Section 12–3

1 FOCUS

Objectives

12.3.1 ***Tell*** how RNA differs from DNA.
12.3.2 ***Name*** the three main types of RNA.
12.3.3 ***Describe*** transcription and the editing of RNA.
12.3.4 ***Identify*** the genetic code.
12.3.5 ***Summarize*** translation.
12.3.6 ***Explain*** the relationship between genes and proteins.

Guide for Reading

Vocabulary Preview

Ask: **What does it mean to transcribe something?** *(To write a copy of it)* Explain that in transcription, DNA is transcribed to produce a molecule of RNA. Ask: **What does it mean to translate something?** *(To express something in another language)* Explain that the message encoded by RNA is translated into a protein sequence during the process of translation.

Reading Strategy

Encourage students to preview all the figures in the section by carefully reading the captions and studying the diagrams. Remind students to refer to the diagrams while reading the section.

2 INSTRUCT

The Structure of RNA

Use Visuals

Figure 12–12 Have students compare and contrast the structures of the three RNA molecules. Make sure students are aware that rRNA also has nitrogenous bases; the scale of the illustration doesn't allow room for them. Ask: **What do all forms of RNA have in common?** *(Single-stranded chain of nucleotides composed of a ribose sugar, a phosphate group, and a nitrogenous base.)* L1 L2

12–3 RNA and Protein Synthesis

Guide for Reading

Key Concepts
- What are the three main types of RNA?
- What is transcription?
- What is translation?

Vocabulary
gene
messenger RNA
ribosomal RNA
transfer RNA
transcription
RNA polymerase
promoter
intron
exon
codon
translation
anticodon

Reading Strategy: Using Visuals Before you read, preview **Figure 12–18.** As you read, notice what happens in each step of translation, or protein synthesis.

The double helix structure explains how DNA can be copied, but it does not explain how a gene works. In molecular terms, **genes** are coded DNA instructions that control the production of proteins within the cell. The first step in decoding these genetic messages is to copy part of the nucleotide sequence from DNA into RNA, or ribonucleic acid. These RNA molecules contain coded information for making proteins.

The Structure of RNA

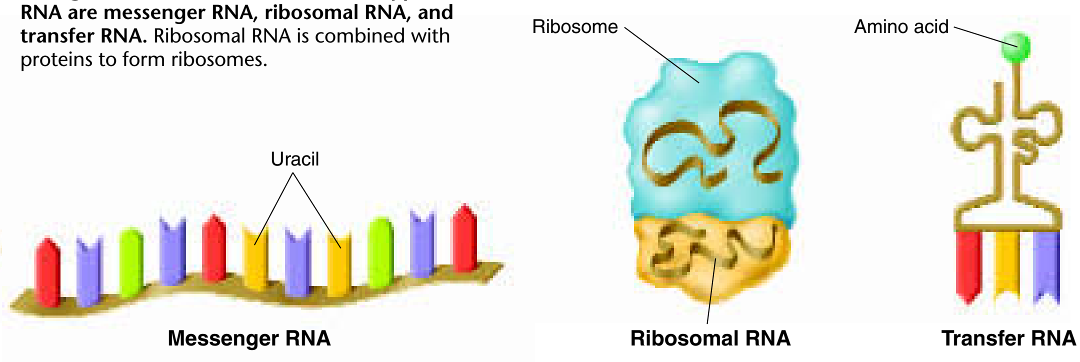
RNA, like DNA, consists of a long chain of nucleotides. As you may recall, each nucleotide is made up of a 5-carbon sugar, a phosphate group, and a nitrogenous base. There are three main differences between RNA and DNA: The sugar in RNA is ribose instead of deoxyribose, RNA is generally single-stranded, and RNA contains uracil in place of thymine.

You can think of an RNA molecule as a disposable copy of a segment of DNA. In many cases, an RNA molecule is a working copy of a single gene. The ability to copy a single DNA sequence into RNA makes it possible for a single gene to produce hundreds or even thousands of RNA molecules.

Types of RNA

RNA molecules have many functions, but in the majority of cells most RNA molecules are involved in just one job—protein synthesis. The assembly of amino acids into proteins is controlled by RNA. **There are three main types of RNA: messenger RNA, ribosomal RNA, and transfer RNA.** The structures of these molecules are shown in **Figure 12–12.**

Figure 12–12 **The three main types of RNA are messenger RNA, ribosomal RNA, and transfer RNA.** Ribosomal RNA is combined with proteins to form ribosomes.



