Essentials of Biology

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Chapter 11
Lecture Outline

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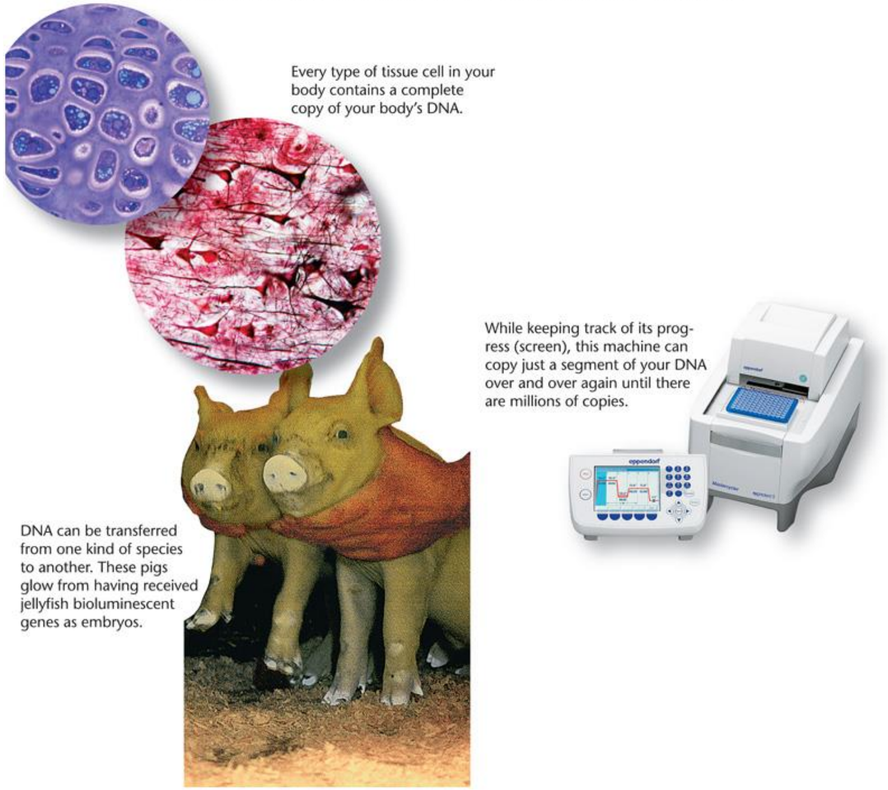

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11.1 DNA and RNA Structure and Function

- The work of Mendel and others provided information about the nature of deoxyribonucleic acid (DNA).
  - Genes occur on chromosomes.
  - Mutations in genes caused metabolic errors.
  - DNA is composed of nucleotides

Structure of DNA

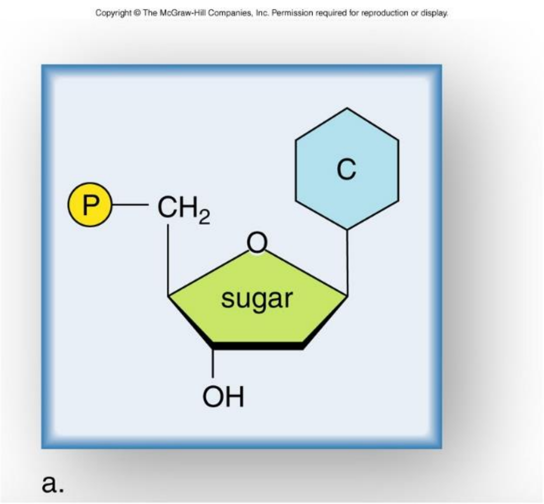
- The research of several scientists helped determine the structure of DNA.
  - Erwin Chargaff
  - Rosalind Franklin
  - James Watson and Frances Crick.

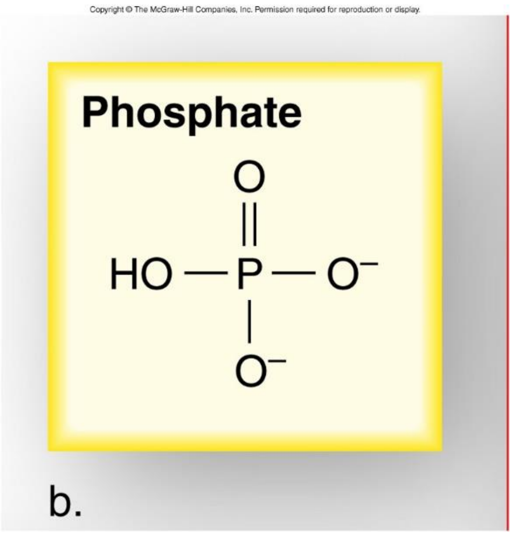
Chargaff's Rules

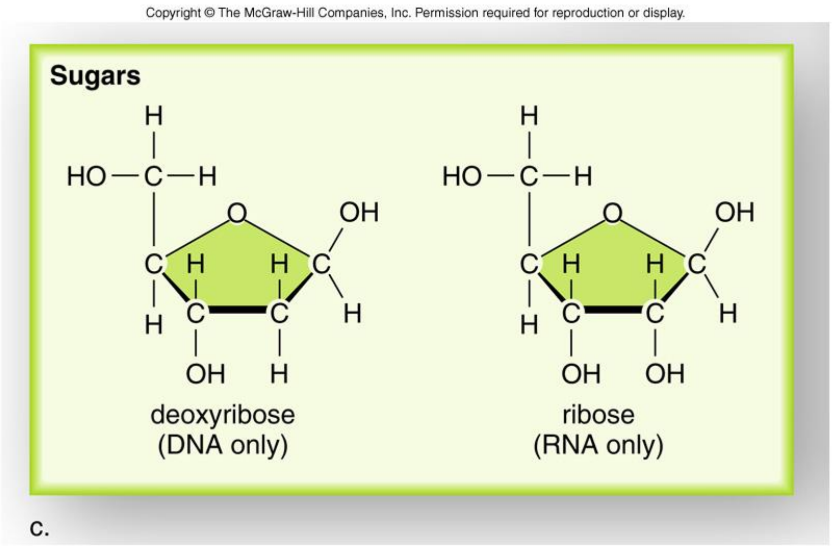
- DNA contains four types of nucleotides,
- Each nucleotide is made of phosphate group, ribose sugar and a nitrogen containing base.
- The nucleotides differ in the nitrogen-containing base each contains.
  - The purine base adenine (A)
  - The pyrimidine base cytosine (C)
  - The purine base guanine (G)
  - The pyrimidine base thymine (T)

- A nucleotide from DNA contains one base, one phosphate group, and the sugar deoxyribose.

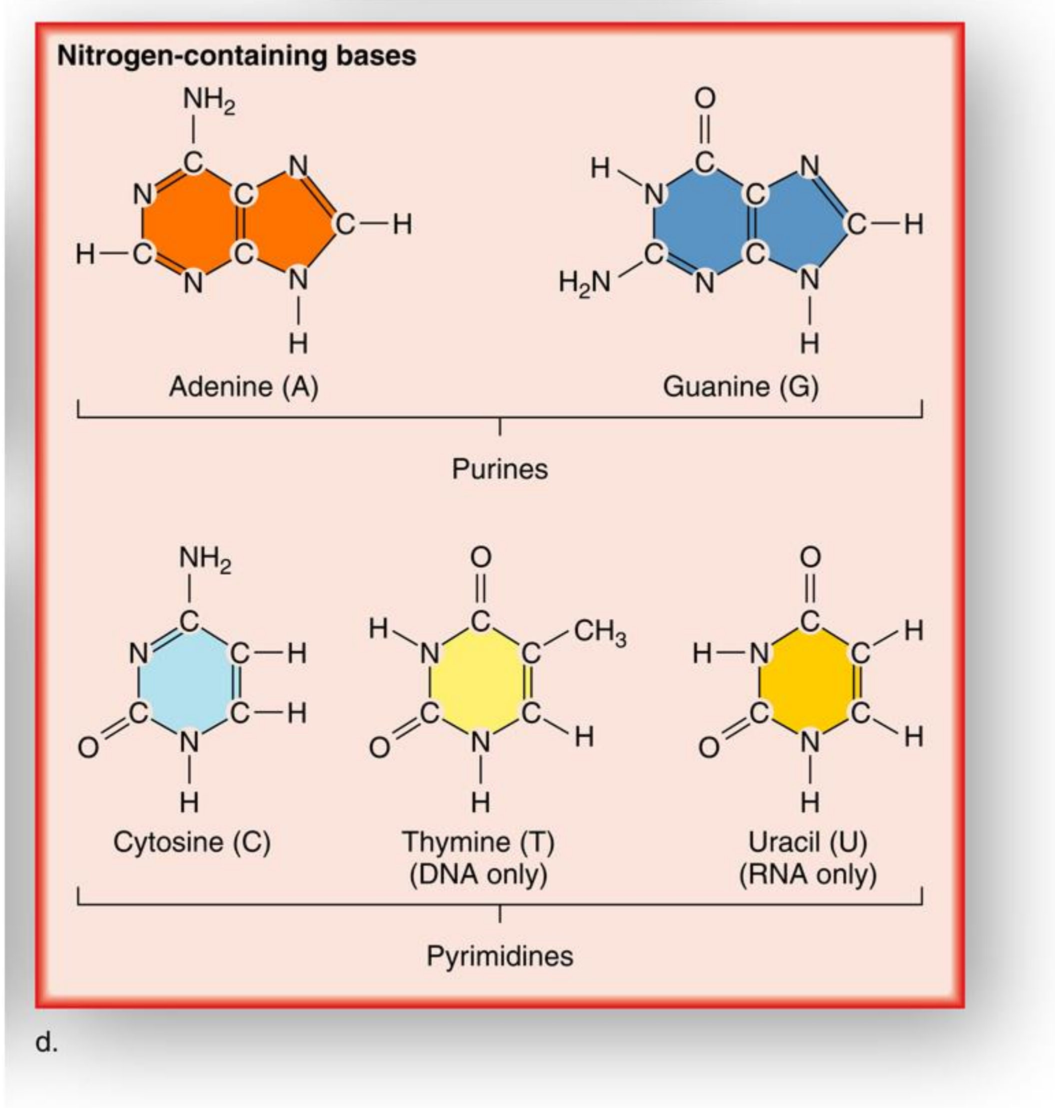
Chargaff's Rules (cont.)







Chargaff's Rules (cont.)



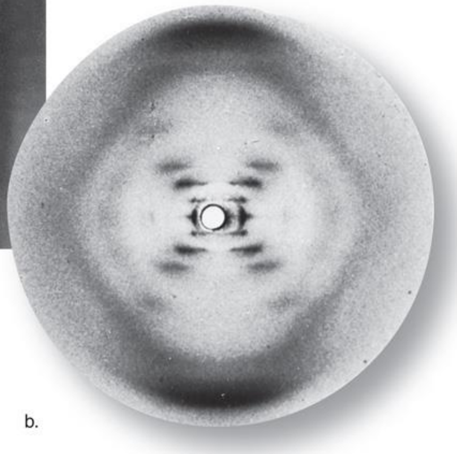
Chargaff’s Rules

- In all organisms, the nucleotide bases are found in specific proportions.
- Chargaff’s rules are based on two observations.
  - The amount of A, C, G, and T varies from species to species.
  - In each species, the amount of A is equal to T and the amount of G is equal to C.
- Equal proportions between two bases indicated that the bases were paired in the structure of DNA.
- The order in which these nucleotides occur differs, producing great variability in the DNA.

Franklin’s X-Ray Diffraction Studies

- Rosalind Franklin used X-ray crystallography to study the structure of DNA.
- The X-ray diffraction pattern suggested that DNA had a helical shape.

a.

