Chapter 5

DNA and Genes

5.1 What is a Gene?
5.2 Chromosomes
5.3 The Structure of DNA
5.4 How DNA Is Copied
5.5 How Proteins Are Built
5.6 Genetic Mutations

Photo credit: Geoff Gallice

5.5 How Proteins Are Built

We now know the structure of DNA and how DNA is copied. We are almost ready to look at how DNA provides cells with the instructions for building proteins. Before we do that, though, we have to introduce one more molecule—RNA.

RNA

Like DNA, **ribonucleic acid**, or **RNA**, consists of a sugar–phosphate backbone attached to nitrogenous bases (Figure 5.7). But RNA differs from DNA in three ways: (1) RNA is single-stranded rather than double-stranded like DNA; (2) RNA uses the sugar ribose instead of deoxyribose; and (3) RNA uses the nitrogenous base uracil (U) instead of thymine (T).

How is the information in DNA used to build a protein? During **transcription**, DNA is used as a template for building a molecule of RNA. During **translation**, this RNA molecule is used to assemble a protein (Figure 5.6).

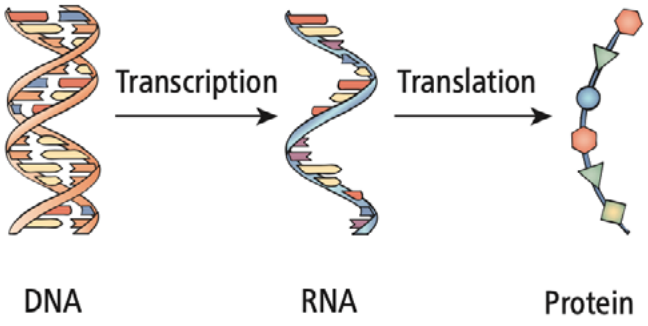

FIGURE 5.6

DNA is used to build a protein through transcription and then translation.

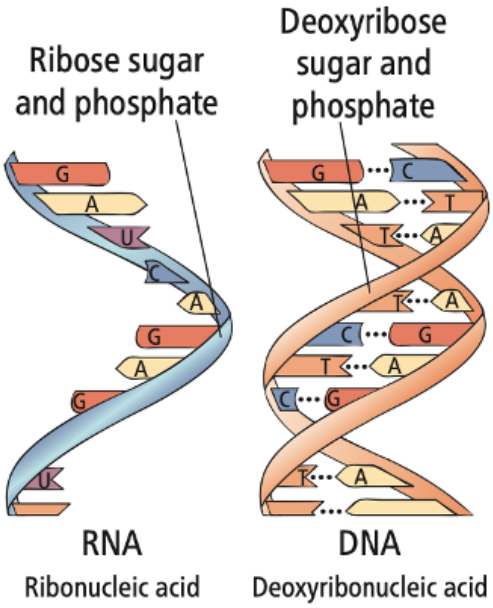

FIGURE 5.7

RNA is a single-stranded nucleic acid. RNA uses the sugar ribose, and it uses the nitrogenous base uracil instead of thymine.

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Transcription

In eukaryotes, transcription occurs in the cell nucleus. The two strands of DNA are separated, and one strand serves as a template for building an RNA transcript. Special nucleotide sequences in the DNA indicate where transcription should begin and end, marking the beginning and end of a gene.

The construction of the RNA molecule follows the same base-pairing rules that exist for DNA, except that RNA uses uracil (U) instead of thymine (T). So, where DNA has the nucleotides A, C, G, and T, the RNA molecule will have the nucleotides U, G, C, and A, respectively (Figure 5.8).

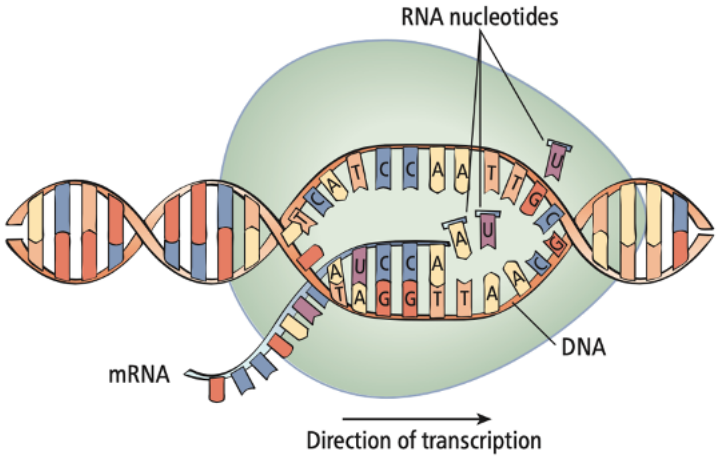

FIGURE 5.8
During transcription, information in DNA is used to build a molecule of RNA.

