### RNA and Protein Synthesis

#### Information and Heredity

**Big Idea:** How does information flow from DNA to RNA to direct the synthesis of proteins?

#### WHAT I KNOW

| 13.1 What is RNA? | **SAMPLE ANSWER:** RNA is a nucleic acid that carries coded genetic information. |
| 13.2 How do cells make proteins? | **SAMPLE ANSWER:** The bases in DNA—A, T, G, and C—form a four-letter “alphabet” that writes the “words” of the genetic code. |
| 13.3 What happens when a cell’s DNA changes? | **SAMPLE ANSWER:** When DNA changes, mistakes can be made. The organism may look or function differently. |
| 13.4 How do cells regulate gene expression? | **SAMPLE ANSWER:** Cell proteins regulate gene expression. |

#### WHAT I LEARNED

| 13.1 What is RNA? | **SAMPLE ANSWER:** RNA contains the sugar ribose and the nitrogenous base uracil instead of thymine. It is usually a single strand. mRNA molecules are made using DNA as a template. |
| 13.2 How do cells make proteins? | **SAMPLE ANSWER:** The genetic code is read in mRNA codons, which are sequences of three bases that correspond to a single amino acid. Ribosomes use the sequence of codons to assemble amino acids into polypeptides. |
| 13.3 What happens when a cell’s DNA changes? | **SAMPLE ANSWER:** Mutations are heritable changes in genetic information. They can involve only one DNA nucleotide or the whole chromosome. Mutations may or may not affect gene function. |
| 13.4 How do cells regulate gene expression? | **SAMPLE ANSWER:** DNA-binding proteins regulate genes by controlling transcription in prokaryotes. In eukaryotes, transcription factors control gene expression by binding DNA sequences in the regulatory regions. |
Lesson Objectives

- Contrast RNA and DNA.
- Explain the process of transcription.

Lesson Summary

**The Role of RNA**

RNA (ribonucleic acid) is a nucleic acid like DNA. It consists of a long chain of nucleotides. The RNA base sequence directs the production of proteins. Ultimately, cell proteins result in phenotypic traits. The main differences between RNA and DNA are:

- The sugar in RNA is ribose instead of deoxyribose.
- RNA is generally single-stranded and not double-stranded like DNA.
- RNA contains uracil in place of thymine.

RNA can be thought of as a disposable copy of a segment of DNA. Most RNA molecules are involved in protein synthesis. The three main types of RNA are:

- **Messenger RNA** (mRNA) carries copies of instructions for polypeptide synthesis from the nucleus to ribosomes in the cytoplasm.
- **Ribosomal RNA** (rRNA) forms an important part of both subunits of the ribosomes, the cell structures where proteins are assembled.
- **Transfer RNA** (tRNA) carries amino acids to the ribosome and matches them to the coded mRNA message.

**RNA Synthesis**

Most of the work of making RNA takes place during transcription. In transcription, segments of DNA serve as templates to produce complementary RNA molecules. In prokaryotes, RNA synthesis and protein synthesis takes place in the cytoplasm. In eukaryotes, RNA is produced in the cell’s nucleus and then moves to the cytoplasm to play a role in the production of protein. The following focuses on transcription in eukaryotic cells.

- The enzyme RNA polymerase binds to DNA during transcription and separates the DNA strands. It then uses one strand of DNA as a template from which to assemble nucleotides into a complementary strand of RNA.
- RNA polymerase binds only to promoters, regions of DNA that have specific base sequences. Promoters are signals to the DNA molecule that show RNA polymerase exactly where to begin making RNA. Similar signals cause transcription to stop when a new RNA molecule is completed.
- RNA may be “edited” before it is used. Portions that are cut out and discarded are called introns. The remaining pieces, known as exons, are then spliced back together to form the final mRNA.
The Role of RNA

1. Complete the table to contrast the structures of DNA and RNA.

<table>
<thead>
<tr>
<th></th>
<th>Sugar</th>
<th>Number of Strands</th>
<th>Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td>deoxyribose</td>
<td>2</td>
<td>A, T, G, and C</td>
</tr>
<tr>
<td>RNA</td>
<td>ribose</td>
<td>usually 1</td>
<td>A, G, and C, but no T; contains U (uracil) instead</td>
</tr>
</tbody>
</table>

2. On the lines provided, identify each kind of RNA.

3. **VISUAL ANALOGY** The master plan of a building shows how to build and place important parts of the building, such as walls, pipes, and electrical outlets. On the building site, workers use copies of the master plan called blueprints to show them what to do. The master plan is kept in the office. Explain how mRNA works like a blueprint in constructing proteins.

