Hogeschool van Arnhem en Nijmegen
HAN University of Applied Sciences

Course bi5b chemistry: Chapter 25
Nucleic Acids and Protein Synthesis



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Reference

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Fundamentals of General, Organic, and Biological

Chemistry

Seventh Edition

John McMurry
Cornell University

David S. Ballantine
Northern Illinois University

Carl A. Hoeger
University of California, San Diego

Virginia E. Peterson
University of Missouri, Columbia

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(Reference: Chapter 25 from McMurry et al.)

Chapter goals

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CHAPTER GOALS

1. **What are the compositions of the nucleic acids, DNA and RNA?**
   THE GOAL: Be able to describe and identify the components of nucleosides, nucleotides, DNA, and RNA. (◀◀◀ B, D.)
2. **What is the structure of DNA?**
   THE GOAL: Be able to describe the double helix and base pairing in DNA. (◀◀◀ A, B, D.)
3. **How is DNA reproduced?**
   THE GOAL: Be able to explain the process of DNA replication. (◀◀◀ A, B.)
4. **What are the functions of RNA?**
   THE GOAL: Be able to list the types of RNA, their locations in the cell, and their functions. (◀◀◀ A, B.)
5. **How do organisms synthesize messenger RNA?**
   THE GOAL: Be able to explain the process of transcription. (◀◀◀ A, B.)
6. **How does RNA participate in protein synthesis?**
   THE GOAL: Be able to explain the genetic code, and describe the initiation, elongation, and termination steps of translation. (◀◀◀ A, B, C.)

CONCEPTS TO REVIEW

◀◀◀

A. Hydrogen Bonding
(Section 8.2)

B. Phosphoric Acid Derivatives
(Section 17.8)

C. Protein Structure
(Sections 18.7, 18.8)

D. Carbohydrate Structure
(Section 21.4)

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(Reference: Chapter 25 from McMurry et al.)

Inhoud

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(Reference: Chapter 25 from McMurry et al.)

25.1 DNA, Chromosomes, and Genes

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- **Chromosome: coloured body**

  A structure in the cell nucleus carrying genetic information

- **Gene:**

  A portion of a chromosome controlling specific inheritable trait (e.g. brown eyes, red hair)

- **DNA:**

  Deoxyribonucleic acid: carrier of genetic information (histones)

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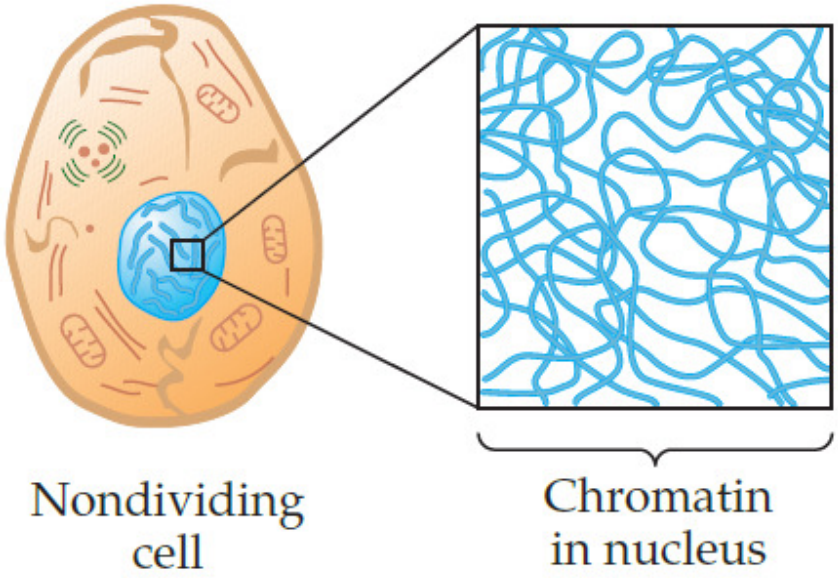
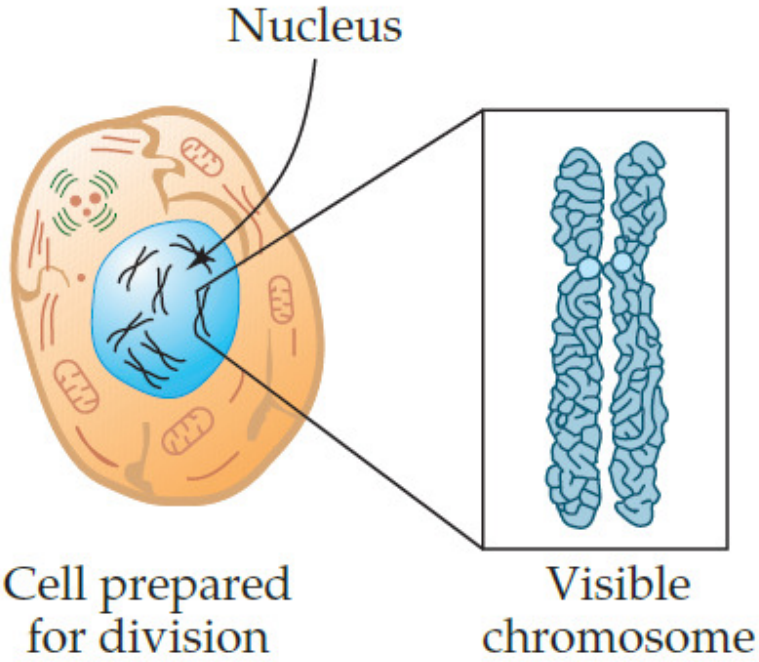
(Reference: Chapter 25 from McMurry et al.)

25.1 DNA, Chromosomes, and Genes





(Reference: Chapter 25 from McMurry et al.)

Inhoud

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(Reference: Chapter 25 from McMurry et al.)

