Review of Biochemistry and Cell Biology

TABLE 18.1 Functional Groups of Importance in Biochemical Molecules

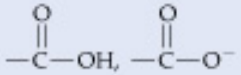
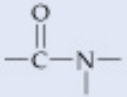
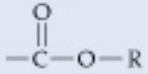
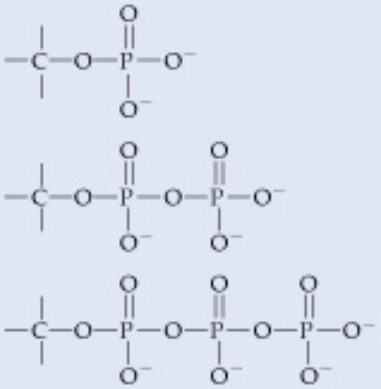
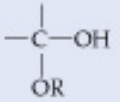
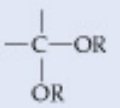
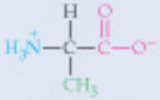
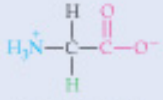
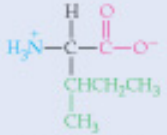
Functional Group	Structure	Type of Biomolecule
Amino group	$-NH_3^+$, $-NH_2$	Amino acids and proteins (Sections 18.3, 18.7)
Hydroxyl group	$-OH$	Monosaccharides (carbohydrates) and glycerol: a component of triacylglycerols (lipids) (Sections 22.4, 24.2)
Carbonyl group		Monosaccharides (carbohydrates); in acetyl group (CH_3CO) used to transfer carbon atoms during catabolism (Sections 22.4, 21.4, 21.8)
Carboxyl group		Amino acids, proteins, and fatty acids (lipids) (Sections 18.3, 18.7, 24.2)
Amide group		Links amino acids in proteins; formed by reaction of amino group and carboxyl group (Section 18.7)
Carboxylic acid ester		Triacylglycerols (and other lipids); formed by reaction of carboxyl group and hydroxyl group (Section 24.2)
Phosphates, mono-, di-, tri-		ATP and many metabolism intermediates (Sections 17.8, 21.5, and throughout metabolism sections)
Hemiacetal group		Cyclic forms of monosaccharides; formed by a reaction of carbonyl group with hydroxyl group (Sections 16.7, 22.4)
Acetal group		Connects monosaccharides in disaccharides and larger carbohydrates; formed by reaction of carbonyl group with hydroxyl group (Sections 16.7, 22.7, 22.9)

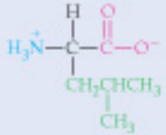
TABLE 18.3 The 20 Protein Amino Acids with their Abbreviations and Isoelectric Points. The structures are written here in their fully ionized forms. These ions and the isoelectric points given in parantheses are explained in Section 18.4.

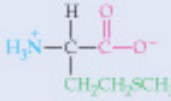
Nonpolar Side Chains

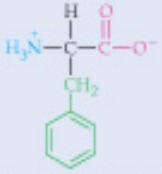

Alanine, Ala (6.0)

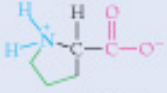

Glycine, Gly (6.0)

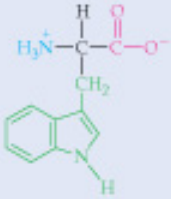

Isoleucine, Ile (6.0)

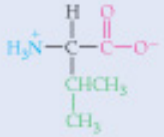

Leucine, Leu (6.0)


Methionine, Met (5.7)

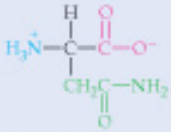

Phenylalanine, Phe (5.5)

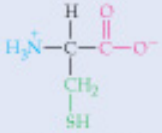

Proline, Pro (6.3)

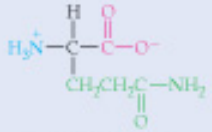

Tryptophan, Trp (5.9)

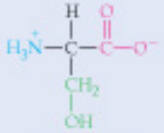

Valine, Val (6.0)

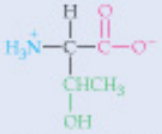
Polar, Neutral Side Chains

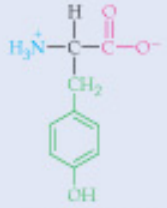

Asparagine, Asn (5.4)


Cysteine, Cys (5.0)

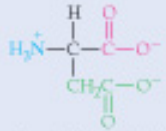

Glutamine, Gln (5.7)

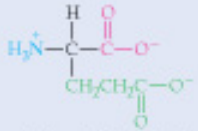

Serine, Ser (5.7)


Threonine, Thr (5.6)


Tyrosine, Tyr (5.7)

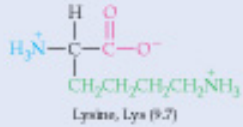
Acidic Side Chains

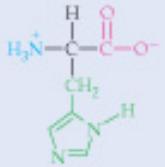

Aspartic acid, Asp (3.0)
(Aspartate)

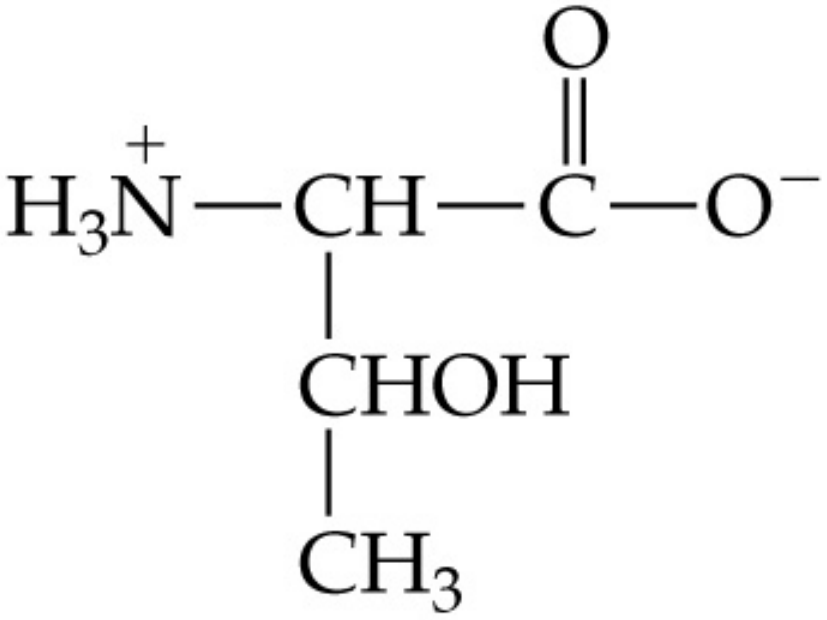

Glutamic acid, Glu (3.2)
(Glutamate)

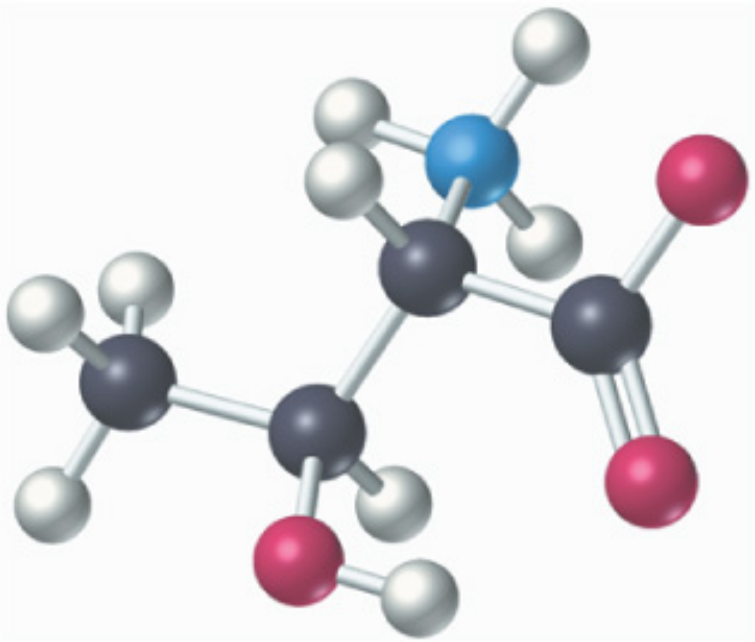
Basic Side Chains


Arginine, Arg (10.8)


Lysine, Lys (9.7)


Histidine, His (7.6)

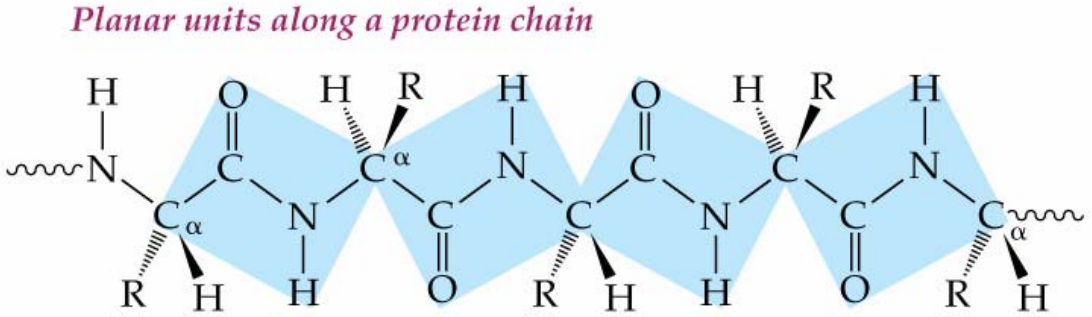


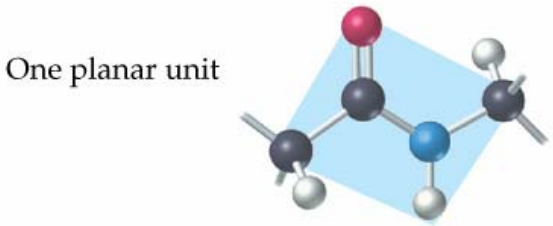


Threonine—zwitterion

Primary Protein Structure

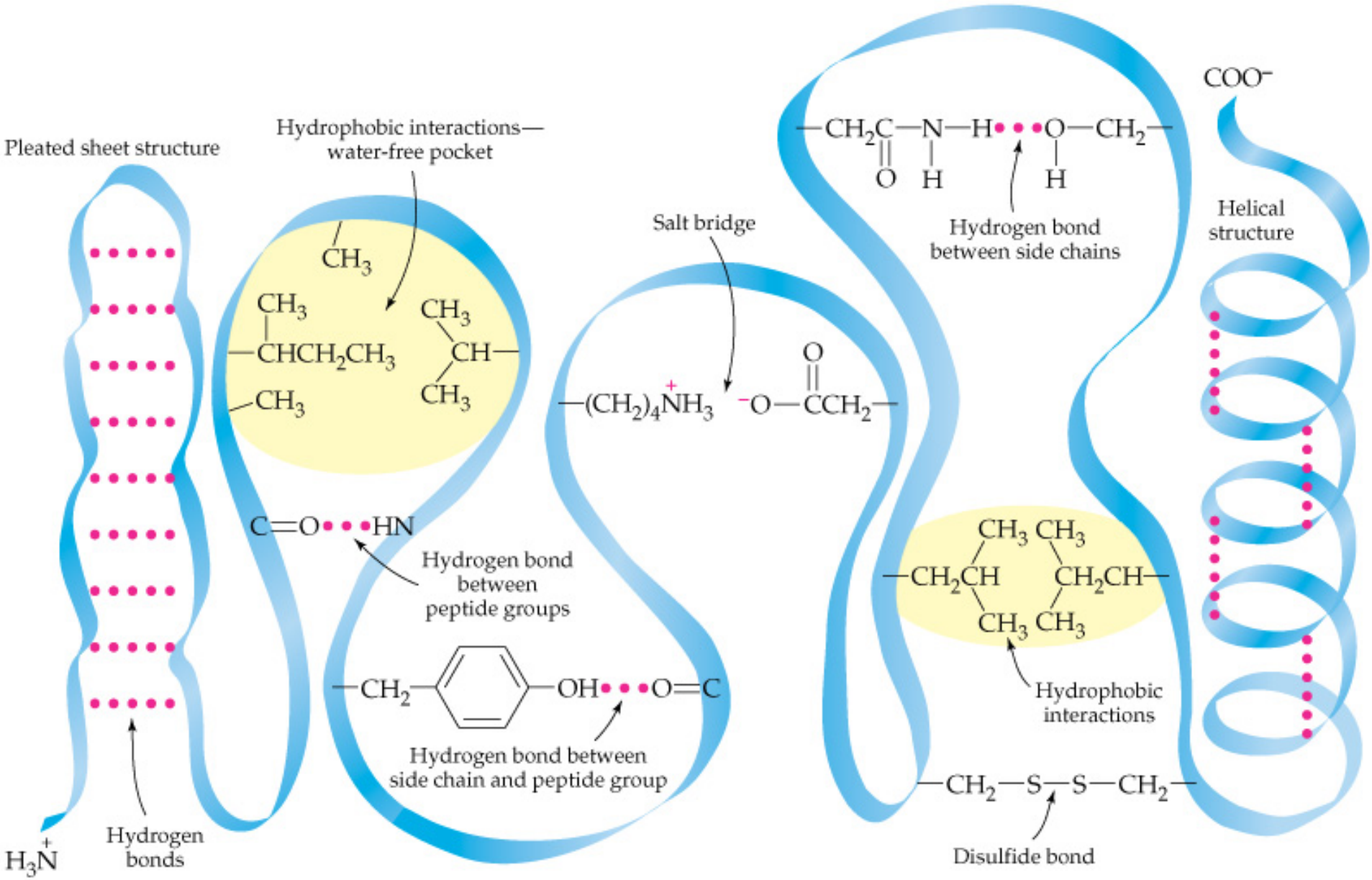
- Primary structure of a proteins is the sequence of amino acids connected by peptide bonds. Along the backbone of the proteins is a chain of alternating peptide bonds and α-carbons and the amino acid side chains are connected to these

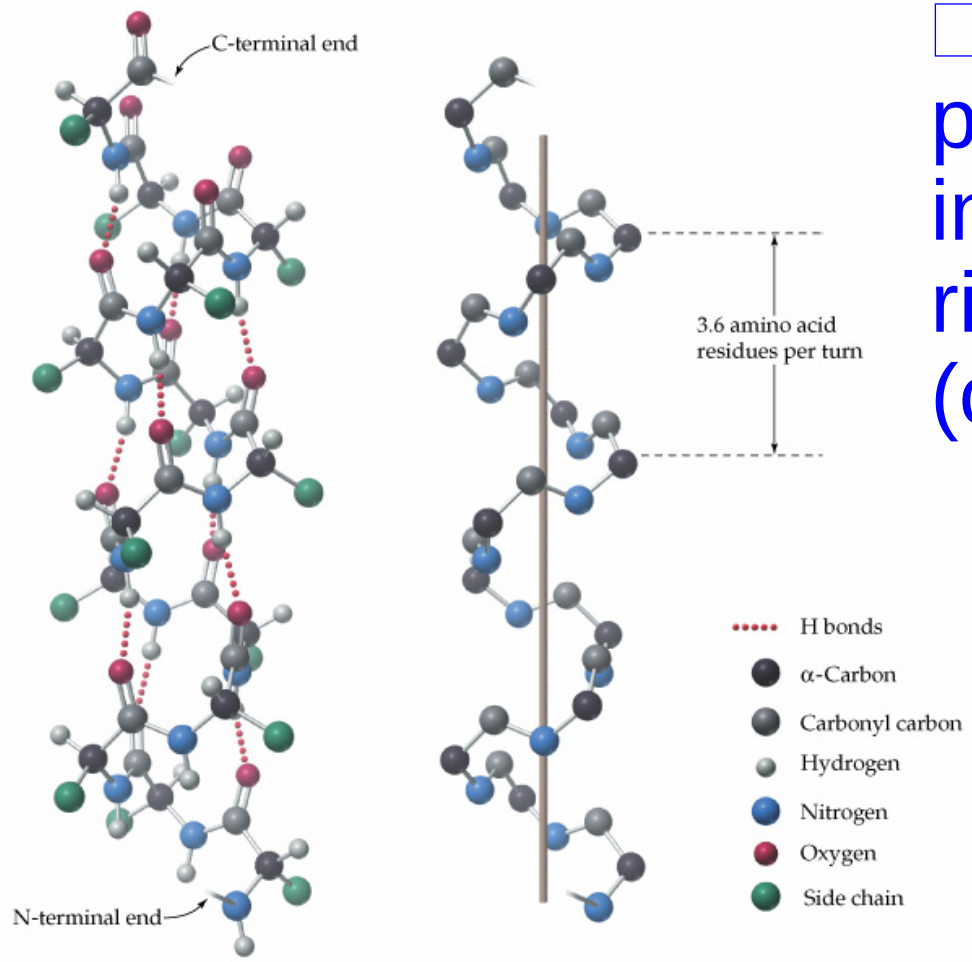




Secondary Protein Structure

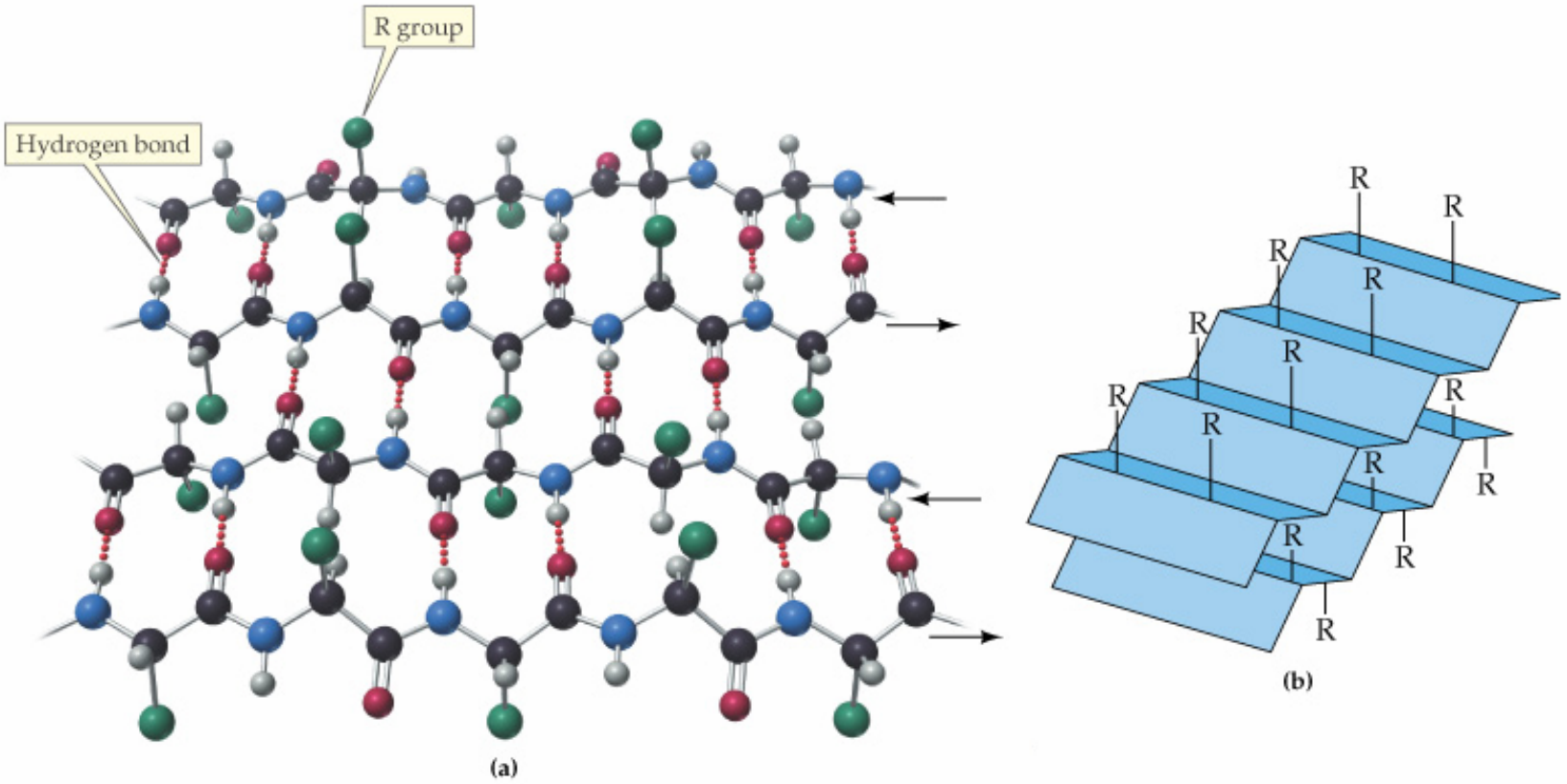
- Secondary structure of a protein is the arrangement of polypeptide backbone of the protein in space. The secondary structure includes two kinds of repeating pattern known as the *α-helix* and *β-sheet*.
- Hydrogen bonding between backbone atoms are responsible for both of these secondary structures.

