Section 10.3 Outline

- **10.3 How Is the Base Sequence of a Messenger RNA Molecule Translated into Protein?**
  - Messenger RNA Carries Information for Protein Synthesis from the DNA to Ribosomes
  - Ribosomes Consist of Two Subunits, Each Composed of Ribosomal RNA and Protein

Section 10.3 Outline

- **10.3 How Is the Base Sequence of a Messenger RNA Molecule Translated into Protein? (continued)**
  - Transfer RNA Molecules Decode the Sequence of Bases in mRNA into the Amino Acid Sequence of a Protein
  - During Translation, mRNA, tRNA, and Ribosomes Cooperate in Protein Synthesis
  - Summary of Transcription and Translation

mRNA

- An intermediate molecule is required to convey DNA gene sequence to the ribosome
- **Messenger RNA (mRNA)** performs this function by serving as the complementary copy of a DNA gene that is read by a ribosome

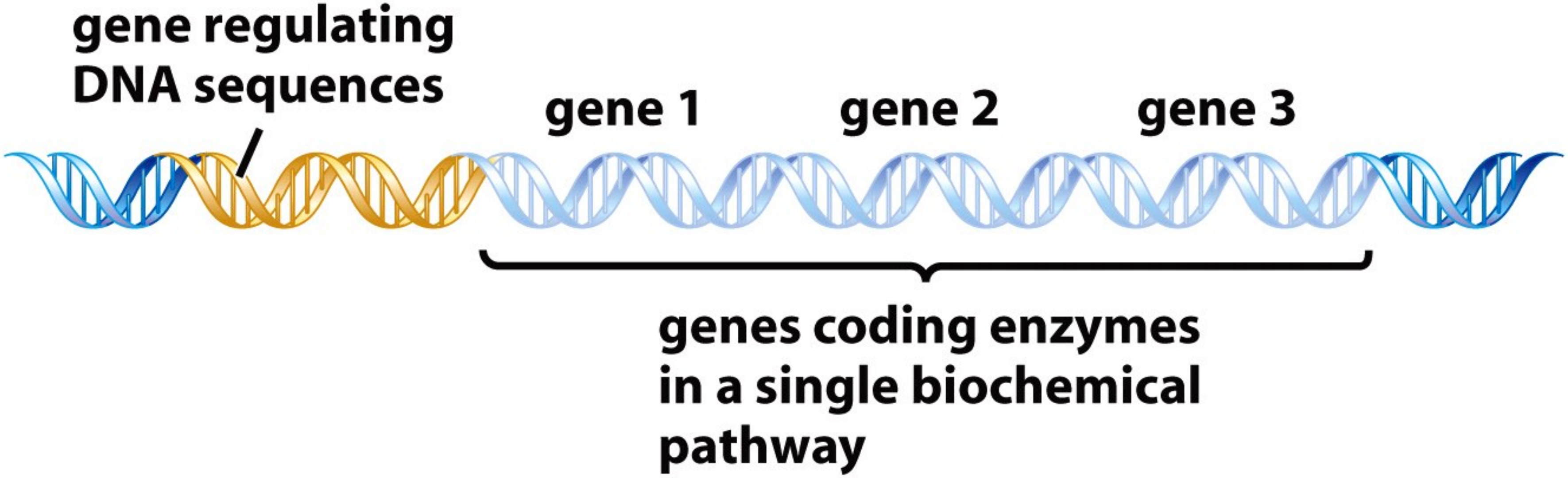


Figure 10-6a Biology: Life on Earth, 8/e

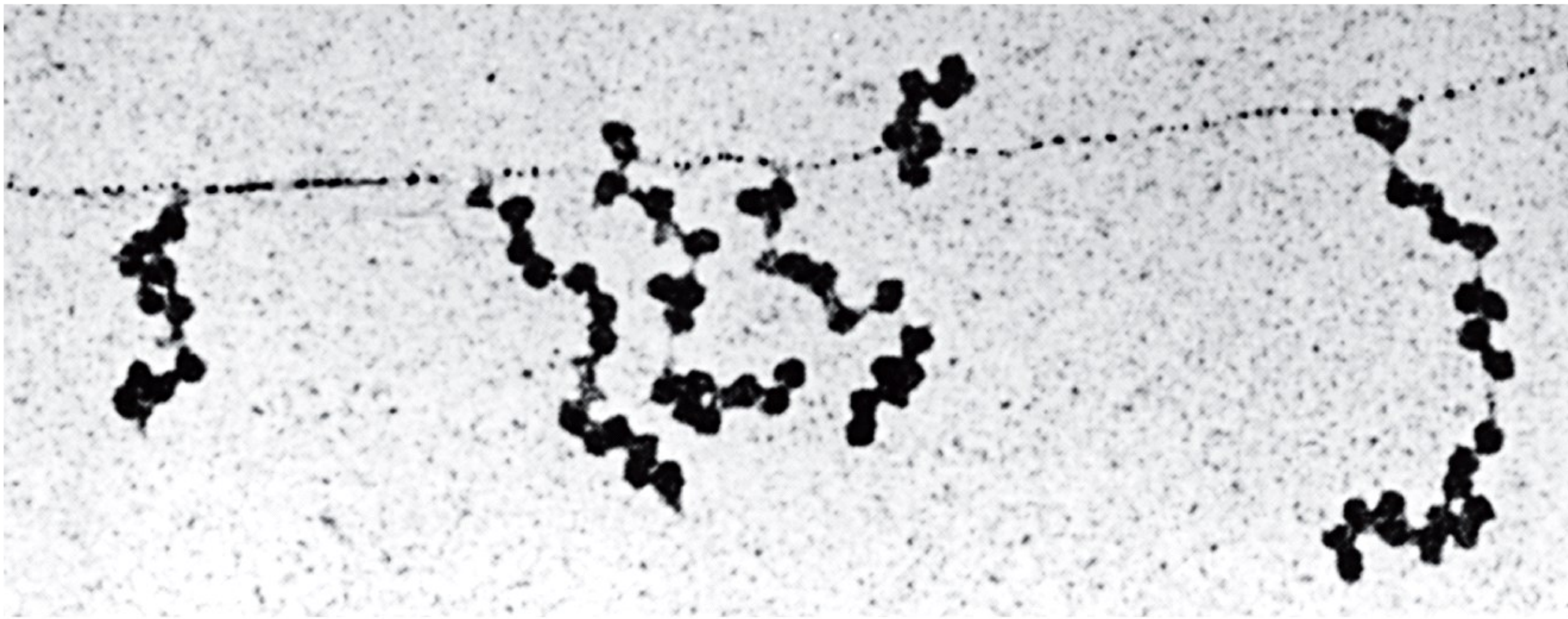


Figure 10-6b Biology: Life on Earth, 8/e

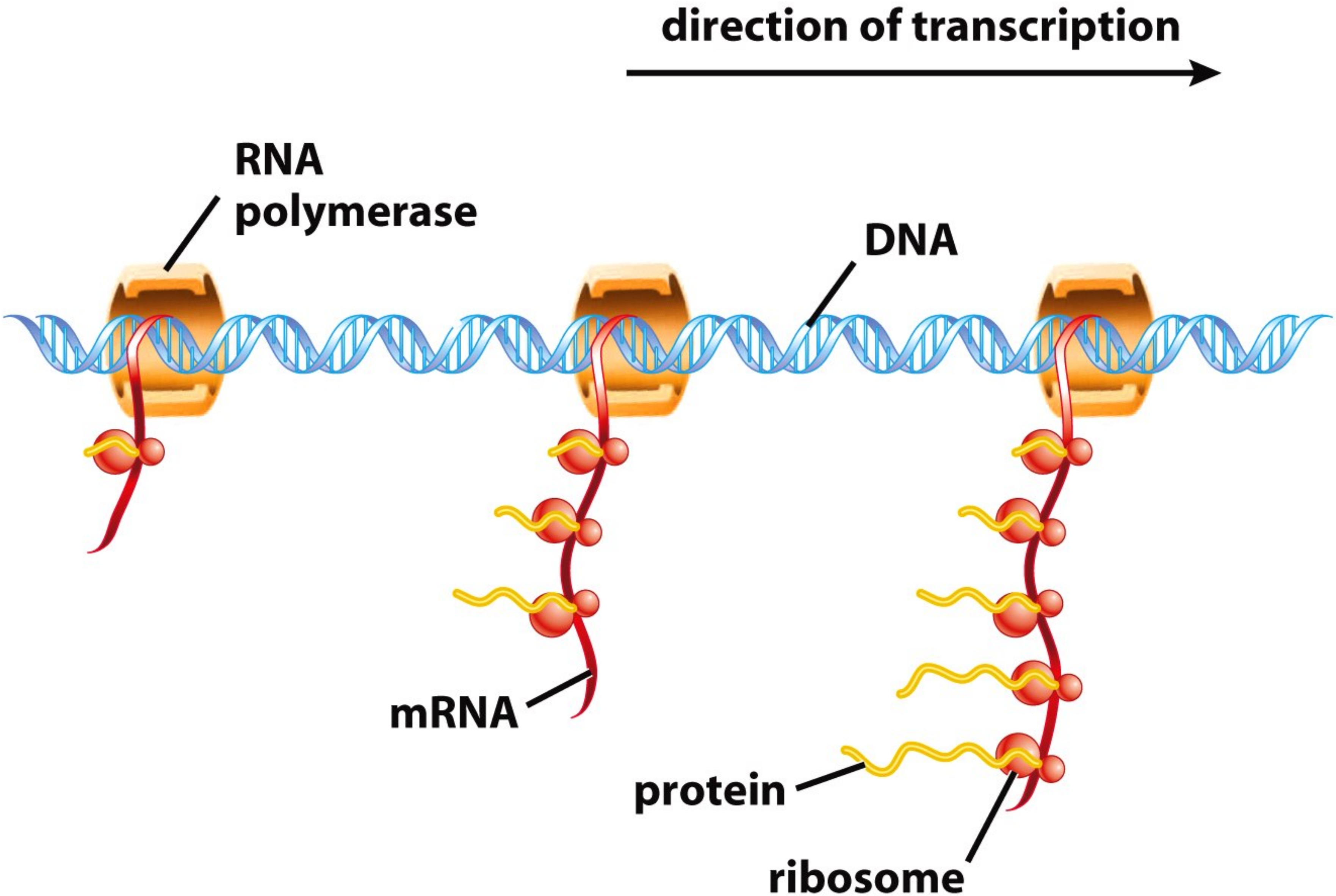


Figure 10-6c Biology: Life on Earth, 8/e

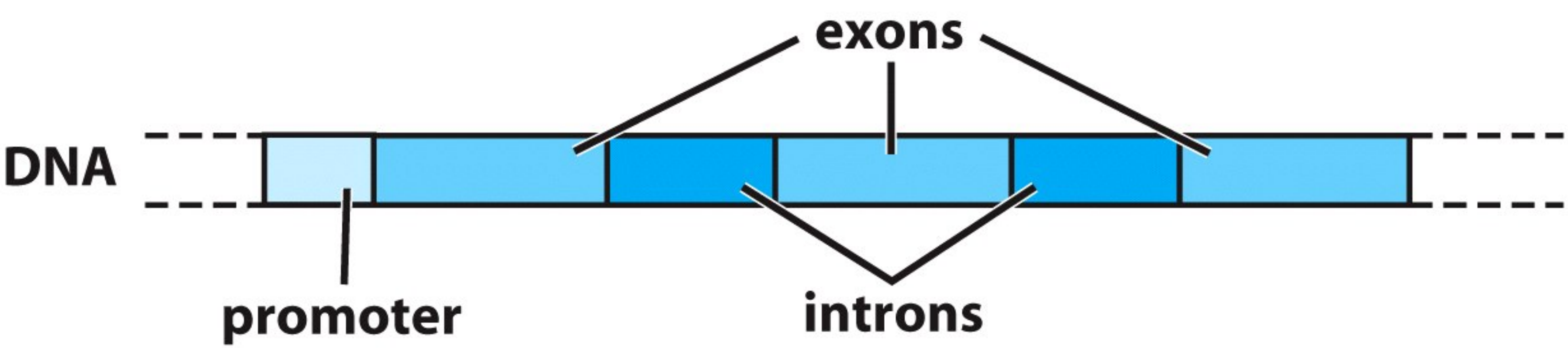
mRNA

- In eukaryotes
  - The DNA is in the nucleus and the ribosomes are in the cytoplasm
  - The genes that encode the proteins for a biochemical pathway are not clustered together on the same chromosome

mRNA

- In eukaryotes (continued)
  - Each gene consists of multiple segments of DNA that encode for protein, called **exons**
  - Exons are interrupted by other segments that are not translated, called **introns**