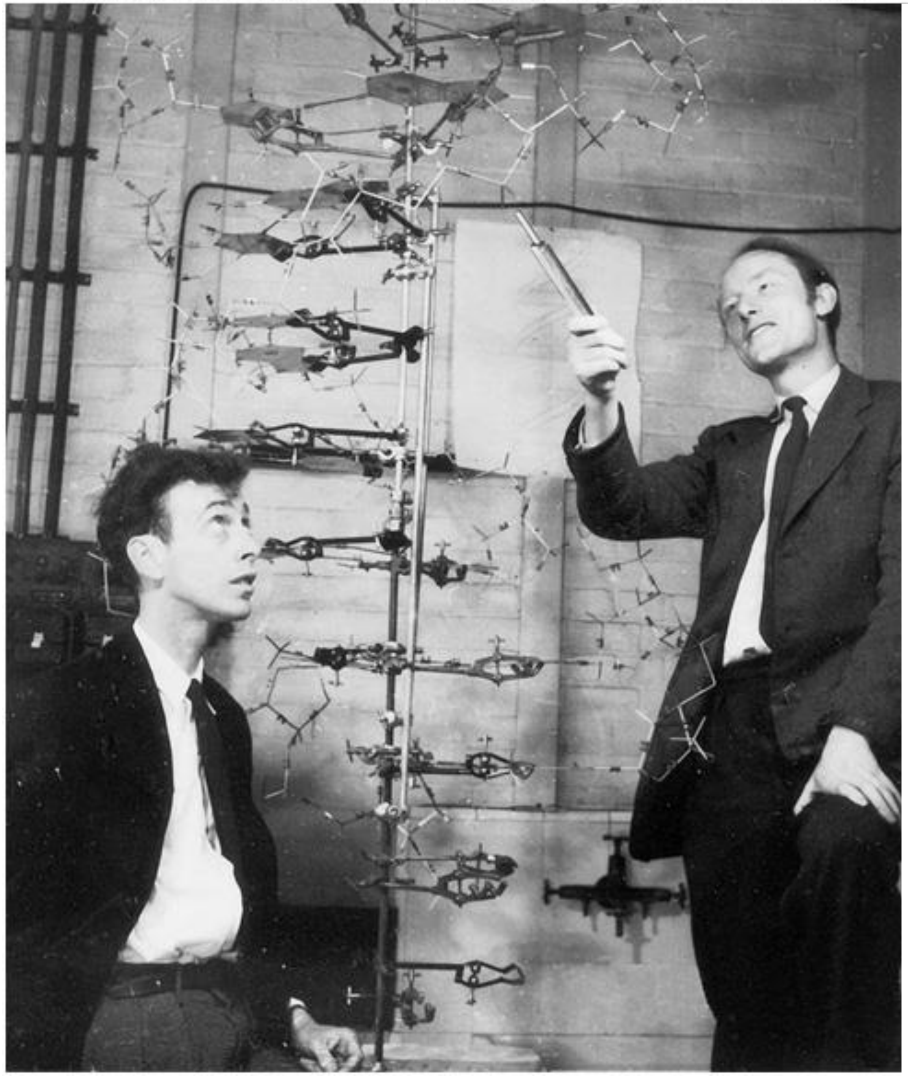


b.

The Watson and Crick Model

- Watson and Crick developed the definitive model of DNA structure.
  - The sugar and phosphate groups are bonded in alternating sequences to form the sides of a twisted ladder (the backbone).
  - Bases are joined by hydrogen bonds to form the rungs of the ladder.
  - Complementary base pairing occurs, meaning A only bonds with T and G with C.

The Watson and Crick Model



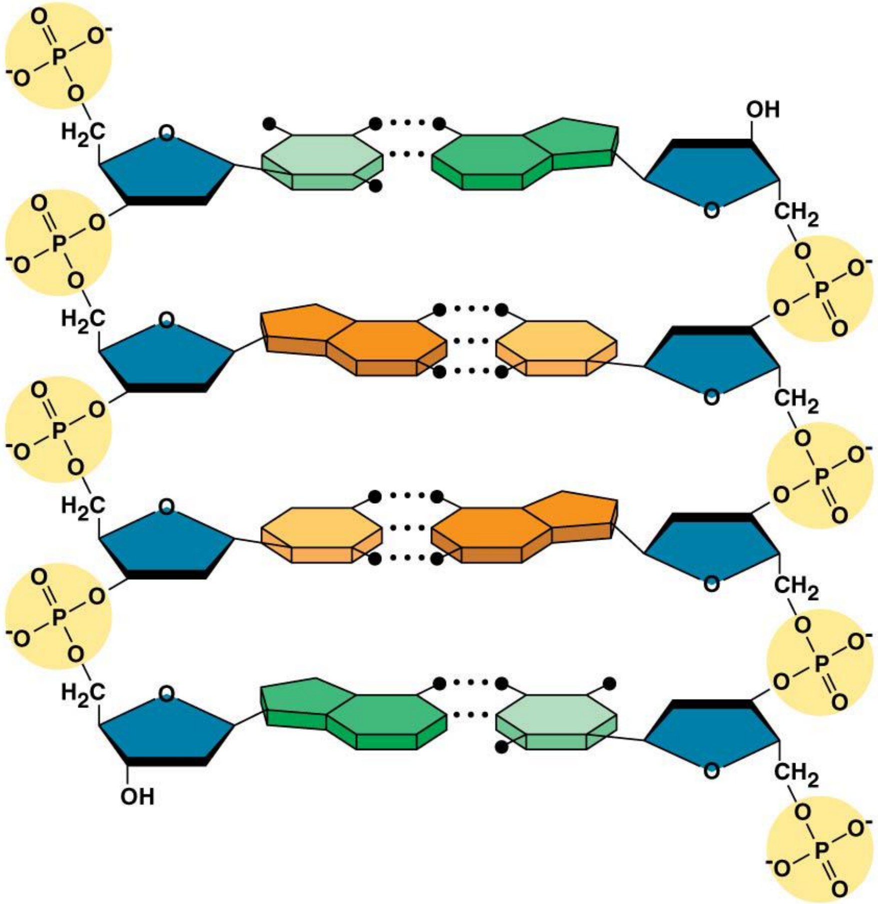
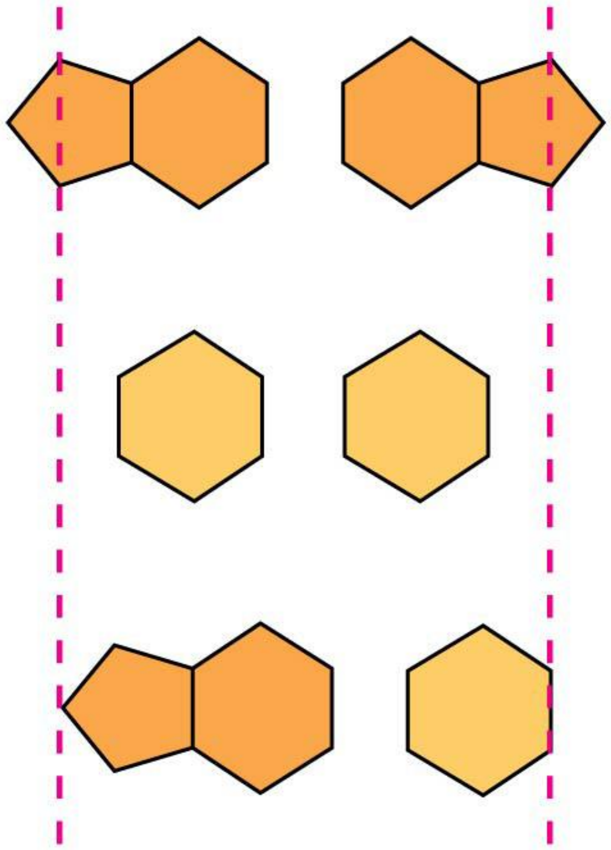


Figure 16.UN02



Purine + purine: too wide

Pyrimidine + pyrimidine: too narrow

Purine + pyrimidine: width consistent with X-ray data

The Replication of DNA

- DNA replication is the process of copying a DNA molecule.
- During replication, the original strands serve as templates for the new DNA.
- DNA replication is considered semiconservative because one of the original strands is present in each new DNA helix.

Figure 16.10

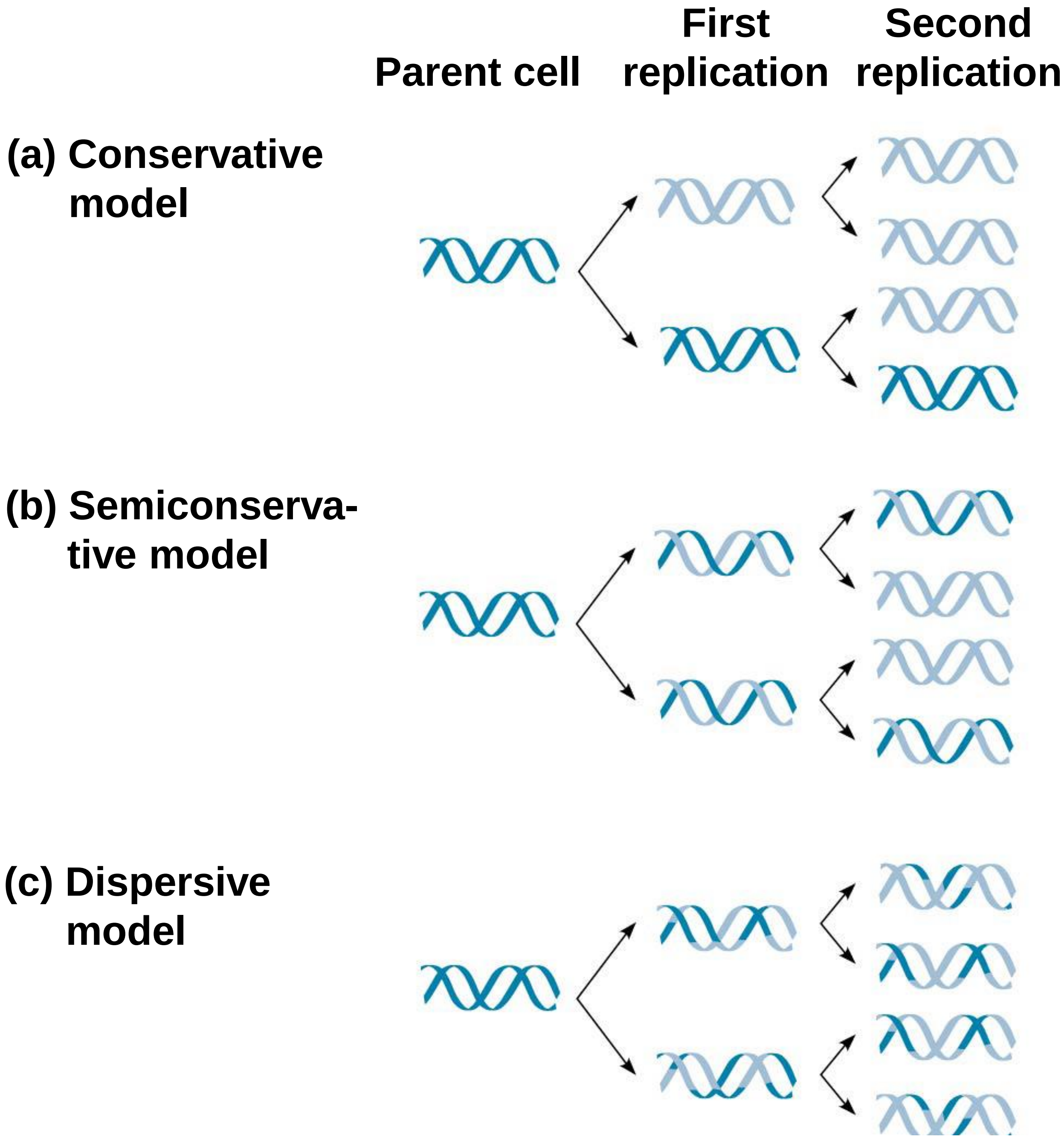
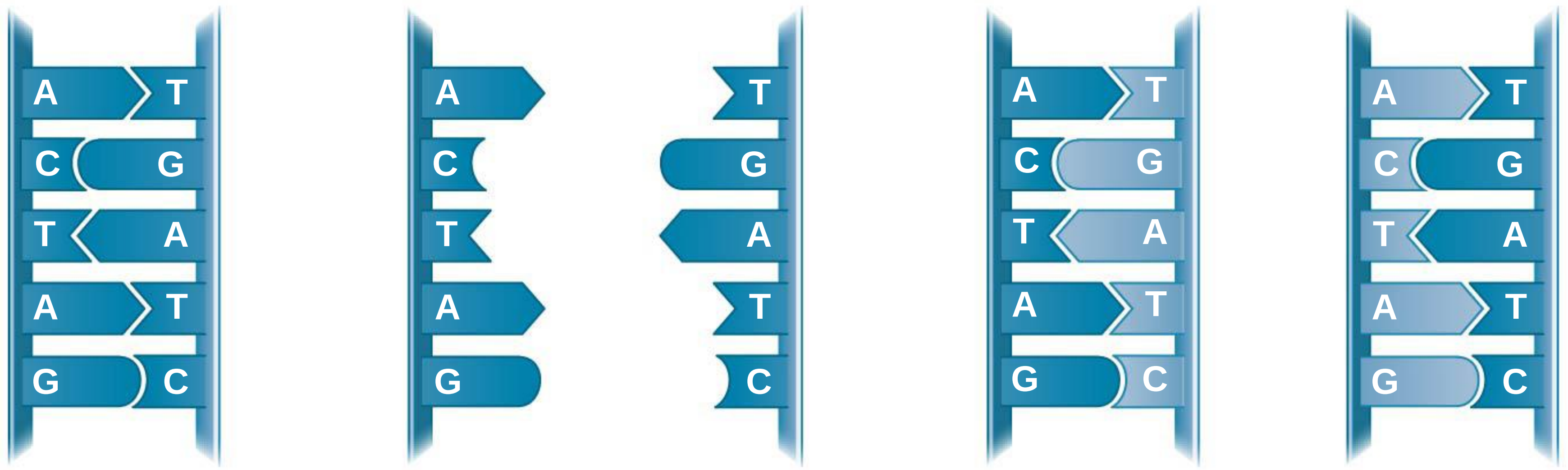

Parent cell
First replication
Second replication
(a) Conservative model
(b) Semiconservative model
(c) Dispersive model

Figure 16.9-3

The Replication of DNA



(a) Parental molecule

(b) Separation of parental strands into templates

(c) Formation of new strands complementary to template strands

The Replication of DNA (cont.)