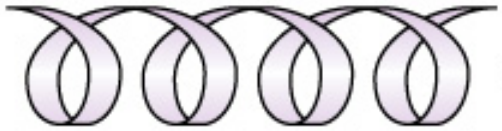

Pleated sheet structure
Hydrophobic interactions—
water-free pocket
Salt bridge
Hydrogen bond
between side chains
Helical
structure
Hydrogen bond
between
peptide groups
Hydrogen bond between
side chain and peptide group
Hydrophobic
interactions
Hydrogen
bonds
Disulfide bond



- ***α-Helix:*** A single protein chain coiled in a spiral with a right-handed (clockwise) twist.

□***β*-Sheet:** The polypeptide chain is held in place by hydrogen bonds between pairs of peptide units along neighboring backbone segments.



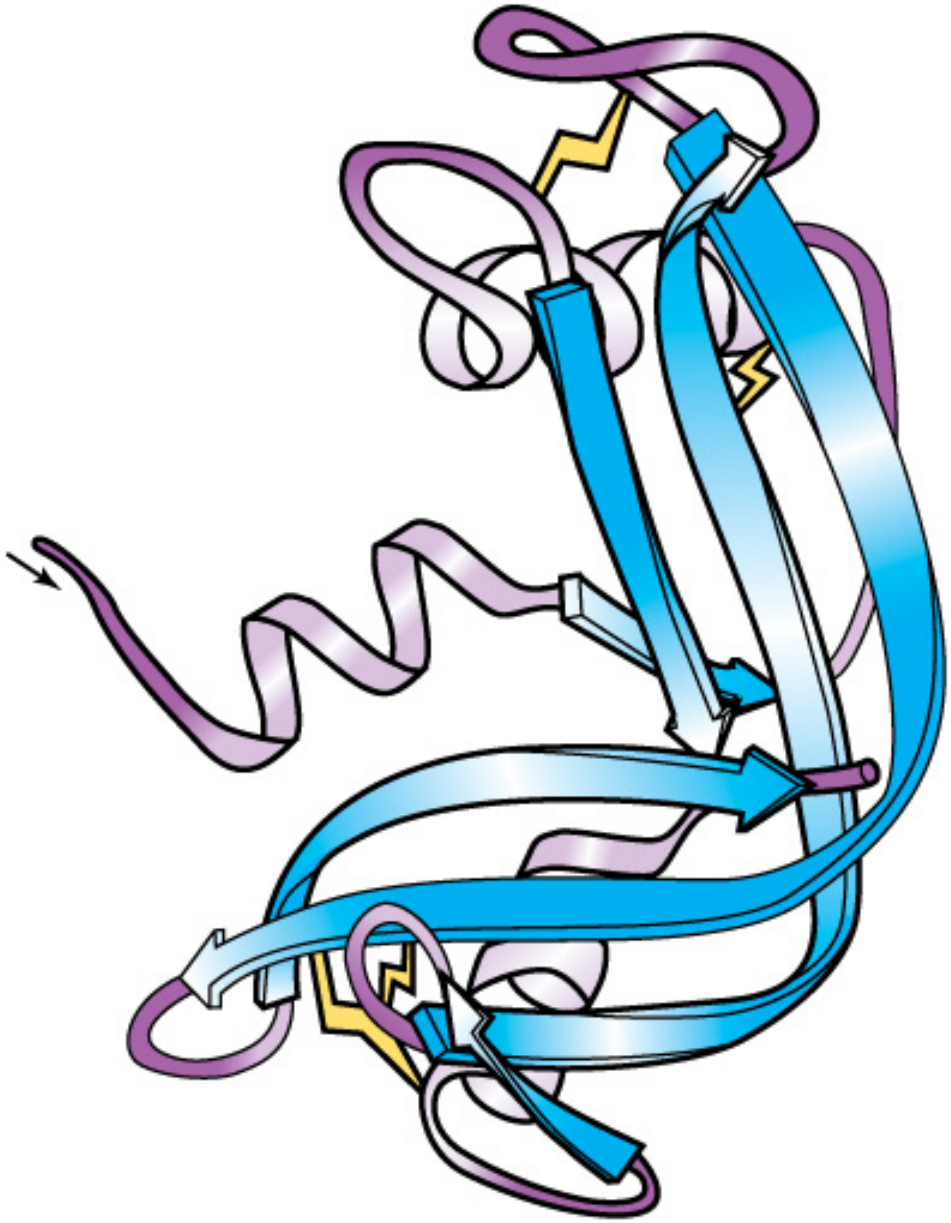


α Helix

β Sheet

Connecting loop

—S—S— links



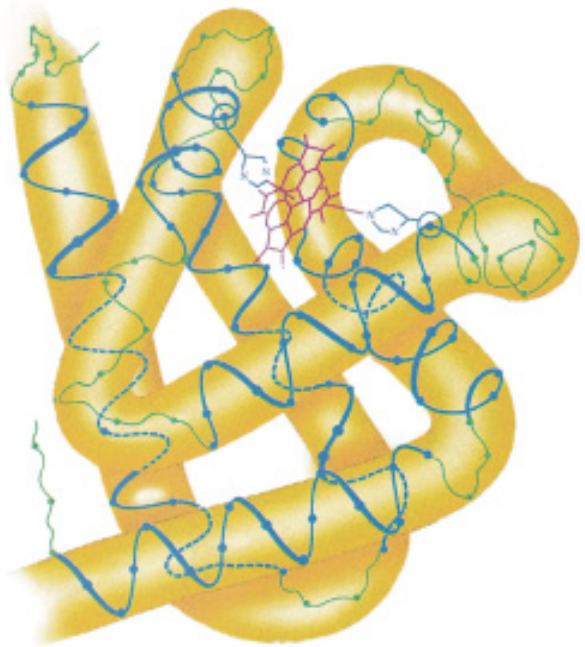
Ribonuclease

Shape-Determining Interactions in Proteins

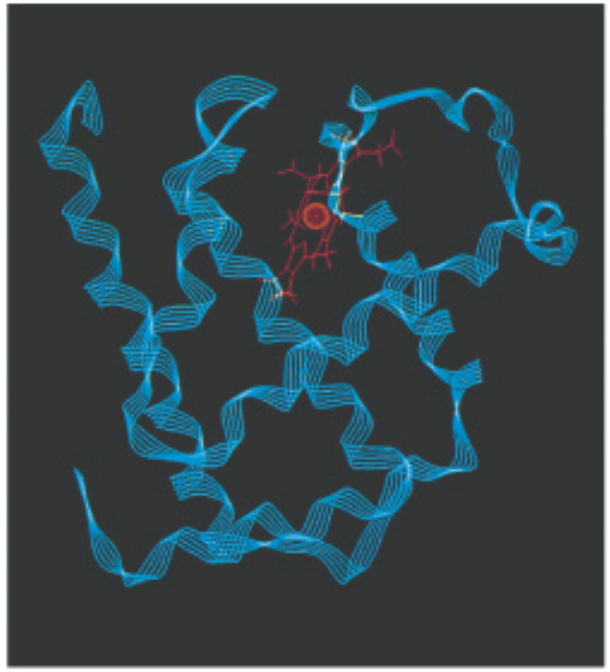
- The essential structure-function relationship for each protein depends on the polypeptide chain being held in its necessary shape by the interactions of atoms in the side chains.

Tertiary Protein Structure

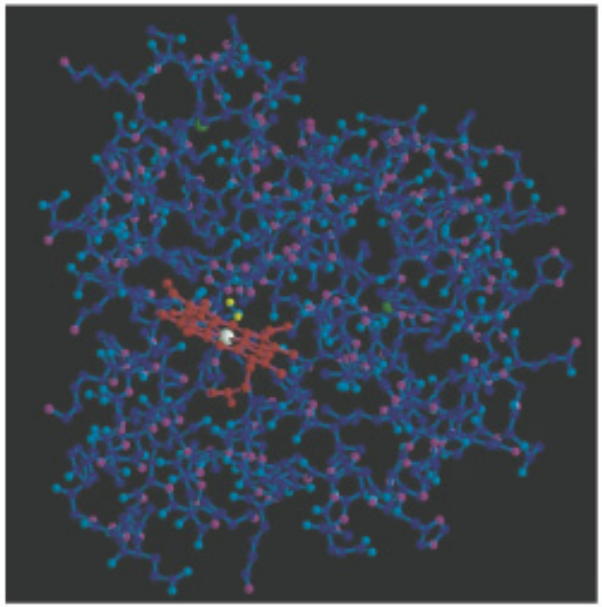
- ***Tertiary Structure of a proteins*** The overall three dimensional shape that results from the folding of a protein chain. Tertiary structure depends mainly on attractions of amino acid side chains that are far apart along the same backbone. Non-covalent interactions and disulfide covalent bonds govern tertiary structure.
- A protein with the shape in which it exist naturally in living organisms is known as a *native protein.*



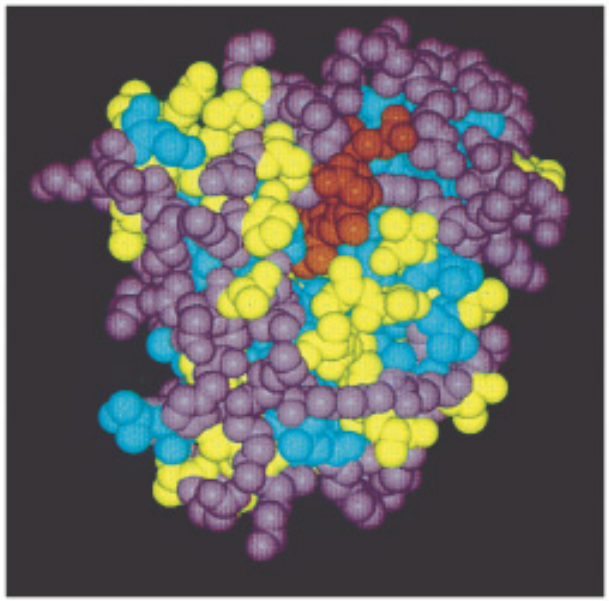
(a)



(b)



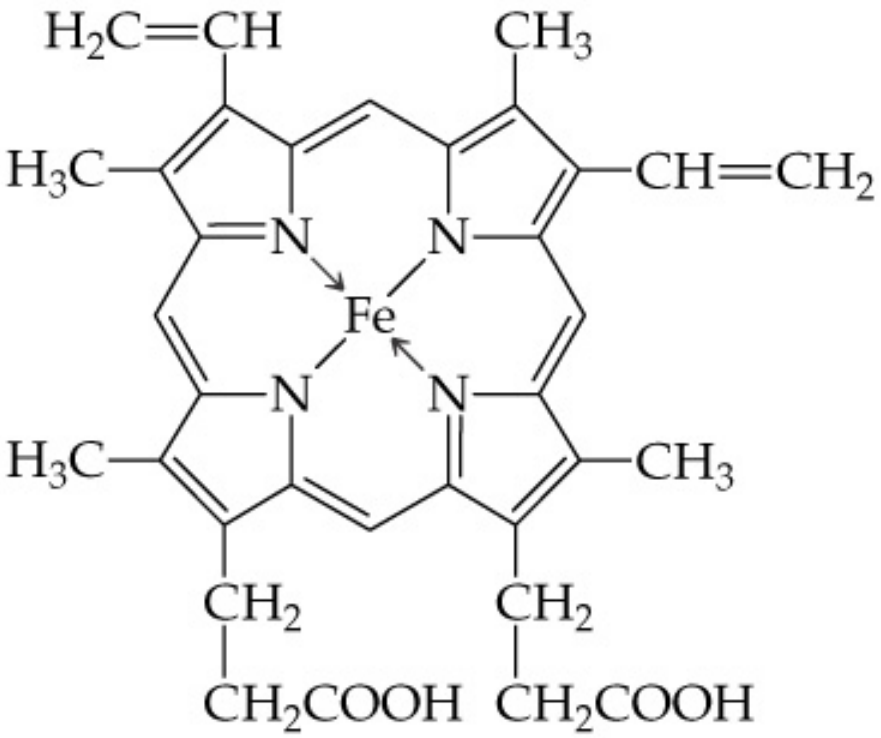
(c)



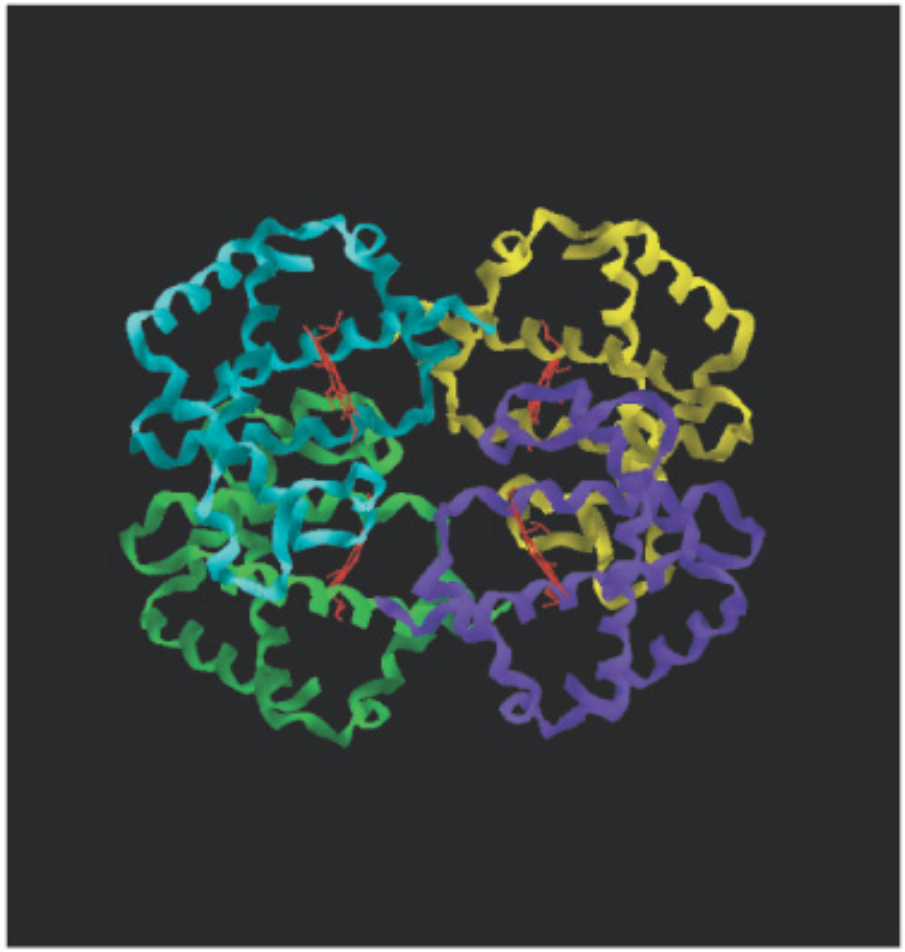
(d)

Quaternary Protein Structure

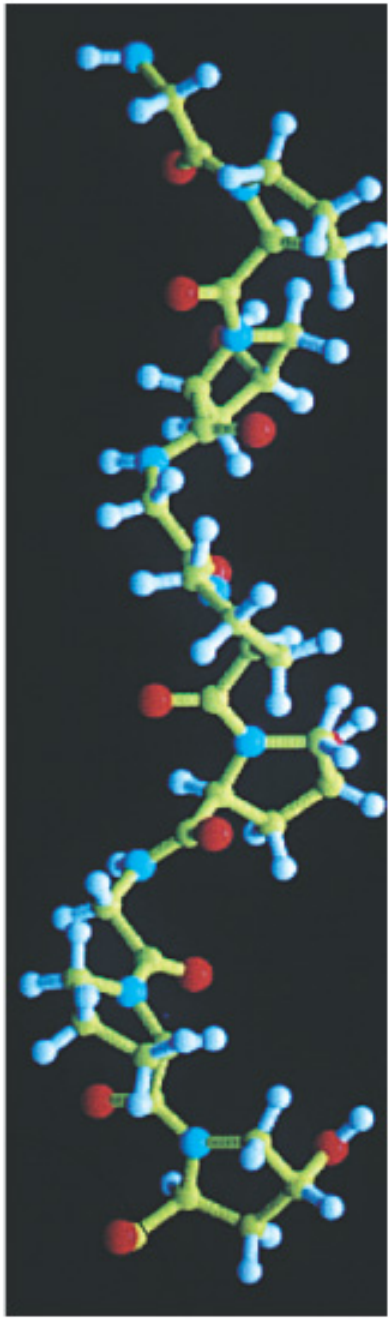
•***Quaternary protein structure***: The way in which two or more polypeptide sub-units associate to form a single three-dimensional protein unit. Non-covalent forces are responsible for quaternary structure essential to the function of proteins.



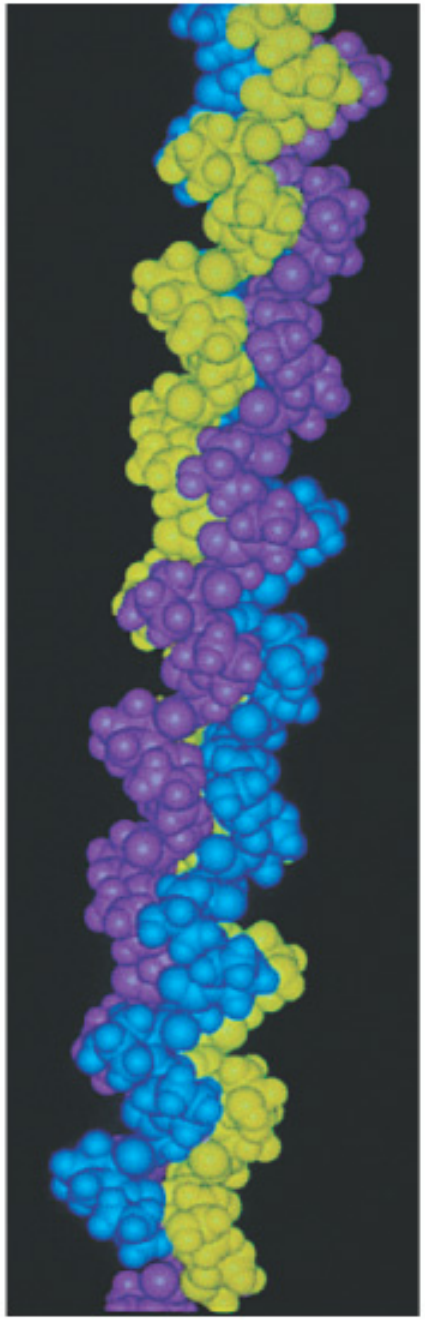
(a)



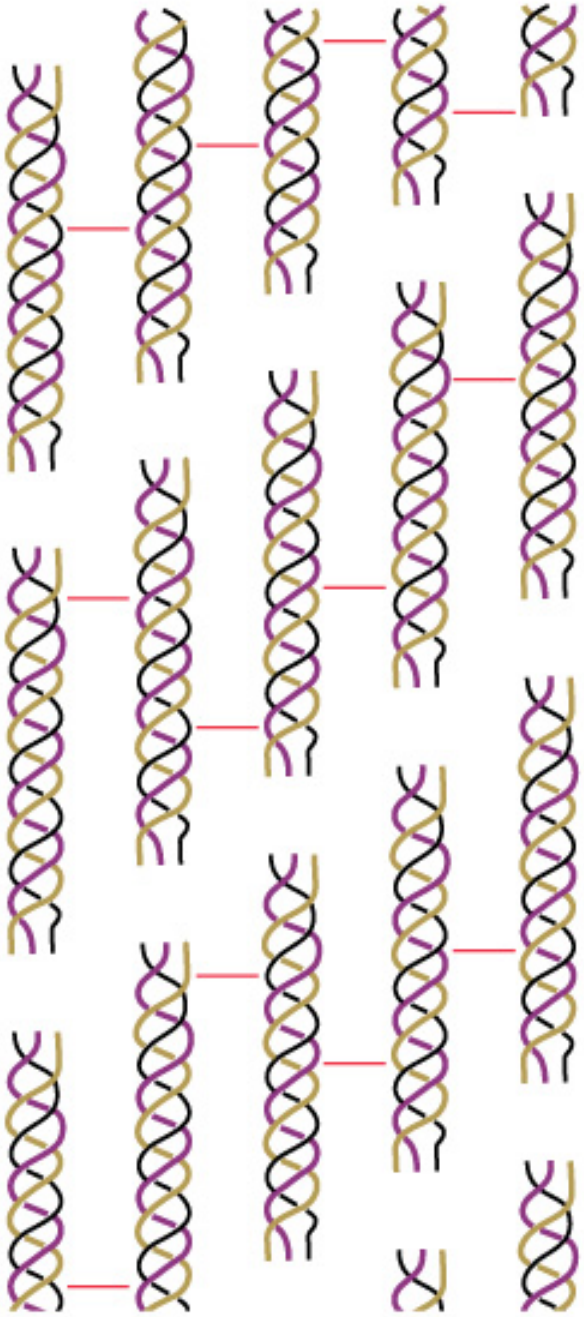
(b)



(a)



(b)

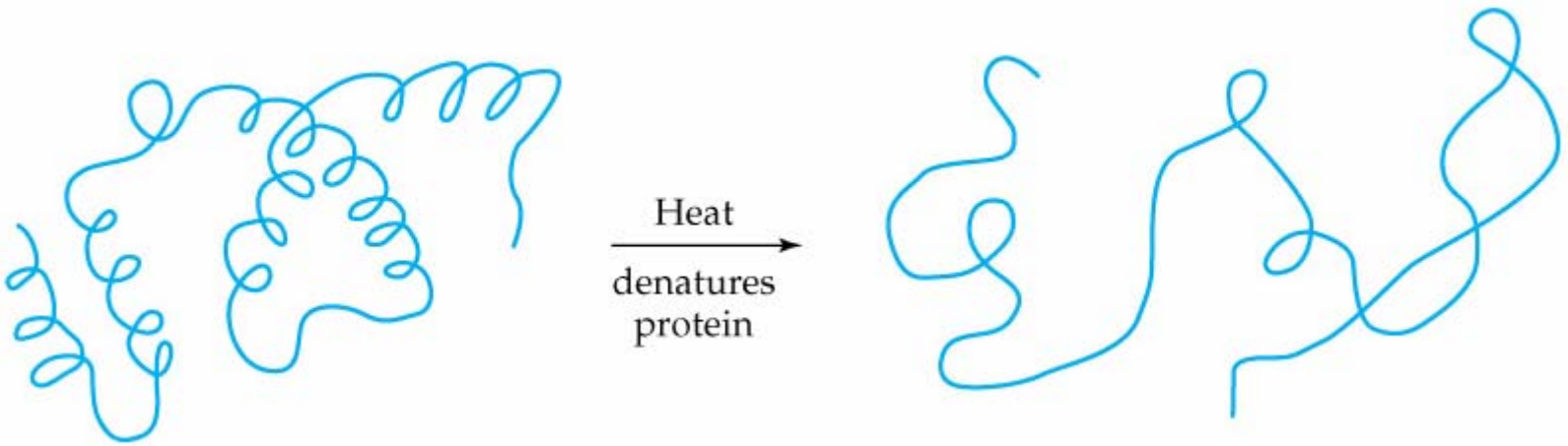


(c)

Chemical Properties of Proteins

- *Protein hydrolysis:* In protein hydrolysis, peptide bonds are hydrolyzed to yield amino acids. This is reverse of protein formation.