As free RNA nucleotides pair up with complementary nucleotides on the DNA strand, they are added to the growing RNA molecule. Once transcription is complete, the DNA zips back up and the newly built RNA is ready for the next step, which is a processing phase.

The cell processes the RNA molecule into a mature **messenger RNA** molecule, or **mRNA** molecule. First, stretches of nucleotides that are not used to build the protein, called introns, are removed (Figure 5.9). The stretches of nucleotides that are used to build the protein, called exons, remain. It is as if a starting transcript of Shakespeare's Hamlet contained the line "aggfr uidosa to be dfjklsdf or rewerwe not to be," and the irrelevant parts had to be removed in order to leave the coherent "to be or not to be." (If you have trouble remembering which parts are removed and which parts are kept in the transcript, you can think to yourself, "EXons EXpressed, INtrons IN the trash.") Scientists are not sure why introns exist. However, a single RNA transcript can sometimes be processed in multiple ways, resulting in different mRNA molecules. Second, a "cap" and "tail" are added to the beginning and end of the RNA molecule. The cap and tail allow the cell to recognize the molecule as mRNA. Once processing is complete, the mRNA molecule moves from the nucleus of the cell to the cytoplasm, where it will be translated to build a protein.

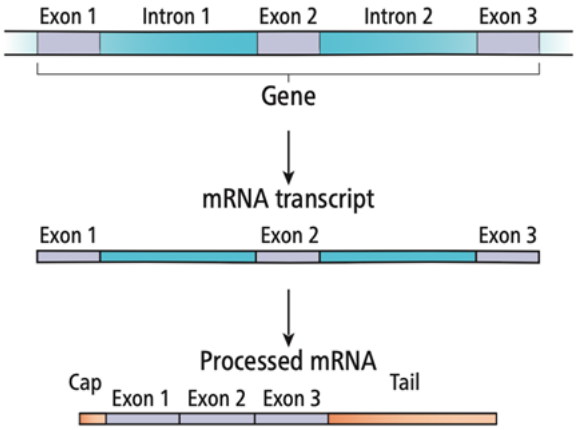

FIGURE 5.9

The RNA transcript goes through a processing phase in which introns are removed and a cap and tail are added. The result is an mRNA molecule that is ready for translation.

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Translation

During translation, mRNA is used to build a protein. Translation takes place in the cell cytoplasm at organelles called ribosomes. Ribosomes are composed of proteins and a type of RNA called *ribosomal RNA*, or *rRNA*.

How does translation work? Remember that a protein is a folded chain of amino acids. In translation, three nucleotides along the mRNA strand form a three-letter "word" called a **codon**. During translation, codons are "read" from the mRNA molecule one at a time. Most of these codons tell the ribosome to add a specific amino acid to the protein being built. A few codons tell the ribosome that there are no more amino acids in the protein and that translation is complete.

The *genetic code* tells us what each codon stands for (Table 5.1). For example, the codon AGU translates to the amino acid serine, and the codon GUG translates to the amino acid valine. Certain codons, such as UAA, are called *stop codons* because they tell the ribosome that there are no more amino acids in the protein. The first codon to be translated from mRNA is always AUG—methionine. Interestingly, the genetic code is the same for practically all living organisms. So, you read the codons in mRNA, string together amino acids in the right order, and presto! You have a protein.

Table 5.1 The genetic code.