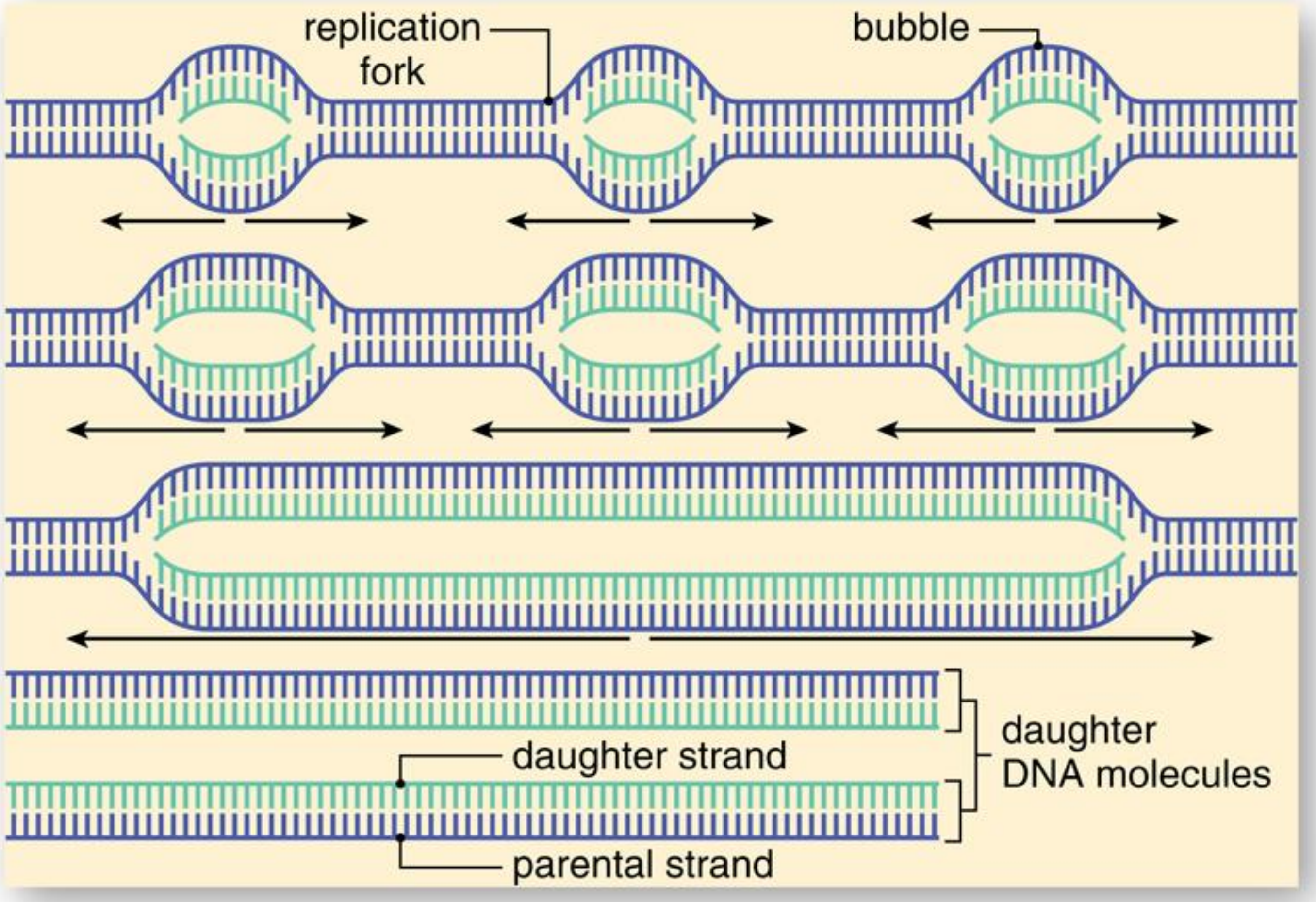
- DNA replication requires several steps, each requires certain enzymes.
  - The enzyme helicase unwinds (opens) the old strands of the DNA helix.
  - New nucleotides are added by complementary base pairing by the enzyme DNA polymerase.
  - DNA ligase repairs breaks in the backbone.

The Replication of DNA (cont.)

- In eukaryotic cells, DNA replication is initiated at multiple points along the DNA strand, or origins of replication.

- The replication bubbles spread bidirectionally until they meet.

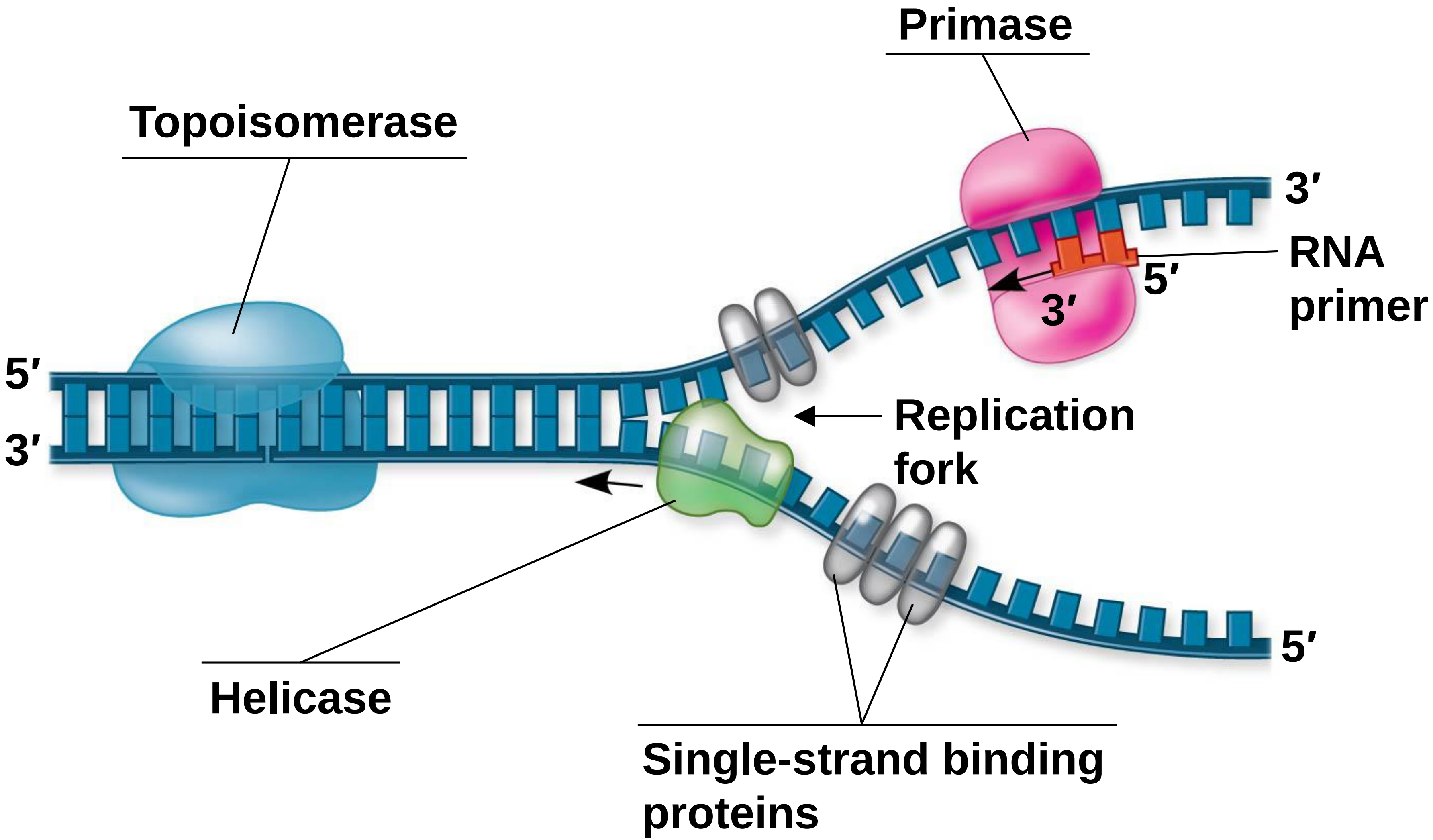
The Replication of DNA



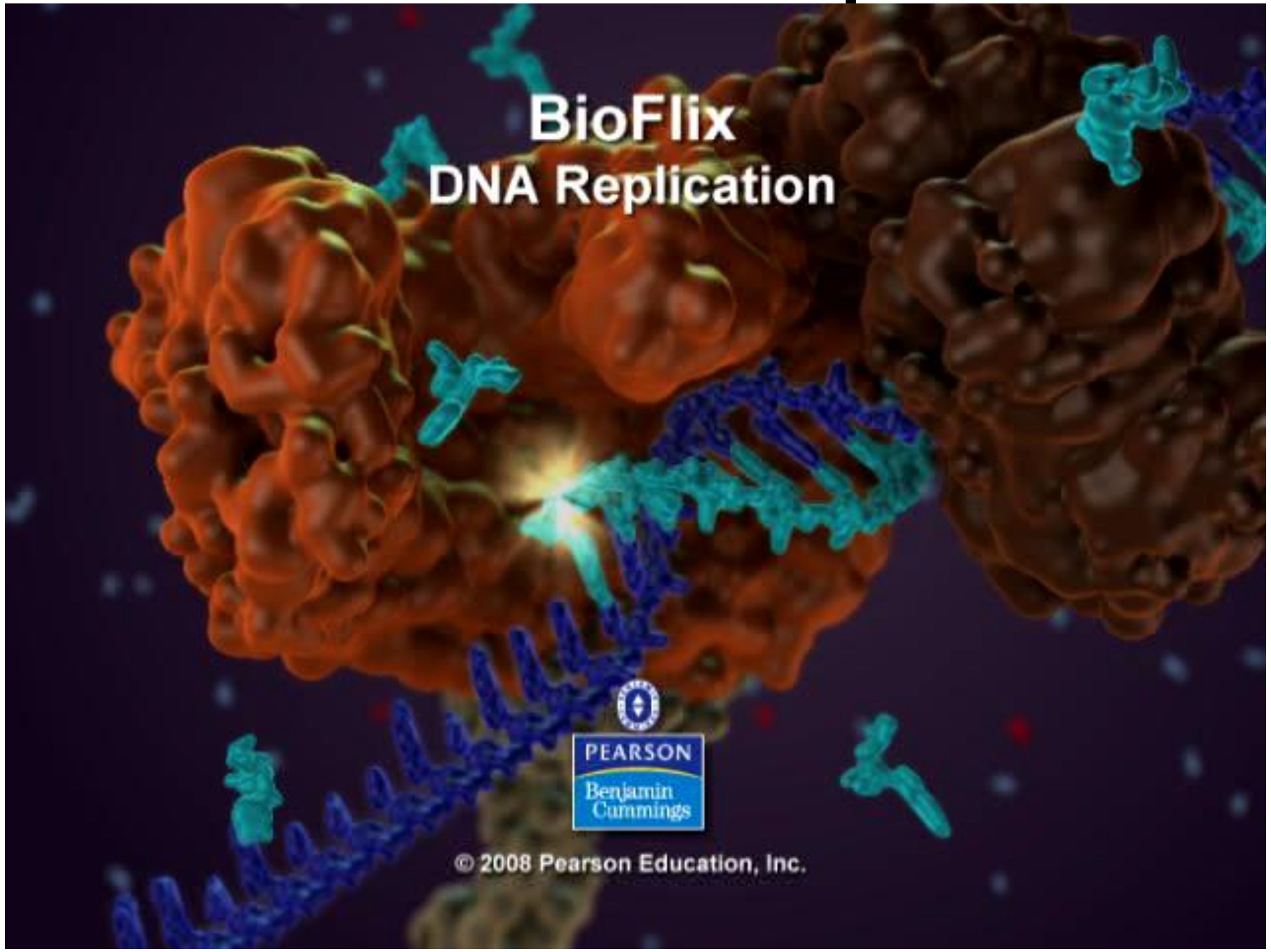
- At the end of each replication bubble is a **replication fork**, a Y-shaped region where new DNA strands are elongating
- **Helicases** are enzymes that untwist the double helix at the replication forks
- **Single-strand binding proteins** bind to and stabilize single-stranded DNA
- **Topoisomerase** corrects "overwinding" ahead of replication forks by breaking, swiveling, and rejoining DNA strands

- DNA polymerases cannot initiate synthesis of a polynucleotide; they can only add nucleotides to an existing 3′ end
- An enzyme called **primase** can start an RNA chain from scratch and adds RNA nucleotides one at a time using the parental DNA as a template
- The initial nucleotide strand is a short RNA **primer. Its** is short (5–10 nucleotides long), and the 3′ end serves as the starting point for the new DNA strand.
- Now, DNA polymerase can continue building the strand using DNA nucleotides.