- *Protein denaturation*: The loss of secondary, tertiary, or quaternary protein structure due to disruption of non-covalent interactions and or disulfide bonds that leaves peptide bonds and primary

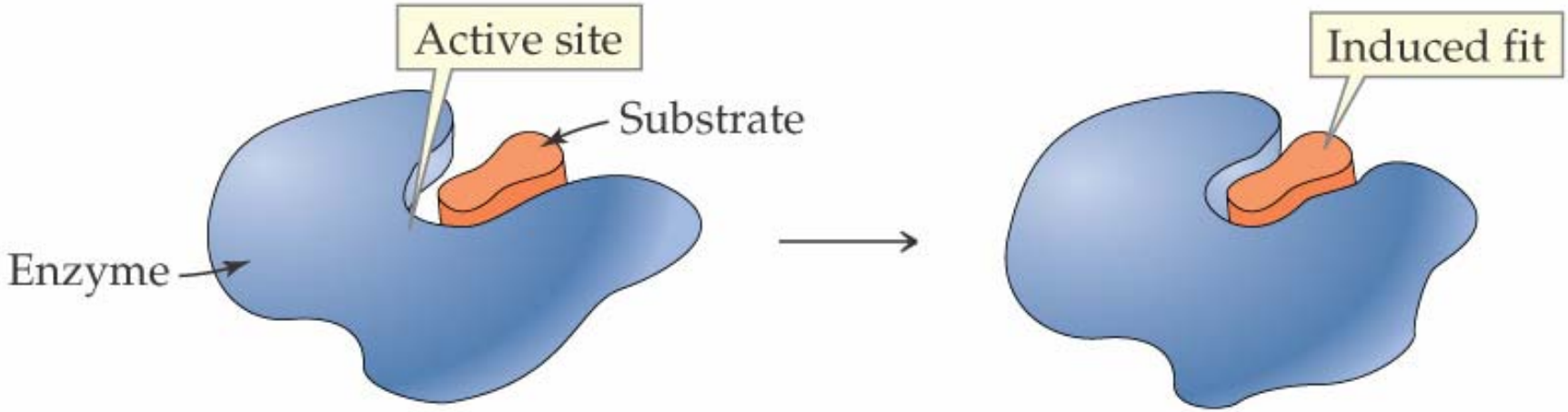


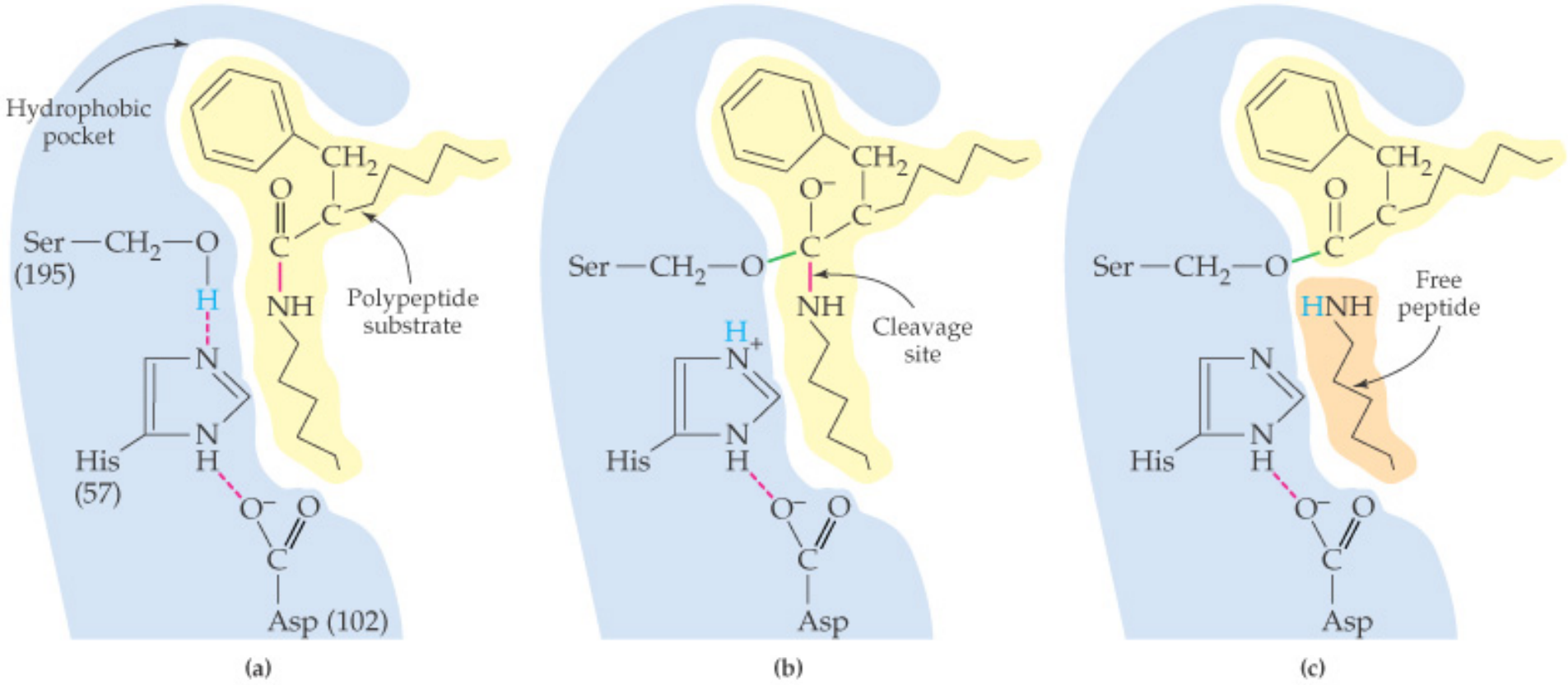
Catalysis by Enzymes

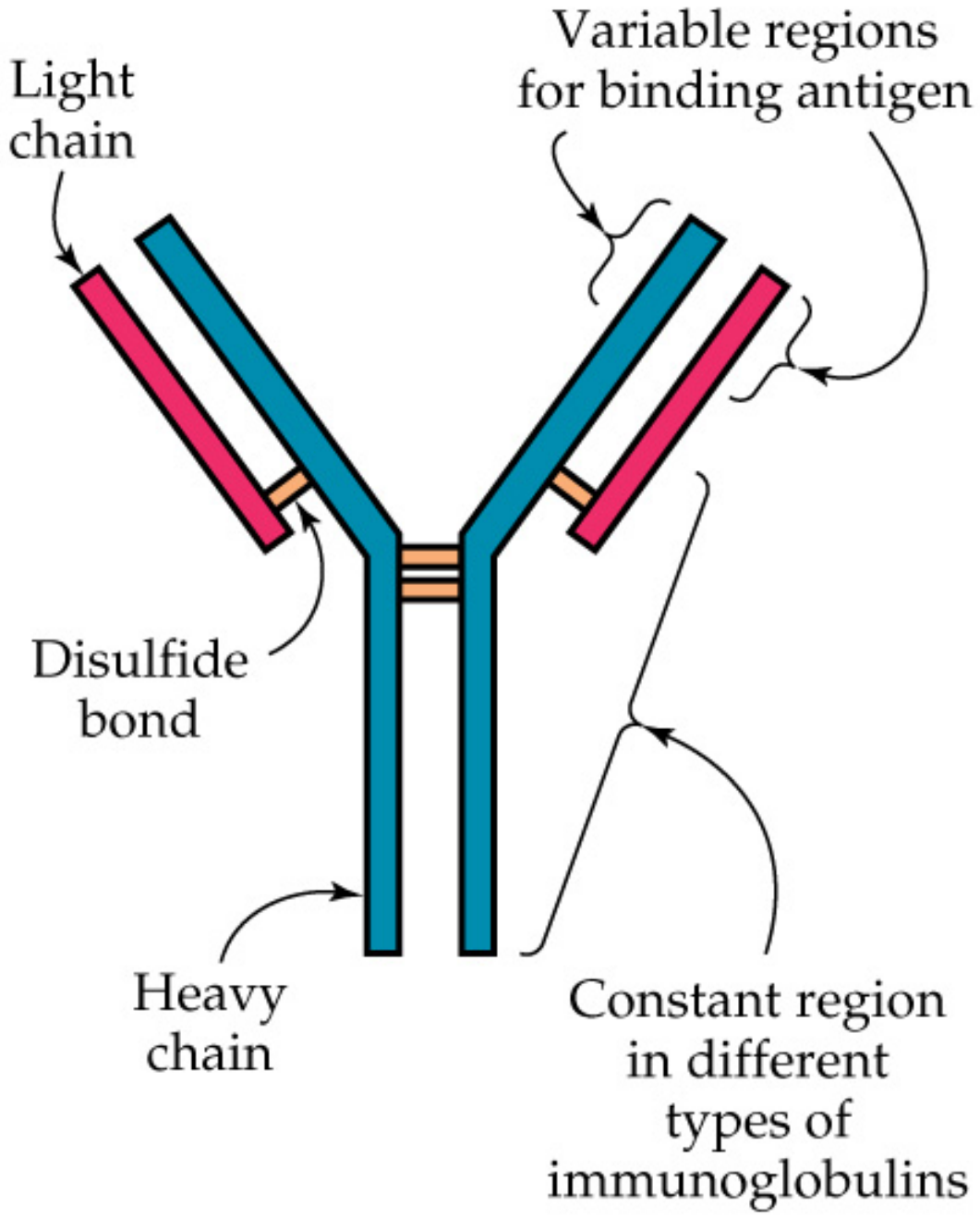
- ***Enzyme*** A protein that acts as a catalyst for a biochemical reaction.
- ***Active site*** A pocket in an enzyme with the specific shape and chemical makeup necessary to bind a substrate and where the reaction takes place.
- ***Substrate*** A reactant in an enzyme catalyzed reaction.

How Enzyme Work

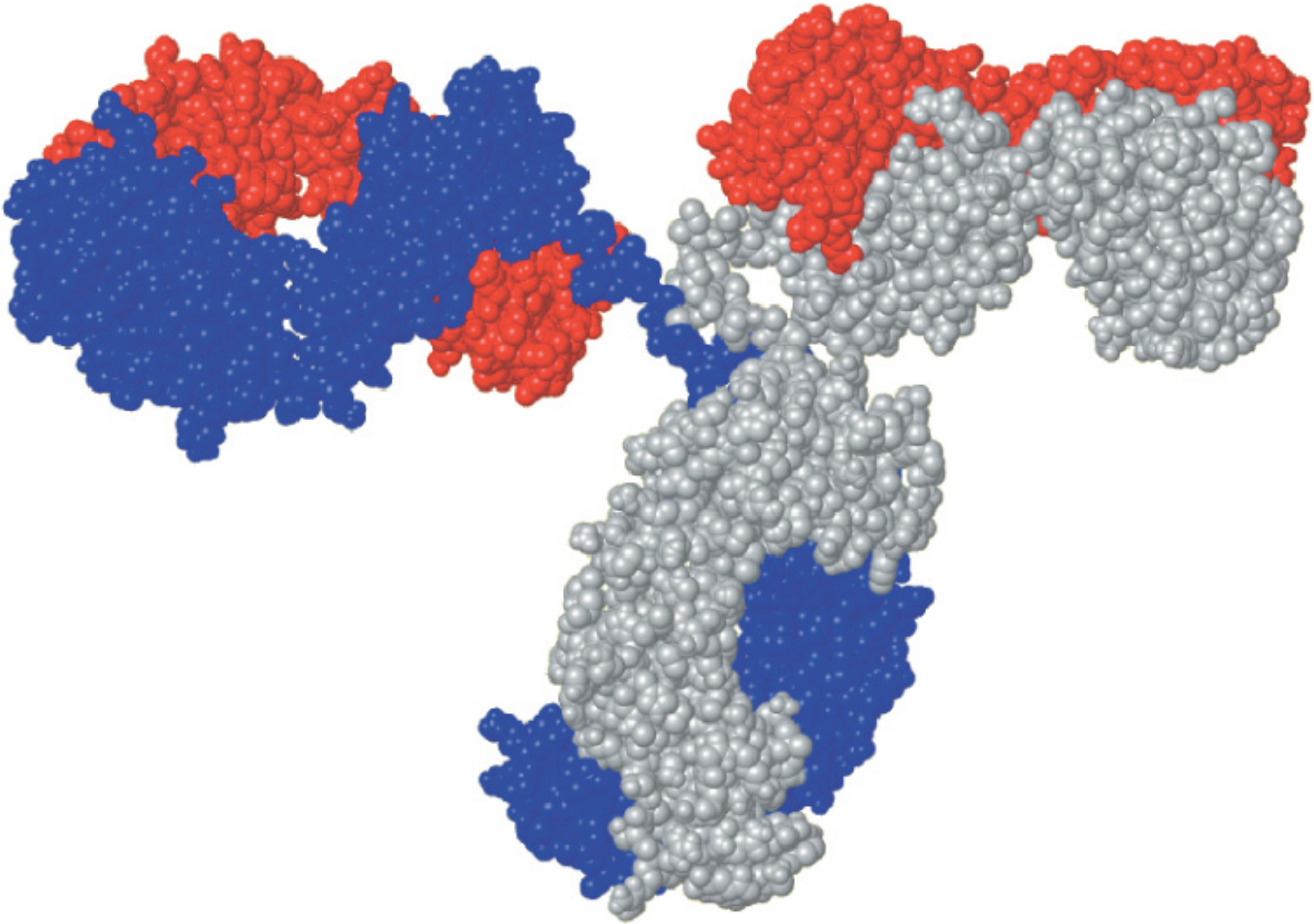
- Two modes are invoked to represent the interaction between substrate and enzymes. These are:
- ***Lock-and-key model***: The substrate is described as fitting into the active site as a key fit into a lock.
- ***Induced-fit-model***: The enzyme has a flexible active site that changes shape to accommodate the substrate and facilitate the reaction.


Active site
Substrate
Enzyme
Induced fit

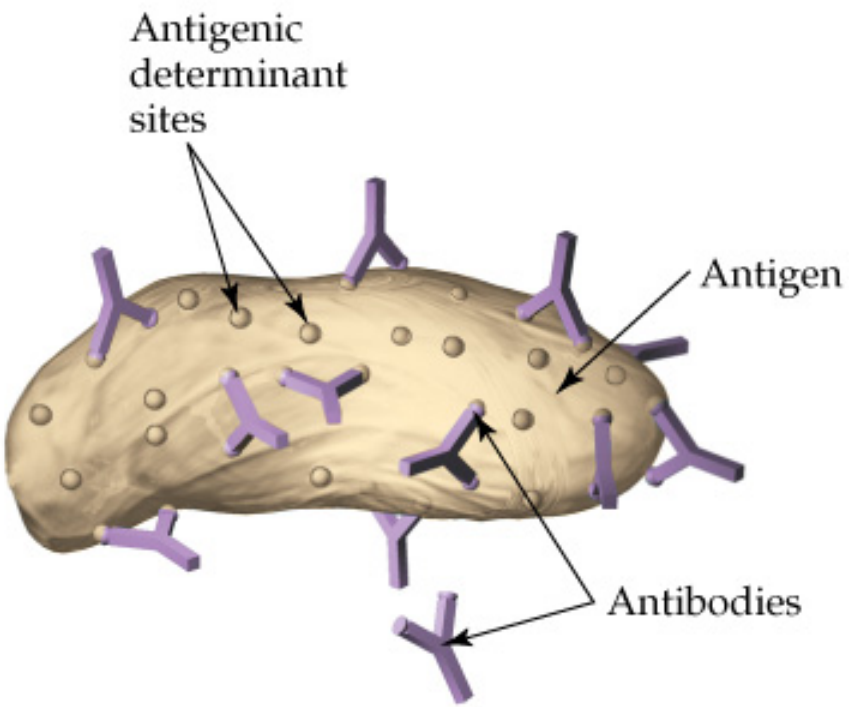

Hydrophobic pocket
Ser —CH2—O
(195)
His
(57)
Asp (102)
Polypeptide substrate
(a)
Cleavage site
(b)
Free peptide
HNH
(c)


Light chain
Variable regions for binding antigen
Disulfide bond
Heavy chain
Constant region in different types of immunoglobulins

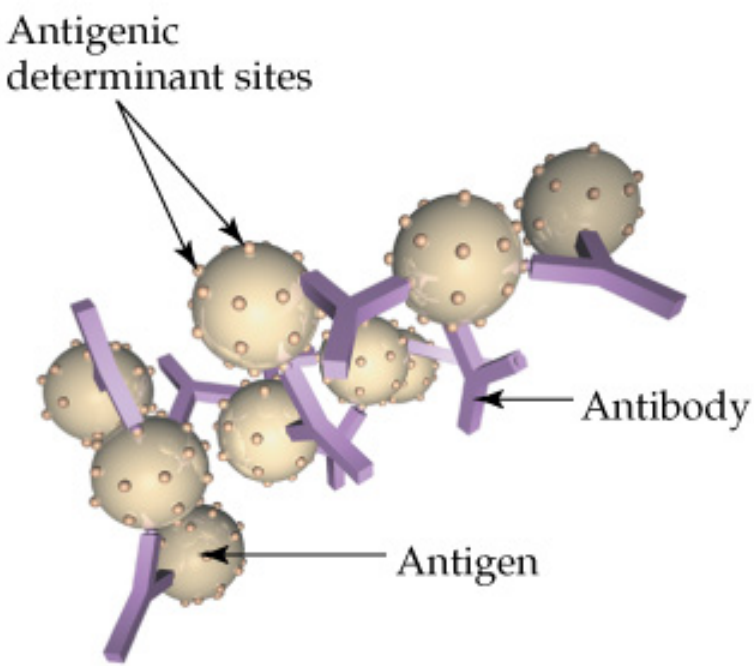
(a)



(b)


Antigenic
determinant
sites
Antigen
Antibodies

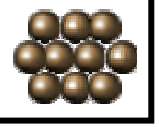
(a)


Antigenic
determinant sites
Antibody
Antigen

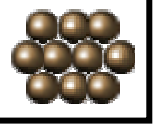
(b)

An Introduction to Carbohydrates

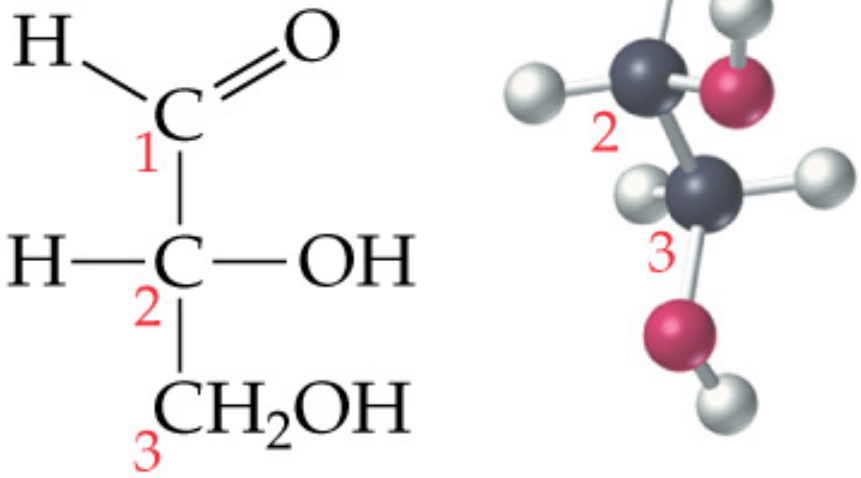
- *Carbohydrates* are a large class of naturally occurring polyhydroxy aldehydes and ketones.
- Monosaccharides also known as simple sugars, are the simplest carbohydrates containing 3-7 carbon atoms.
- sugar containing an aldehydes is known as an aldose.
- sugar containing a ketones is known as a ketose.