   *The master plan is the DNA molecule. The cell uses this molecule to prepare mRNA “blueprints.” The mRNA carries the instructions for protein synthesis from the nucleus to the ribosomes in the cytoplasm, where the proteins are built.*
RNA Synthesis

For Questions 4–10, complete each statement by writing the correct word or words.

4. The process of using DNA to produce complementary RNA molecules is called ________

5. The sequence of ________ bases in mRNA complements the sequence in the DNA template.

6. In eukaryotes, RNA is formed in the ________ and then travels to the ________.

7. The enzyme ________ RNA polymerase ________ binds to DNA during transcription.

8. RNA polymerase binds to regions of DNA called ________ promoters ________.

9. ________ are portions of RNA that are cut out and discarded.

10. ________ are spliced together to make the final mRNA.

11. THINK VISUALLY Sketch the sequence in which pre-mRNA is “edited” after it is made on the DNA template and before it is ready to function as mRNA in the cytoplasm. Show the original DNA, the pre-mRNA, and the final mRNA. Be sure to label exons and introns.

Drawing should show a DNA strand with introns and exons labeled. The introns and exons are contained in the pre-mRNA strand, but introns are removed and exons spliced together to form the mRNA. Drawing should resemble the figure in the textbook.

Apply the Big idea

12. Use the analogy of the master plan and blueprints used by builders to identify what represents messenger RNA, where the “ribosome” is, and who performs the same kind of job as transfer RNA.

Explain your reasoning.

The blueprints represent messenger RNA because they carry instructions for the building from the office (the “nucleus”) to the outside (“cytoplasm”). The “ribosome” is the job site where the building is being constructed. In the cell, proteins are “built” on the ribosome. The people at the job site are like transfer RNA because they carry the building materials, such as bricks and blocks (“amino acids”) and match their placement to the instructions in the blueprint.
13.2 Ribosomes and Protein Synthesis

Lesson Objectives

- Identify the genetic code and explain how it is read.
- Summarize the process of translation.
- Describe the “central dogma” of molecular biology.

Lesson Summary

The Genetic Code  A specific sequence of bases in DNA carries the directions for forming a polypeptide, a chain of amino acids. The types and order of amino acids in a polypeptide determine the properties of the protein. The sequence of bases in mRNA is the genetic code. The four bases, A, C, G, and U, act as “letters.”

- The 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.
- Some codons serve as “start” and “stop” signals for protein synthesis.

Translation  Ribosomes use the sequence of codons in mRNA to assemble amino acids into polypeptide chains. The process of decoding of an mRNA message into a protein is translation.

- Messenger RNA is transcribed in the nucleus and then enters the cytoplasm.
- On the ribosome, translation begins at the start codon. Each codon attracts an anticodon, the complementary sequence of bases on tRNA.
- Each tRNA carries one kind of amino acid. The match between the codon and anticodon ensures that the correct amino acid is added to the growing chain.
- The amino acids bond together, each in turn. The ribosome moves along the mRNA, exposing codons that attract still more tRNAs with their attached amino acids.
- The process concludes when a “stop code” is reached. The newly formed polypeptide and the mRNA molecule are released from the ribosome.

The Molecular Basis of Heredity  Molecular biology seeks to explain living organisms by studying them at the molecular level, using molecules like DNA and RNA.

- The central dogma of molecular biology is that information is transferred from DNA to RNA to protein.
- Gene expression is the way in which DNA, RNA, and proteins are involved in putting genetic information into action in living cells.
- The genetic code is generally the same in all organisms.
The Genetic Code

Use the diagram to answer Questions 1–7.

1. What are the words along the outside of the circle?
   They are the names of amino acids.

2. What can you find by reading this diagram from the inside out?
   the mRNA codons for amino acids

3. For which amino acid is AAA a codon?
   AAA is a codon for lysine.

4. What is the codon for tryptophan?
   The codon for tryptophan is UGG.

5. For which amino acid is GGA a codon?
   GGA is a codon for glycine.

6. What is a codon for alanine?
   A codon for alanine is GCC.

7. What are three other codons for alanine?
   GCG, GCA, GCU
Translation

Use the diagram to answer Questions 8–10.

