13.2 Ribosomes and Protein Synthesis

Key Questions

🔑 ***What is the genetic code, and how is it read?***

🔑 ***What role does the ribosome play in assembling proteins?***

🔑 ***What is the "central dogma" of molecular biology?***

Vocabulary

polypeptide • genetic code • codon • translation • anticodon • gene expression

Taking Notes

Outline Before you read, write down the green headings in this lesson. As you read, keep a list of the main points, and then write a summary for each heading.

THINK ABOUT IT How would you build a system to read the messages that are coded in genes and transcribed into RNA? Would you read the bases one at a time, as if the code were a language with just four words—one word per base? Perhaps you would read them, as we do in English, as individual letters that can be combined to spell longer words.

The Genetic Code

🔑 ***What is the genetic code, and how is it read?***

The first step in decoding genetic messages is to transcribe a nucleotide base sequence from DNA to RNA. This transcribed information contains a code for making proteins. You learned in Chapter 2 that proteins are made by joining amino acids together into long chains, called **polypeptides.** As many as 20 different amino acids are commonly found in polypeptides.

The specific amino acids in a polypeptide, and the order in which they are joined, determine the properties of different proteins. The sequence of amino acids influences the shape of the protein, which in turn determines its function. How is the order of bases in DNA and RNA molecules translated into a particular order of amino acids in a polypeptide?

As you know from Lesson 13.1, RNA contains four different bases: adenine, cytosine, guanine, and uracil. In effect, these bases form a "language" with just four "letters": A, C, G, and U. We call this language the **genetic code.** How can a code with just four letters carry instructions for 20 different amino acids? 🔑 **The genetic code is read three "letters" at a time, so that each "word" is three bases long and corresponds to a single amino acid.** Each three-letter "word" in mRNA is known as a **codon.** As shown in **Figure 13–5,** a codon consists of three consecutive bases that specify a single amino acid to be added to the polypeptide chain.

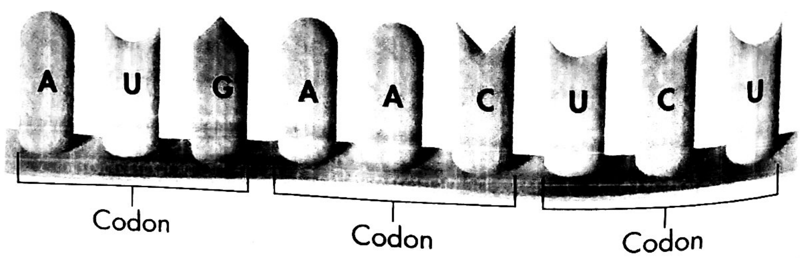
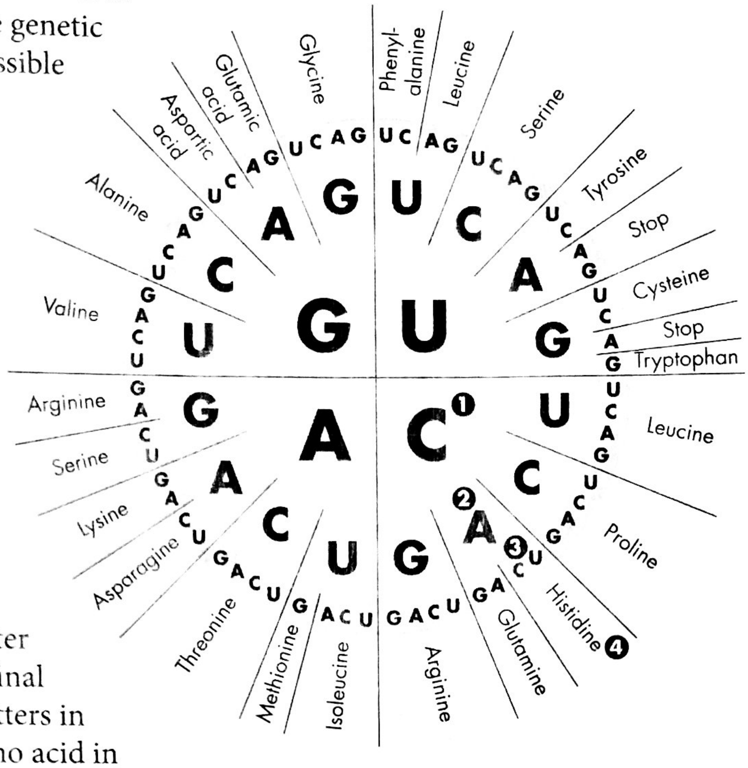


