The Structure of the Genetic Material

10.1 Scientific Thinking: Experiments Showed That DNA Is the Genetic Material (1 of 2)

- Early in the 20th century, the molecular basis for inheritance was a mystery.
- In 1928, Frederick Griffith was surprised to find that when he killed pathogenic bacteria, then mixed the bacterial remains with living harmless bacteria,
  - some living bacterial cells became pathogenic and
  - all of the descendants of the transformed bacteria inherited the newly acquired ability to cause disease.

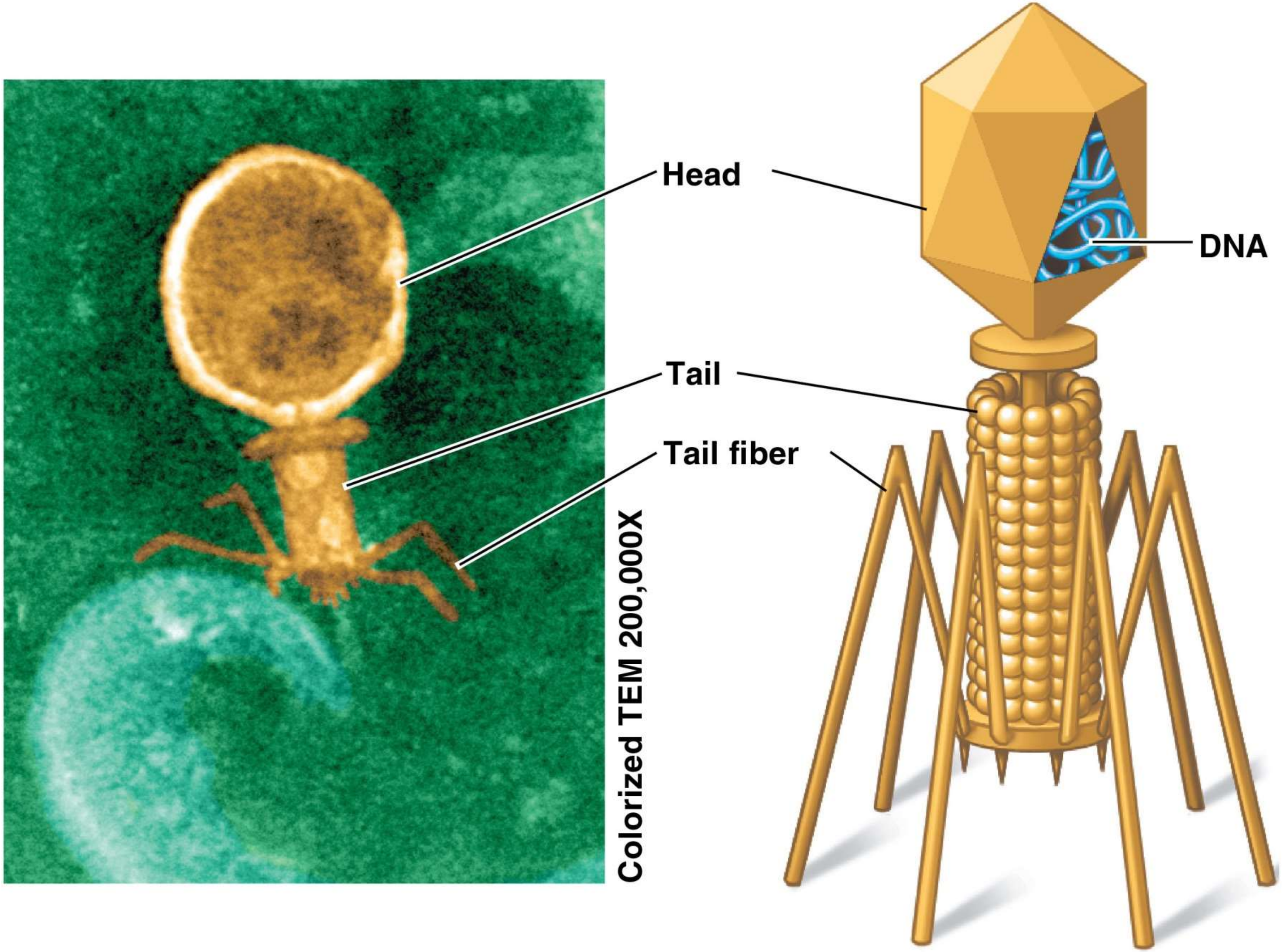
10.1 Scientific Thinking: Experiments Showed That DNA Is the Genetic Material (2 of 2)

- By carefully choosing their model organism, Hershey and Chase were able to show that certain **bacteriophages** (or **phages,** bacterial viruses) reprogram host cells to produce more phages by injecting their DNA.

Checkpoint question What structural feature of viruses like phage T2 made them ideally suited for the Hershey-Chase experiment?

Phage T2 has a very simple structure consisting of just two "ingredients"—DNA and protein—making it easier to identify the functions of each component.

Figure 10.1a



Pearson

Figure 10.1b

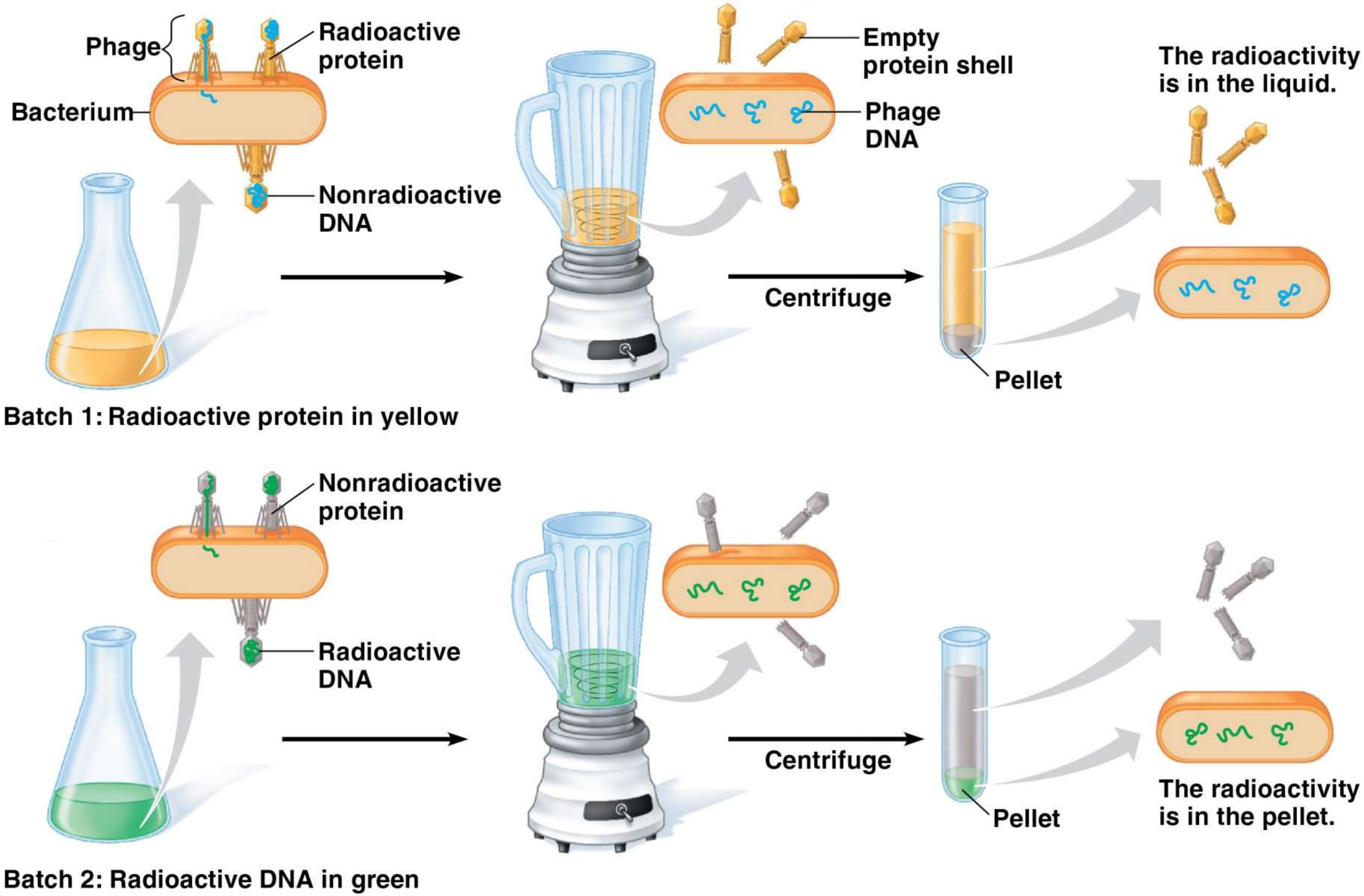
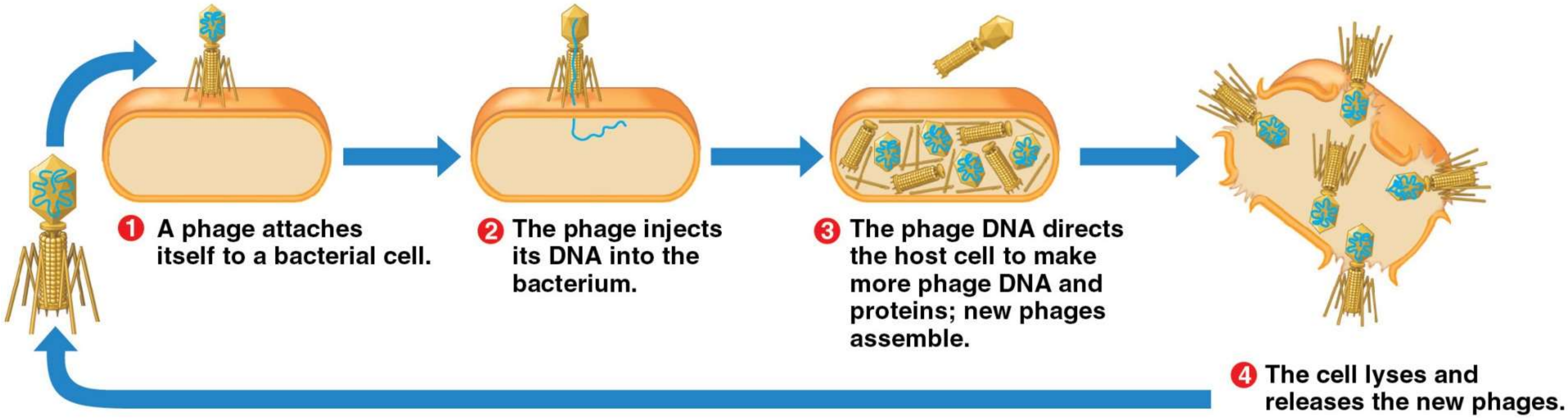

Phage
Radioactive protein
Bacterium
Nonradioactive DNA
Empty protein shell
Phage DNA
The radioactivity is in the liquid.
Centrifuge
Pellet
Batch 1: Radioactive protein in yellow
Nonradioactive protein
Radioactive DNA
Centrifuge
Pellet
The radioactivity is in the pellet.
Batch 2: Radioactive DNA in green

Figure 10.1c


1 A phage attaches itself to a bacterial cell.
2 The phage injects its DNA into the bacterium.
3 The phage DNA directs the host cell to make more phage DNA and proteins; new phages assemble.
4 The cell lyses and releases the new phages.

10.2 DNA and RNA Are Polymers of Nucleotides (1 of 3)

- DNA and RNA are nucleic acids consisting of long chains (polymers) of chemical units (monomers) called **nucleotides**.
- One of the two strands of DNA is a DNA **polynucleotide**, a nucleotide polymer (chain).

10.2 DNA and RNA Are Polymers of Nucleotides (2 of 3)

- A nucleotide is composed of a
  - nitrogenous base,
  - five-carbon sugar, and
  - phosphate group.
- The nucleotides are joined to one another by a **sugar-phosphate backbone**.
- Each type of DNA nucleotide has a different nitrogen-containing base: **adenine** (A), **cytosine** (C), **thymine** (T), and **guanine** (G).