Figure 16.13

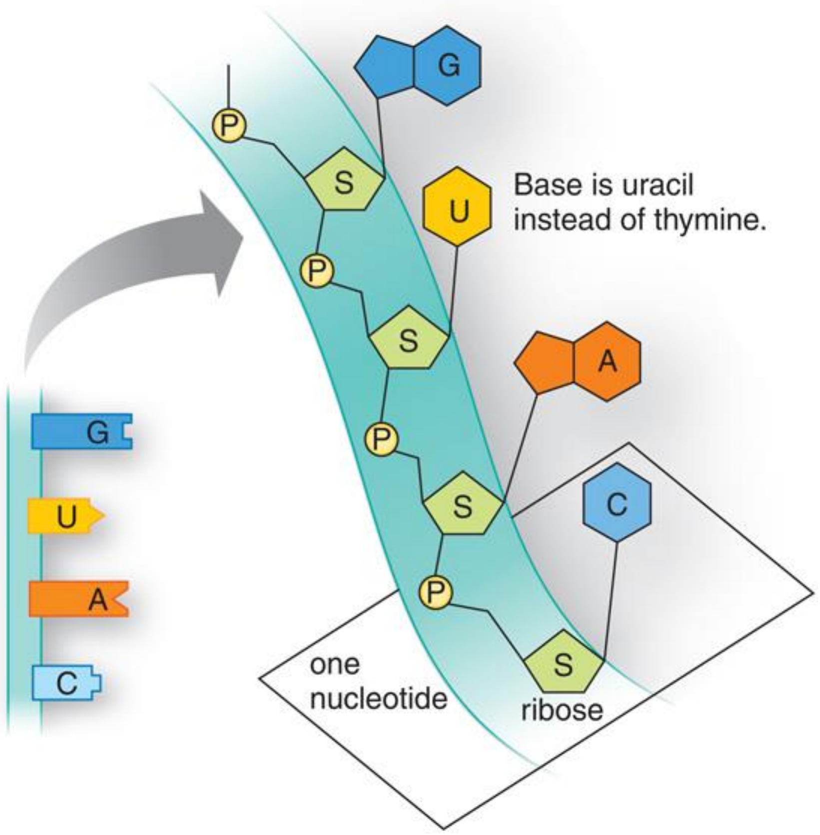

Primase
Topoisomerase
3′
RNA primer
5′
3′
5′
3′
Replication fork
Helicase
Single-strand binding proteins
5′

BioFlix: DNA Replication



RNA Structure and Function

- Ribonucleic acid (RNA) also consists of nucleotides, but these nucleotides contain the sugar ribose.
- RNA has adenine, cytosine, guanine, and a fourth base called uracil.
- There are three types of RNA and each is involved in protein synthesis.



Messenger RNA

- Messenger RNA (mRNA) is produced in the nucleus by a process called transcription.

- Messenger RNA carries genetic information from DNA to the cytosol.

Transfer RNA

- Transfer RNA (tRNA) is a carrier molecule for amino acids, delivering them to the site of protein synthesis.

- As there are 20 different amino acids, there are also 20 different types of tRNA.

Ribosomal RNA

- The ribosomal RNA (rRNA) is used along with proteins to synthesize the small ribosomal subunit and the large ribosomal subunit in the nucleus, then these 2 subunits are joined together in the cytosol to form the ribosomes.
- All forms of ribosomes (free ribosomes, polyribosomes, and ribosomes attached to the ER) all synthesize proteins.

Gene Expression

- **Gene expression**, the process by which DNA directs protein synthesis, includes two stages: transcription and translation

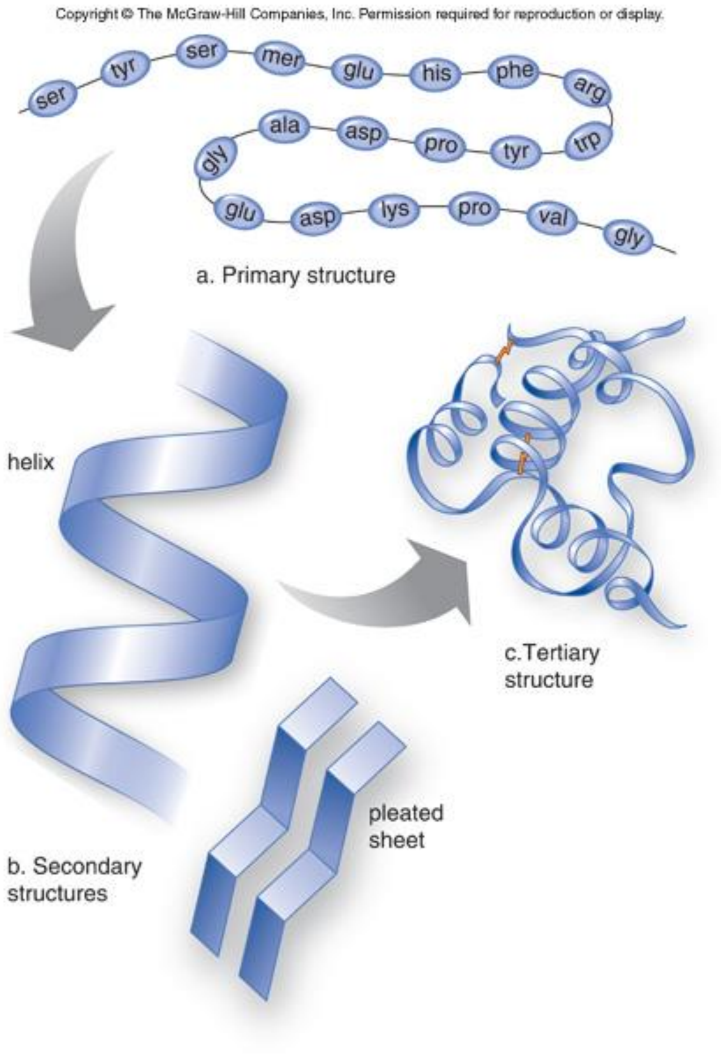
- DNA and RNA are involved in the synthesis of proteins.

- The genes in DNA contain the instructions for the amino acid sequence of a protein.

Structure and Function of Proteins

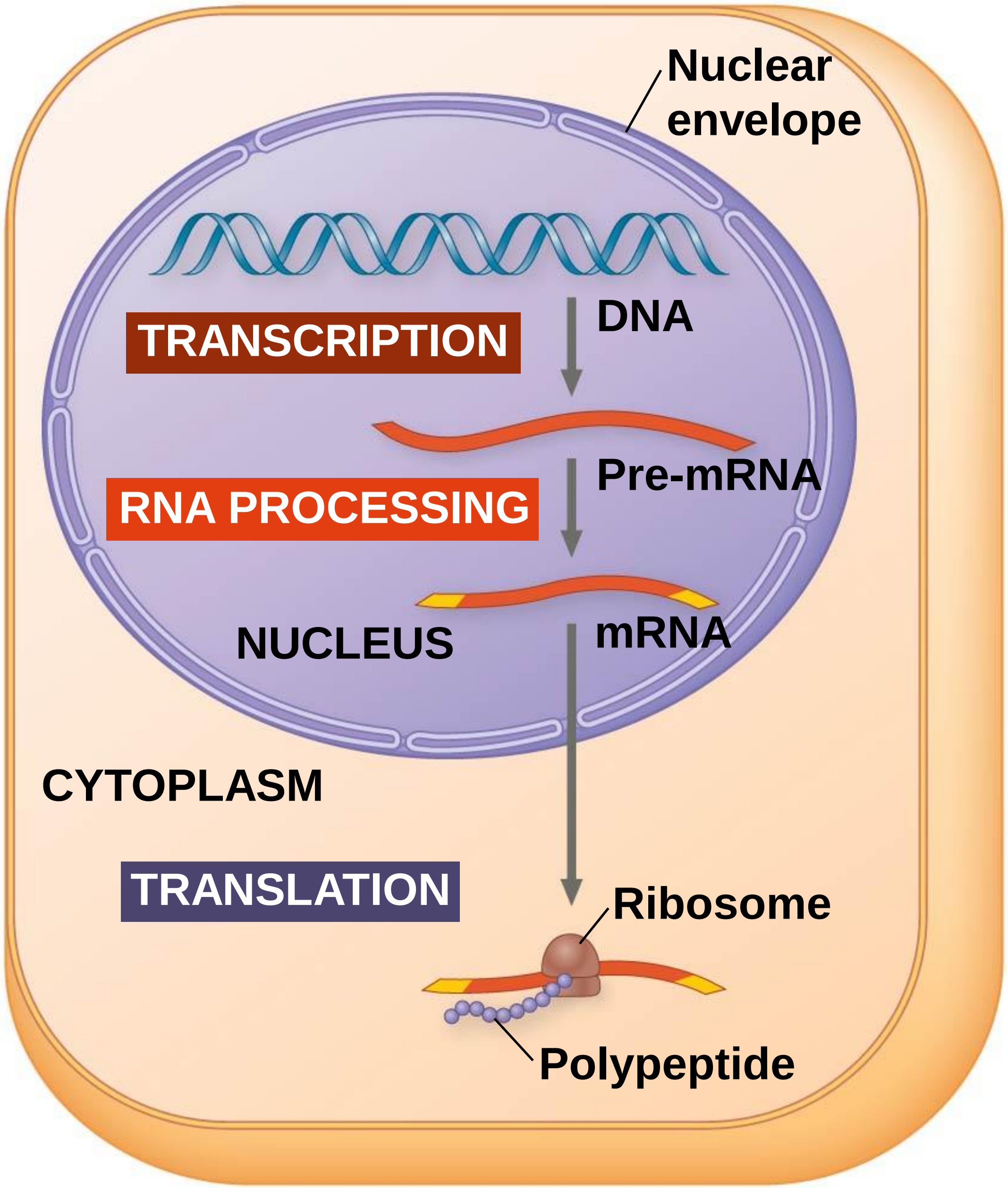
- Remember than proteins are polymers made of monomers called amino acids, joined together by peptide bonds.
- Proteins differ in the number and sequence of amino acids.
- This sequence of amino acids gives each protein a unique shape and function.
- The shape of a protein has different levels of organization.
  - Primary structure
  - Secondary structure
  - Tertiary structure

Structure and Function of Proteins (cont.)



From DNA to RNA to Protein

- In order to synthesize a protein, the genetic information in the DNA must be converted to an amino acid sequence.
- Transcription involves the synthesis of mRNA from template DNA.
- During translation, the mRNA directs the sequence of amino acids in the protein.