FIGURE 13–5 Codons A codon is a group of three nucleotide bases in messenger RNA that specifies a particular amino acid. **Observe** ***What are the three-letter groups of the codons shown here?***

How to Read Codons Because there are four different bases in RNA, there are 64 possible three-base codons (4 × 4 × 4 = 64) in the genetic code. **Figure 13–6** shows these possible combinations. Most amino acids can be specified by more than one codon. For example, six different codons—UUA, UUG, CUU, CUC, CUA, and CUG—specify leucine. But only one codon—UGG—specifies the amino acid tryptophan.

Decoding codons is a task made simple by use of a genetic code table. Just start at the middle of the circle with the first letter of the codon, and move outward. Next, move out to the second ring to find the second letter of the codon. Find the third and final letter among the smallest set of letters in the third ring. Then read the amino acid in that sector.



❶ To decode the codon CAC, find the first letter in the set of bases at the center of the circle.

❷ Find the second letter of the codon A, in the "C" quarter of the next ring.

❸ Find the third letter, C, in the next ring, in the "C-A" grouping.

❹ Read the name of the amino acid in that sector—in this case histidine.

FIGURE 13–6 Reading Codons
This circular table shows the amino acid to which each of the 64 codons corresponds. To read a codon, start at the middle of the circle and move outward.

Start and Stop Codons Any message, whether in a written language or the genetic code, needs punctuation marks. In English, punctuation tells us where to pause, when to sound excited, and where to start and stop a sentence. The genetic code has punctuation marks, too. The methionine codon AUG, for example, also serves as the initiation, or "start," codon for protein synthesis. Following the start codon, mRNA is read, three bases at a time, until it reaches one of three different "stop" codons, which end translation. At that point, the polypeptide is complete.

Quick Lab
GUIDED INQUIRY

How Does a Cell Interpret Codons?

❶ A certain gene has the following base sequence:

GACAAGTCCACAATC

Write this sequence on a separate sheet of paper.

❷ From left to right, write the sequence of the mRNA molecule transcribed from this gene.

❸ Using **Figure 13–6,** read the mRNA codons from left to right. Then write the amino acid sequence of the polypeptide.

❹ Repeat step 2, reading the sequence of the mRNA molecule from right to left.

Analyze and Conclude

1. Apply Concepts Why did steps 3 and 4 produce different polypeptides?

2. Infer Do cells usually decode nucleotides in one direction only or in either direction?

Translation

What role does the ribosome play in assembling proteins?

The sequence of nucleotide bases in an mRNA molecule is a set of instructions that gives the order in which amino acids should be joined to produce a polypeptide. Once the polypeptide is complete, it then folds into its final shape or joins with other polypeptides to become a functional protein.

If you've ever tried to assemble a complex toy, you know that instructions alone don't do the job. You need to read them and then put the parts together. In the cell, a tiny factory—the ribosome—carries out both these tasks. **Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains.** The decoding of an mRNA message into a protein is a process known as **translation.**

Steps in Translation Transcription isn't part of the translation process, but it is critical to it. Transcribed mRNA directs that process. In a eukaryotic cell, transcription goes on in the cell's nucleus; translation is carried out by ribosomes after the transcribed mRNA enters the cell's cytoplasm. Refer to **Figure 13–7** as you read about translation.