GPd3

25.2 Composition of Nucleic Acids

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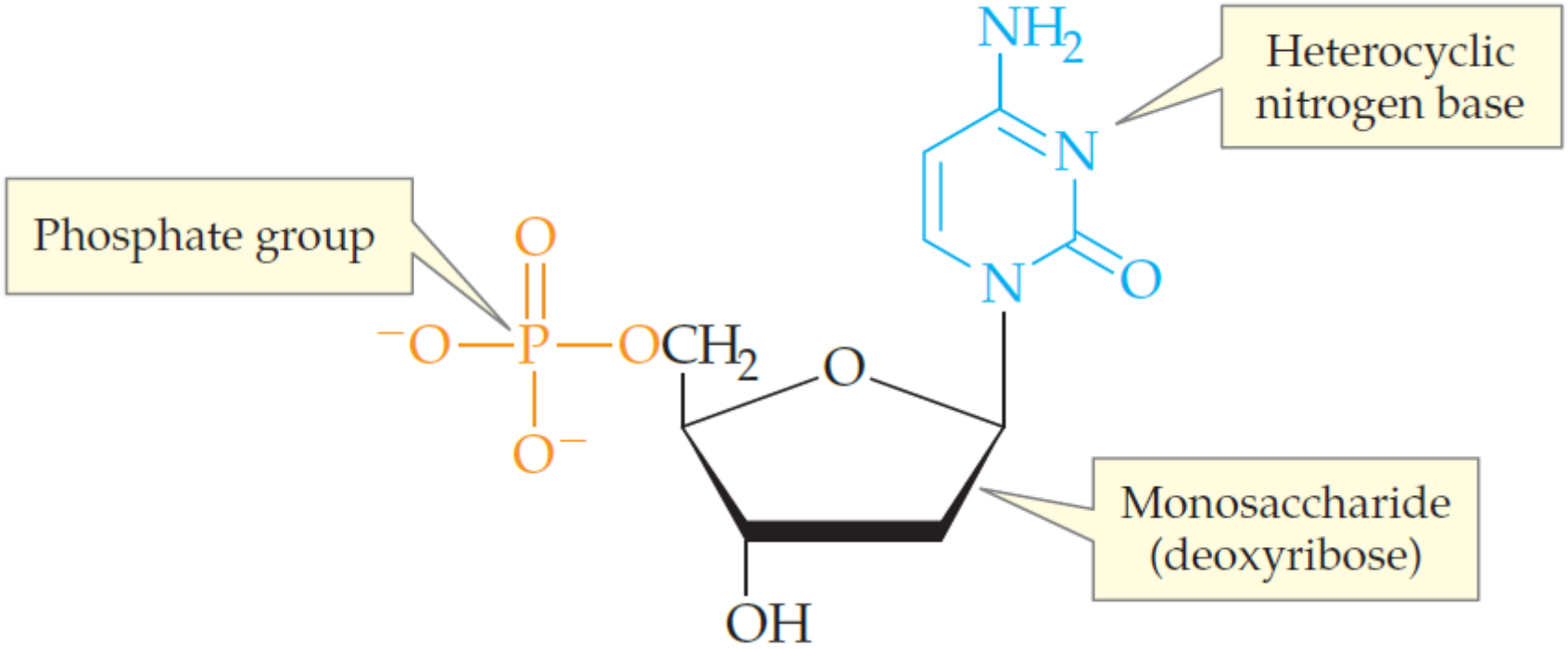
A nucleotide



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(Reference: Chapter 25 from McMurry et al.)

GPd3 2 classes: DNA & RNA

Groot Philip de; 23-10-2017

GPd3

25.2 Composition of Nucleic Acids - Sugars

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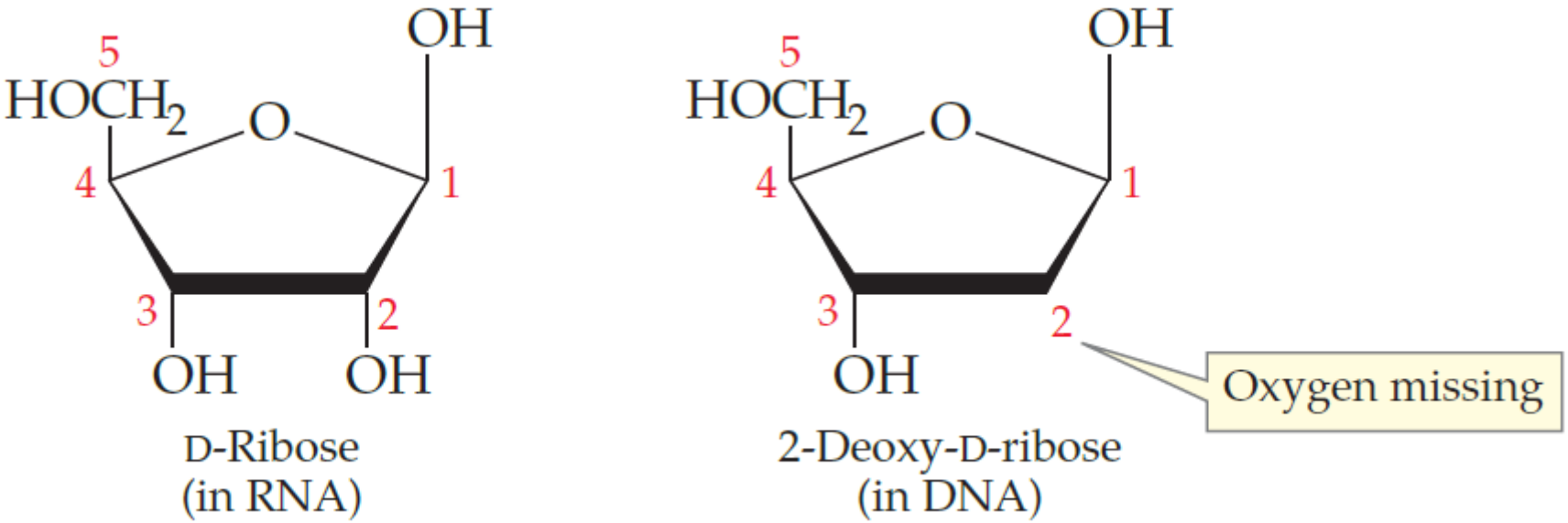

ribonucleic acid

deoxyribonucleic acid

(2-deoxy: oxygen atom is missing on the C2 position of ribose)

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(Reference: Chapter 25 from McMurry et al.)

GPd3 2 classes: DNA & RNA

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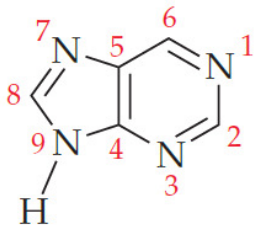
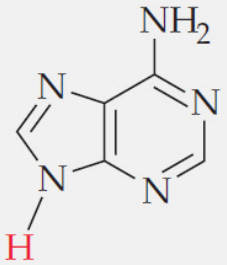
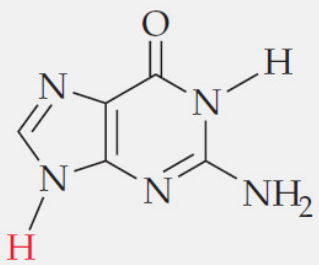
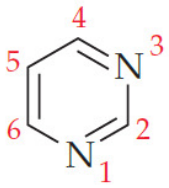
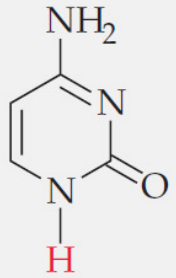
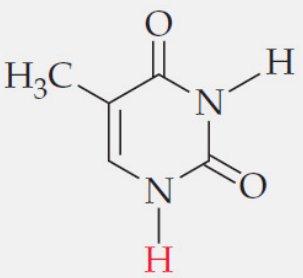
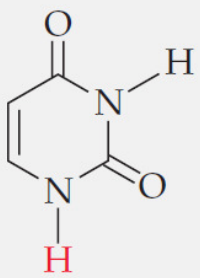
GPd3

