Molecular Biology of the Gene

10

Focus on the Concepts

Genes are made of nucleic acids. This chapter covers the structure and function of DNA, the role of DNA and RNA in the manufacture of proteins, and the molecular biology of bacteria and viruses. Focus on these concepts:

- Experiments with viruses and bacteria demonstrated that DNA is the genetic material. DNA and RNA are polymers of nucleotides. DNA consists of two long polynucleotide strands, twisted in a "double helix" and held together by pairs of complementary nucleotide bases. It is the sequence of bases that carries genetic information.
- The structure of DNA—base pairing—relates to one of DNA's important functions—replication. Helped by enzymes and other cell machinery, the two strands of a DNA separate, and each strand acts as a template for the nucleotide-by-nucleotide assembly of a complementary strand. The end result is two identical double-stranded DNAs.
- A gene consists of hundreds or thousands of DNA nucleotides. The genetic code consists of three-base codons. Each codon represents an amino acid; a sequence of codons spells out an amino acid sequence. Thus the information in the DNA base sequence is expressed in proteins, which shape phenotype.
- The genetic code is "read" to build proteins in a two-step process, consisting of transcription and translation. First, a complimentary messenger RNA molecule is transcribed from a portion of the DNA. In eukaryotes, this RNA may then be "edited," or processed. At a ribosome, mRNA code is then translated into protein. Transfer RNAs match each mRNA codon with a specific amino acid, and the amino acids are linked to form a polypeptide with a specific amino acid sequence.
- Errors in DNA base sequence, called mutations, may change the meaning of genes. Because there are multiple codons representing each amino acid, base substitutions may or may not change the protein. Base deletions or additions alter the three-base reading frame of every codon "downstream" and usually have more drastic effects. Most mutations are harmful, but they do spawn the genetic diversity that makes natural selection and adaptation possible.
- Viruses are simple packages of nucleic acid—DNA or RNA—wrapped in protein, sometimes covered by a membranous envelope. Bacteriophages are viruses that attack bacteria. Other viruses infect animals and plants. A virus infects a host by slipping its nucleic acid into a host cell and taking over. The host cell helps make viral nucleic acid and protein, which then assemble into more viruses, which infect new cells.

- Bacteria reproduce asexually by replicating their DNA and undergoing binary fission. They can assemble new combinations of genes by taking up foreign DNA from their surroundings (transformation), acquiring DNA from another bacterium via a virus (transduction), or "mating" and sharing DNA with another bacterium (conjugation).

Review the Concepts

Work through the following exercises to review the concepts in this chapter. For additional review, check out the activities at www.masteringbiology.com. The website offers a pre-test that will help you plan your studies.

Exercise 1 (Introduction and Modules 10.1–10.3)

