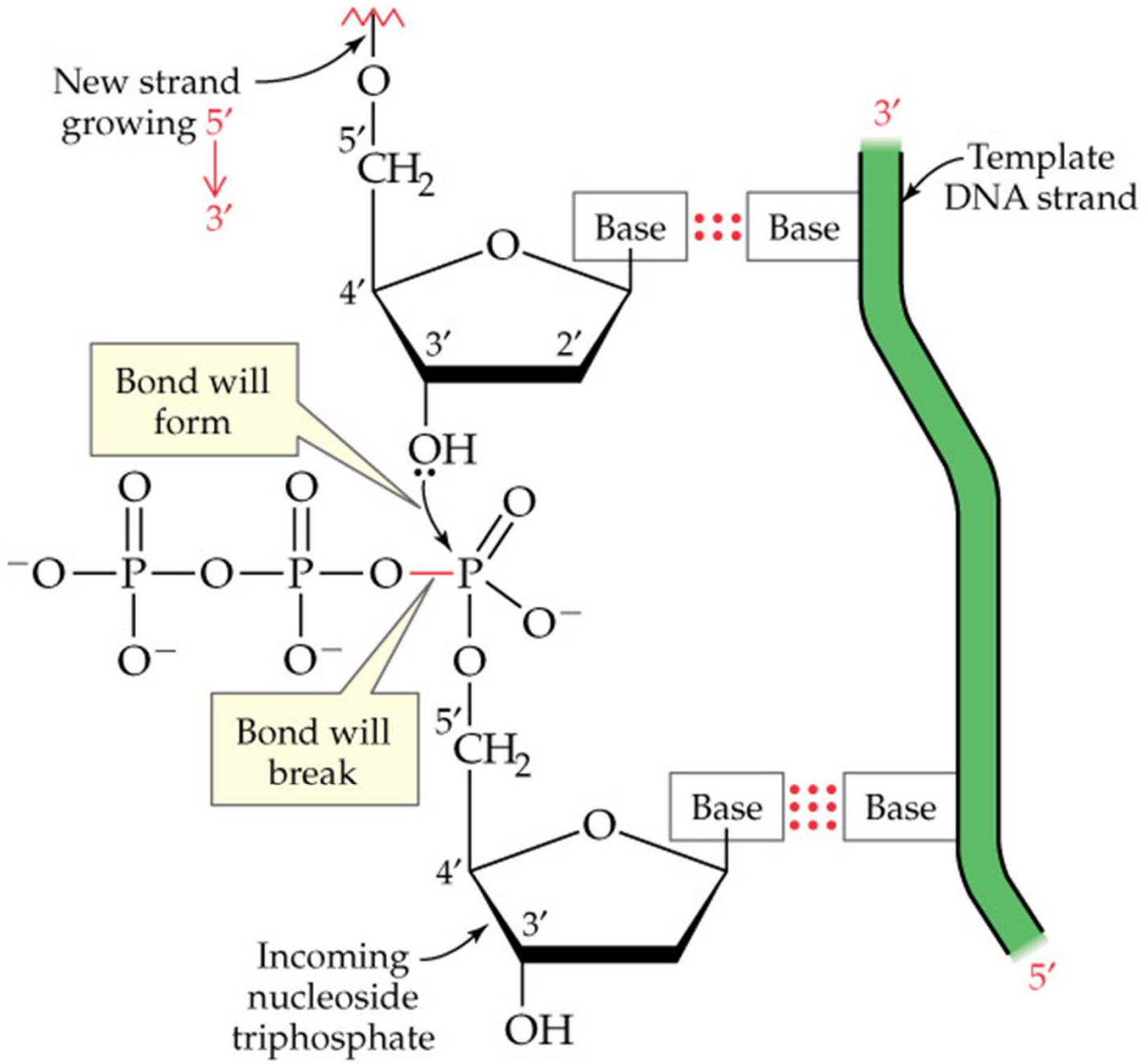
(a)

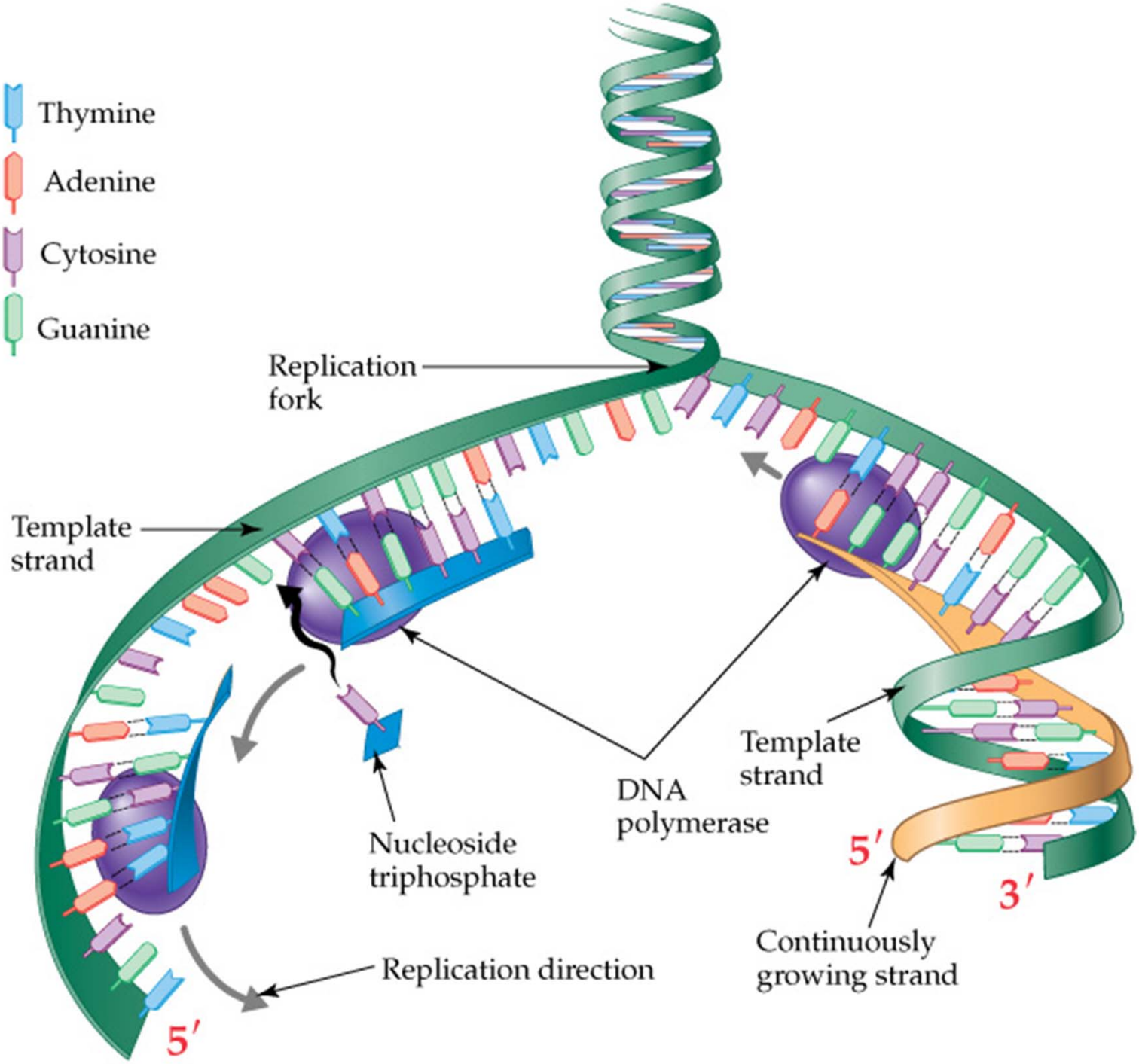


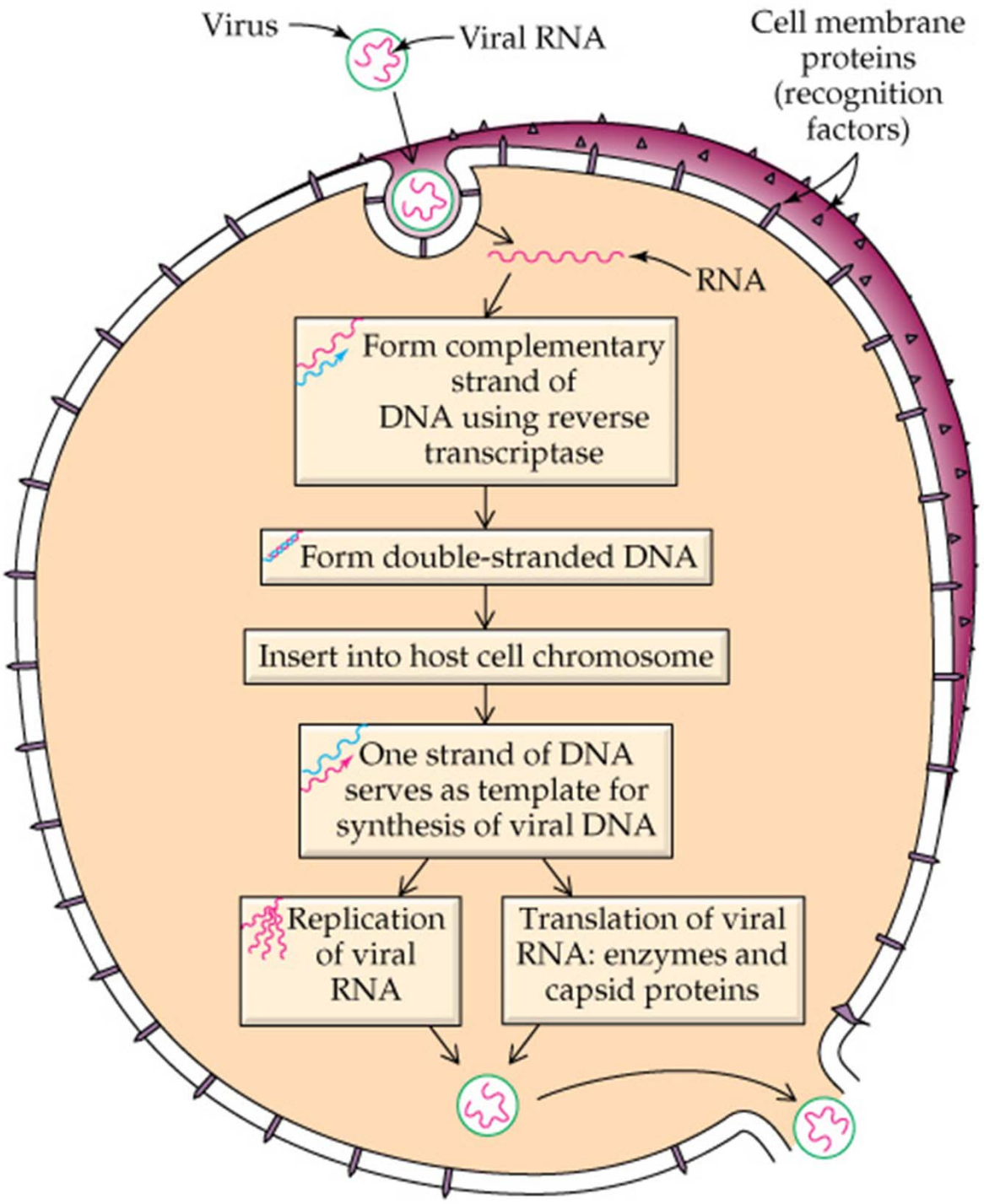
(b)

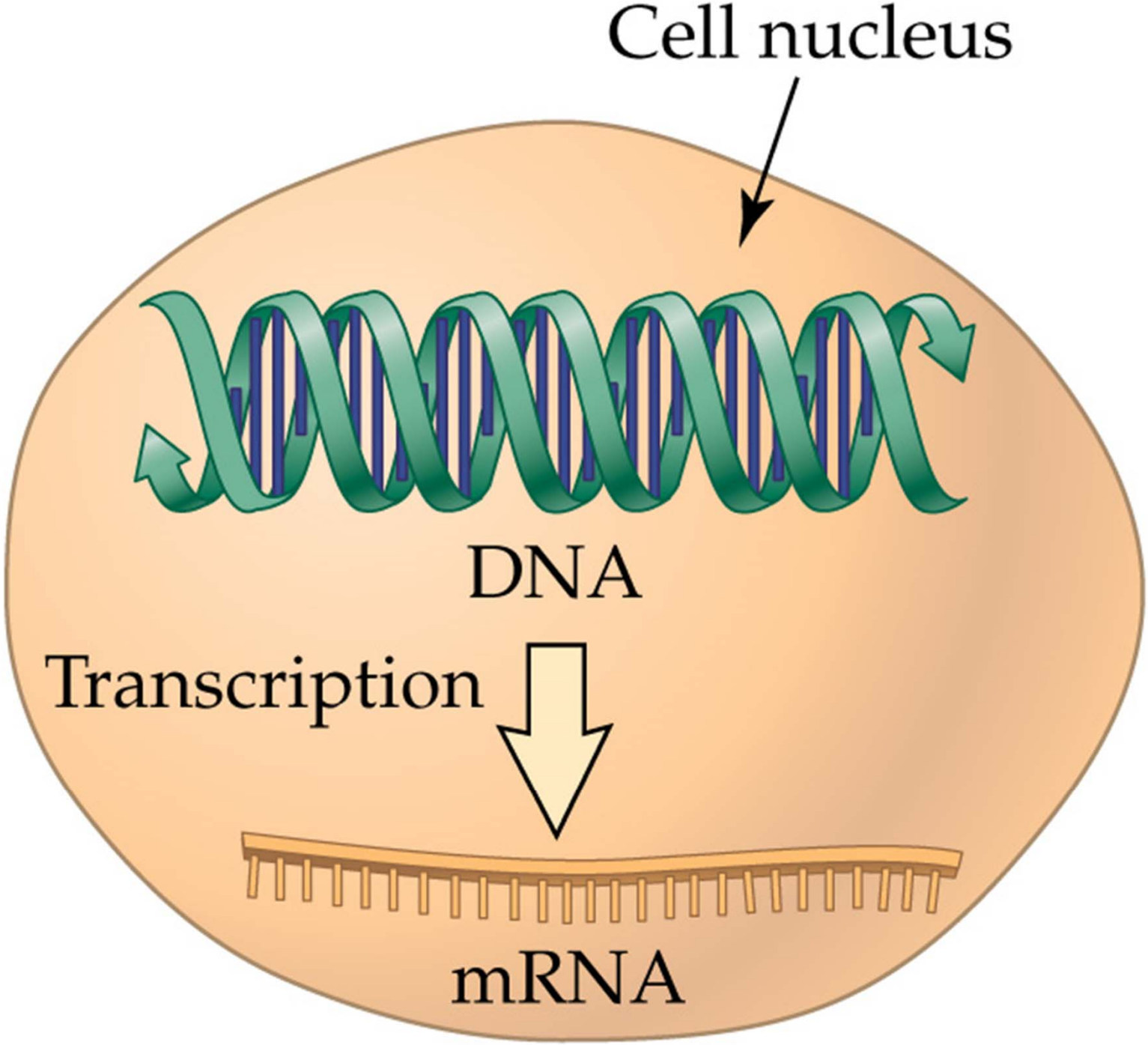
(c)