25.2 Composition of Nucleic Acids – The Bases

TABLE 25.1 Bases in DNA and RNA

PURINE BASES IN NUCLEIC ACIDS			PYRIMIDINE BASES IN NUCLEIC ACIDS			
						
Purine (Parent)	Adenine (DNA, RNA)	Guanine (DNA, RNA)	Pyrimidine (Parent)	Cytosine (DNA, RNA)	Thymine* (DNA)	Uracil (RNA)

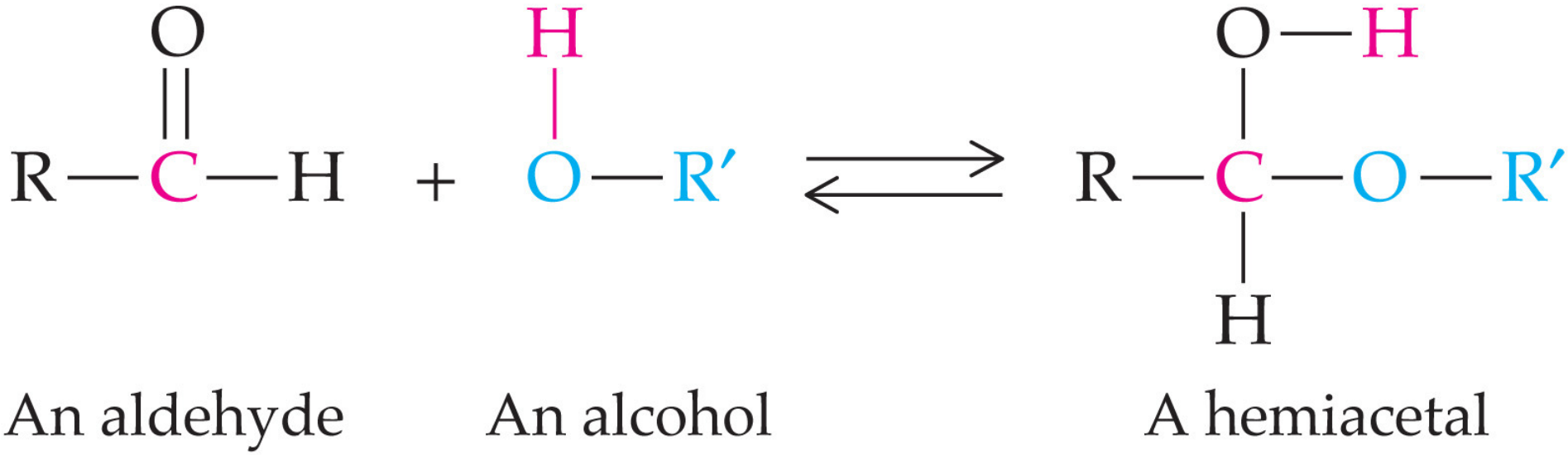
- Thymine is present only in DNA molecules (with rare exceptions).
- Uracil is present only in RNA molecules.
- Adenine, guanine, and cytosine are present in both DNA and RNA.

(Reference: Chapter 25 from McMurry et al.)