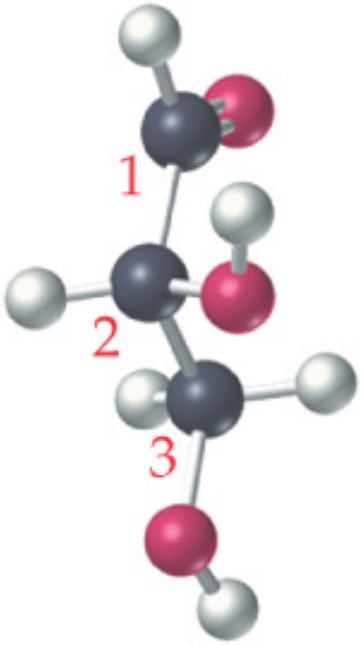


- *Carbohydrates* are a large class of naturally occurring polyhydroxy aldehydes and ketones.
- Monosaccharides also known as simple sugars, are the simplest carbohydrates containing 3-7 carbon atoms.
- sugar containing an aldehydes is known as an aldose.
- sugar containing a ketones is known as a ketose.
- The family name ending -ose indicates a carbohydrate.
- Simple sugars are known by common names such as glucose, ribose, fructose, etc.

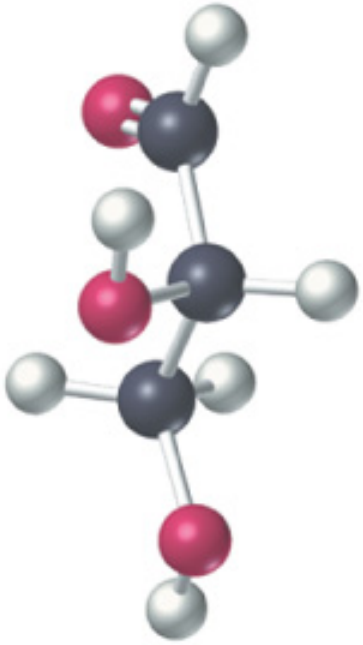


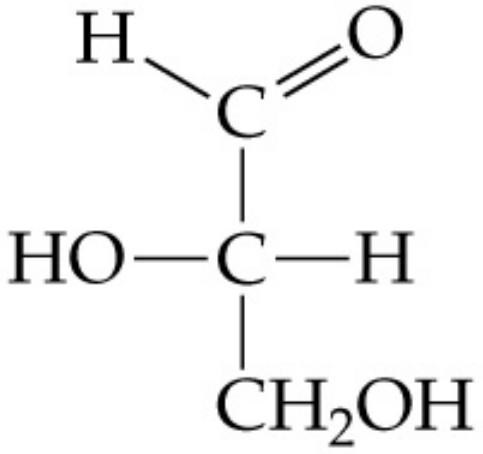
- The number of carbon atoms in an aldose or ketose may be specified as by tri, tetr, pent, hex, or hept. For example, glucose is aldohexose and fructose is ketohexose.
- Monosaccharides react with each other to form disaccharides and polysaccharides.
- Monosaccharides are chiral molecules and exist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



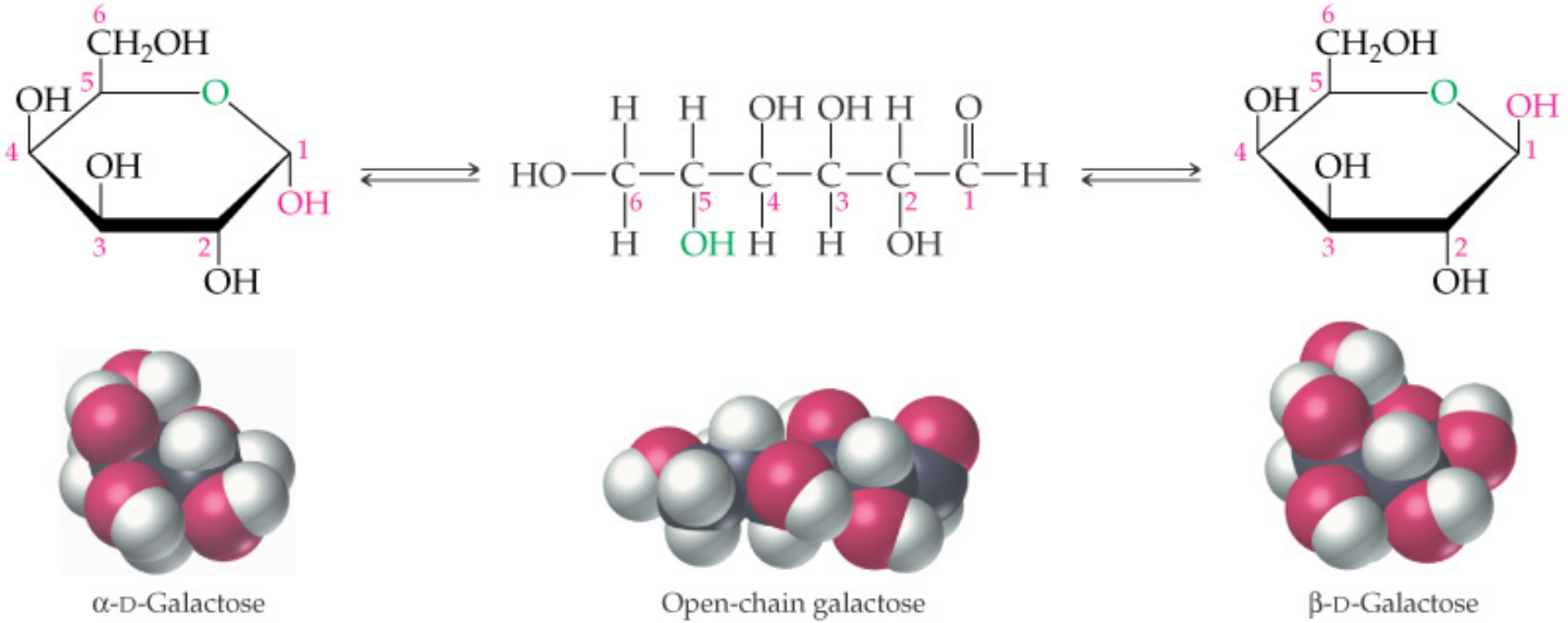


D-Glyceraldehyde
Right-handed



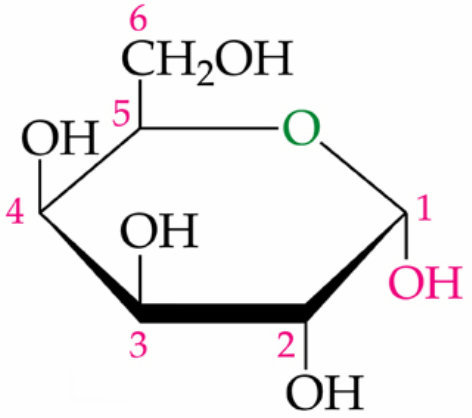


L-Glyceraldehyde
Left-handed

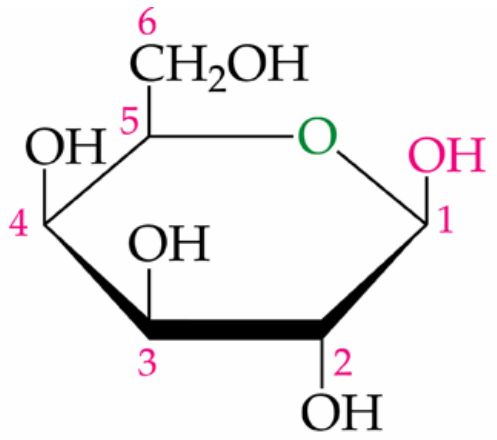

α-D-Galactose
Open-chain galactose
β-D-Galactose

Some Important Monosaccharides

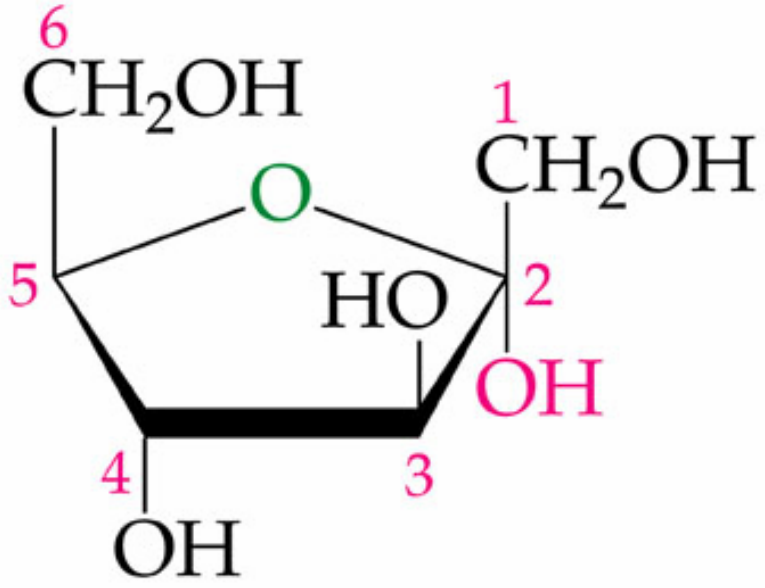
Monosaccharides are generally high-melting, white, crystalline solids that are soluble in water and insoluble in nonpolar solvents. Most monosaccharides are sweet tasting, digestible, and nontoxic.



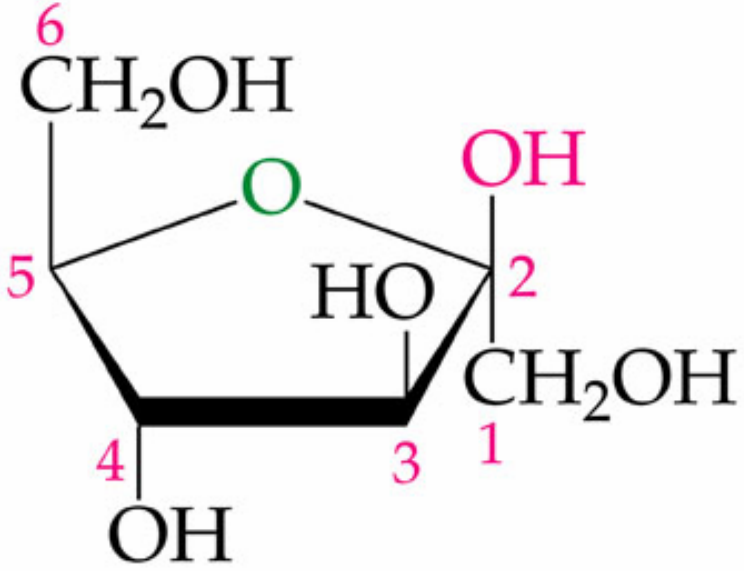
α-D-Galactose



β-D-Galactose

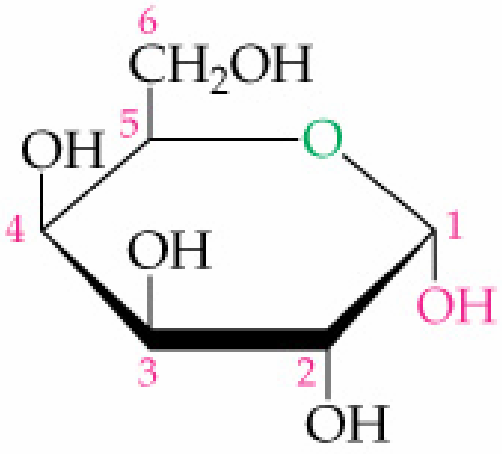


α-D-Fructose

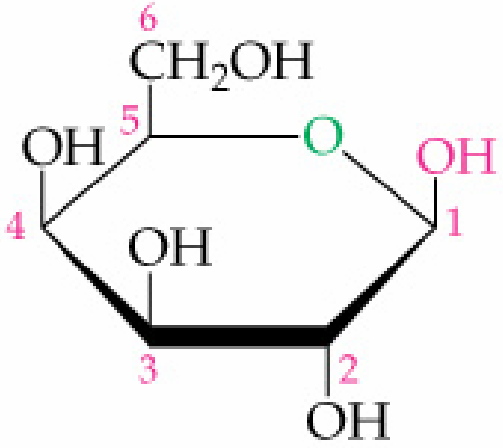


β-D-Fructose

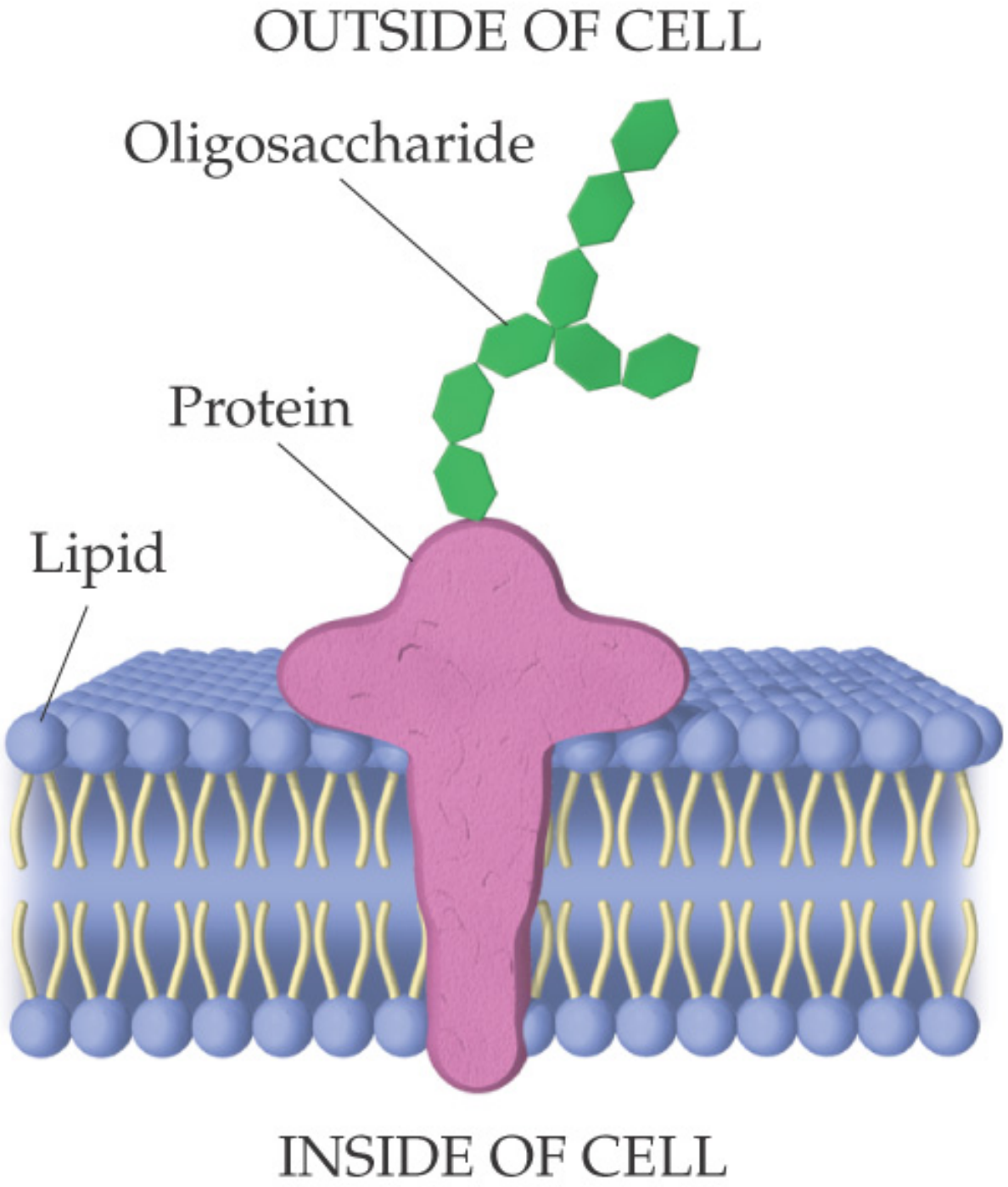
- *Anomers:* Cyclic sugars that differs only in positions of substituents at the hemiacetal carbon; the α-form has the –OH group on the opposite side from the $–CH_2OH$; the β-form the –OH group on the same side as the $–CH_2OH$ group.