SECTION RESOURCES

Print:
- ***Teaching Resources,*** Section Review 12–3
- ***Reading and Study Workbook A,*** Section 12–3
- ***Adapted Reading and Study Workbook B,*** Section 12–3
- ***Lesson Plans,*** Section 12–3

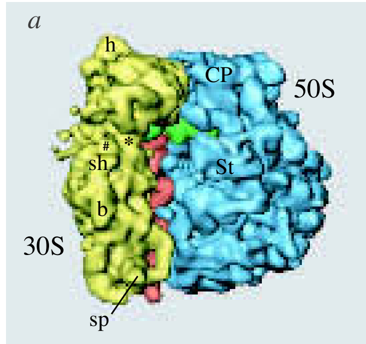
Technology:
- ***iText,*** Section 12–3
- ***Animated Biological Concepts Videotape Library,*** 25, 26
- ***Transparencies Plus,*** Section 12–3

Most genes contain instructions for assembling amino acids into proteins. The RNA molecules that carry copies of these instructions are known as **messenger RNA** (mRNA) because they serve as "messengers" from DNA to the rest of the cell.

Proteins are assembled on ribosomes, shown in **Figure 12–13.** Ribosomes are made up of several dozen proteins, as well as a form of RNA known as **ribosomal RNA** (rRNA).

During the construction of a protein, a third type of RNA molecule transfers each amino acid to the ribosome as it is specified by coded messages in mRNA. These RNA molecules are known as **transfer RNA** (tRNA).

CHECKPOINT *What are ribosomes made of?*



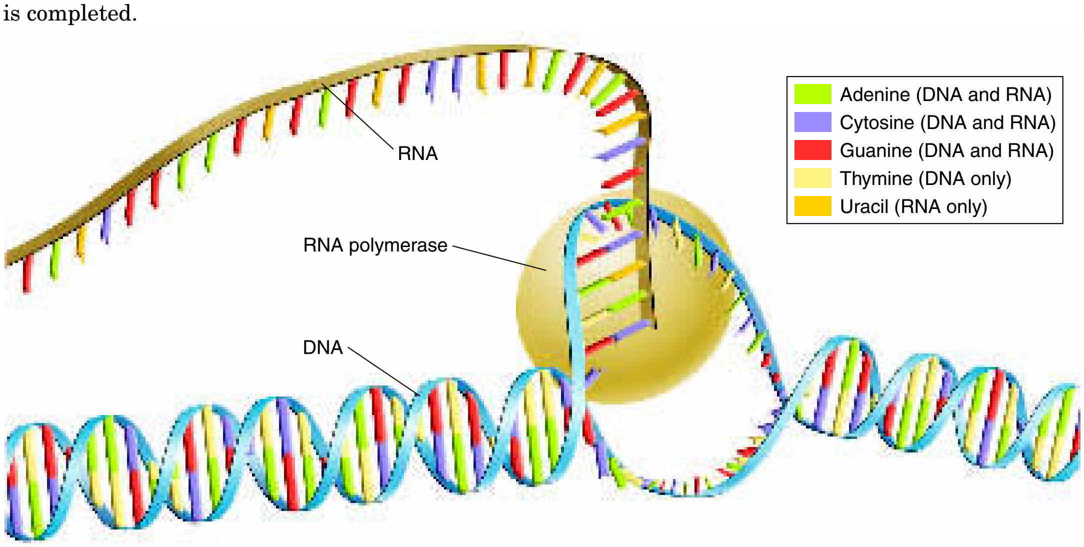
▲ **Figure 12–13** In this detailed model of a ribosome, the two subunits of the ribosome are shown in yellow and blue. The model was produced using cryo-electron microscopy. Data from more than 73,000 electron micrographs, taken at ultra-cold temperatures to preserve ribosome structure, were analyzed to produce the model.