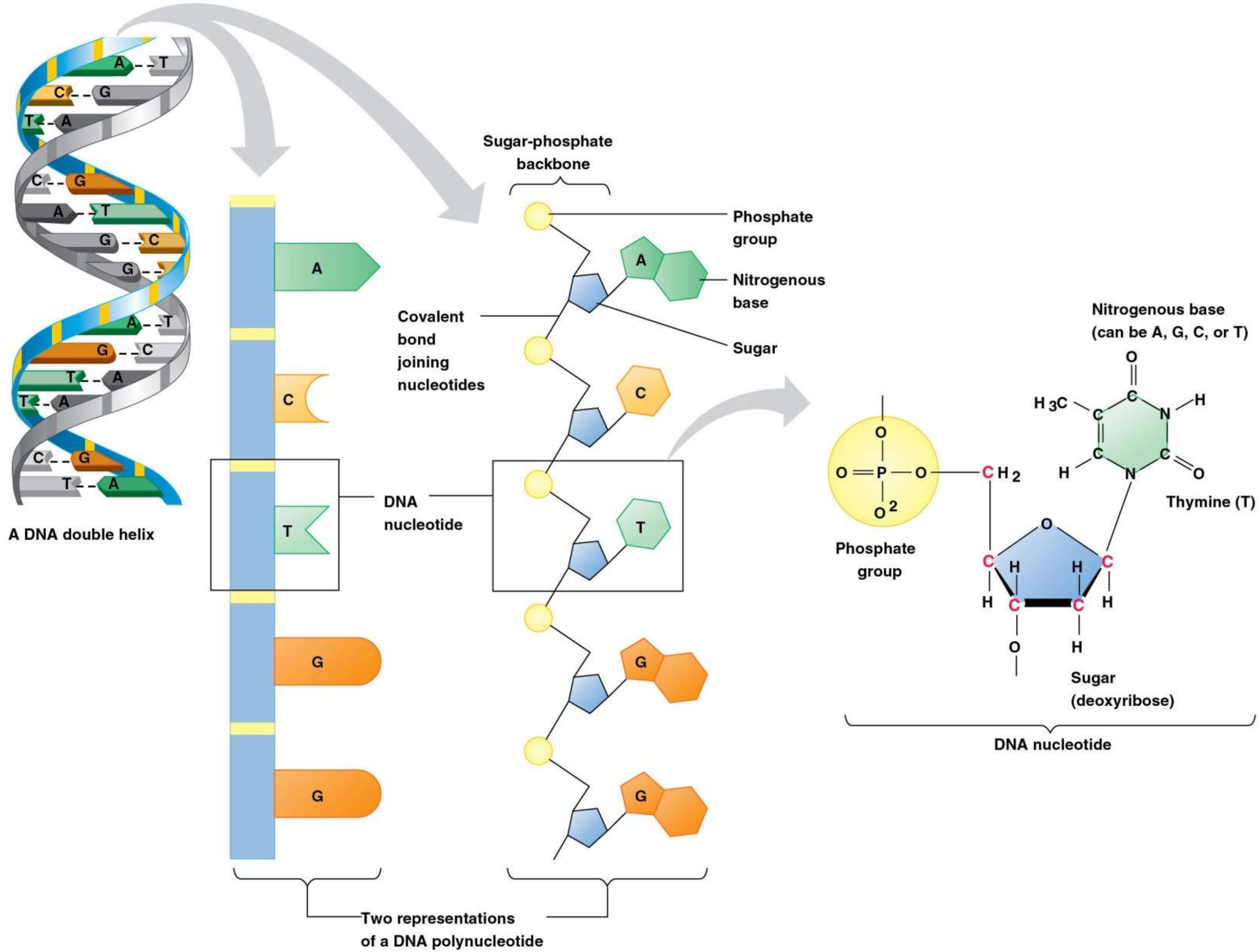
10.2 DNA and RNA Are Polymers of Nucleotides (3 of 3)

- The full name for **DNA** is **deoxyribonucleic acid**, with *nucleic* referring to DNA's location in the nuclei of eukaryotic cells.
- RNA (ribonucleic acid) is unlike DNA in that it
  - uses the sugar ribose (instead of deoxyribose in DNA) and
  - has a nitrogenous base **uracil** (U) instead of thymine.

Checkpoint question Compare and contrast DNA and RNA polynucleotides.

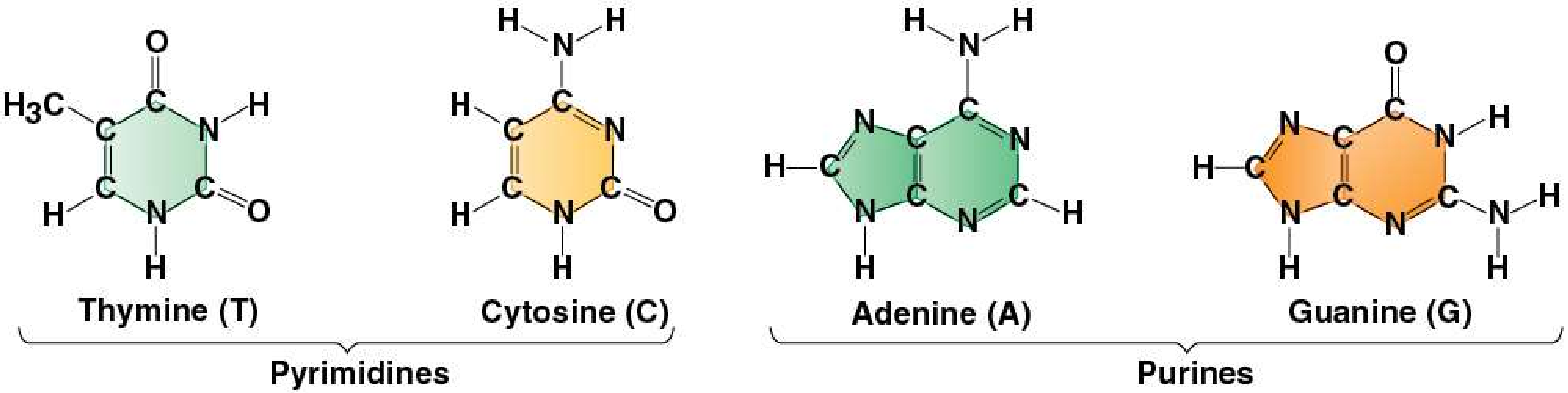
Both are polymers of nucleotides consisting of a sugar, a nitrogenous base, and a phosphate. In RNA, the sugar is ribose; in DNA, it is deoxyribose. Both RNA and DNA have the bases A, G, and C, but DNA has a T and RNA has a U.

Figure 10.2a



A DNA double helix
Sugar-phosphate backbone
Phosphate group
Nitrogenous base
Sugar
Covalent bond joining nucleotides
DNA nucleotide
Two representations of a DNA polynucleotide
Nitrogenous base (can be A, G, C, or T)
Thymine (T)
Phosphate group
Sugar (deoxyribose)
DNA nucleotide

Figure 10.2b



Thymine (T)
Cytosine (C)
Adenine (A)
Guanine (G)
Pyrimidines
Purines

10.3 DNA Is a Double-Stranded Helix (1 of 4)

- After the 1952 Hershey-Chase experiment convinced most biologists that DNA was the material that stored genetic information, a race was on to determine how the structure of this molecule could account for its role in heredity.
- Researchers focused on discovering the three-dimensional shape of DNA.

10.3 DNA Is a Double-Stranded Helix (2 of 4)

- Watson and Crick worked out the three-dimensional structure of DNA: two polynucleotide strands wrapped around each other in a **double helix**.
  - Hydrogen bonds between bases hold the strands together.
  - Each base pairs with a complementary partner: A with T, G with C.

10.3 DNA Is a Double-Stranded Helix (3 of 4)

- In 1962, the Nobel Prize was awarded to James D. Watson, Francis Crick, and Maurice Wilkins.
  – Rosalind Franklin probably would have received the prize as well but for her death from cancer in 1958.
  – Nobel Prizes are never awarded posthumously.
- The Watson-Crick model gave new meaning to the words *genes* and *chromosomes.* The genetic information in a chromosome is encoded in the nucleotide sequence of DNA.

10.3 DNA Is a Double-Stranded Helix (4 of 4)

- **Checkpoint question** Along one strand of a double helix is the nucleotide sequence GGCATAGGT. What is the complementary sequence for the other DNA strand?

CCGTATCCA

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DNA Replication

10.4 DNA Replication Depends on Specific Base Pairing (1 of 2)

- DNA replication starts with the separation of DNA strands.
- Enzymes then use each strand as a template to assemble new nucleodes into a complementary strand.

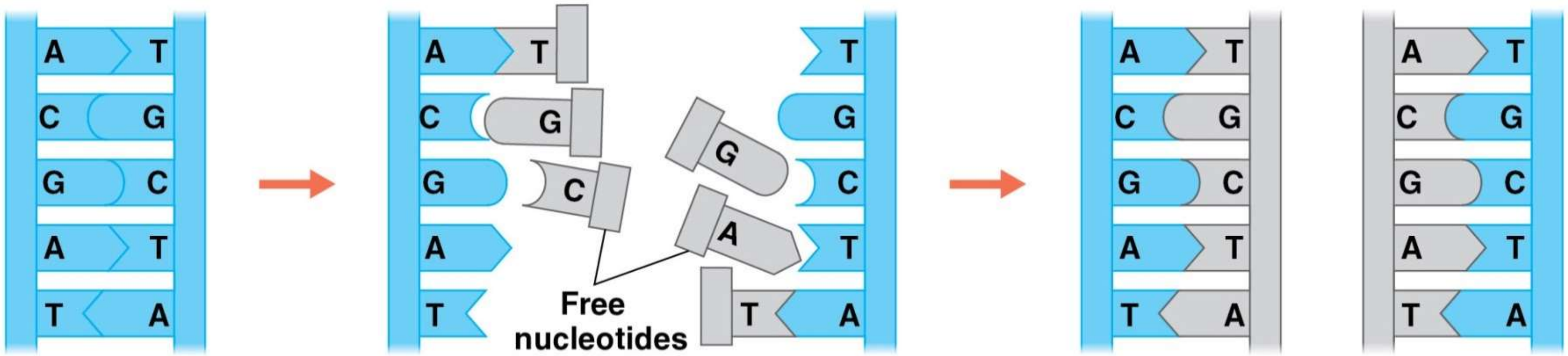
10.4 DNA Replication Depends on Specific Base Pairing (2 of 2)

- DNA replication follows a **semiconservative model**.
  - The two DNA strands separate.
  - Each strand then becomes a template for the assembly of a complementary strand from a supply of free nucleotides.
  - Each new DNA helix has one old strand with one new strand.

Checkpoint question How does complementary base pairing make possible the replication of DNA?

When the two strands of the double helix separate, free nucleotides can base-pair along each strand, leading to the synthesis of new complementary strands.

Figure 10.4a_3



A parental molecule of DNA

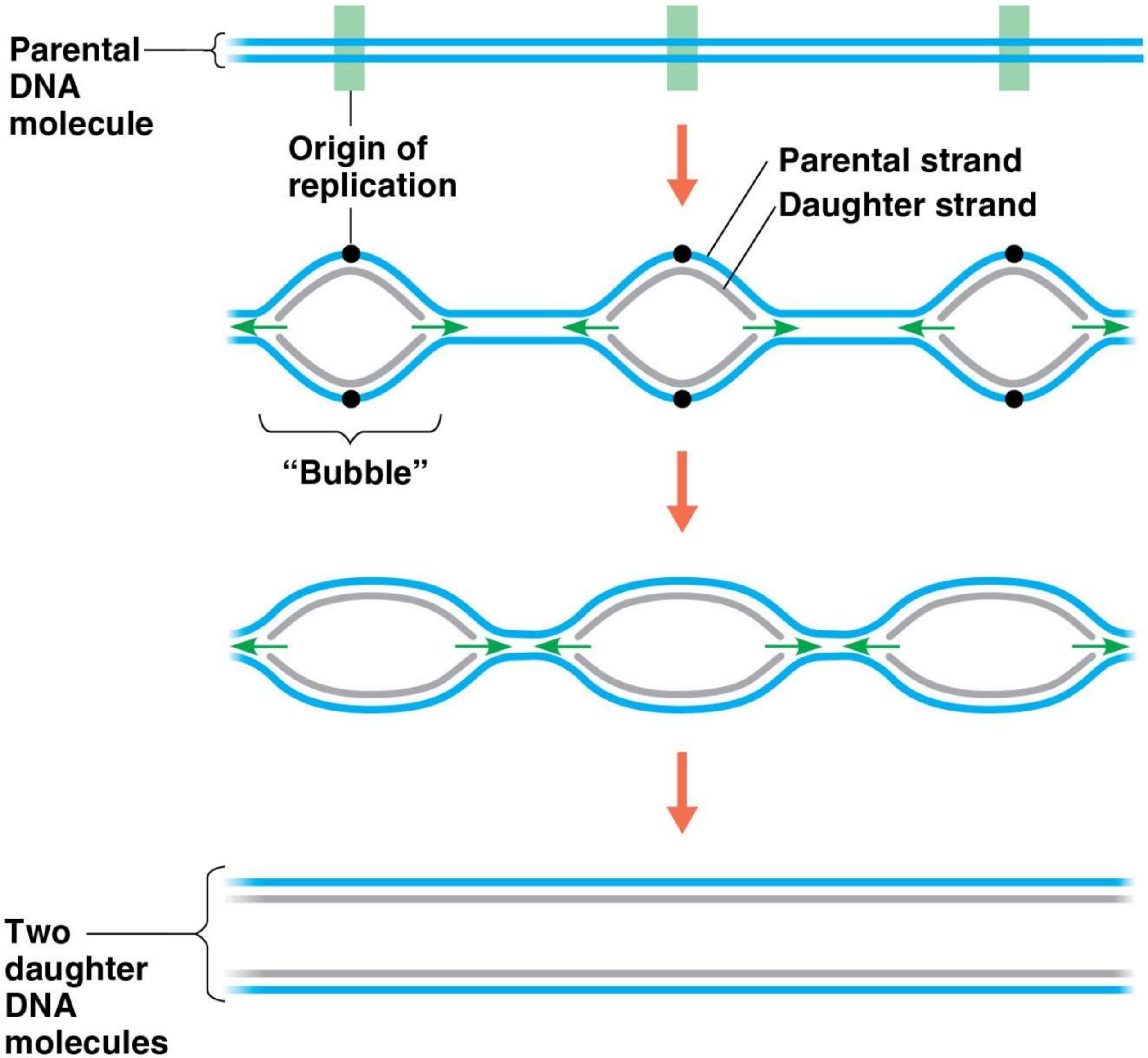
The parental strands separate and serve as templates

Two identical daughter molecules of DNA are formed

10.5 DNA Replication Proceeds in Two Directions at Many Sites Simultaneously

- Using the enzyme **DNA polymerase**, the cell synthesizes one daughter strand as a continuous piece.
- The other strand is synthesized as a series of short pieces, which are then connected by the enzyme **DNA ligase**.