A Translation begins when a ribosome attaches to an mRNA molecule in the cytoplasm. As each codon passes through the ribosome, tRNAs bring the proper amino acids into the ribosome. One at a time, the ribosome then attaches these amino acids to the growing chain.

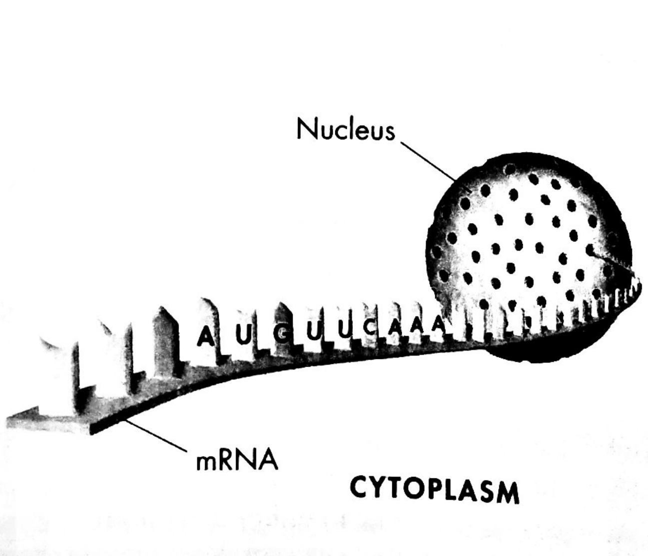
VISUAL SUMMARY

TRANSLATION

FIGURE 13–7 During translation, or protein synthesis, the cell uses information from messenger RNA to produce proteins.

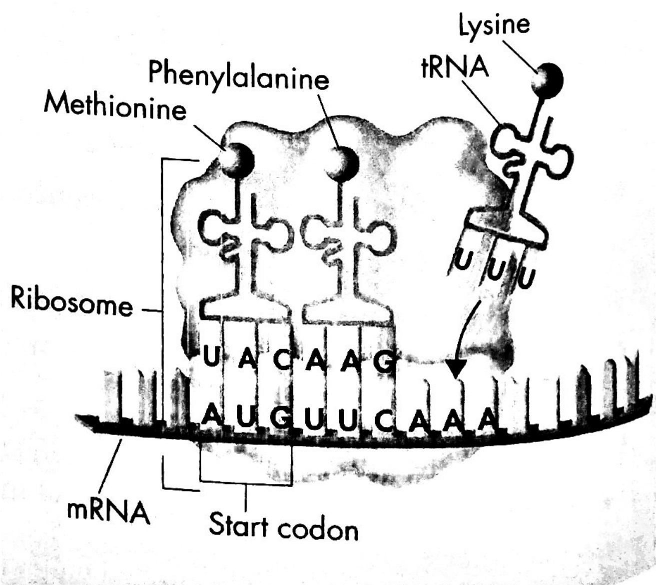
Messenger RNA

Messenger RNA is transcribed in the nucleus and then enters the cytoplasm.



A Transfer RNA

Translation begins at AUG, the start codon. Each transfer RNA has an anticodon whose bases are complementary to the bases of a codon on the mRNA strand. The ribosome positions the start codon to attract its anticodon, which is part of the tRNA that binds methionine. The ribosome also binds the next codon and its anticodon.



Each tRNA molecule carries just one kind of amino acid. In addition, each tRNA molecule has three unpaired bases, collectively called the **anticodon.** Each tRNA anticodon is complementary to one mRNA codon.

