8.5 Translation

KEY CONCEPT Translation converts an mRNA message into a polypeptide, or protein.

MAIN IDEAS

- Amino acids are coded by mRNA base sequences.
- Amino acids are linked to become a protein.

VOCABULARY

translation, p. 243
codon, p. 243
stop codon, p. 244
start codon, p. 244
anticodon, p. 245

Review
peptide bond

REVIEW AT CLASSZONE.COM

Connect As you know, translation is a process that converts a message from one language into another. For example, English words can be translated into Spanish words, into Chinese characters, or into the hand shapes and gestures of sign language. Translation occurs in cells too. Cells translate an RNA message into amino acids, the building blocks of proteins. But unlike people who use many different languages, all cells use the same genetic code.

MAIN IDEA

Amino acids are coded by mRNA base sequences.

Translation is the process that converts, or translates, an mRNA message into a polypeptide. One or more polypeptides make up a protein. The "language" of nucleic acids uses four nucleotides—A, G, C, and T in DNA; or A, G, C, and U in RNA. The "language" of proteins, on the other hand, uses 20 amino acids. How can four nucleotides code for 20 amino acids? Just as letters are strung together in the English language to make words, nucleotides are strung together to code for amino acids.

***Connecting* CONCEPTS**

Biochemistry Recall from **Chapter 2** that amino acids are the building blocks of proteins. Although there are many types of amino acids, only the same 20 types make up the proteins of almost all organisms.

Triplet Code

Different words have different numbers of letters. In the genetic code, however, all of the "words," called codons, are made up of three letters. A **codon** is a three-nucleotide sequence that codes for an amino acid. Why is the genetic code read in units of three nucleotides? Well, we can't entirely answer that question, but consider the possibilities. If one nucleotide coded for one amino acid, RNA could code for only four amino acids. If two nucleotides coded for one amino acid, RNA could code for 16 (4^2) amino acids—still not enough. But if three nucleotides coded for one amino acid, RNA could code for 64 (4^3) amino acids, plenty to cover the 20 amino acids used to build proteins in the human body and most other organisms.

VISUAL VOCAB

A **codon** is a sequence of three nucleotides that codes for an amino acid.

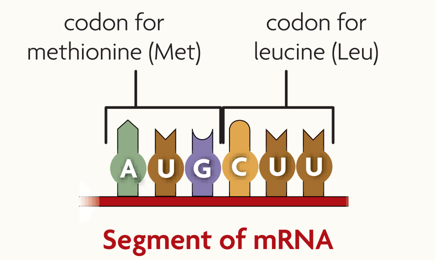


FIGURE 8.13 Genetic Code: mRNA Codons

The genetic code matches each mRNA codon with its amino acid or function.

Suppose you want to determine which amino acid is encoded by the CAU codon.

1. Find the first base, C, in the left column.
2. Find the second base, A, in the top row. Find the box where these two intersect.
3. Find the third base, U, in the right column. CAU codes for histidine, abbreviated as His.

First base	Second base: U		Second base: C		Second base: A		Second base: G		Third base
U	UUU	phenylalanine (Phe)	UCU	serine (Ser)	UAU	tyrosine (Tyr)	UGU	cysteine (Cys)	U
	UUC		UCC		UAC		UGC		C
	UUA	leucine (Leu)	UCA		UAA	STOP	UGA	STOP	A
	UUG		UCG		UAG	STOP	UGG	tryptophan (Trp)	G
C	CUU	leucine (Leu)	CCU	proline (Pro)	**CAU**	**histidine** (His)	CGU	arginine (Arg)	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	glutamine (Gln)	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	isoleucine (Ile)	ACU	threonine (Thr)	AAU	asparagine (Asn)	AGU	serine (Ser)	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	lysine (Lys)	AGA	arginine (Arg)	A
	AUG	methionine (Met)	ACG		AAG		AGG		G
G	GUU	valine (Val)	GCU	alanine (Ala)	GAU	aspartic acid (Asp)	GGU	glycine (Gly)	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	glutamic acid (Glu)	GGA		A
	GUG		GCG		GAG		GGG		G

Apply **Which amino acid would be encoded by the mRNA codon CGA?**

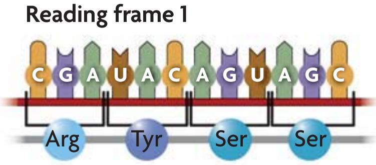
As you can see in **FIGURE 8.13**, many amino acids are coded for by more than one codon. The amino acid leucine, for example, is represented by six different codons: CUU, CUC, CUA, CUG, UUA, and UUG. There is a pattern to the codons. In most cases, codons that represent the same amino acid share the same first two nucleotides. For example, the four codons that code for alanine each begin with the nucleotides GC. Therefore, the first two nucleotides are generally the most important in coding for an amino acid. As you will learn in Section 8.7, this feature makes DNA more tolerant of many point mutations.