Figure 10.5a



Parental DNA molecule
Origin of replication
Parental strand
Daughter strand
"Bubble"
Two daughter DNA molecules

Figure 10.5b

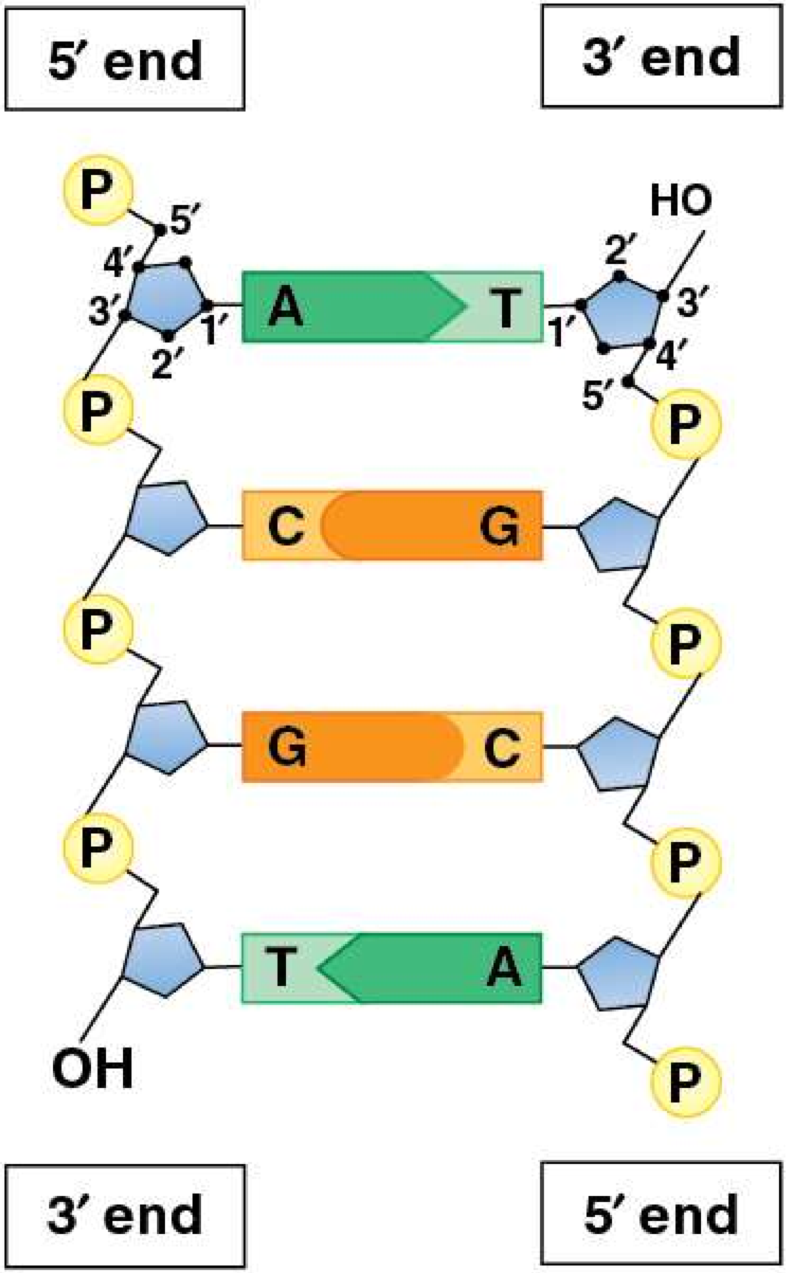
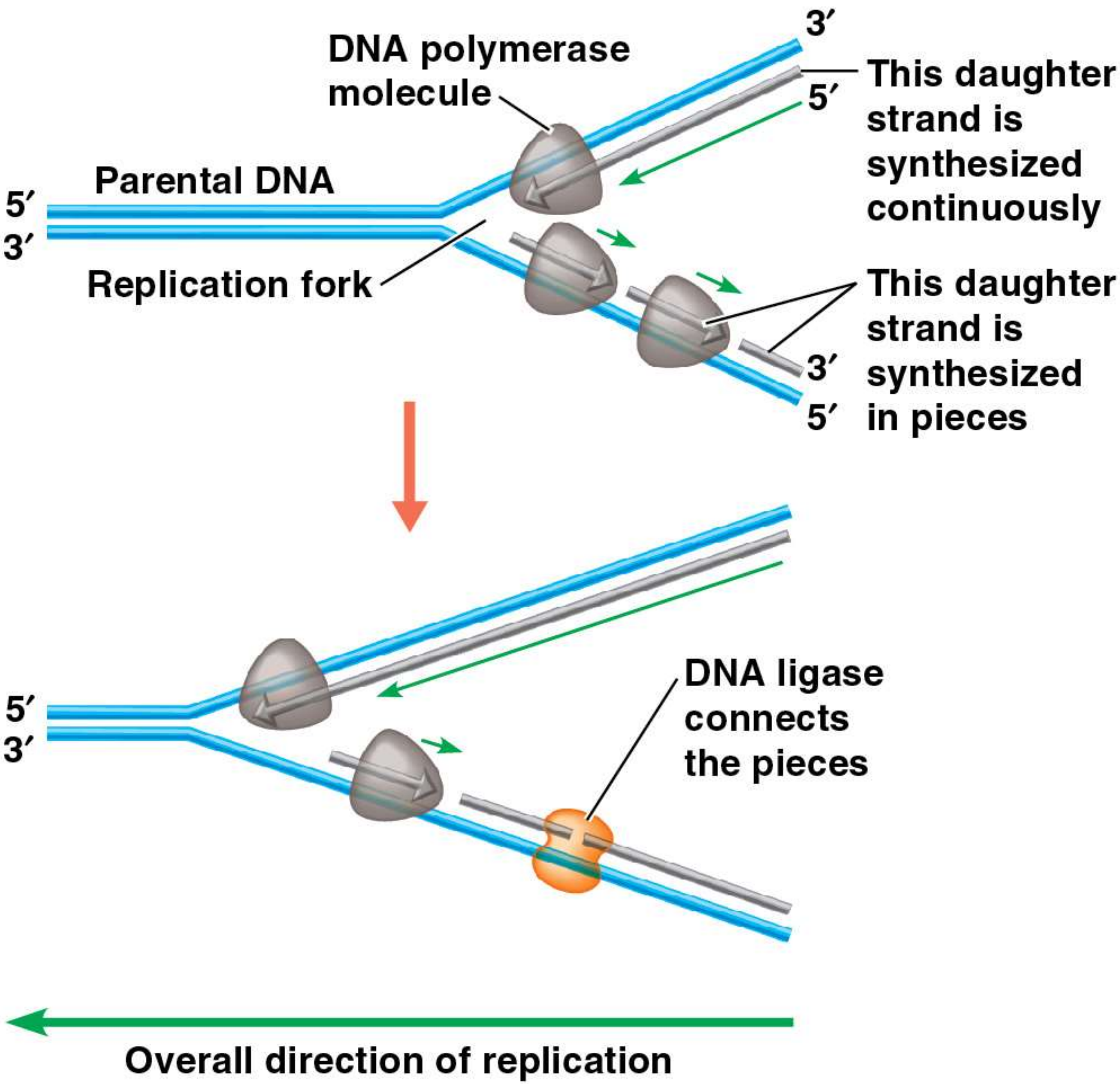


Figure 10.5c



Pearson

The Flow of Genetic Information from DNA to RNA to Protein

10.6 Genes Control Phenotypic Traits Through the Expression of Proteins (1 of 2)

- The DNAof a gene—a linear sequence of many nucleotides—is transcribed into RNA, which is translated into a polypeptide.
- **Transcription** is the synthesis of RNA under the direction of DNA.
- **Translation** is the synthesis of proteins under the direction of RNA.

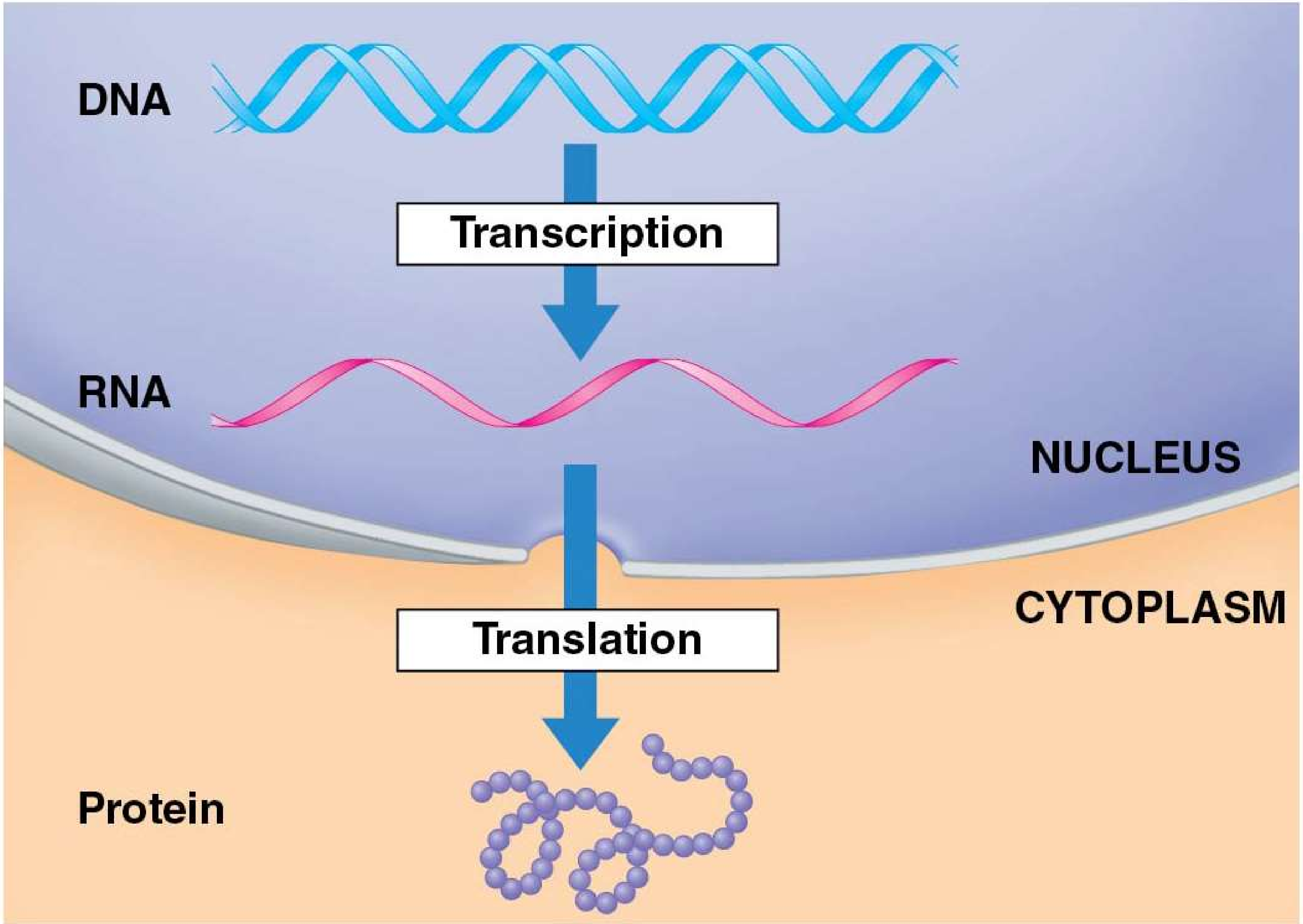
10.6 Genes Control Phenotypic Traits Through the Expression of Proteins (2 of 2)

- Currently, a gene is defined as a region of DNA that can be expressed to produce a functional product that is either a polypeptide or an RNA molecule.

Checkpoint question What are the functions of transcription and translation?

Transcription is the transfer of information from DNA to RNA. Translation is the use of the information in RNA to make a polypeptide.

Figure 10.6a_3



10.7 Genetic Information Written in Codons Is Translated into Amino Acid Sequences (1 of 2)

- The sequence of nucleotides in DNA provides a code for constructing a protein.
- Translation requires the conversion of the nucleic acid language to the polypeptide language.
- During translation, there is a change in language from the nucleotide sequence of the RNA to the amino acid sequence of the polypeptide.

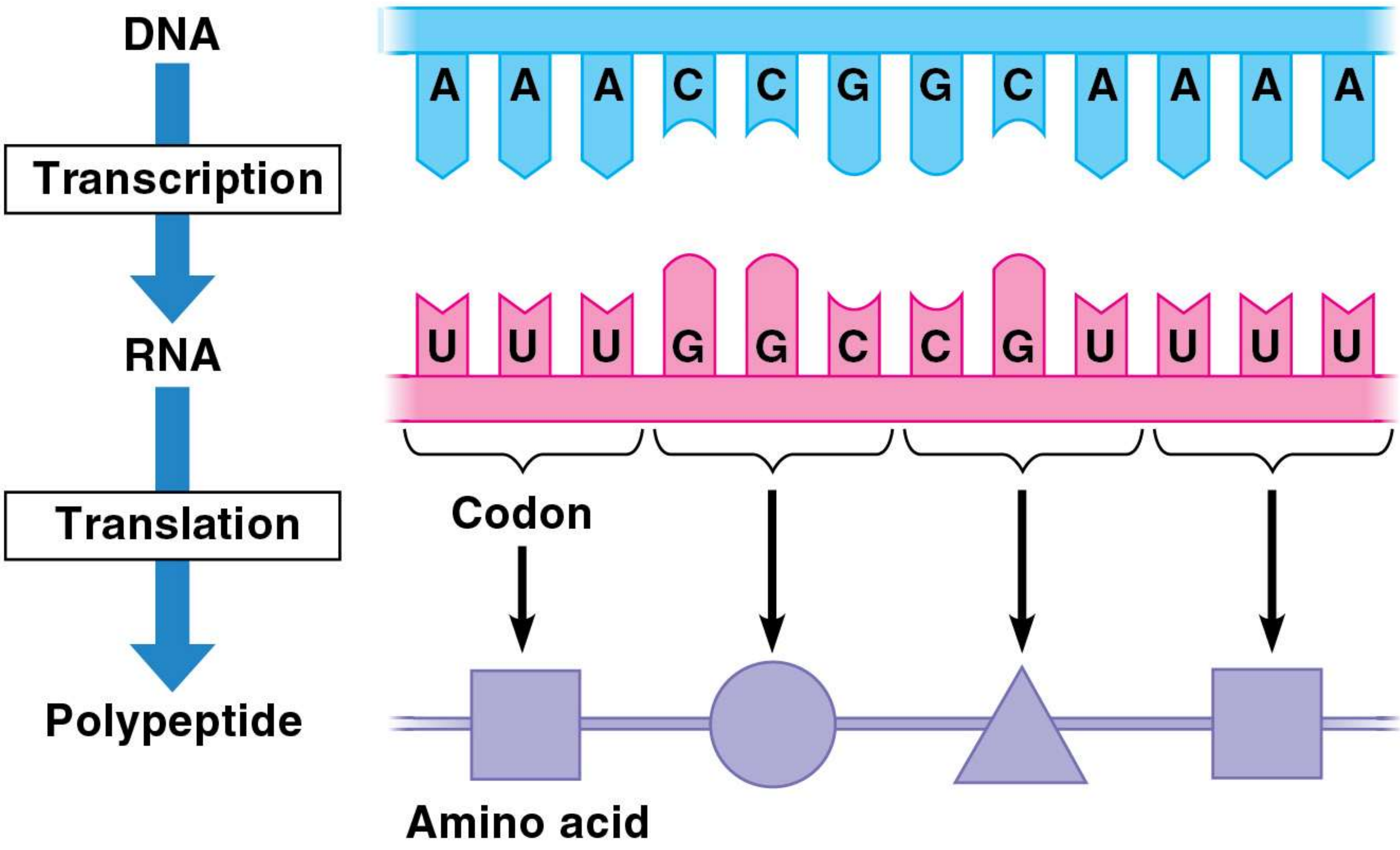
10.7 Genetic Information Written in Codons Is Translated into Amino Acid Sequences (2 of 2)

- Experiments have verified that the flow of information from gene to protein is based on a **triplet code**: The genetic instructions for the amino acid sequence of a polypeptide chain are written in DNA and RNA as a series of nonoverlapping three-base "words" called **codons**.