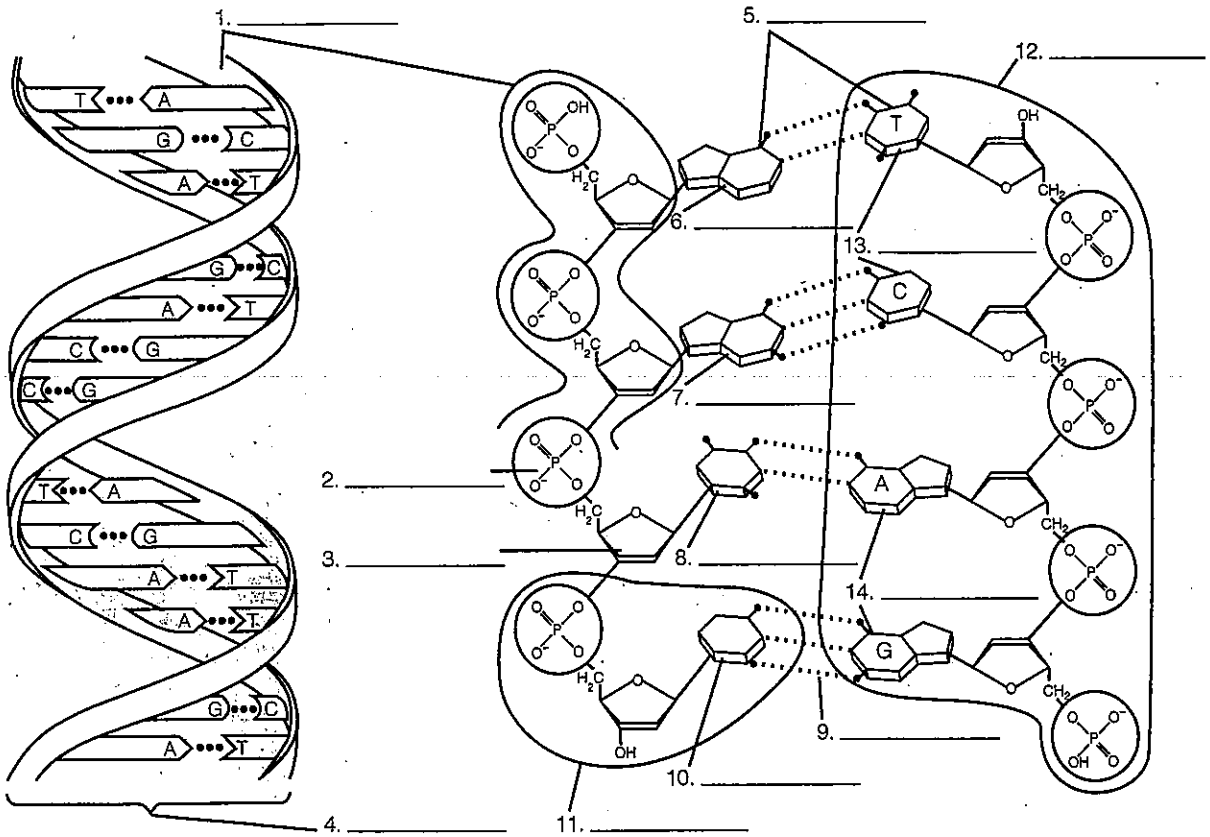
Review the experiments that showed that DNA is the genetic material and the structures of DNA and RNA. Then match each phrase on the left with the correct term(s) on the right. Note that some answers are used more than once, and some questions have multiple answers.

_____ 1. The basic chemical unit of a nucleic acid
_____ 2. The "transforming factor" that alters pneumonia bacteria
_____ 3. The two kinds of nucleic acids
_____ 4. The three parts of every nucleotide
_____ 5. A pair of these forms a "rung" in the DNA ladder
_____ 6. Used to "label" DNA and protein in experiments
_____ 7. The component of a bacteriophage that enters the host cell
_____ 8. Two alternating parts that form the nucleic acid "backbone"
_____ 9. The four bases in DNA
_____ 10. The DNA base complementary to T
_____ 11. A virus that attacks bacteria
_____ 12. The substance a phage leaves outside its host cell
_____ 13. Ribose in RNA and deoxyribose in DNA
_____ 14. Watson and Crick deduced the structure of this molecule
_____ 15. Attacked by herpesvirus
_____ 16. The DNA base complementary to G
_____ 17. A bacterium attacked by T2 phages
_____ 18. The sequence of these encodes DNA information
_____ 19. Eukaryotic chromosomes consist of this and DNA
_____ 20. The overall shape of a DNA molecule
_____ 21. Links adjacent nucleotides in a polynucleotide chain
_____ 22. Machine used to separate particles of different weights
_____ 23. Links a complementary pair of bases together
_____ 24. The four bases in RNA
_____ 25. Two larger purine bases
_____ 26. A polymer of nucleotides
_____ 27. Causes cold sores, chickenpox, and other diseases
_____ 28. This part makes DNA an acid
_____ 29. These two bases form three hydrogen bonds
_____ 30. The amount of this in DNA equals the amount of thymine (T)
_____ 31. RNA base that is not in DNA
_____ 32. Three smaller pyrimidine bases

A. Adenine (A)
B. Base
C. Cytosine (C)
D. DNA
E. *E. coli*
F. Double helix
G. Guanine (G)
H. Hydrogen bond
I. Radioactive isotope
J. Covalent bond
K. Bacteriophage
L. Protein
M. Nucleic acid
N. Nucleotide
O. Centrifuge
P. Phosphate
Q. Polynucleotide
R. RNA
S. Sugar
T. Thymine (T)
U. Uracil (U)
V. Herpesvirus
W. Nerve cell

