8.4 Transcription

KEY CONCEPT Transcription converts a gene into a single-stranded RNA molecule.

MAIN IDEAS

- RNA carries DNA's instructions.
- Transcription makes three types of RNA.
- The transcription process is similar to replication.

VOCABULARY

central dogma, p. 239
RNA, p. 239
transcription, p. 240
RNA polymerase, p. 240
messenger RNA (mRNA), p. 240
ribosomal RNA (rRNA), p. 240
transfer RNA (tRNA), p. 240

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Connect Suppose you want to play skeeball at a game center, but the skeeball lane only takes tokens. You only have quarters. Do you go home in defeat? Stand idly by as someone else becomes high scorer? No, you exchange your quarters for tokens and then proceed to show the other players how it's done. In a similar way, your cells cannot make proteins directly from DNA. They must convert the DNA into an intermediate molecule called RNA, or ribonucleic acid. That conversion process, called transcription, is the focus of this section.

MAIN IDEA

RNA carries DNA's instructions.

Soon after his discovery of DNA structure, Francis Crick defined the **central dogma** of molecular biology, which states that information flows in one direction, from DNA to RNA to proteins. The central dogma involves three processes, as shown in **FIGURE 8.10.**

- Replication, as you just learned, copies DNA (blue arrow).
- Transcription converts a DNA message into an intermediate molecule, called RNA (red arrow).
- Translation interprets an RNA message into a string of amino acids, called a polypeptide. Either a single polypeptide or many polypeptides working together make up a protein (green arrow).

In prokaryotic cells, replication, transcription, and translation all occur in the cytoplasm at approximately the same time. In eukaryotic cells, where DNA is located inside the nuclear membrane, these processes are separated both in location and time. Replication and transcription occur in the nucleus, while translation occurs in the cytoplasm. In addition, the RNA in eukaryotic cells goes through a processing step before it can be transported out of the nucleus. Unless otherwise stated, the rest of this chapter describes how these processes work in eukaryotic cells.

RNA acts as an intermediate link between DNA in the nucleus and protein synthesis in the cytoplasm. Like DNA, **RNA,** or ribonucleic acid, is a chain of nucleotides, each made of a sugar, a phosphate group, and a nitrogen-containing base. You can think of RNA as a temporary copy of DNA that is used and then destroyed.

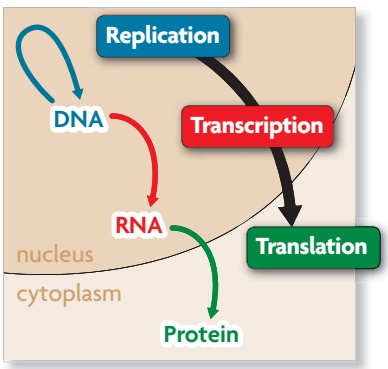
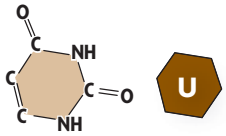


FIGURE 8.10 The central dogma describes the flow of information from DNA to RNA to proteins. It involves three major processes, shown in a eukaryotic cell below.

Connecting CONCEPTS

DNA Structure As you learned in **Section 8.2**, nucleotides are made of a phosphate group, a sugar, and a nitrogen-containing base. In DNA, the four bases are adenine, cytosine, guanine, and thymine. In RNA, uracil (below) replaces thymine and pairs with adenine.



RNA differs from DNA in three significant ways. First, the sugar in RNA is ribose, which has one additional oxygen atom not present in DNA's sugar (deoxyribose). Second, RNA has the base uracil in place of thymine. Uracil, like thymine, forms base pairs with adenine. Third, RNA is a single strand of nucleotides, in contrast to the double-stranded structure of DNA. This single-stranded structure allows some types of RNA to form complex three-dimensional shapes. As a result, some RNA molecules can catalyze reactions much as enzymes do.

Contrast **How do DNA and RNA differ?**

MAIN IDEA

Transcription makes three types of RNA.

Transcription is the process of copying a sequence of DNA to produce a complementary strand of RNA. During the process of transcription, a gene—not an entire chromosome—is transferred into an RNA message. Just as replication is catalyzed by DNA polymerase, transcription is catalyzed by **RNA polymerases,** enzymes that bond nucleotides together in a chain to make a new RNA molecule. RNA polymerases are very large enzymes composed of many proteins that play a variety of roles in the transcription process. **FIGURE 8.11** shows the basic steps of transcription in eukaryotic cells.