Checkpoint question What is the minimum number of nucleotides necessary to code for 100 amino acids?

300

Figure 10.7_1


DNA
Transcription
RNA
Translation
Polypeptide
A A A C C G G C A A A A
U U U G G C C G U U U U
Codon
Amino acid

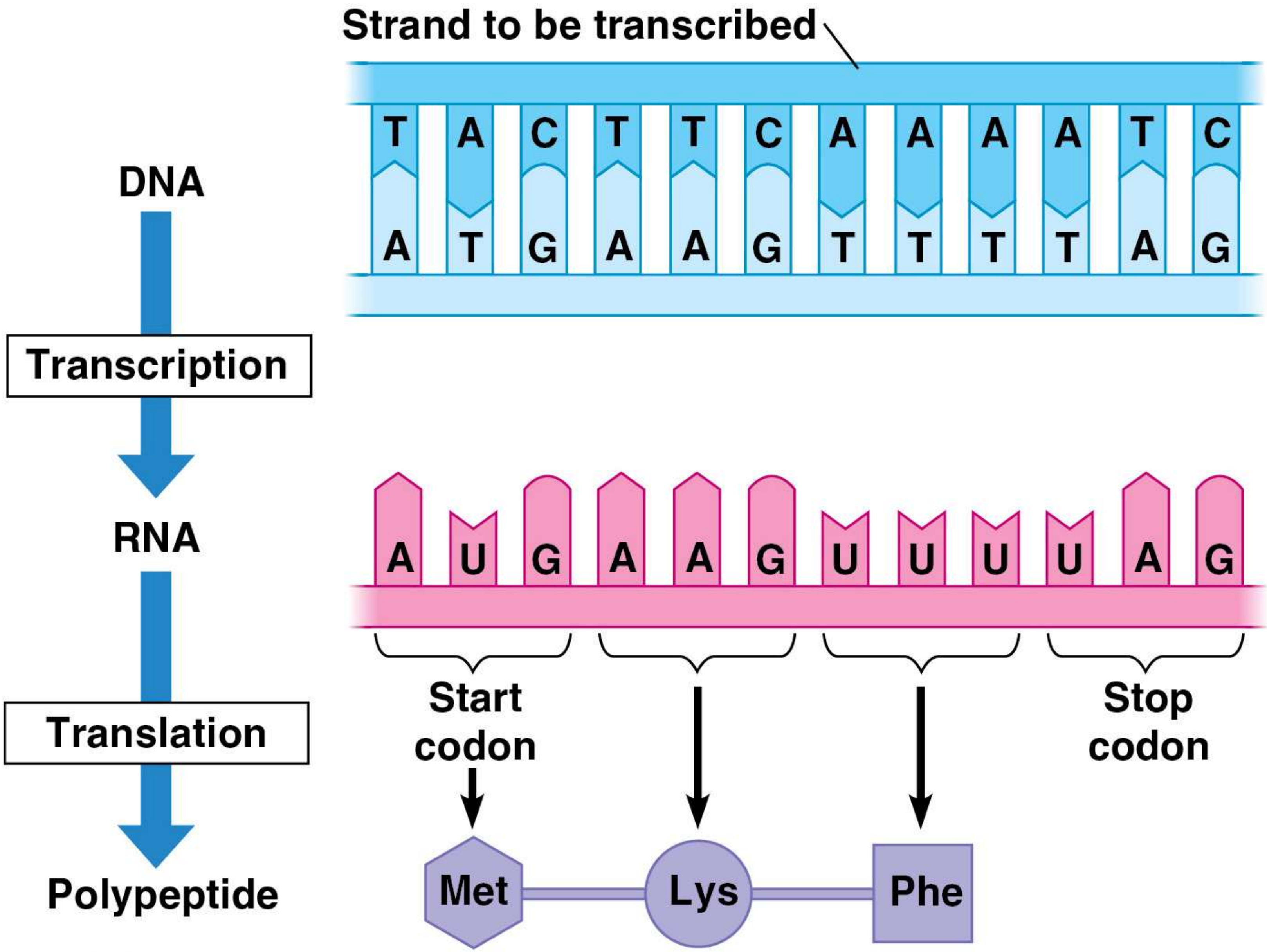
10.8 The Genetic Code Dictates How Codons Are Translated into Amino Acids

- The **genetic code** is the set of rules that dictates the amino acid translations of each of the mRNA nucleotide triplets.
- Nearly all organisms use an identical genetic code to convert the mRNA codons transcribed from a gene to the amino acid sequence of a polypeptide.

Checkpoint question Translate the RNA sequence CCAUU UACG into the corresponding amino acid sequence.

Pro-Phe-Thr

Figure 10.8b_3



Pearson

10.9 Visualizing the Concept: Transcription Produces Genetic Messages in the Form of RNA (1 of 2)

- In the nucleus, the DNA helix unzips, and RNA nucleotides line up ,and **RNA polymerase** joins them along one strand of the DNA, following the base-pairing rules.
  - A specific nucleotide sequence called a **promoter** acts as a binding site for RNA polymerase and determines where transcription starts.

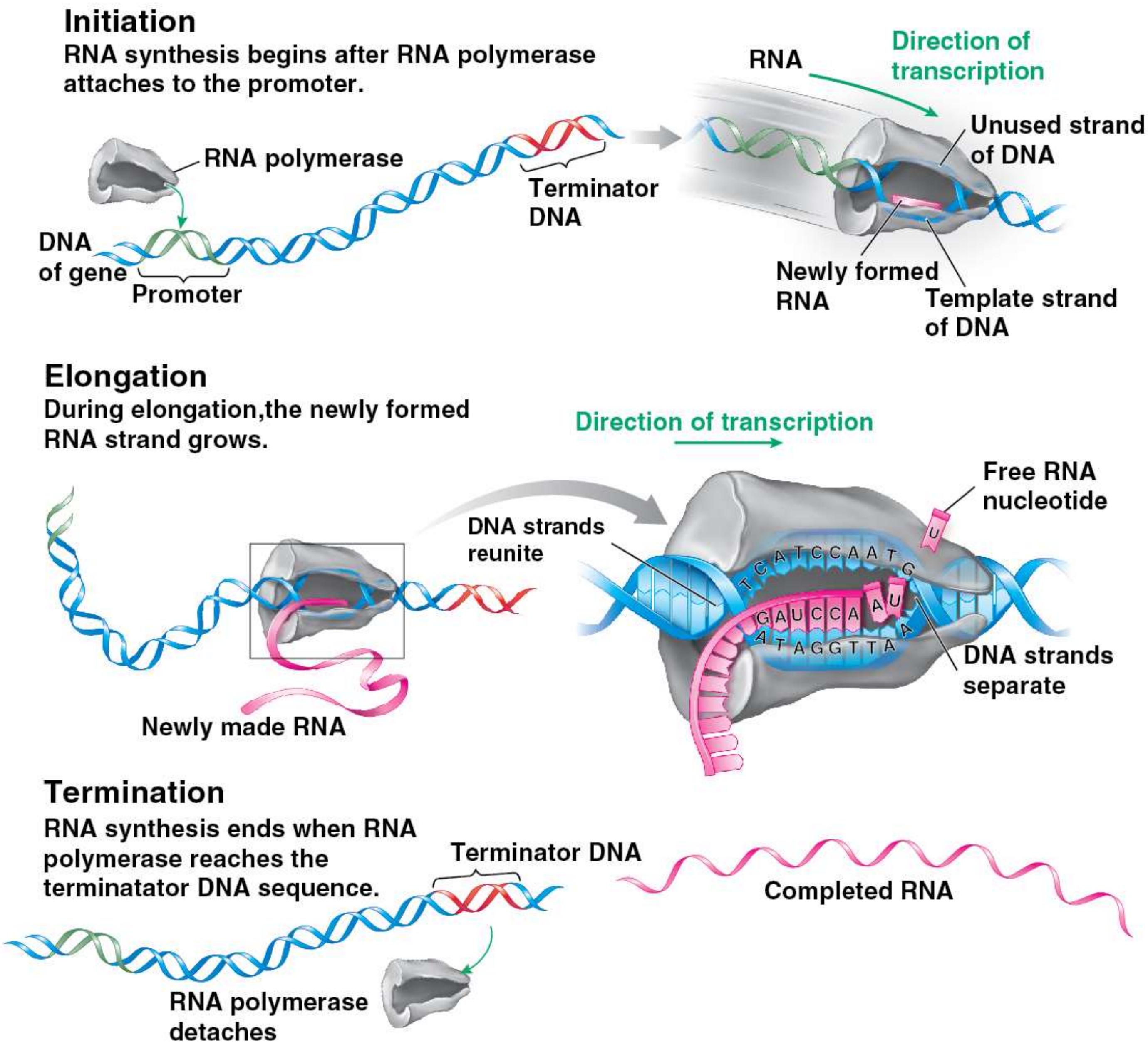
10.9 Visualizing the Concept: Transcription Produces Genetic Messages in the Form of RNA (2 of 2)

  - RNA polymerase adds RNA nucleotides until it reaches a sequence of DNA bases called the **terminator**, which signals the end of the gene.

Checkpoint question How does RNA polymerase recognize the start and end of the gene?

Special DNA sequences mark the start (promoter) and end (terminator) of a gene.

Figure 10.9_3


Initiation
RNA synthesis begins after RNA polymerase attaches to the promoter.
RNA polymerase
DNA of gene
Promoter
Terminator DNA
RNA
Direction of transcription
Unused strand of DNA
Newly formed RNA
Template strand of DNA
Elongation
During elongation,the newly formed RNA strand grows.
Direction of transcription
Free RNA nucleotide
U
DNA strands reunite
TCATCCAATG
GAUCCAAU
ATAGGTTA
DNA strands separate
Newly made RNA
Termination
RNA synthesis ends when RNA polymerase reaches the terminatator DNA sequence.
Terminator DNA
Completed RNA
RNA polymerase detaches

10.10 Eukaryotic RNA Is Processed Before Leaving the Nucleus as mRNA (1 of 2)

- The kind of RNA that encodes amino acid sequences is called **messenger RNA (mRNA)** because it conveys genetic messages from DNA to the translation machinery of the cell.

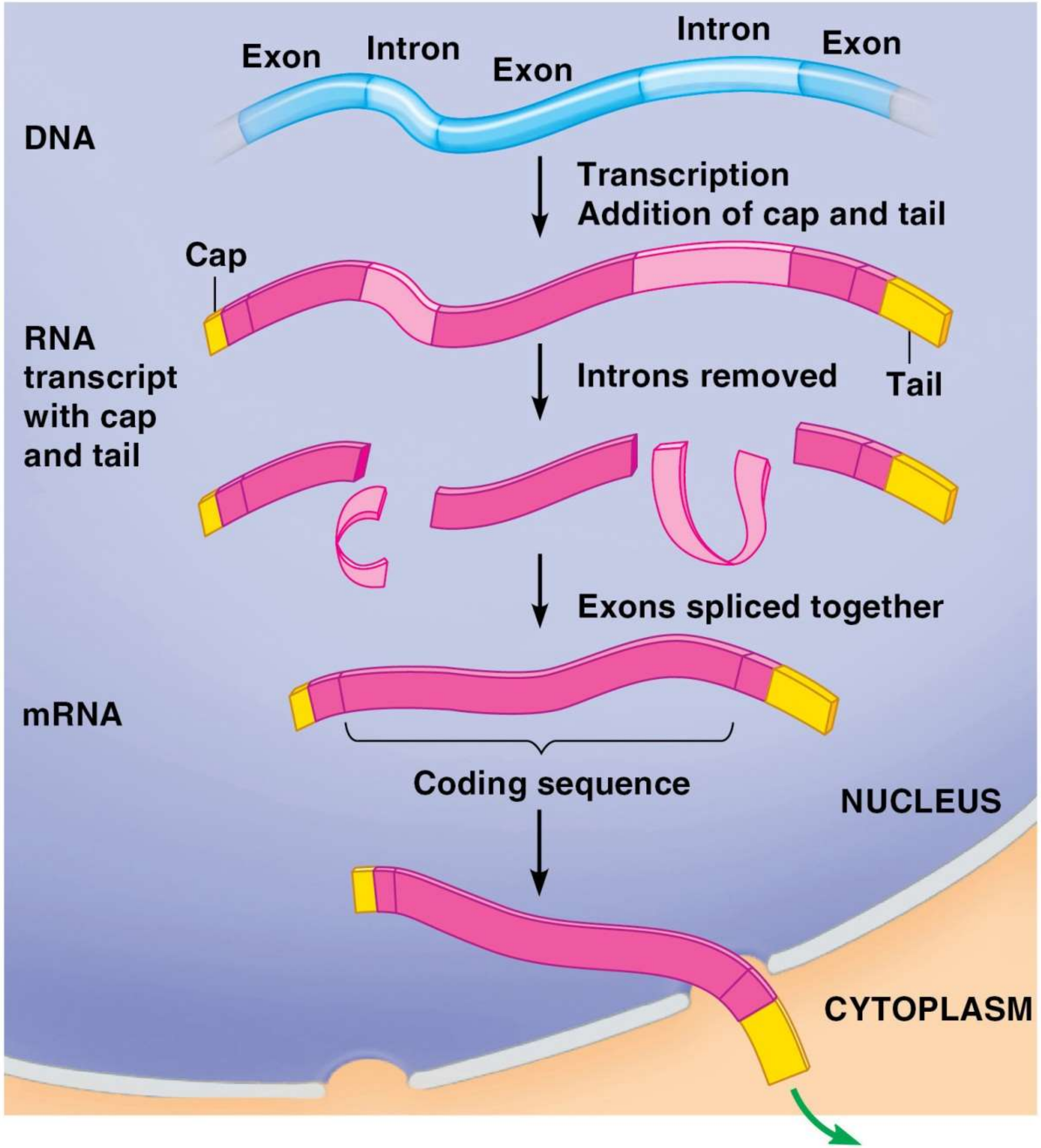
10.10 Eukaryotic RNA Is Processed Before Leaving the Nucleus as mRNA (2 of 2)

- Before leaving the nucleus as mRNA, eukaryotic transcripts undergo **RNA splicing**, in which
  - **introns (**noncoding segments of RNA) are spliced out,
  - **exons** (the parts of a gene that are expressed) are spliced together, and
  - a cap and tail are added to the ends of the mRNA.