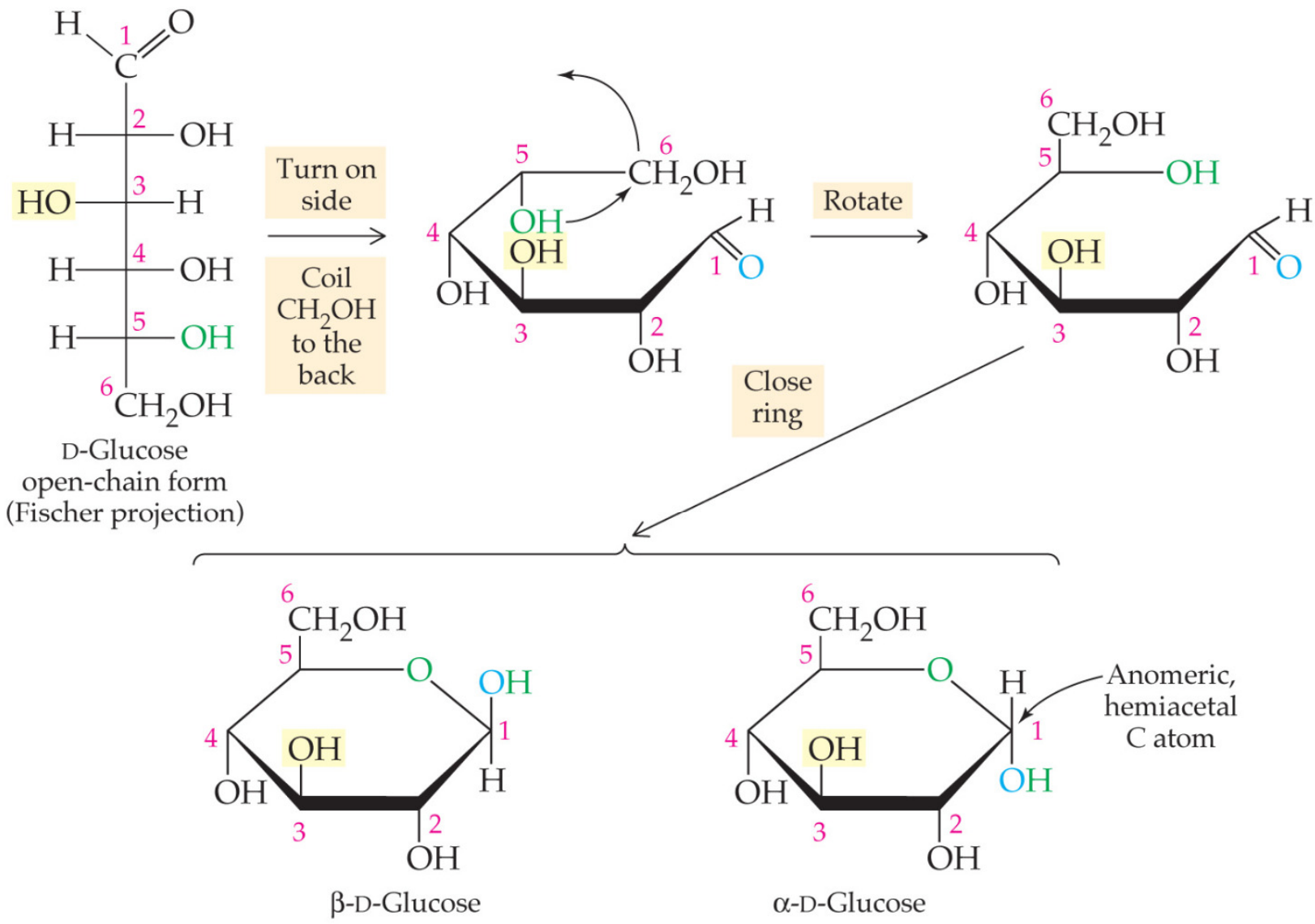
GPd3 2 classes: DNA & RNA

Groot Philip de; 23-10-2017

21.4 Structuur van monosacharides



21.4 Structuur van monosacharides



21.6 Reacties van monosacharides

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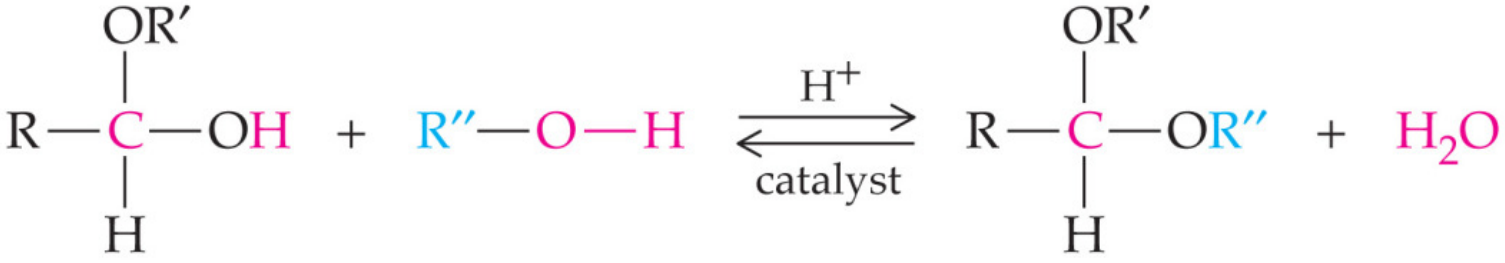
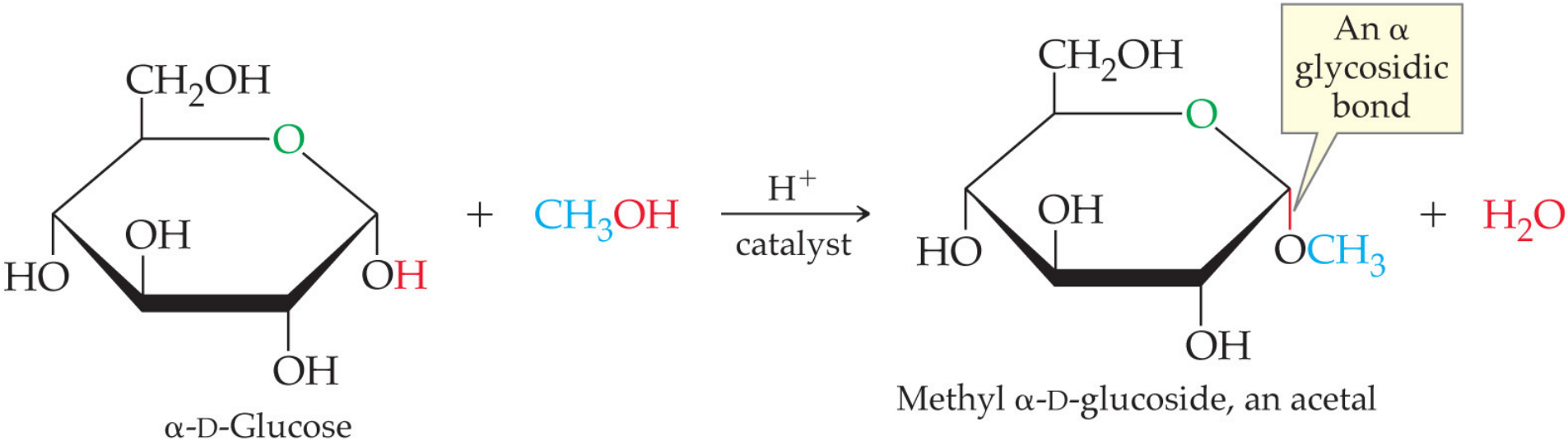
Glycoside



Formation of a glycoside



21.6 Reacties van monosacharides

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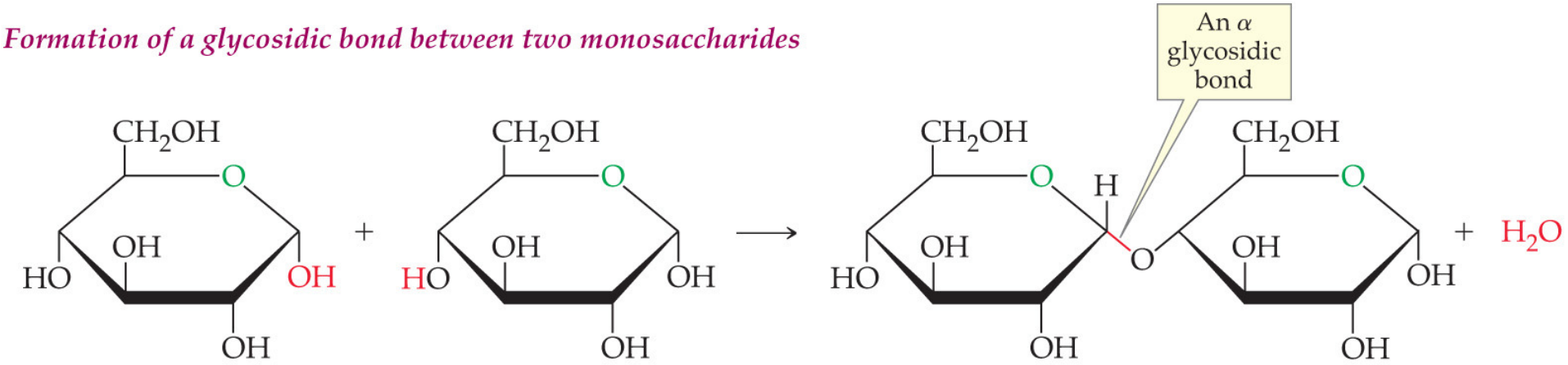
Hydrolyse disacharide

