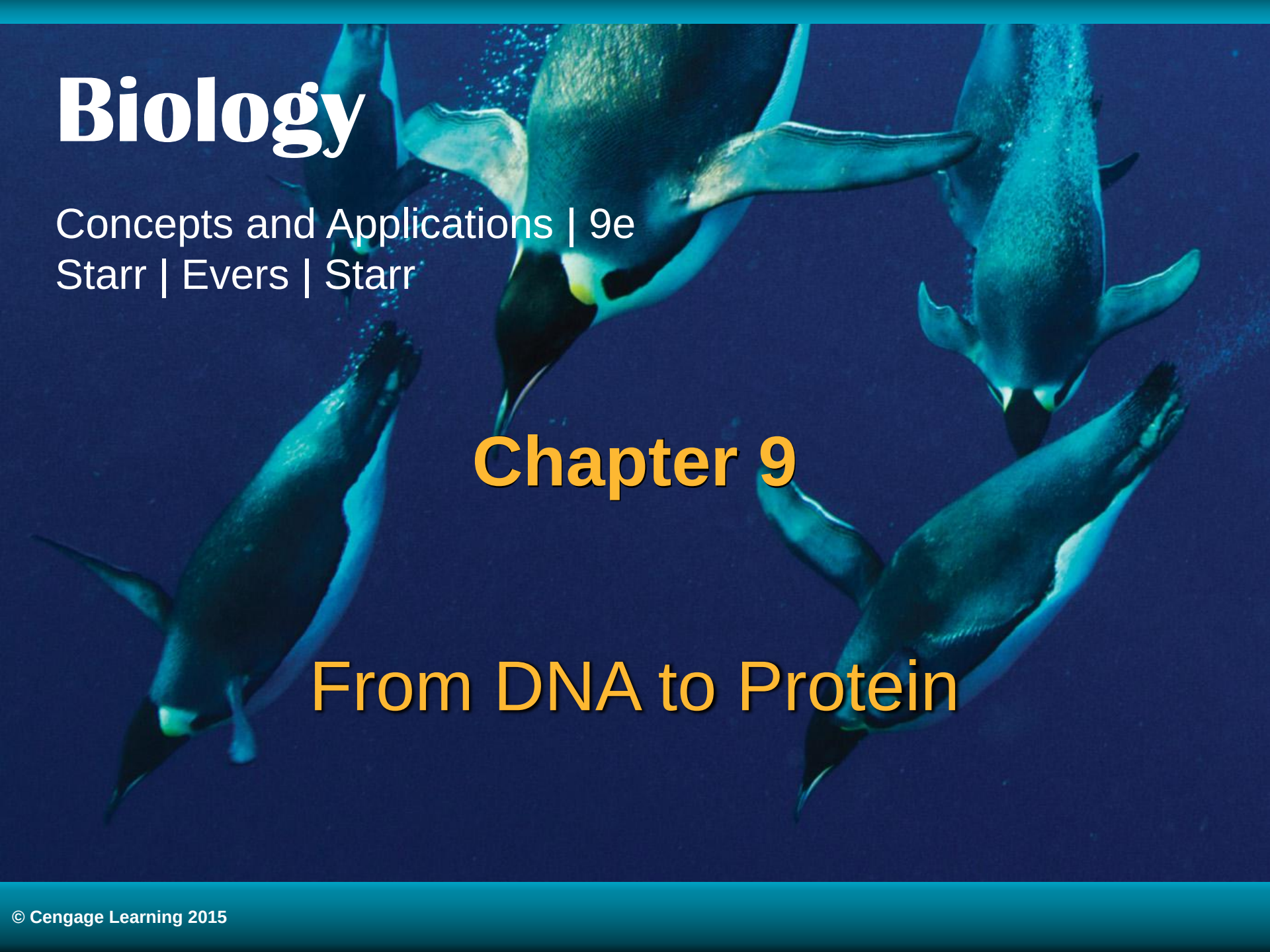

Biology

Concepts and Applications | 9e
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Chapter 9

From DNA to Protein

9.1 What Is the Information Carried in DNA?

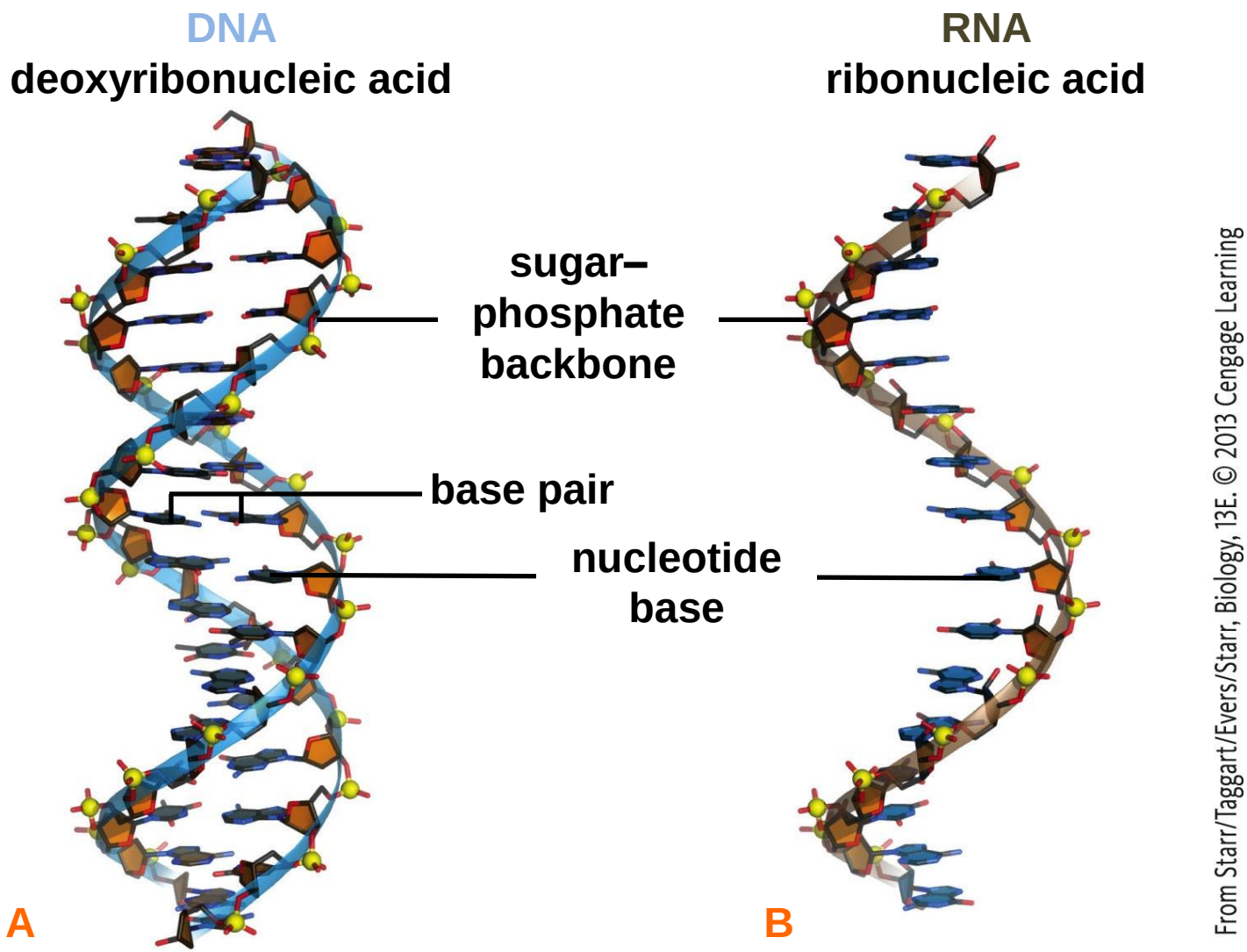
- DNA to RNA
  - The DNA sequence of a *gene* encodes (contains instructions for building) an RNA or protein product
  - Converting the information encoded by a gene into a product starts with *transcription* (RNA synthesis)
  - During transcription, enzymes use the gene's DNA sequence as a template to assemble a strand of RNA