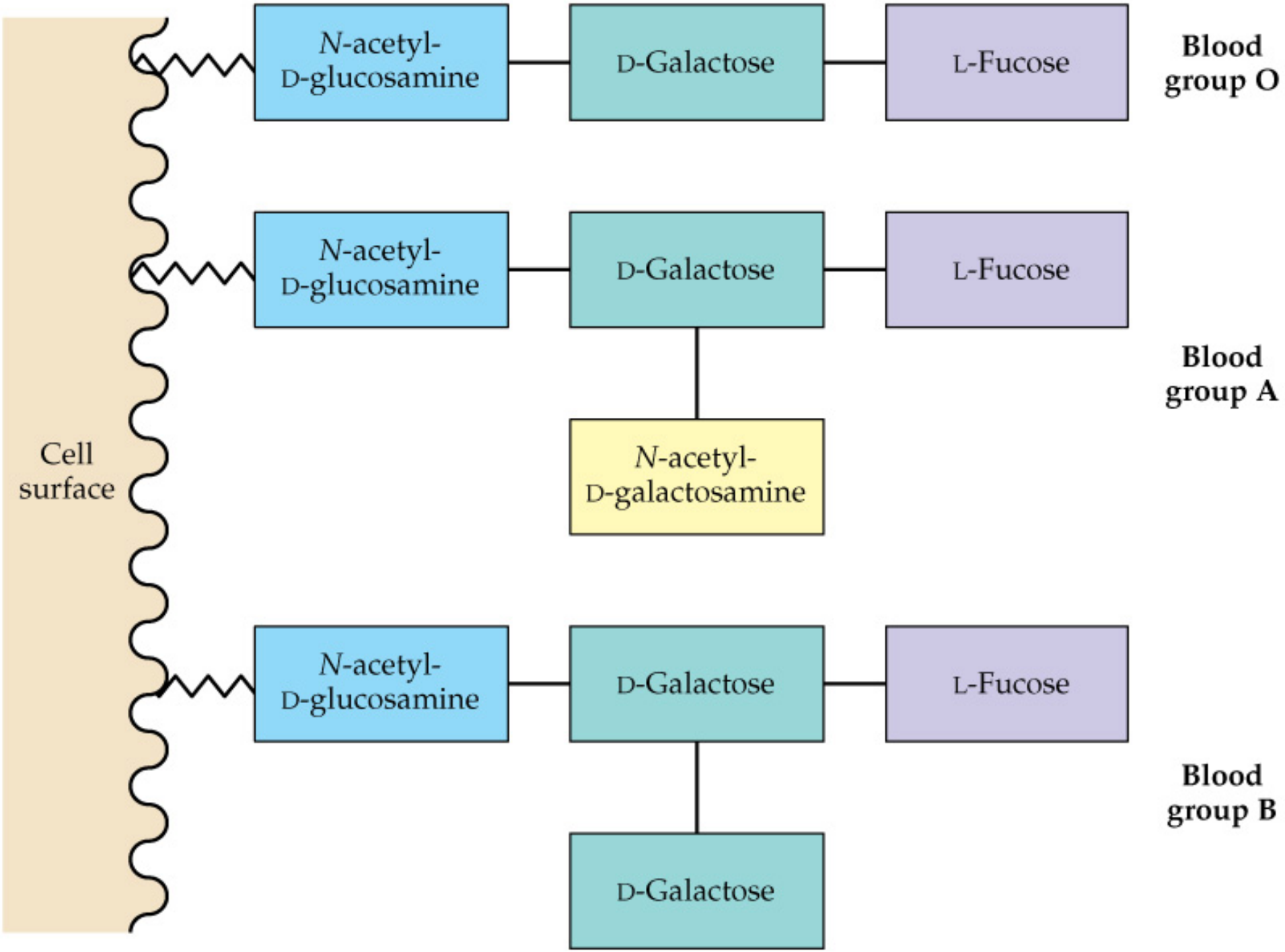


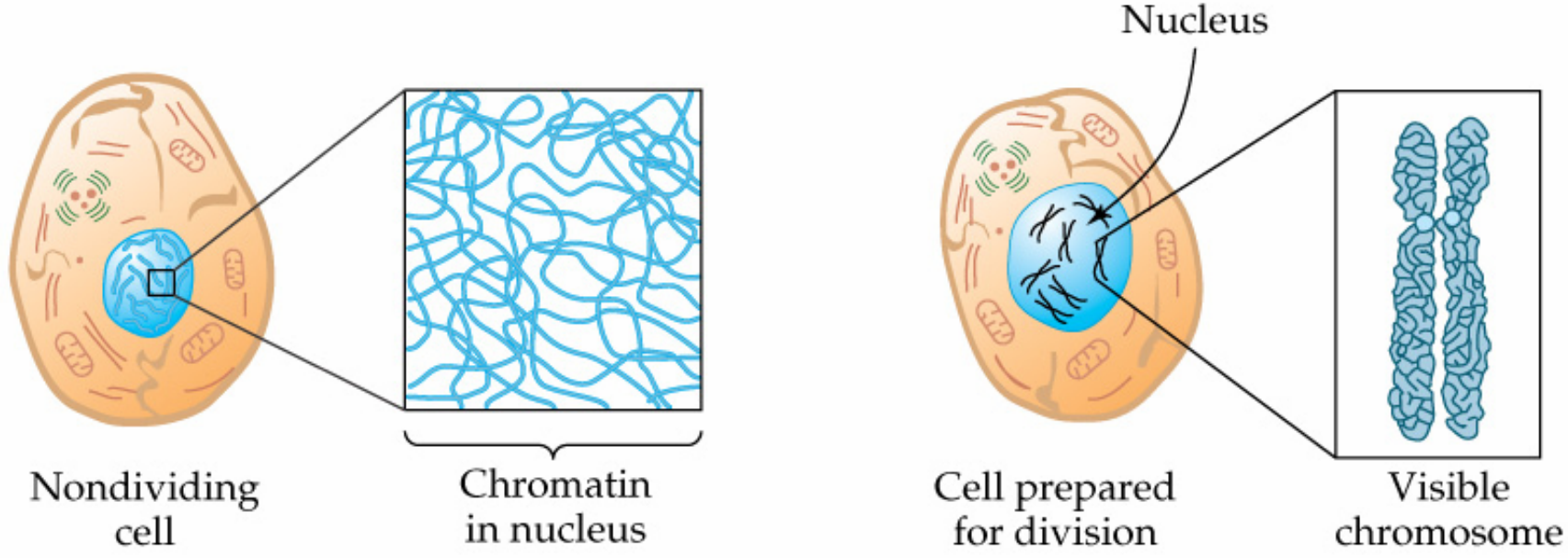
α-D-Galactose



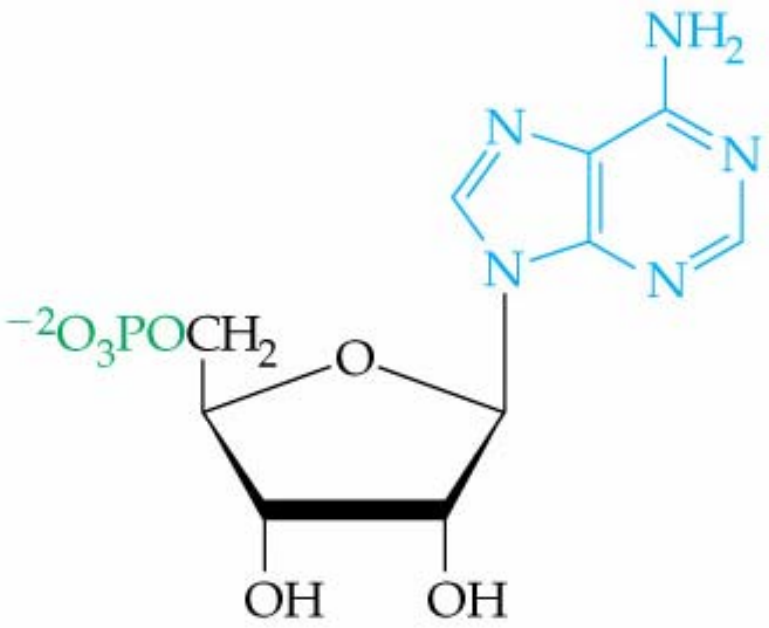
β-D-Galactose


OUTSIDE OF CELL
Oligosaccharide
Protein
Lipid
INSIDE OF CELL

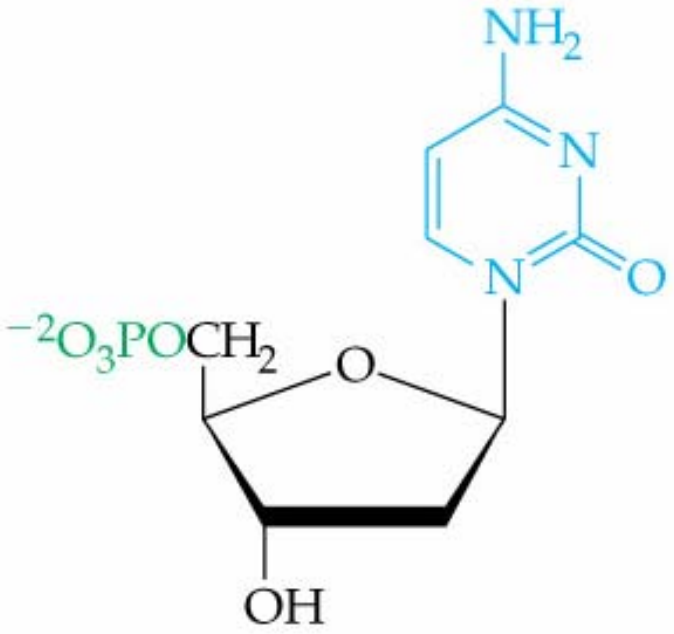

N-acetyl-
D-glucosamine
D-Galactose
L-Fucose
Blood
group O
N-acetyl-
D-glucosamine
D-Galactose
L-Fucose
Blood
group A
Cell
surface
N-acetyl-
D-galactosamine
N-acetyl-
D-glucosamine
D-Galactose
L-Fucose
Blood
group B
D-Galactose


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

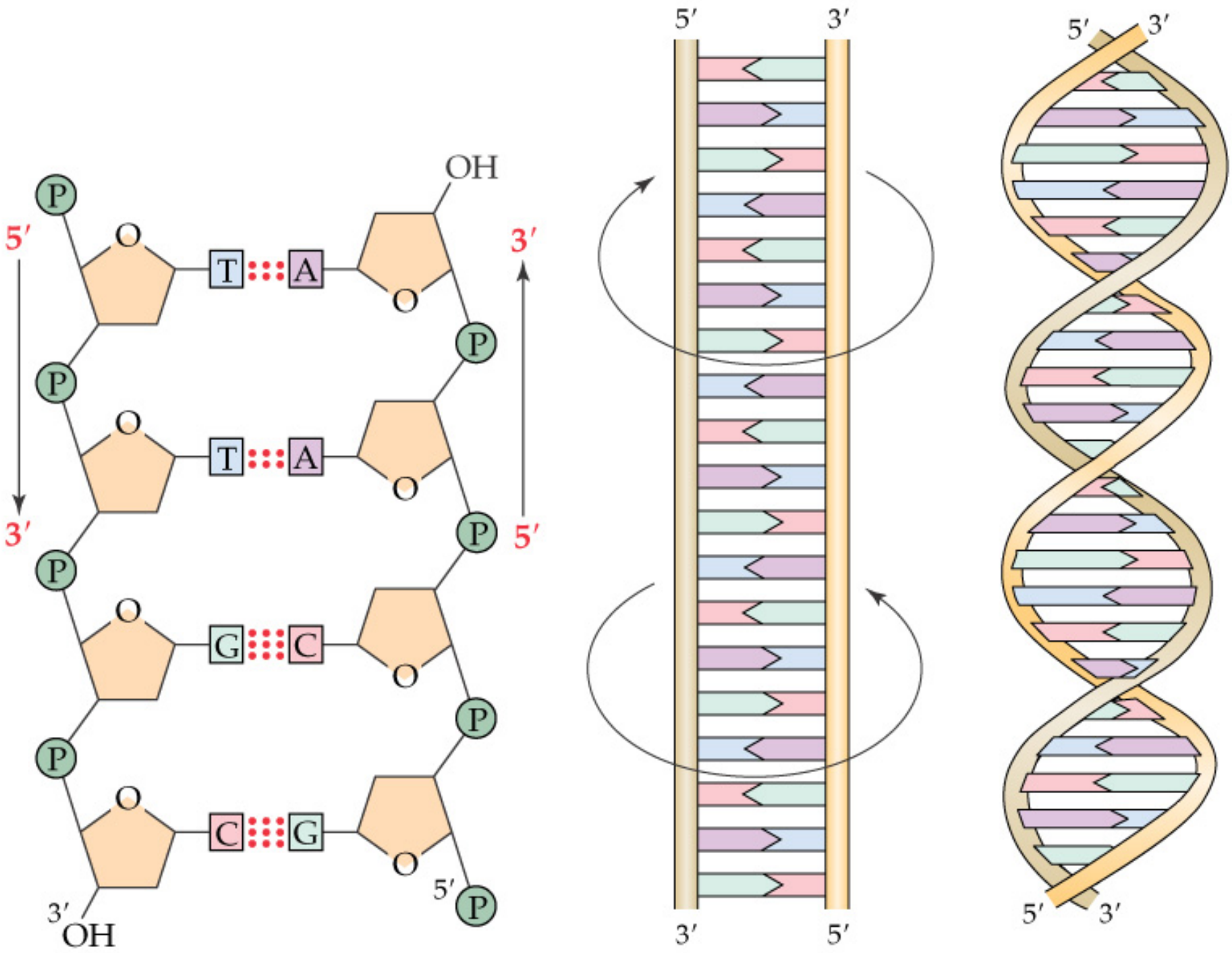
- In RNA, the sugar is ribose.
- In DNA, the sugar is deoxyribose.



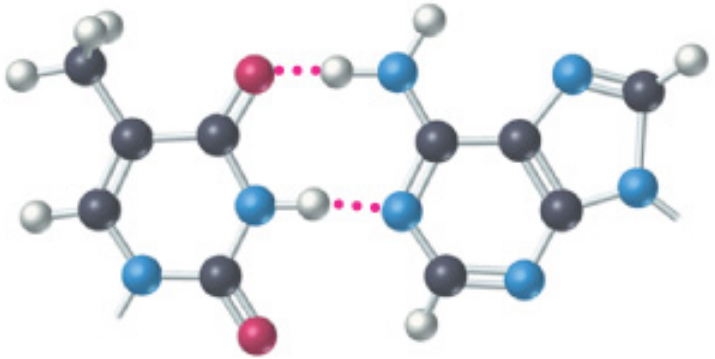
Adenosine 5′-monophosphate (AMP)
(a ribonucleotide)

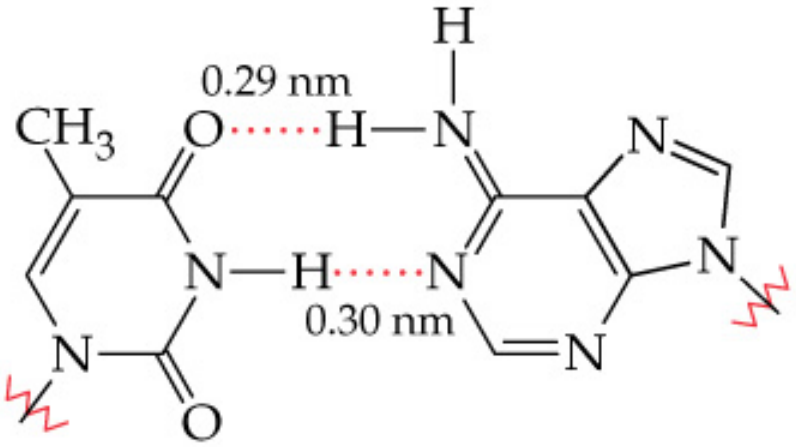


Deoxycytidine 5′-monophosphate (dCMP)
(a deoxyribonucleotide)

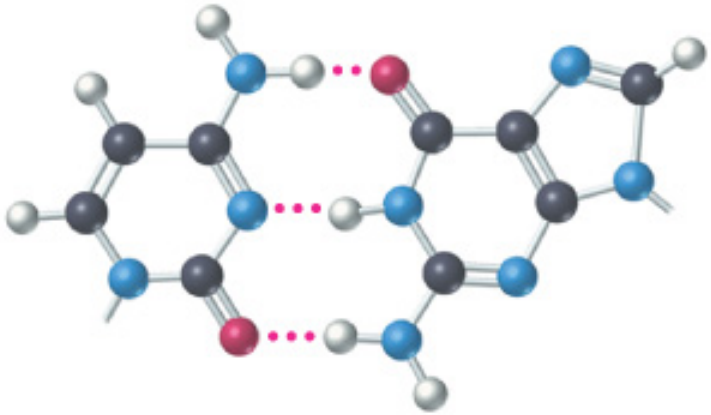

5′
3′
OH
P
O
T
A
G
C
3′
OH
5′
P
5′
3′
3′
5′
5′
3′
5′
3′

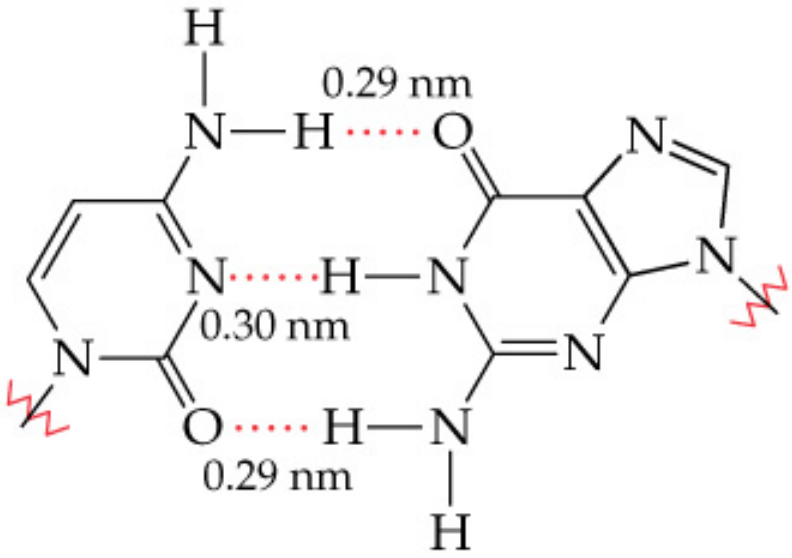
Thymine–Adenine

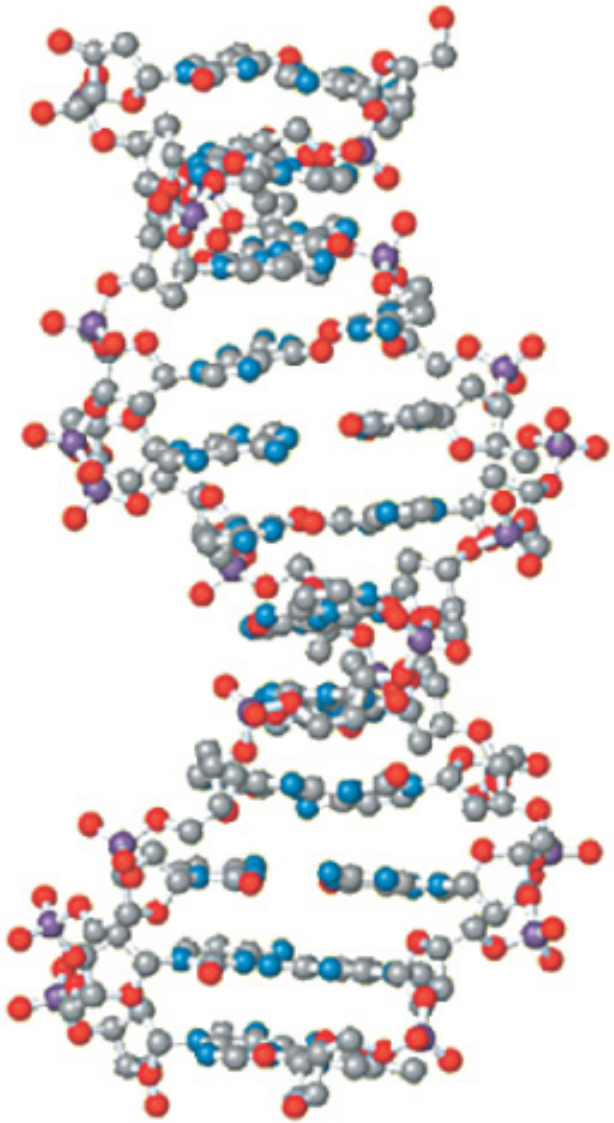




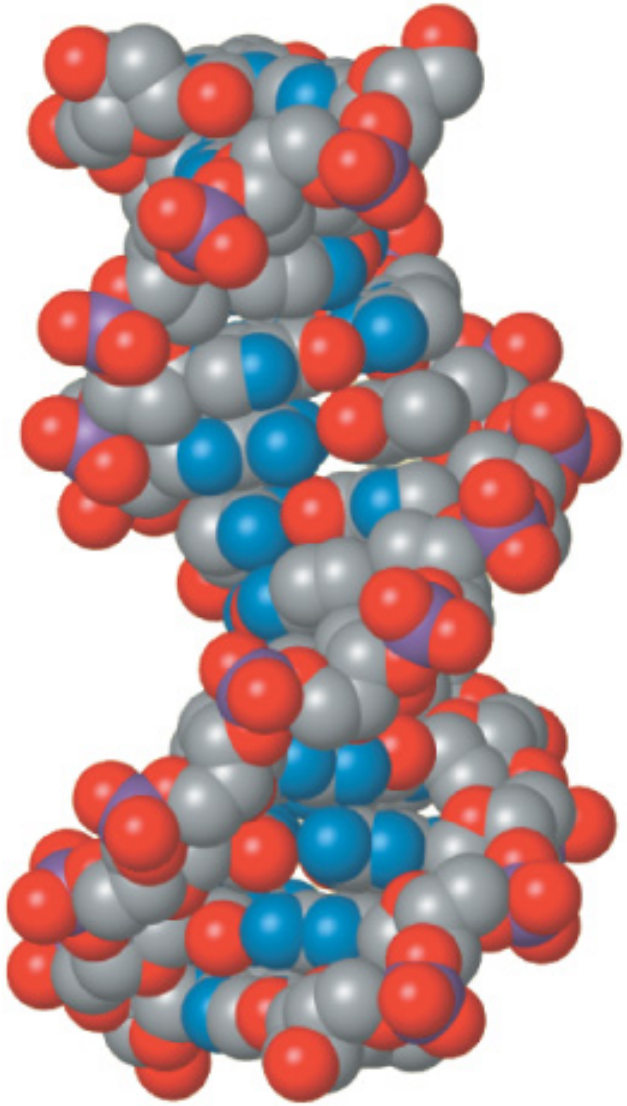
Cytosine–Guanine





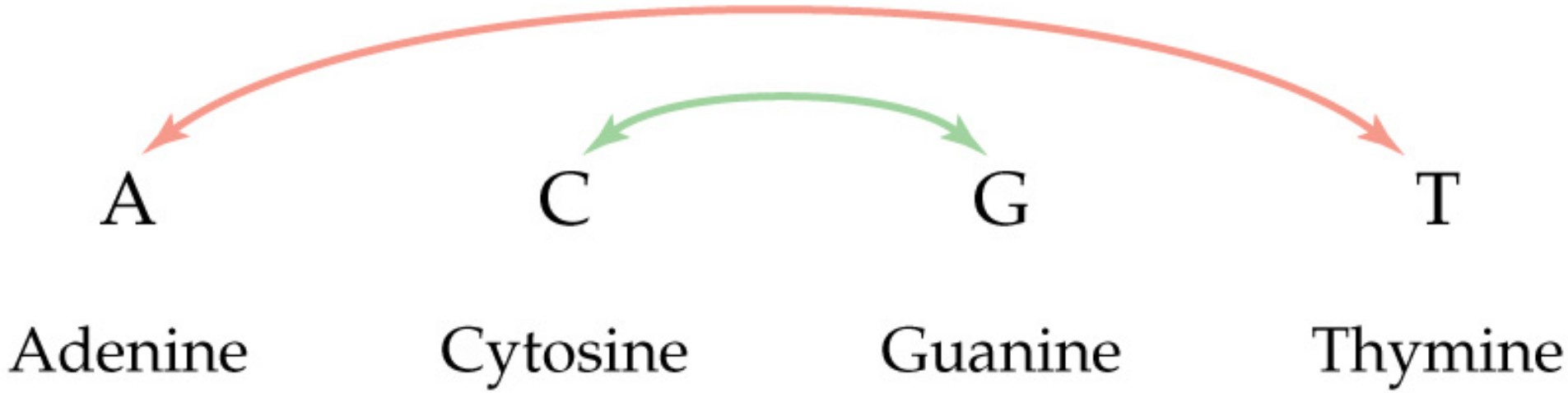


(a)