Bond formation in DNA replication

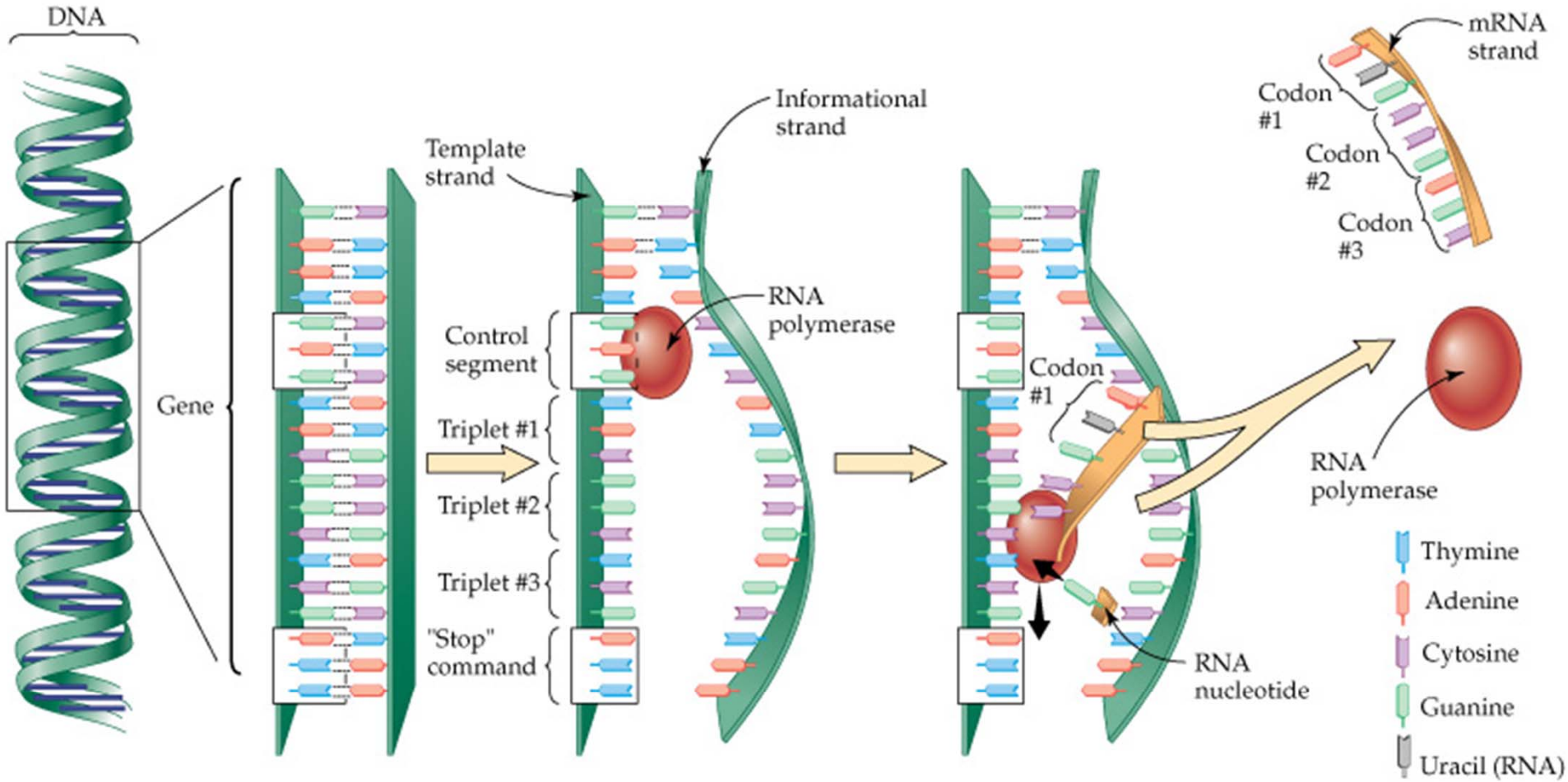


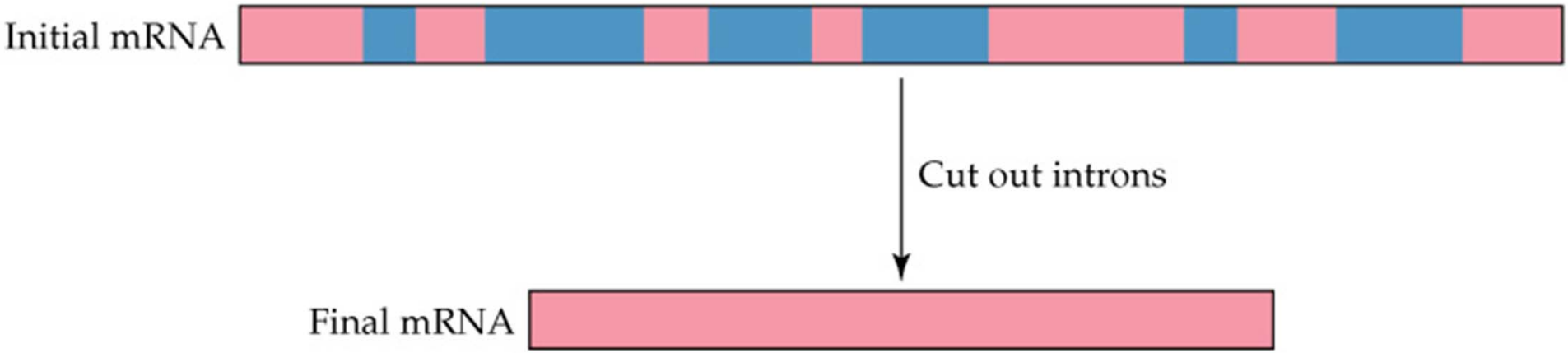

Thymine
Adenine
Cytosine
Guanine
Replication fork
Template strand
Nucleoside triphosphate
DNA polymerase
Template strand
5′
3′
Continuously growing strand
Replication direction
5′

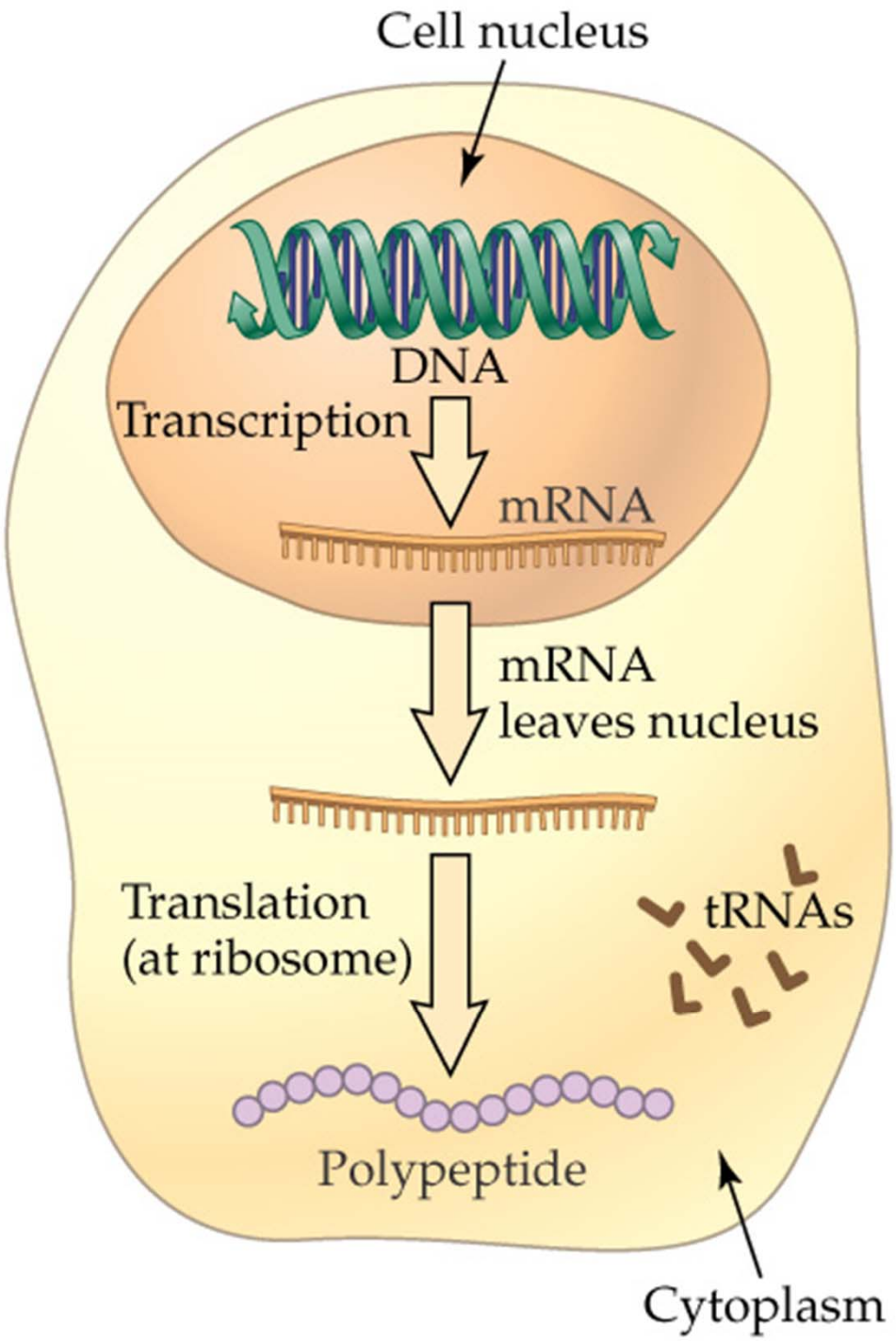

Virus
Viral RNA
Cell membrane proteins (recognition factors)
RNA
Form complementary strand of DNA using reverse transcriptase
Form double-stranded DNA
Insert into host cell chromosome
One strand of DNA serves as template for synthesis of viral DNA
Replication of viral RNA
Translation of viral RNA: enzymes and capsid proteins

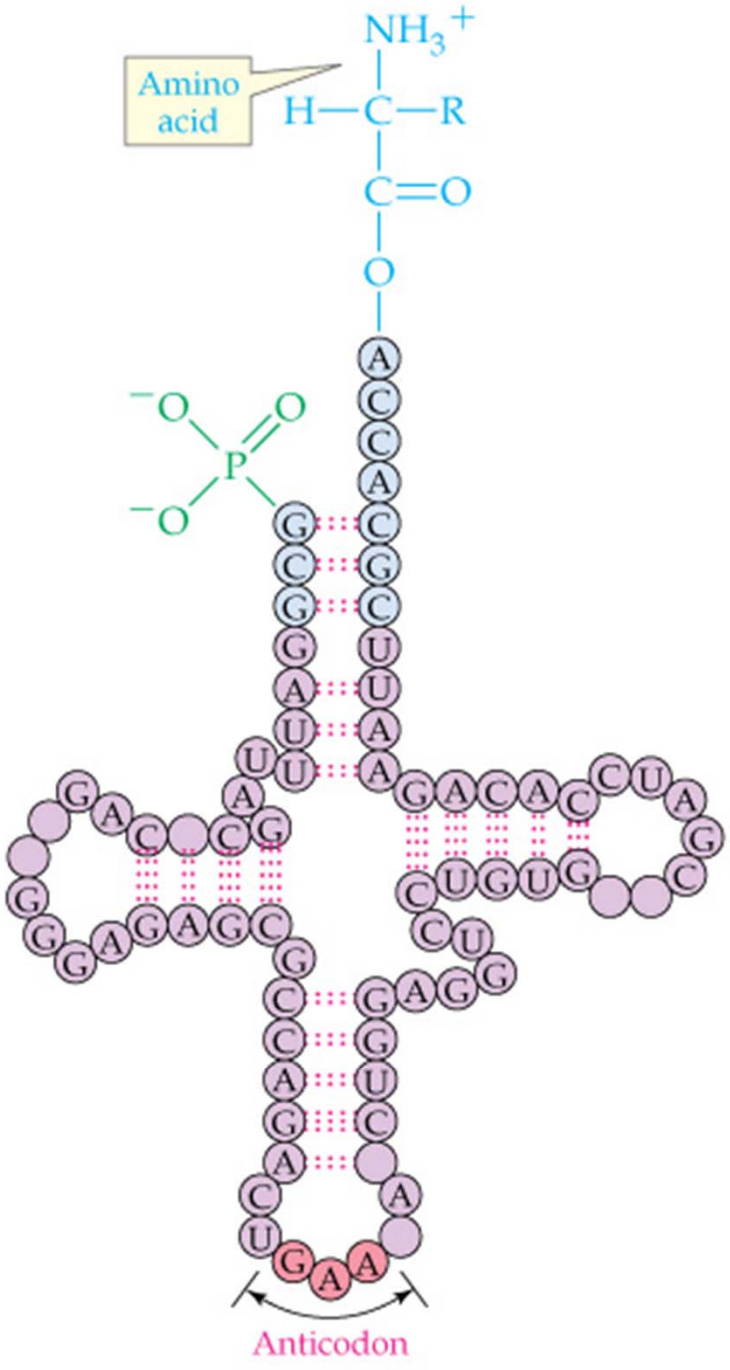

Cell nucleus
DNA
Transcription
mRNA

- The following three RNA make it possible for the encoded information carried by the DNA to be put to use in the synthesis of proteins.
- ***Ribosome RNA***: The granular organelles in the cell where protein synthesis takes place. These organelles are composed of protein and ribosomal RNA (rRNA).
- ***Messenger RNA (mRNA)***: The RNA that carries the code transcribed from DNA and directs protein synthesis.
- ***Transfer RNA (tRNA)***: The smaller RNA that delivers amino acids one by one to protein chains growing at ribosomes. Each tRNA recognizes and carries only one amino acid.

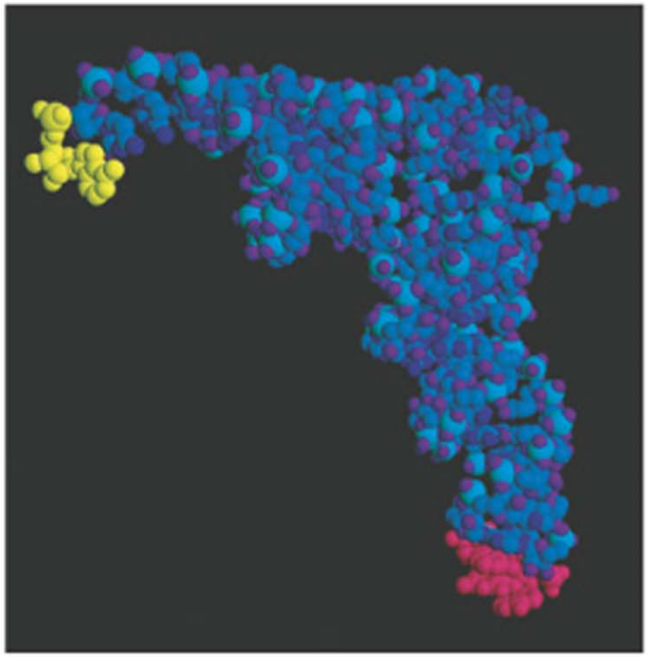

DNA
Gene
Template strand
Informational strand
RNA polymerase
Control segment
Triplet #1
Triplet #2
Triplet #3
"Stop" command
Codon #1
Codon #2
Codon #3
mRNA strand
RNA polymerase
RNA nucleotide
Thymine
Adenine
Cytosine
Guanine
Uracil (RNA)


Initial mRNA
Cut out introns
Final mRNA

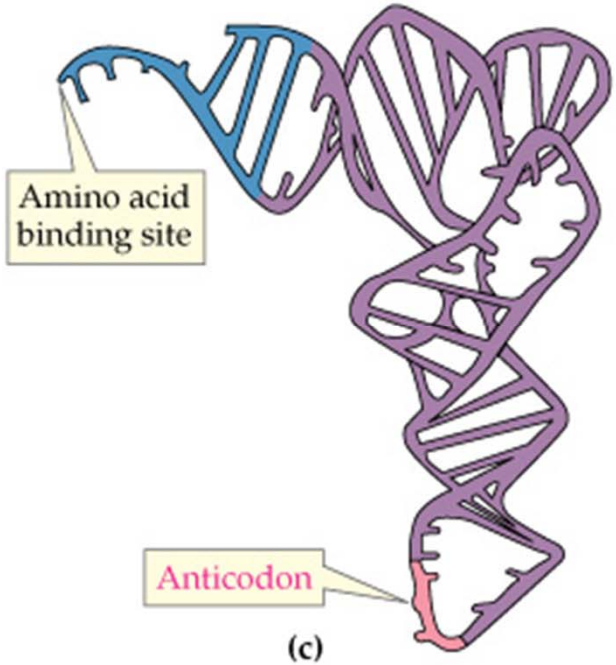

Cell nucleus
DNA
Transcription
mRNA
mRNA
leaves nucleus
Translation
(at ribosome)
tRNAs
Polypeptide
Cytoplasm