DNA to RNA (cont'd.)

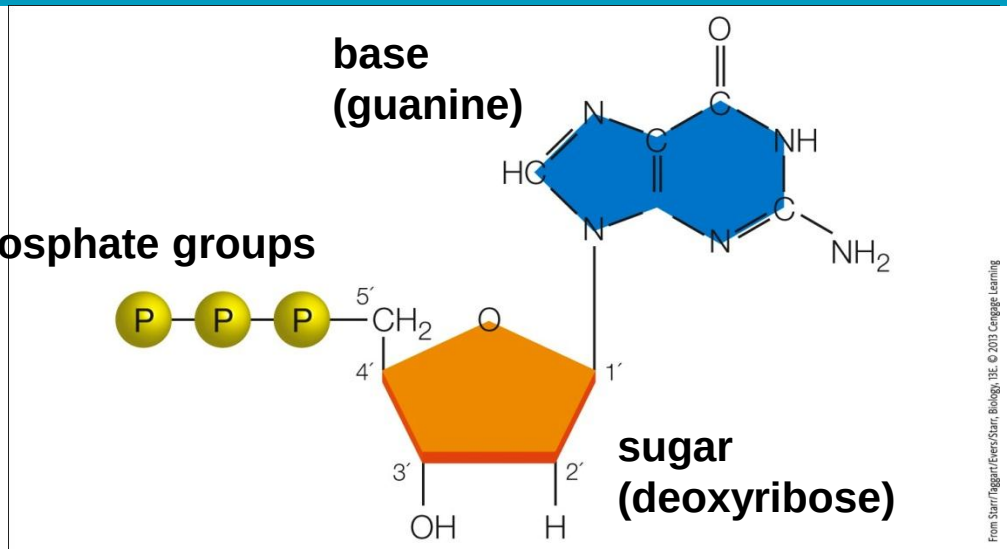
DNA to RNA (cont'd.)

- RNA is composed of a single-strand chain of nucleotides
- An RNA nucleotide has three phosphate groups, a sugar, and one of four bases
  - Unlike DNA, the sugar is a ribose
  - RNA contains three of the same bases found in DNA (adenine, cytosine, and guanine)
  - RNA's fourth base is uracil, not thymine (as found in DNA)

DNA to RNA (cont'd.)



DNA to RNA (cont'd.)



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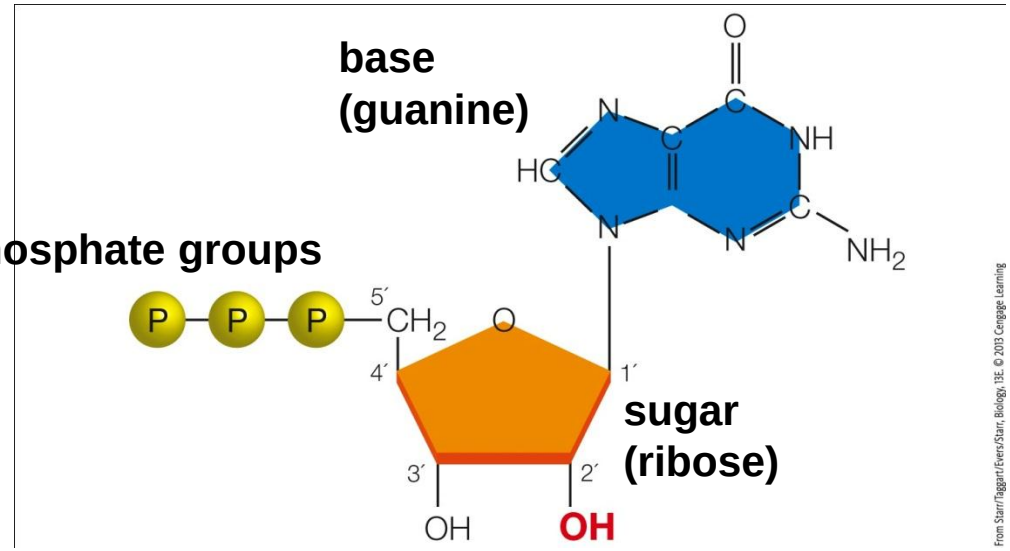


B

DNA to RNA (cont'd.)

- Three types of RNA:
  - Ribosomal RNA (rRNA): the main component of ribosomes, which assemble amino acids into polypeptide chains
  - Transfer RNA (tRNA): delivers amino acids to a ribosome during protein synthesis
  - Messenger RNA (mRNA): contains the protein-building message; specifies order of amino acid sequence

RNA to Protein

- An mRNA's protein-building message is encoded by sets of three nucleotides
- By the process of *translation*, the protein-building information in an mRNA is decoded (translated) into a sequence of amino acids
  - Results in a polypeptide chain that twists and folds into a protein

RNA to Protein (cont'd.)

RNA to Protein (cont'd.)

- Transcription and translation are part of *gene expression*:
  - Multistep process by which information encoded in a gene guides the assembly of an RNA or protein product
  - Information flows from DNA to RNA to protein

RNA to Protein (cont'd.)

RNA to Protein (cont'd.)

- A cell's DNA sequence contains all the information it needs to make the molecules of life
  - Each gene encodes an RNA, and RNAs interact to assemble proteins
  - Proteins assemble lipids and carbohydrates, replicate DNA, make RNA, and perform many other functions that keep the cell alive

9.2 How is RNA Assembled?

- The same base-pairing rules for DNA also govern RNA synthesis in transcription
  - An RNA strand is so similar to a DNA strand that the two can base-pair if their nucleotide sequences are complementary
  - G pairs with C, and A pairs with U (uracil)

How is RNA Assembled? (cont'd.)