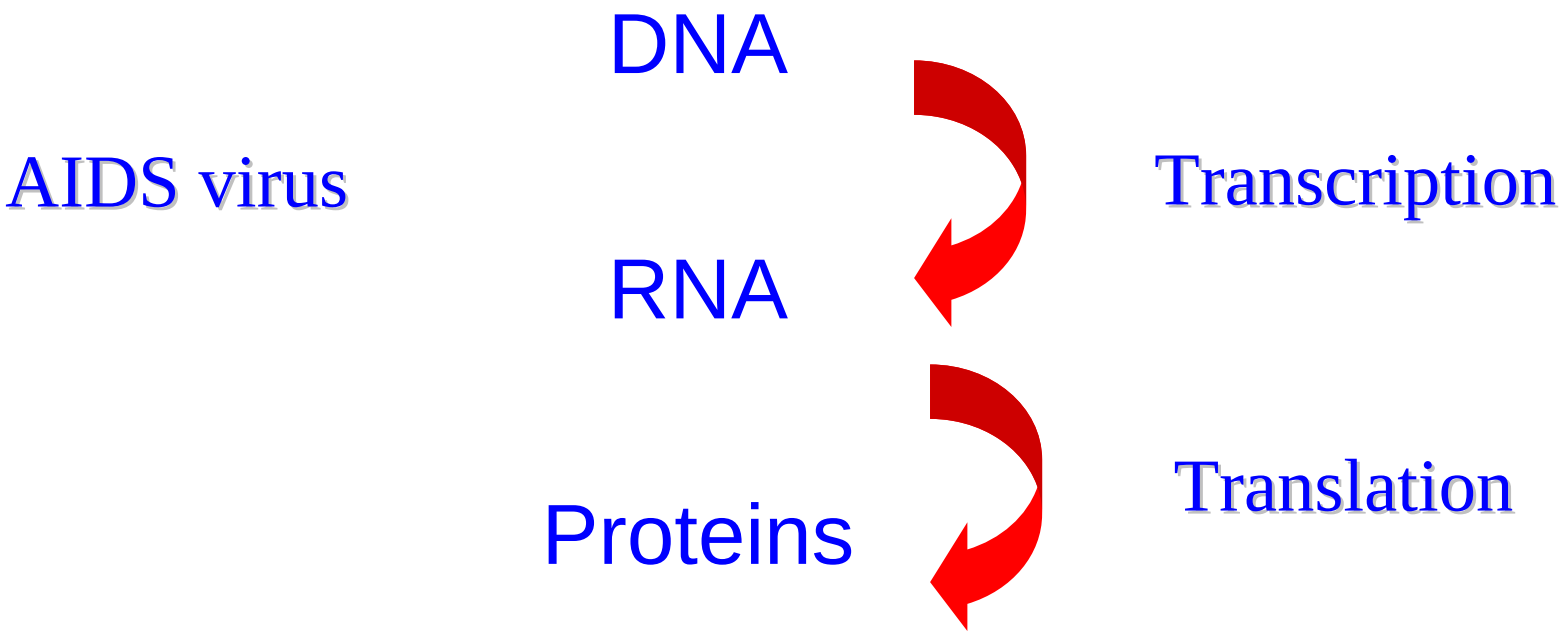


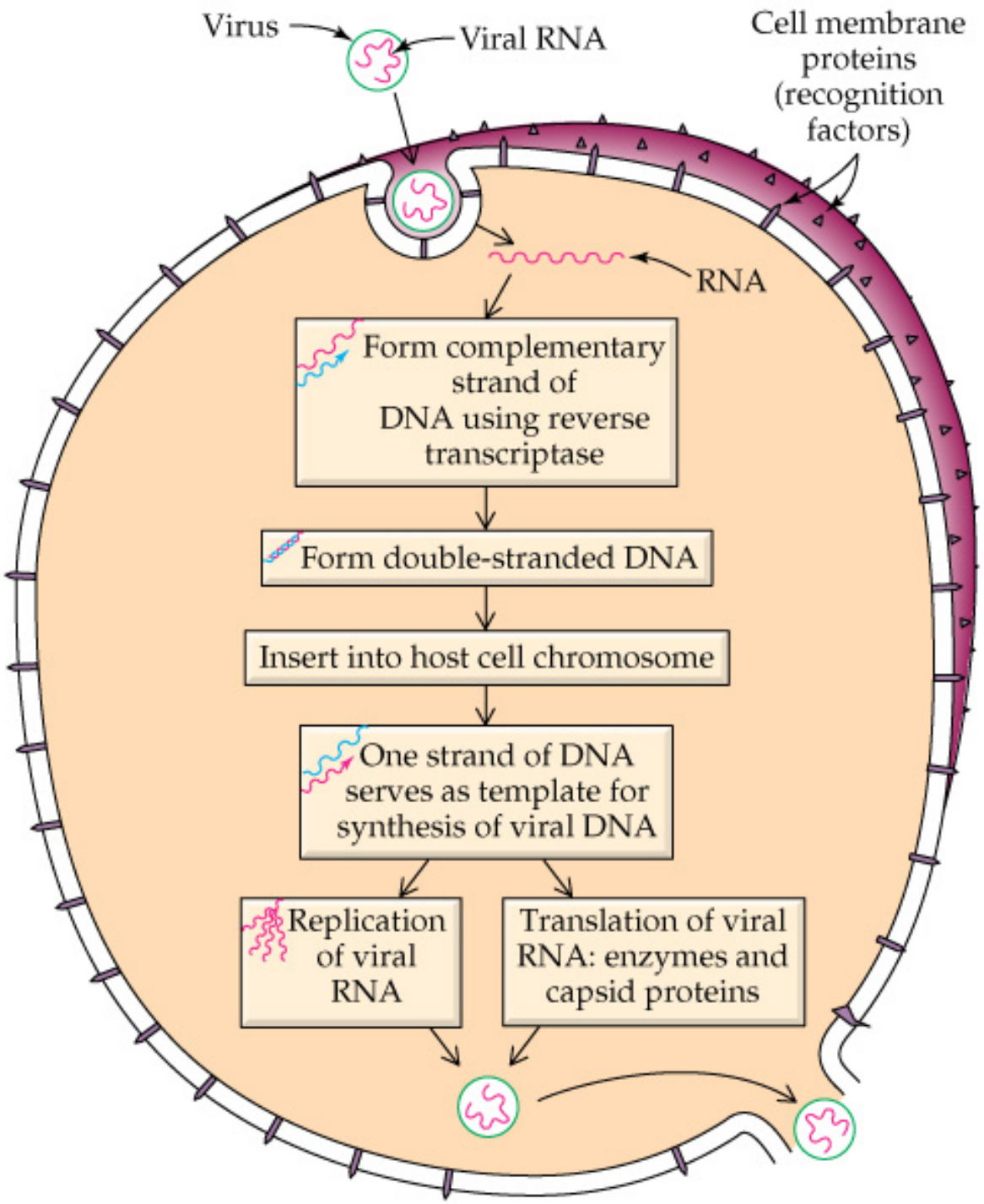
(b)

(c)

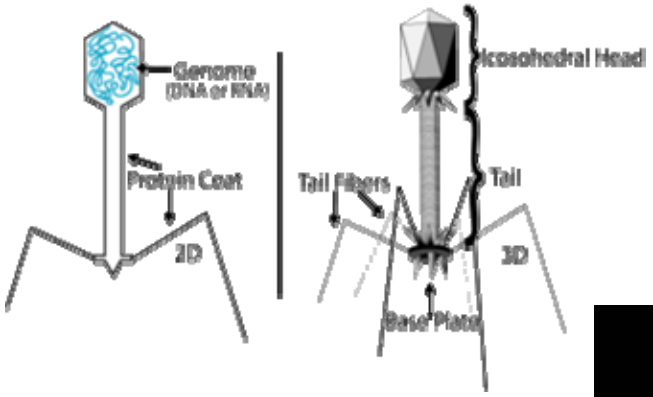

A
C
G
T
Adenine
Cytosine
Guanine
Thymine

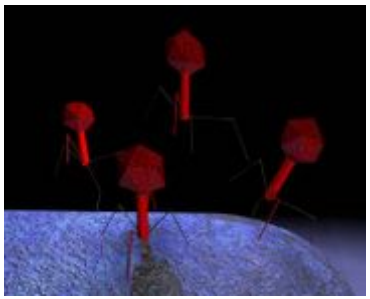
Central Dogma

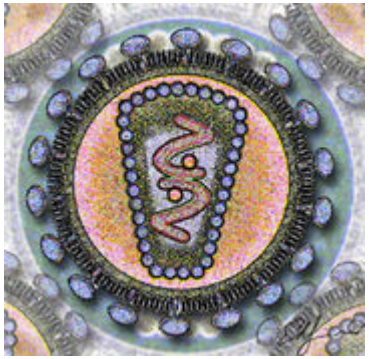


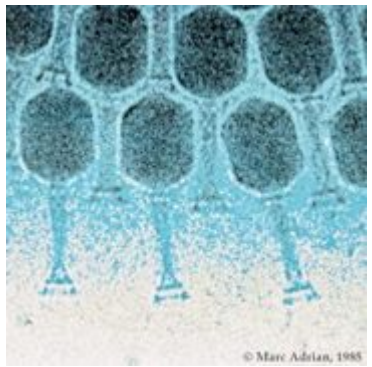

Virus
Viral RNA
Cell membrane proteins (recognition factors)
RNA
Form complementary strand of DNA using reverse transcriptase
Form double-stranded DNA
Insert into host cell chromosome
One strand of DNA serves as template for synthesis of viral DNA
Replication of viral RNA
Translation of viral RNA: enzymes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

Virus

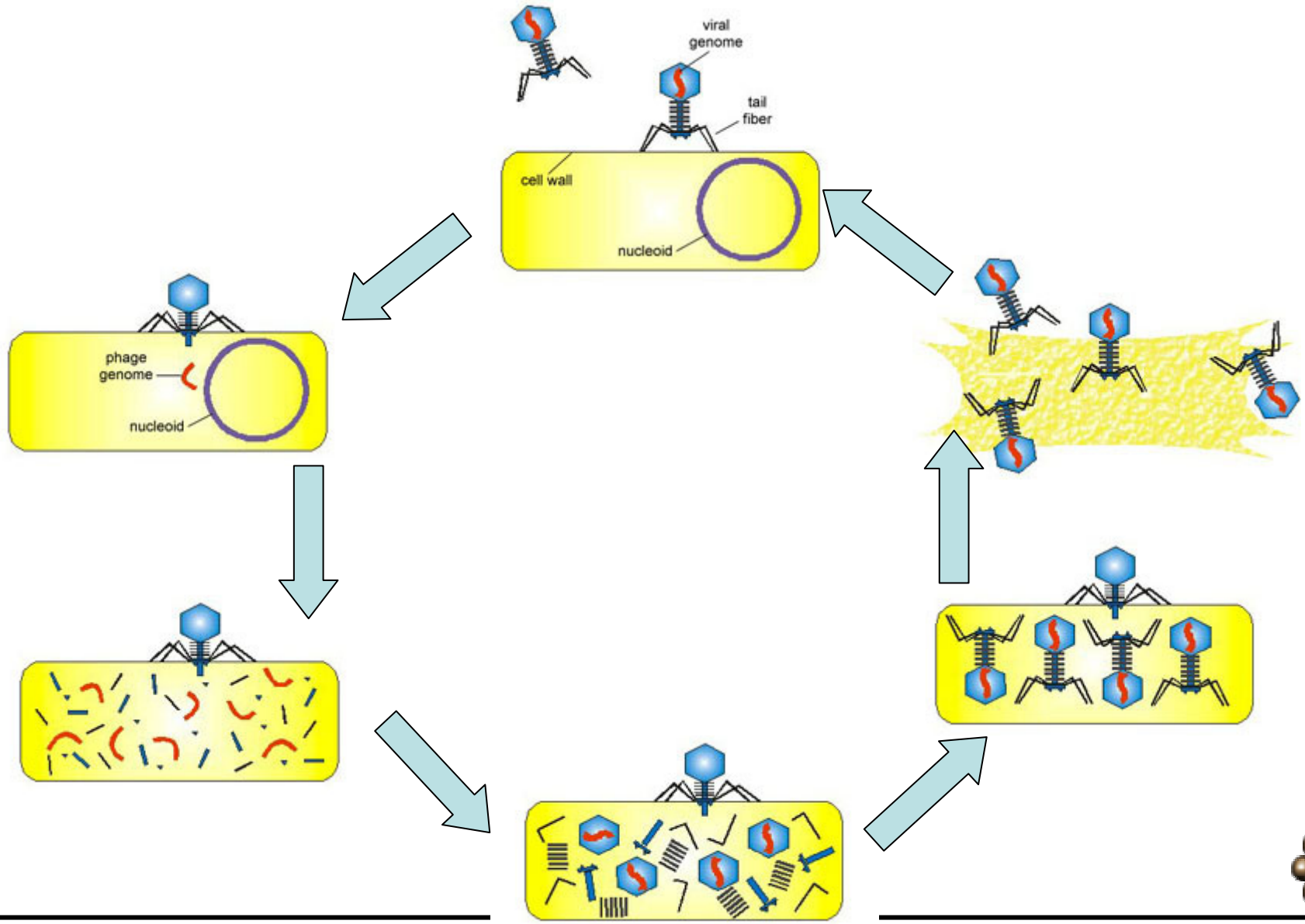

Genome
(DNA or RNA)
Protein Coat
2D
Icosohedral Head
Tail Fibers
Tail
Base Plate
3D