Checkpoint question Explain why most eukaryotic genes are longer than the mRNA that leaves the nucleus.

These genes have introns, noncoding sequences of nucleotides that are spliced out of the initial RNA transcript to produce mRNA.

Figure 10.10

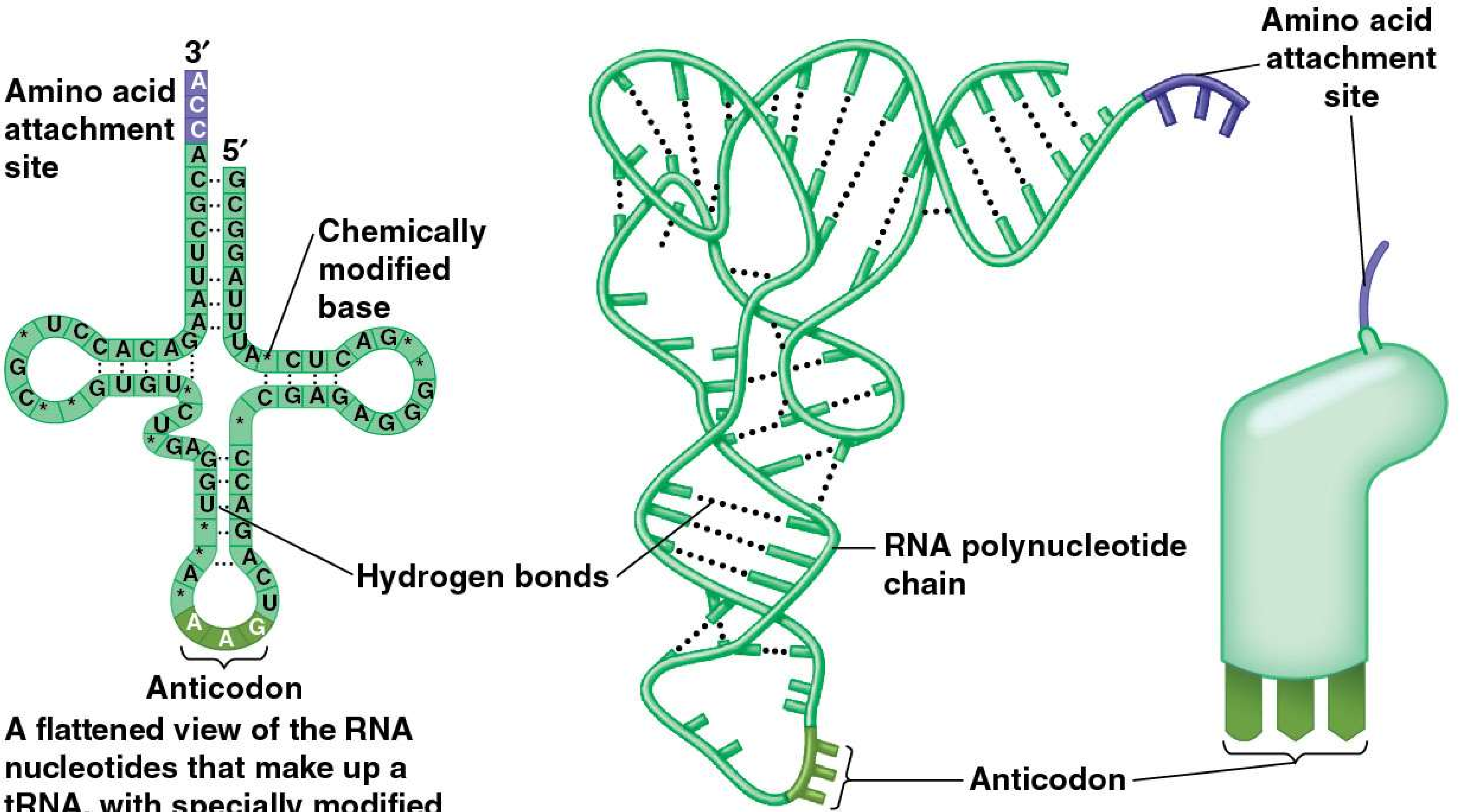


Exon
Intron
Exon
Intron
Exon
DNA
Transcription
Addition of cap and tail
Cap
RNA transcript with cap and tail
Introns removed
Tail
Exons spliced together
mRNA
Coding sequence
NUCLEUS
CYTOPLASM

10.11 Transfer RNA Molecules Serve as Interpreters During Translation

- Translation takes place in the cytoplasm.
  - A ribosome attaches to the mRNA and translates its message into a specific polypeptide, aided by **transfer RNAs (tRNAs)**.
  - Each tRNA is a folded molecule bearing a base triplet called an **anticodon** on one end and a specific amino acid attachment site at the other end.

Figure 10.11a



A flattened view of the RNA nucleotides that make up a tRNA, with specially modified bases marked with asterisks

A tRNA molecule, showing its folded polynucleotide strand and the hydrogen bonds that hold it in shape

A simplified representation of a tRNA, showing its overall shape

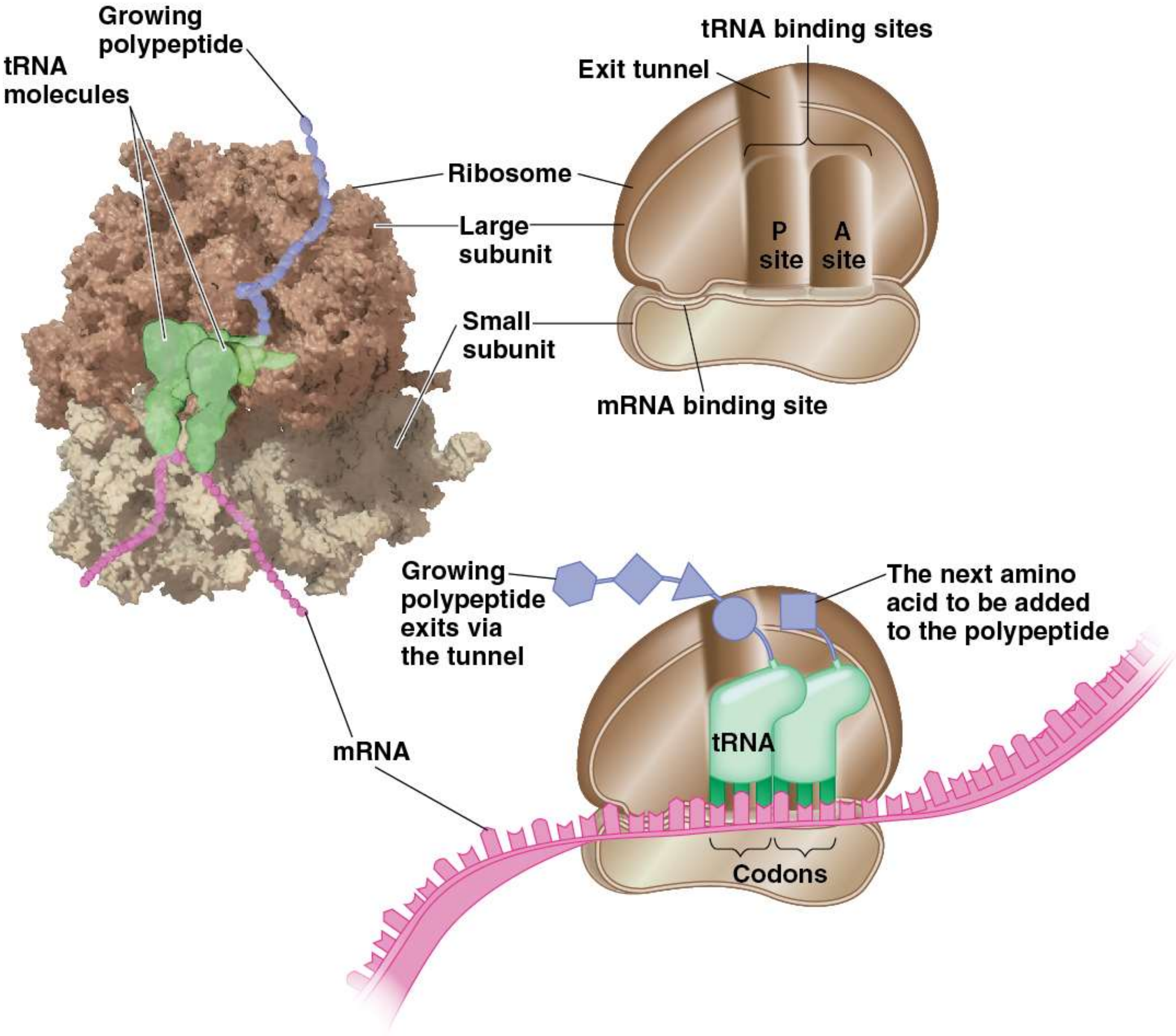
10.12 Ribosomes Build Polypeptides

- **Ribosomes** are structures in the cytoplasm that coordinate functioning of mRNA and tRNA and catalyze the synthesis of polypeptides.
  - Ribosomes are made of **ribosomal RNA (rRNA)** and proteins and
  - have binding sites for tRNAs and mRNA.

Checkpoint question How does a ribosome facilitate protein synthesis?

A ribosome holds mRNA and tRNAs together and connects amino acids from the tRNAs to the growing polypeptide chain.

Figure 10.12



Growing polypeptide
tRNA molecules
Ribosome
Large subunit
Small subunit
mRNA
tRNA binding sites
Exit tunnel
P site
A site
mRNA binding site
Growing polypeptide exits via the tunnel
The next amino acid to be added to the polypeptide
tRNA
Codons

10.13 An Initiation Codon Marks the Start of an mRNA Message (1 of 2)

- Translation can be divided into the same three phases as transcription:
  1. initiation,
  2. elongation, and
  3. termination.

10.13 An Initiation Codon Marks the Start of an mRNA Message (2 of 2)

- Initiation brings together
  - mRNA,
  - a tRNA bearing the first amino acid, and
  - the two subunits of a ribosome.
- Initiation occurs in two steps (Figure 10.13B).

Checkpoint question What would happen if a genetic mutation in a gene changed a start codon to some other codon?

The messenger RNA transcribed from the mutated gene would be nonfunctional because ribosomes could not initiate translation correctly.

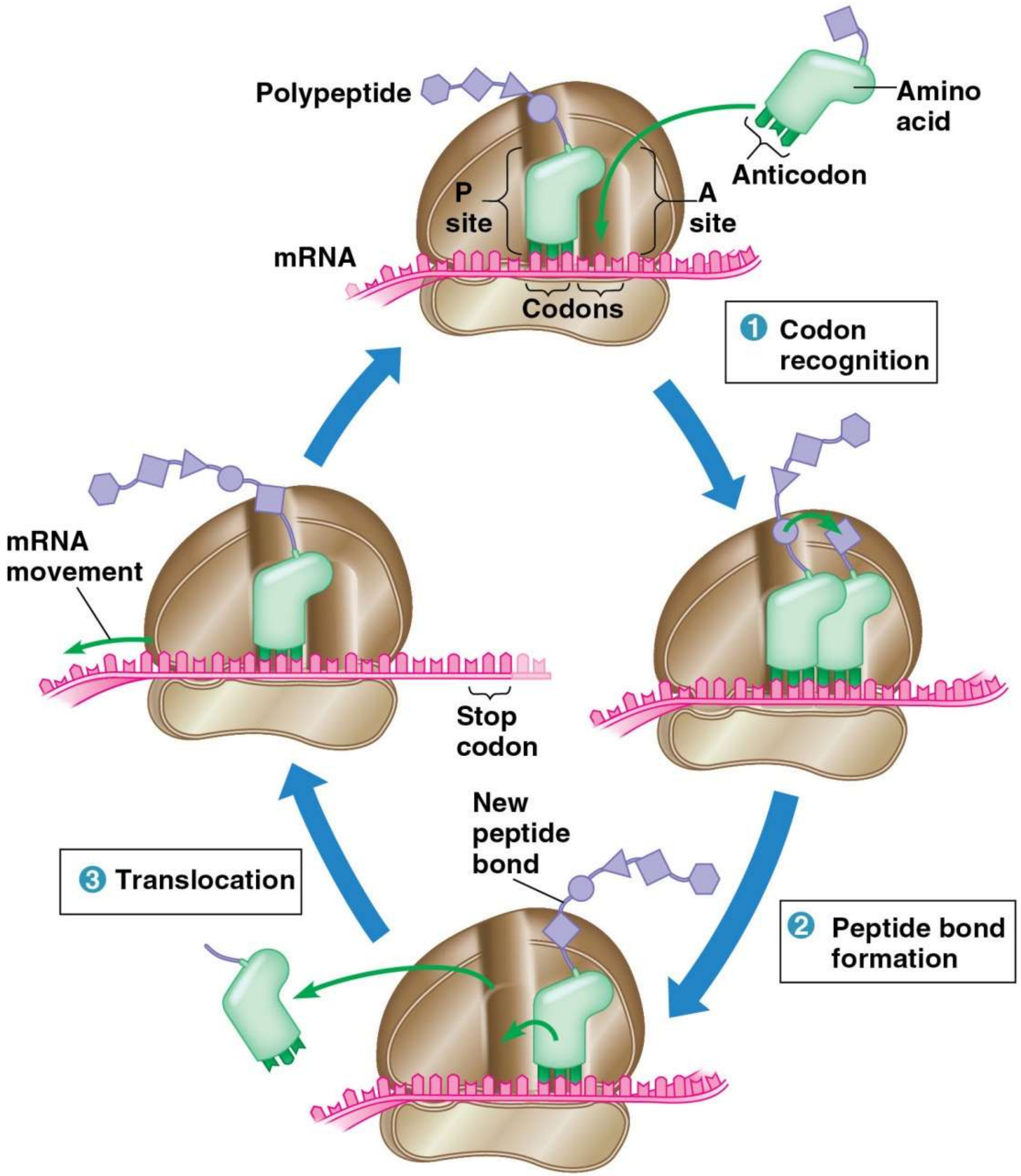
10.14 Elongation Adds Amino Acids to the Polypeptide Chain until a Stop Codon Terminates Translation

- As the mRNA moves one codon at a time relative to the ribosome, a tRNA with a complementary anticodon pairs with each codon, adding its amino acid to the growing polypeptide chain.
- Elongation continues until a **stop codon** reaches the ribosome's A site.