Formation of a glycosidic bond between two monosaccharides



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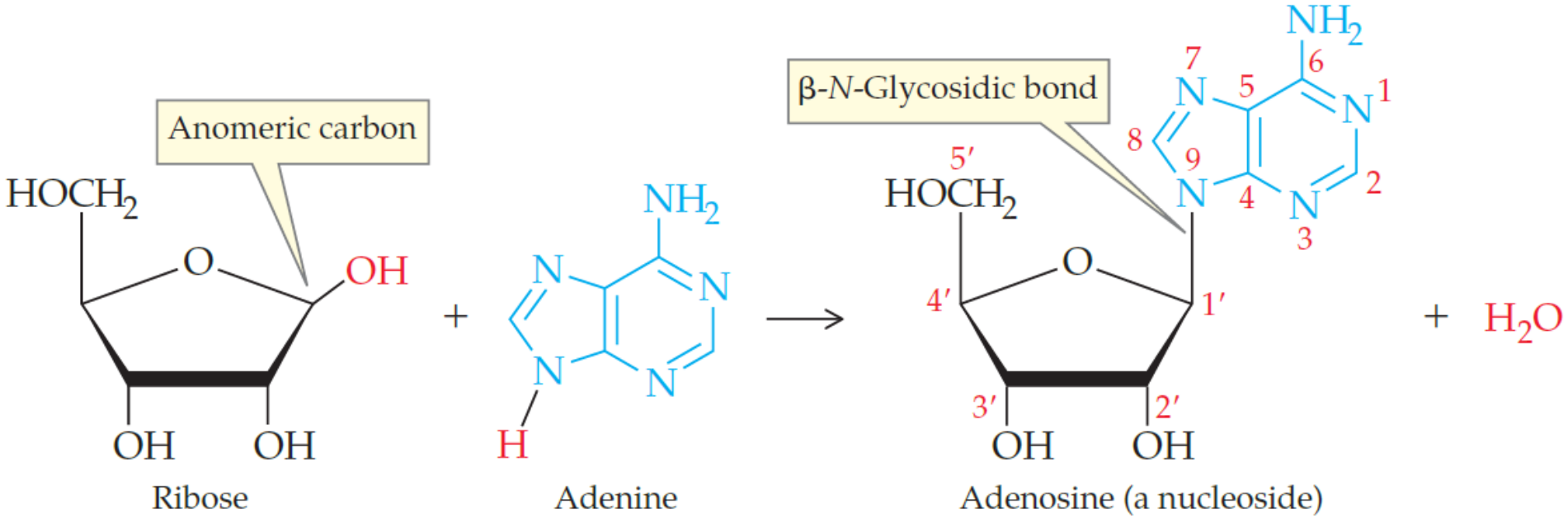
(Reference: Chapter 21 from McMurry et al.)

25.2 Composition of Nucleic Acids – The Bases (vervolg)

Sugar + Base = Nucleoside

Nucleoside A 5-carbon sugar bonded to a cyclic amine base; like a nucleotide but with no phosphate group.



Ribose Adenine Adenosine (a nucleoside)

(Reference: Chapter 25 from McMurry et al.)

Slide 15

GPd4 Let op de nummering en de prime!

Groot Philip de; 23-10-2017

25.2 Composition of Nucleic Acids – The Bases (vervolg)

RNA nucleosides	DNA nucleosides
Adenosine	deoxyadenosine
Guanosine	deoxyguanosine
Cytidine	deoxycytidine
Uridine	deoxythymidine

(Reference: Chapter 25 from McMurry et al.)

25.2 Worked example 25.1

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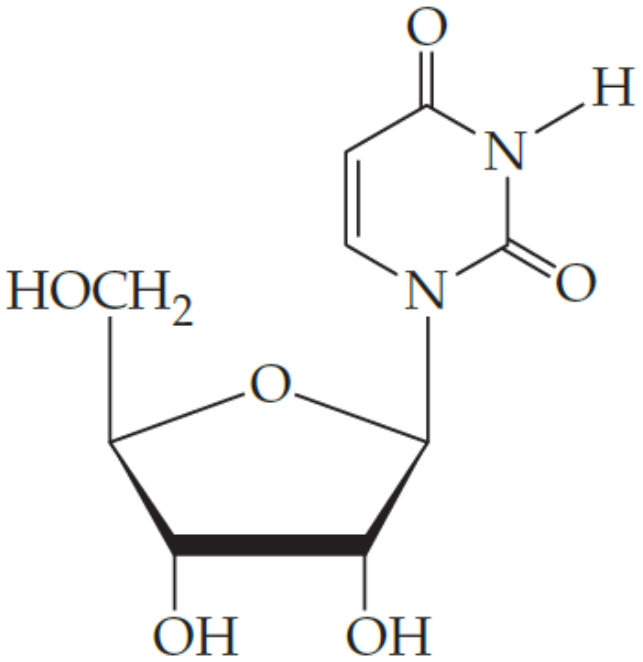
Is the compound shown here a nucleoside or a nucleotide? Identify its sugar and base components, and name the compound.



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(Reference: Chapter 25 from McMurry et al.)

25.2 Worked example 25.1

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ANALYSIS The compound contains a sugar, recognizable by the oxygen atom in the ring and the —OH groups. It also contains a nitrogenous base, recognizable by the nitrogen-containing ring. The sugar has an —OH in the 2′ position and is therefore ribose (if it were missing the —OH in the 2′ position, it would be a *deoxy*ribose). Checking the base structures in Table 25.1 shows that this is uracil, a pyrimidine base, requiring its name to end in *-idine*.

SOLUTION

The compound is a nucleoside, and its name is uridine.