In addition to codons that code for amino acids, three **stop codons** signal the end of the amino acid chain. There is also one **start codon,** which signals the start of translation and the amino acid methionine. This means that translation always begins with methionine. However, in many cases, this methionine is removed later in the process.

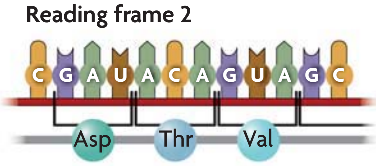
For the mRNA code to be translated correctly, codons must be read in the right order. Codons are read, without spaces, as a series of three nonoverlapping nucleotides. This order is called the reading frame. Changing the reading frame completely changes the resulting protein. It may even keep a protein from being made if a stop codon turns up early in the translation process. Therefore, punctuation—such as a clear start codon—plays an important role in the genetic code. **FIGURE 8.14** shows how a change in reading frame changes

FIGURE 8.14 Codons are read as a series of three nonoverlapping nucleotides. A change in the reading frame changes the resulting protein.

Reading frame 1



Reading frame 2



the resulting protein. When the mRNA strand is read starting from the first nucleotide, the resulting protein includes the amino acids arginine, tyrosine, and two serines. When the strand is read starting from the second nucleotide, the resulting protein includes aspartic acid, threonine, and valine.

Common Language

The genetic code is shared by almost all organisms—and even viruses. That means, for example, that the codon UUU codes for phenylalanine when that codon occurs in an armadillo, a cactus, a yeast, or a human. With a few minor exceptions, almost all organisms follow this genetic code. As a result, the code is often called universal. The common nature of the genetic code suggests that almost all organisms arose from a common ancestor. It also means that scientists can insert a gene from one organism into another organism to make a functional protein.

Calculate Suppose an mRNA molecule in the cytoplasm had 300 nucleotides. How many amino acids would be in the resulting protein?

MAIN IDEA

Amino acids are linked to become a protein.

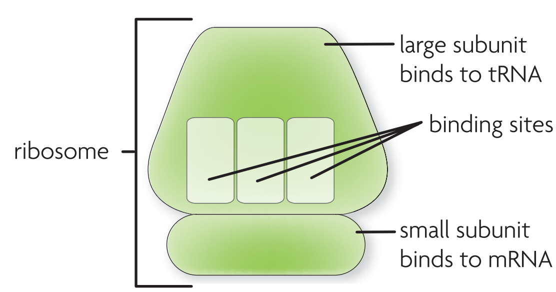
Let's take a step back to look at where we are in the process of making proteins. You know mRNA is a short-lived molecule that carries instructions from DNA in the nucleus to the cytoplasm. And you know that this mRNA message is read in sets of three nucleotides, or codons. But how does a cell actually translate a codon into an amino acid? It uses two important tools: ribosomes and tRNA molecules, as illustrated in **FIGURE 8.15.**

Recall from Chapter 3 that ribosomes are the site of protein synthesis. Ribosomes are made of a combination of rRNA and proteins, and they catalyze the reaction that forms the bonds between amino acids. Ribosomes have a large and small subunit that fit together and pull the mRNA strand through. The small subunit holds onto the mRNA strand, and the large subunit holds onto the growing protein.

The tRNA acts as a sort of adaptor between mRNA and amino acids. You would need an adaptor to plug an appliance with a three-prong plug into an outlet with only two-prong openings. Similarly, cells need tRNA to carry free-floating amino acids from the cytoplasm to the ribosome. The tRNA molecules fold up in a characteristic L shape. One end of the L is attached to a specific amino acid. The other end of the L, called the anticodon, recognizes a specific codon. An **anticodon** is a set of three nucleotides that is complementary to an mRNA codon. For example, the anticodon CCC pairs with the mRNA codon GGG.

FIGURE 8.15 TRANSLATION MACHINERY

Ribosomes The large and small ribosomal subunits pull mRNA through the ribosome, reading it one codon at a time.



tRNA In cells, tRNA forms a characteristic L shape. One end of the L has an anticodon that recognizes an mRNA codon. The other end is attached to an amino acid.