VOCABULARY

The word *transcribe* means "to make a written copy of." *Transcription* is the process of transcribing. A *transcript* is the copy produced by transcription.

1. With the help of other proteins and DNA sequences, RNA polymerase recognizes the transcription start site of a gene. A large transcription complex consisting of RNA polymerase and other proteins assembles on the DNA strand and begins to unwind a segment of the DNA molecule, until the two strands separate from each other.
2. RNA polymerase, using only one strand of DNA as a template, strings together a complementary strand of RNA nucleotides. RNA base pairing follows the same rules as DNA base pairing, except that uracil, not thymine, pairs with adenine. The growing RNA strand hangs freely as it is transcribed, and the DNA helix zips back together.
3. Once the entire gene has been transcribed, the RNA strand detaches completely from the DNA. Exactly how RNA polymerase recognizes the end of a transcription unit is complicated. It varies with the type of RNA.

Transcription produces three major types of RNA molecules. Not all RNA molecules code for proteins, but most play a role in the translation process. Each type of RNA molecule has a unique function.

- **Messenger RNA (mRNA)** is an intermediate message that is translated to form a protein.
- **Ribosomal RNA (rRNA)** forms part of ribosomes, a cell's protein factories.
- **Transfer RNA (tRNA)** brings amino acids from the cytoplasm to a ribosome to help make the growing protein.

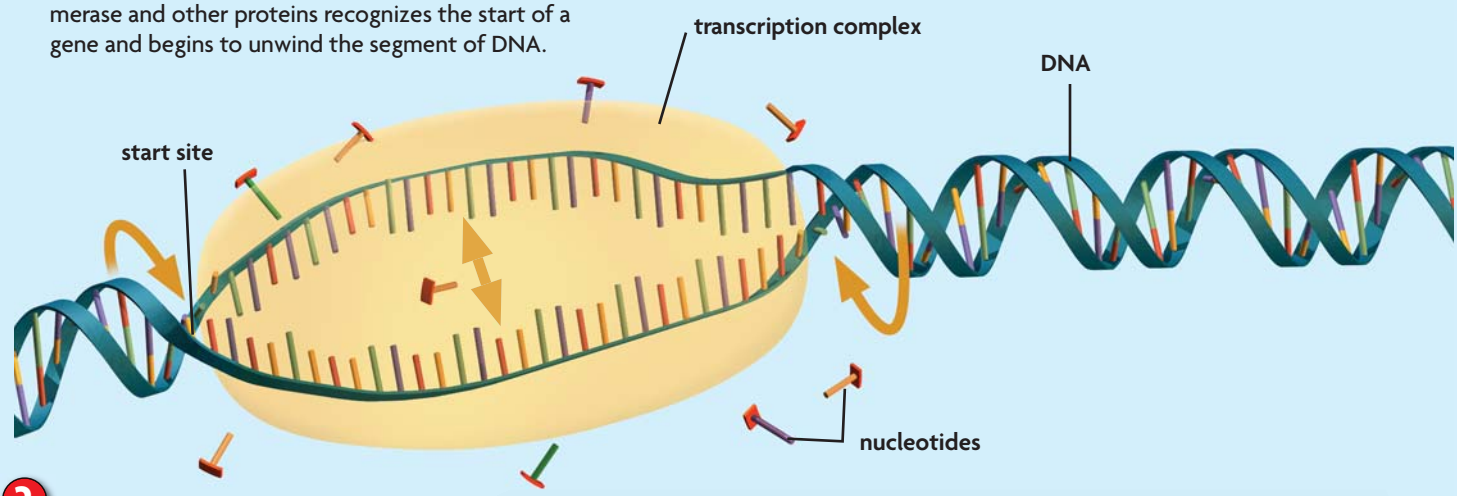
Remember that the RNA strand must be processed before it can exit the nucleus of a eukaryotic cell. This step occurs during or just after transcription. However, we will next examine translation and then return to processing.