Amino acid
NH_3^+
H—C—R
C=O
O
^-O
O
P
^-O
Anticodon

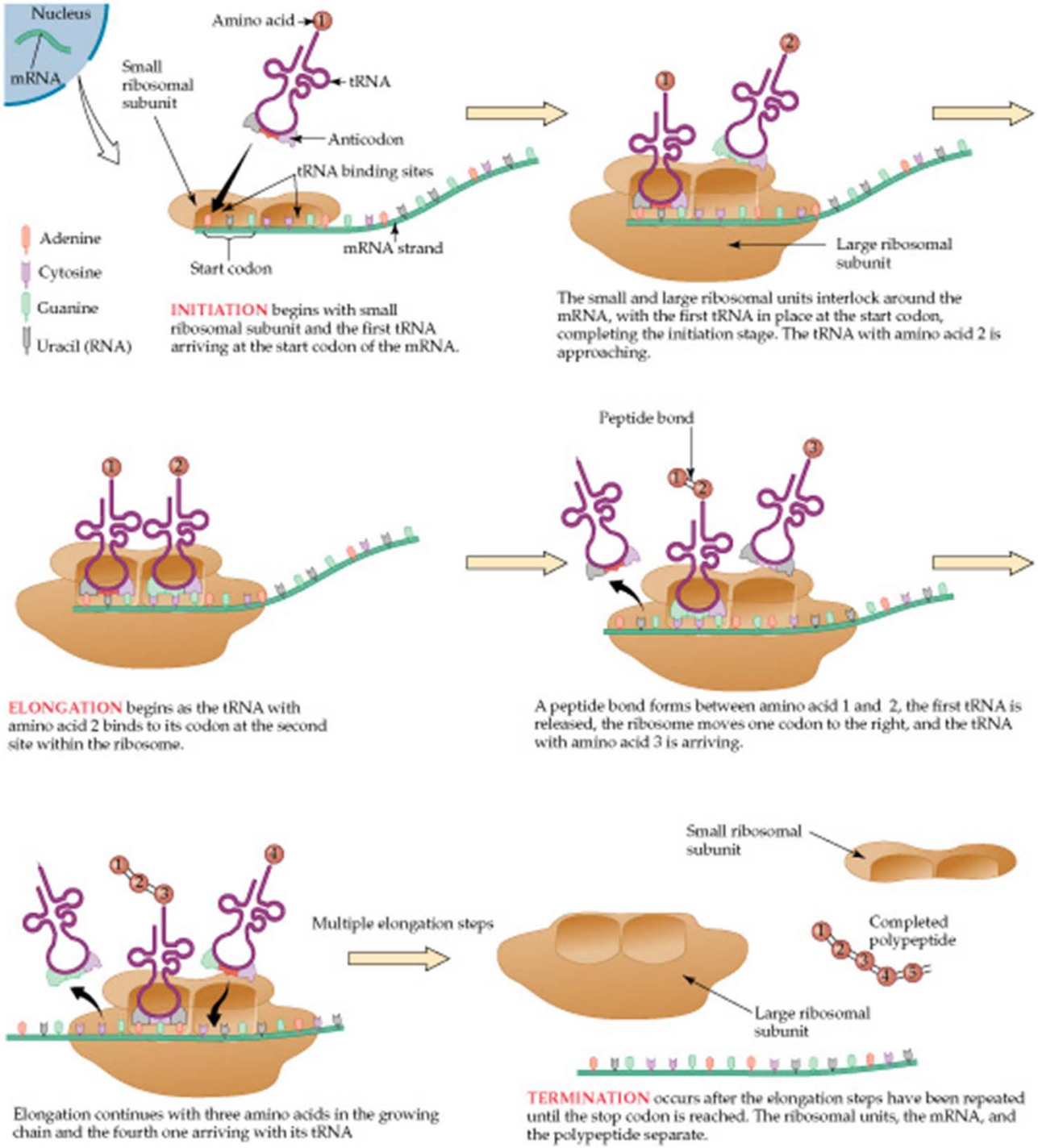
(a)

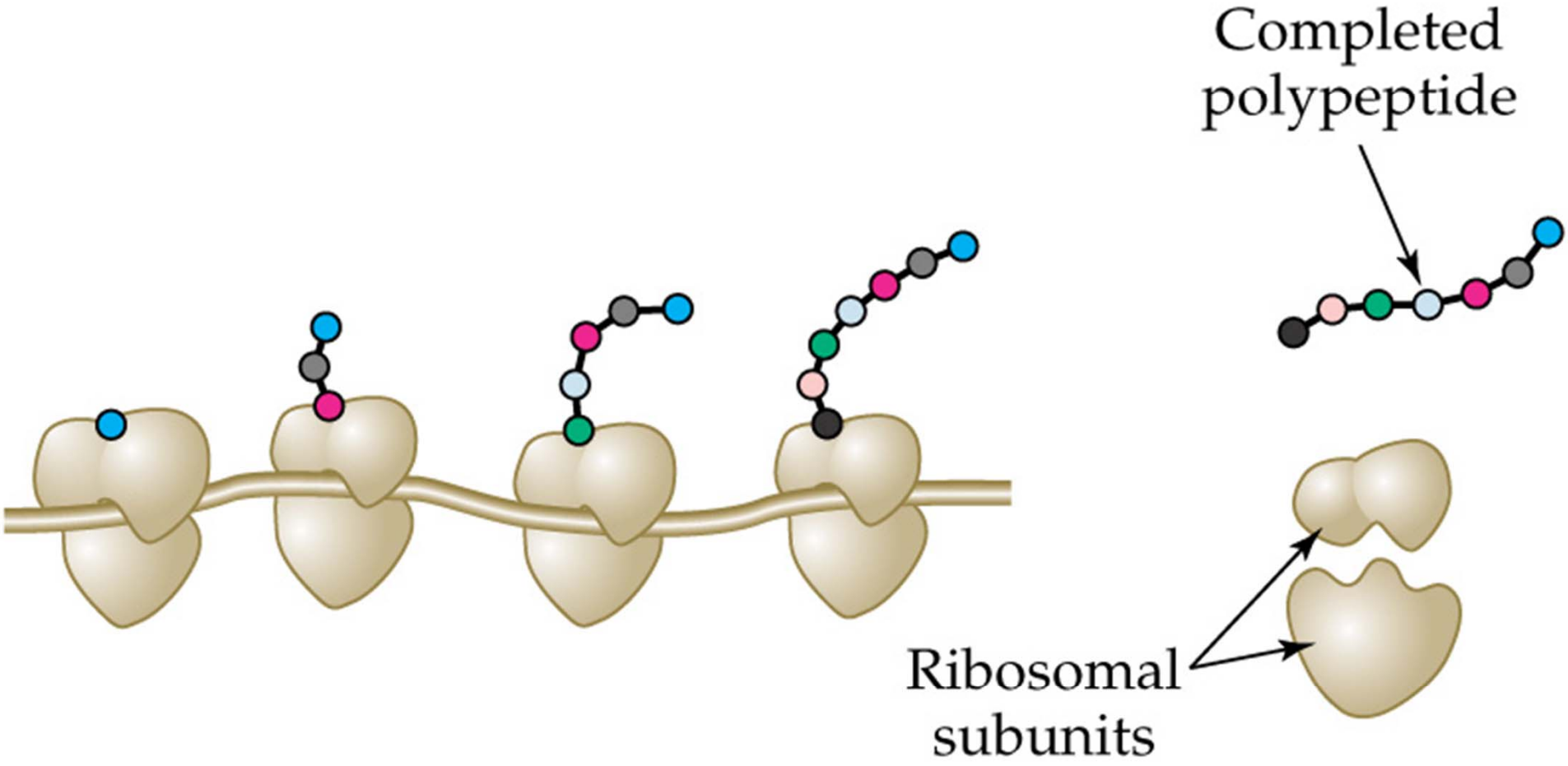


(b)


Amino acid binding site
Anticodon

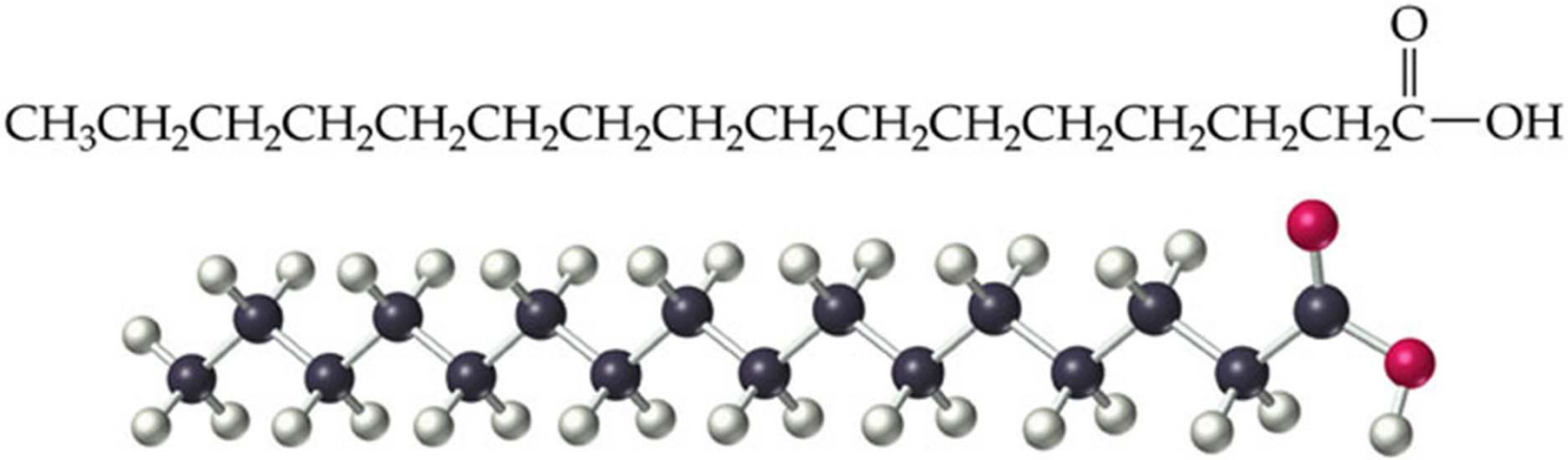
(c)


Nucleus
mRNA
Amino acid
1
tRNA
Small ribosomal subunit
Anticodon
tRNA binding sites
mRNA strand
Start codon
Adenine
Cytosine
Guanine
Uracil (RNA)
INITIATION begins with small ribosomal subunit and the first tRNA arriving at the start codon of the mRNA.
2
Large ribosomal subunit
The small and large ribosomal units interlock around the mRNA, with the first tRNA in place at the start codon, completing the initiation stage. The tRNA with amino acid 2 is approaching.
ELONGATION begins as the tRNA with amino acid 2 binds to its codon at the second site within the ribosome.
Peptide bond
3
A peptide bond forms between amino acid 1 and 2, the first tRNA is released, the ribosome moves one codon to the right, and the tRNA with amino acid 3 is arriving.
4
Elongation continues with three amino acids in the growing chain and the fourth one arriving with its tRNA
Multiple elongation steps
Small ribosomal subunit
Completed polypeptide
5
Large ribosomal subunit
TERMINATION occurs after the elongation steps have been repeated until the stop codon is reached. The ribosomal units, the mRNA, and the polypeptide separate.

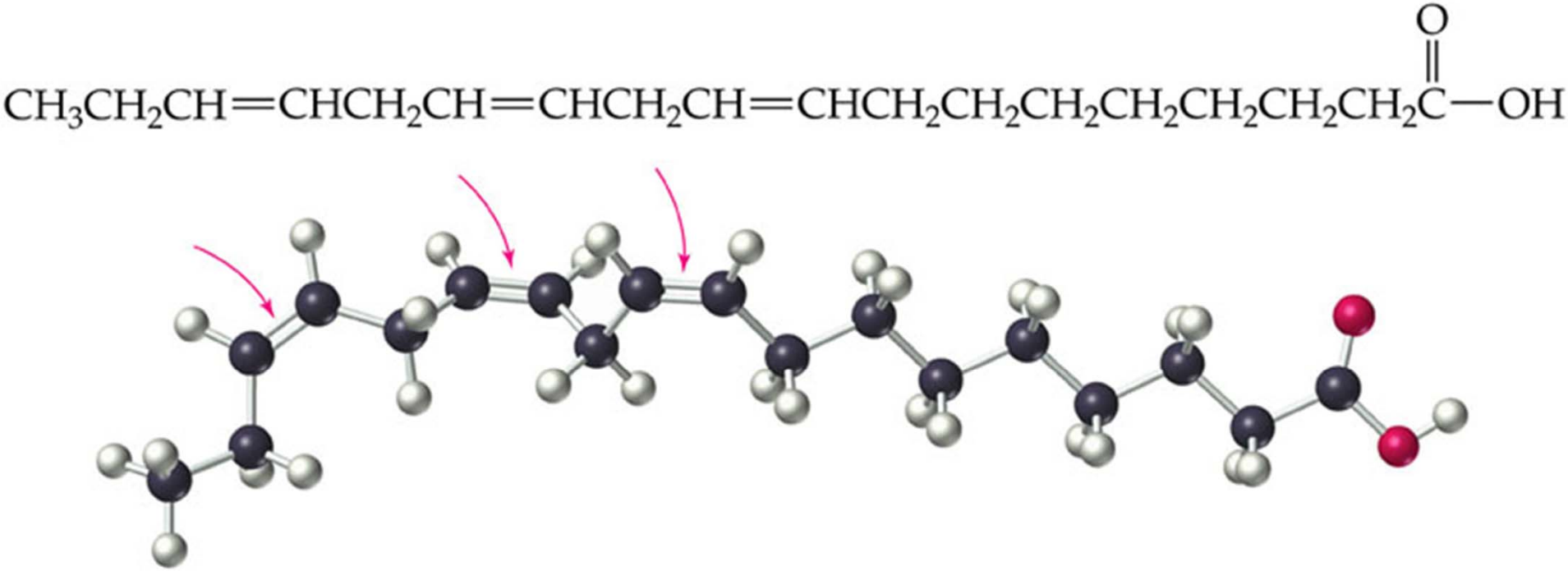

Completed
polypeptide
Ribosomal
subunits

Lipid

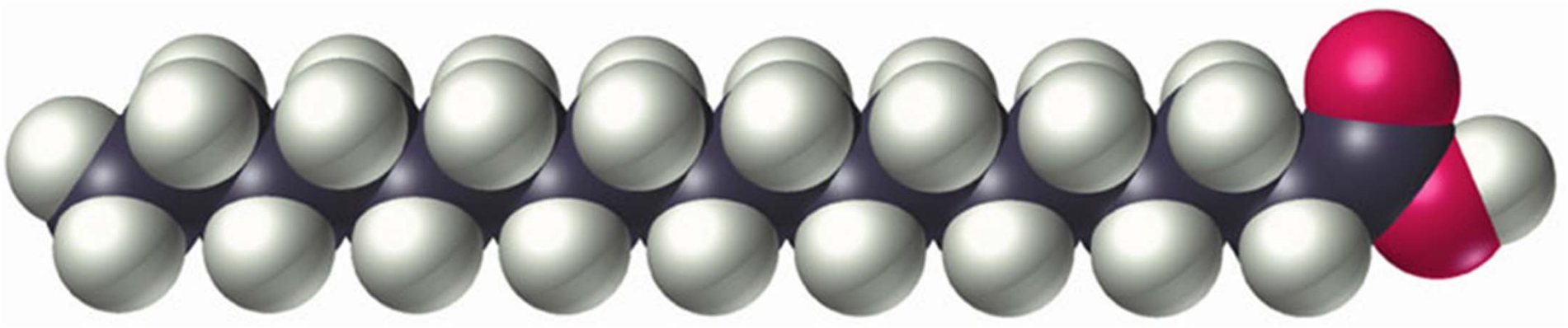
- ***Lipids*** are naturally occurring molecules from plants or animals that are soluble in nonpolar organic solvents.
- Lipid molecules contain large hydrocarbon portion and not many polar functional group, which accounts for their solubility behavior.