How is RNA Assembled? (cont'd.)

- During transcription, a strand of DNA acts as a template upon which a complementary strand of RNA is assembled from nucleotides
- In contrast with DNA replication, only part of one DNA strand, not the whole molecule, is used as a template for transcription

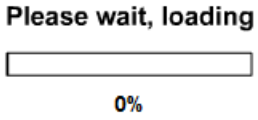
How is RNA Assembled? (cont'd.)

- The enzyme RNA polymerase adds nucleotides to the end of a growing RNA
- In contrast to DNA replication, transcription produces a single strand of RNA
- In eukaryotic cells, transcription occurs in the nucleus; in prokaryotes, it occurs in cytoplasm

How is RNA Assembled? (cont'd.)

- Transcription begins when an RNA polymerase and regulatory proteins attach to a DNA site called a *promoter*
  - RNA polymerase moves over a gene region and unwinds the double helix a bit so it can "read" the base sequence of the DNA strand
  - The polymerase joins free RNA nucleotides into a chain (at 3' end of strand), in the order dictated by that DNA sequence

ANIMATION: Gene transcription details



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ANIMATION: Pre-mRNA transcript processing

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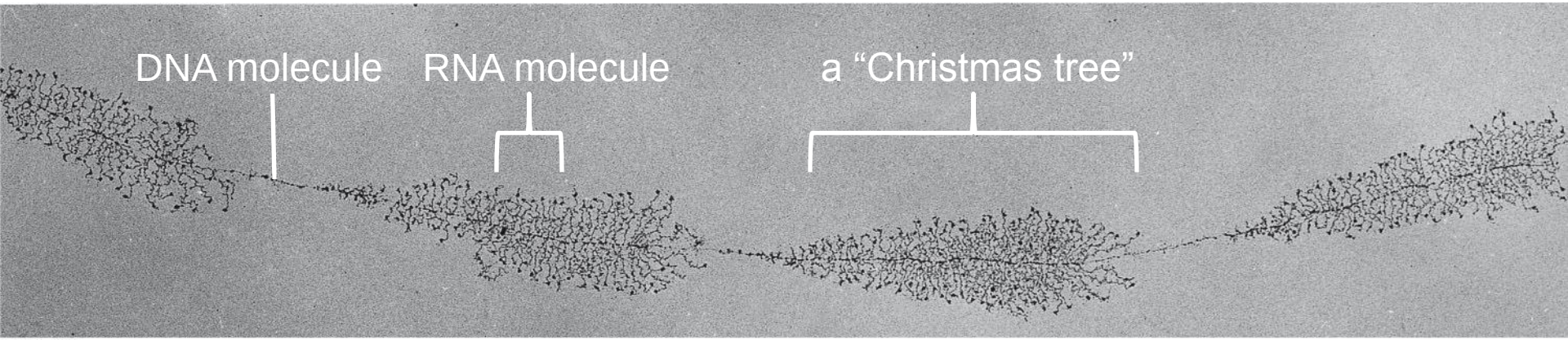
How is RNA Assembled? (cont'd.)

- When the polymerase reaches the end of the gene region, it releases the DNA and the new RNA
- Typically, many polymerases transcribe a particular gene region at the same time, so many new RNA strands can be produced very quickly

How is RNA Assembled? (cont'd.)



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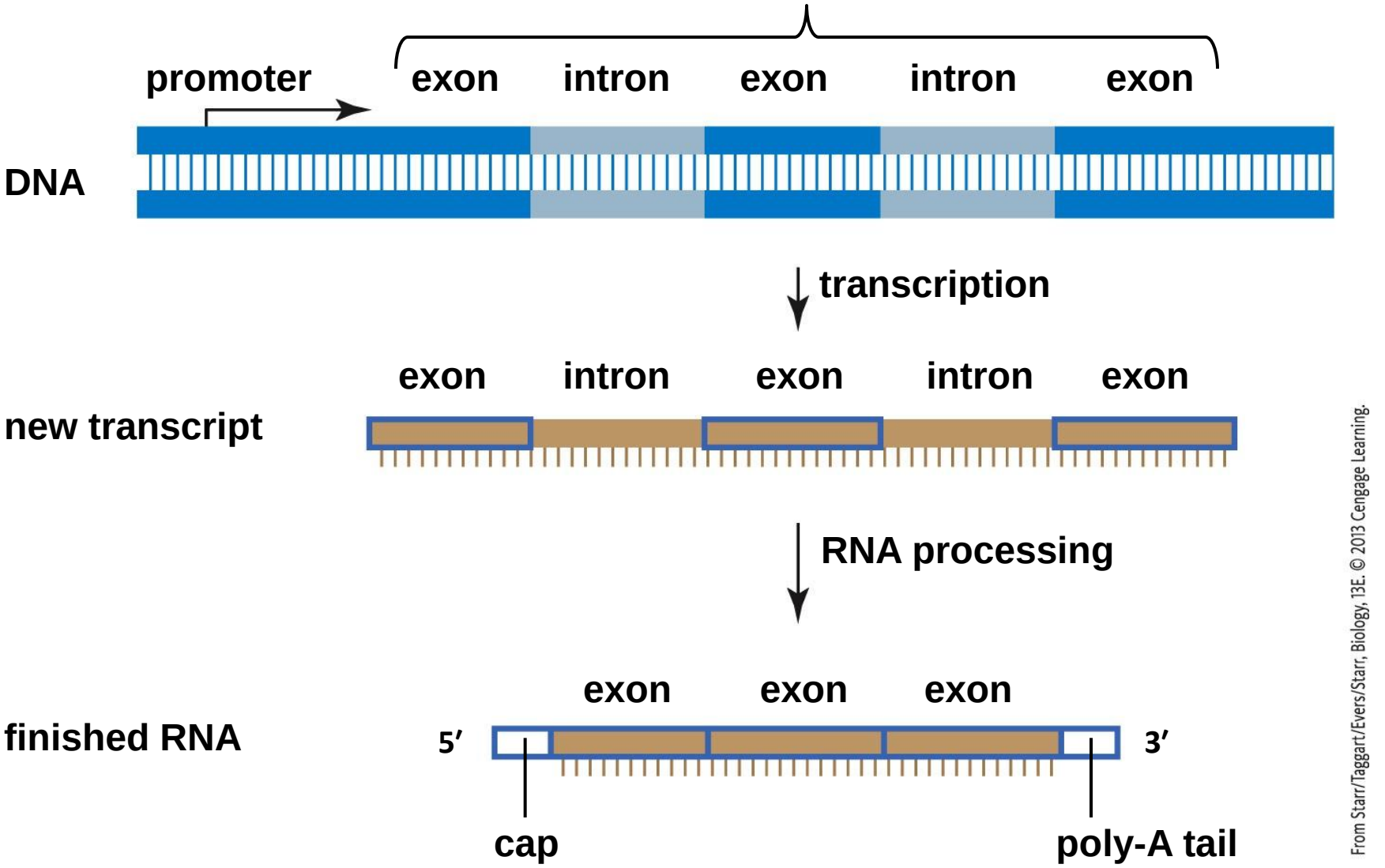
Post-Transcriptional Modifications

- Most eukaryotic genes contain intervening sequences called *introns*
  - Introns are removed from a newly transcribed RNA before it leaves the nucleus
- Sequences that stay in the RNA are called *exons*

Post-Transcriptional Modifications (cont'd.)