8. What is the anticodon for leucine? **GAC**

9. What is the codon for leucine? **CUG**

10. List the amino acids in the order they would appear in the polypeptide coded for by this mRNA.  
    methionine, phenylalanine, lysine, leucine

11. What is the difference between transcription and translation?
    RNA is produced from DNA templates during transcription. In translation, that RNA is read to form polypeptide chains. In a eukaryotic cell, transcription goes on in the nucleus and translation is carried out by ribosomes.

12. Complete the table to describe the steps in protein synthesis.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning of translation</td>
<td>Translation begins when a ribosome attaches to an mRNA molecule at a “start” codon. Transfer RNA molecules carry amino acids to the mRNA, where the anticodon matches the codon and ensures the placement of the correct amino acid.</td>
</tr>
<tr>
<td>Assembly of polypeptide</td>
<td>Amino acids join one at a time onto the growing chain, and a tRNA floats away after it releases its amino acid. The ribosome moves along the mRNA, binding a new tRNA molecule and the amino acid it carries.</td>
</tr>
<tr>
<td>Completing the polypeptide</td>
<td>The process continues until a “stop” codon is reached, the polypeptide is complete, and the mRNA is released from the ribosome.</td>
</tr>
</tbody>
</table>

13. Describe the role of rRNA during translation.
    rRNA molecules make up part of a ribosome. These 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

For Questions 14–18, write the letter of the correct answer on the line at the left.

14. The instructions for assembling proteins are contained in the
   A. genes.
   B. ribosomes.
   C. exons.
   D. introns.

15. The central dogma of molecular biology is that information is transferred from
   A. RNA to protein to DNA.
   B. DNA to protein to RNA.
   C. protein to DNA to RNA.
   D. DNA to RNA to protein.

16. An exception to the central dogma is
   A. the infection of a virus by a bacteriophage.
   B. the ability of some viruses to transfer information from RNA to DNA.
   C. the expression of different genes during different stages of development.
   D. the translation of the codon into the anticodon of tRNA.

17. The way in which DNA, RNA, and proteins are all involved in putting genetic information into action in living cells is called
   A. translation.
   B. transcription.
   C. gene expression.
   D. viral transfer.

18. All organisms are mostly the same in
   A. the proteins they make on their ribosomes.
   B. how their proteins catalyze chemical reactions.
   C. the size of their genes.
   D. the molecular biology of their genes.

19. Whether the organism is a pea plant or a human being, the information in the DNA of the cell’s nucleus directs synthesis of proteins in the cytoplasm. Why, then, are pea plants and human beings so different?
   They contain different DNA, which directs the synthesis of different proteins. Those proteins form different structures and functions, making pea plant cells very different from human cells.
13.3 Mutations

Lesson Objectives

- Define mutations and describe the different types of mutations.
- Describe the effects mutations can have on genes.

Lesson Summary

Types of Mutations Mutations are heritable changes in genetic information. There are two categories of mutations: gene mutations and chromosomal mutations.

- **Gene mutations** produce changes in a single gene. **Point mutations** involve only one or a few nucleotides. Substitutions, insertions, and deletions are all types of point mutations.
  - In a substitution, one base is changed to a different base, which may affect only a single amino acid and have no effect at all.
  - In insertions and deletions, one base is inserted or removed from the DNA sequence. Insertions and deletions are called **frameshift mutations** because they shift the “reading frame” of the genetic message. Frameshift mutations can change every amino acid that follows the point of mutation and can have dramatic effects on the organism.

- **Chromosomal mutations** produce changes in the number or structure of chromosomes. They include deletions, duplications, inversions, and translocations.
  - Deletion involves the loss of all or part of a chromosome.
  - Duplication produces an extra copy of all or part of a chromosome.
  - Inversion reverses the direction of parts of a chromosome.
  - Translocation occurs when part of one chromosome breaks off and attaches to another.

Effects of Mutations Genetic material can be altered by natural events or by artificial means. Errors can be made during replication. Environmental conditions may increase the rate of mutation. Mutagens are chemical or physical agents in the environment that cause mutations.

The effects of mutations on genes vary widely:

- Some mutations have little or no effect.
- Some mutations produce beneficial variations. One example is polyploidy in plants, in which an organism has extra sets of chromosomes. Polyploid plants are often larger and stronger than diploid plants. Mutations can also produce proteins with new or altered functions that can be useful to organisms in different or changing environments.
- Some mutations negatively disrupt gene function or dramatically change protein structure. Genetic disorders such as sickle cell disease can result.
Types of Mutations

For Questions 1–8, match the term with its definition.