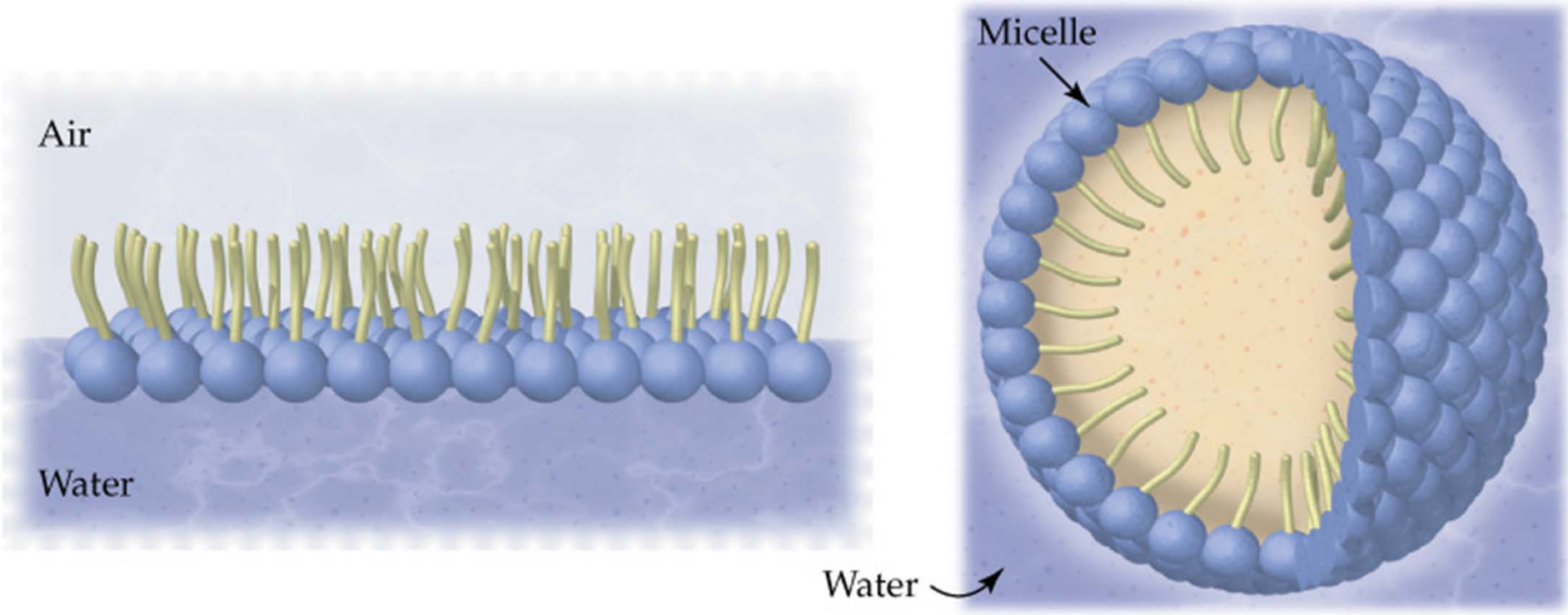
A saturated fatty acid
(palmitic acid)

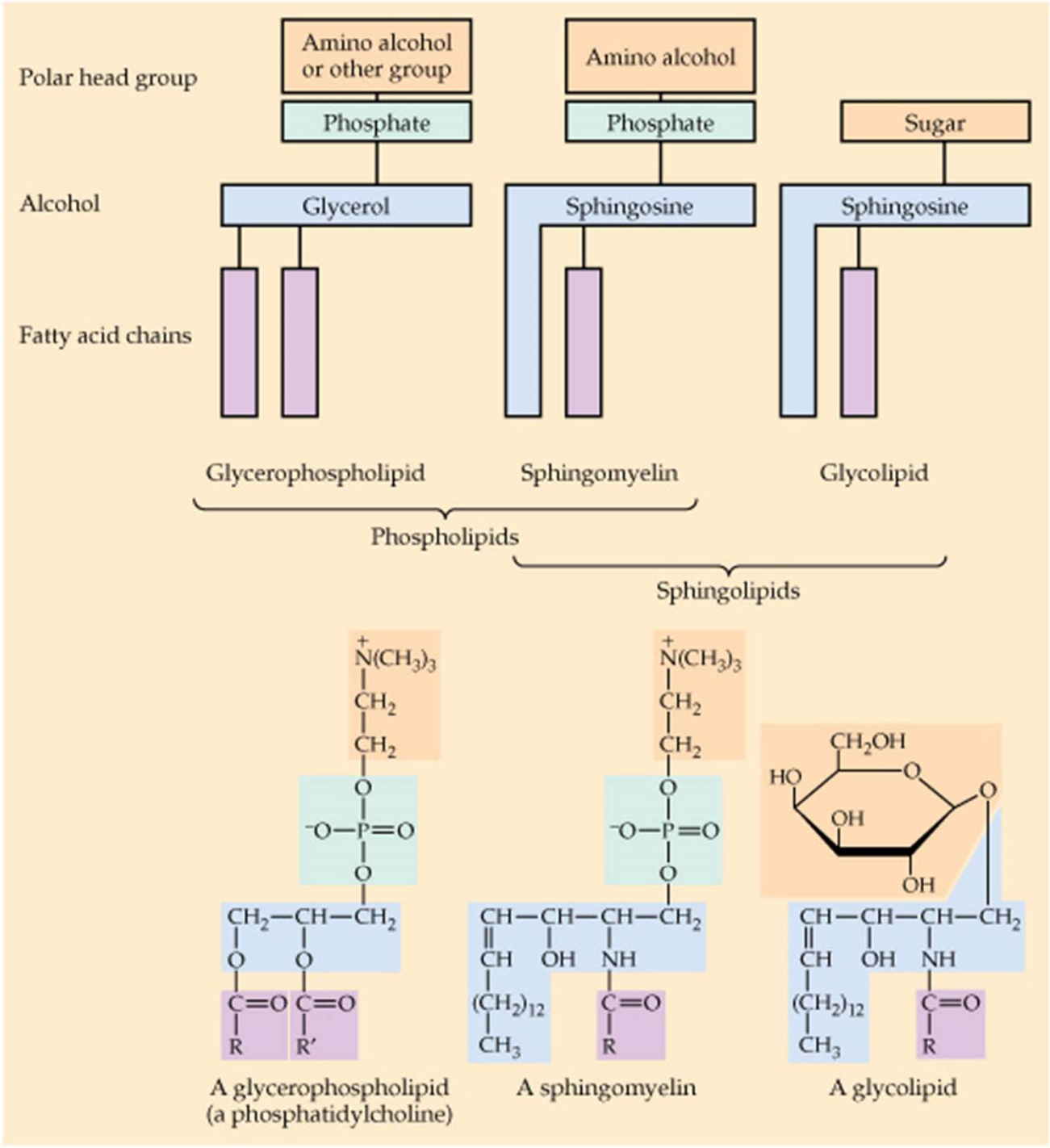


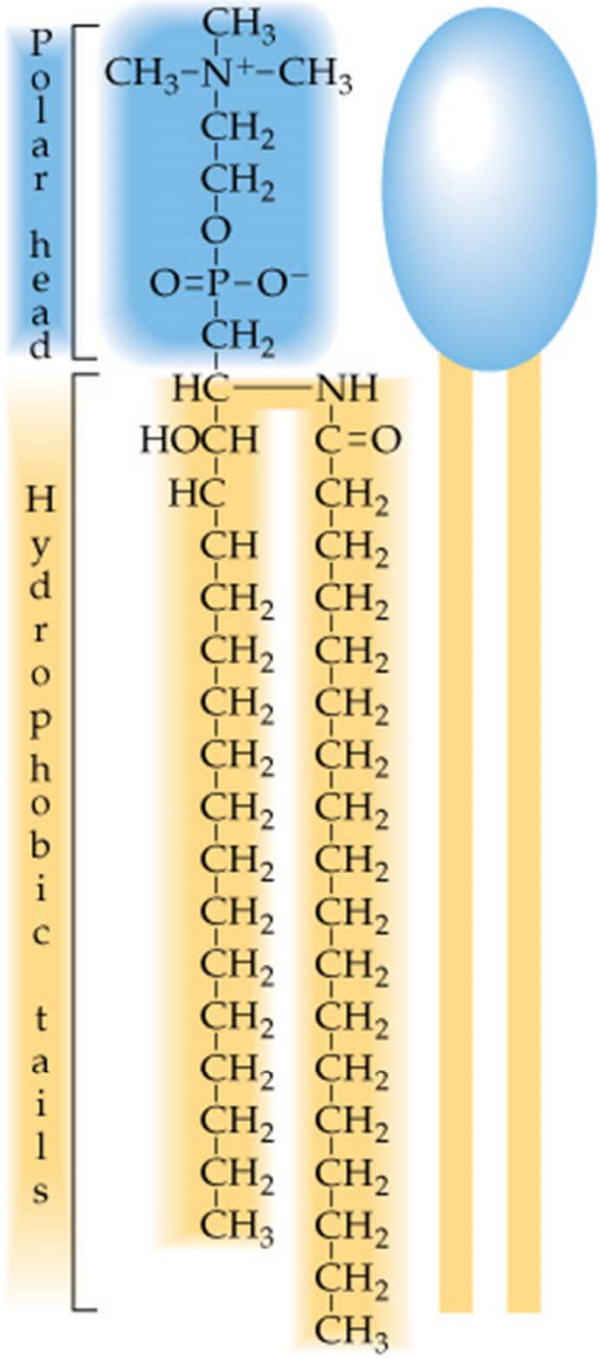
A *cis* unsaturated fatty acid
(linolenic acid)



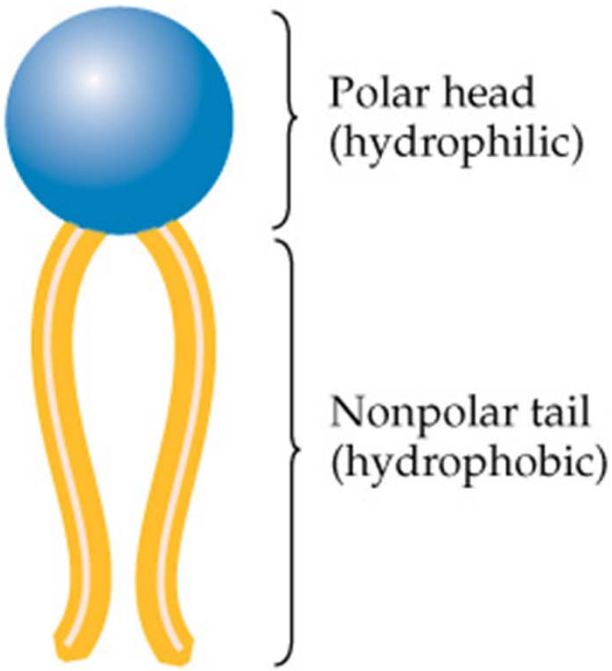
Stearic acid, an 18-carbon saturated fatty acid


Air
Water
Micelle
Water

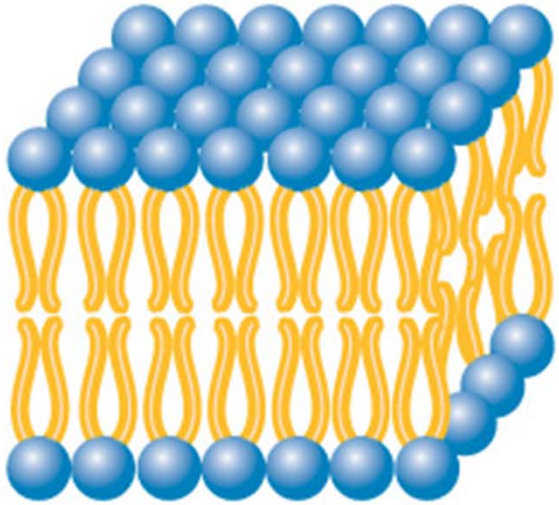

Polar head group
Alcohol
Fatty acid chains
Amino alcohol or other group
Phosphate
Glycerol
Amino alcohol
Phosphate
Sphingosine
Sugar
Sphingosine
Glycerophospholipid
Sphingomyelin
Glycolipid
Phospholipids
Sphingolipids
A glycerophospholipid (a phosphatidylcholine)
A sphingomyelin
A glycolipid



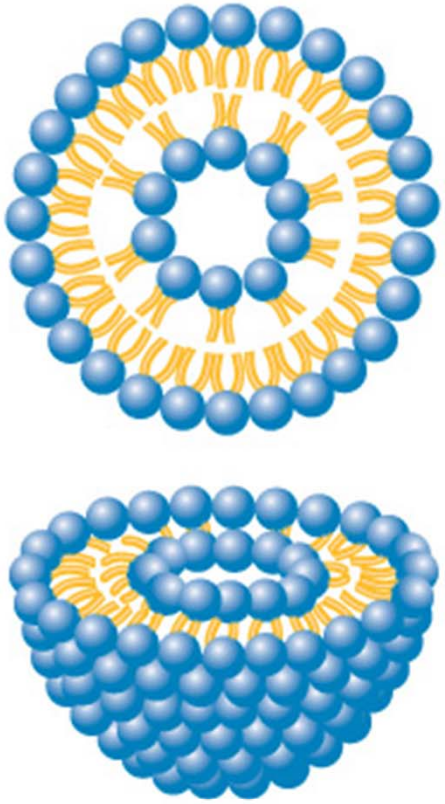
A sphingomyelin



Membrane lipid



Lipid bilayer



Liposome

Properties of cell membranes:

- Cell membranes are composed of a fluid like phospholipid bilayer.
- The bilayer incorporates cholesterol, proteins, and glycolipids.
- Small nonpolar molecules cross by diffusion through the lipid bilayer.
- Small ions and polar molecules diffuse through the aqueous media in protein pores.
- Glucose and certain other substances cross with the aid of proteins without energy input.
- Na^+, K^+, and other substances that maintain concentration gradients inside and outside the cell cross with expenditure of energy and the aid of proteins.