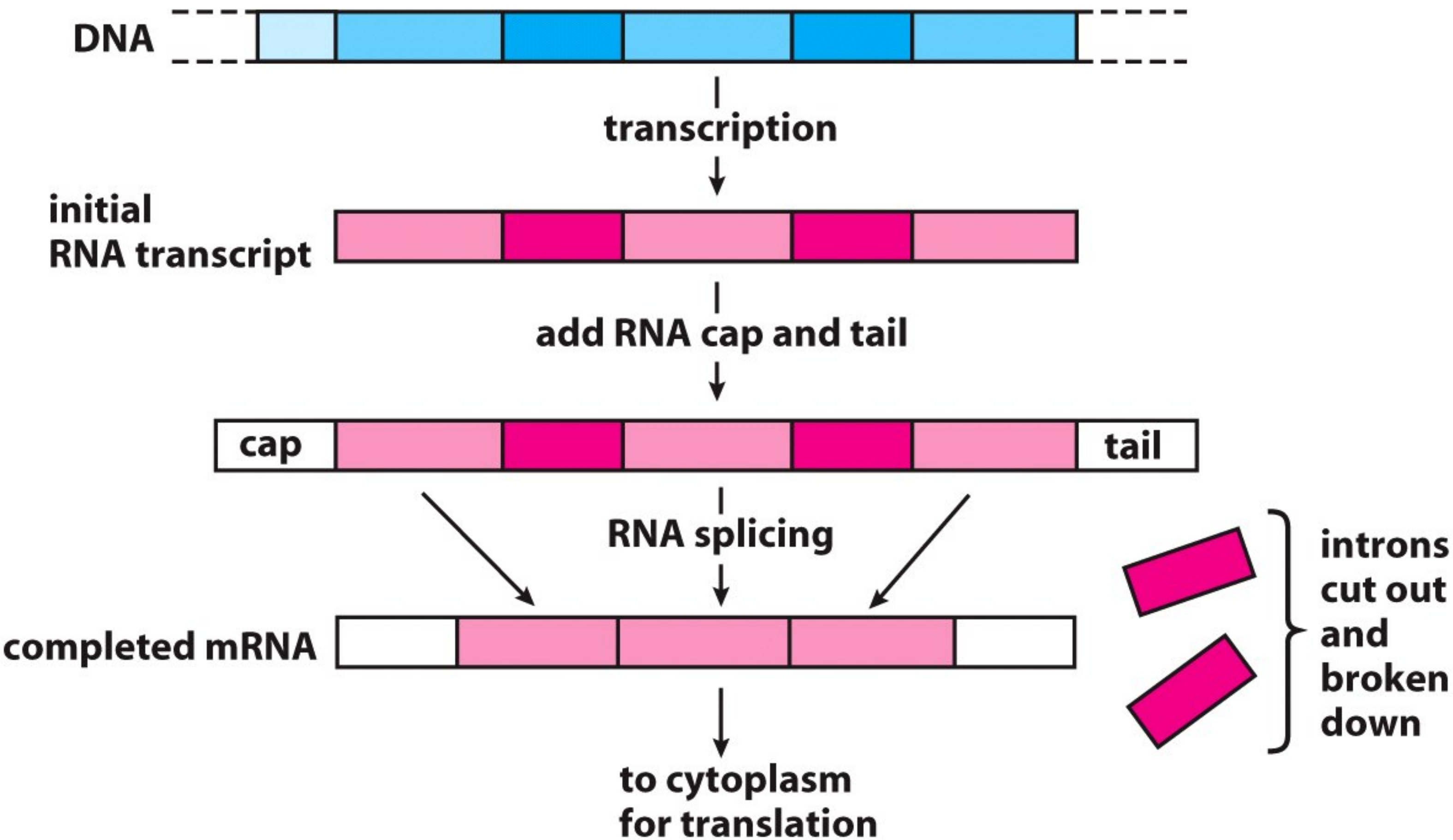
Eukaryotic gene structure



A typical eukaryotic gene consists of sequences of DNA called exons, which code for the amino acids of a protein (medium blue), and intervening sequences called introns (dark blue), which do not. The promoter (light blue) determines where RNA polymerase will begin transcription.

Figure 10-7a Biology: Life on Earth, 8/e

RNA synthesis and processing in eukaryotes



RNA polymerase transcribes both the exons and introns, producing a long RNA molecule. Enzymes in the nucleus then add further nucleotides at the beginning (cap) and end (tail) of the RNA transcript. Other enzymes cut out the RNA introns and splice together the exons to form the true mRNA, which moves out of the nucleus and is translated on the ribosomes.

Figure 10-7b Biology: Life on Earth, 8/e

mRNA

- In eukaryotes (continued)
  - Transcription of a gene produces a very long RNA strand that contains introns and exons
  - Enzymes in the nucleus cut out the introns and splice together the exons to make true mRNA
  - mRNA exits the nucleus through a membrane pore and associates with a ribosome

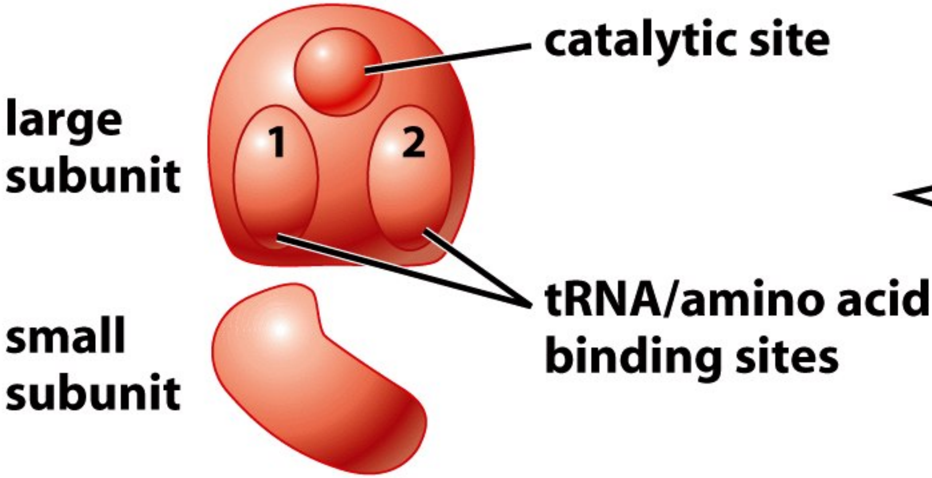
mRNA

- Why are eukaryotic genes split up into exons and introns?
  - Through "alternate" splicing, a cell can make multiple proteins from a single gene*
  - **Exception to the one gene/one protein relationship*

Ribosomes

- Ribosomes are large complexes of proteins and rRNA

Ribosome: contains ribosomal RNA (rRNA)



rRNA combines with proteins to form ribosomes. The small subunit binds mRNA. The large subunit binds tRNA and catalyzes peptide bond formation between amino acids during protein synthesis.