- In a process called *alternative splicing*, exons can be rearranged and spliced together in different combinations
- Further modifications of mRNA include:
  - A modified guanine "cap" is added to the 5′ end (helps mRNA bind to a ribosome)
  - A poly-A tail (multiple adenines) are added to the 3′ end (enables exportation from the nucleus)

Post-Transcriptional Modifications (cont'd.)



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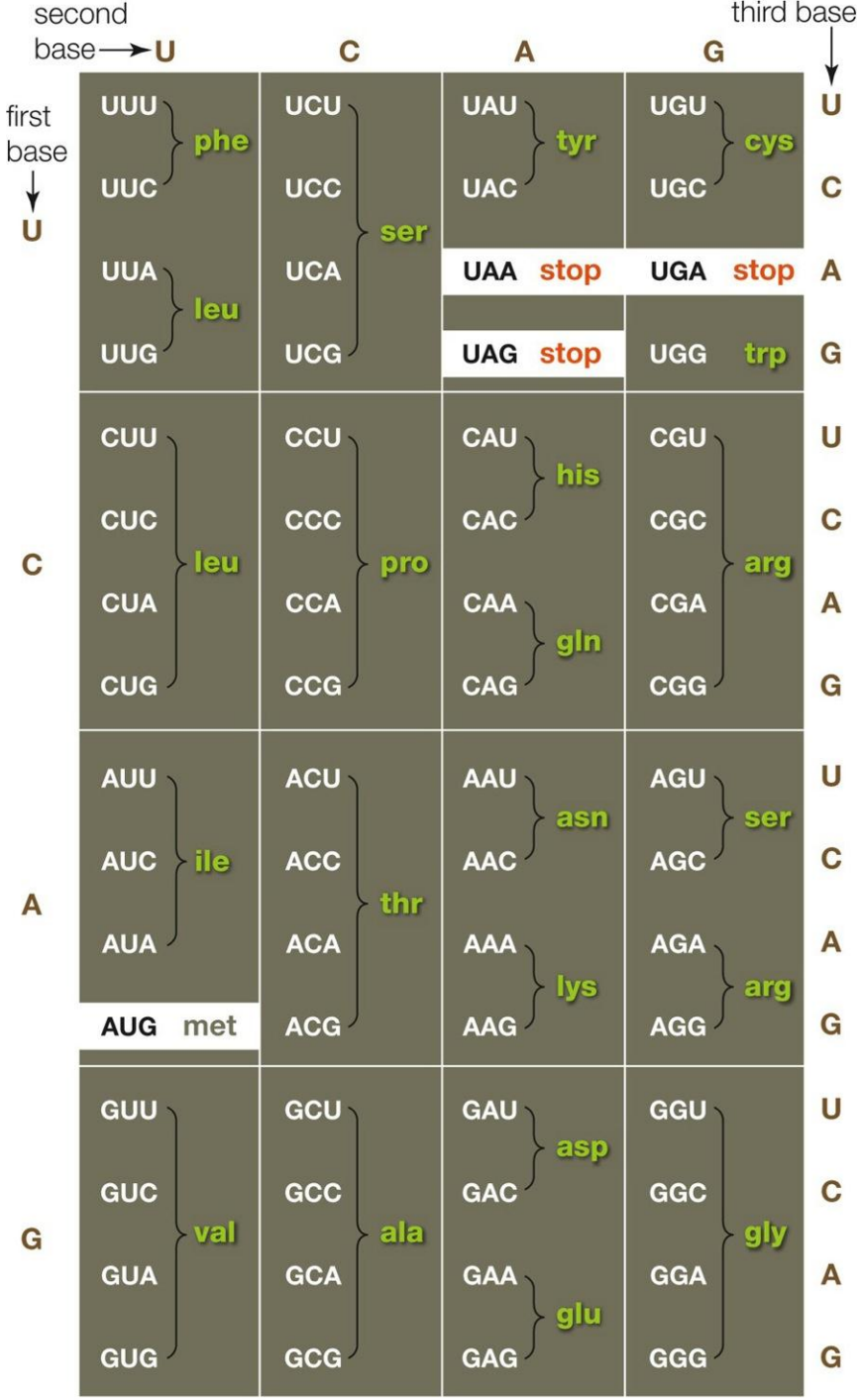
9.3 What Roles Do mRNA, rRNA, and tRNA Play During Translation?

- The messenger: mRNA
  - Codon: an mRNA nucleotide base triplet that codes for an amino acid (or stop signal)
  - There are a total of sixty-four mRNA codons that constitute the *genetic code*
  - The sequence of bases in a triplet determines which amino acid the codon specifies
    - Example: UUU codes for the amino acid phenylalanine, and UUA codes for leucine