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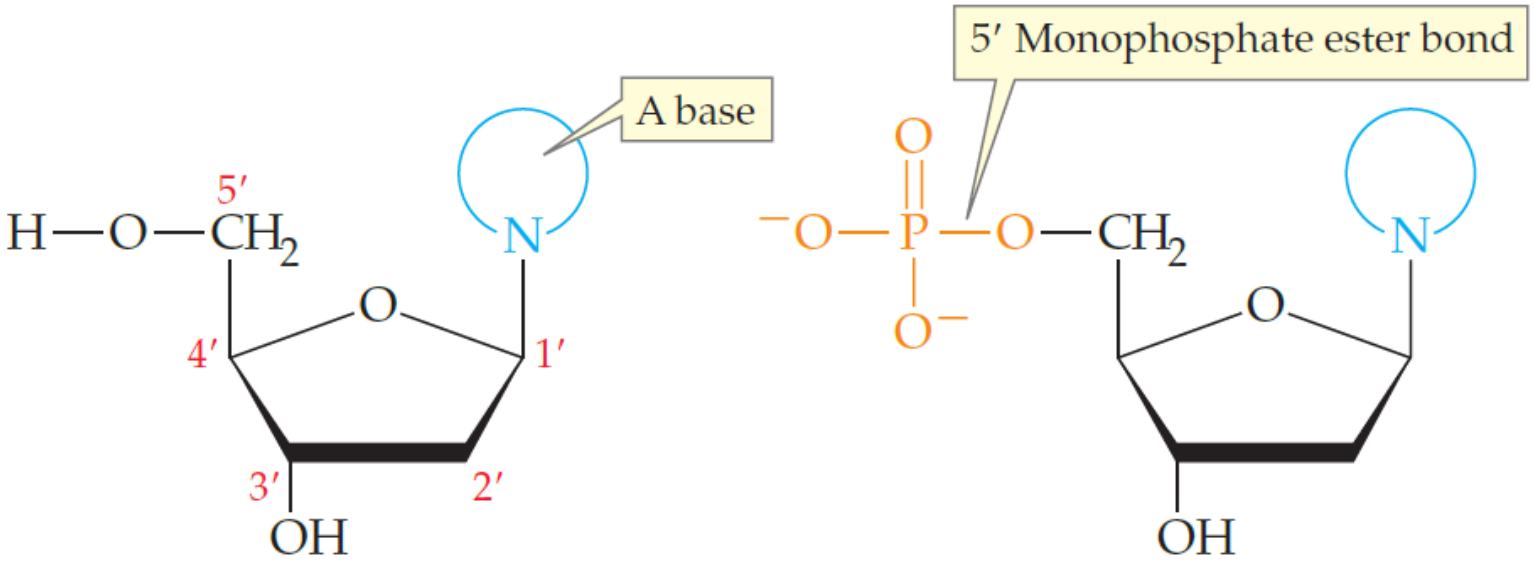
(Reference: Chapter 25 from McMurry et al.)

25.2 Composition of Nucleic Acids – The Bases (vervolg)

Nucleoside + Phosphate = Nucleotide

Nucleotides are the building blocks of nucleic acids; they are the monomers of the DNA and RNA polymers. Each nucleotide is a 5′-monophosphate ester of a nucleoside:

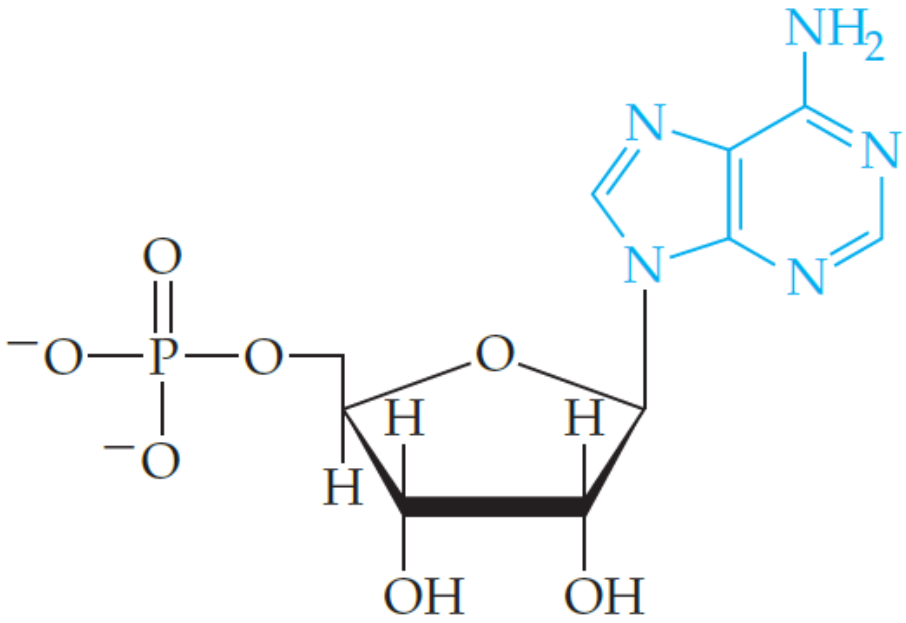


A deoxyribonucleoside

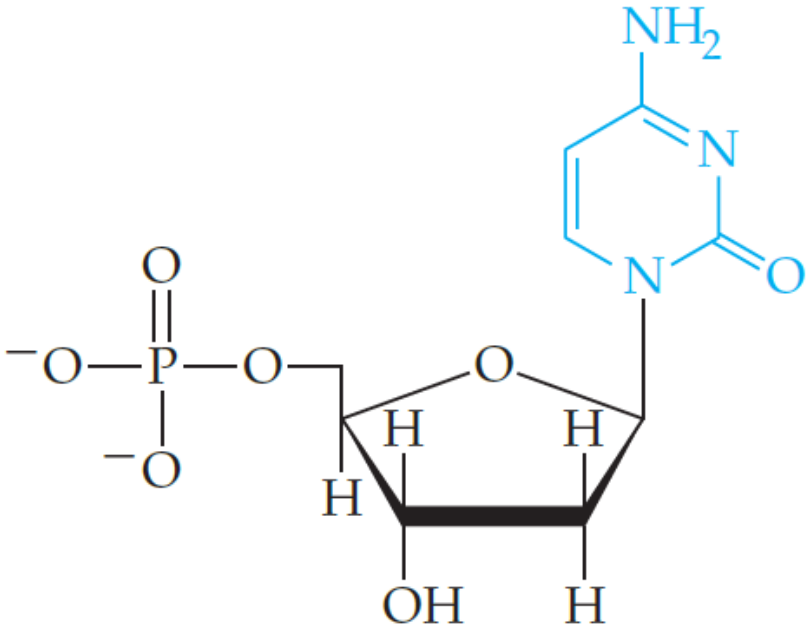
A deoxyribonucleotide

(Reference: Chapter 25 from McMurry et al.)

25.2 Composition of Nucleic Acids – The Bases (vervolg)



Adenosine 5′-monophosphate (AMP)
(a ribonucleotide)



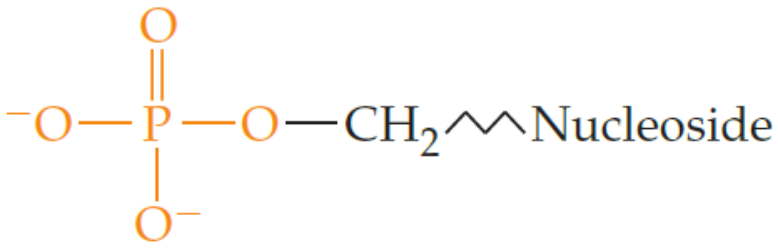
Deoxycytidine 5′-monophosphate (dCMP)
(a deoxyribonucleotide)

Ribonucleotide A nucleotide that contains D-ribose.