Figure 10-2b Biology: Life on Earth, 8/e

Ribosomes

- Ribosomes are composed of two subunits
  - Small subunit has binding sites for mRNA and a tRNA
  - Large subunit has binding sites for two tRNA molecules and catalytic site for peptide bond formation

Transfer RNAs

- Transfer RNAs hook up to and bring amino acids to the ribosome
- There is at least one type of tRNA assigned to carry each of the twenty different amino acids

Transfer RNAs

- Each tRNA has three exposed bases called an **anticodon**
- The bases of the tRNA anticodon pair with an mRNA codon within a ribosome binding site

Translation

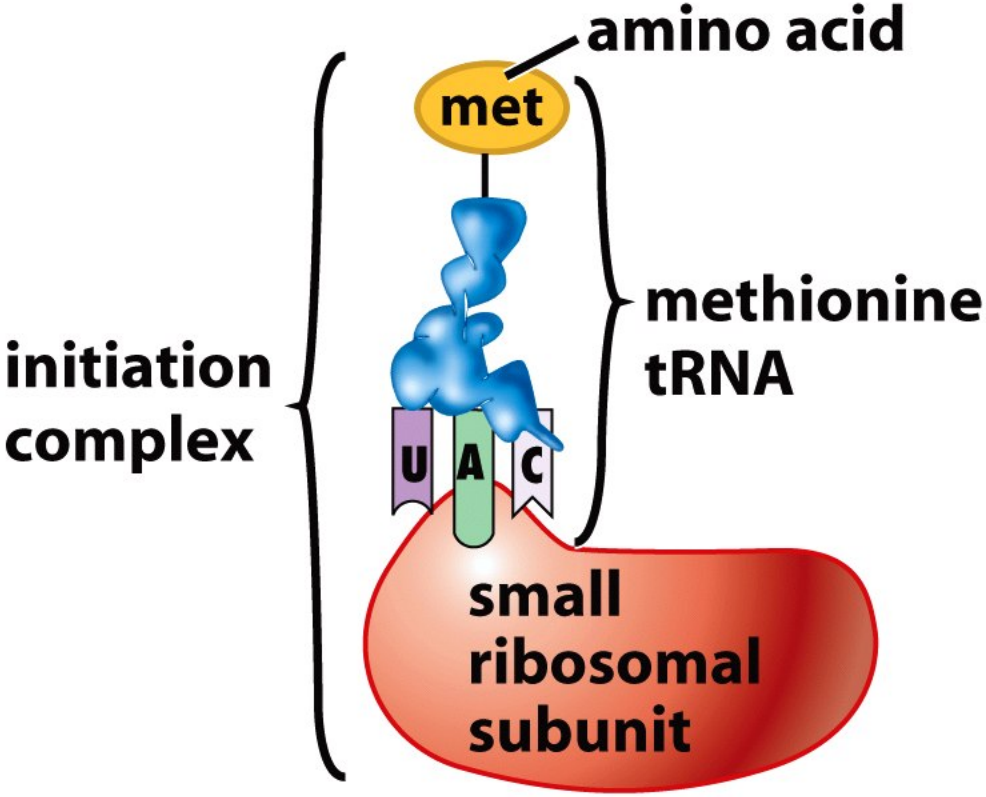
Ribosomes, tRNA, and mRNA cooperate in protein synthesis, which begins with **initiation:**

1. The mRNA binds to the small ribosomal subunit
2. The mRNA slides through the subunit until the first AUG (start codon) is exposed in the first tRNA binding site…

Translation

3. The first tRNA carrying methionine (and anticodon UAC) binds to the mRNA start codon completing the **initiation complex**
4. The large ribosomal subunit joins the complex

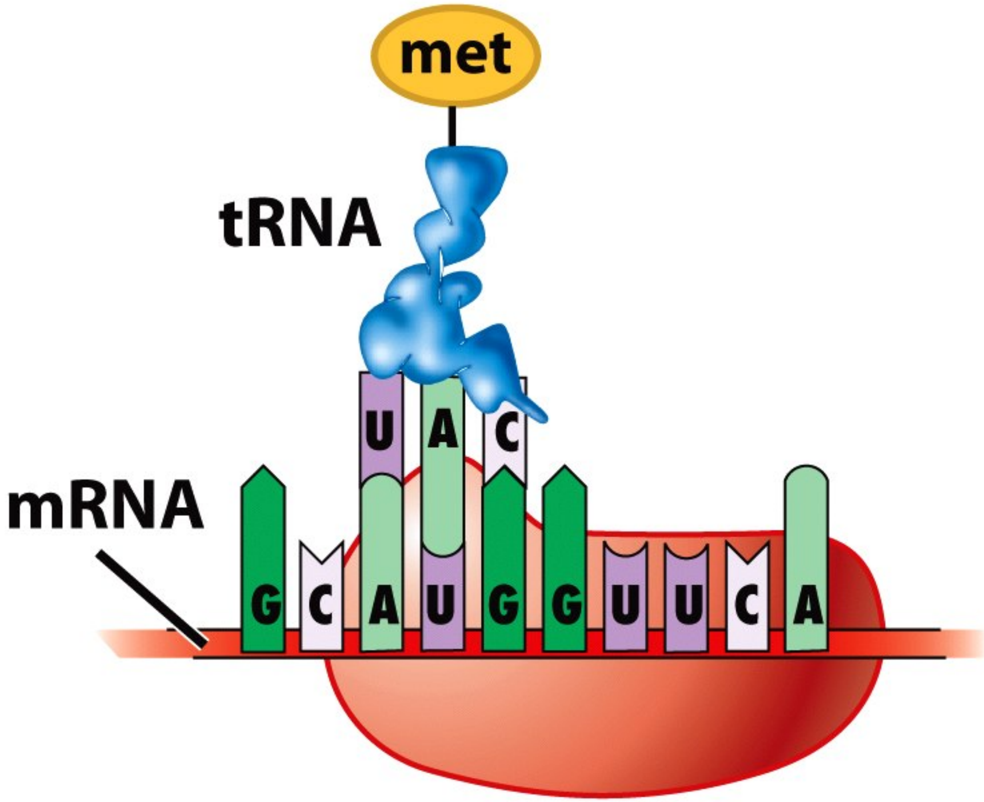
Initiation:



A tRNA with an attached methionine amino acid binds to a small ribosomal subunit, forming an initiation complex.