Transcription

RNA molecules are produced by copying part of the nucleotide sequence of DNA into a complementary sequence in RNA, a process called **transcription.** Transcription requires an enzyme known as **RNA polymerase** that is similar to DNA polymerase. **During transcription, RNA polymerase binds to DNA and separates the DNA strands. RNA polymerase then uses one strand of DNA as a template from which nucleotides are assembled into a strand of RNA.** The process of transcription is shown in **Figure 12–14.**

How does RNA polymerase "know" where to start and stop making an RNA copy of DNA? The answer to this question begins with the observation that RNA polymerase doesn't bind to DNA just anywhere. The enzyme will bind only to regions of DNA known as **promoters,** which have specific base sequences. In effect, promoters are signals in DNA that indicate to the enzyme where to bind to make RNA. Similar signals in DNA cause transcription to stop when the new RNA molecule is completed.

▼ **Figure 12–14 During transcription, RNA polymerase uses one strand of DNA as a template to assemble nucleotides into a strand of RNA.**



Types of RNA

Build Science Skills

Predicting Explain that each type of RNA has a specific job in the process of making proteins. Have students examine the structures of each type of RNA molecule. Either provide diagrams of your own or have students look at the diagrams in Figure 12–12. From the structures of each type of RNA, challenge students to predict what function that RNA has in protein synthesis. Students should write their predictions and their reasons for making them. After studying transcription and translation, have students review their predictions. L2

Transcription

Use Visuals

Figure 12–14 As students study the diagram, ask: **Where is DNA located in the eukaryotic cell?** *(In the nucleus)* **Where does transcription take place?** *(In the nucleus)* **Where does protein synthesis take place?** *(In the cytoplasm)* Discuss the role of mRNA and its significance as a copy of DNA. Challenge students to consider why DNA stays inside the nucleus and produces expendable copies of RNA that leave the nucleus to direct protein synthesis. L2

Address Misconceptions

Some students might think that mRNA is transcribed from DNA and then processed into tRNA and/or rRNA. Review the roles and the structures of each form of RNA. Point out that rRNA and tRNA must bind to other proteins in the cytoplasm of the cell before they are activated. Emphasize that mRNA is transcribed only from genes that encode proteins. Ribosomal RNA and transfer RNA are transcribed from other genes that cannot be translated into proteins. L1 L2

ESL SUPPORT FOR ENGLISH LANGUAGE LEARNERS

Vocabulary: Writing

Beginning Help students understand the functions of—and differences between—messenger RNA, ribosomal RNA, and transfer RNA. Point to each type of RNA in Figures 12–12 and 12–18. Then, pair beginning ESL students with English-proficient students. The pairs can collaborate to make a table that compares the three kinds of RNA (column heads: *Where Located* and *Function*). They can use the two illustrations. L1

Intermediate Have students draw a cell and label the locations of messenger RNA, transfer RNA, and ribosomal RNA. Then, ask students to write explanations of the functions of the three kinds of RNA. Model the process by writing the function of messenger RNA on the board. L2

Answer to . . .

CHECKPOINT *Proteins and rRNA*

12–3 (continued)

RNA Editing

Demonstration

Show students what occurs during RNA editing by using a length of string to represent the pre-mRNA molecule. Color the string with markers to show which segments are introns and which are exons. Remind students that this process occurs in the nucleus before the mRNA moves into the cytoplasm. Demonstrate that the introns form loops so that the exons are situated next to each other. Cut the introns off with scissors and tape together the adjacent exons. Then, tape yarn to both ends of the string to represent the cap and the tail added to the mRNA sequence before it leaves the nucleus. L1 L2

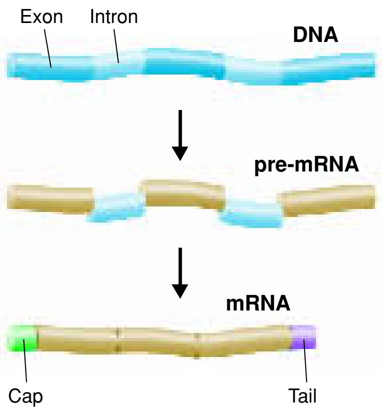
The Genetic Code

Build Science Skills

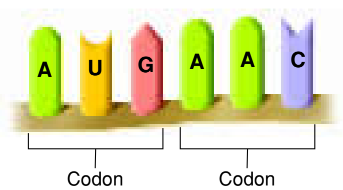
Applying Concepts Give student pairs different sequences of DNA, and tell them that a mutation has occurred in the sequence that changed one of the nucleotide bases. Have students show two possible sites for this mutation, one that affects the protein product and one that does not. Ask students to explain how the genetic code can help prevent some DNA mutations from affecting an organism's phenotypes. Direct them to review Figure 12–17 as they try to formulate their explanation. *(A mutation can change a nucleotide base, but the resulting codon can specify the same amino acid as the original codon.)* L2 L3