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- Glucose and certain other substances cross with the aid of proteins without energy input.
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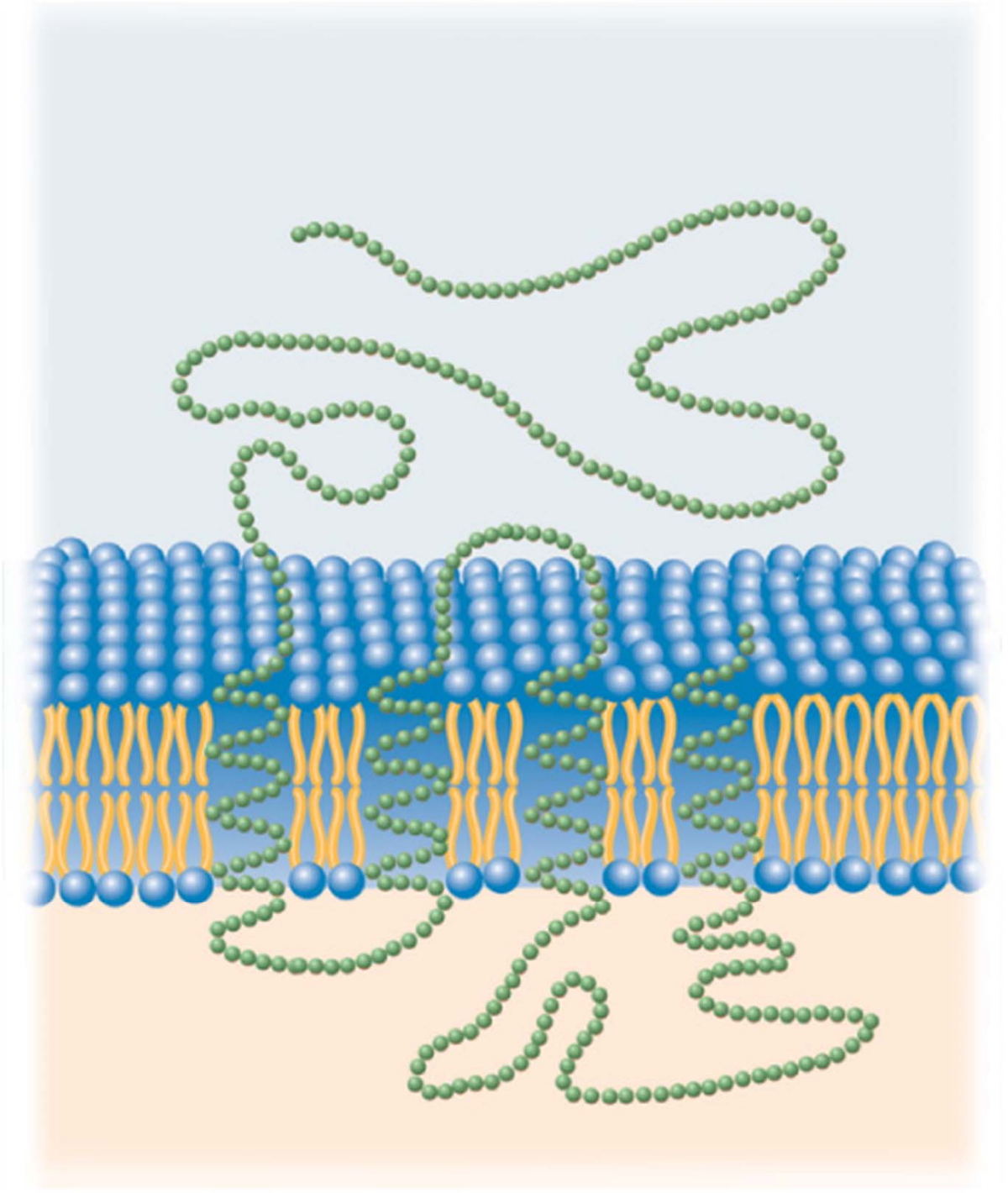
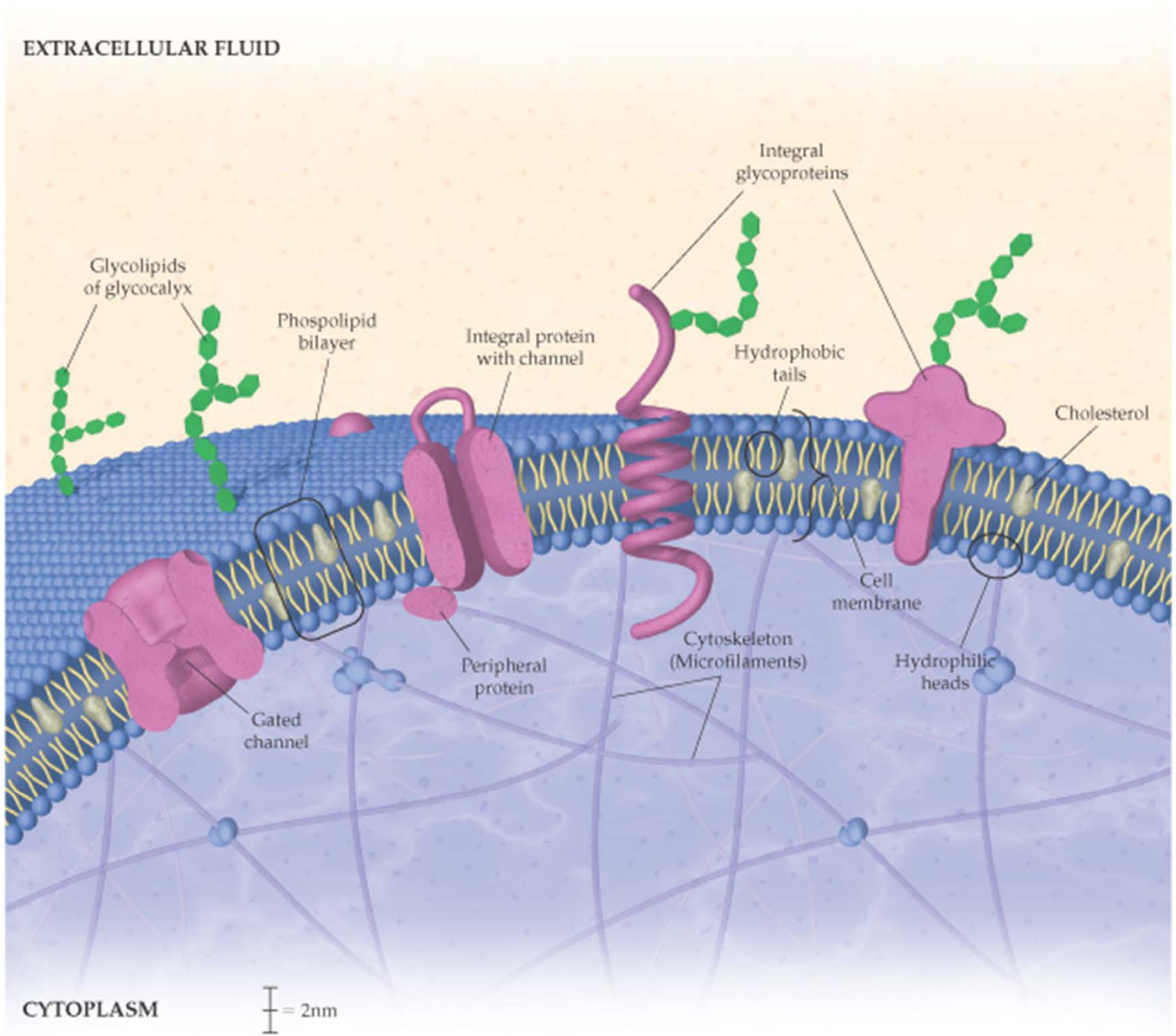
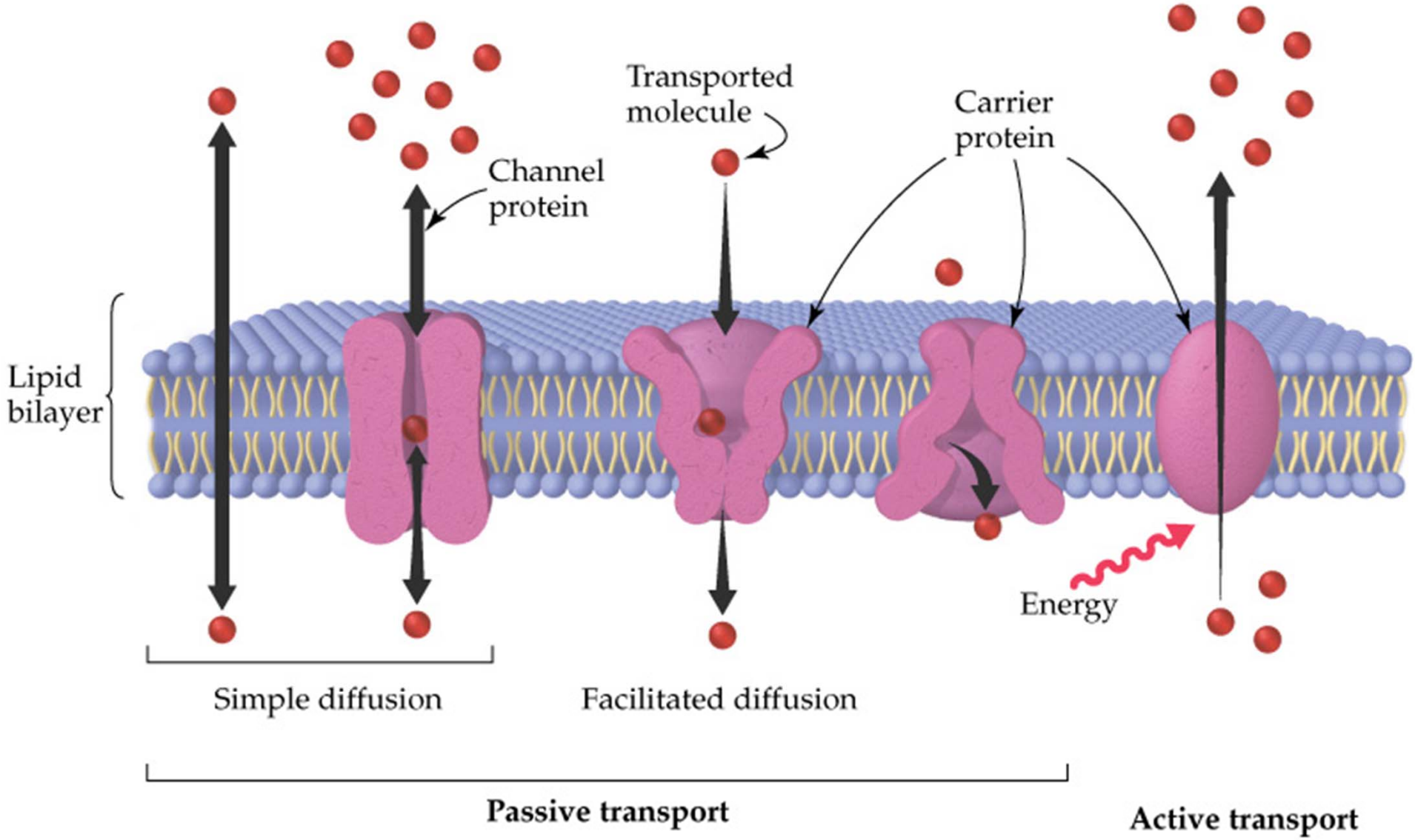
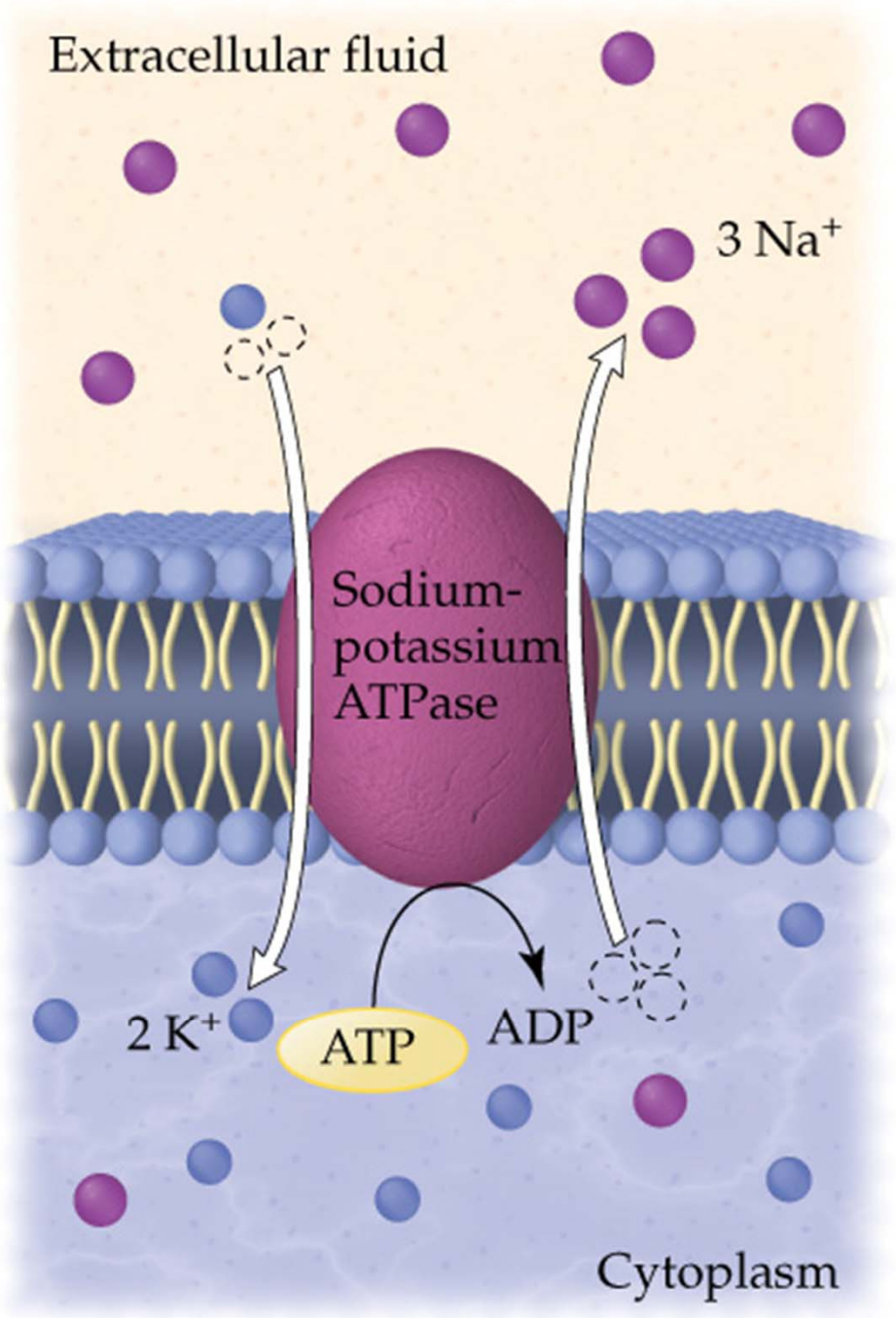
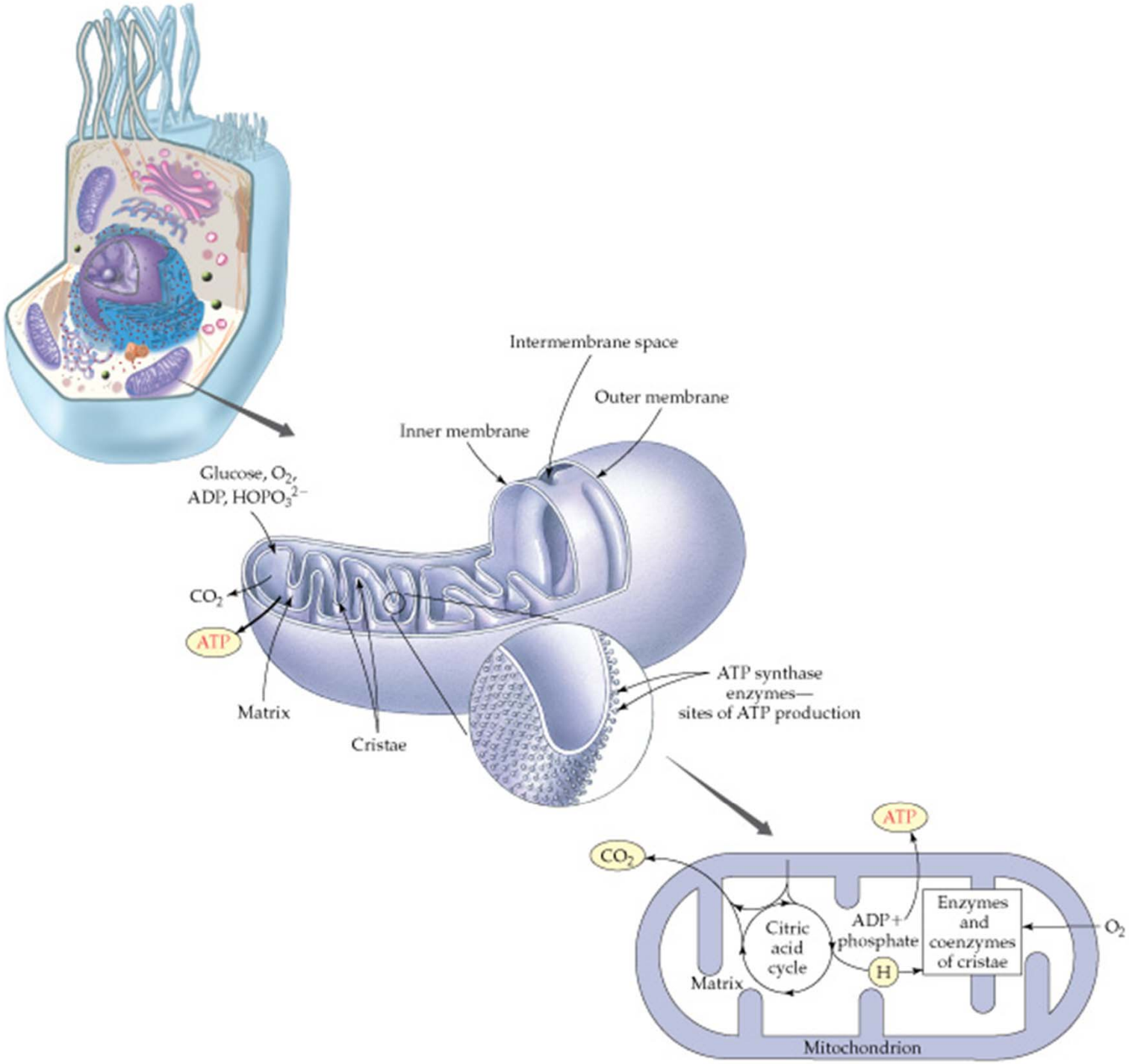