Analyze **Explain why transcription occurs in the nucleus of eukaryotes.**

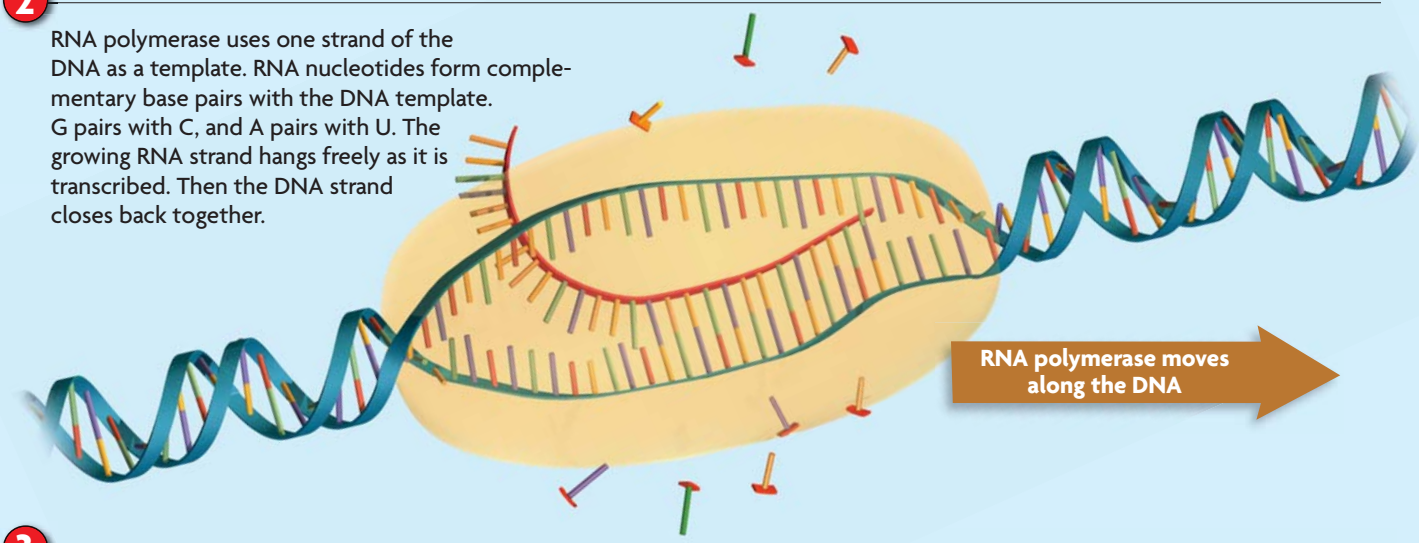
FIGURE 8.11 Transcription

Transcription produces an RNA molecule from a DNA template. Like DNA replication, this process takes place in the nucleus in eukaryotic cells and involves both DNA unwinding and nucleotide base pairing.

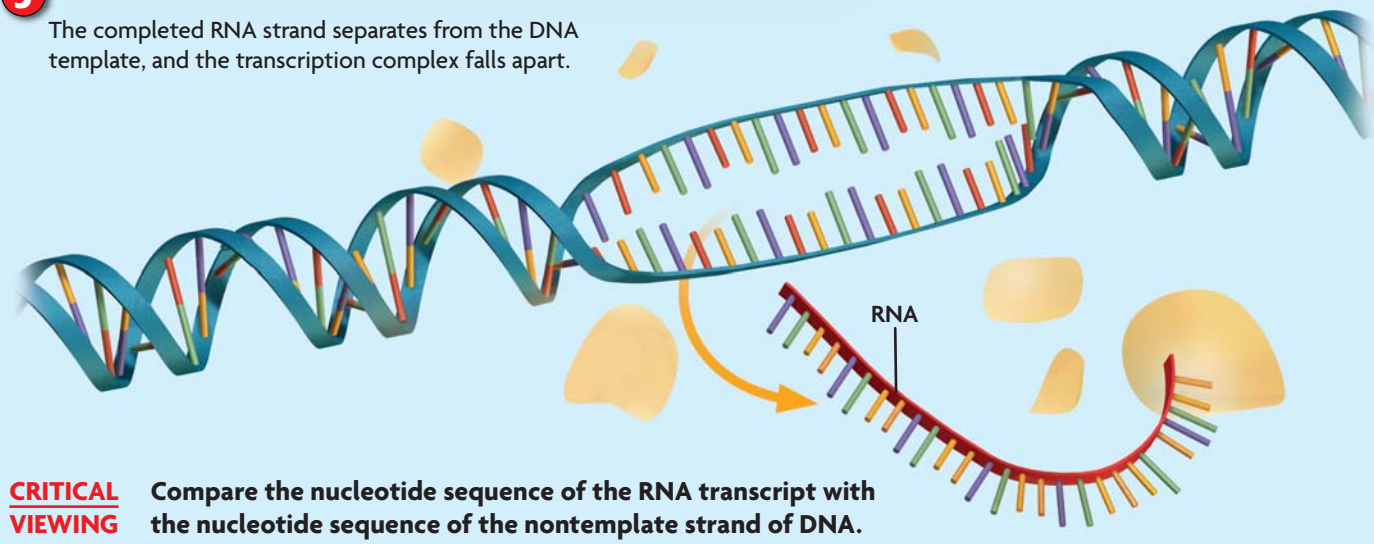
1 A large transcription complex made of RNA polymerase and other proteins recognizes the start of a gene and begins to unwind the segment of DNA.