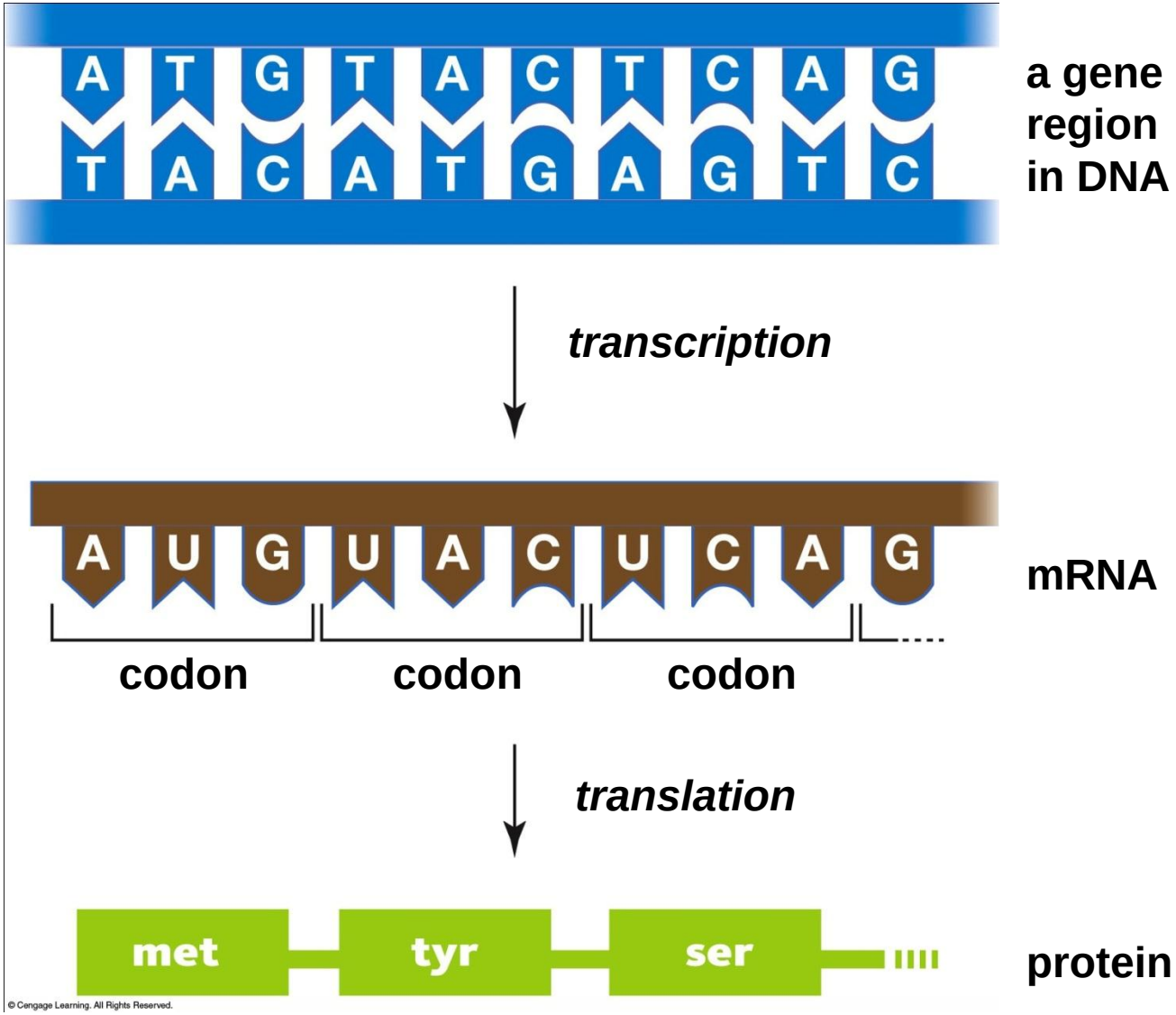
The Messenger: mRNA (cont'd.)



The Messenger: mRNA (cont'd.)

- Codons occur one after another along the length of an mRNA
- When an mRNA is translated, the order of its codons determines the order of amino acids in the resulting polypeptide

The Messenger: mRNA (cont'd.)



The Messenger: mRNA (cont'd.)

- With a few exceptions, twenty naturally occurring amino acids are encoded by the genetic code
  - Some amino acids are specified by more than one codon
    - Example: the amino acid tyrosine is specified by two codons: UAA and UAC

The Messenger: mRNA (cont'd.)

- Some codons signal the beginning and end of a protein-coding sequence
  - The first AUG in an mRNA: signal to start translation
  - UAA, UAG, and UGA: signals that stop translation
- The genetic code is highly conserved

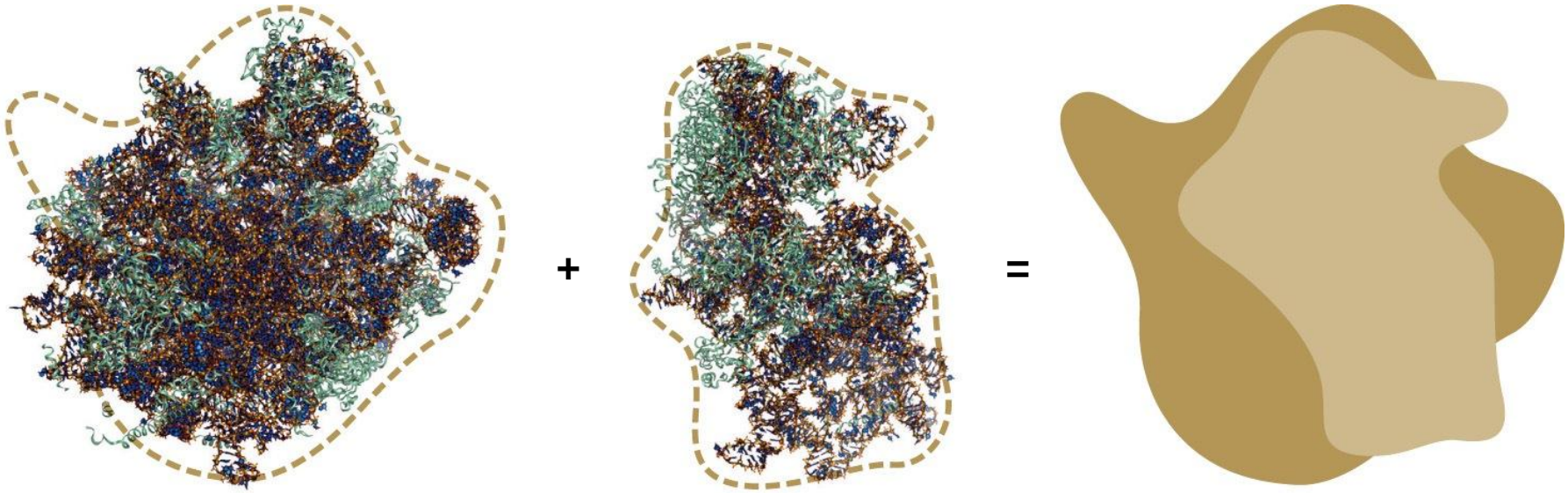
The Translators: rRNA and tRNA

- Ribosomes interact with transfer RNAs (tRNAs) to translate the sequence of codons in an mRNA into a polypeptide

The Translators: rRNA and tRNA (cont'd.)