1. The change of one base to another in a DNA sequence
   - Term: B. substitution

2. A change in one or a few nucleotides that occur at a single point in the DNA sequence
   - Term: C. point mutation

3. Part of one chromosome breaks off and attaches to another
   - Term: F. translocation

4. A heritable change in genetic information
   - Term: A. mutation

5. A mutation that produces an extra copy of all or part of a chromosome
   - Term: H. duplication

6. A chromosomal mutation that reverses the direction of parts of a chromosome
   - Term: G. inversion

7. A kind of mutation that can change every amino acid that follows the point of mutation
   - Term: D. frameshift mutation

8. The addition of a base to the DNA sequence
   - Term: E. insertion

9. Complete the table to describe the processes and outcomes of the different types of gene (point) mutations.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substitution</td>
<td>One base is changed to a different base.</td>
<td>usually affects no more than a single amino acid, and sometimes has no effect at all</td>
</tr>
<tr>
<td>Insertion</td>
<td>An extra base is inserted into the DNA sequence.</td>
<td>The effects can be dramatic. The groupings of bases shift in every codon that follows the mutation.</td>
</tr>
<tr>
<td>Deletion</td>
<td>A base is removed from the DNA sequence.</td>
<td>The effects can be dramatic. The groupings of bases shift in every codon that follows the mutation.</td>
</tr>
</tbody>
</table>

10. Deletion can happen as a gene mutation or as a chromosomal mutation. What is the difference?

    In a gene mutation, a deletion happens when a base is removed from the DNA sequence. In a chromosomal mutation, deletion involves the loss of all or part of a chromosome.
Effects of Mutations

For Questions 10–17, write the letter of the correct answer on the line at the left.

10. The cellular machinery that replicates DNA inserts an incorrect base
   A. most of the time.
   B. about half the time.
   C. roughly once in every million bases.
   D. roughly once in every 10 million bases.

11. Small changes in genes
   A. disappear quickly.
   B. gradually accumulate over time.
   C. prevent the next generation from developing.
   D. do not affect future generations.

12. A possible mutagen is
   A. an anticodon.
   B. translocation.
   C. hemoglobin.
   D. ultraviolet light.

13. What happens when cells cannot repair the damage caused by a mutagen?
   A. The DNA base sequence changes permanently.
   B. The DNA base sequence is not affected.
   C. The organism is not affected.
   D. The organism is affected temporarily.

14. Which of the following most accurately summarizes the effects of mutations on living things?
   A. Most mutations are harmful, but some have little effect.
   B. Many mutations have little or no effect, but some can be harmful or beneficial.
   C. Most mutations are beneficial and a few are harmful.
   D. About half of mutations are beneficial and half are harmful.

15. Mutations are important to the evolution of a species because they
   A. happen over the long period of time that evolution requires.
   B. cut out and replace damaged or useless genes.
   C. are a source of genetic variability.
   D. accelerate the transcription rate of DNA.

16. Cancer is the product of a mutation that
   A. causes the uncontrolled growth of cells.
   B. changes the structure of hemoglobin in the blood.
   C. brings about stunted growth and severe pain.
   D. causes a translocation in a pair of chromosomes.
17. Polyploidy is the condition in which
   A. a piece of a chromosome breaks off and reattaches to another chromosome.
   B. an organism has an extra set of chromosomes.
   C. a mutagen speeds the mutation rate.
   D. an insect develops a resistance to a pesticide.

18. In the space below, draw an example of a normal blood cell and an example of a sickle cell.

Students' drawings should look like those in the textbook.

19. A gene that codes for one of the polypeptide chains of the blood protein hemoglobin lies on chromosome 11 in humans. A substitution mutation in that gene causes the amino acid valine to be incorporated into hemoglobin in a place where glutamic acid would normally lie. The result is sickle cell disease. Explain how a change in a single base in DNA can bring about such a serious disorder.

A single DNA base-pair change in a gene can create an incorrect codon in the mRNA molecule made from this DNA. When the incorrect codon is “read” on the ribosome, the wrong amino acid (in this case valine rather than glutamic acid) is placed into the polypeptide. With the wrong amino acid sequence, the protein does not form or function properly.