Use Visuals

Figure 12–17 Encourage students to closely examine the genetic code in the diagram. Make sure students are reading the diagram correctly to decode a codon. Ask: **What amino acid is specified by CAU?** *(Histidine)* **What is the codon for tryptophan?** *(UGG)* **What are two possible codons for glutamine?** *(CAG, CAA)* **What amino acid is usually the first amino acid of a protein?** *(Methionine)* **How do you know?** *(AUG is the start codon.)* L1 L2



▲ **Figure 12–15** Many RNA molecules have sections, called introns, edited out of them before they become functional. The remaining pieces, called exons, are spliced together. Then, a cap and tail are added to form the final RNA molecule. **Predicting** ***What do you think would happen if the introns were not removed from the pre-mRNA?***



▲ **Figure 12–16** A codon is a group of three nucleotides on messenger RNA that specify a particular amino acid. **Observing** ***What are the three-letter groups of the two codons shown here?***

RNA Editing

Like a writer's first draft, many RNA molecules require a bit of editing before they are ready to go into action. Remember that an RNA molecule is produced by copying DNA. Surprisingly, the DNA of eukaryotic genes contains sequences of nucleotides, called **introns,** that are not involved in coding for proteins. The DNA sequences that code for proteins are called **exons** because they are "expressed" in the synthesis of proteins. When RNA molecules are formed, both the introns and the exons are copied from the DNA. However, the introns are cut out of RNA molecules while they are still in the nucleus. The remaining exons are then spliced back together to form the final mRNA as shown in **Figure 12–15.**

Why do cells use energy to make a large RNA molecule and then throw parts of it away? That's a good question, and biologists still do not have a complete answer to it. Some RNA molecules may be cut and spliced in different ways in different tissues, making it possible for a single gene to produce several different forms of RNA. Introns and exons may also play a role in evolution. This would make it possible for very small changes in DNA sequences to have dramatic effects in gene expression.

CHECKPOINT ***What are introns and exons?***

The Genetic Code

Proteins are made by joining amino acids into long chains called polypeptides. Each polypeptide contains a combination of any or all of the 20 different amino acids. The properties of proteins are determined by the order in which different amino acids are joined together to produce polypeptides. How, you might wonder, can a particular order of nitrogenous bases in DNA and RNA molecules be translated into a particular order of amino acids in a polypeptide?

The "language" of mRNA instructions is called the genetic code. As you know, RNA contains four different bases: A, U, C, and G. In effect, the code is written in a language that has only four "letters." 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" of the coded message is three bases long. Each three-letter "word" in mRNA is known as a codon, as shown in **Figure 12–16.** A **codon** consists of three consecutive nucleotides that specify a single amino acid that is to be added to the polypeptide. For example, consider the following RNA sequence:

UCGCACGGU

This sequence would be read three bases at a time as:

UCG-CAC-GGU

The codons represent the different amino acids:

UCG-CAC-GGU

Serine-Histidine-Glycine

BIO INSIGHTS

FACTS AND FIGURES

RNA wobble

Cells do not produce 61 tRNA molecules—one for each codon. Most cells produce between 22 and 30 kinds of tRNA. The third nucleotide base in a codon is often called the wobble position, because the strength of the bond between the codon and the anticodon is weak. Because of this weakness, Chargaff's rules can be broken, and bases that would not normally pair up, do. This wobble effect is evident in the genetic code. In many cases, the first two bases are the most important in specifying an amino acid. It often does not matter what the third base is.