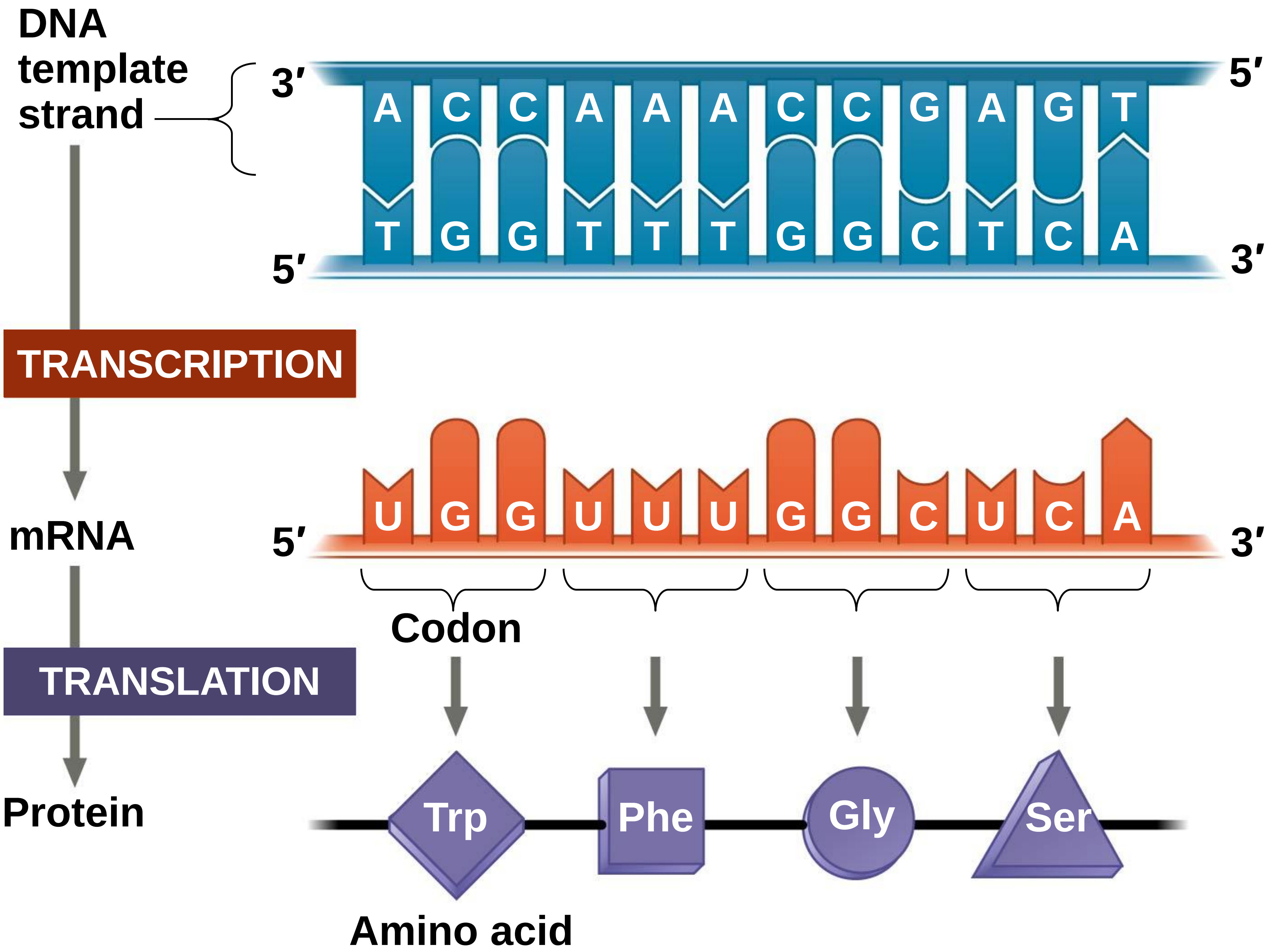

Nuclear envelope
DNA
TRANSCRIPTION
Pre-mRNA
RNA PROCESSING
mRNA
NUCLEUS
CYTOPLASM
TRANSLATION
Ribosome
Polypeptide

The Genetic Code

- Within a gene, information for the amino acid sequence of a protein is encoded in a triplet code.

- This triplet code is transcribed into the codons in mRNA.

- These codons provide redundant sequences for the placement of amino acids in a protein.


DNA template strand
3′
5′
A C C A A A C C G A G T
T G G T T T G G C T C A
5′
3′
TRANSCRIPTION
mRNA
5′
U G G U U U G G C U C A
3′
Codon
TRANSLATION
Protein
Trp
Phe
Gly
Ser
Amino acid

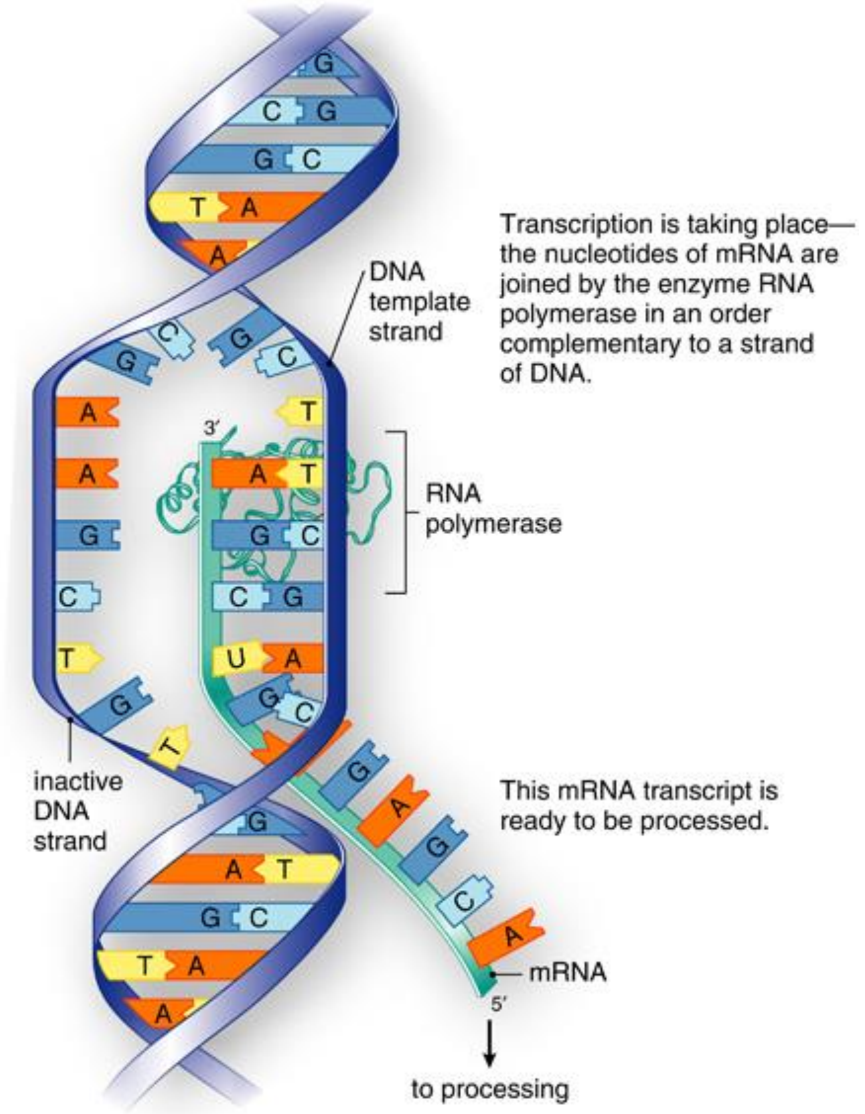
The Genetic Code (cont.)

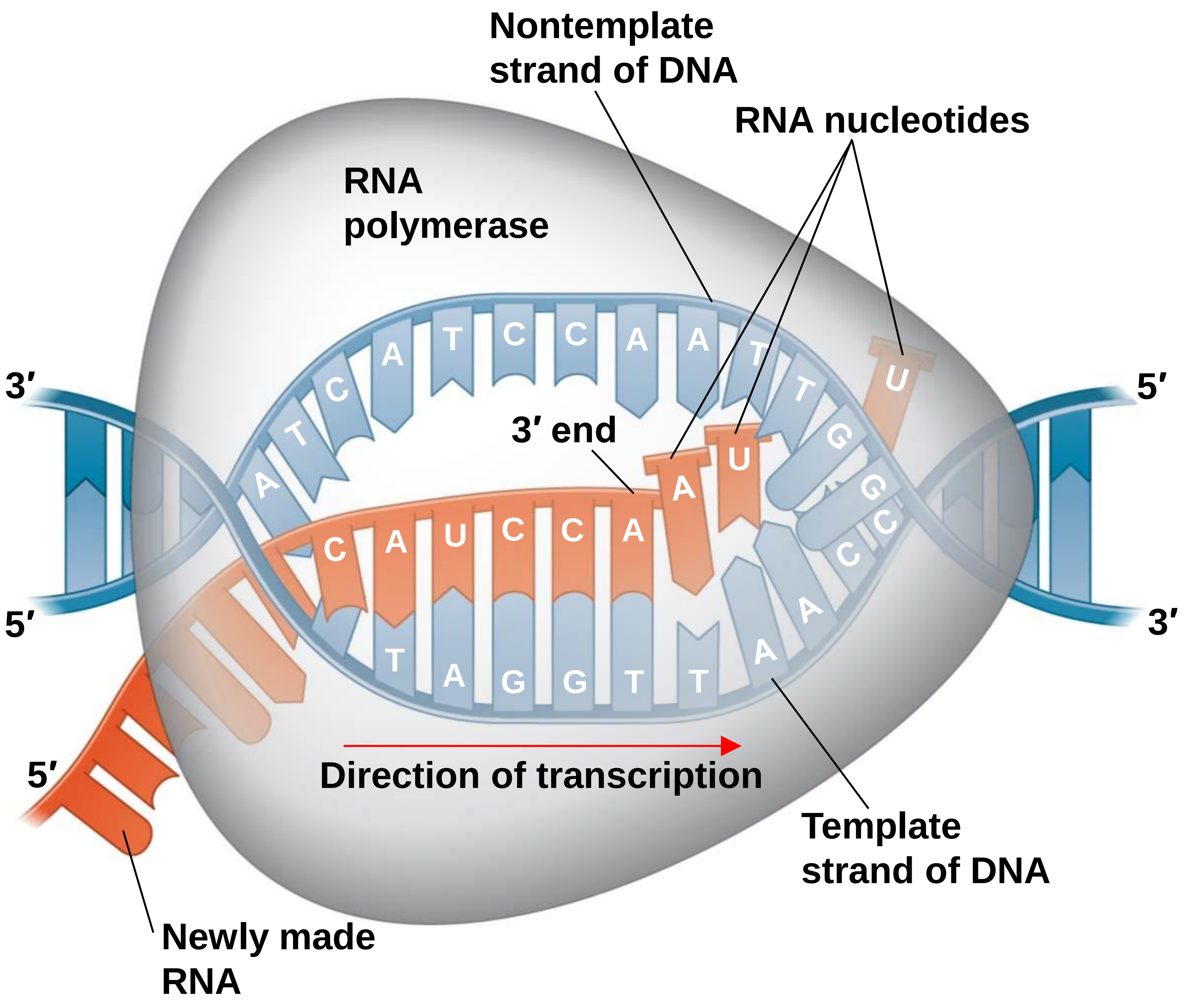
Second base

First base	U	C	A	G	Third base
U	UUU, UUC – phenylalanine (phe) UUA, UUG – leucine (leu)	UCU, UCC, UCA, UCG – serine (ser)	UAU, UAC – tyrosine (tyr) UAA **stop** UAG **stop**	UGU, UGC – cysteine (cys) UGA **stop** UGG tryptophan (trp)	U C A G
C	CUU, CUC, CUA, CUG – leucine (leu)	CCU, CCC, CCA, CCG – proline (pro)	CAU, CAC – histidine (his) CAA, CAG – glutamine (gln)	CGU, CGC, CGA, CGG – arginine (arg)	U C A G
A	AUU, AUC, AUA – isoleucine (ile) AUG methionine (met) (**start**)	ACU, ACC, ACA, ACG – threonine (thr)	AAU, AAC – asparagine (asn) AAA, AAG – lysine (lys)	AGU, AGC – serine (ser) AGA, AGG – arginine (arg)	U C A G
G	GUU, GUC, GUA, GUG – valine (val)	GCU, GCC, GCA, GCG – alanine (ala)	GAU, GAC – aspartic acid (asp) GAA, GAG – glutamic acid (glu)	GGU, GGC, GGA, GGG – glycine (gly)	U C A G

Transcription

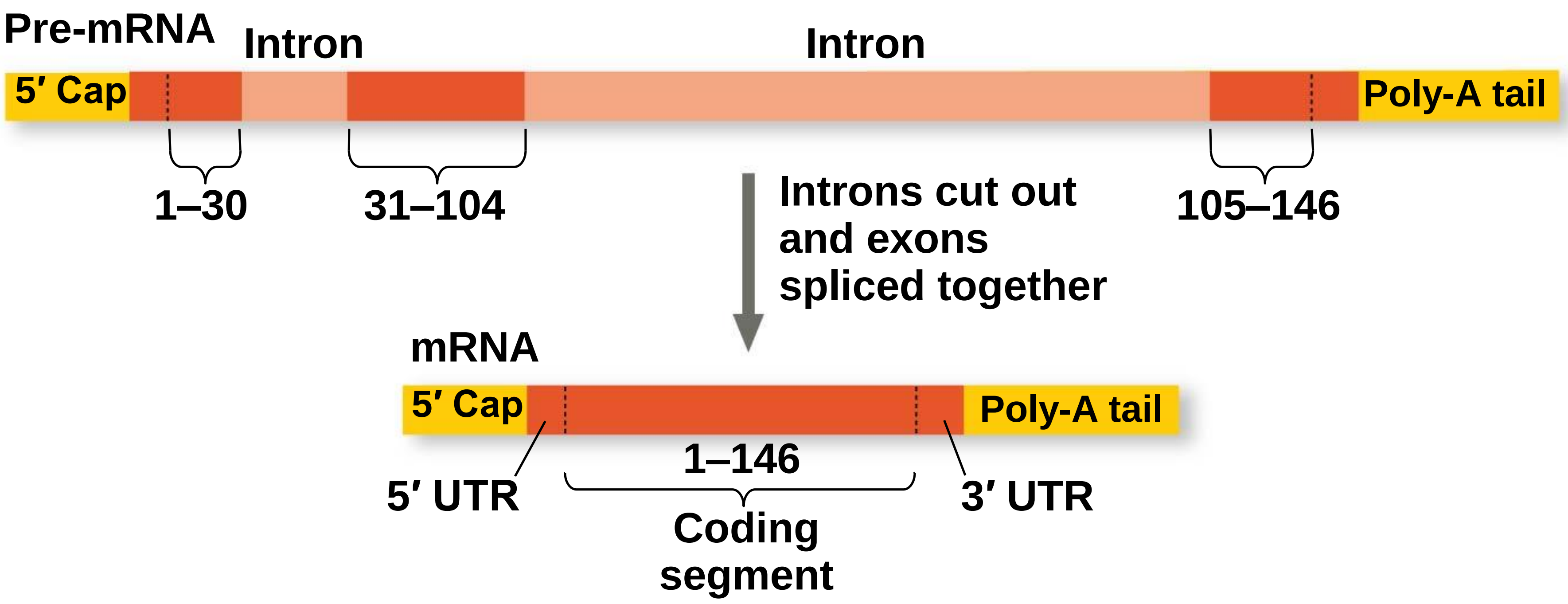
- During transcription, a strand of mRNA is formed that is complementary to the sequence within the DNA.
- Transcription begins when RNA polymerase binds to the DNA promoter for a gene. It untwists the DNA and adds new RNA nucleotides (does not need any primer)
- The RNA is complementary to the DNA template strand