- A ribosome has two subunits, one large and one small that consist mainly of rRNA
  - During translation, a large and a small ribosomal subunit converge as an intact ribosome on an mRNA
- rRNA catalyzes formation of a peptide bond between amino acids as they are delivered to the ribosome

The Translators: rRNA and tRNA (cont'd.)



large subunit **small subunit** **intact ribosome**

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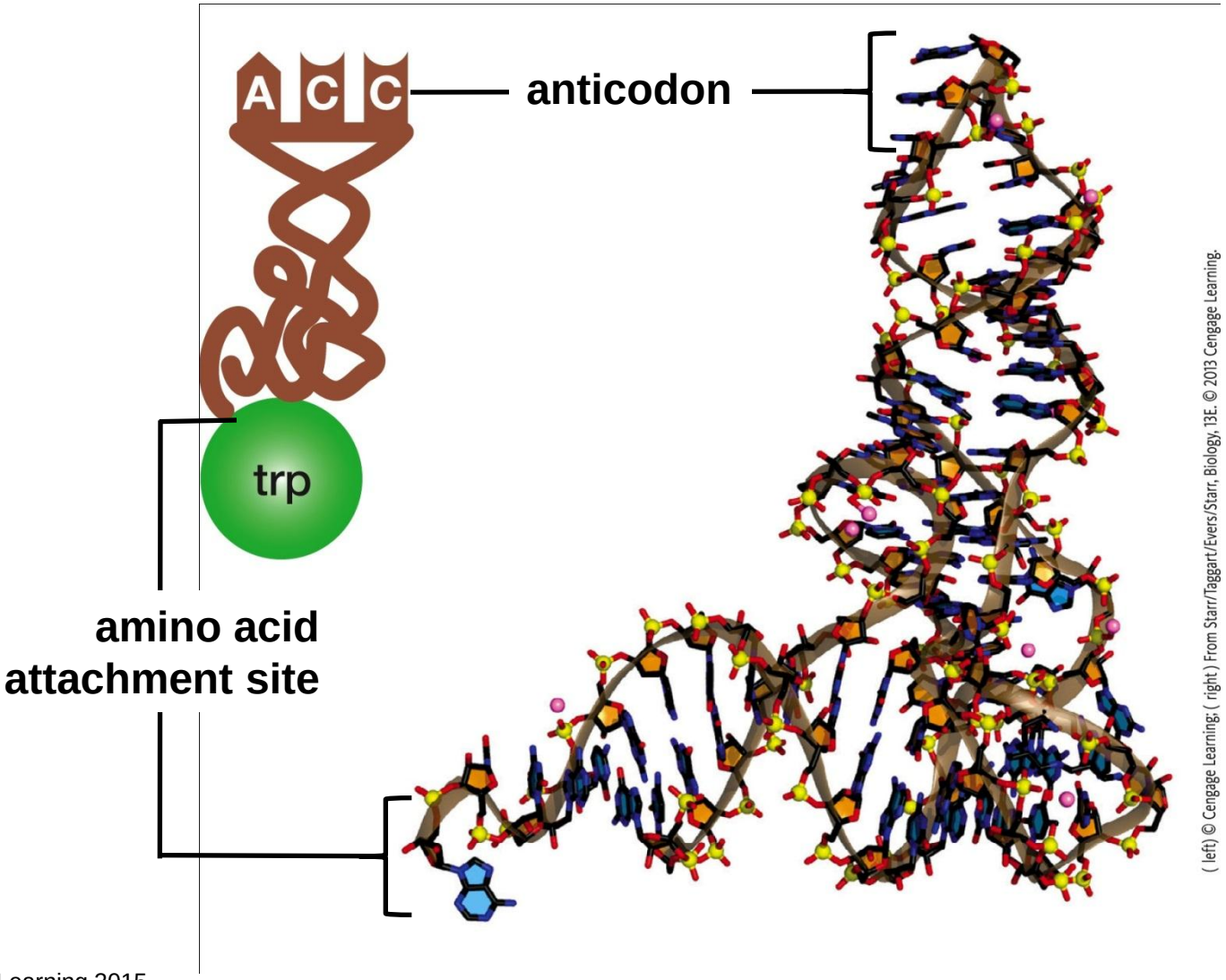
The Translators: rRNA and tRNA (cont'd.)

- Each tRNA has two attachment sites:
  - Anticodon: a triplet of nucleotides that base-pairs with an mRNA codon
  - The other attachment site binds to an amino acid (as specified by the codon)

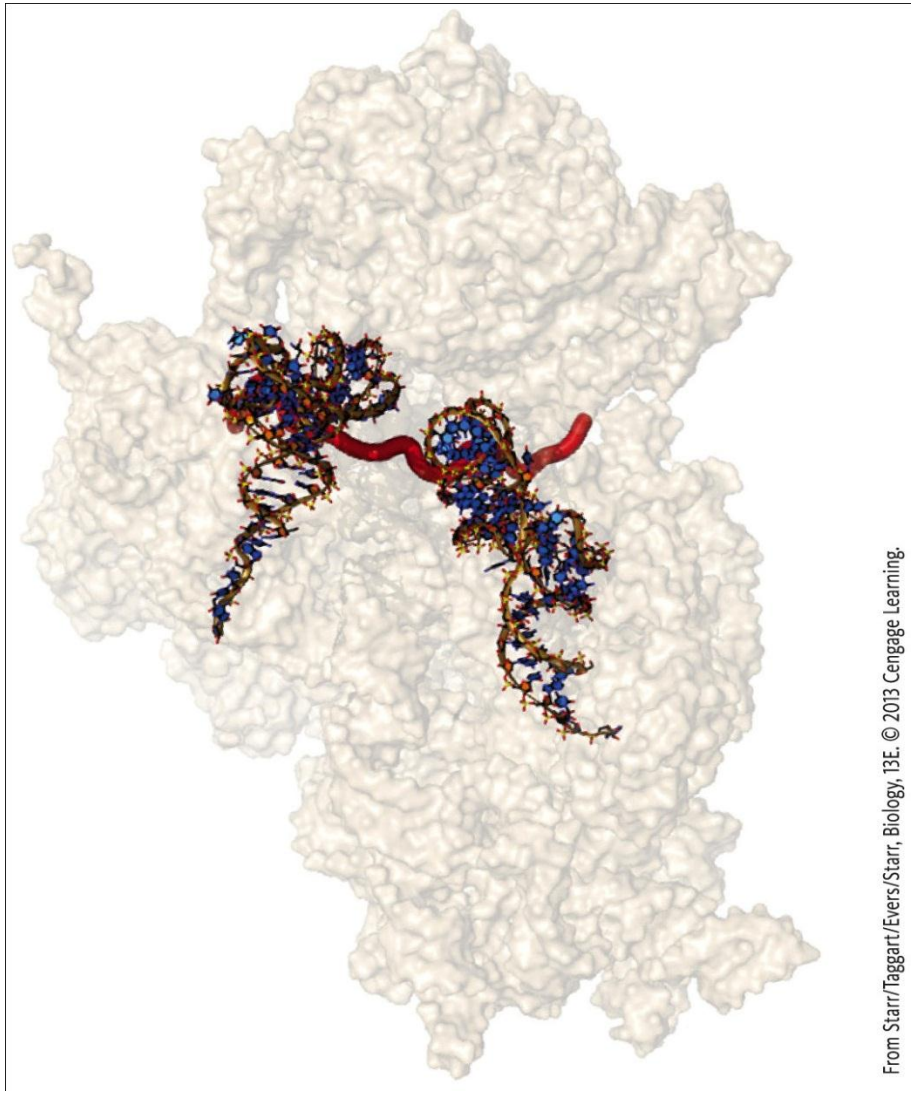
The Translators: rRNA and tRNA (cont'd.)