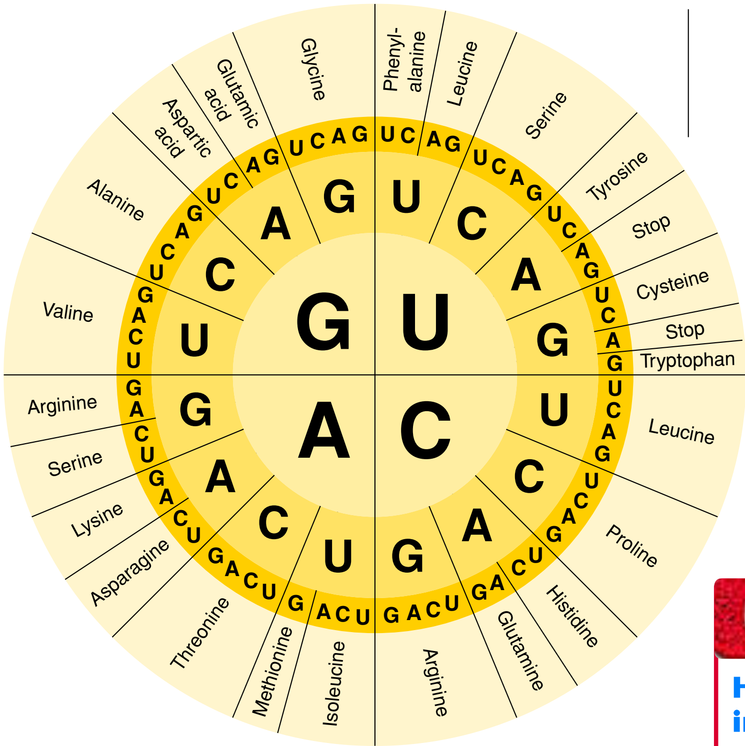


Figure 12–17 The genetic code shows the amino acid to which each of the 64 possible codons corresponds. To decode a codon, start at the middle of the circle and move outward. **Interpreting Graphics** *For what amino acid does the codon UGC code?*

Because there are four different bases, there are 64 possible three-base codons (4 × 4 × 4 = 64). **Figure 12–17** shows all 64 possible codons of the genetic code. As you can see, some amino acids can be specified by more than one codon. For example, six different codons specify the amino acid leucine, and six others specify arginine.

There is also one codon, AUG, that can either specify methionine or serve as the initiation, or "start," codon for protein synthesis. Notice also that there are three "stop" codons that do not code for any amino acid. Stop codons act like the period at the end of a sentence; they signify the end of a polypeptide, which consists of many amino acids.

Translation

The sequence of nucleotide bases in an mRNA molecule serves as instructions for the order in which amino acids should be joined together to produce a polypeptide. However, anyone who has tried to assemble a complex toy knows that instructions generally don't do the job themselves. They need something to read them and put them to use. In the cell, that "something" is a tiny factory called the ribosome.

Quick Lab

How does a cell interpret DNA?

Procedure

1. A certain gene has the following sequence of nucleotides:
   GACAAGTCCACAATC
   Write this sequence on a sheet of paper.
2. From left to right, write the sequence of the mRNA molecule transcribed from this gene.
3. Look at **Figure 12–17.** Reading the mRNA codons from left to right, write the amino acid sequence of the polypeptide translated from the mRNA.
4. Repeat step 3, reading the codons from right to left.

Analyze and Conclude

1. **Applying Concepts** Why did steps 3 and 4 produce different polypeptides?
2. **Inferring** Do cells usually decode nucleotides in one direction only or in either direction?

Translation

Build Science Skills

Using Models Give small groups of students a diagram of a simple object to build using colored blocks or other building sets. Explain that the diagram must stay in one spot and the building materials and building site must be in a different spot. Instruct students to devise a method by which they can build the object accurately despite the distance between the building plan and site. L2

Quick Lab

Objective Students will be able to conclude how a cell interprets DNA. L2

Skills Focus **Applying Concepts, Drawing Conclusions**

Time 15 minutes

Strategy Diagram a molecule of DNA on the board, or show students a three-dimensional model of one. Show students that ends of the DNA are different and that the molecule is directional. Discuss the importance of the directionalism of DNA and how it affects the sequence of amino acids making up proteins.

Expected Outcomes Students should conclude that translation in both directions yields two different amino acid sequences.

Analyze and Conclude

1. The mRNA sequence is not the same in both directions. Reading the sequence backward specifies a different amino acid sequence.
2. Cells usually decode nucleotides in only one direction.

TEACHER TO TEACHER

To help my students better understand how DNA encodes proteins, I like to give them a worksheet on which they practice transcribing and translating DNA. More specifically, I instruct them to write the mRNA sequence of the DNA, then write the tRNA anticodon sequence that is complementary to the mRNA. However, instead of using amino acids, I substitute words so that students produce a sentence instead of a protein sequence. I like to make up sentences such as "I love biology." or "Biology is often fun." I also instruct students to write their own DNA molecules and have their lab partners decode them.

