Chapter 17  Nucleic Acids and Protein Synthesis

17.1 Components of Nucleic Acids

17.2 Primary Structure of Nucleic Acids

Nucleic acids are:
• molecules that store information for cellular growth and reproduction.
• deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).
• large molecules consisting of long chains of monomers called nucleotides.

Nucleic Acids

The nucleic acids DNA and RNA consist of monomers called nucleotides that consist of a
• pentose sugar.
• base.
• phosphate.

Bases in DNA and RNA

DNA contains the bases
• Cytosine (C)
• Guanine (G)  same in both DNA and RNA
• Adenine (A)
• Thymine (T) different in DNA than RNA

RNA contains the bases
• Cytosine (C)
• Guanine (G)  same in both DNA and RNA
• Adenine (A)
• Uracil (U) different in RNA than DNA

Bases

The bases in DNA and RNA are
• pyrimidines C, T, and U.
• purines A and G.

Pentose Sugars

The pentose (five-carbon) sugar
• in RNA is ribose.
• in DNA is deoxyribose with no O atom on carbon 2’.
• has carbon atoms numbered with primes to distinguish them from the atoms in the bases.
A nucleoside
- has a base linked by a glycosidic bond to C1' of a sugar (ribose or deoxyribose).
- is named by changing the base ending to -osine for purines and -idine for pyrimidines.

A nucleotide
- is a nucleoside that forms a phosphate ester with the C5'–OH group of a sugar (ribose or deoxyribose).
- is named using the name of the nucleoside, followed by 5'-monophosphate.

Formation of a Nucleotide
A nucleotide forms when the –OH on C5' of a sugar bonds to phosphoric acid.

Nucleosides and Nucleotides with Purines

Nucleosides and Nucleotides with Pyrimidines

Names of Nucleosides and Nucleotides

<table>
<thead>
<tr>
<th>Base</th>
<th>Nucleosides</th>
<th>Nucleotides</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RNA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Learning Check

Give the name and abbreviation for the following, and list its base and sugar.

Guanosine 5’-monophosphate (GMP)
base: guanine
sugar: ribose

Primary Structure of Nucleic Acids

In the primary structure of nucleic acids,

- nucleotides are joined by phosphodiester bonds.
- the 3'-OH group of the sugar in one nucleotide forms an ester bond to the phosphate group on the 5'-carbon of the sugar of the next nucleotide.

A nucleic acid
- has a free 5'-phosphate group at one end and a free 3'-OH group at the other end.
- is read from the free 5'-end using the letters of the bases.
- This example reads —A—C—G—T—.

Example of RNA Structure

The primary structure of RNA,
- is a single strand of nucleotides with bases A, C, G, and U.
- is linked by phosphodiester bonds between ribose and phosphate.
17.3 DNA Double Helix

In DNA,
• nucleotides containing bases A, C, G, and T are linked by ester bonds between deoxyribose sugars and phosphate groups.

DNA Double Helix

A double helix
• is the structure of DNA.
• has two strands of nucleotides that wind together.
• is held in place by two hydrogen bonds that form between the base pairs A–T.
• is held in place by three hydrogen bonds that form between the base pairs G–C.

Complementary Base Pairs

DNA contains complementary base pairs in which
• Adenine is always linked by two hydrogen bonds with thymine (A–T).
• Guanine is always linked by three hydrogen bonds with cytosine (G–C).

Double Helix of DNA

In the double helix of DNA,
• two strands of nucleotides form a double helix structure like a spiral staircase.
• hydrogen bonds link bases A–T and G–C.
• the bases along one strand complement the bases along the other.

Learning Check

Write the complementary base sequence for the matching strand in the following DNA section:

A  G  T  C  C  A  T  C

Example of DNA

DNA (deoxyribonucleic acid)

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Write the complementary base sequence for the matching strand in the following DNA section:

\[ \text{--A--G--T--C--C--A--A--T--C--} \]

\[ \text{--T--C--A--G--G--T--T--A--G--} \]

In DNA replication,
- genetic information is maintained each time a cell divides.
- the DNA strands unwind.
- each parent strand bonds with new complementary bases.
- two new DNA strands form that are exact copies of the original DNA.

In DNA replication, genetic information is maintained each time a cell divides. The DNA strands unwind, each parent strand bonds with new complementary bases, and two new DNA strands form that are exact copies of the original DNA.

**DNA Replication**

**RNA**

- transmits information from DNA to make proteins.
- has several types
  - Messenger RNA (mRNA) carries genetic information from DNA to the ribosomes.
  - Transfer RNA (tRNA) brings amino acids to the ribosome to make the protein.
  - Ribosomal RNA (rRNA) makes up 2/3 of ribosomes, where protein synthesis takes place.