Figure 10-8a Biology: Life on Earth, 8/e

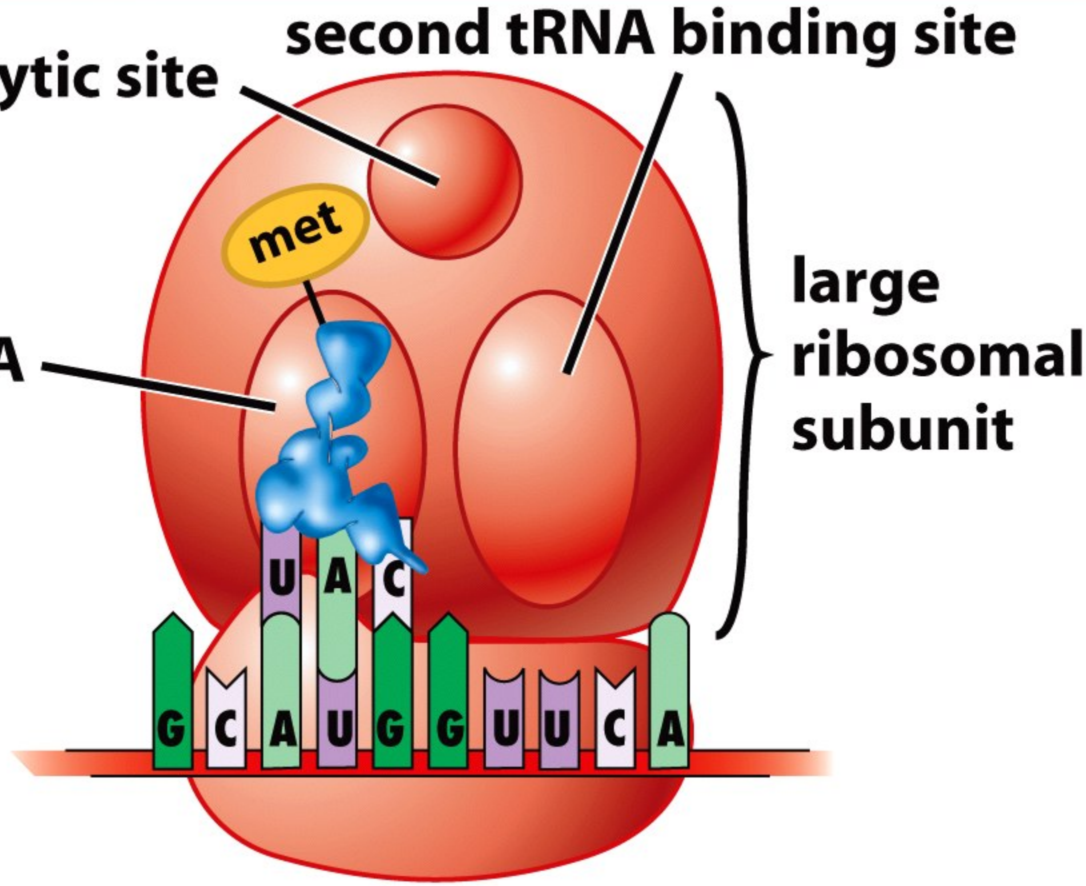
Initiation:



The initiation complex binds to an mRNA molecule. The methionine (met) tRNA anticodon (UAC) base-pairs with the start codon (AUG) of the mRNA.

Figure 10-8b Biology: Life on Earth, 8/e

Initiation:



The large ribosomal subunit binds to the small subunit. The methionine tRNA binds to the first tRNA site on the large subunit.

Figure 10-8c Biology: Life on Earth, 8/e

Translation

Middle phase of protein synthesis: **Elongation** (continued)

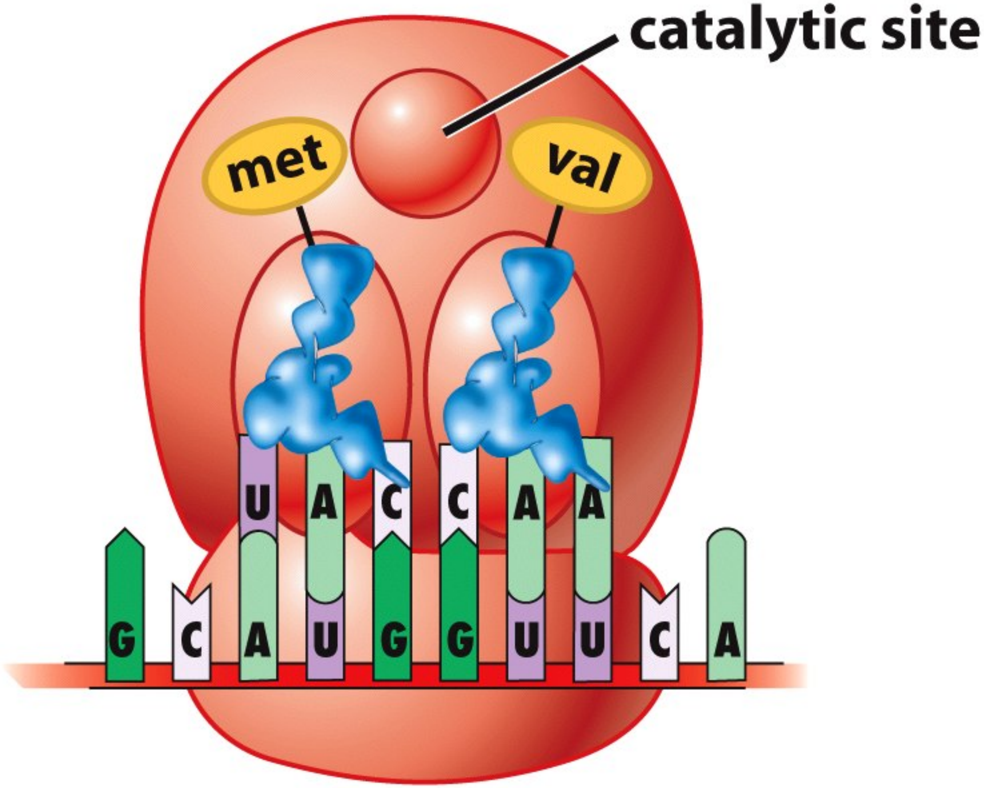
1. A second tRNA binds to the second tRNA binding site adjacent to the first tRNA
2. The anticodon of the second tRNA is complementary to the mRNA codon exposed in the second tRNA binding site…

Translation

Middle phase of protein synthesis: **Elongation**

3. A peptide bond forms between the methionine and second amino acid through the action of the ribosome catalytic site
4. The first amino acid is released from the tRNA in the first tRNA binding site…