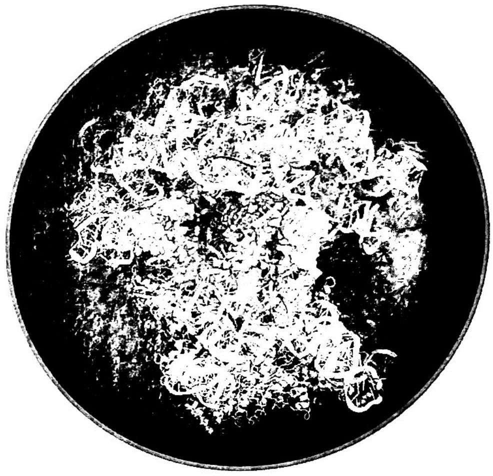
In the case of the tRNA molecule for methionine, the anticodon is UAC, which pairs with the methionine codon, AUG. The ribosome has a second binding site for a tRNA molecule for the next codon. If that next codon is UUC, a tRNA molecule with an AAG anticodon fits against the mRNA molecule held in the ribosome. That second tRNA molecule brings the amino acid phenylalanine into the ribosome.

B Like an assembly-line worker who attaches one part to another, the ribosome helps form a peptide bond between the first and second amino acids—methionine and phenylalanine. At the same time, the bond holding the first tRNA molecule to its amino acid is broken. That tRNA then moves into a third binding site, from which it exits the ribosome. The ribosome then moves to the third codon, where tRNA brings it the amino acid specified by the third codon.

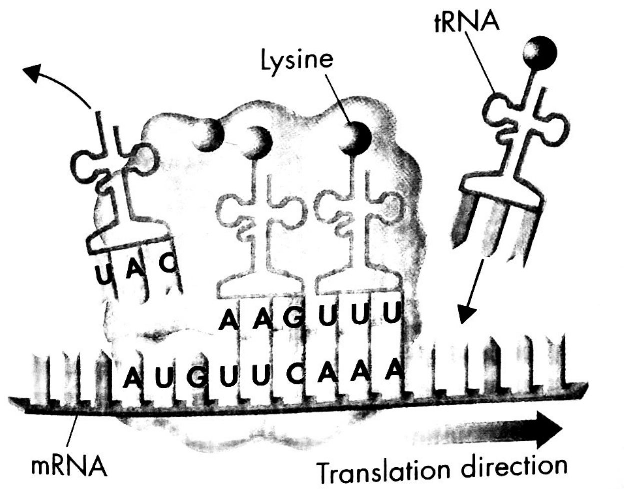
C The polypeptide chain continues to grow until the ribosome reaches a "stop" codon on the mRNA molecule. When the ribosome reaches a stop codon, it releases both the newly formed polypeptide and the mRNA molecule, completing the process of translation.

In Your Notebook *Briefly summarize the three steps in translation.*

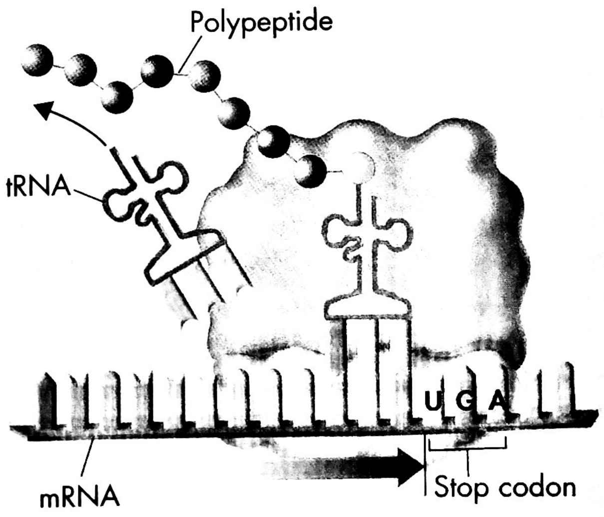
FIGURE 13–8 Molecular Model of a Ribosome This model shows ribosomal RNA and associated proteins as colored ribbons. The large subunit is blue, green, and purple. The small subunit is shown in yellow and orange. The three solid elements in the center are tRNA molecules.



B The Polypeptide "Assembly Line"
The ribosome joins the two amino acids—methionine and phenylalanine—and breaks the bond between methionine and its tRNA. The tRNA floats away from the ribosome, allowing the ribosome to bind another tRNA. The ribosome moves along the mRNA, from right to left, binding new tRNA molecules and amino acids.