EXTRACELLULAR FLUID
Integral glycoproteins
Glycolipids of glycocalyx
Phospolipid bilayer
Integral protein with channel
Hydrophobic tails
Cholesterol
Cell membrane
Cytoskeleton (Microfilaments)
Peripheral protein
Hydrophilic heads
Gated channel
CYTOPLASM
= 2nm


Transported molecule
Carrier protein
Channel protein
Lipid bilayer
Energy
Simple diffusion
Facilitated diffusion
Passive transport
Active transport

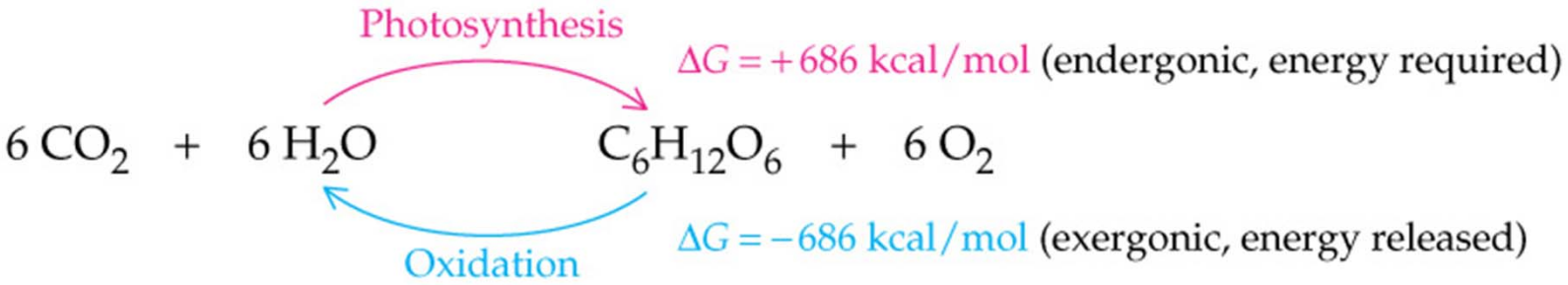

Extracellular fluid
3 Na+
Sodium-
potassium
ATPase
2 K+
ATP
ADP
Cytoplasm


Intermembrane space
Outer membrane
Inner membrane
Glucose, O_2, ADP, $HOPO_3^{2-}$
CO_2
ATP
Matrix
Cristae
ATP synthase enzymes—sites of ATP production
ATP
CO_2
Citric acid cycle
ADP + phosphate
Enzymes and coenzymes of cristae
O_2
H
Matrix
Mitochondrion

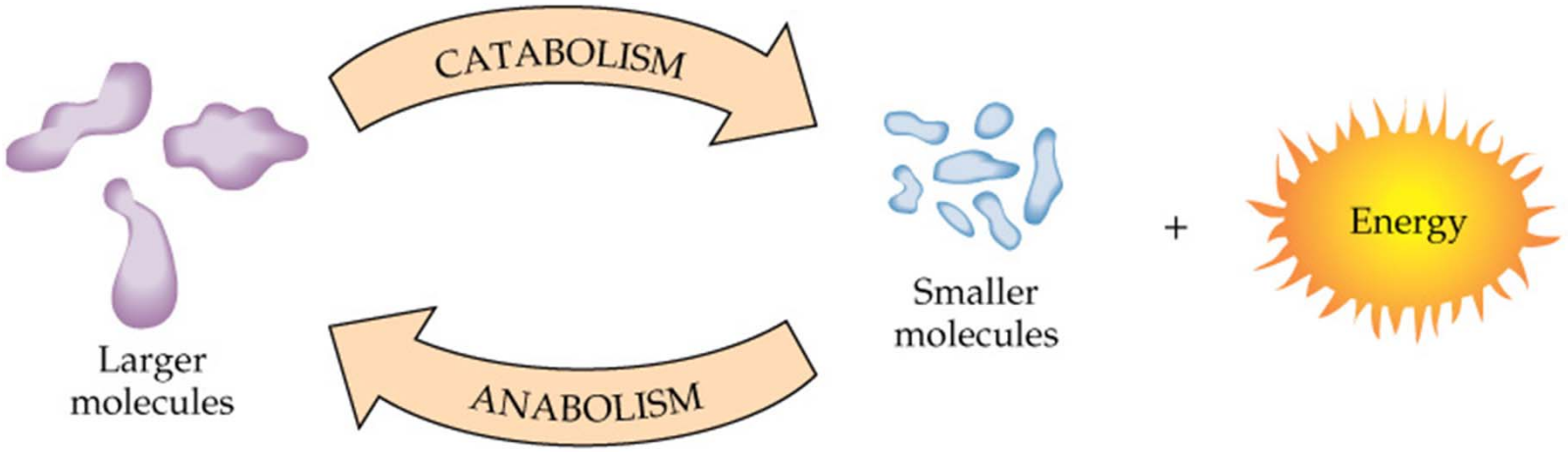
Energy and Biochemical Reactions

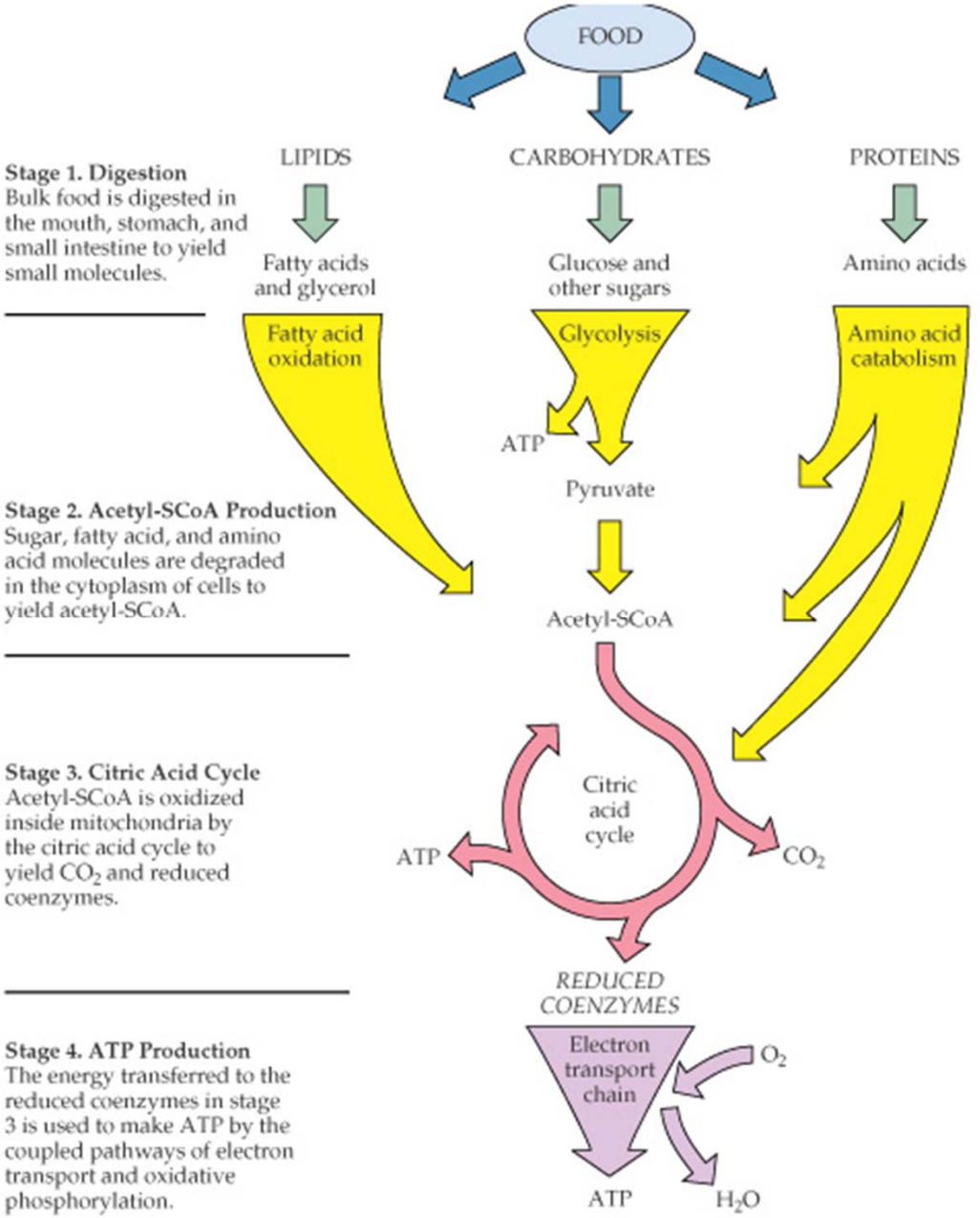
- Reactions in living organisms are similar to reactions in a chemical laboratory.
- Spontaneous reactions, those are favorable in the forward direction, release free energy and the energy released is available to do work.
- Spontaneous reactions , also known as *exergonic* reactions, are the source of our biochemical energy.
- Products of exergonic reactions are more stable than the reactants and the free energy change ΔG has a negative value.

- *Photosynthesis* in plants, converts CO_2 and H_2O to glucose plus O_2 which is the reverse of oxidation of glucose. The sun provides the necessary external energy for photosynthesis (686 kcal of free energy per mole of glucose formed).



- The *mitochondria* is often called the cell's power plants. Within the mitochondria, small molecules are broken down to provide the energy for an organism and also the principle energy carrying molecule adenosine triphosphate (ATP) is produced.


CATABOLISM
Larger molecules
Smaller molecules
+
Energy
ANABOLISM



Stage 1. Digestion
Bulk food is digested in the mouth, stomach, and small intestine to yield small molecules.

Stage 2. Acetyl-SCoA Production
Sugar, fatty acid, and amino acid molecules are degraded in the cytoplasm of cells to yield acetyl-SCoA.

Stage 3. Citric Acid Cycle
Acetyl-SCoA is oxidized inside mitochondria by the citric acid cycle to yield CO_2 and reduced coenzymes.

Stage 4. ATP Production
The energy transferred to the reduced coenzymes in stage 3 is used to make ATP by the coupled pathways of electron transport and oxidative phosphorylation.

ATP and Energy Transfer

- Adenosine triphosphate (ATP) transport energy in living organisms.
- ATP has three $-PO_3^-$ groups.
- Removal of one of the $-PO_3^-$ groups from ATP by hydrolysis produces adenosine diphosphate (ADP). Since this reaction is an exergonic process, it releases energy.
- The reverse of ATP hydrolysis reaction is known as phosphorylation reaction. Phosphorylation reactions are endergonic.

•Biochemical energy production, transport, and use all depends on the ATP ⇌ ADP interconversions.

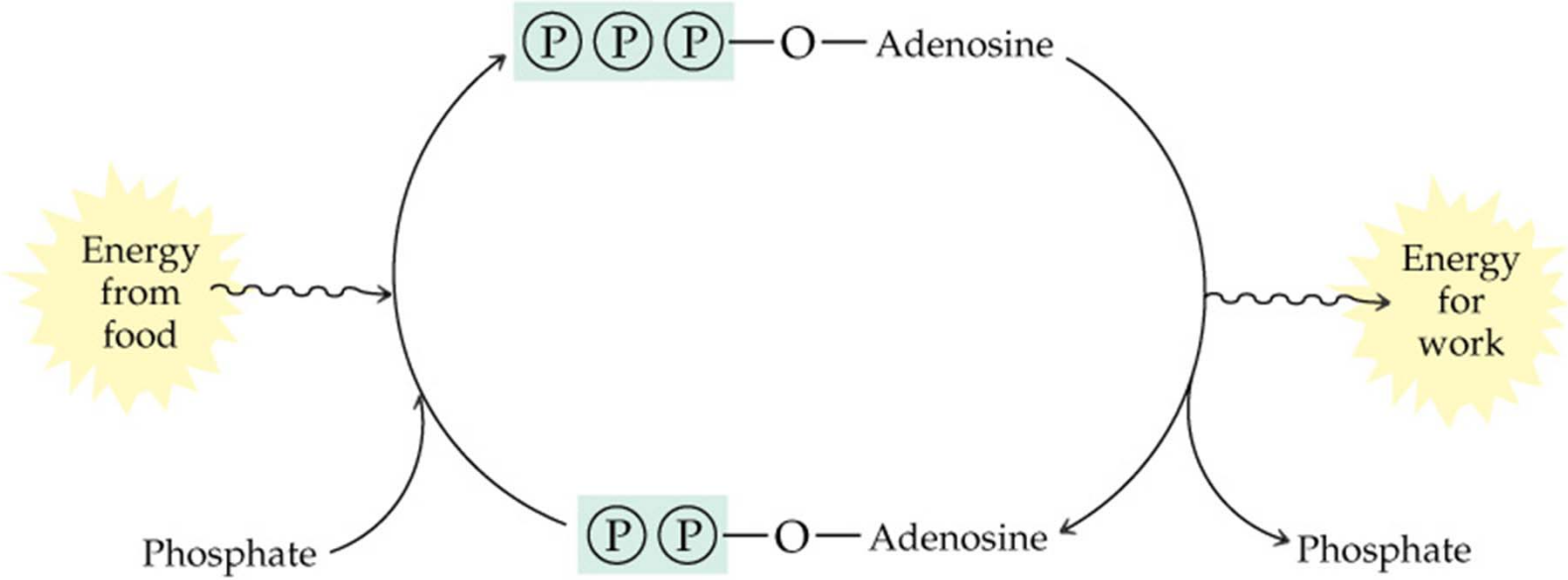
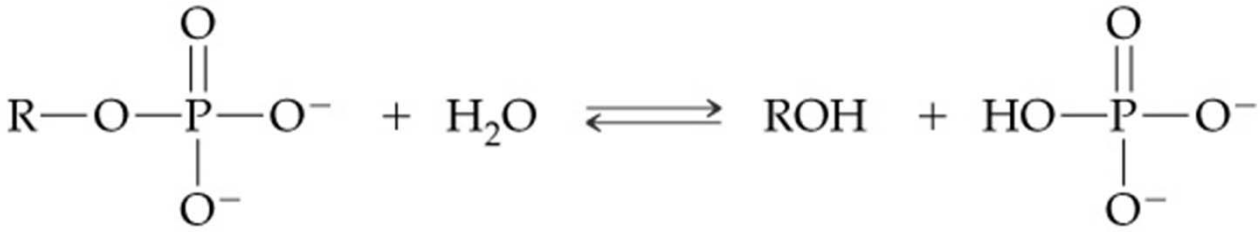