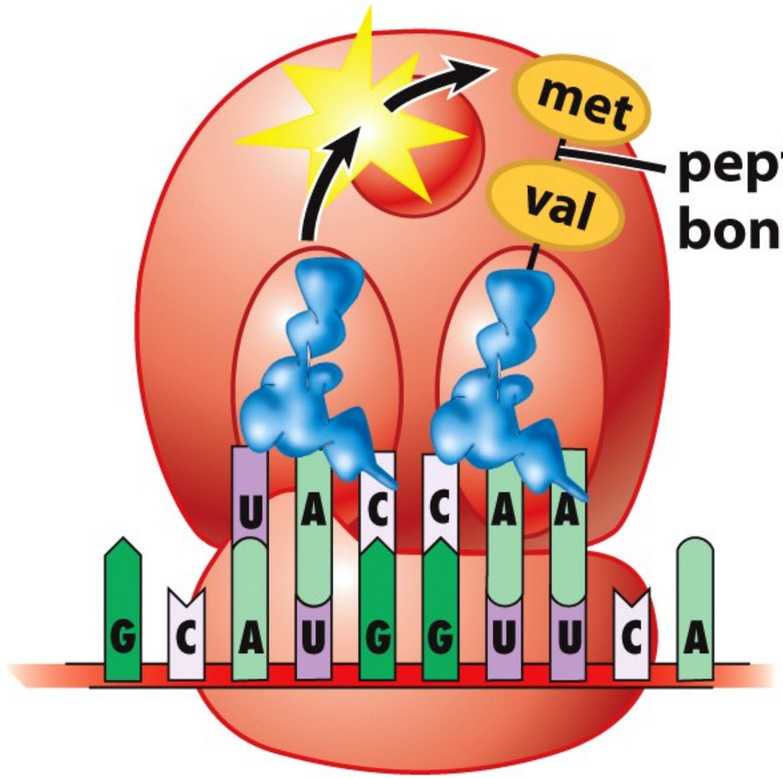
Elongation:



The second codon of mRNA (GUU) base-pairs with the anticodon (CAA) of a second tRNA carrying the amino acid valine (val). This tRNA binds to the second tRNA site on the large subunit.

Figure 10-8d Biology: Life on Earth, 8/e

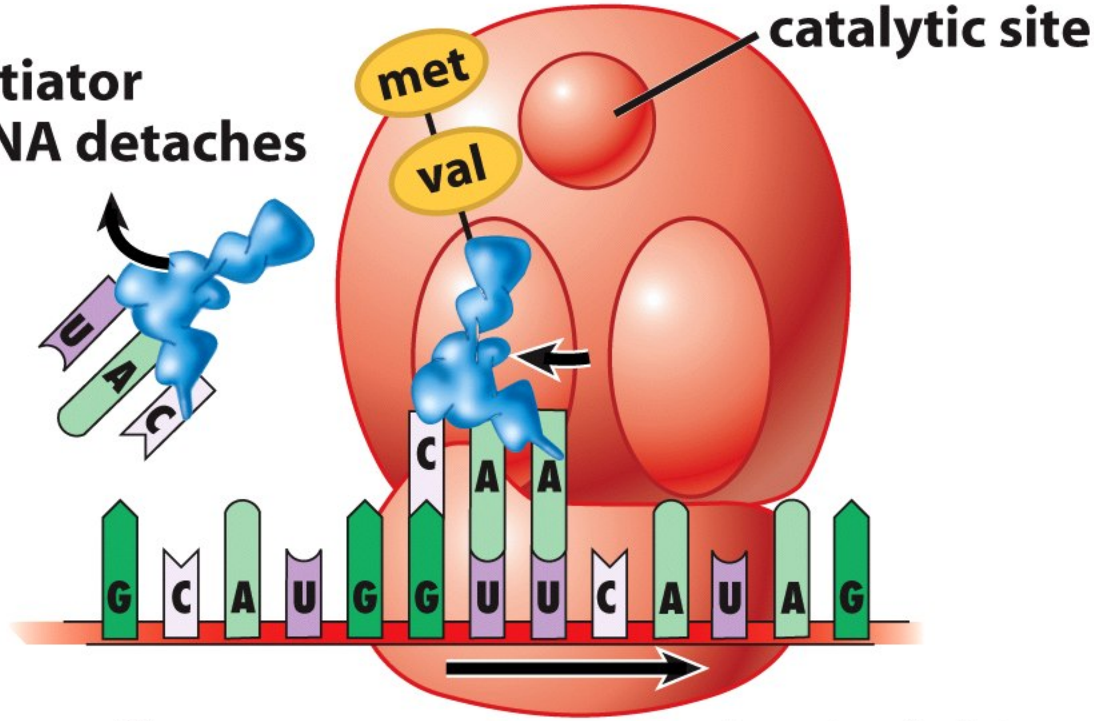
Elongation:



The catalytic site on the large subunit catalyzes the formation of a peptide bond linking the amino acids methionine and valine. The two amino acids are now attached to the tRNA in the second binding position.

Figure 10-8e Biology: Life on Earth, 8/e

Elongation:



The "empty" tRNA is released and the ribosome moves down the mRNA, one codon to the right. The tRNA that is attached to the two amino acids is now in the first tRNA binding site and the second tRNA binding site is empty.

Figure 10-8f Biology: Life on Earth, 8/e

Translation

Middle phase of protein synthesis: **Elongation** (continued)

5. The “empty” tRNA in the first binding site leaves the ribosome
6. The ribosome moves down the mRNA by one codon, transferring the tRNA holding the amino acid chain to the first tRNA binding site…

Translation

Middle phase of protein synthesis: **Elongation** (continued)

7. A new tRNA with anticodon complementary to the newly exposed codon in the second tRNA binding site approaches and the whole elongation cycle repeats
8. Empty tRNAs are reloaded with their appropriate amino acids by enzymes in the cytoplasm

Translation

End phase of protein synthesis: **Termination**

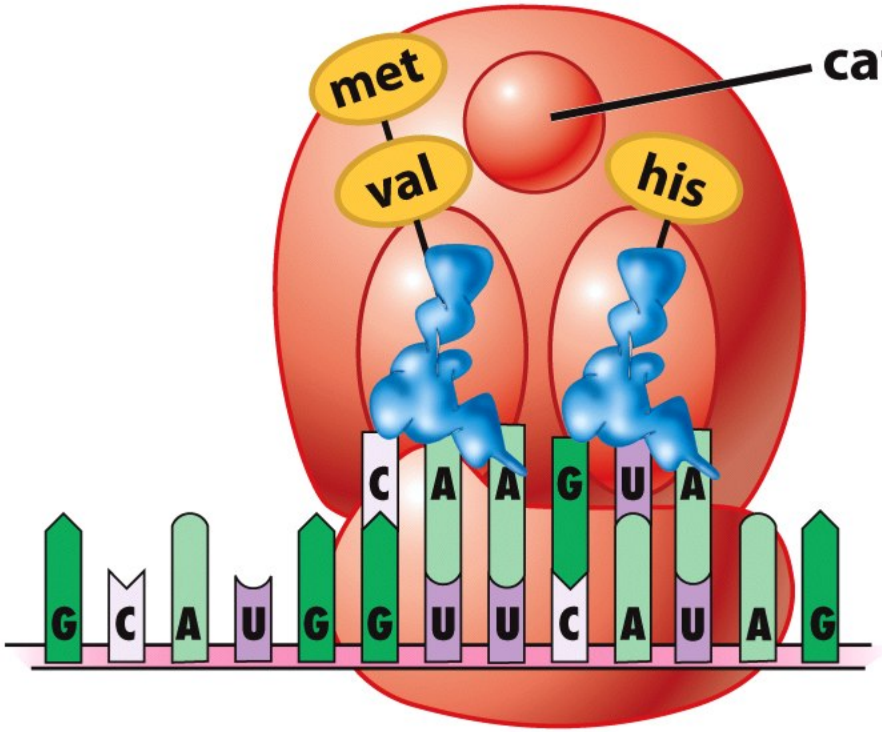
1. A stop codon on the mRNA slides into the second tRNA binding site
2. A special protein binds to the stop codon
3. The ribosome breaks into separate subunits…