C Completing the Polypeptide
The process continues until the ribosome reaches one of the three stop codons. Once the polypeptide is complete, it and the mRNA are released from the ribosome.



The Roles of tRNA and rRNA in Translation All three major forms of RNA—mRNA, tRNA, and rRNA—come together in the ribosome during translation. The mRNA molecule, of course, carries the coded message that directs the process. The tRNA molecules deliver exactly the right amino acid called for by each codon on the mRNA. The tRNA molecules are, in effect, adaptors that enable the ribosome to "read" the mRNA's message accurately and to get the translation just right.

Ribosomes themselves are composed of roughly 80 proteins and three or four different rRNA molecules. These rRNA molecules help hold ribosomal proteins in place and help locate the beginning of the mRNA message. They may even carry out the chemical reaction that joins amino acids together.

The Molecular Basis of Heredity

What is the "central dogma" of molecular biology?

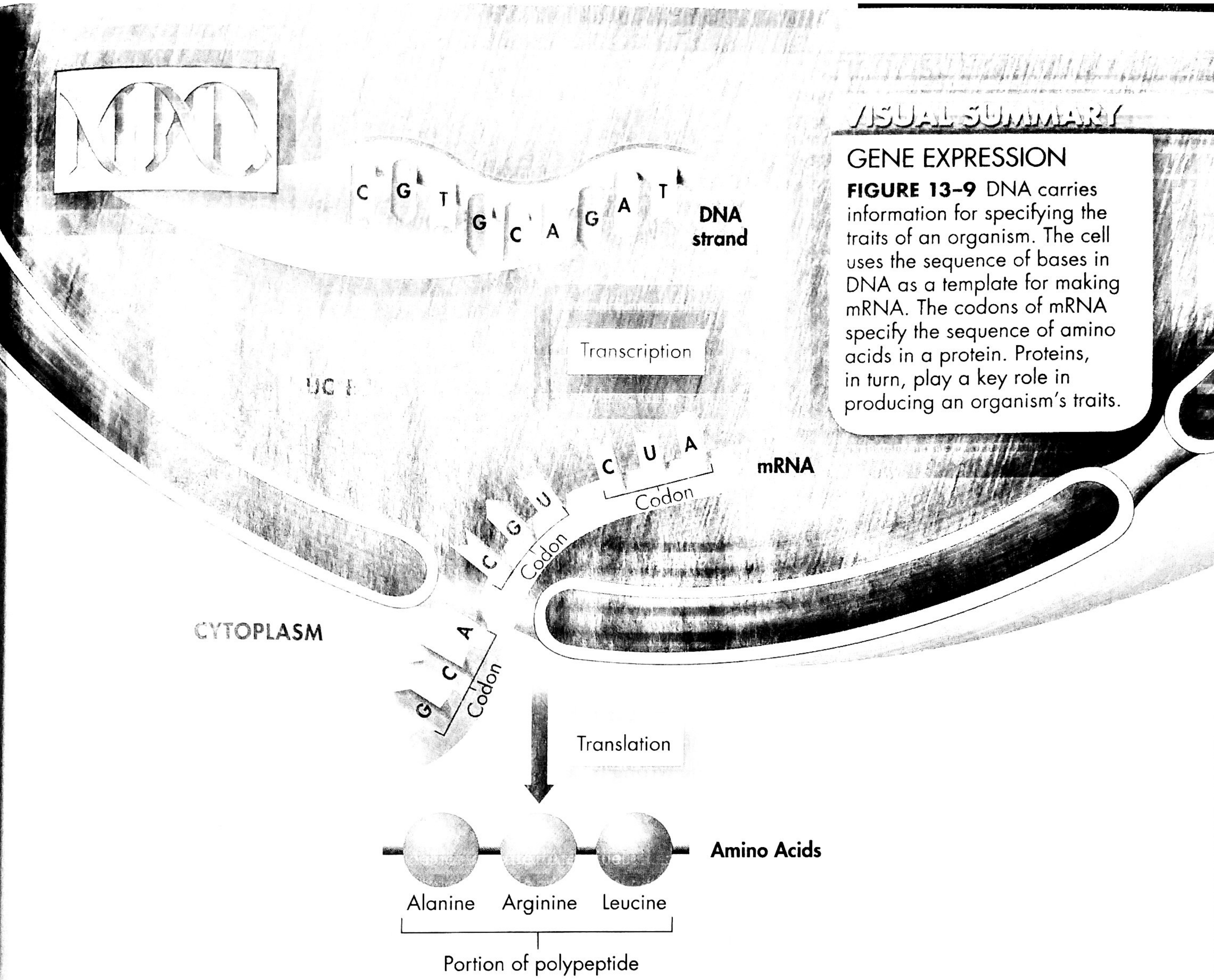
Gregor Mendel might have been surprised to learn that most genes contain nothing more than instructions for assembling proteins. He might have asked what proteins could possibly have to do with the color of a flower, the shape of a leaf, or the sex of a newborn baby. The answer is that proteins have everything to do with these traits. Remember that many proteins are enzymes, which catalyze and regulate chemical reactions. A gene that codes for an enzyme to produce pigment can control the color of a flower. Another gene produces proteins that regulate patterns of tissue growth in a leaf. Yet another may trigger the female or male pattern of development in an embryo. In short, proteins are microscopic tools, each specifically designed to build or operate a component of a living cell.