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU, UUC: Phenylalanine (Phe)	UCU, UCC, UCA, UCG: Serine (Ser)	UAU, UAC: Tyrosine (Tyr)	UGU, UGC: Cysteine (Cys)	U C A G
	UUA, UUG: Leucine (Leu)		UAA: Stop; UAG: Stop	UGA: Stop; UGG: Tryptophan (Trp)	
C	CUU, CUC, CUA, CUG: Leucine (Leu)	CCU, CCC, CCA, CCG: Proline (Pro)	CAU, CAC: Histidine (His); CAA, CAG: Glutamine (Gln)	CGU, CGC, CGA, CGG: Arginine (Arg)	U C A G
A	AUU, AUC, AUA: Isoleucine (Ile)	ACU, ACC, ACA, ACG: Threonine (Thr)	AAU, AAC: Asparagine (Asn); AAA, AAG: Lysine (Lys)	AGU, AGC: Serine (Ser); AGA, AGG: Arginine (Arg)	U C A G
	AUG: Methionine or start				
G	GUU, GUC, GUA, GUG: Valine (Val)	GCU, GCC, GCA, GCG: Alanine (Ala)	GAU, GAC: Aspartic acid(Asp); GAA, GAG: Glutamic acid (Glu)	GGU, GGC, GGA, GGG: Glycine (Gly)	U C A G

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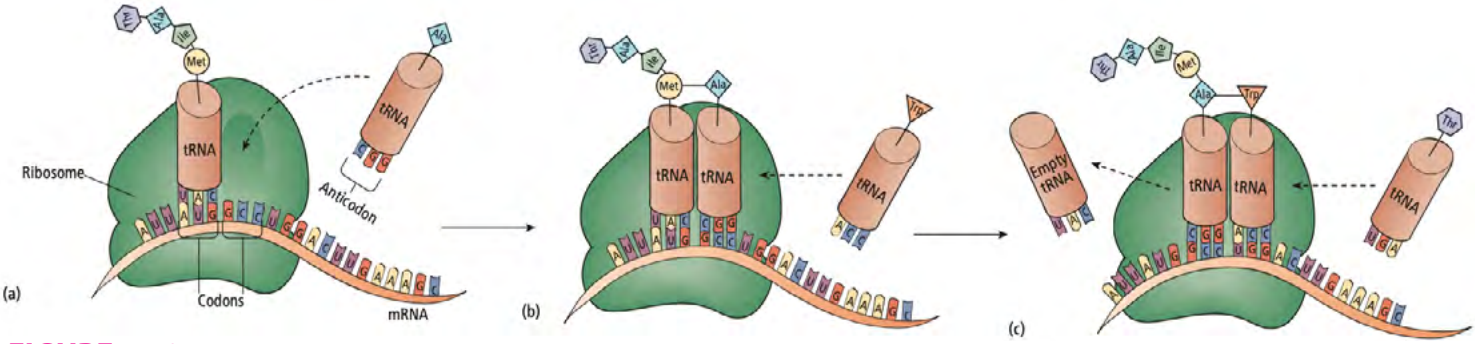

FIGURE 5.10

During translation, an mRNA molecule is translated to build a protein. (a) The anticodon of a tRNA molecule binds to a codon in the mRNA molecule. (b) The amino acid carried by the anticodon is added to the growing protein. (c) The mRNA molecule is shifted so that a new codon can be translated.

Now, how is all this accomplished? Translation requires another type of RNA, **transfer RNA**, or **tRNA**. A tRNA molecule includes a sequence of three nucleotides called an anticodon and carries a single, specific amino acid.

During translation, the mRNA molecule binds to a ribosome. The codon being translated is positioned at a specific site. A tRNA molecule with the appropriate anticodon binds to the codon (Figure 5.10a). The binding of anticodon to codon follows the usual rules—A binds with U, and G binds with C. The amino acid carried by the tRNA is then added to the growing protein (Figure 5.10b). After this, the ribosome shifts the mRNA so that a new codon can be translated (Figure 5.10c). This process is repeated until a stop codon is reached. As translation proceeds, the growing protein folds up into its appropriate three-dimensional shape. It takes a ribosome less than a minute to build a typical protein molecule.

READING CHECK

1. **A molecule of mRNA has the codon GUC. What is the anticodon on the tRNA that binds to it during translation? What amino acid does the tRNA carry?**

2. **If a stretch of DNA has the nucleotide sequence ACCTGAT, what sequence will the RNA transcript have?**

CHECK YOUR ANSWERS

1. The tRNA has the anticodon CAG. Looking at the genetic code table, we see that this tRNA molecule carries the amino acid valine. (When you use the genetic code table, remember that you need to look up the codon: GUC translates to valine.)

2. The RNA transcript will have the nucleotide sequence UGGACUA.

This video reviews transcription and translation:

https://www.youtube.com/watch?v=6YqPLgNjR4Q

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