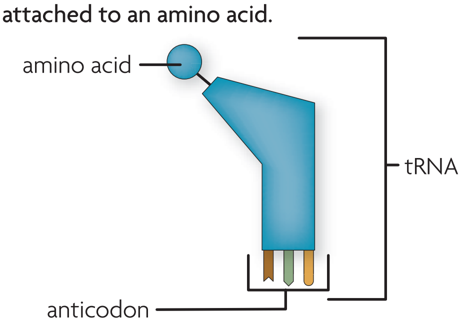
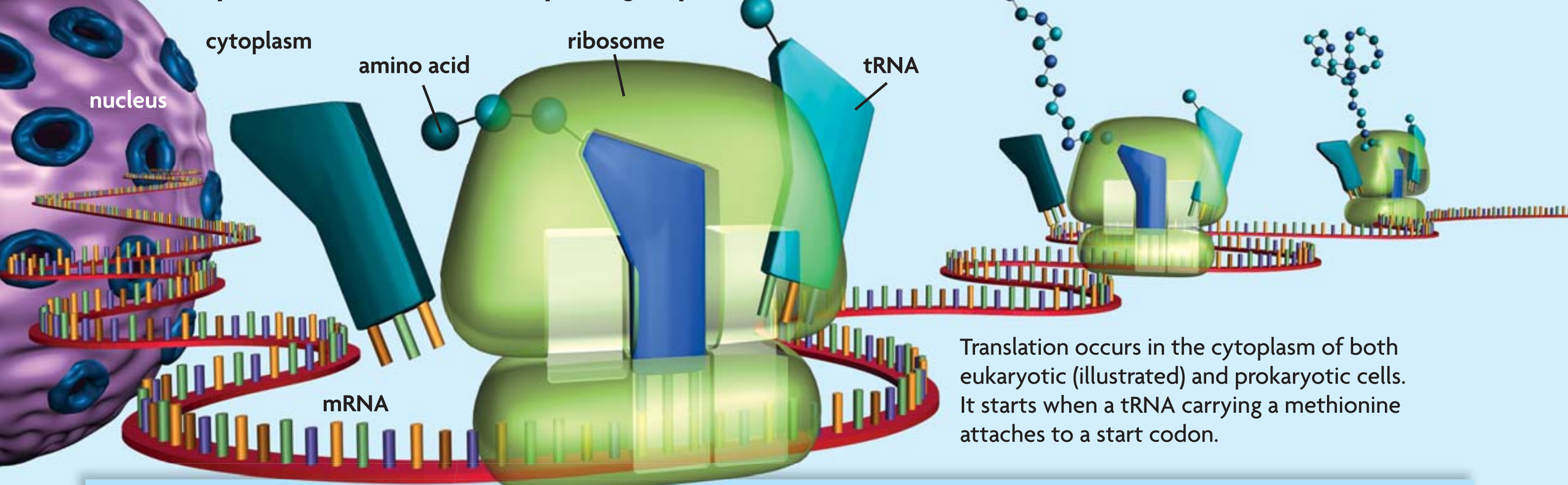


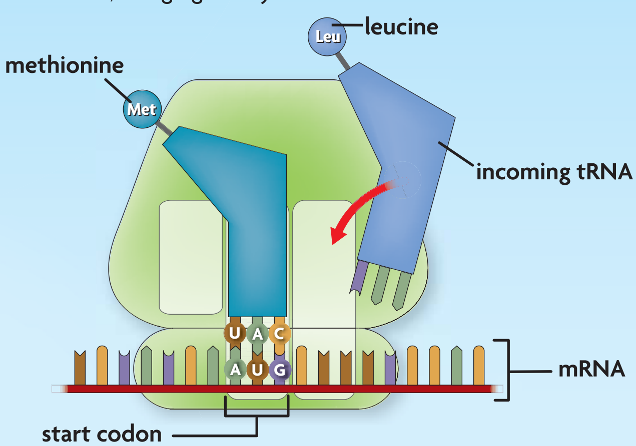
FIGURE 8.16 Translation

Translation converts an mRNA transcript into a polypeptide. The process consists of three repeating steps.

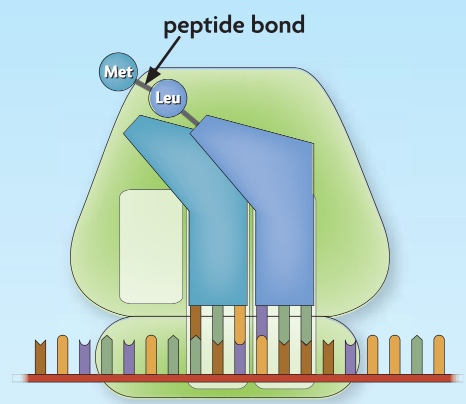


Translation occurs in the cytoplasm of both eukaryotic (illustrated) and prokaryotic cells. It starts when a tRNA carrying a methionine attaches to a start codon.