Translation

End phase of protein synthesis: **Termination**

4. The finished protein chain is released
5. The mRNA is released and can be used to make another protein

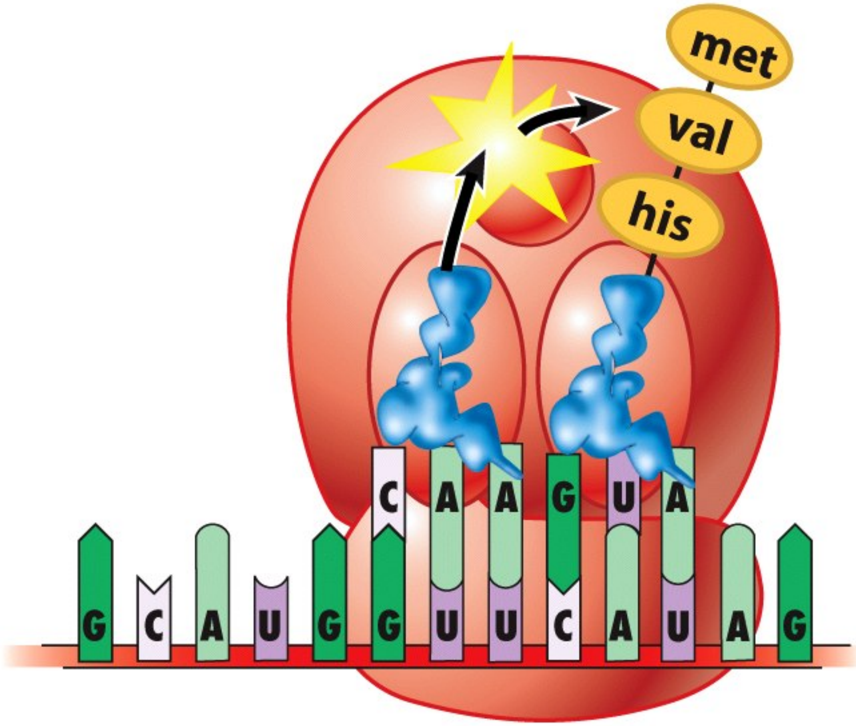
Elongation:



The third codon of mRNA (CAU) base-pairs with the anticodon (GUA) of a tRNA carrying the amino acid histidine (his). This tRNA enters the second tRNA binding site on the large subunit.

Figure 10-8g Biology: Life on Earth, 8/e

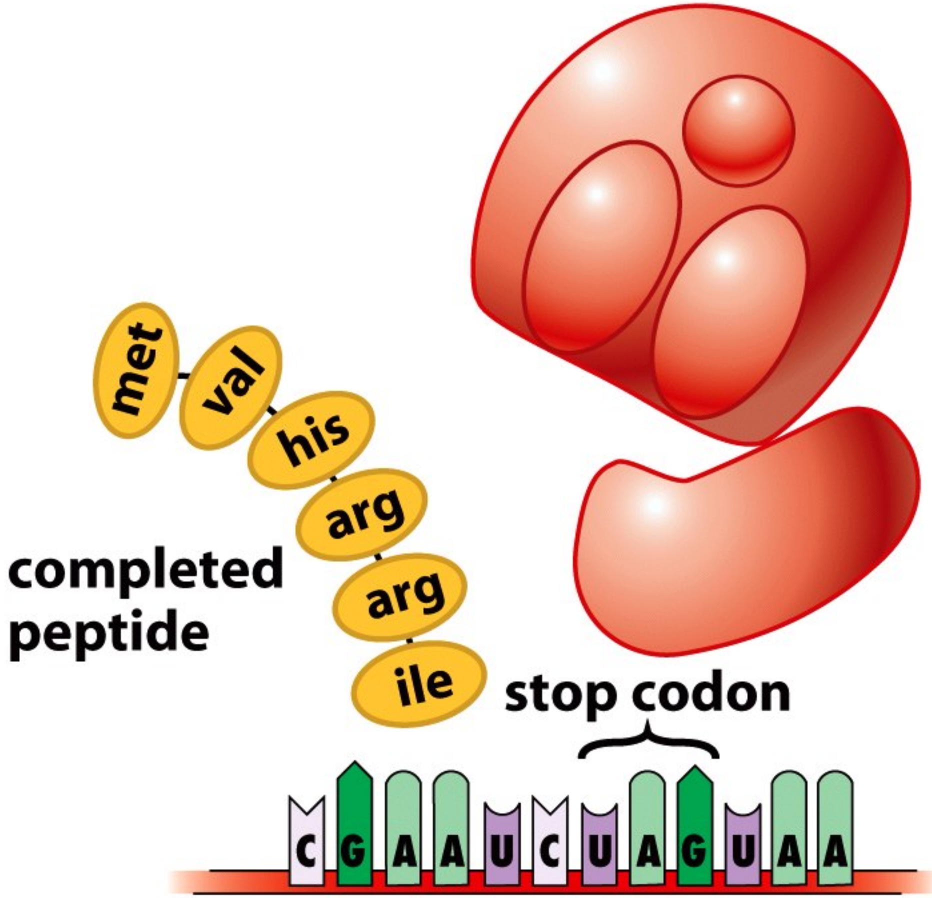
Elongation:



The catalytic site forms a new peptide bond between valine and histidine. A three-amino- acid chain is now attached to the tRNA in the second binding site. The tRNA in the first site leaves, and the ribosome moves one codon over on the mRNA.

Figure 10-8h Biology: Life on Earth, 8/e

Termination:



This process repeats until a stop codon is reached; the mRNA and the completed peptide are released from the ribosome, and the subunits separate.