Nontemplate strand of DNA
RNA nucleotides
RNA polymerase
3′
5′
3′ end
5′
3′
5′
Direction of transcription
Template strand of DNA
Newly made RNA
A T C A T C C A A T T G G
C A U C C A A U U
T A G G T T A A C C

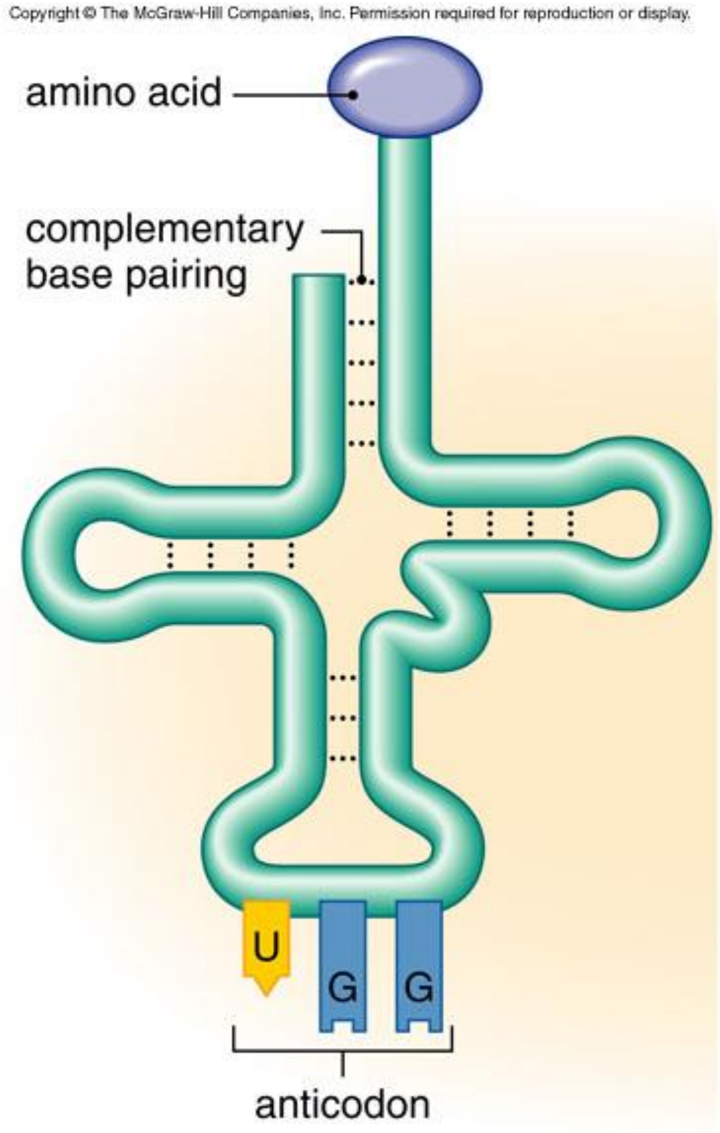
- RNA synthesis follows the same base-pairing rules as DNA, except that uracil substitutes for thymine.
- The resulting mRNA is called:primary mRNA.
- The primary mRNA undergoes modifications called “mRNA Processing”
- Parts of primary mRNA are cut out (they are called introns), then the remaining parts (called exons) are joined together.
- The 5′ end receives a modified nucleotide 5′ cap and the 3′ end gets a poly-A tail.
- Now, we have mature mRNA

Figure 17.11


Pre-mRNA
Intron
Intron
5′ Cap
Poly-A tail
1–30
31–104
105–146
Introns cut out and exons spliced together
mRNA
5′ Cap
Poly-A tail
1–146
5′ UTR
3′ UTR
Coding segment

Translation: An Overview

- The translation of a mature mRNA into proteins requires several enzymes, tRNA, and rRNA.
- The tRNA is a single-stranded RNA molecule with an amino acid bound to one end and an anticodon on the other end.



a. tRNA–amino acid

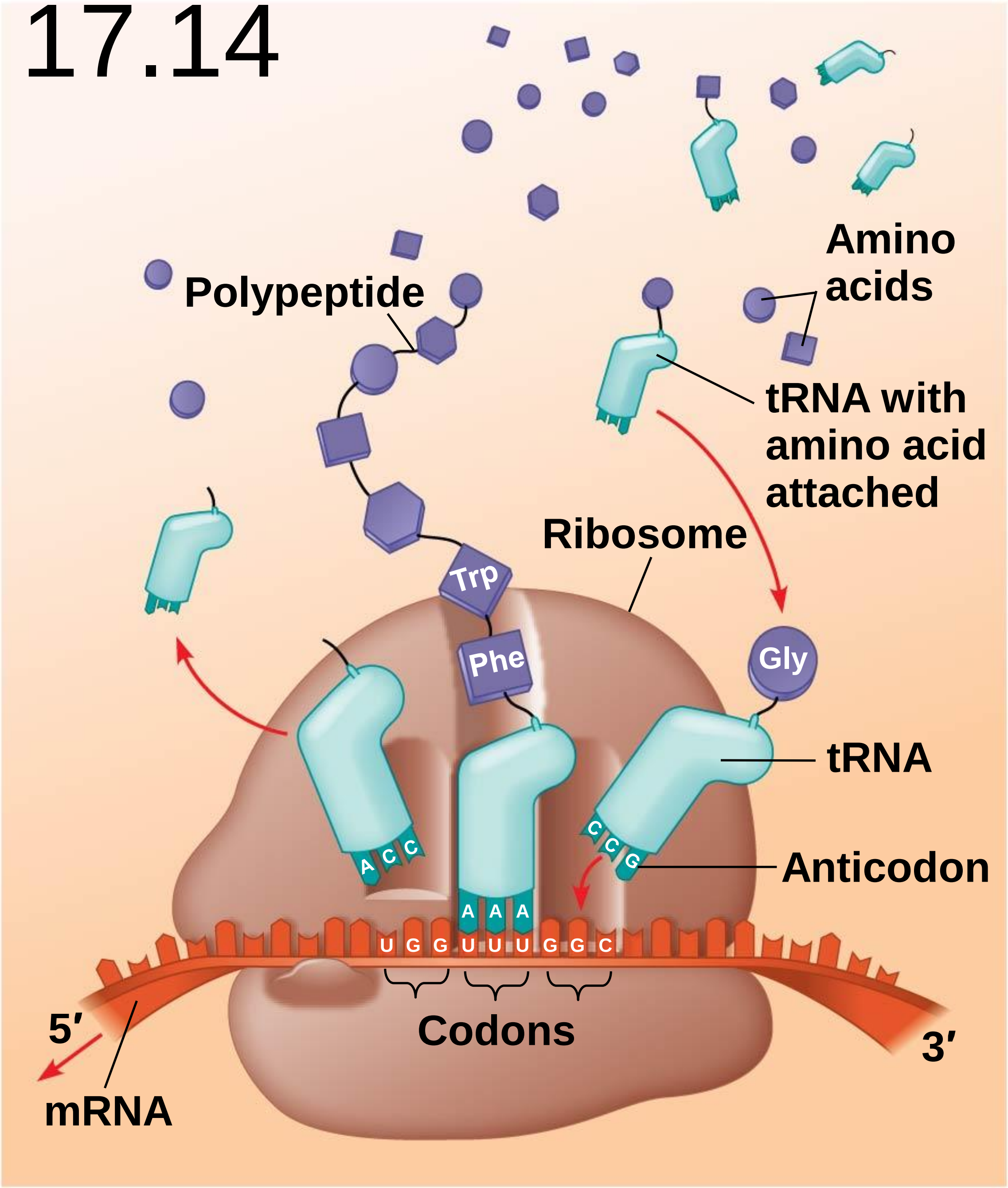
Translation: An Overview (cont.)

- The anticodon is complementary to the corresponding mRNA codon.

- As a mature mRNA moves to a ribosome, the sequence of codons in the mRNA dictates the sequence of anticodons.

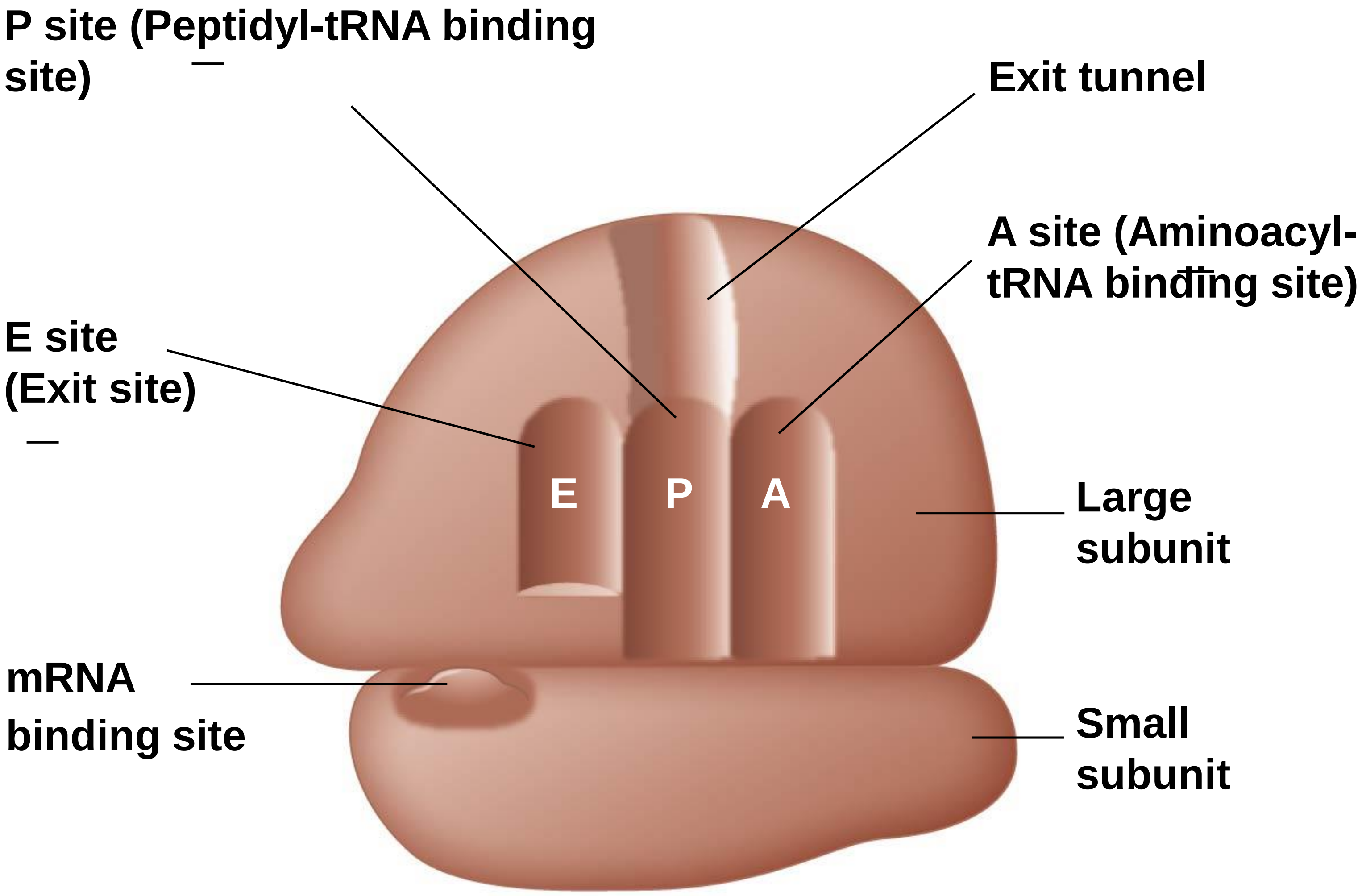
- The order of the tRNA molecules determines the order of the amino acids.