—*James Boal*
Biology Teacher
Natrona County High School
Casper, WY

Answers to . . .

CHECKPOINT *Introns: sequences of mRNA not involved in coding for proteins; exons: expressed sequences of mRNA*

Figure 12–15 *The protein would be made incorrectly.*

Figure 12–16 *AUG, AAC*

Figure 12–17 *Cysteine*

12–3 (continued)

Use Visuals

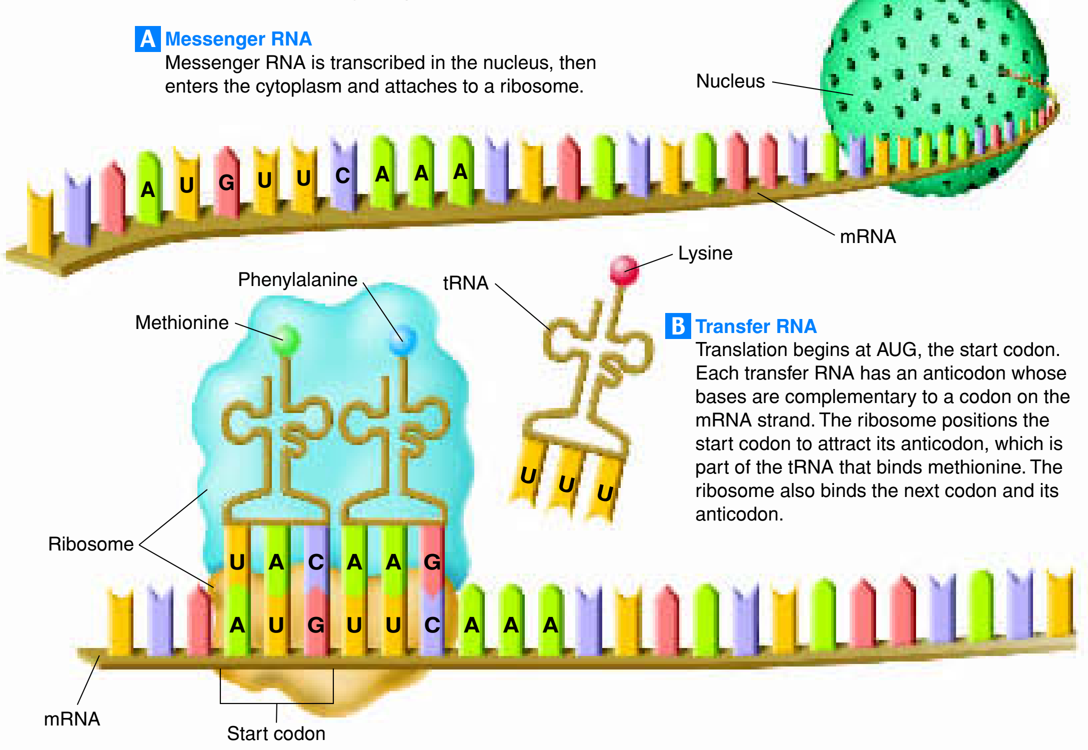
Figure 12–18 As students study the process of translation in the diagram, discuss the roles of mRNA, tRNA, and rRNA. Explain that ribosomes begin translation by binding to mRNA at an initiation site, which includes the start codon, AUG. Also point out that as soon as the initiation site is open on mRNA, another ribosome binds to it and begins translating another polypeptide. For example, B lymphocytes are infection-fighting white blood cells. When stimulated by invading germs, they begin a frenzy of cell division, forming huge numbers of plasma cells. These cells produce vast amounts of protein antibody, each cell secreting 2000 molecules per second throughout its short, four-day life span. Make sure students understand where translation occurs within a cell *(in the cytoplasm)*. L2

Go Online NSTA SCI*LINKS*

Download a worksheet on protein synthesis for students to complete, and find additional teacher support from NSTA SciLinks.

TRANSLATION

Figure 12–18 **During translation, or protein synthesis, the cell uses information from messenger RNA to produce proteins.** The cell uses all three main forms of RNA during this process.



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For: Links on protein synthesis
Visit: www.SciLinks.org
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The decoding of an mRNA message into a polypeptide chain (protein) is known as **translation.** Translation takes place on ribosomes. **During translation, the cell uses information from messenger RNA to produce proteins.** Refer to **Figure 12–18** as you read about translation.