**Chapter 17 Nucleic Acids and Protein Synthesis**

**RNA and the Genetic Code**

**Types of RNA**

<table>
<thead>
<tr>
<th>Type</th>
<th>Abbreviation</th>
<th>Percentage of Total RNA</th>
<th>Function in the Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribosomal RNA</td>
<td>rRNA</td>
<td>75</td>
<td>Major component of the ribosomes</td>
</tr>
<tr>
<td>Messenger RNA</td>
<td>mRNA</td>
<td>5–10</td>
<td>Carries information for protein synthesis from the DNA to the ribosomes.</td>
</tr>
<tr>
<td>Transfer RNA</td>
<td>tRNA</td>
<td>10–15</td>
<td>Brings amino acids to the ribosomes for protein synthesis.</td>
</tr>
</tbody>
</table>

Each tRNA has a triplet called an anticodon that complements a codon on mRNA. It bonds to a specific amino acid at the acceptor stem.
Protein Synthesis

Protein synthesis involves

- **transcription**
  mRNA is formed from a gene on a DNA strand.

- **translation**
  tRNA molecules bring amino acids to mRNA to build a protein.

During transcription,

- a section of DNA containing the gene unwinds.
- one strand of DNA bases is used as a template.
- mRNA is synthesized using complementary base pairing with uracil (U) replacing thymine (T).
- the newly formed mRNA moves out of the nucleus to ribosomes in the cytoplasm.

RNA Polymerase

During transcription,

- **RNA polymerase** moves along the DNA template to synthesize the corresponding mRNA.
- the mRNA is released at the termination point.

Learning Check

What is the sequence of bases in mRNA produced from a section of the template strand of DNA that has the sequence of bases – C – T – A – A – G – G – ?

1. – G – A – T – C – C – C –
2. – G – A – U – U – C – C –
3. – C – T – A – A – G – G –

Solution

What is the sequence of bases in mRNA produced from a section of the template strand of DNA that has the sequence of bases – C – T – A – A – G – G – ?

1. – C – T – A – A – G – G –
2. – G – A – U – U – C – C –
Genetic Code

The genetic code
• is a sequence of amino acids in a mRNA that determines the amino acid order for the protein.
• consists of sets of three bases (triplet) along the mRNA called codons.
• has a different codon for all 20 amino acids needed to build a protein.
• contains certain codons that signal the "start" and "end" of a polypeptide chain.

The Genetic Code: mRNA Codons

<table>
<thead>
<tr>
<th>mRNA Codons</th>
<th>Amino Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCU</td>
<td>Proline</td>
</tr>
<tr>
<td>AGC</td>
<td>Serine</td>
</tr>
<tr>
<td>GGA</td>
<td>Glycine</td>
</tr>
<tr>
<td>CUU</td>
<td>Leucine</td>
</tr>
</tbody>
</table>

This mRNA section codes for an amino acid sequence of
—CCU —AGC—GGA—CUU—
—Pro — Ser — Gly — Leu —

Codons and Amino Acids

Determine the amino acids from the following codons in a section of mRNA.
—GCC—GUA—GAC—

According to the genetic code, the amino acids for these codons are
GCC = Alanine
GAC = Aspartic acid
CUC = Leucine
GUA = Valine

This mRNA section codes for an amino acid sequence of
—GCC—GUA—GAC—
—Ala — Val — Asp —

Learning Check

Write the order of amino acids coded for by a section of mRNA with the base sequence
—GCC—GUA—GAC—

GGC = Glycine
GAC = Aspartic acid
CUC = Leucine
GUA = Valine
GCC = Alanine
CGC = Arginine

Solution

GGC = Glycine
CUC = Leucine
GCC = Alanine

—GCC—GUA—GAC—
Ala — Val — Asp

Chapter 17 Nucleic Acids and Protein Synthesis

17.5 Protein Synthesis
For the **initiation** of protein synthesis, 
- a mRNA attaches to a ribosome.
- the start codon (AUG) binds to a tRNA with methionine.
- the second codon attaches to a tRNA with the next amino acid.
- a peptide bond forms between the adjacent amino acids at the first and second codons.

During **translocation**, 
- the first tRNA detaches from the ribosome.
- the ribosome shifts to the adjacent codon on the mRNA.
- a new tRNA/amino acid attaches to the open binding site.
- a peptide bond forms and that tRNA detaches.
- the ribosome shifts down the mRNA to read the next codon.

In the **termination** step, 
- all the amino acids are linked.
- the ribosome reaches a "stop" codon: UGA, UAA, or UAG.
- there is no tRNA with an anticodon for the "stop" codons.
- the polypeptide detaches from the ribosome.

**Learning Check**

Match the following.
1) activation  2) initiation  3) translocation  4) termination

A. Ribosomes move along mRNA, adding amino acids to a growing peptide chain.
B. A completed peptide chain is released.
C. A tRNA attaches to its specific amino acid.
D. A tRNA binds to the AUG codon of the mRNA on the ribosome.
### Solution

Match the following:

1) activation  2) initiation  3) translocation  4) termination

A. 3 Ribosomes move along mRNA, adding amino acids to a growing peptide chain.
B. 4 A completed peptide chain is released.
C. 1 A tRNA attaches to its specific amino acid.
D. 2 A tRNA binds to the AUG codon of the mRNA on the ribosome.