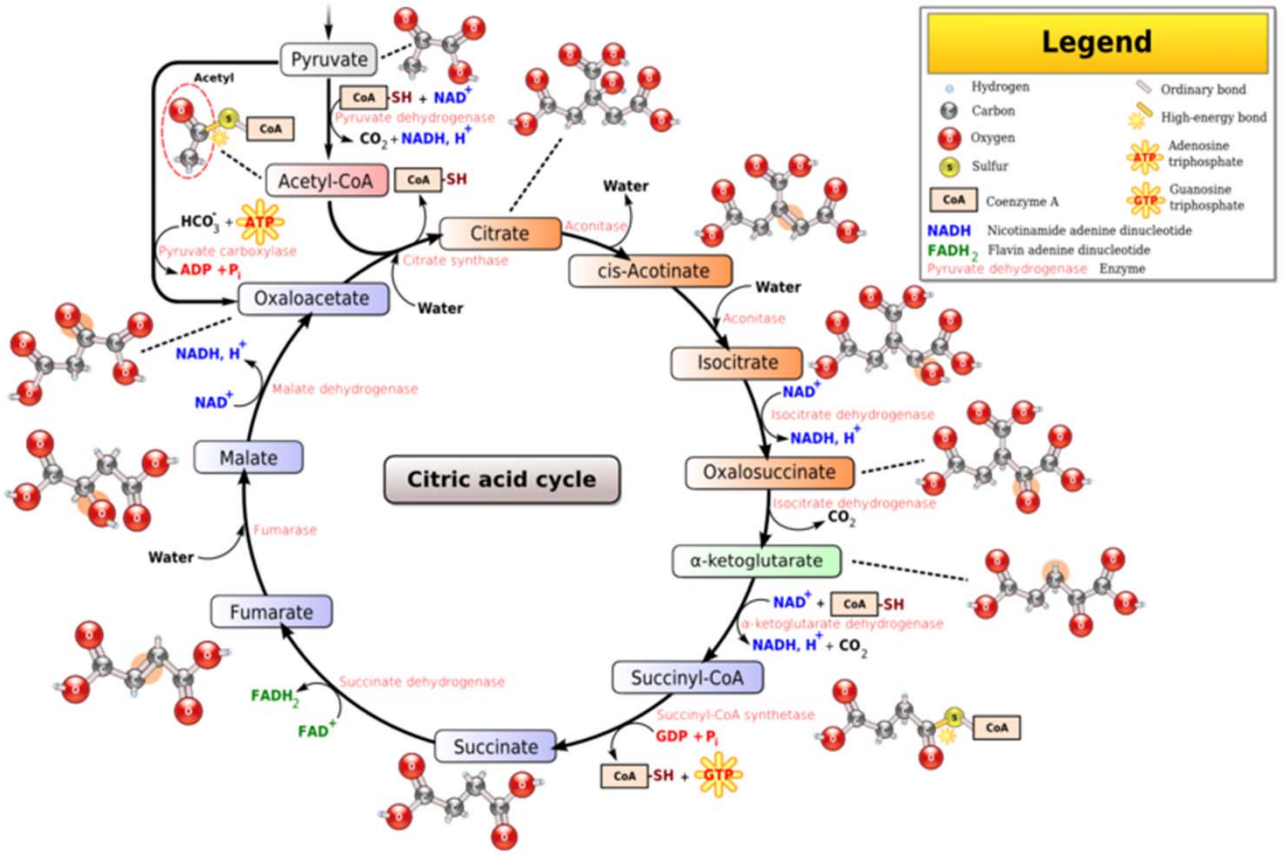
TABLE 21.1 Free Energies of Hydrolysis of Some Phosphates



Compound Name	Function	ΔG (kcal/mol)
Phosphoenol pyruvate	Final intermediate in conversion of glucose to pyruvate (glycolysis)—stage 2, Figure 21.5	−14.8
1, 3-Bisphosphoglycerate	Another intermediate in glycolysis	−11.8
Creatine phosphate	Energy storage in muscle cells	−10.3
ATP (⟶ ADP)	Principal energy carrier	−7.3
Glucose 1-phosphate	First intermediate in breakdown of carbohydrates stored as starch or glycogen	−5.0
Glucose 6-phosphate	First intermediate in glycolysis	−3.3
Fructose 6-phosphate	Second intermediate in glycolysis	−3.3

- A few enzymes continuously cycle between their oxidized and reduced forms

Coenzyme	As Oxidizing Agent	As Reducing Agent
Nicotinamide adenine dinucleotide	NAD^+	$NADH/H^+$
Nicotinamide adenine dinucleotide phosphate	$NADP^+$	$NADPH/H^+$
Flavin adenine dinucleotide	FAD	$FADH_2$
Flavin mononucleotide	FMN	$FMNH_2$

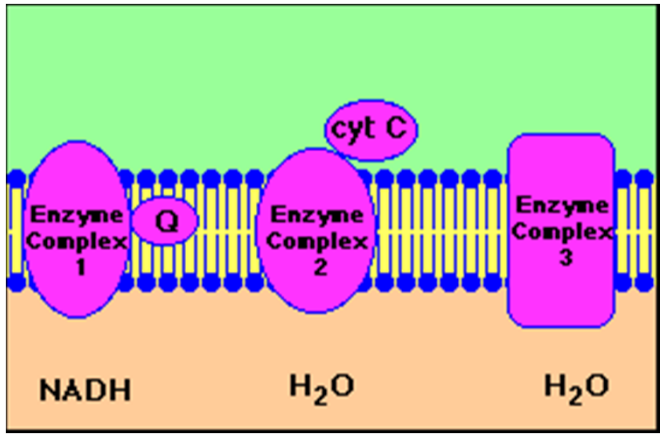


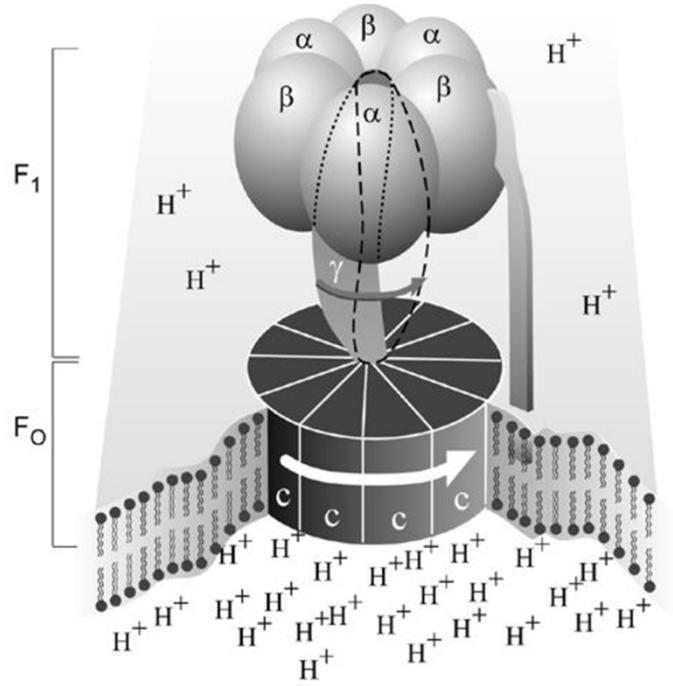
Acetyl-CoA + 3 NAD+ + FAD + GDP + Pi + 2H20
<==> CoASH + 3 NADH + FADH2 + GTP + 2CO2 + 3H

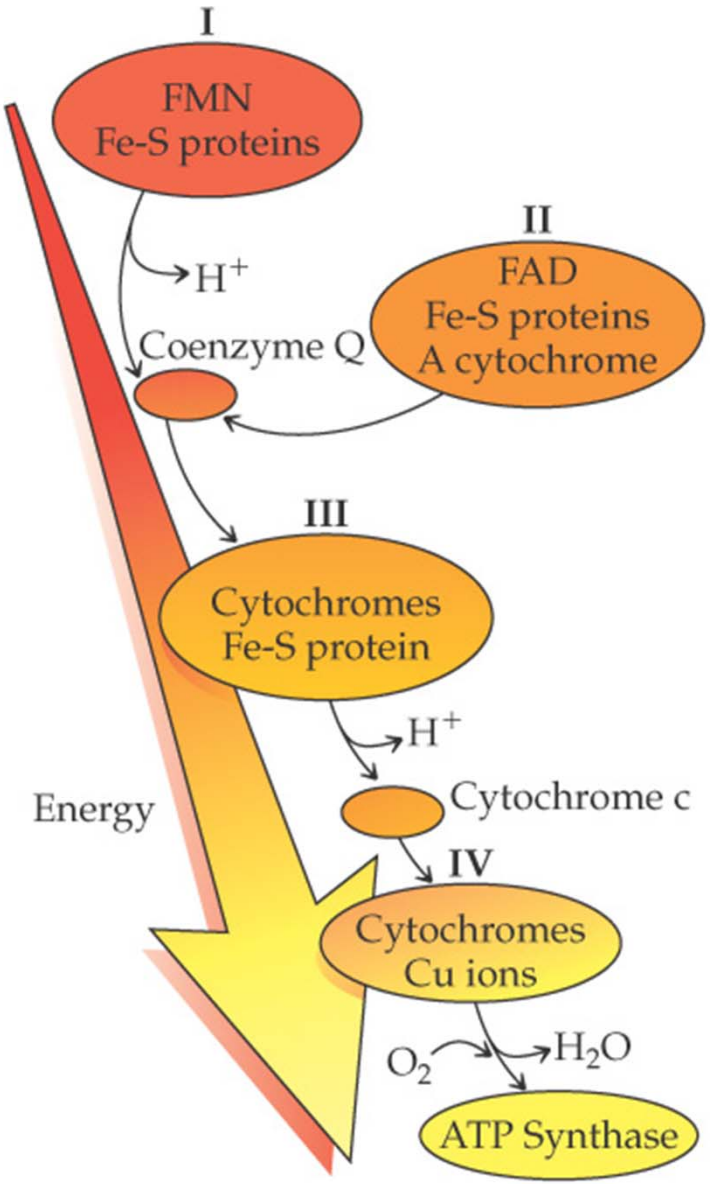
The citric acid cycle

The Electron-Transport Chain and ATP Production

- Electron transport chain: The series of biochemical reactions that passes electrons from reduced coenzymes to oxygen and is coupled to ATP formation. The electrons combine with the oxygen we breathe and with hydrogen ions from their surrounding to produce water.
- Electron transport involves four enzyme complexes held in fixed positions within the inner membrane of mitochondria and two electron carriers move from one complex to another.