Checkpoint question What would happen if a mutation caused a codon in the middle of an mRNA to change from UUA to UAA?

Translation would stop prematurely, because a stop codon was introduced.

Figure 10.14_4



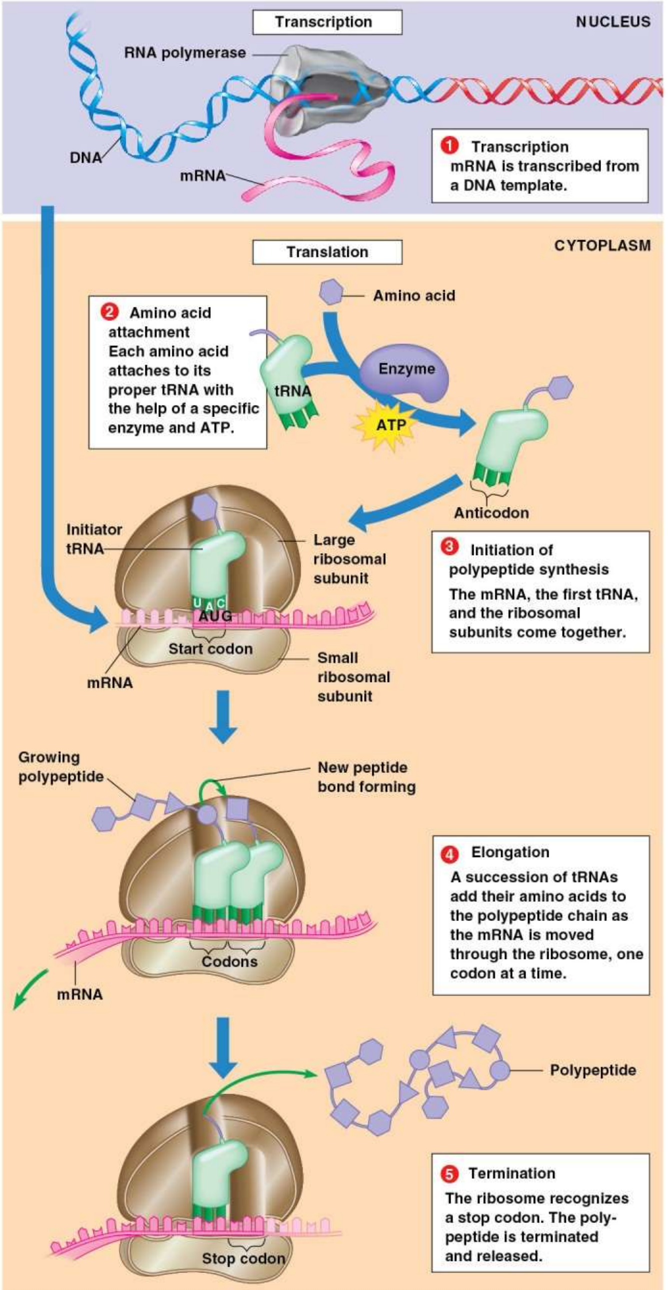
10.15 Review: The Flow of Genetic Information in the Cell is DNA → RNA → Protein

- The sequence of codons in DNA, via the sequence of codons in mRNA, spells out the primary structure of a polypeptide.

Checkpoint question Which of the types of nucleic acids you've learned about does not participate directly in translation?

DNA

Figure 10.15_5



10.16 Mutations Can Affect Genes

- **Mutations** are changes in the genetic information of a cell or virus, caused by errors in DNA replication or recombination, or by physical or chemical agents called **mutagens**.
- Substituting, inserting, or deleting nucleotides alters a gene, with varying effects.

Checkpoint question How could a single nucleotide substitution result in a shortened protein product?

A substitution that changed an amino acid codon into a stop codon would produce a prematurely terminated polypeptide.

Figure 10.16a

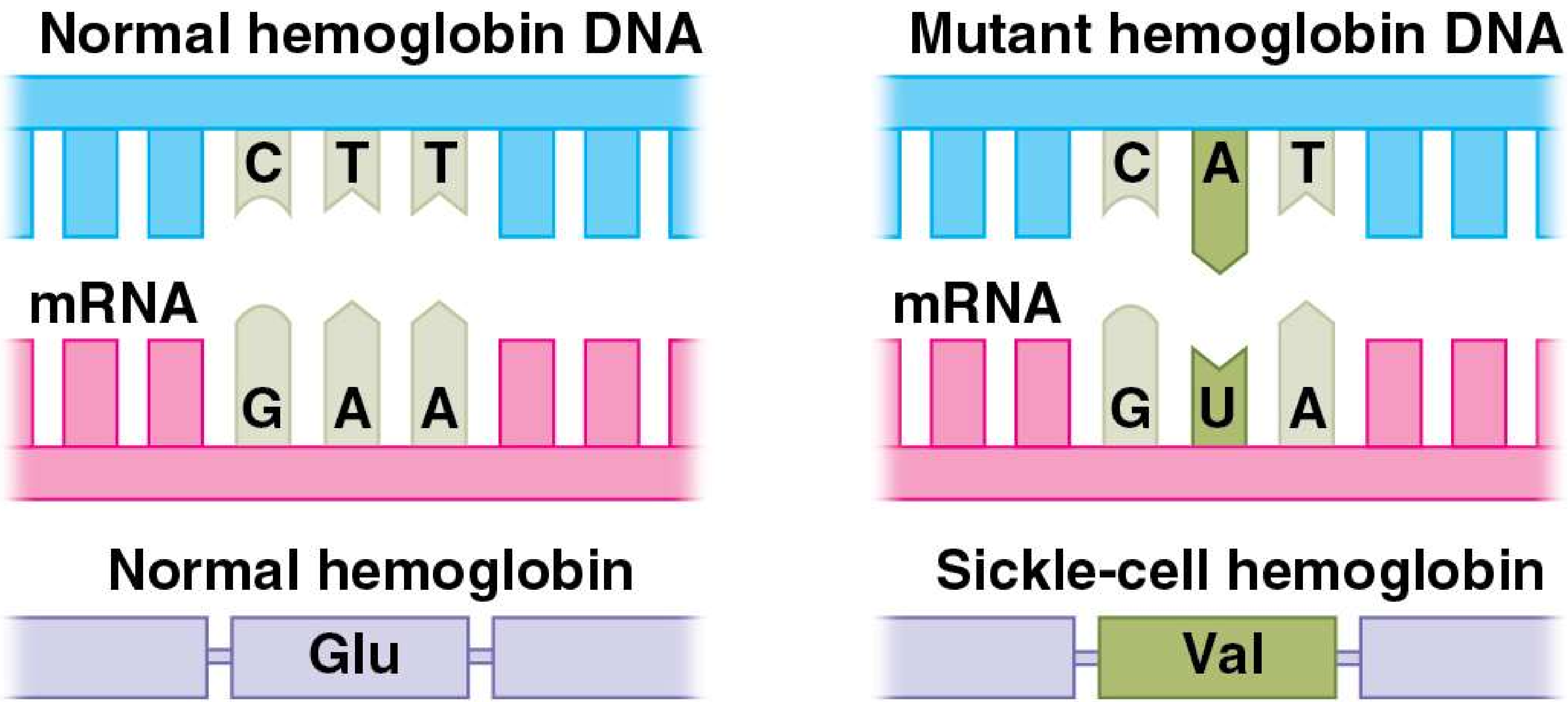
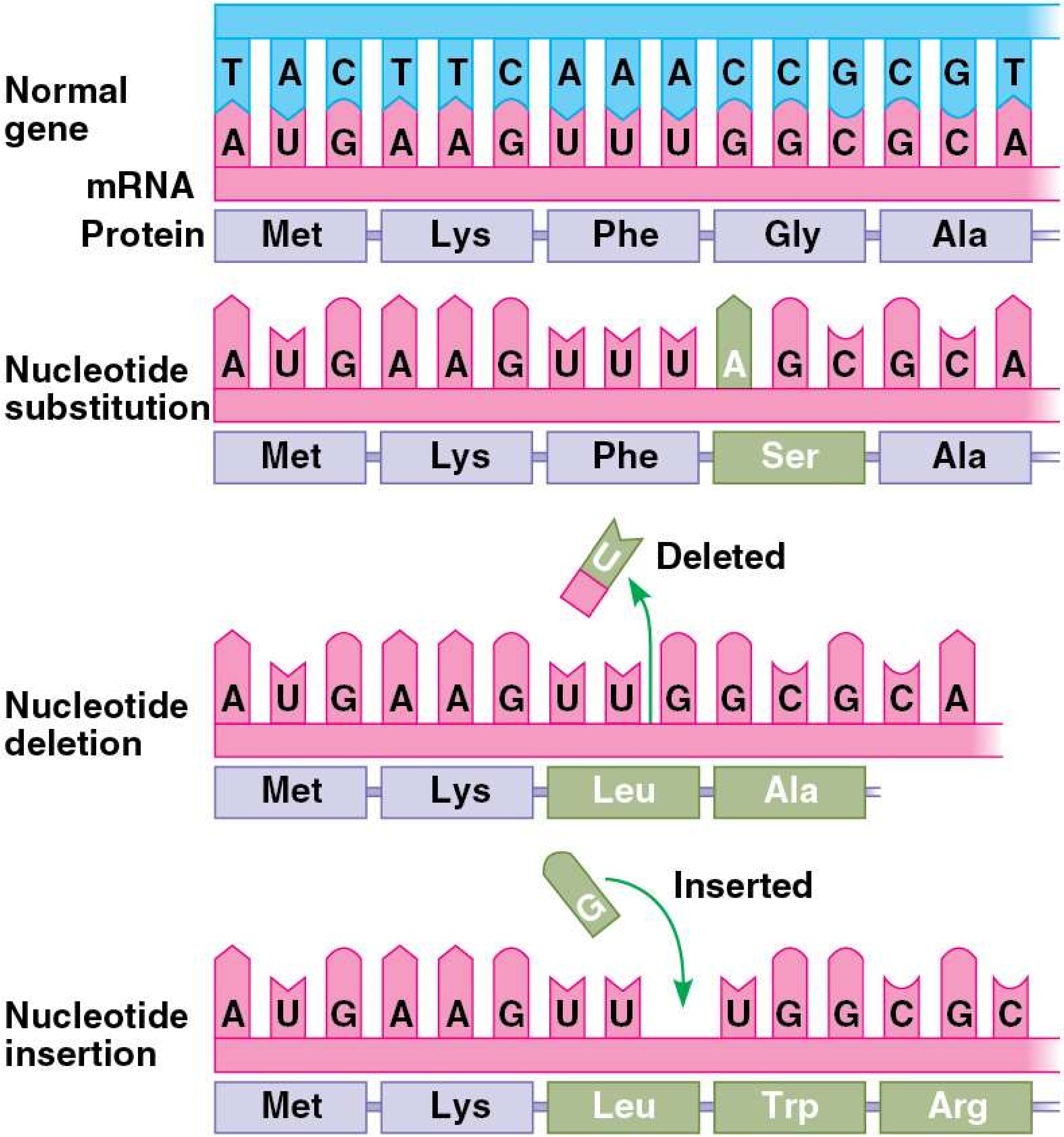


Figure 10.16b



The Genetics of Viruses and Bacteria

10.17 Viral DNA May Become Part of the Host Chromosome (1 of 2)

- A **virus** is an infectious particle consisting of little more than "genes in a box": a bit of nucleic acid wrapped in a protein coat called a **capsid** and, in some cases, a membrane envelope.
- When phage DNA enters a **lytic cycle** inside a bacterium, it is replicated, transcribed, and translated.
- The new viral DNA and protein molecules then assemble into new phages, which burst from the host cell.