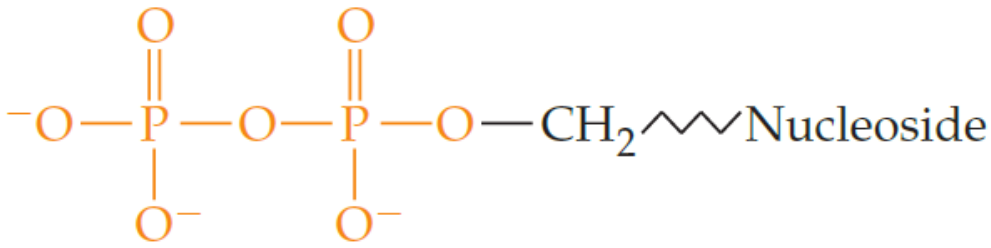
Deoxyribonucleotide A nucleotide that contains 2-deoxy-D-ribose.

(Reference: Chapter 25 from McMurry et al.)

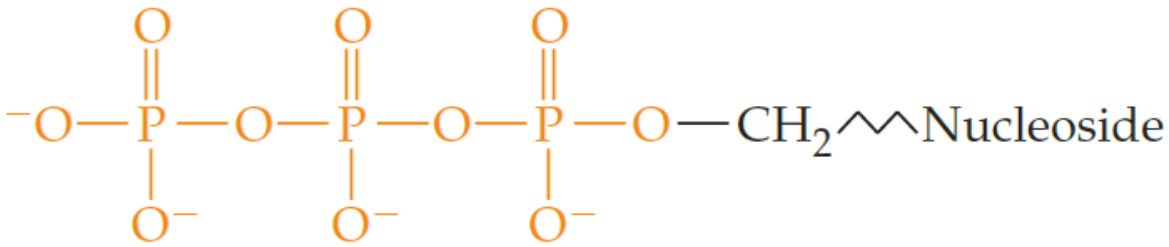
25.2 Composition of Nucleic Acids – The Bases (vervolg)



Nucleoside monophosphate



Nucleoside diphosphate



Nucleoside triphosphate

25.2 Composition of Nucleic Acids – Summary

Summary—Nucleoside, Nucleotide, and Nucleic Acid Composition

Nucleoside

- A sugar and a base

Nucleotide

- A sugar, a base, and a phosphate group ($-OPO_3^{2-}$)

DNA (deoxyribonucleic acid)

- A polymer of deoxyribonucleotides
- The sugar is 2-deoxy-D-ribose
- The bases are adenine, guanine, cytosine, and *thymine*

RNA (ribonucleic acid)

- A polymer of ribonucleotides
- The sugar is D-ribose
- The bases are adenine, guanine, cytosine, and *uracil*

25.2 Key concept problem 25.3

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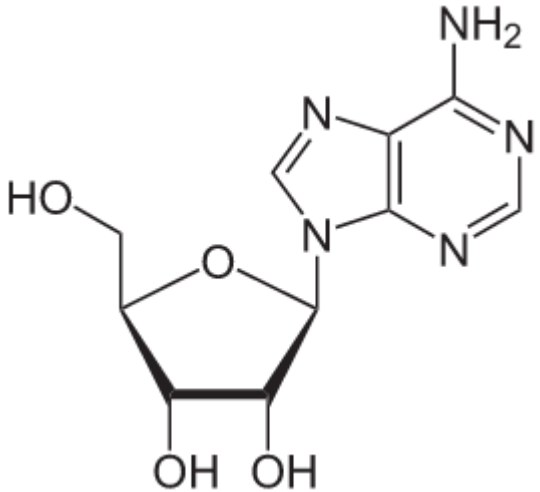
KEY CONCEPT PROBLEM 25.3

Draw the structure of 2′-deoxyadenosine 5′-monophosphate, and use the primed-unprimed format to number all the atoms in the rings.



Adenosine

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(Reference: Chapter 25 from McMurry et al.)

25.2 Key concept problem 25.3

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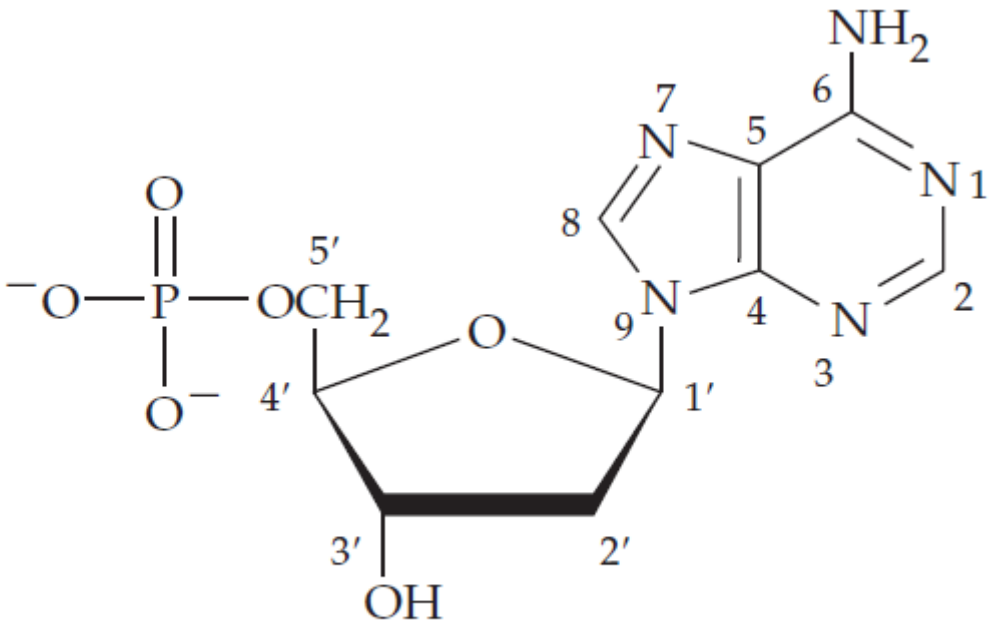
KEY CONCEPT PROBLEM 25.3

Draw the structure of 2′-deoxyadenosine 5′-monophosphate, and use the primed-unprimed format to number all the atoms in the rings.