Figure 17.14

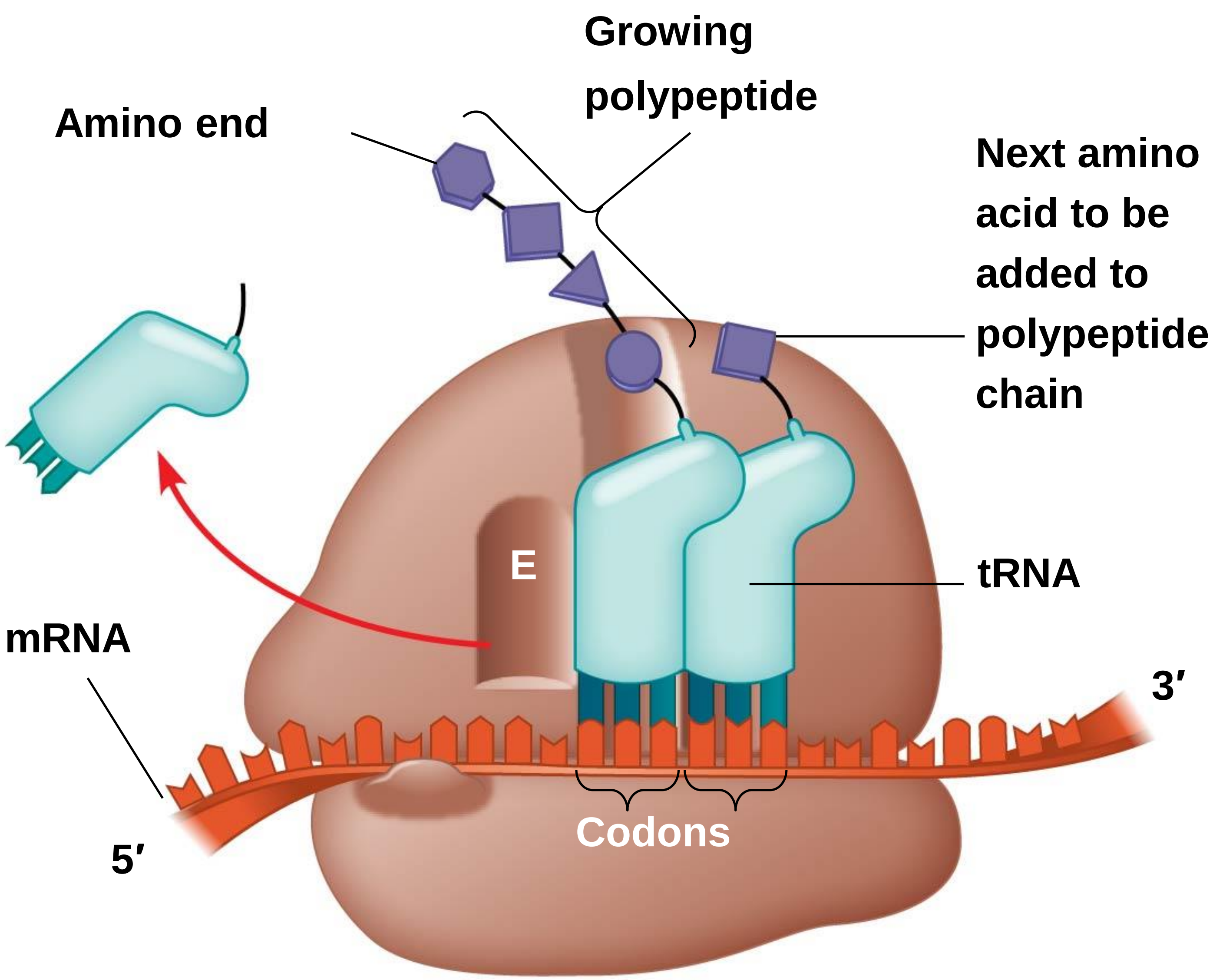


Polypeptide
Amino acids
tRNA with amino acid attached
Ribosome
Trp
Phe
Gly
tRNA
Anticodon
A C C
A A A
C C G
U G G U U U G G C
Codons
5′
3′
mRNA

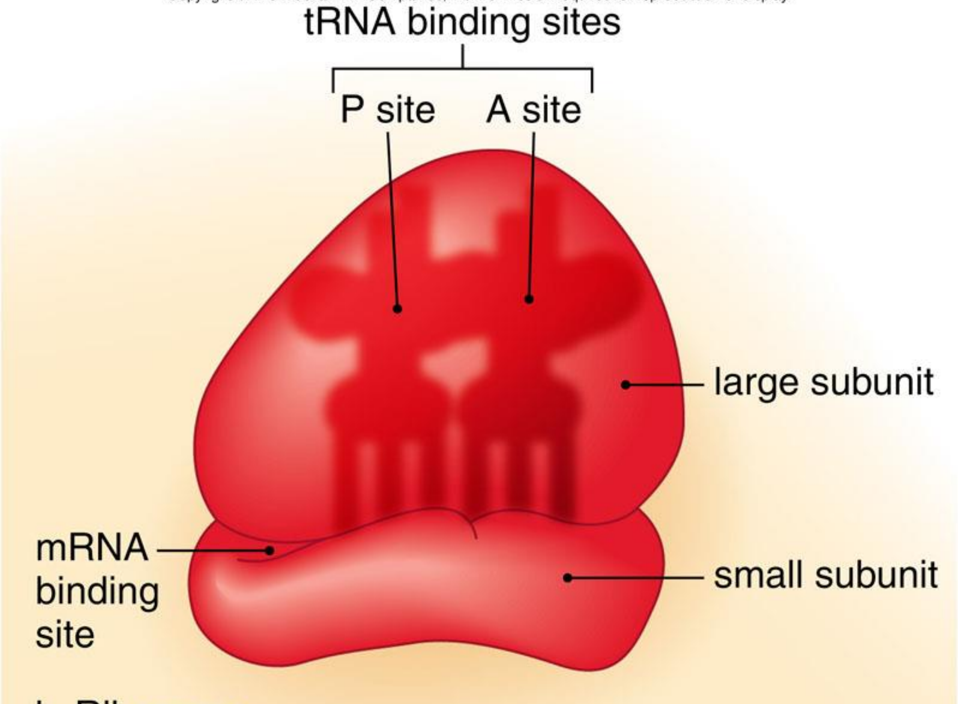
- A ribosome has three binding sites for tRNA
  - The **P site** holds the tRNA that carries the growing polypeptide chain
  - The **A site** holds the tRNA that carries the next amino acid to be added to the chain
  - The **E site** is the exit site, where discharged tRNAs leave the ribosome



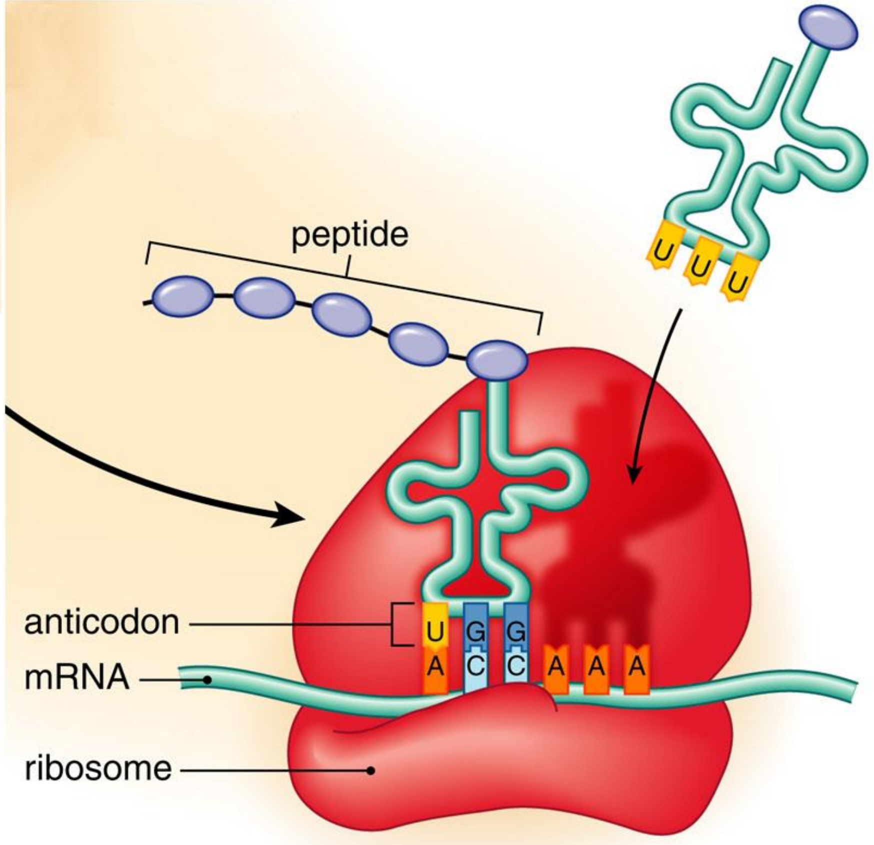
(b) Schematic model showing binding sites



(c) Schematic model with mRNA and tRNA



b. Ribosome



c. tRNA–amino acid at ribosome

Translation Has Three Phases

- Three stages of translation:

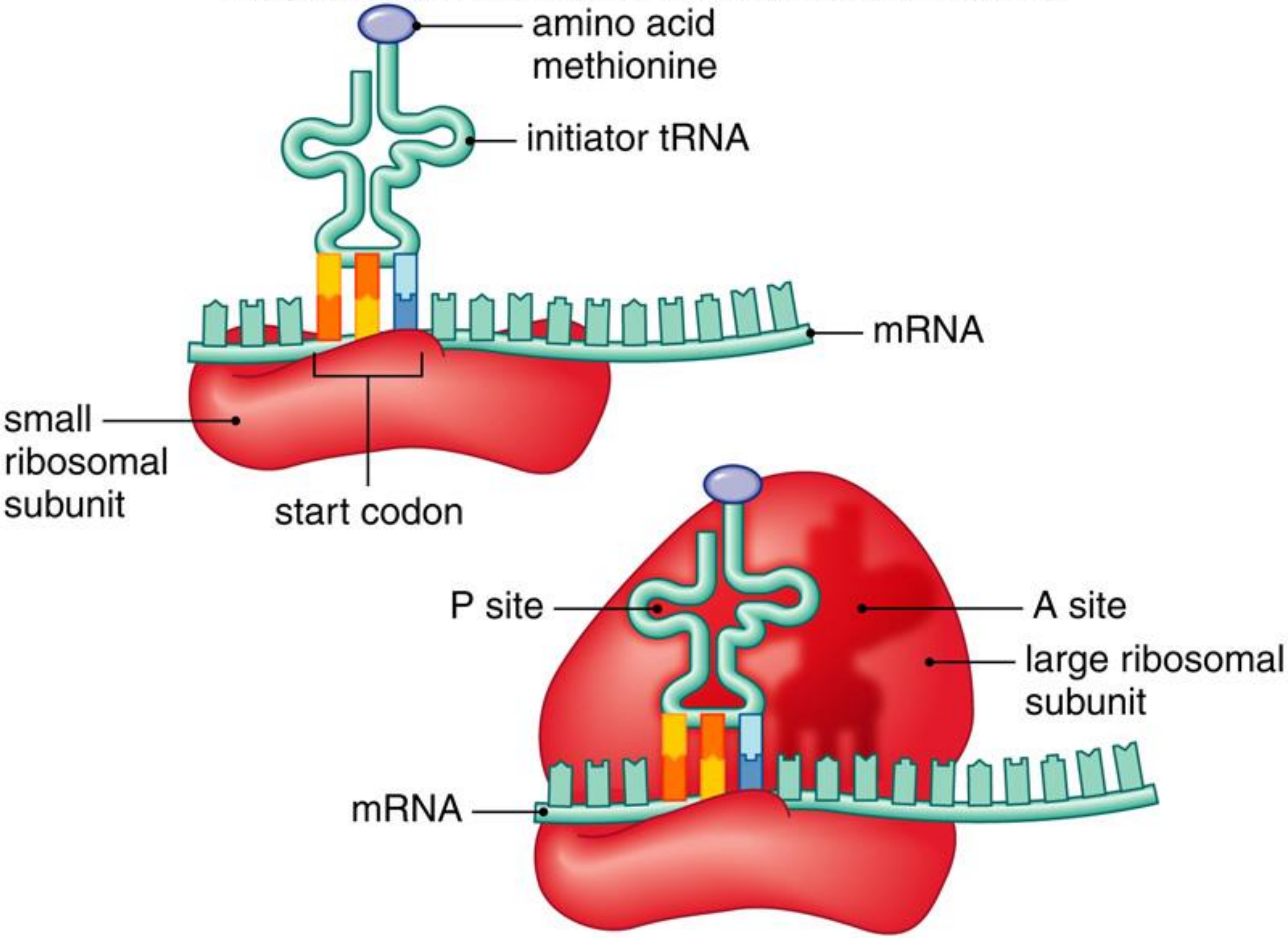
1- Initiation

2- Elongation

3- Termination

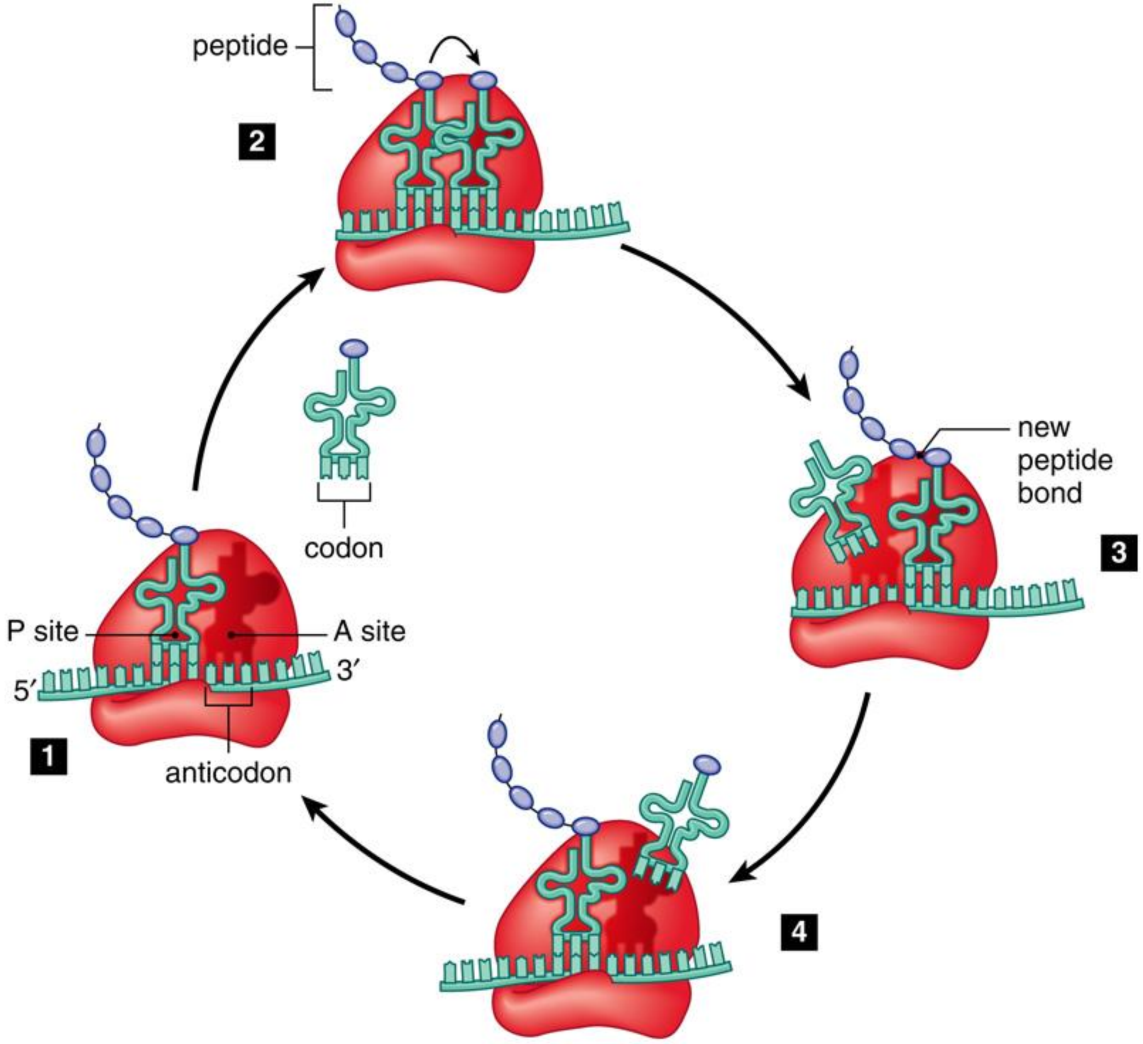
- In initiation, the small ribosomal subunit, large ribosomal subunit, the mRNA.Then the small subunit moves along the mRNA until it reaches the start codon (AUG), then a tRNA carrying a methionine bond to the mRNA to start transcription.

First Step: Initiation



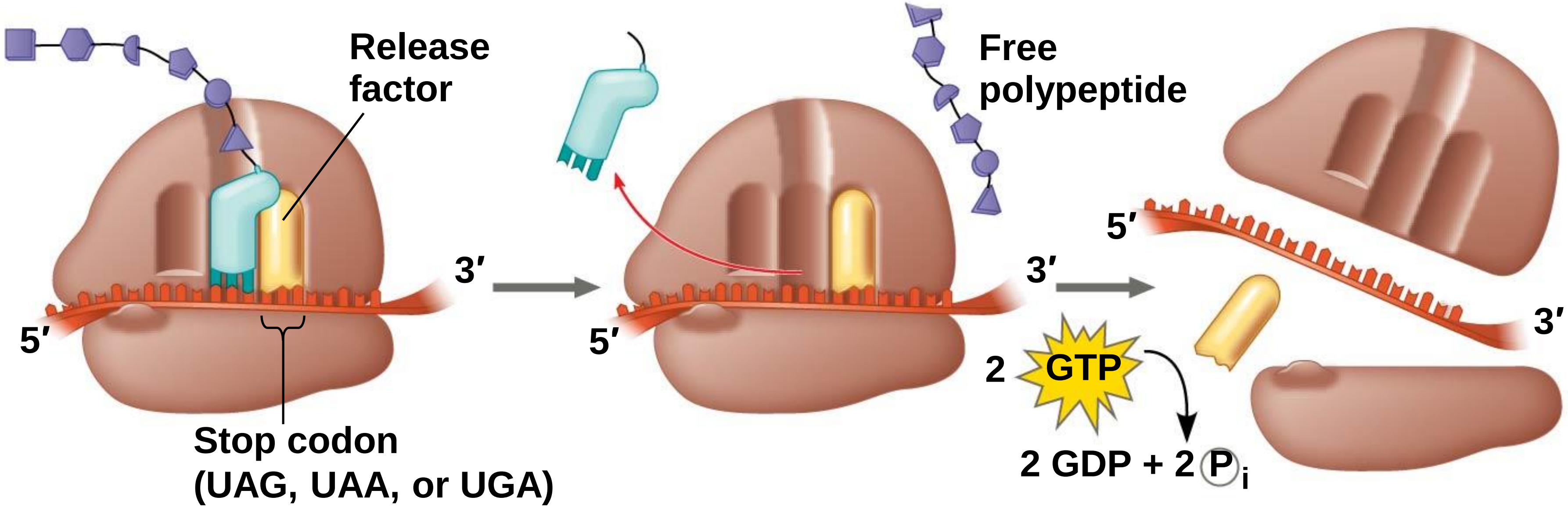
- During elongation, amino acids are added one by one to the growing polypeptide chain.
- Each addition involves three steps: codon recognition, peptide bond formation, and translocation

Second Step: Elongation



- • Termination occurs when protein synthesis is completed. A stop codon in the mRNA reaches the A site of the ribosome.
- Instead of tRNA, the A site accepts a protein called a release factor
- The release factor causes the addition of a water molecule instead of an amino acid
- This reaction releases the polypeptide, and the translation assembly comes apart

Step Three: Termination

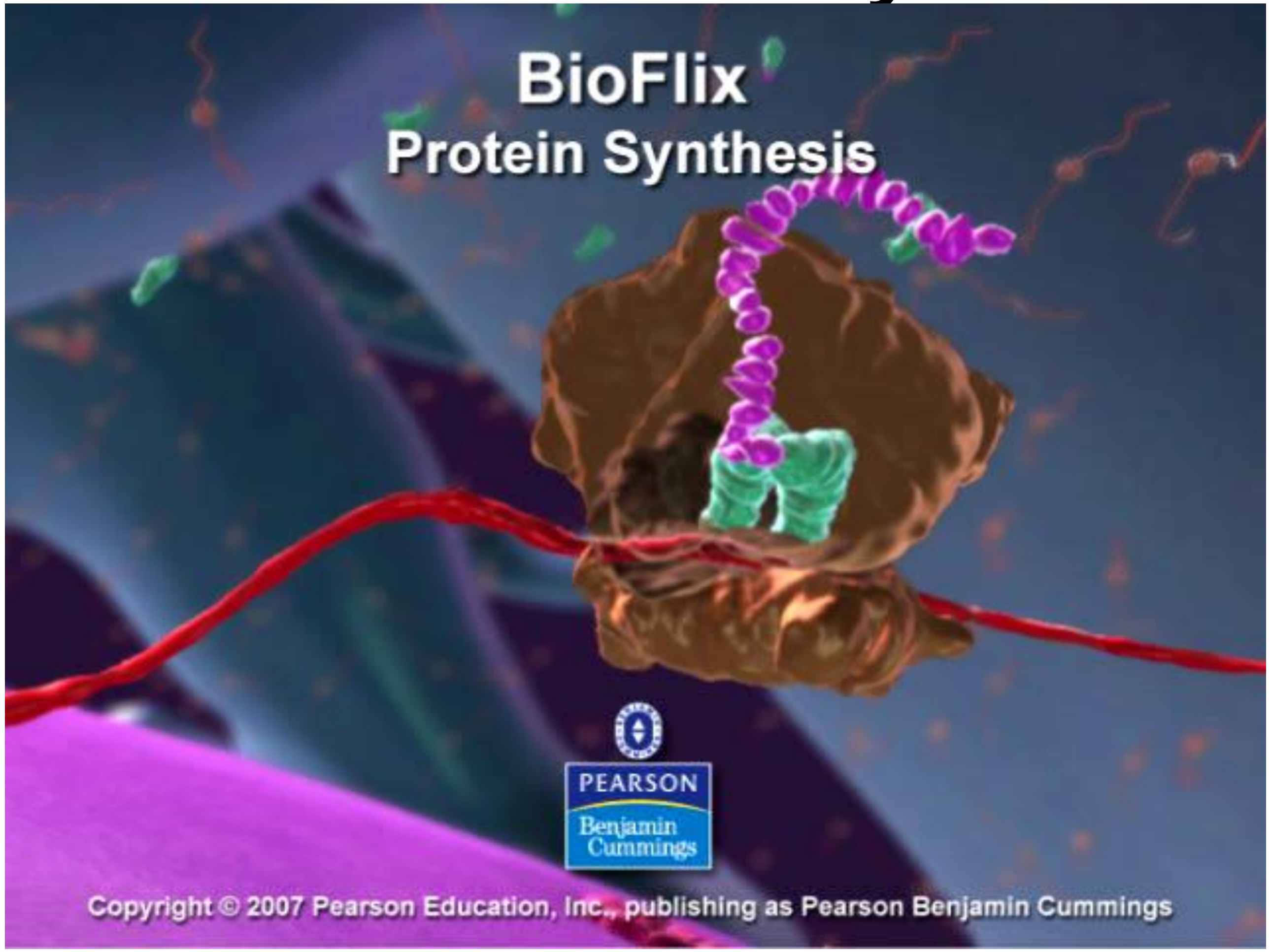


1 Ribosome reaches a stop codon on mRNA.

2 Release factor promotes hydrolysis.

3 Ribosomal subunits and other components dissociate.

BioFlix: Protein Synthesis



Genes and Gene Mutations

- A gene mutation changes the sequence of bases in the DNA.

- Mutations in DNA are rare (one in 100 million cell divisions).

- Mutations can be caused by mutagens.
  - Physical Radiation (radioactivity, X-rays, UV light)
  - Chemicals (pesticides, cigarette chemicals)

Effects of Mutations

- Mutations that are inherited (can be passed to offsprings) are called germ-line mutations.
- Somatic mutations occur in an organism after birth and can lead to cancer.
- Point mutations involve the mutation (change) of a single DNA nucleotide. The change of a single nucleotide in a DNA template strand can lead to the production of an abnormal protein.

Effects of Mutations (cont.)

- In a frame shift mutation, the triplet sequence of the DNA is altered, throwing the mRNA codons out of phase.

Sickle Cell Anemia: A point mutation