The Translators: rRNA and tRNA (cont'd.)

- During translation, tRNAs deliver amino acids to a ribosome
  - One after the next in the order specified by the codons in an mRNA
- As the amino acids are delivered, the ribosome joins them via peptide bonds into a new polypeptide

The Translators: rRNA and tRNA (cont'd.)



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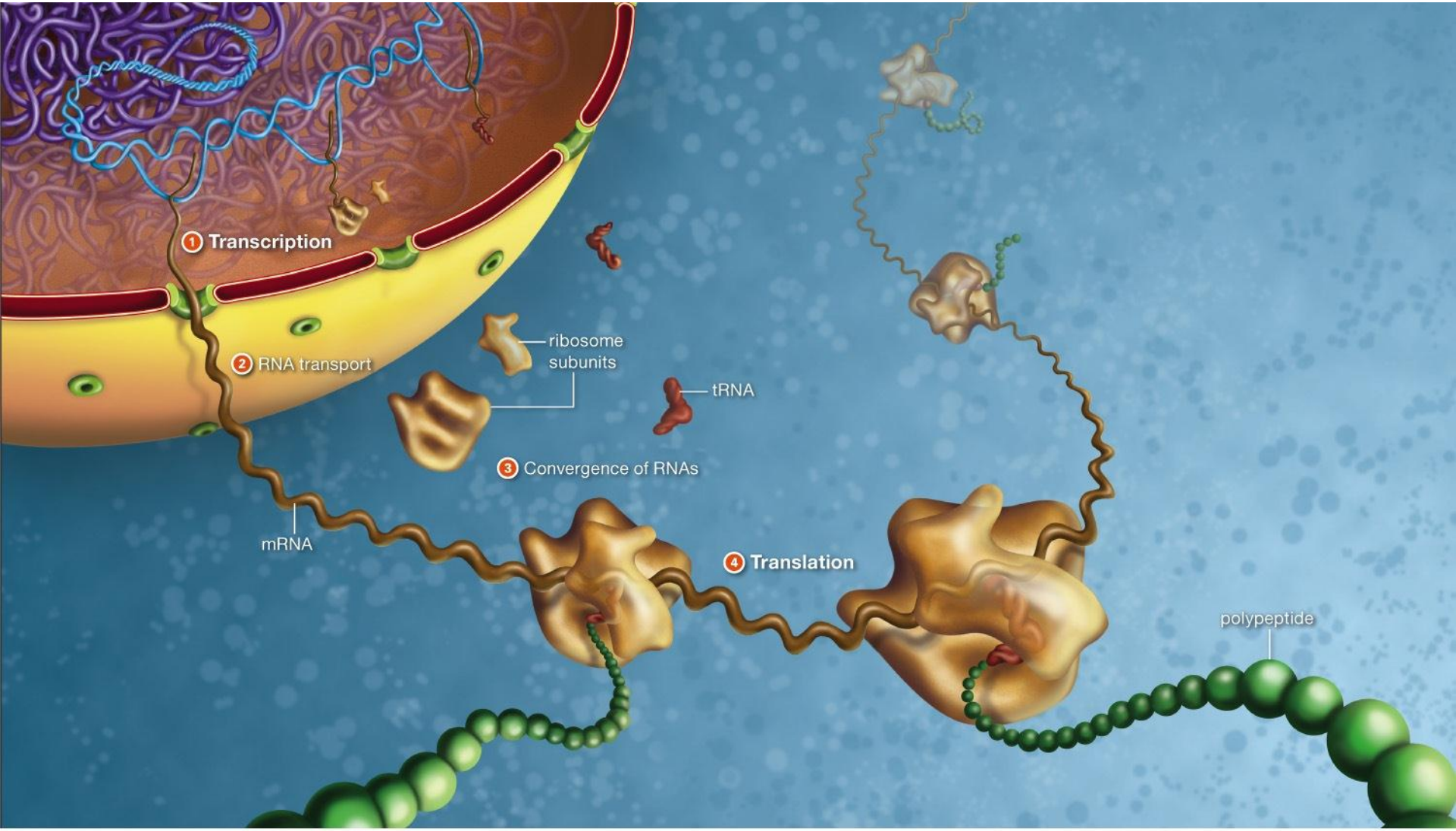
9.4 How Is mRNA Translated Into Protein?

- Steps of translation:
  - Translation begins in the cytoplasm when a small ribosomal subunit binds to the mRNA
  - Next, the anticodon of a special tRNA called an initiator base-pairs with the first AUG codon of the mRNA
  - A large ribosomal subunit joins the small subunit, and the intact ribosome begins to assemble a polypeptide chain as it moves along the mRNA

How Is mRNA Translated Into Protein?



How Is mRNA Translated Into Protein? (cont'd.)

- Steps of translation (cont'd.)
  - Initiator tRNAs carry methionine
    - The first amino acid of all new polypeptide chains
  - Another tRNA joins the complex when its anticodon base-pairs with the second codon
  - The ribosome catalyzes formation of a peptide bond between first two amino acids
  - As the ribosome moves to the next codon, it releases the first tRNA

ANIMATION: Translation

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9.5 What Happens After a Gene Becomes Mutated?

- Types of mutations:
  - Base-pair substitution: a single base pair changes
  - Deletion: one or more nucleotides are lost
  - Insertion: one or more nucleotides become inserted into DNA

What Happens After a Gene Becomes Mutated? (cont'd.)

- Mutations are relatively uncommon events in a normal cell:
  - Chromosomes in a diploid human cell consist of about 6.5 billion nucleotides
    - About 175 nucleotides change during DNA replication
    - Only about 3 percent of the cell's DNA encodes protein products
    - There is a low probability that any of those mutations will be in a protein-coding region

What Happens After a Gene Becomes Mutated? (cont'd.)

- When a mutation does occur in a protein-coding region, the redundancy of the genetic code offers a margin of safety
  - Example: a mutation that changes a CCC codon to CCG may not have further effects, because both of these codons specify the amino acid serine

What Happens After a Gene Becomes Mutated? (cont'd.)

- Other mutations may change an amino acid in a protein, or result in a premature stop codon that shortens it
- Mutations that alter a protein can have drastic effects on an organism

What Happens After a Gene Becomes Mutated? (cont'd.)