A Before translation occurs, messenger RNA is transcribed from DNA in the nucleus and released into the cytoplasm.

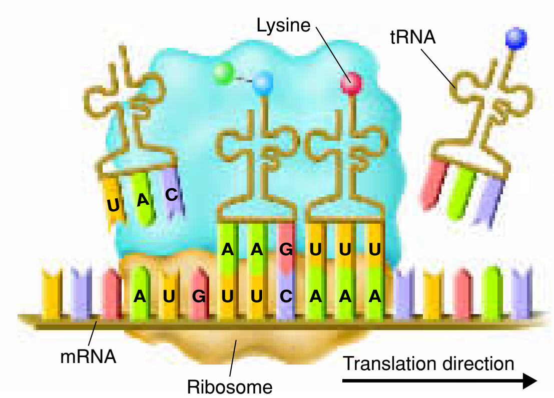
B Translation begins when an mRNA molecule in the cytoplasm attaches to a ribosome. As each codon of the mRNA molecule moves through the ribosome, the proper amino acid is brought into the ribosome by tRNA. In the ribosome, the amino acid is transferred to the growing polypeptide chain.

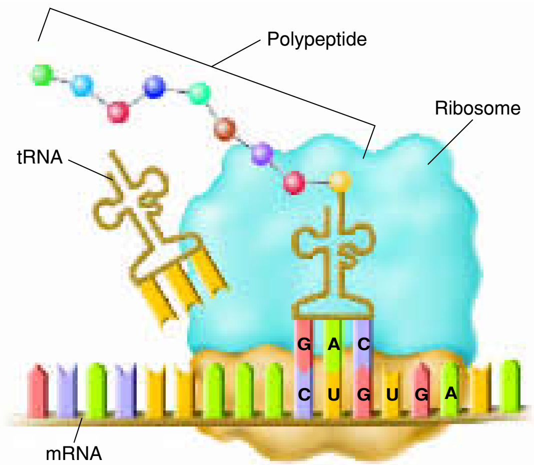
Each tRNA molecule carries only one kind of amino acid. For example, some tRNA molecules carry methionine, others carry arginine, and still others carry serine. In addition to an amino acid, each tRNA molecule has three unpaired bases. These bases, called the **anticodon,** are complementary to one mRNA codon.

BIO INSIGHTS — FACTS AND FIGURES

The importance of protein synthesis
The synthesis of proteins is a carefully orchestrated and controlled process that begins with a coded message on a DNA molecule. The cell goes to a lot of trouble to synthesize proteins correctly because proteins define what the cell looks like, how it functions, how it grows, and how it passes this information to its daughter cells. Some of the specific roles played by proteins include enzymatic action, transport, motion, protection, support, communication, and regulation.

C 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, binding new tRNA molecules and amino acids.





D Completing the Polypeptide
The process continues until the ribosome reaches one of the three stop codons. The result is a complete polypeptide.

In the case of the tRNA molecule for methionine, the anticodon bases are UAC, which pair 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 would fit against the mRNA molecule held in the ribosome. That second tRNA molecule would bring the amino acid phenylalanine into the ribosome.

C Like an assembly line worker who attaches one part to another, the ribosome forms a peptide bond between the first and second amino acids, methionine and phenylalanine. At the same time, the ribosome breaks the bond that had held the first tRNA molecule to its amino acid and releases the tRNA molecule. The ribosome then moves to the third codon, where a tRNA molecule brings it the amino acid specified by the third codon.

D 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 the newly formed polypeptide and the mRNA molecule, completing the process of translation.

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active art
For: Protein Synthesis activity
Visit: PHSchool.com
Web Code: cbp-4123

Build Science Skills

Asking Questions After studying translation, invite students to choose one component of the process to consider in depth. They might choose a ribosome, tRNA, mRNA, or a step in the process, such as ribosomal binding or elongation of the polypeptide chain. Then, have students write a question or a series of questions about their component of choice. Challenge students to refine their questions so they could potentially be answered by experimentation. L2

Go Online
active art
For: Protein Synthesis activity
Visit: PHSchool.com
Web Code: cbe-4123
Students interact with the art of protein synthesis online.