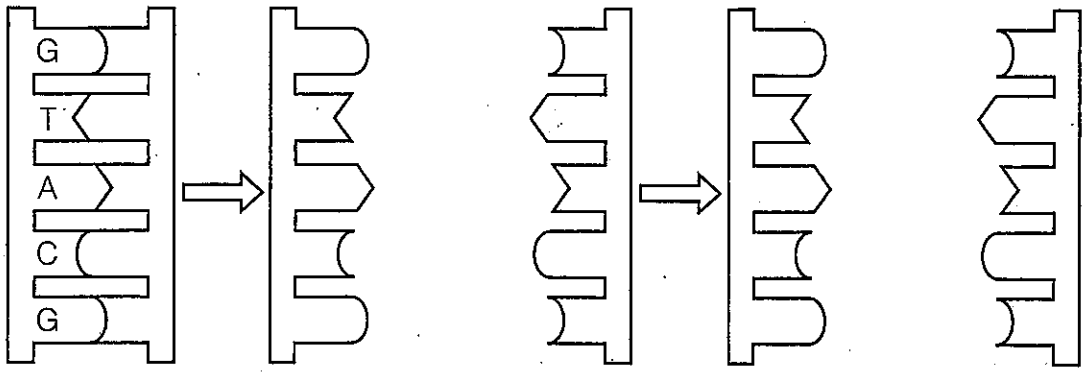
Exercise 2 (Modules 10.2–10.3)

Review the structure of DNA by labeling these diagrams. Include **nucleotide, polynucleotide, sugar (deoxyribose), phosphate group, sugar-phosphate backbone, pyrimidine bases, purine bases, thymine (T), adenine (A), guanine (G), cytosine (C), hydrogen bond, complementary base pair,** and **double helix.**



Exercise 3 (Module 10.4)

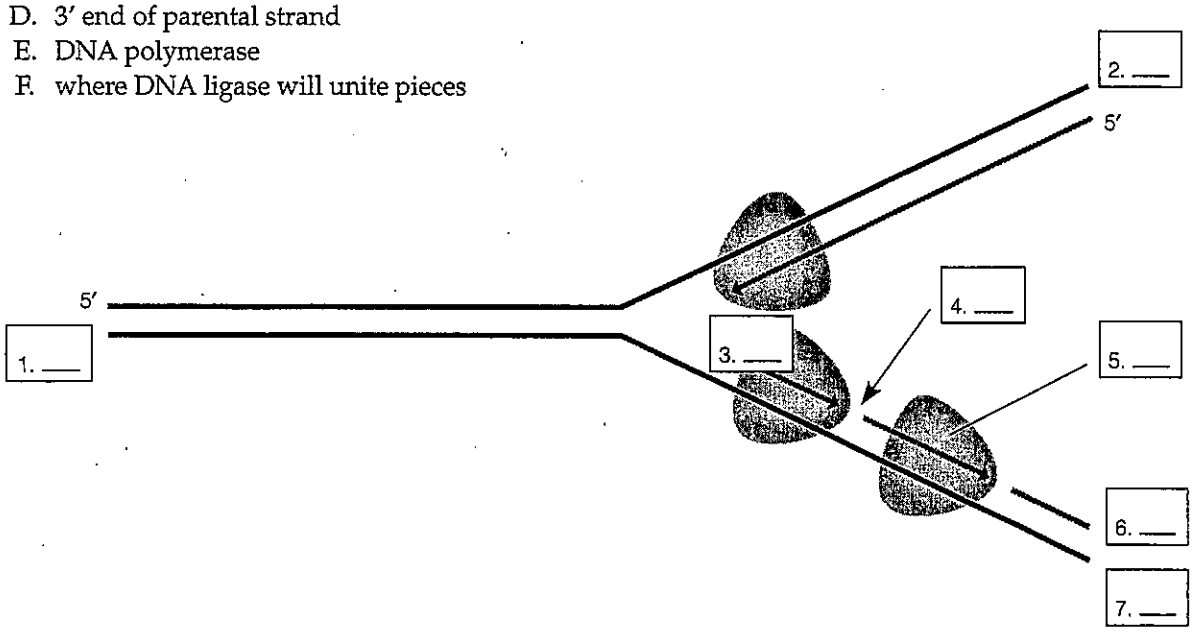
Reproduction and inheritance involve copying DNA instructions so that they can be passed to the next generation. This process is carried out by DNA polymerases, enzymes that use each strand of the DNA helix as a template on which to build a complementary strand. Review DNA replication by completing the simplified diagrams that follow. The first diagram shows the parent DNA molecule; label the nucleotides in the right-hand strand. Add five or six nucleotides to the second diagram so that it shows the parent strands separating and being used as templates. (Make sure you match complementary nucleotides correctly!) Complete the third diagram so that it shows two completed daughter molecules of DNA. Color the original DNA strands blue and the new strands gray.