- Sickle cell anemia
  - Occurs because of a base-pair substitution in the beta globin gene of hemoglobin
  - Causes hemoglobin molecules to clump together
    - Cause red blood cells to form a crescent (sickle) shape
  - Sickled cells clog tiny blood vessels, thus disrupting blood circulation throughout the body

ANIMATION: Frameshift mutation

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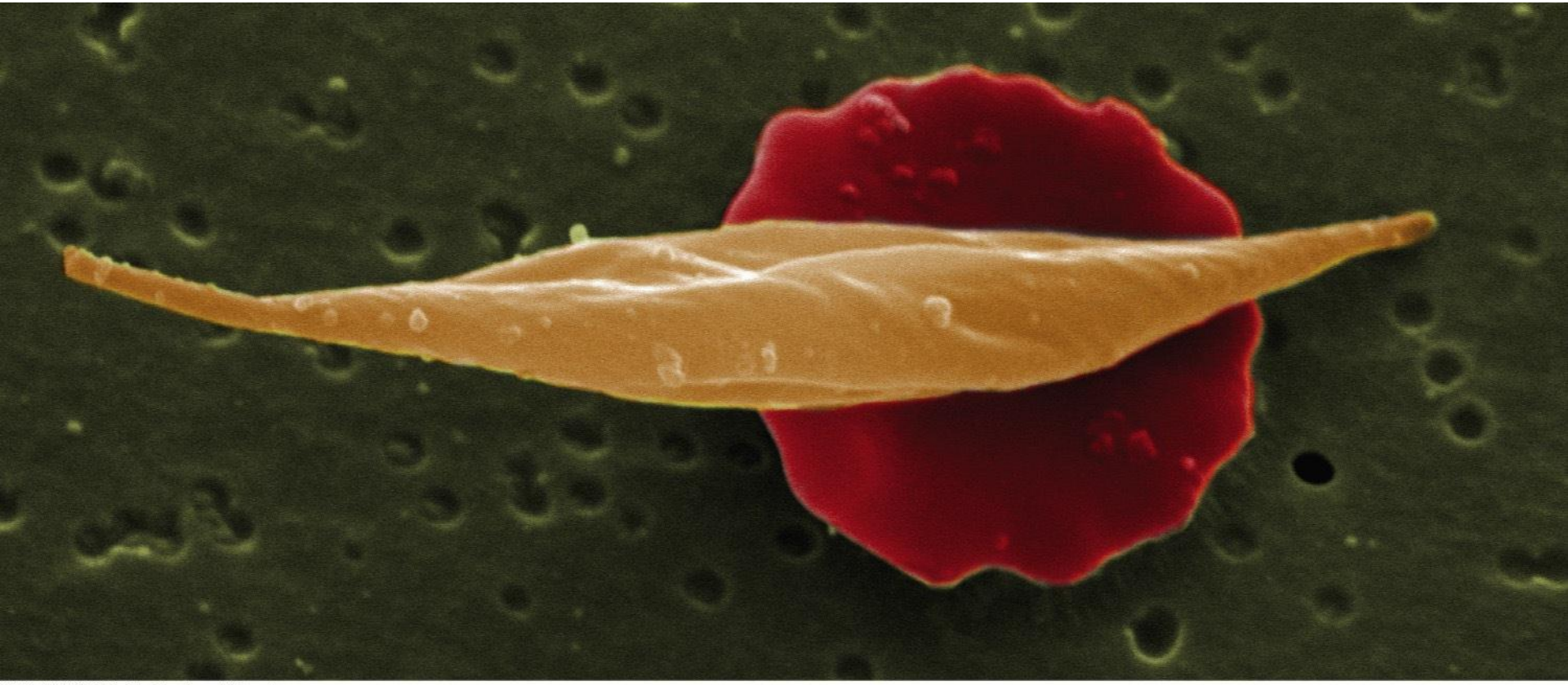
What Happens After a Gene Becomes Mutated? (cont'd.)



EM Unit, UCL Medical School, Royal Free Campus/Wellcome Images.

What Happens After a Gene Becomes Mutated? (cont'd.)

- Beta thalassemia
  - Caused by the deletion of the twentieth nucleotide in the coding region of the beta globin gene
    - Causes the reading frame of the mRNA codons to shift
  - Results in a polypeptide that differs drastically from normal beta globin

What Happens After a Gene Becomes Mutated? (cont'd.)

- Beta thalassemia can also be caused by insertion mutations, which, like deletions, often result in frameshifts

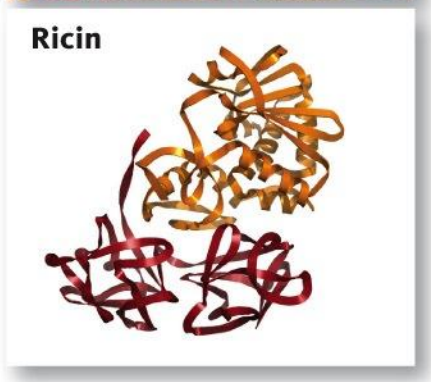
9.6 Application: The Aptly Acronymed RIPs

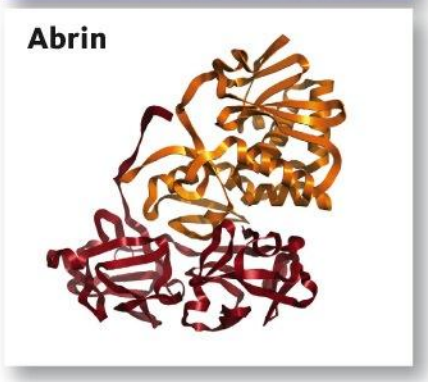
- A dose of ricin as small as a few grains of salt can kill an adult human
- Ricin is a ribosome-inactivating protein (RIP)
  - RIPs remove adenine bases from rRNAs in the heavy subunit
  - Elongation stops and protein synthesis halts
  - Death from ricin exposure occurs in days due to low blood pressure and respiratory failure

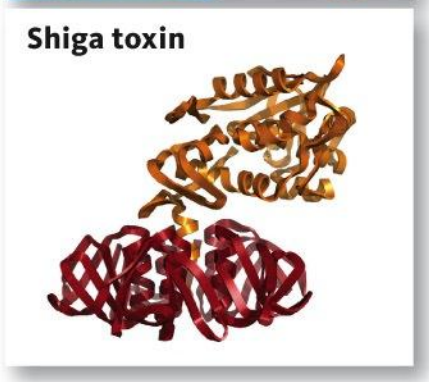
Application: The Aptly Acronymed RIPs (cont'd.)

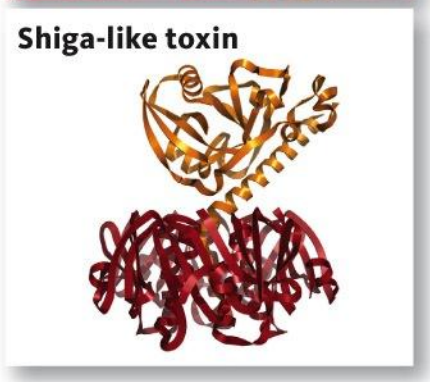
Cary Wolinsky/National Geographic Creative.

Application: The Aptly Acronymed RIPs (cont'd.)









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