Figure 10-8i Biology: Life on Earth, 8/e

Recap

- Each DNA gene codes for a single protein
- Transcription produces an mRNA strand complementary to the DNA gene template strand

Recap

- The mRNA strand associates with a ribosome
- Transfer RNAs in the cytoplasm are loaded with their appropriate amino acids by cytoplasmic enzymes

Recap

- The ribosome “selects” the tRNAs based on the base pairing of the **anticodon** with the exposed mRNA **codon**
- The mRNA contains start and stop signals to define where protein synthesis begins and ends

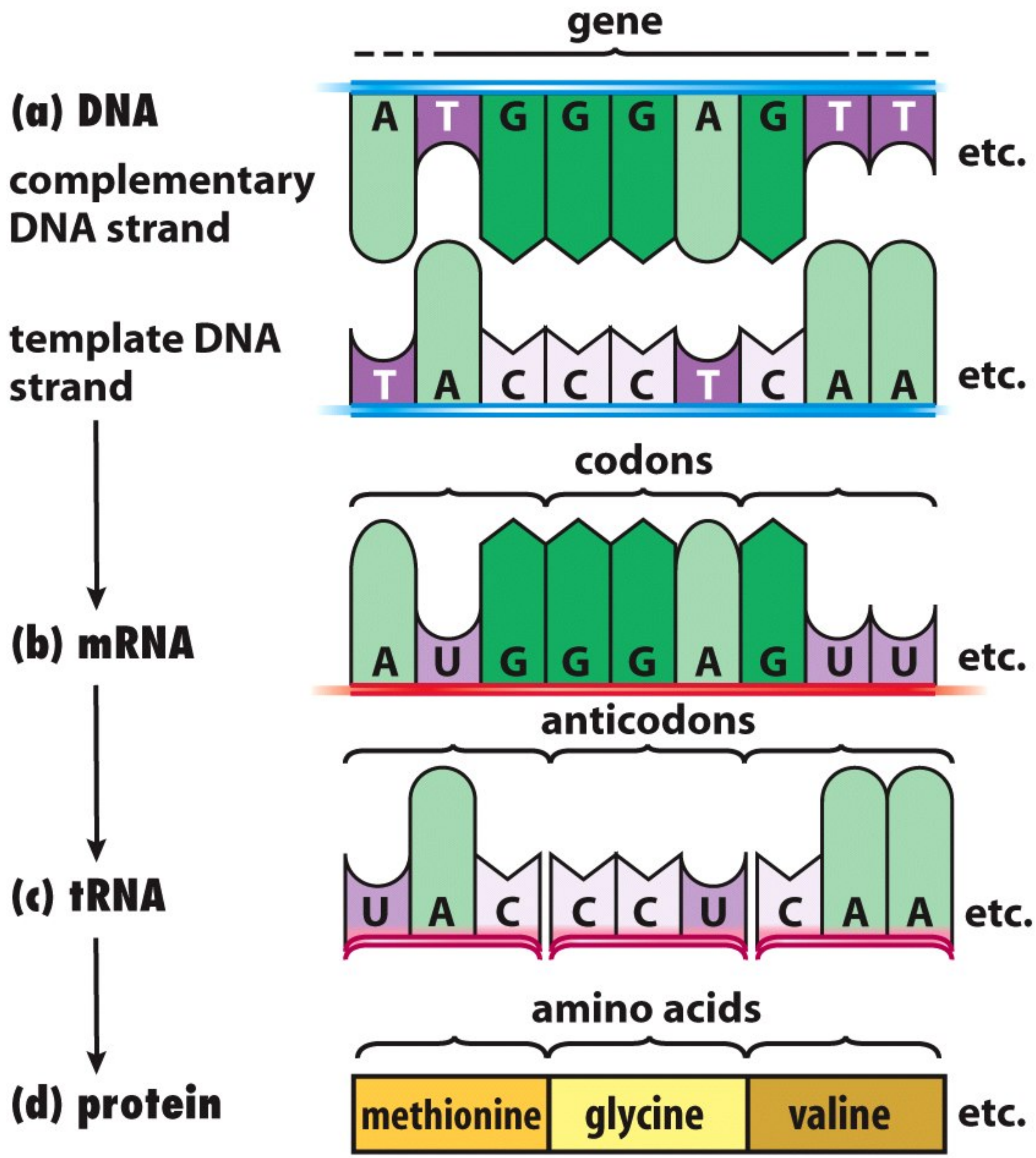


Figure 10-9 Biology: Life on Earth, 8/e

Section 10.4 Outline

- **10.4 How Do Mutations in DNA Affect the Function of Genes?**
  - Mutations May Have a Variety of Effects on Protein Structure and Function
  - Mutations Provide the Raw Material for Evolution

Effects of Mutations on Proteins

- Recall that mutations are changes in the base sequence of DNA
- Most mutations are categorized as
  - Substitutions
  - Deletions
  - Insertions
  - Inversions
  - Translocations

Effects of Mutations on Proteins

- Inversions and translocations
  - When pieces of DNA are broken apart and reattached in different orientation or location
  - Not problematic if entire gene is moved
  - If gene is split in two it will no longer code for a complete, functional protein

Effects of Mutations on Proteins

- Insertions or deletions
  - Nucleotides are added or subtracted from a gene
  - Reading frame of RNA codons is changed
    - **THEDOGSAWTHECAT** is changed by deletion of the letter "S" to **THEDOGAWTHECAT**
  - Resultant protein has very different amino acid sequence; almost always is non-functional

Effects of Mutations on Proteins

- Nucleotide substitutions (point mutations)
  - An incorrect nucleotide takes the place of a correct one
  - Protein structure and function is unchanged because many amino acids are encoded by multiple codons
  - Protein may have amino acid changes that are unimportant to function (**neutral mutations**)

Effects of Mutations on Proteins

- Effects of nucleotide substitutions
  - Protein function is changed by an altered amino acid sequence (as in gly →val in hemoglobin in sickle cell anemia)
  - Protein function is destroyed because DNA mutation creates a premature stop codon

Table 10-4 Effects of Mutations in the Hemoglobin Gene

	DNA (template strand)	mRNA	Amino Acid	Properties of Amino Acid	Functional Effect on Protein	Disease
Original codon 6	CTC	GAG	Glutamic acid	Hydrophilic	Normal protein function	None
Mutation 1	CTT	GAA	Glutamic acid	Hydrophilic	Neutral; normal protein function	None
Mutation 2	GTC	CAG	Glutamine	Hydrophilic	Neutral; normal protein function	None
Mutation 3	CAC	GUG	Valine	Hydrophobic	Loses water solubility; compromises protein function	Sickle-cell anemia
Original codon 17	TTC	AAG	Lysine	Hydrophilic	Normal protein function	None
Mutation 4	ATC	UAG	Stop codon	Ends translation after amino acid 16	Synthesizes only part of protein; eliminates protein function	Beta-thalassemia

Table 10-4 Biology: Life on Earth, 8/e

Mutations Fuel Evolution

- Mutations are heritable changes in the DNA
- Approx. 1 in 10^5-10^6 eggs or sperm carry a mutation
- Most mutations are harmful or neutral

Mutations Fuel Evolution

- Mutations create new gene sequences and are the ultimate source of genetic variation
- Mutant gene sequences that are beneficial may spread through a population and become common