17.4
RNA and the Genetic Code

Transcription
mRNA
Translation
Protein
Amino acids

© 2009 Pearson Prentice Hall, Inc.
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.
## 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 in the nucleus 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>

Copyright © 2009 Pearson Prentice Hall, Inc.
Each tRNA

- has a triplet called an anticodon that complements a codon on mRNA.
- bonds to a specific amino acid at the acceptor stem.
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.
During transcription,
- **RNA polymerase** moves along the DNA template to synthesize the corresponding mRNA.
- the mRNA is released at the termination point.
Protein Synthesis: Transcription

1. mRNA is made on DNA template
2. mRNA leaves nucleus, attaches to ribosome, and translation begins
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 – T – C – C –
2. – G – A – U – U – C – C –
3. – C – T – A – A – G – G –
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 –
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.
### Table 17.3 mRNA Codons: The Genetic Code for Amino Acids

<table>
<thead>
<tr>
<th>First Letter</th>
<th>Second Letter</th>
<th>Third Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>C</td>
</tr>
<tr>
<td>U</td>
<td>UUU Phe</td>
<td>UCU</td>
</tr>
<tr>
<td>U</td>
<td>UUC Ser</td>
<td>UCC</td>
</tr>
<tr>
<td>U</td>
<td>UUA Leu</td>
<td>UCA</td>
</tr>
<tr>
<td>U</td>
<td>UUG</td>
<td>UCG</td>
</tr>
<tr>
<td>C</td>
<td>CUU</td>
<td>CCU</td>
</tr>
<tr>
<td>C</td>
<td>CUC Pro</td>
<td>CCC</td>
</tr>
<tr>
<td>C</td>
<td>CUA Leu</td>
<td>CCA</td>
</tr>
<tr>
<td>C</td>
<td>CUG</td>
<td>CCG</td>
</tr>
<tr>
<td>A</td>
<td>AUU Ile</td>
<td>ACU</td>
</tr>
<tr>
<td>A</td>
<td>AUC Thr</td>
<td>ACC</td>
</tr>
<tr>
<td>A</td>
<td>AUA</td>
<td>ACA</td>
</tr>
<tr>
<td>A</td>
<td>AUG Met/start</td>
<td>ACG</td>
</tr>
<tr>
<td>G</td>
<td>GUU Val</td>
<td>GCU</td>
</tr>
<tr>
<td>G</td>
<td>GUC</td>
<td>GCC</td>
</tr>
<tr>
<td>G</td>
<td>GUA</td>
<td>GCA</td>
</tr>
<tr>
<td>G</td>
<td>GUG</td>
<td>GCG</td>
</tr>
</tbody>
</table>

*a Codon that signals the start of a peptide chain. STOP codons signal the end of a peptide chain.

Copyright © 2009 Pearson Prentice Hall, Inc.
Determine the amino acids from the following codons in a section of mRNA.

—CCU —AGC—GGA—CUU—

According to the genetic code, the amino acids for these codons are

CCU = proline    AGC = serine
GGA = glycine    CUU = leucine

This mRNA section codes for an amino acid sequence of

—Pro — Ser — Gly — Leu —
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
GGC = Glycine
CUC = Leucine
GCC = Alanine
GAC = Aspartic acid
GUA = Valine
CGC = Arginine

—GCC—GUA—GAC—

Ala ➔ Val ➔ Asp
Chapter 17  Nucleic Acids and Protein Synthesis

17.5  Protein Synthesis

Copyright © 2009 by Pearson Education, Inc.
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 \textit{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.
Peptide Formation

Peptide chain starts to form

tRNA

 anticodons

 UAC   AGA

 Met   Ser

 AUG  UCU  CUC

 Met

 Ser

 Leu

 AGA  GAG

 AUG  UCU  CUC  UUU

 Ribosome

 ribosome shifts
Protein Synthesis

Copyright © 2009 Pearson Prentice Hall, Inc.

translation
In the \textit{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.
The following section of DNA is used to build mRNA for a protein.

—GAA—CCC—TTT—

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?
A. What is the corresponding mRNA sequence?
—CUU—GGG—AAA— mRNA

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?
—CUU—GGG—AAA— mRNA
Leu — Gly — Lys
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.
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
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
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.

(b) Substitution of one base

DNA (coding strand)

Substitution of C by T

mRNA

Change in amino acid sequence

Incorrect order →

Wrong amino acid

Copyright © 2009 by Pearson Education, Inc.
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. 2 Cytosine (C) enters the DNA sequence.
B. 2 One adenosine is removed from the DNA sequence.
C. 1 A base sequence of TGA in DNA changes to TAA.
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.
Viruses

Cellular enzymes make viral proteins and viral DNA, which assemble into viruses.
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.
Reverse Transcription

- Virus
- Viral RNA
- Reverse transcriptase
- Viral DNA
- Provirus
- mRNA
- Protease
- Proteins
- Viral RNA
- New virus

Copyright © 2009 Pearson Prentice Hall, Inc.
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 ddl are incorporated into viral DNA, the virus is unable to replicate.
AIDS Treatment

Azidothymine (AZT)  Dideoxyinosine (ddI)
Another type of AIDS treatment involves protease inhibitors such as saquinavir, indinavir, and ritonavir. Protease inhibitors modify the active site of the protease enzyme, which prevents the synthesis of viral proteins.
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
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