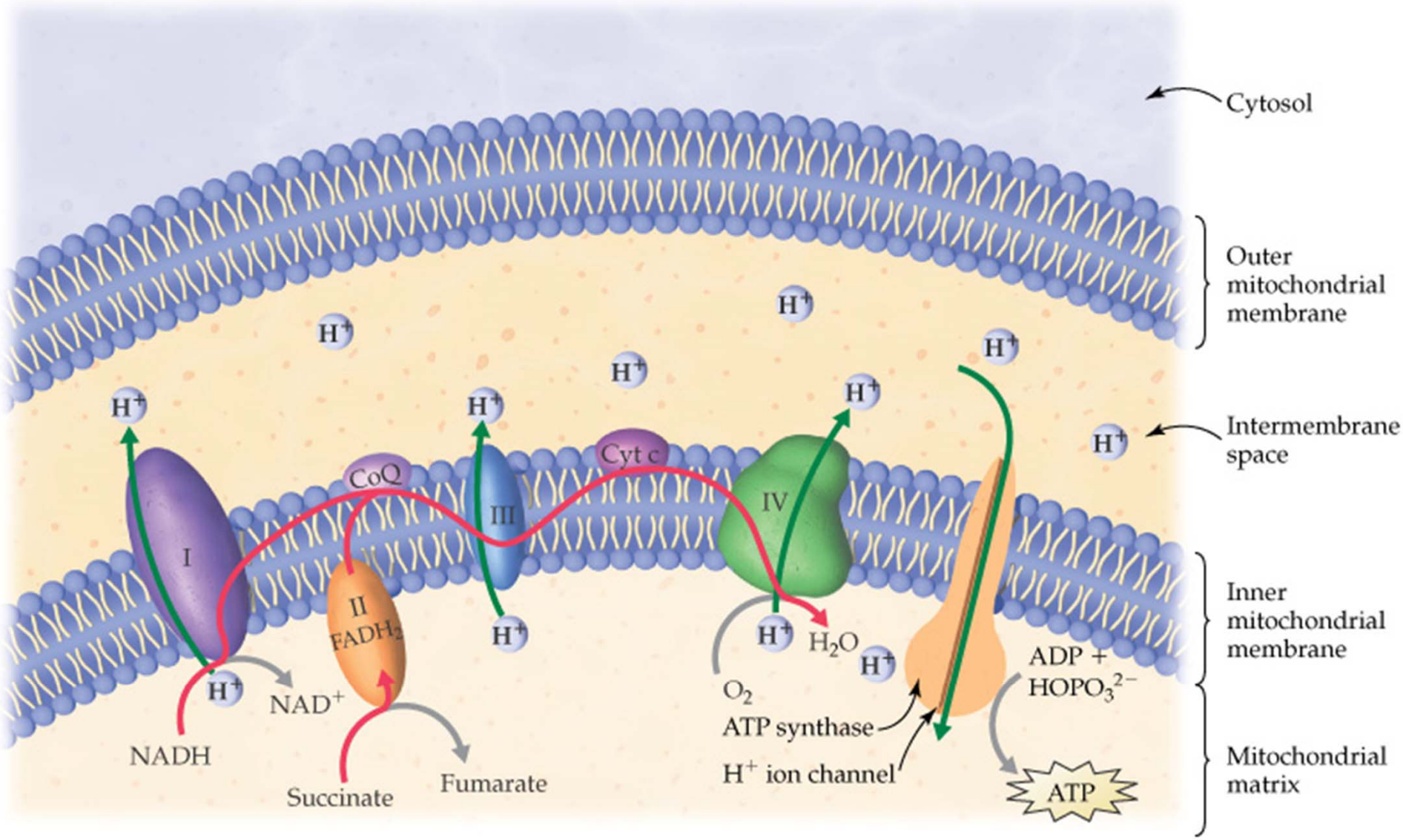


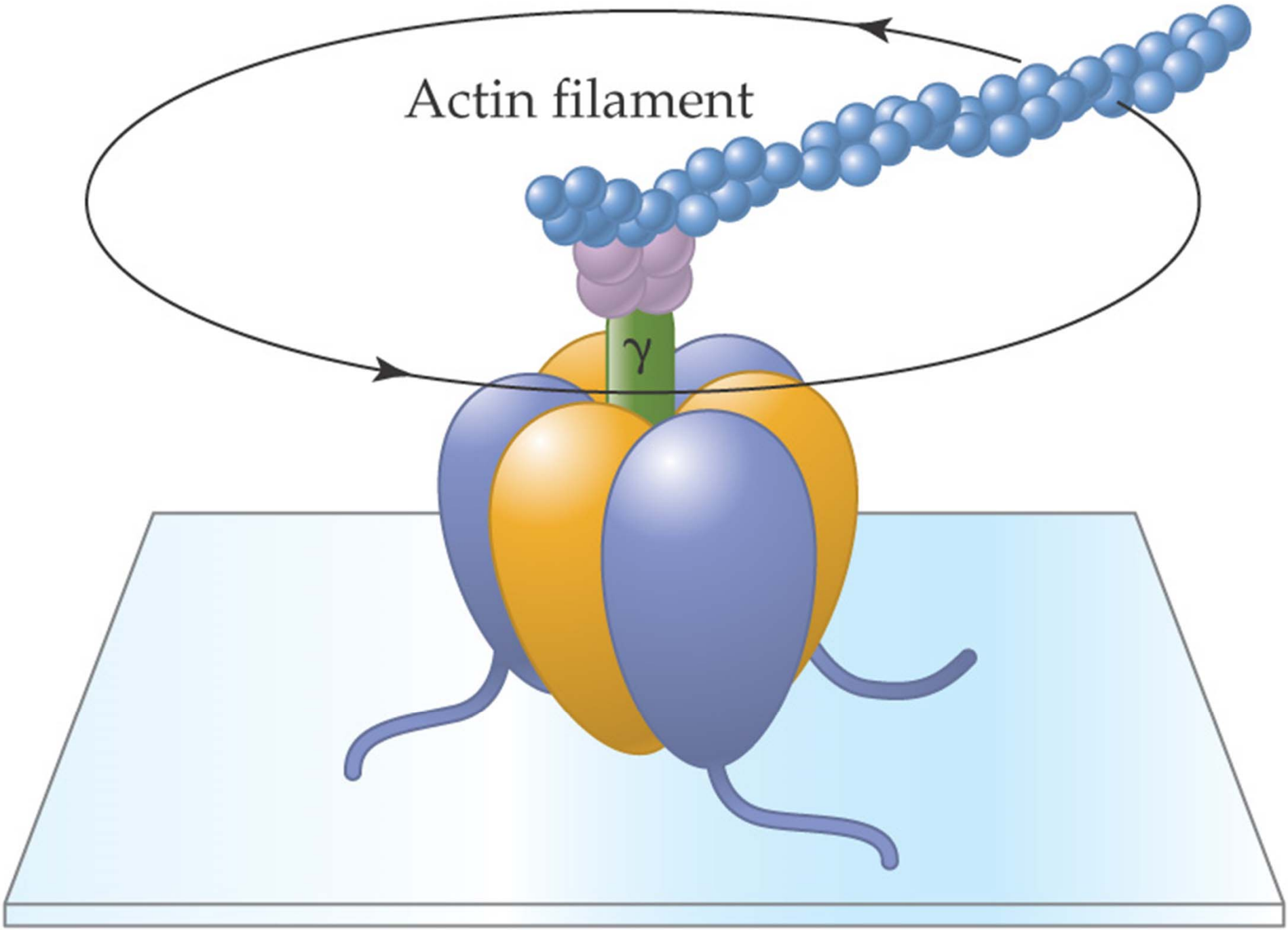


- Pathway of electrons in electron transport

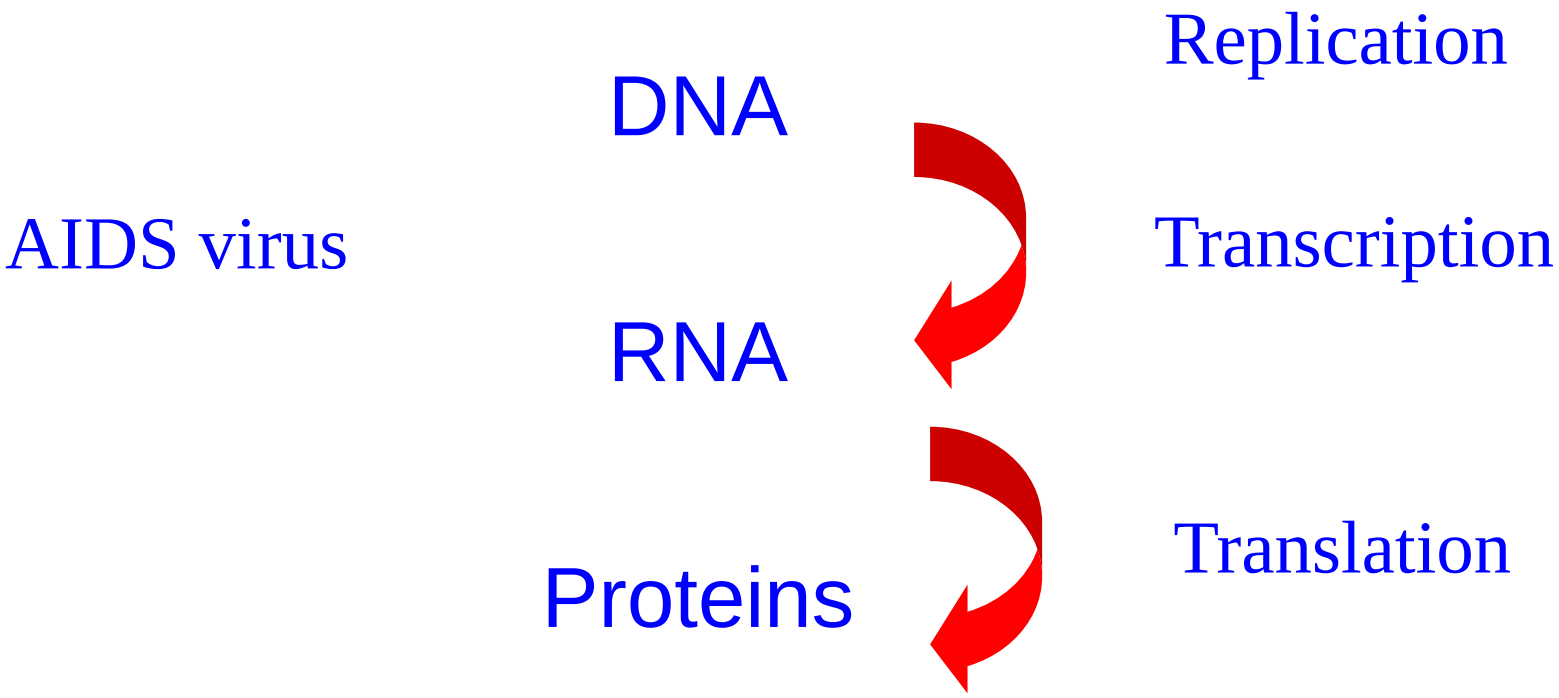
- **ATP Synthesis**
- ADP is converted to ATP by a reaction between ADP and hydrogen phosphate ion. This is both an oxidation and phosphorylation reaction. Energy released in the electron transport chain drives this reaction forward.

Vedio: http://www.iubmb-nicholson.org/swf/ATPSynthase.swf

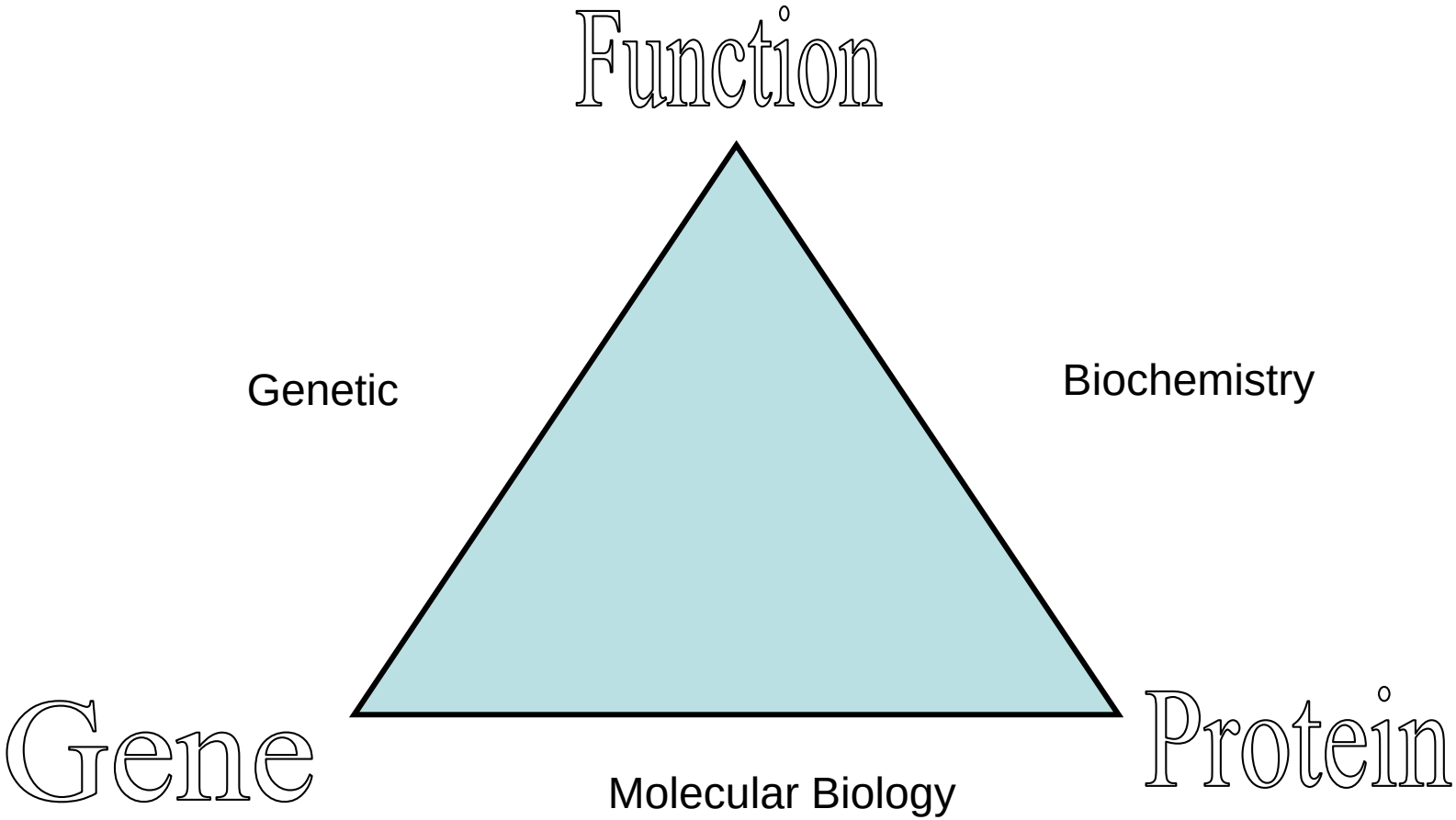

Cytosol
Outer mitochondrial membrane
Intermembrane space
Inner mitochondrial membrane
Mitochondrial matrix
H+
I
II
FADH2
III
IV
CoQ
Cyt c
NADH
NAD+
Succinate
Fumarate
O2
H2O
ATP synthase
H+ ion channel
ADP + HOPO3 2−
ATP

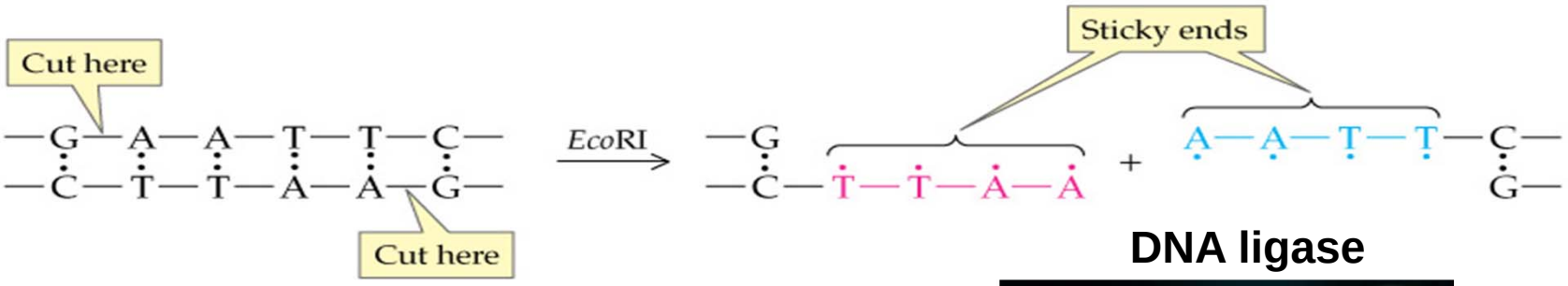

Actin filament
γ

Central Dogma

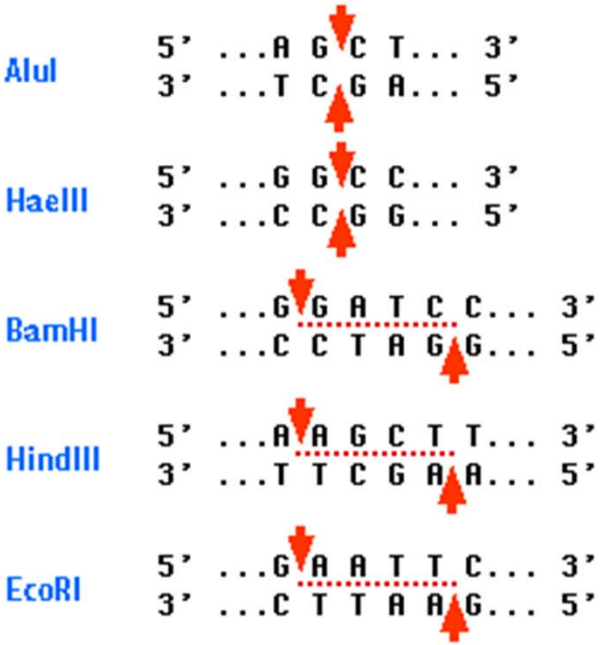


Recombinant DNA





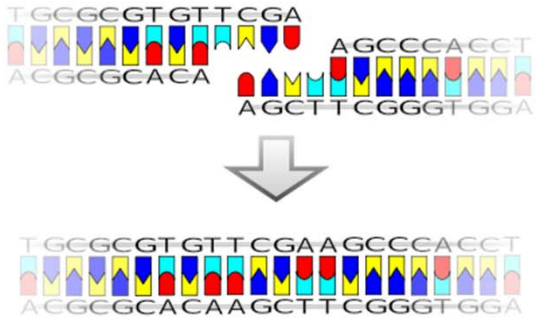
Restriction Enzyme

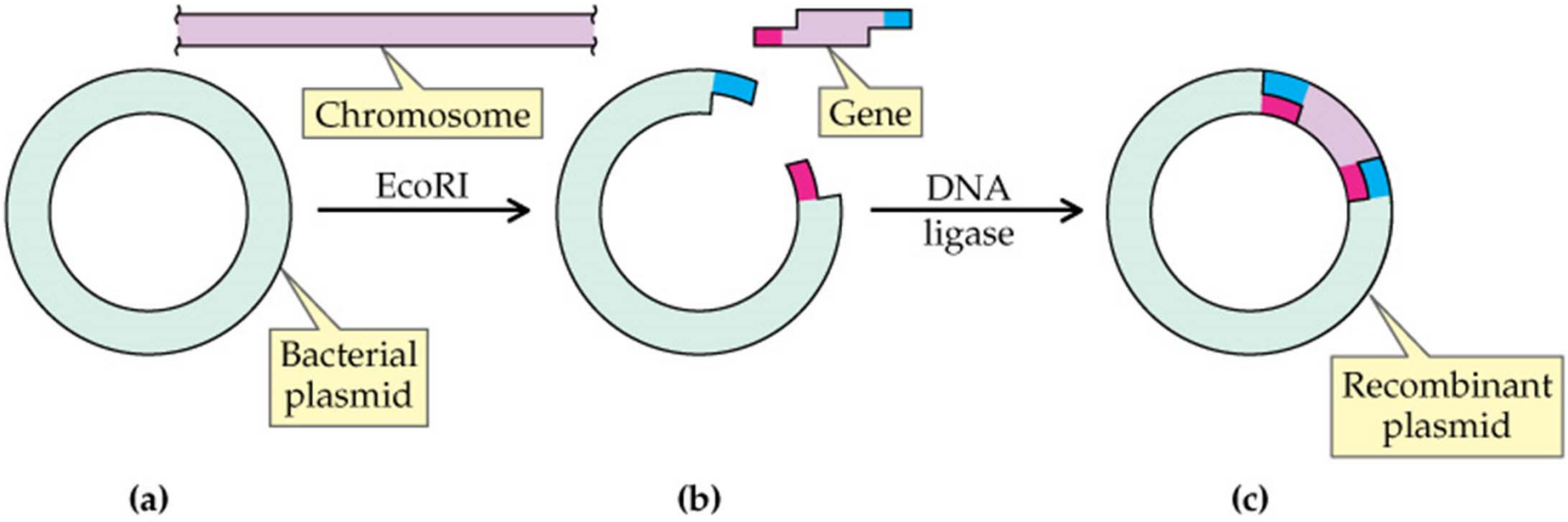


AluI and **HaeIII** produce blunt ends

BamHI **HindIII** and **EcoRI** produce "sticky" ends

DNA ligase




Chromosome
Gene
EcoRI
DNA
ligase
Bacterial
plasmid
Recombinant
plasmid
(a)
(b)
(c)