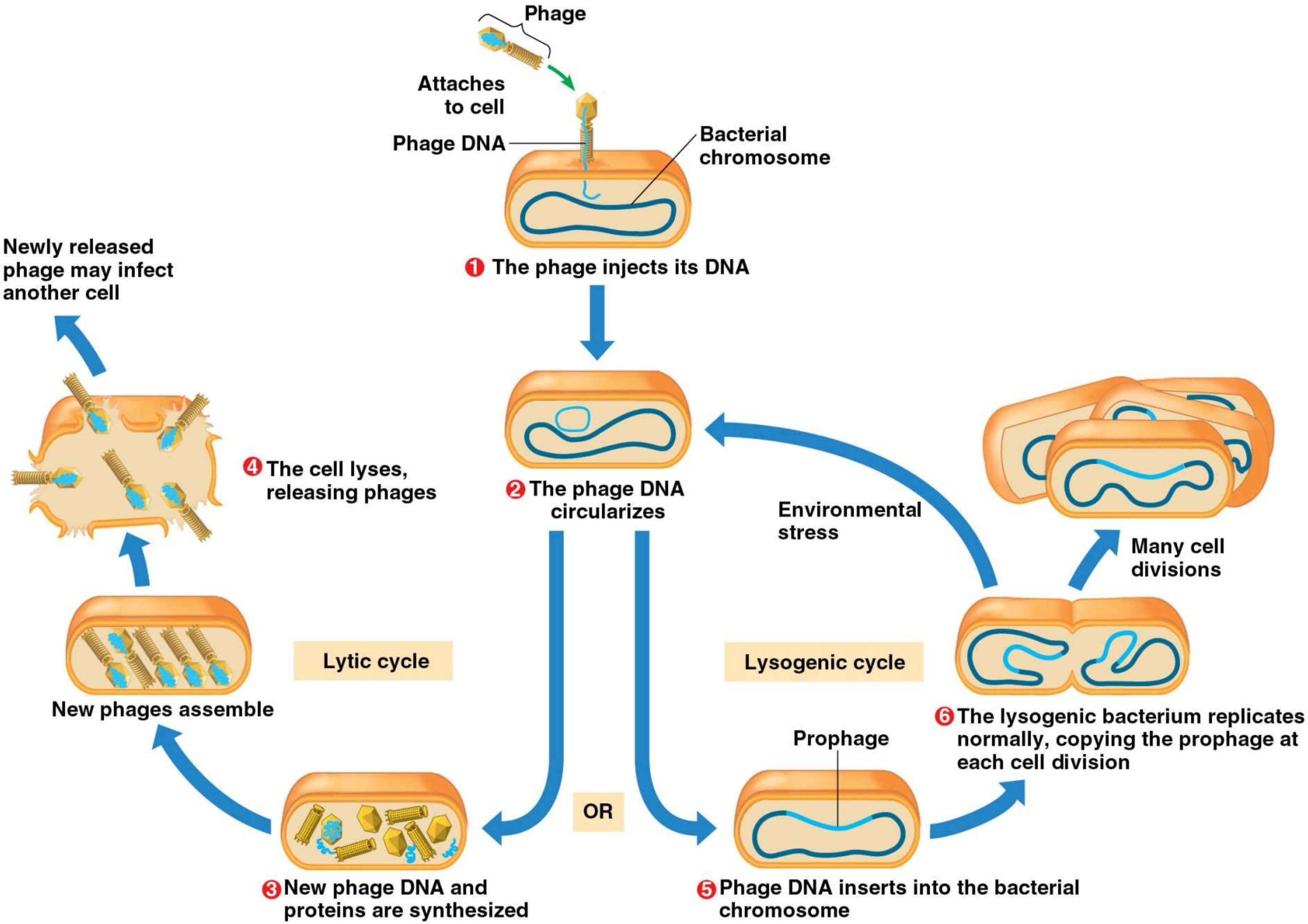
10.17 Viral DNA May Become Part of the Host Chromosome (2 of 2)

- In the **lysogenic cycle**, phage DNA inserts into the host chromosome and is passed on to generations of daughter cells.
  - Once inserted, the phage DNA is referred to as a **prophage**, and most of its genes are inactive.
  - Later, it may initiate phage production.

Checkpoint question Describe one way a virus can perpetuate its genes without destroying its host cell. What is this type of replication cycle called?

Some viruses can insert their DNA into a chromosome of the host cell, which replicates the viral genes when it replicates its own DNA prior to cell division. This is called the lysogenic cycle.

Figure 10.17



Phage
Attaches to cell
Phage DNA
Bacterial chromosome
1 The phage injects its DNA
Newly released phage may infect another cell
4 The cell lyses, releasing phages
2 The phage DNA circularizes
Environmental stress
Many cell divisions
Lytic cycle
Lysogenic cycle
New phages assemble
6 The lysogenic bacterium replicates normally, copying the prophage at each cell division
Prophage
OR
3 New phage DNA and proteins are synthesized
5 Phage DNA inserts into the bacterial chromosome

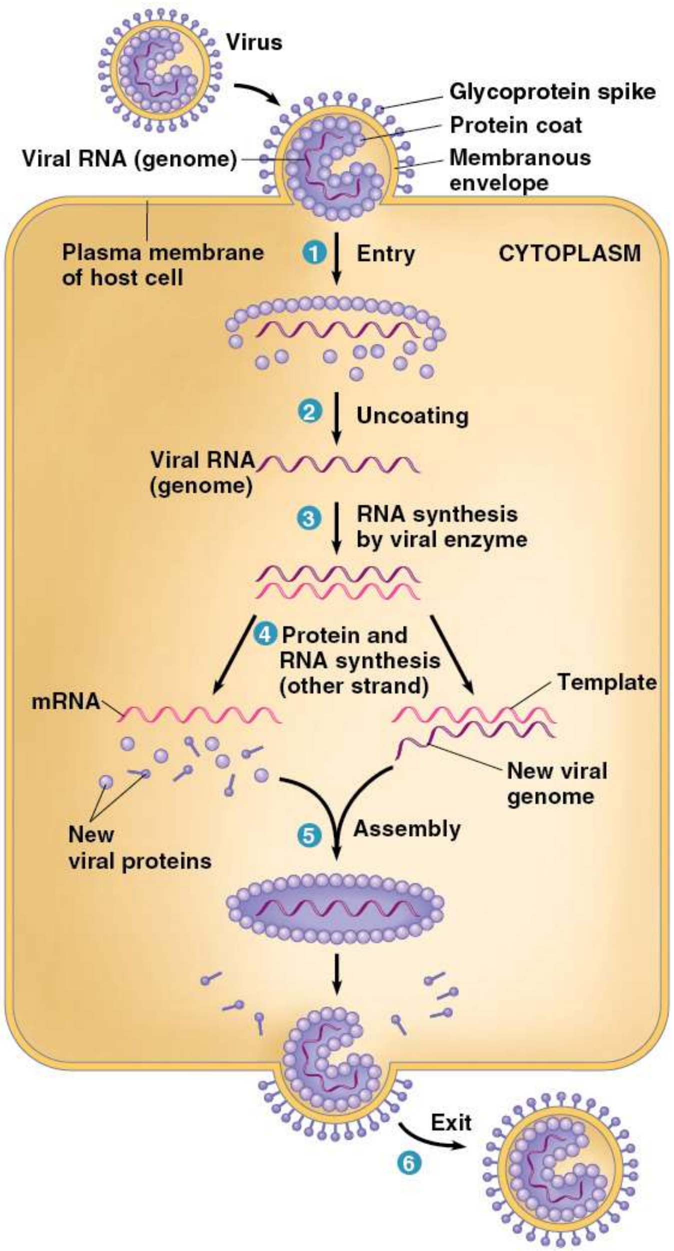
10.18 Connection: Many Viruses Cause Disease in Animals and Plants

- Flu viruses and most plant viruses have RNA, rather than DNA, as their genetic material.
- Some animal viruses steal a bit of host cell membrane as a protective envelope.

Checkpoint question Explain how some viruses replicate without having DNA.

The genetic material of these viruses is RNA, which is replicated inside the host cell by special enzymes encoded by the virus. The viral genome (or its complement) serves as mRNA for the synthesis of viral proteins.

Figure 10.18_6



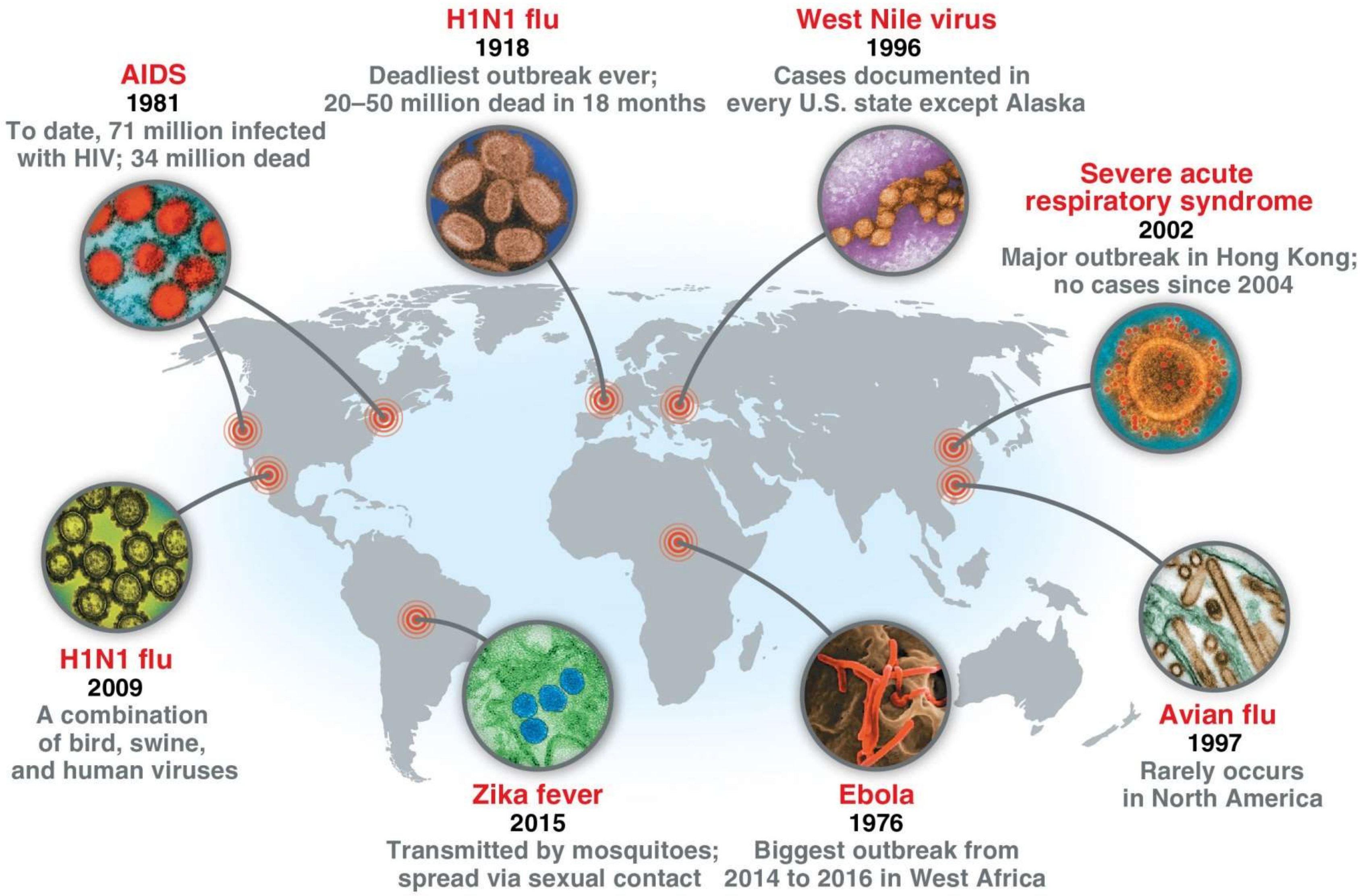
10.19 Evolution Connection: Emerging Viruses Threaten Human Health

- **Emerging viruses** are ones that seem to burst on to the scene, becoming apparent to the medical community quite suddenly.
- One familiar example is **HIV** (human immunodeficiency virus), the virus that causes **AIDS** (acquired immunodeficiency syndrome).

Checkpoint question Why doesn't a flu shot one year give us immunity to flu in subsequent years?

Influenza viruses evolve rapidly by frequent mutation; thus, the strains that infect us later will most likely be different from the ones to which we've been vaccinated.

Figure 10.19


AIDS
1981
To date, 71 million infected with HIV; 34 million dead
H1N1 flu
1918
Deadliest outbreak ever; 20–50 million dead in 18 months
West Nile virus
1996
Cases documented in every U.S. state except Alaska
Severe acute respiratory syndrome
2002
Major outbreak in Hong Kong; no cases since 2004
H1N1 flu
2009
A combination of bird, swine, and human viruses
Zika fever
2015
Transmitted by mosquitoes; spread via sexual contact
Ebola
1976
Biggest outbreak from 2014 to 2016 in West Africa
Avian flu
1997
Rarely occurs in North America

10.20 The AIDS Virus Makes DNA on an RNA Template

- HIV is a **retrovirus**: It uses RNA as a template for making DNA, which then inserts into a host chromosome.
- These viruses carry molecules of an enzyme called **reverse transcriptase**, which catalyzes reverse transcription: the synthesis of DNA on an RNA template.

Checkpoint question Why is HIV reverse transcriptase a good target for anti-AIDS drug therapy?

Reverse transcriptase is unique to HIV; we do not normally copy genetic information from RNA to DNA, so disabling reverse transcriptase would not adversely affect a human.