### Summary of Protein Synthesis

To summarize protein synthesis:
- A mRNA attaches to a ribosome.
- tRNA molecules bonded to specific amino acids attach to the codons on mRNA.
- Peptide bonds form between an amino acid and the peptide chain.
- The ribosome shifts to each codon on the mRNA until it reaches the STOP codon.
- The polypeptide chain detaches to function as an active protein.

### Learning Check

The following section of DNA is used to build mRNA for a protein.

<table>
<thead>
<tr>
<th>DNA Sequence</th>
<th>mRNA Sequence</th>
<th>Amino Acid Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAA—CCC—TTT—</td>
<td>—CUU—GGG—AAA—</td>
<td>Leu — Gly — Lys</td>
</tr>
</tbody>
</table>

A. What is the corresponding mRNA sequence?

B. What are the anticodons on the tRNAs?

C. What is the amino acid order in the peptide?

### Solution

A. What is the corresponding mRNA sequence?

B. What are the anticodons for the tRNAs?

GAA for CUU; CCC for GGG; UUU for AAA

C. What is the amino acid order in the peptide?

<table>
<thead>
<tr>
<th>mRNA Sequence</th>
<th>Amino Acid Order</th>
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<tbody>
<tr>
<td>—CUU—GGG—AAA—</td>
<td>Leu — Gly — Lys</td>
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</table>

### Learning Check

Place the following statements in order of their occurrence in protein synthesis.

A. mRNA attaches to a ribosome.
B. The ribosome moves along a mRNA to add amino acids to the growing peptide chain.
C. A completed polypeptide is released.
D. A tRNA brings an amino acid to its codon on mRNA.
E. DNA produces mRNA.

### Solution

Place the following statements in order of their occurrence in protein synthesis.

E. DNA produces mRNA.
A. mRNA attaches to a ribosome.
D. A tRNA brings an amino acid to its codon on mRNA.
B. The ribosome moves along a mRNA to add amino acids to the growing peptide chain.
C. A completed polypeptide is released.
17.6 Genetic Mutations

17.7 Viruses

Mutations

A mutation can
• alter the nucleotide sequence in DNA.
• result from mutagens such as radiation and chemicals.
• produce one or more incorrect codons in mRNA.
• produce a protein containing one or more incorrect amino acids.
• produce defective proteins and enzymes.
• cause genetic diseases.

Examples of Genetic Diseases

- Galactosemia
- Cystic fibrosis
- Down syndrome
- Muscular dystrophy
- Huntington’s disease
- Sickle-cell anemia
- Hemophilia
- Tay-Sachs disease

Normal DNA Sequence

The normal DNA sequence produces a mRNA that provides instructions for the correct series of amino acids in a protein.

Mutation: Substitution

Substitution
• of a base in DNA changes a codon in the mRNA.
• of a different codon leads to the placement of an incorrect amino acid in the polypeptide.

Frameshift Mutation

In a frameshift mutation,
• an extra base adds to or is deleted from the normal DNA sequence.
• all the codons in mRNA and amino acids are incorrect from the base change.
Learning Check

Identify each type of mutations as 1) substitution or 2) frameshift.

A. Cytidine (C) enters the DNA sequence.
B. One adenosine is removed from the DNA sequence.
C. A base sequence of TGA in DNA changes to TAA.

Solution

Identify each type of mutations as 1) substitution or 2) frame shift.

A. Cytosine (C) enters the DNA sequence.
B. One adenosine is removed from the DNA sequence.
C. A base sequence of TGA in DNA changes to TAA.

Viruses

Viruses
- are small particles of DNA or RNA that require a host cell to replicate.
- cause a viral infection when the DNA or RNA enters a host cell.
- are synthesized in the host cell from the viral RNA produced by viral DNA.

Reverse Transcription

In reverse transcription,
- a retrovirus, which contains viral RNA, but no viral DNA, enters a cell.
- the viral RNA uses reverse transcriptase to produce a viral DNA strand.
- the viral DNA strand forms a complementary DNA strand.
- the new DNA uses the nucleotides and enzymes in the host cell to synthesize new virus particles.
**HIV Virus and AIDS**

The HIV-1 virus
- is a retrovirus that infects T4 lymphocyte cells.
- decreases the T4 level and the immune system fails to destroy harmful organisms.
- causes pneumonia and skin cancer associated with AIDS.

**AIDS Treatment**

- One type of AIDS treatment prevents reverse transcription of the viral DNA.
- When altered nucleosides such as AZT and ddI are incorporated into viral DNA, the virus is unable to replicate.

**Learning Check**

Match the following.
1) virus  2) retrovirus  3) protease inhibitor  4) reverse transcription

A. a virus containing RNA  
B. small particles requiring host cells to replicate  
C. a substance that prevents the synthesis of viral proteins  
D. using viral RNA to synthesize viral DNA

**Solution**

Match the following.
1) virus  2) retrovirus  3) protease inhibitor  4) reverse transcription

A. 2 a virus containing RNA  
B. 1 small particles requiring host cells to replicate  
C. 3 a substance that prevents the synthesis of viral proteins  
D. 4 using viral RNA to synthesize viral DNA