2 RNA polymerase uses one strand of the DNA as a template. RNA nucleotides form complementary base pairs with the DNA template. G pairs with C, and A pairs with U. The growing RNA strand hangs freely as it is transcribed. Then the DNA strand closes back together.



3 The completed RNA strand separates from the DNA template, and the transcription complex falls apart.



CRITICAL VIEWING **Compare the nucleotide sequence of the RNA transcript with the nucleotide sequence of the nontemplate strand of DNA.**

MAIN IDEA

The transcription process is similar to replication.

The processes of transcription and replication share many similarities. Both processes occur within the nucleus of eukaryotic cells. Both are catalyzed by large, complex enzymes. Both involve unwinding of the DNA double helix. And both involve complementary base pairing to the DNA strand. In addition, both processes are highly regulated by the cell. Just as a cell does not replicate its DNA without passing a critical checkpoint, so, too, a cell carefully regulates which genes are transcribed into RNA.

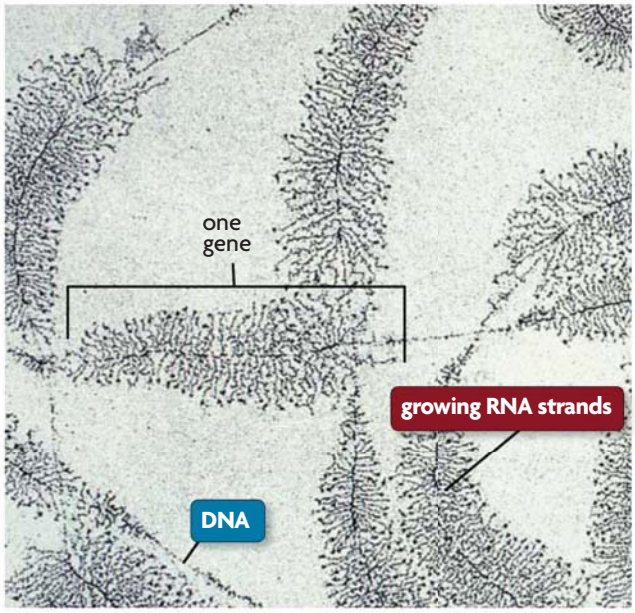


FIGURE 8.12 This TEM shows DNA being transcribed into numerous RNA strands by many RNA polymerases. The RNA strands near the start of each gene are shorter than those near the end. (TEM; magnification unknown)

The end results of transcription and replication, however, are quite different. The two processes accomplish very different tasks. Replication ensures that each new cell will have one complete set of genetic instructions. It does this by making identical sets of double-stranded chromosomes. This double-stranded structure makes DNA especially well suited for long-term storage because it helps protect DNA from being broken down and from potentially harmful interactions with other molecules. Replication occurs only once during each round of the cell cycle because each cell needs to make only one copy of its DNA.

In contrast, a cell may need hundreds or thousands of copies of certain proteins, or the rRNA and tRNA molecules needed to make proteins. Transcription enables a cell to adjust to changing demands. It does so by making a single-stranded complement of only a segment of DNA and only when that particular segment is needed. In addition, many RNA molecules can be transcribed from a single gene at the same time to help produce more protein. Once RNA polymerase has transcribed one portion of a gene and has moved on, another RNA polymerase can attach itself to the beginning of the gene and start the transcription process again. This process can occur over and over again, as shown in **FIGURE 8.12.**

Compare **How are the processes of transcription and replication similar?**

8.4 ASSESSMENT

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REVIEWING MAIN IDEAS

1. What is the **central dogma**?
2. Why can the **mRNA** strand made during **transcription** be thought of as a mirror image of the DNA strand from which it was made?
3. Why might a cell make lots of **rRNA** but only one copy of DNA?

CRITICAL THINKING

4. **Apply** If a DNA segment has the nucleotides AGCCTAA, what would be the nucleotide sequence of the complementary **RNA** strand?
5. **Synthesize** What might geneticists learn about genes by studying RNA?

Connecting CONCEPTS

6. **Cell Cycle** You know that a healthy cell cannot pass the G_2 checkpoint until all of its DNA has been copied. Do you think that a cell must also transcribe all of its genes into RNA to pass this checkpoint? Explain.