Exercise 4 (Module 10.5)

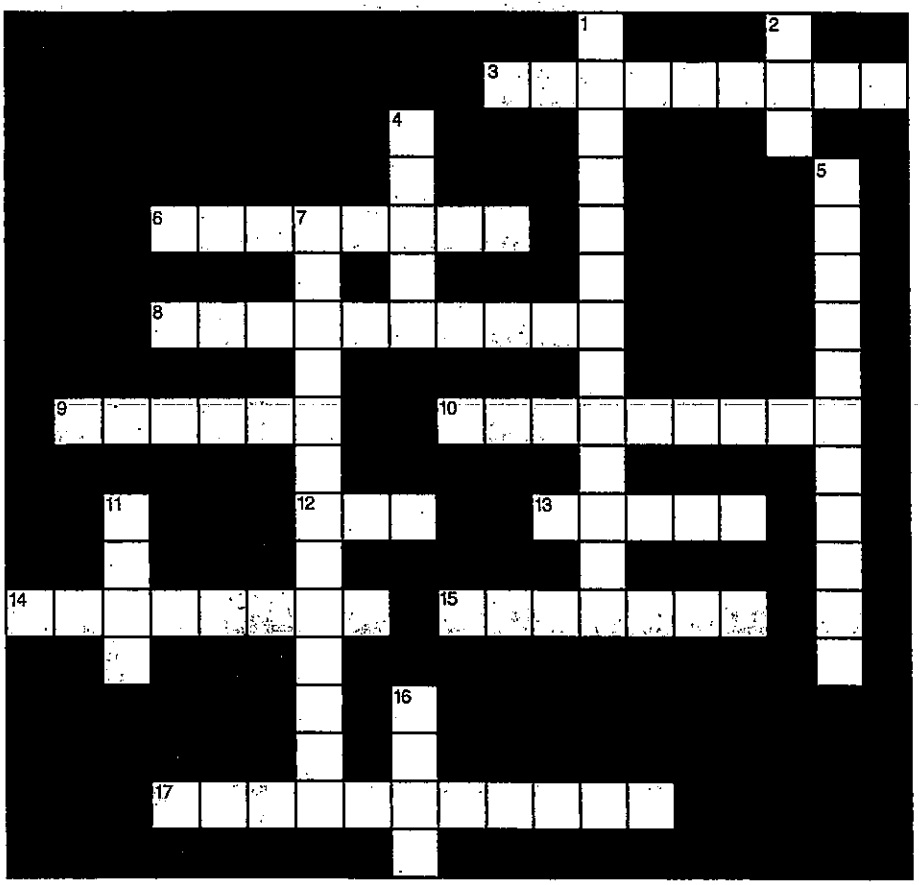
This module describes some of the details of DNA replication. Look at the diagrams carefully and try to visualize what is happening. (Web animations are very helpful too.) Once you think you understand the process, see if you can match each of the numbers in the boxes on the diagram that follows with one of the lettered choices. Choices may be used more than once.

A. 5′ end of daughter strand
B. 3′ end of daughter strand
C. 5′ end of parental strand
D. 3′ end of parental strand
E. DNA polymerase
F. where DNA ligase will unite pieces



Exercise 5 (Modules 10.6–10.7)

In a cell, the genotype (genetic information in DNA) is expressed as phenotype in the form of proteins—structural proteins that shape the organism and enzymes that carry out metabolism. Review the relationship between genotype and phenotype by completing this crossword puzzle.



Across

3. A gene consists of hundreds or ____ of nucleotide bases.
6. The information in DNA specifies the synthesis of ___.
8. Archibald Garrod noted the gene-protein link in "inborn errors of ____."
9. Genetic instructions are written in three-base "words" called ____.
10. An organism's expressed traits (what it looks like) make up its ____.
12. To make a protein, DNA information is first transcribed into ____.
13. The DNA language consists of a linear sequence of nucleotide ____.
14. An organism's genetic makeup is called its ____.
15. Phenotype is expressed via structural proteins, ____, and other proteins.
17. Making a polypeptide according to an RNA message is called ____.