12–3 (continued)

The Roles of RNA and DNA

Build Science Skills

Using Analogies Have students evaluate the analogy used in the text to compare the roles of RNA and DNA. Ask them how well the analogy describes the roles. Then, challenge small groups of students to develop another analogy to describe the roles of DNA and RNA. Lead the class in a discussion about the accuracy of each group's analogy. L2

Genes and Proteins

Address Misconceptions

Some students might have difficulty visualizing the connections between genes, DNA, and proteins. Take this opportunity to put Gregor Mendel's findings into the context of DNA and RNA. Make sure students understand that proteins cause the phenotypes observed by Mendel. Also, emphasize that a DNA sequence that codes for a protein is a gene. L1 L2

3 ASSESS

Evaluate Understanding

Invite student volunteers to give the steps in the processes of transcription and translation. Write the steps on the board in the form of a flowchart.

Reteach

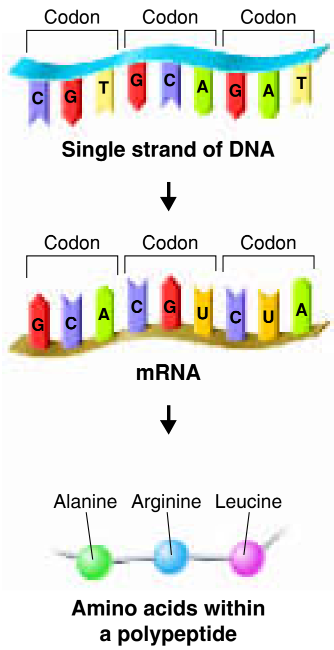
Have students study the process of translation in Figure 12–18. Instruct them to describe the roles of mRNA, tRNA, and rRNA in the synthesis of proteins. Make sure students know where transcription and translation occur in the cell.

Writing in Science

Students' résumés should clearly describe the functions of each type of RNA.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 12–3.



▲ **Figure 12–19** This diagram illustrates how information for specifying the traits of an organism is carried in DNA. The sequence of bases in DNA is used as a template for mRNA. The codons of mRNA specify the sequence of amino acids in a protein, and proteins play a key role in producing an organism's traits.

The Roles of RNA and DNA

You can compare the different roles played by DNA and RNA molecules in directing protein synthesis to the two types of plans used by builders. A master plan has all the information needed to construct a building. But builders never bring the valuable master plan to the building site, where it might be damaged or lost. Instead, they prepare inexpensive, disposable copies of the master plan called blueprints. The master plan is safely stored in an office, and the blueprints are taken to the job site. Similarly, the cell uses the vital DNA "master plan" to prepare RNA "blueprints." The DNA molecule remains within the safety of the nucleus, while RNA molecules go to the protein-building sites in the cytoplasm—the ribosomes.

Genes and Proteins

Gregor Mendel might have been surprised to learn that most genes contain nothing more than instructions for assembling proteins, as shown in **Figure 12–19.** He might have asked what proteins could possibly have to do with the color of a flower, the shape of a leaf, a human blood type, or the sex of a newborn baby.

The answer is that proteins have everything to do with these things. 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 an enzyme specialized for the production of red blood cell surface antigen. This molecule determines your blood type. Genes for certain proteins can regulate the rate and pattern of growth throughout an organism, controlling its size and shape. In short, proteins are microscopic tools, each specifically designed to build or operate a component of a living cell.

12–3 Section Assessment

1. **Key Concept** List the three main types of RNA.
2. **Key Concept** What happens during transcription?
3. **Key Concept** What happens during translation?
4. Describe the three main differences between RNA and DNA.
5. **Critical Thinking Applying Concepts** Using the genetic code, identify the amino acids that have the following messenger RNA strand codes: UGGCAGUGC.

Writing in Science

Creative Writing

An RNA molecule is looking for a job in a protein synthesis factory, and it asks you to write its résumé. This RNA molecule is not yet specialized and could, with some structural changes, function as either mRNA, tRNA, or rRNA. The résumé you create should reflect the qualifications needed for each type of RNA.

12–3 Section Assessment

1. Messenger RNA, transfer RNA, ribosomal RNA
2. RNA polymerase binds to DNA, separates the strands, and then uses one strand as a template to assemble RNA.
3. The cell uses information from messenger RNA to produce proteins.
4. The sugar in RNA is ribose instead of deoxyribose; RNA is generally single-stranded; RNA contains uracil in place of thymine.
5. Tryptophan-glutamine-cysteine