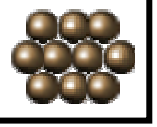

© Marc Adrian, 1985

Virus Reproduction

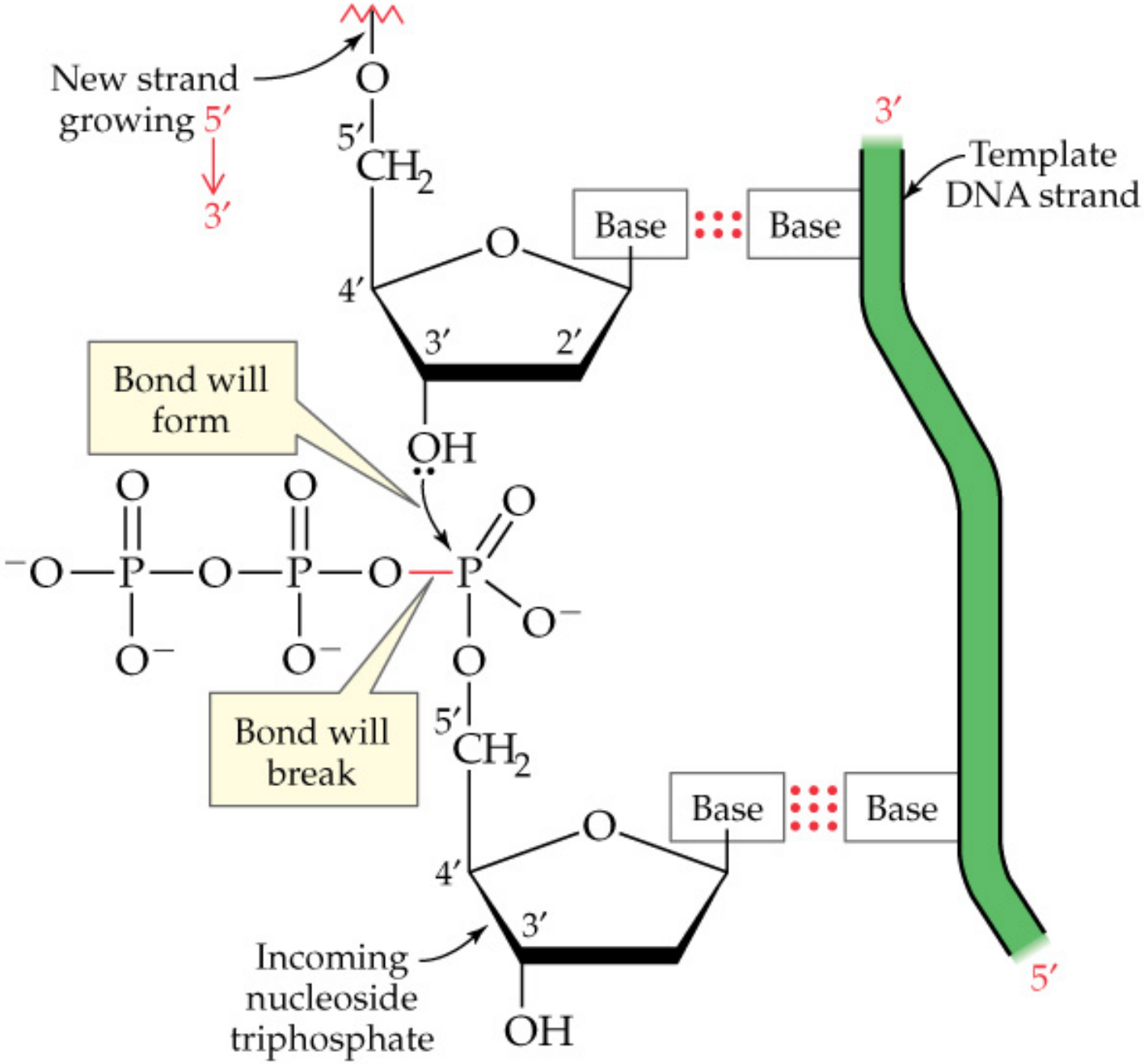


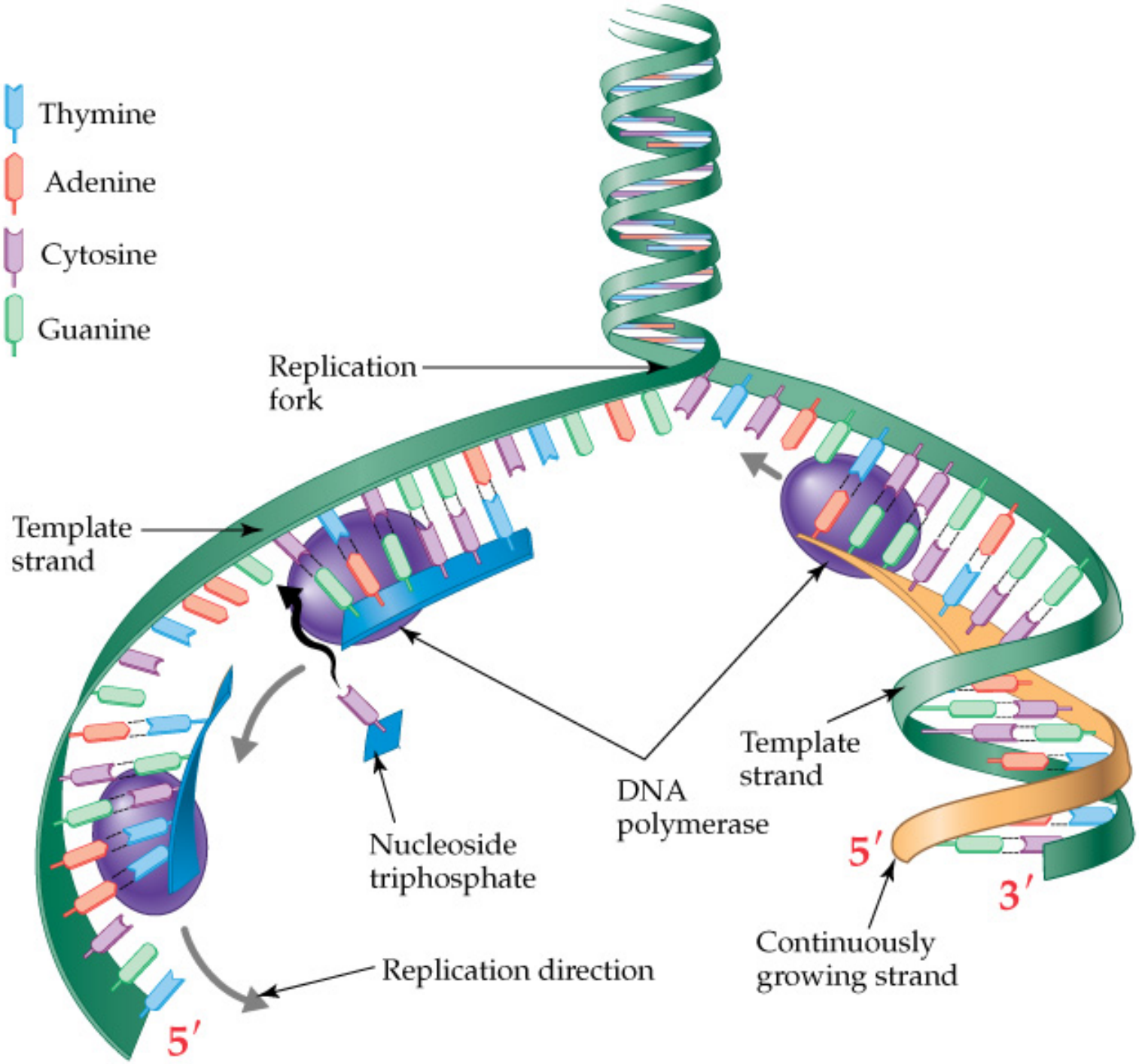
Life

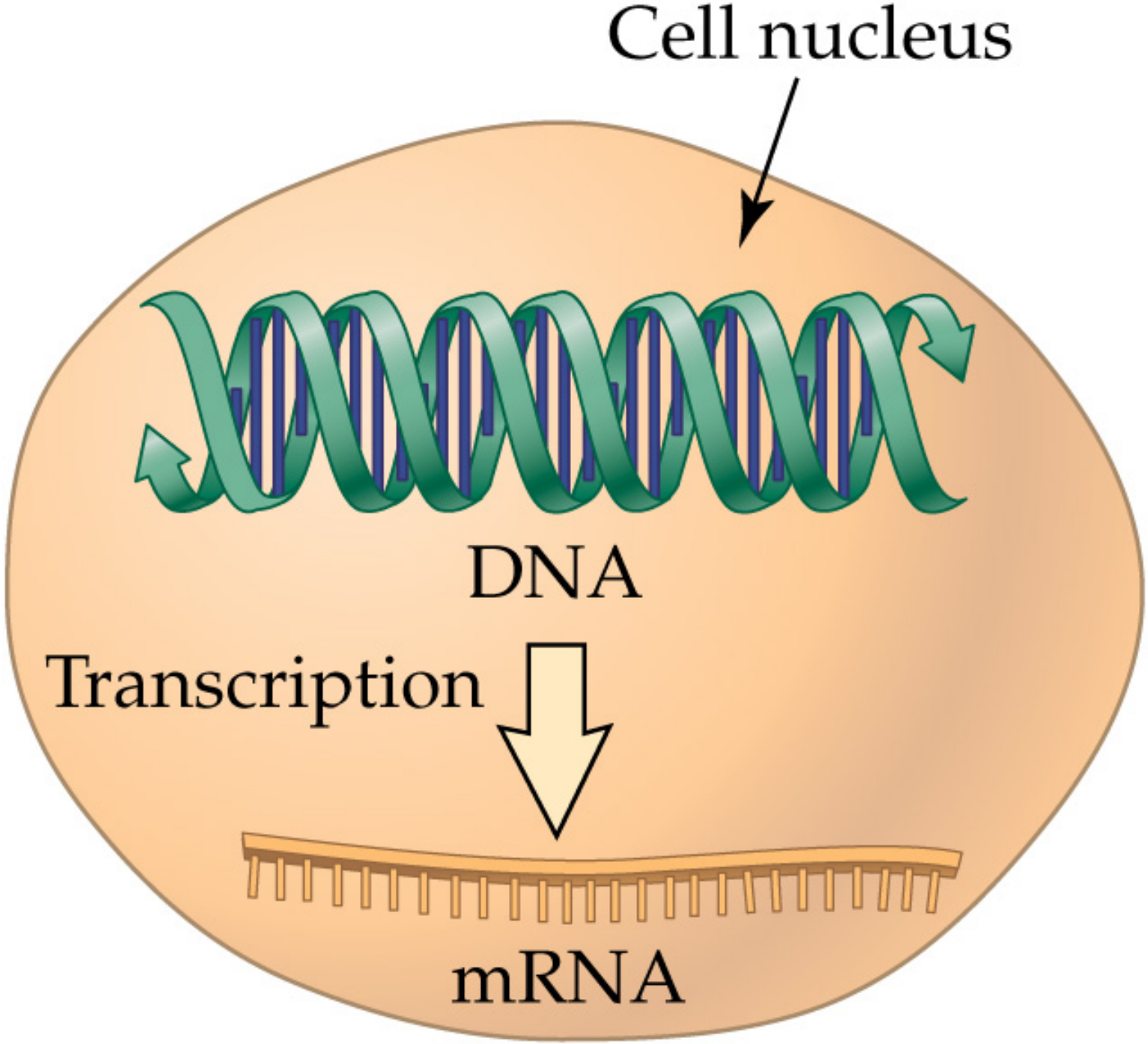
- Replication: reproduction
- Function: catalytic functions
- RNA world:
- Virus is not alive



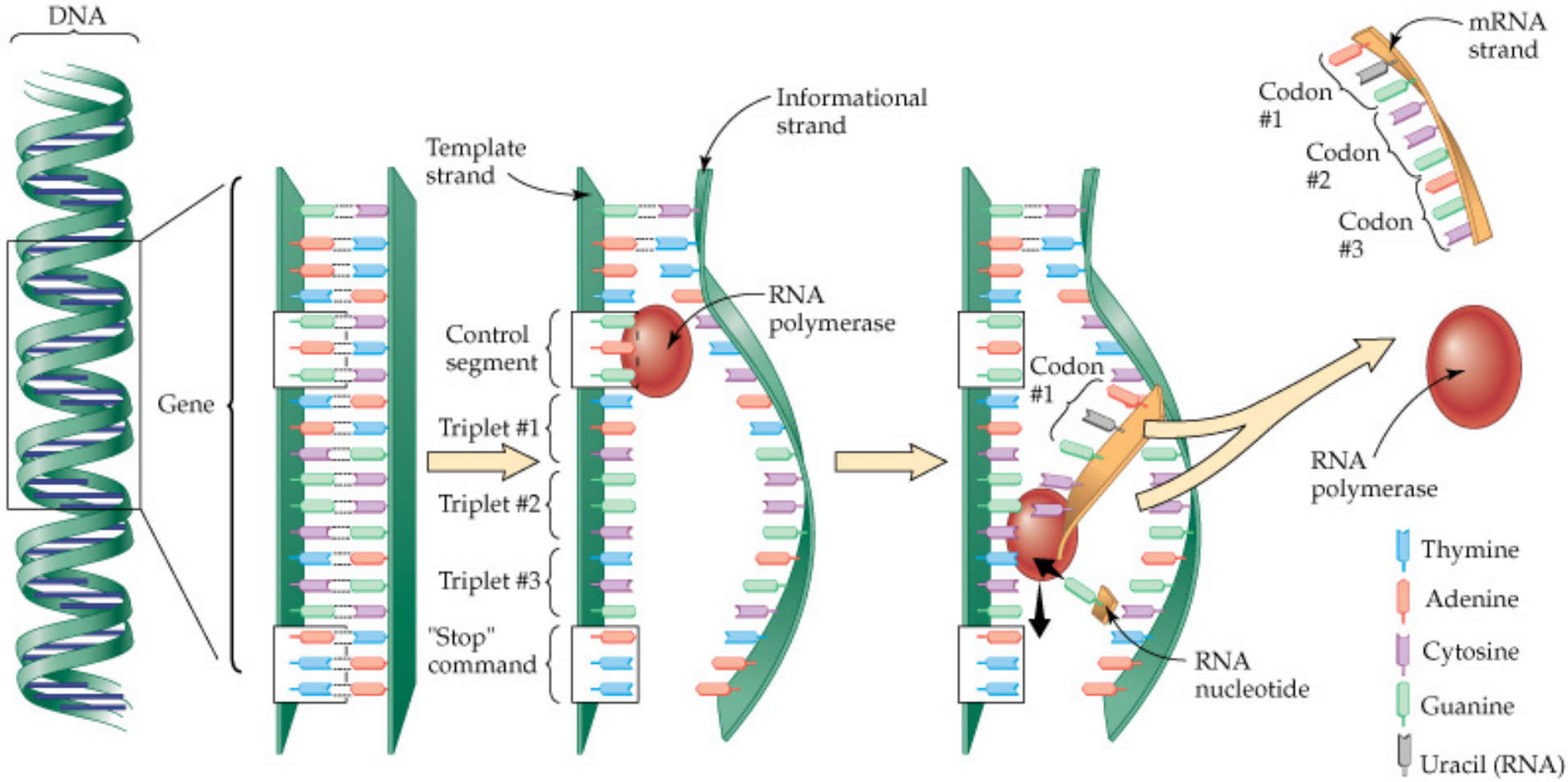
Bond formation in DNA replication

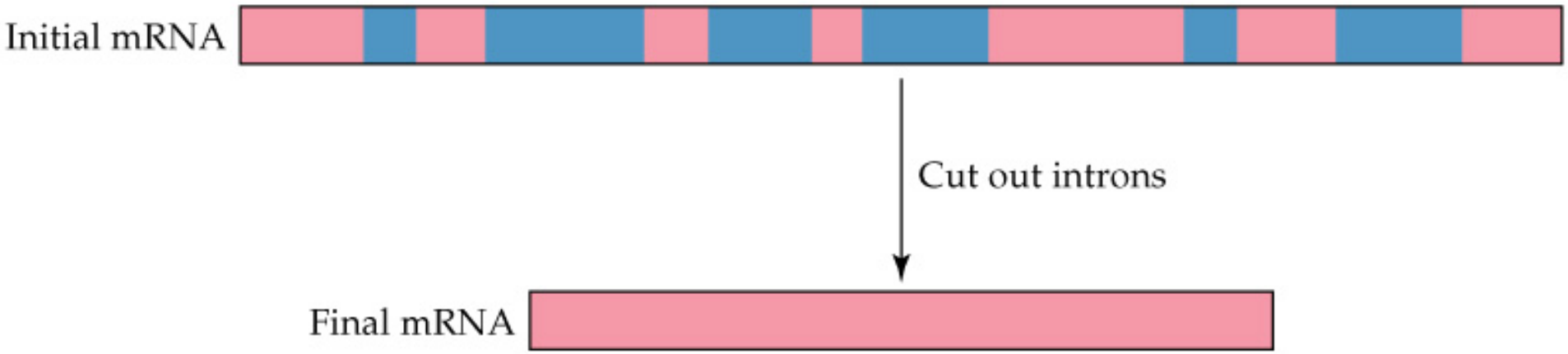


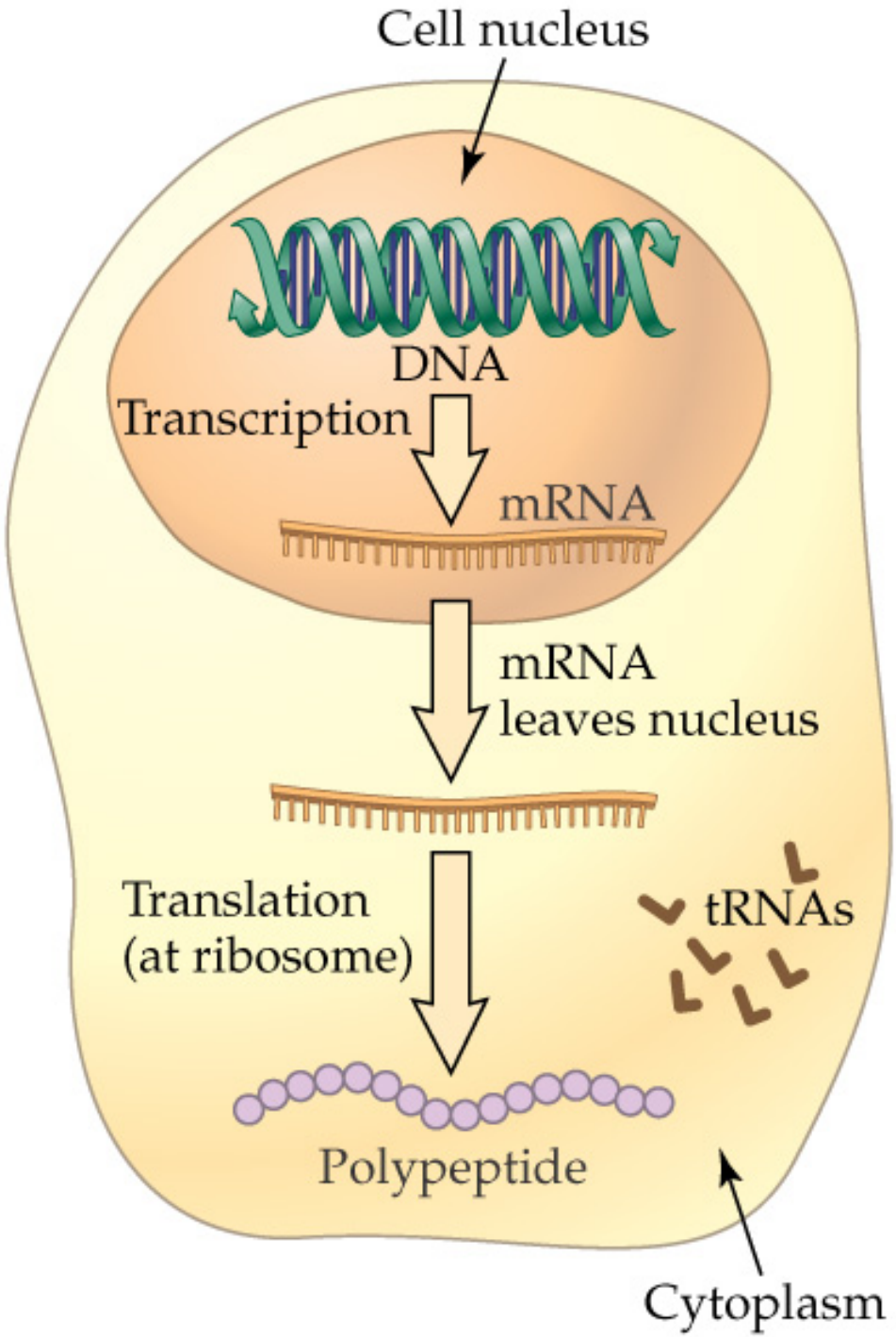

Thymine
Adenine
Cytosine
Guanine
Replication fork
Template strand
Nucleoside triphosphate
DNA polymerase
Template strand
5′
3′
Continuously growing strand
Replication direction
5′

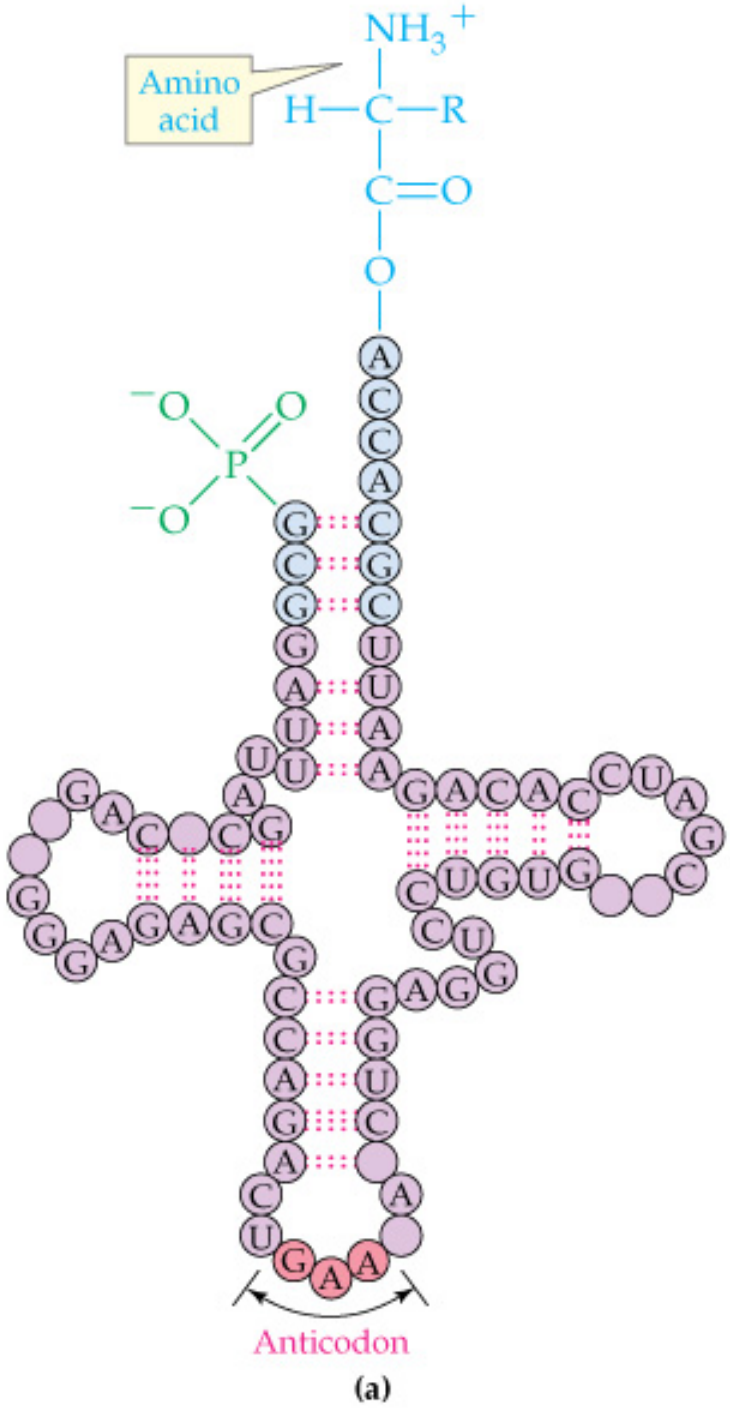

Cell nucleus
DNA
Transcription
mRNA

- 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.