Figure 10.20a

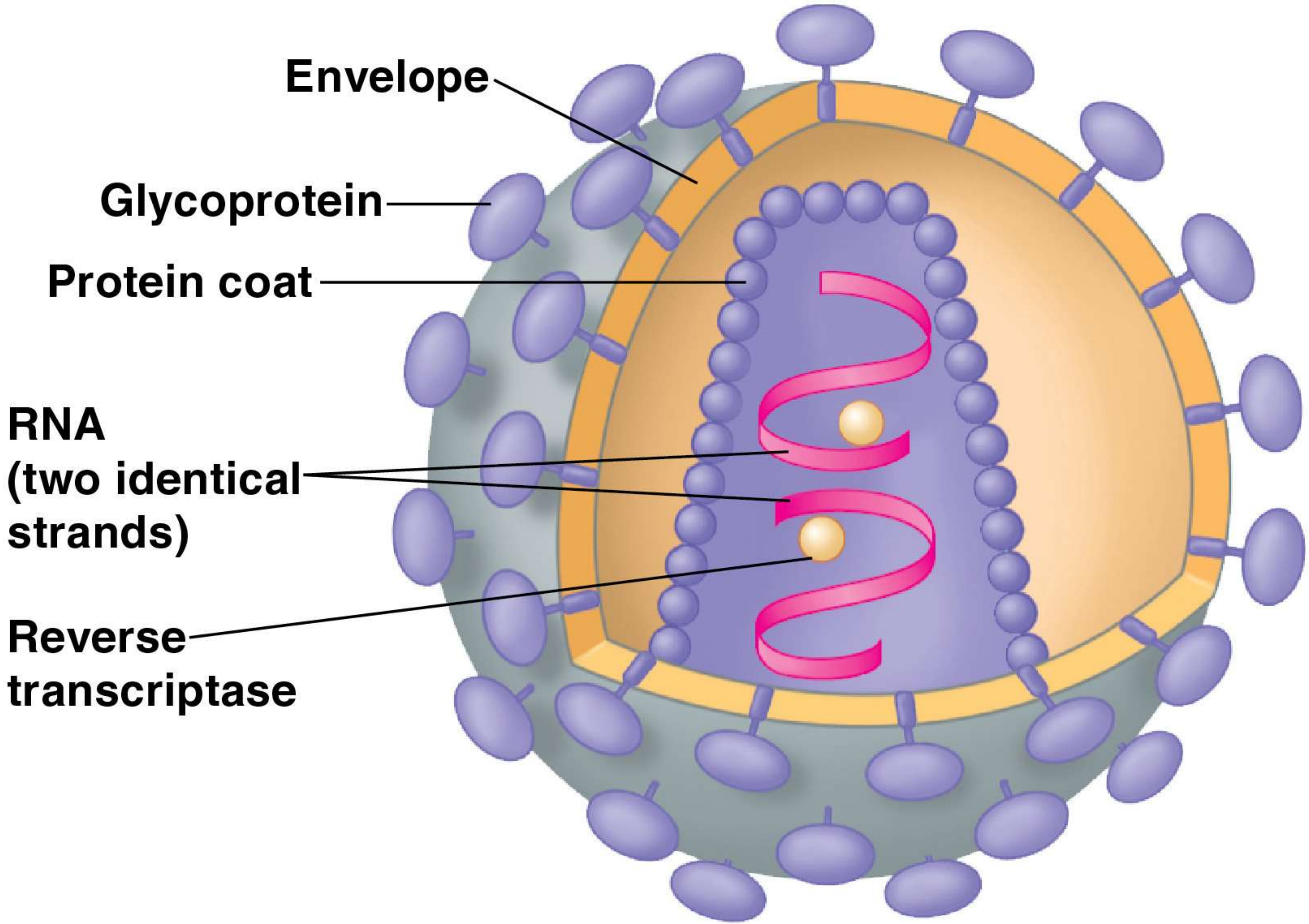
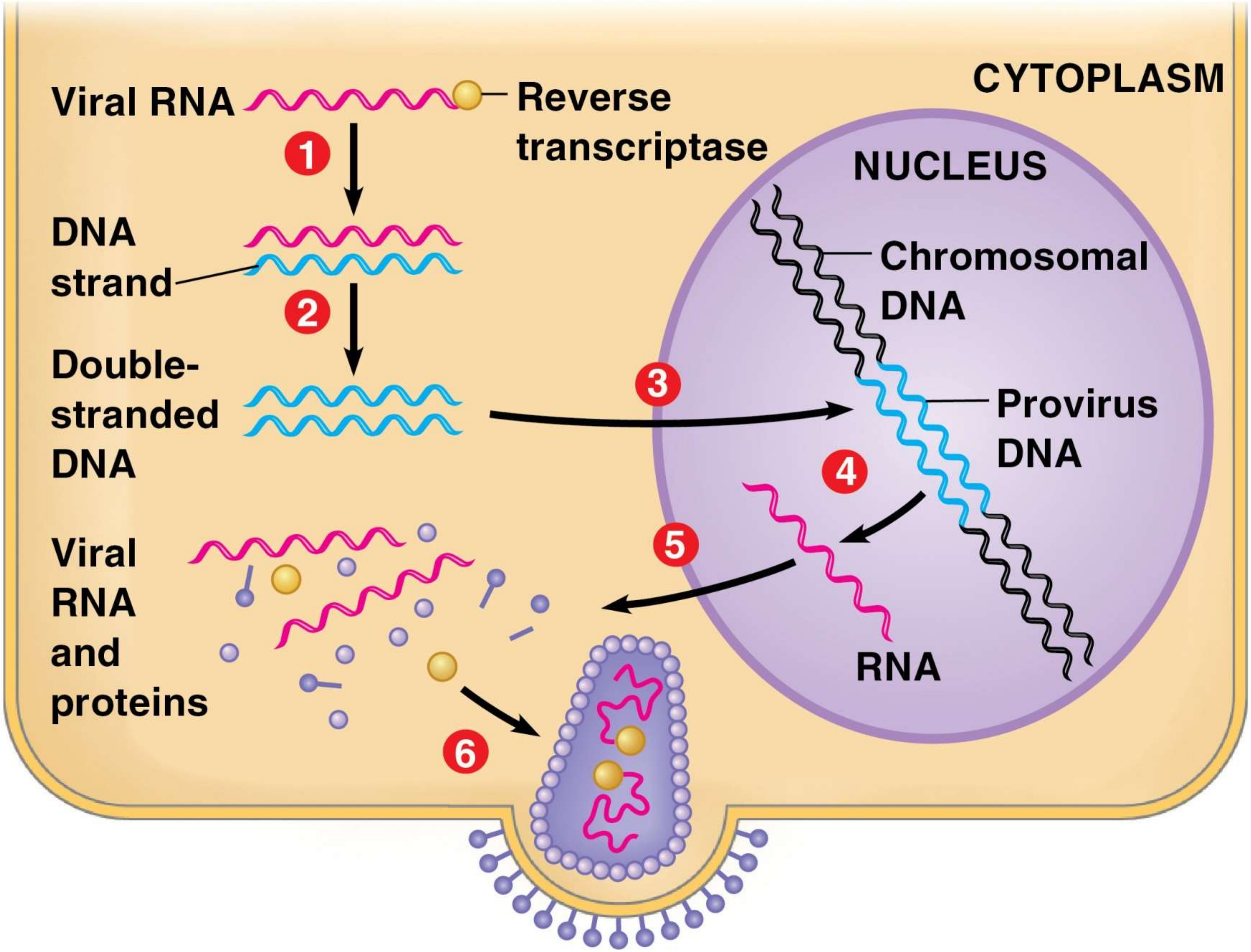


Figure 10.20b



10.21 Prions Are Infectious Proteins

- **Prions** are infectious proteins that can cause brain diseases in animals.
- When the prion gets into a cell containing the normal form of the protein, the prion somehow converts normal protein molecules to misfolded versions.

Checkpoint question What makes prions different from all other known infectious agents?

Prions are proteins and have no nucleic acid.

10.22 Bacteria Can Transfer DNA in Three Ways

- Bacteria use three mechanisms to move genes from cell to cell.
  1. **Transformation** is the uptake of DNA from the surrounding environment.
  2. **Transduction** is gene transfer by phages.
  3. **Conjugation** is the transfer of DNA from a donor to a recipient bacterial cell.
- Once new DNA gets into a bacterial cell by any mechanism, part of it may then integrate into the recipient's chromosome.

Figure 10.22a

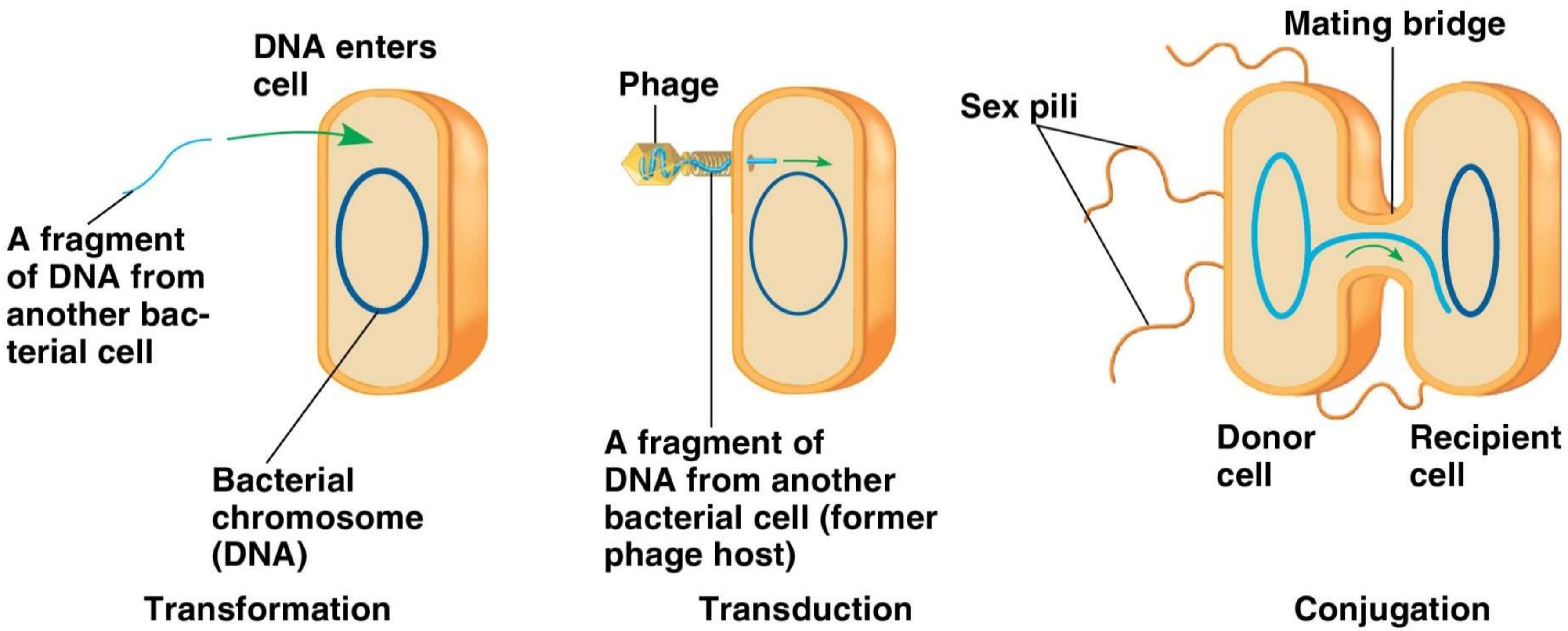
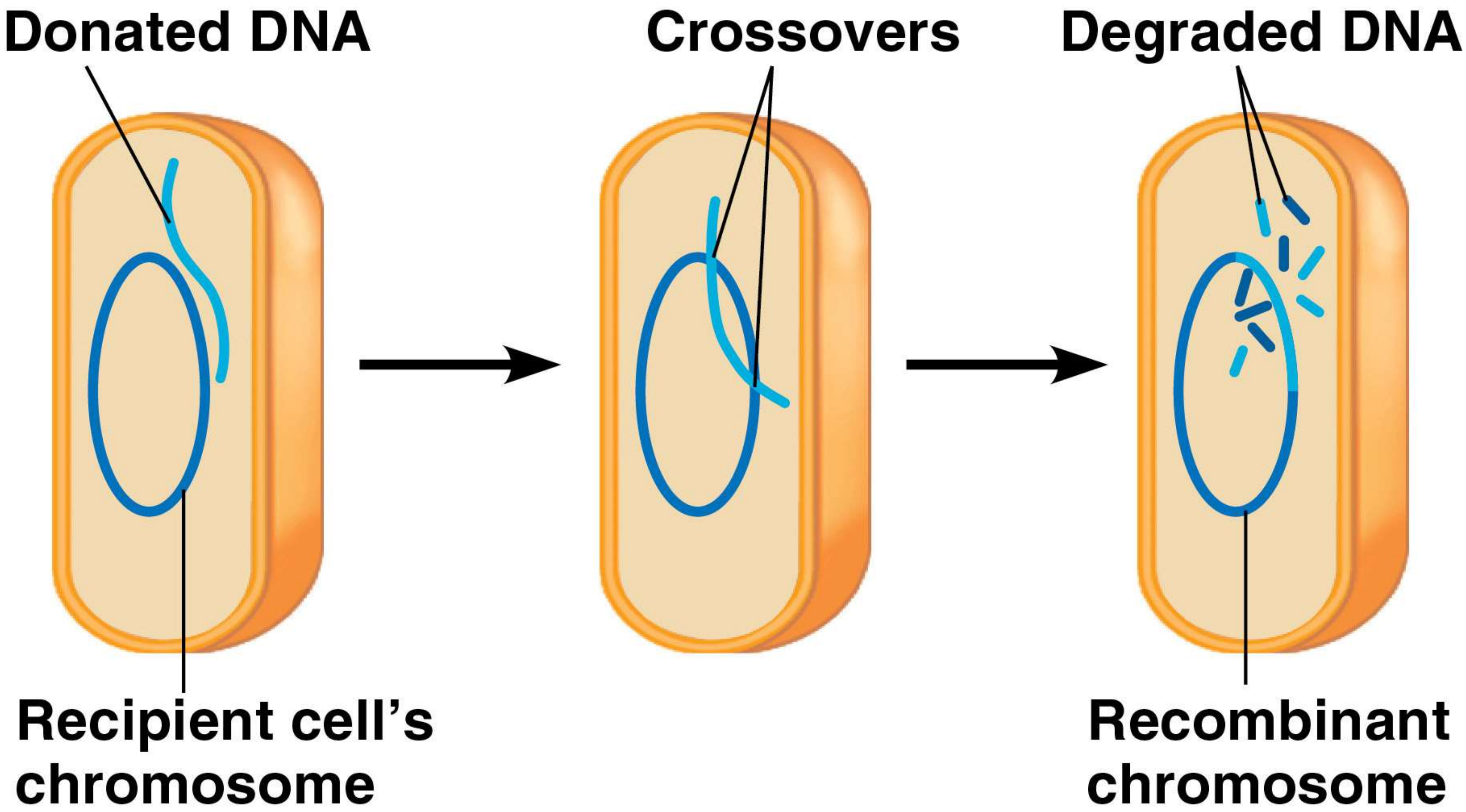


Figure 10.22b



10.23 Bacterial Plasmids Can Serve as Carriers for Gene Transfer

- The ability of a donor *E. coli* cell to carry out conjugation is usually due to a specific piece of DNA called the **F factor** (F for fertility).
  - An F factor can exist as a **plasmid**, a small, circular D N A molecule separate from the bacterial chromosome.
  - **R plasmids** pose serious problems for human medicine by carrying genes for enzymes that destroy antibiotics.

Checkpoint question Plasmids are useful tools for genetic engineering. Can you guess why?