As you've seen, once scientists learned that genes were made of DNA, a series of other discoveries soon followed. Before long, with the genetic code in hand, a new scientific field called molecular biology had been established. Molecular biology seeks to explain living organisms by studying them at the molecular level, using molecules like DNA and RNA. One of the earliest findings came to be known, almost jokingly, as the field's "central dogma." **The central dogma of molecular biology is that information is transferred from DNA to RNA to protein.** In reality, there are many exceptions to this "dogma," including viruses that transfer information in the opposite direction, from RNA to DNA. Nonetheless, it serves as a useful generalization that helps to explain how genes work. **Figure 13–9** illustrates **gene expression,** the way in which DNA, RNA, and proteins are involved in putting genetic information into action in living cells.

One of the most interesting discoveries of molecular biology is the near-universal nature of the genetic code. Although some organisms show slight variations in the amino acids assigned to particular codons, the code is always read three bases at a time and in the same direction. Despite their enormous diversity in form and function, living organisms display remarkable unity at life's most basic level, the molecular biology of the gene.

MYSTERY
CLUE

What features of the genetic code make it possible for a mouse's gene to work inside the cells of a fly?



VISUAL SUMMARY

GENE EXPRESSION

FIGURE 13–9 DNA carries information for specifying the traits of an organism. The cell uses the sequence of bases in DNA as a template for making mRNA. The codons of mRNA specify the sequence of amino acids in a protein. Proteins, in turn, play a key role in producing an organism's traits.

13.2 Assessment

Review Key Concepts

1. a. Review How does a cell interpret the genetic code?

b. Explain What are codons and anticodons?

c. Apply Concepts Using the table in **Figure 13–6,** identify the amino acids specified by codons: UGG, AAG, and UGC.

2. a. Review What happens during translation?

b. Compare and Contrast How is protein synthesis different from DNA replication? (*Hint*: Revisit Lesson 12.3.)

3. a. Review Why is the genetic code considered universal?

b. Explain What does the term *gene expression* mean?

c. Infer In what way does controlling the proteins in an organism control the organism's characteristics?

Apply the Big idea

Information and Heredity

4. Choose one component of translation to consider in depth. For instance, you might choose to consider one form of RNA or one step in the process. Then write a question or a series of questions about that component. Select one question, and use it to form a hypothesis that could be tested in an experiment.