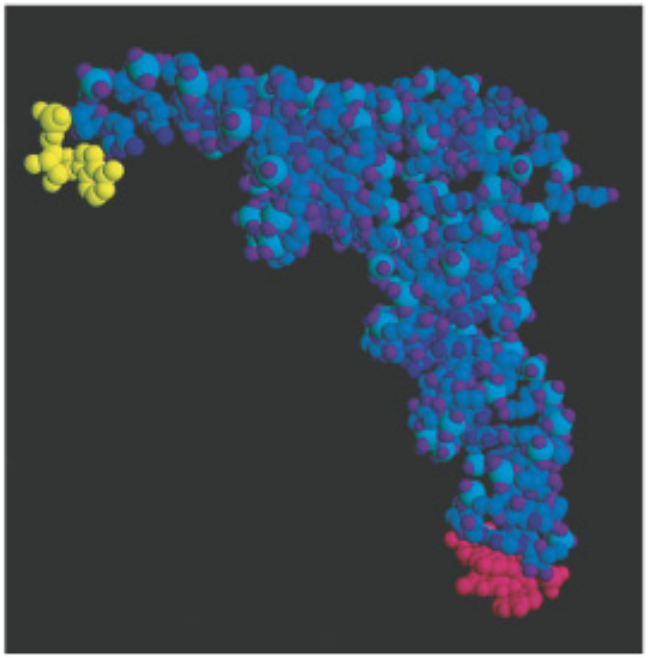

DNA
Gene
Template strand
Informational strand
RNA polymerase
Control segment
Triplet #1
Triplet #2
Triplet #3
"Stop" command
Codon #1
Codon #2
Codon #3
mRNA strand
RNA nucleotide
Thymine
Adenine
Cytosine
Guanine
Uracil (RNA)


Initial mRNA
Cut out introns
Final mRNA

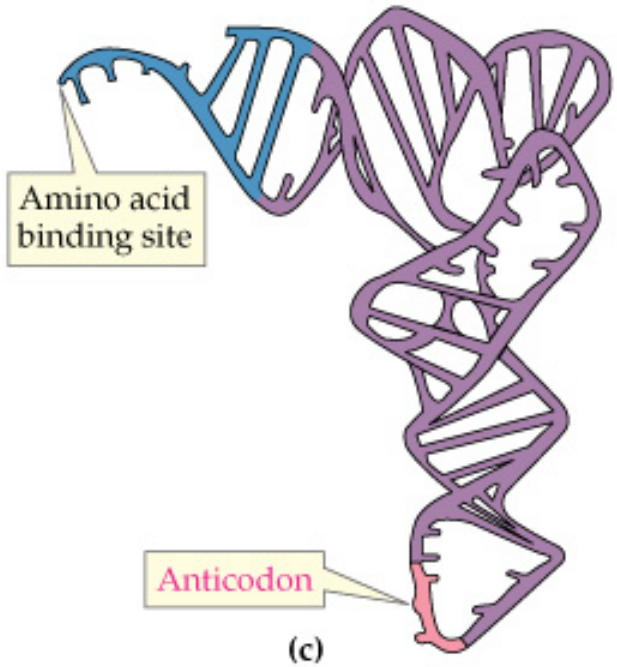

Cell nucleus
DNA
Transcription
mRNA
mRNA
leaves nucleus
Translation
(at ribosome)
tRNAs
Polypeptide
Cytoplasm


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

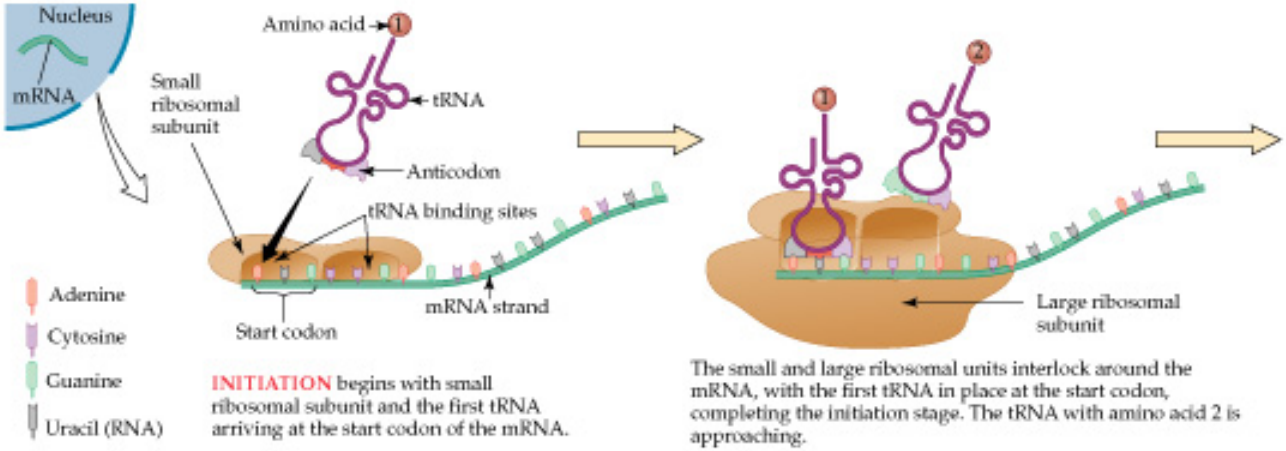
(a)



(b)

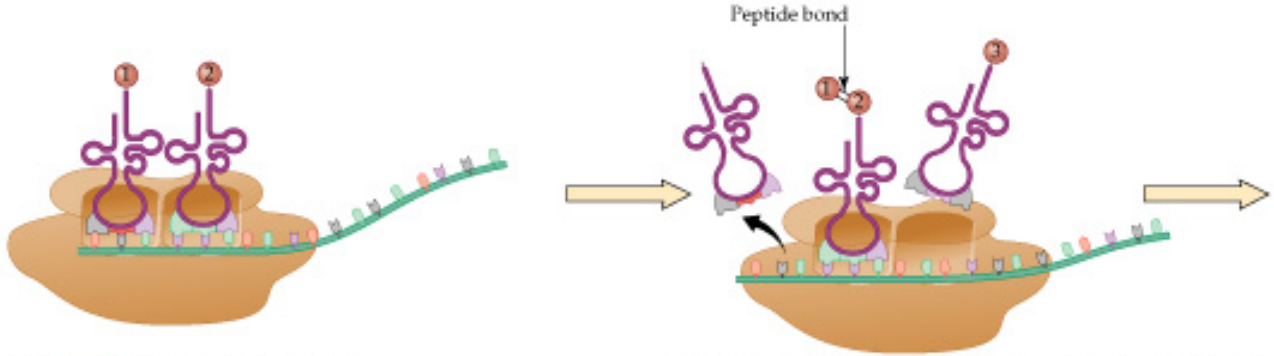

Amino acid binding site
Anticodon

(c)



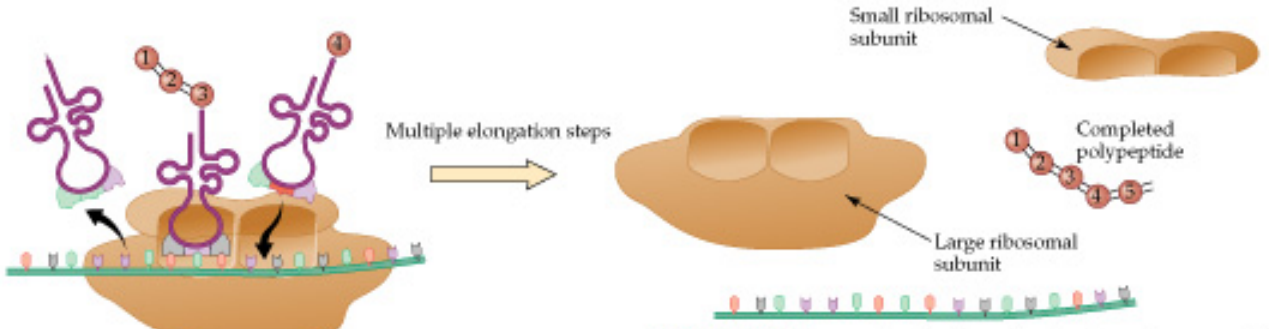
INITIATION begins with small ribosomal subunit and the first tRNA arriving at the start codon of the mRNA.

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.



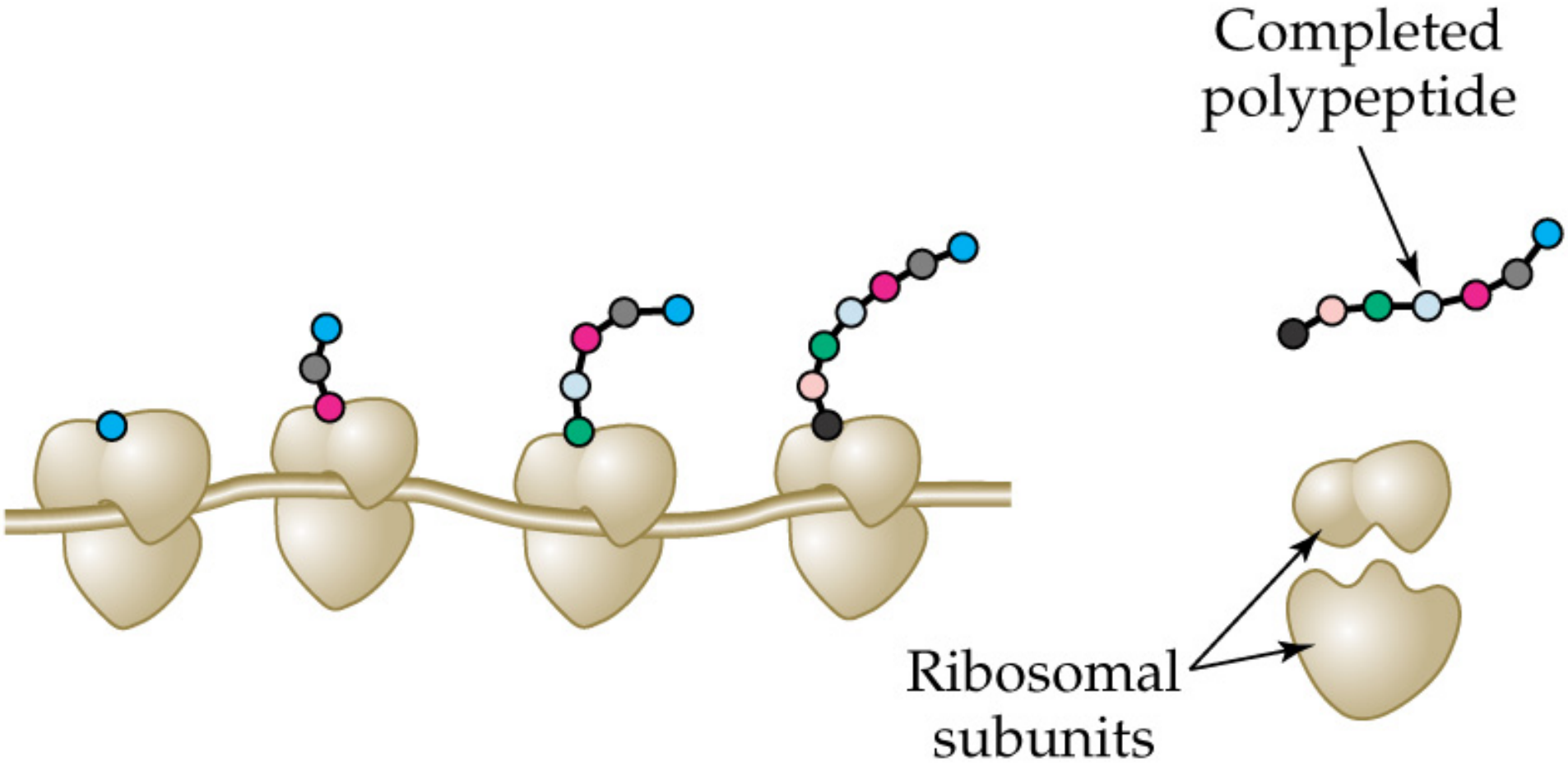
ELONGATION begins as the tRNA with amino acid 2 binds to its codon at the second site within the ribosome.

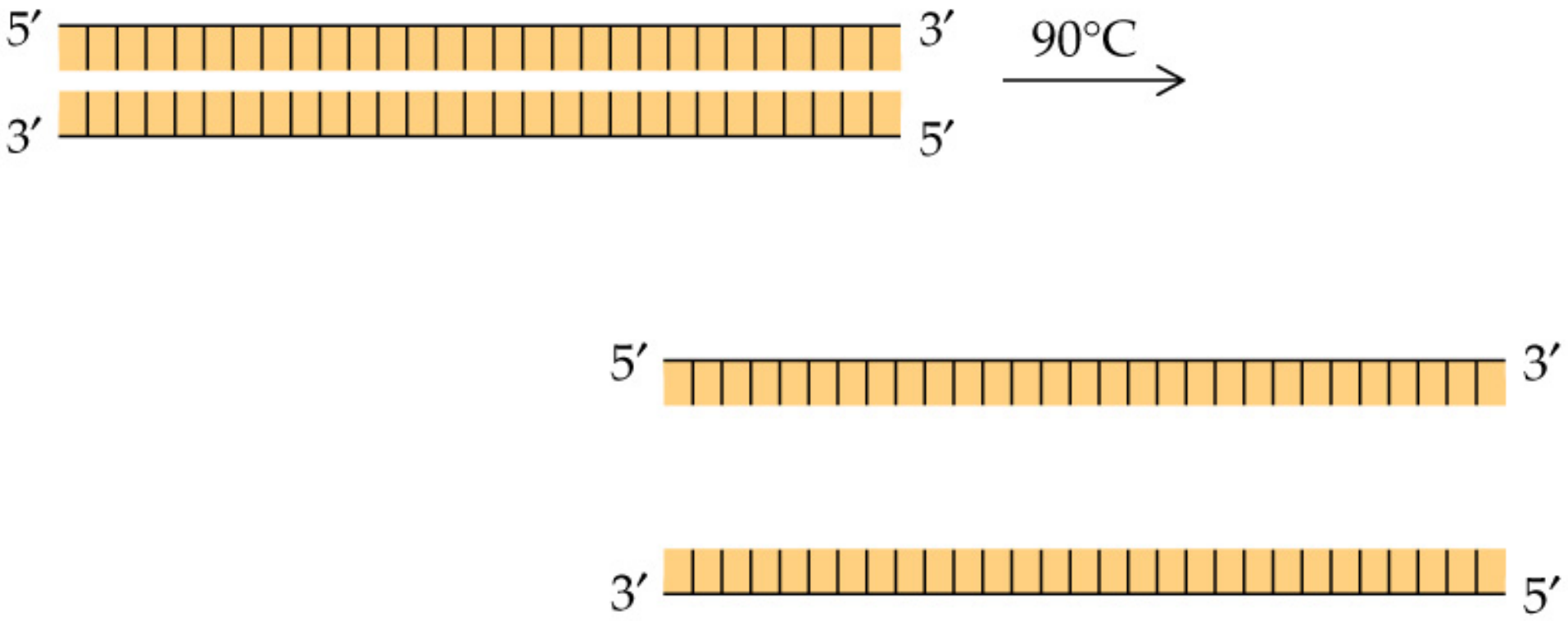
A peptide bond forms between amino acid 1 and 2, the first tRNA is released, the ribosome moves one codon to the right, and the tRNA with amino acid 3 is arriving.

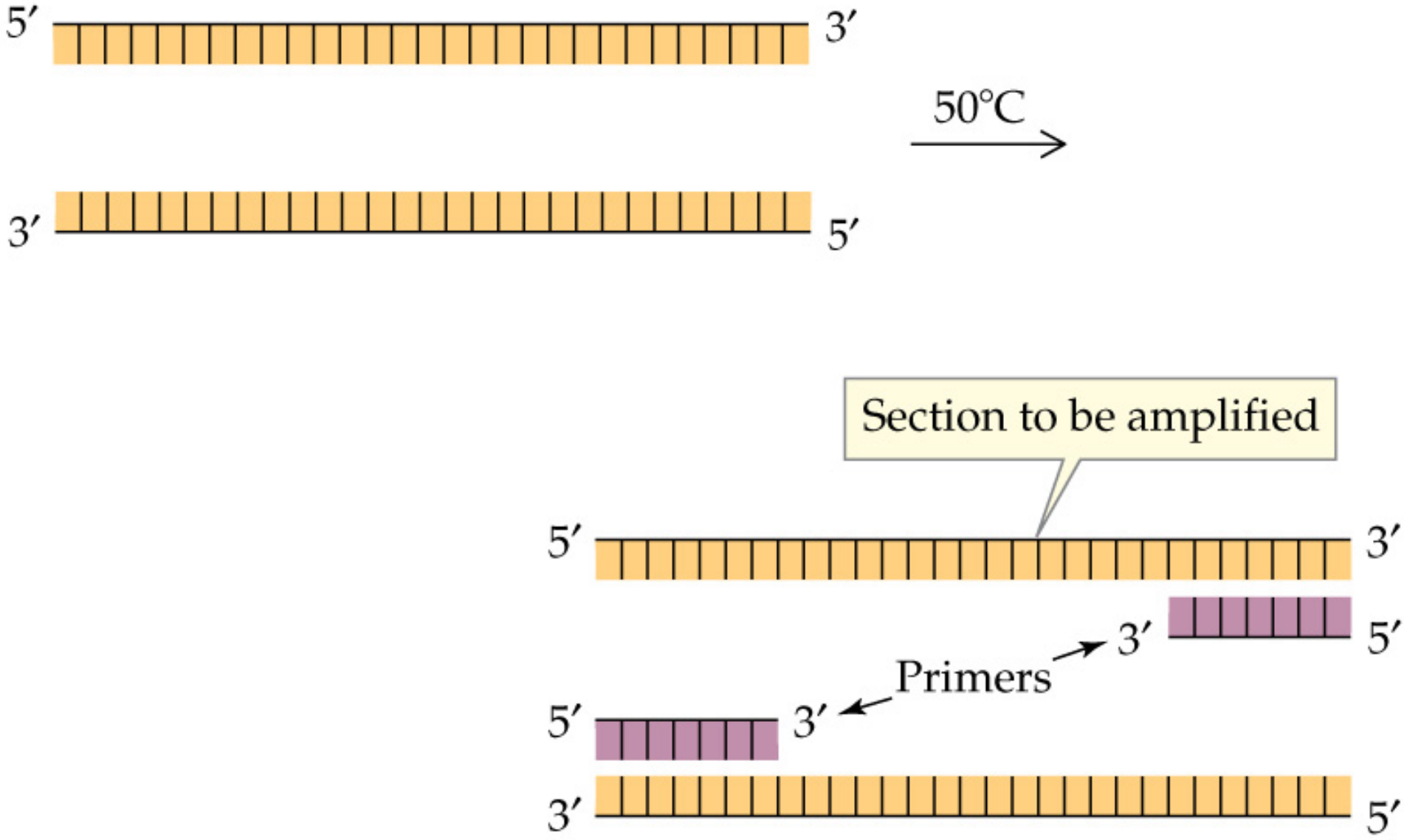


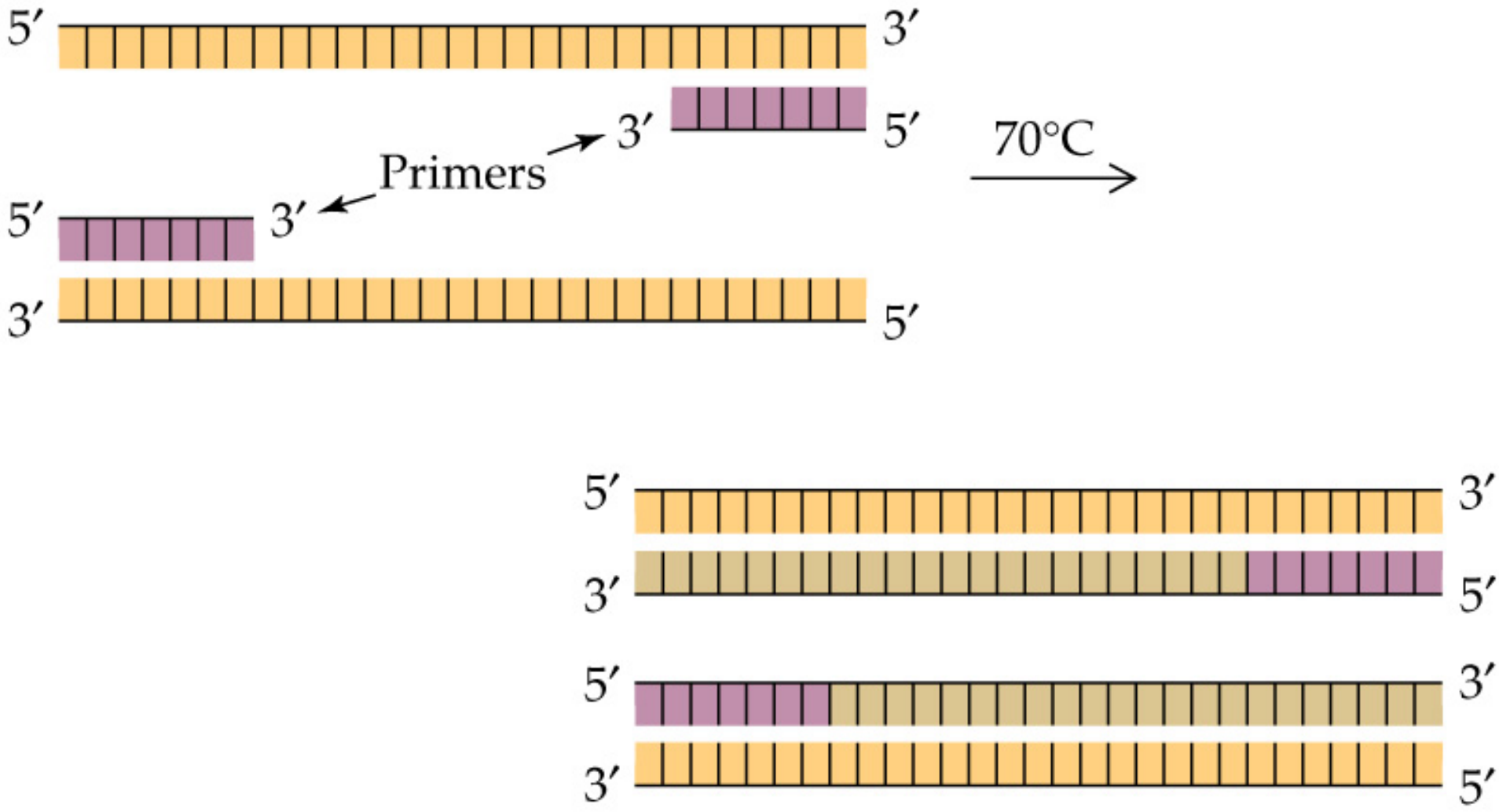
Elongation continues with three amino acids in the growing chain and the fourth one arriving with its tRNA

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


5′
3′
3′
5′
90°C
5′
3′
3′
5′


5′
3′
50°C
3′
5′
Section to be amplified
5′
3′
3′
5′
Primers
5′
3′
3′
5′


5′
3′
3′
5′
Primers
70°C
5′
3′
3′
5′
5′
3′
3′
5′
5′
3′
3′
5′