Down

1. The base sequence of RNA is ____ to the DNA from which it is transcribed.
2. Genotype is the inheritable information encoded in ____.
4. Each codon in DNA and RNA specifies a certain ____ acid in a polypeptide.
5. Translation is conversion of an RNA message into a ____.
7. Transfer of information from DNA into an RNA molecule is called ____.
11. One ____ specifies how to build one polypeptide.
16. Using bread ____, Beadle and Tatum showed that a gene codes for an enzyme.

Exercise 6 (Modules 10.7–10.15)

These modules explain how the information in genes is used to build proteins. Review the processes of transcription and translation by filling in the blanks that follow.

The first step in making a protein is transcription of a gene. This occurs in the [1]_____ of a eukaryotic cell. An enzyme called [2]_____ carries out the process of transcribing RNA from the DNA. It starts at a specific nucleotide sequence called a [3]_____, next to the gene. RNA polymerase attaches, and the two DNA strands separate. RNA polymerase moves along one strand, and as it does, RNA [4]_____ take their places one at a time along the DNA template. They form hydrogen bonds with complementary DNA bases, following the same pairing rules as in DNA—C with G, and U (replacing T in RNA) with A. As the RNA molecule elongates, it peels away from the DNA. Finally, RNA polymerase reaches the [5]_____, a base sequence that signals the end of the gene, and the enzyme lets go of the gene and the RNA molecule. In a prokaryote, the RNA transcribed from a gene, called [6]_____ (mRNA), can be used immediately in polypeptide synthesis. In a eukaryotic cell, the RNA is further modified, or [7]_____, before leaving the nucleus as mRNA. Extra nucleotides are added to the ends of the transcript, and noncoding regions called [8]_____ are removed. The remaining coding regions, called [9]_____, are spliced together to form a continuous coding sequence. The finished mRNA leaves the nucleus and enters the [10]_____, where translation into protein takes place.

Translation of the "words" of the mRNA message into the [11]_____ sequence of a protein requires an interpreter—[12]_____ (tRNA)—which matches the appropriate [13]_____ with each [14]_____ in the mRNA message. A tRNA molecule is a folded strand of RNA. At one end, a special [15]_____ links the tRNA to a specific amino acid. The other end of the tRNA molecule bears three bases called the [16]_____, which is complementary to a particular mRNA codon. During the translation process, the tRNA matches its amino acid with an mRNA codon.

[17]_____ are the "factories" where the information in mRNA is translated and polypeptide chains are constructed. A ribosome consists of protein and [18]_____ (rRNA). Each ribosome has a groove that serves as a binding site for mRNA. There are two binding sites for tRNA: The P site holds the tRNA carrying the growing [19]_____, while the A site holds a tRNA bearing the next amino acid.

Translation begins with initiation. An mRNA and a special [20]_____ tRNA bind to the ribosome and a specific mRNA codon, the [21]_____, where translation begins. The initiator tRNA generally carries the amino acid methionine (Met). Its anticodon UAC binds to the start codon, AUG. The initiator tRNA fits into the P site on the ribosome.

The next step in [22]_____synthesis is elongation—adding amino acids to the growing chain. The anticodon of an incoming tRNA, carrying its amino acid, pairs with the mRNA codon at the open A site. With help from the ribosome, the polypeptide attached to the tRNA in the P site separates from its tRNA and forms a

peptide bond with the [23]_____ attached to the tRNA in the A site. Then the "empty" tRNA in the P site leaves the ribosome, and the tRNA in the A site, with the polypeptide chain, is shifted to the P site. The mRNA and tRNA move as a unit, allowing the next codon to enter the A site. Another tRNA, with a complementary anticodon, brings its amino acid to the A site. Its amino acid is added to the chain, the tRNA leaves, and the complex shifts again. In this way, [24]_____ are added to the chain, one at a time.

Finally, a [25]_____ in the mRNA reaches the A site of the [26]_____, terminating the polypeptide. A stop codon causes the polypeptide to separate from the last tRNA and the [27]_____. The polypeptide folds up, and it may join with other polypeptides to form a larger [28]_____ molecule.

Exercise 7 (Module 10.15)

This module summarizes the key steps in the flow of genetic information from DNA to RNA to protein. Study the diagrams carefully, and then label the numbered parts and processes.