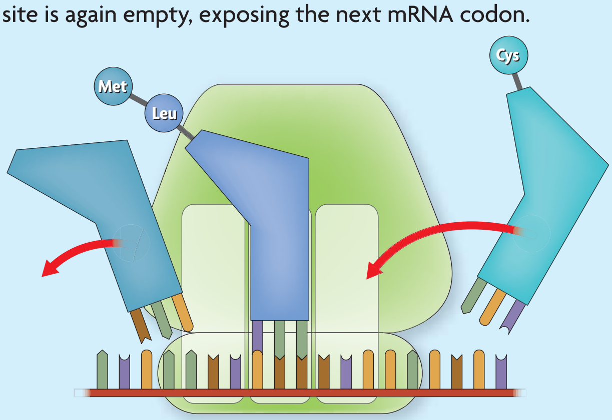
1 The exposed codon in the first site attracts a complementary tRNA bearing an amino acid. The tRNA anticodon pairs with the mRNA codon, bringing it very close to the other tRNA molecule.



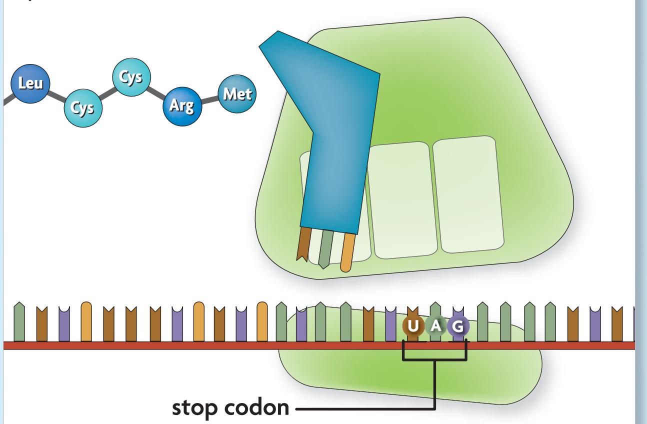
2 The ribosome forms a peptide bond between the two amino acids and breaks the bond between the first tRNA and its amino acid.



3 The ribosome pulls the mRNA strand the length of one codon. The first tRNA is shifted into the exit site, where it leaves the ribosome and returns to the cytoplasm to recharge. The first site is again empty, exposing the next mRNA codon.



The ribosome continues to translate the mRNA strand until it reaches a stop codon. Then it releases the new protein and disassembles.



CRITICAL VIEWING **The figure above shows how the first two amino acids are added to a growing protein. Draw a series of sketches to show how the next two amino acids are added.**

Translation, shown in **FIGURE 8.16**, has many steps and takes a lot of energy from a cell. It happens in the cytoplasm of both prokaryotic and eukaryotic cells. Before translation can begin, a small ribosomal subunit must bind to an mRNA strand in the cytoplasm. Next, a tRNA with methionine attached binds to the AUG start codon. This binding signals a large ribosomal subunit—which has three binding sites for tRNA molecules—to join. The ribosome pulls the mRNA strand through itself one codon at a time. As the strand moves, the start codon and its complementary tRNA molecule shift into the second site inside the large subunit. This shift leaves the first site empty, which exposes the next mRNA codon. The illustration shows the process in one ribosome, but in a cell many ribosomes may translate the same gene at the same time.

1. The exposed codon attracts a complementary tRNA molecule bearing an amino acid. The tRNA anticodon pairs with the mRNA codon. This action brings the new tRNA molecule very close to the tRNA molecule occupying the second site.
2. Next, the ribosome helps form a peptide bond between the two amino acids. The ribosome then breaks the bond between the tRNA molecule in the second site and its amino acid.
3. The ribosome pulls the mRNA strand the length of one codon. The tRNA molecule in the second site is shifted into the third site, which is the exit site. The tRNA leaves the ribosome and returns to the cytoplasm to be charged with another amino acid. The tRNA molecule that was in the first site shifts into the second site. The first site is again empty, exposing the next mRNA codon.

Another complementary tRNA molecule is attracted to the exposed mRNA codon, and the process continues. The ribosome moves down the mRNA strand, attaching new amino acids to the growing protein, until it reaches a stop codon. Then it lets go of the new protein and falls apart.

Summarize **Explain the different roles of the large and small ribosomal subunits.**

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8.5 ASSESSMENT

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REVIEWING MAIN IDEAS

1. Explain the connection between a **codon** and an amino acid.
2. Briefly describe how the process of **translation** is started.

CRITICAL THINKING

3. **Synthesize** Suppose a tRNA molecule had the **anticodon** AGU. What amino acid would it carry?
4. **Hypothesize** The DNA of eukaryotic cells has many copies of genes that code for rRNA molecules. Suggest a hypothesis to explain why a cell needs so many copies of these genes.

Connecting CONCEPTS

5. **Biochemical Reactions** Enzymes have shapes that allow them to bind to a substrate. Some types of RNA also form specific three-dimensional shapes. Why do you think RNA, but not DNA, catalyzes biochemical reactions?