25.3



2′-Deoxyadenosine 5′-monophosphate

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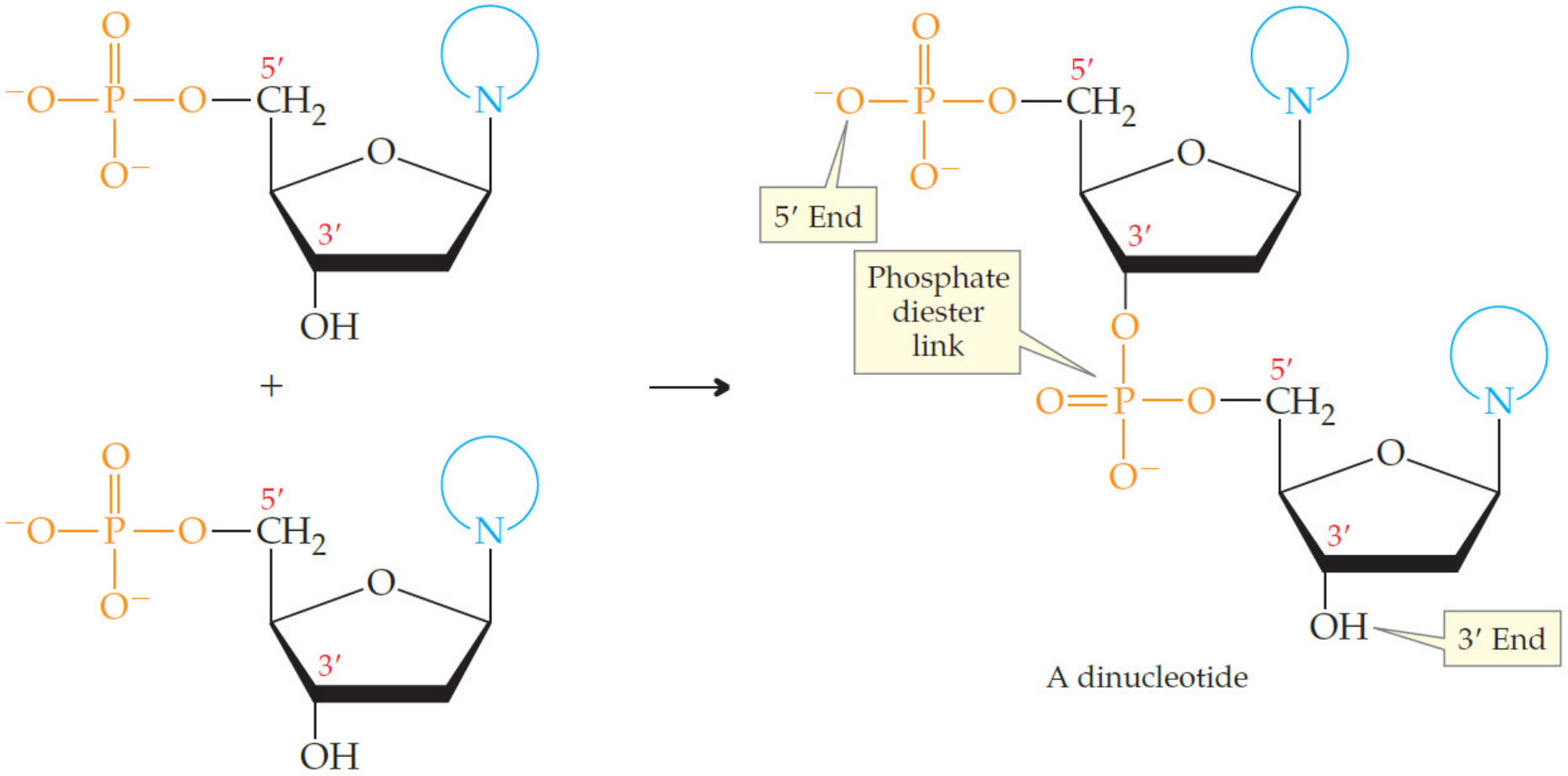
(Reference: Chapter 25 from McMurry et al.)

25.3 The structure of Nucleic Acid Chains



25.3 The structure of Nucleic Acid Chains

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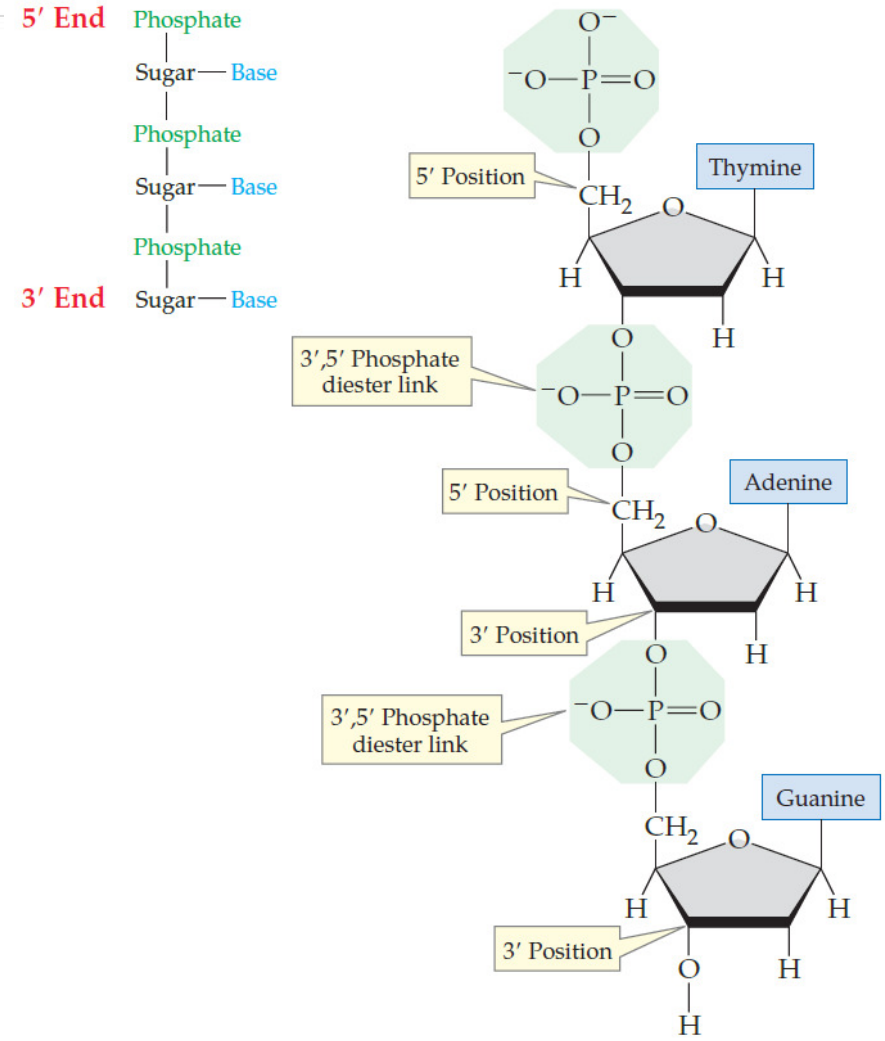

▲ **Figure 25.1**
A deoxytrinucleotide.
In all polynucleotides, as shown here, there is a phosphate group at the 5′ end; there is a sugar —OH group at the 3′ end; and the nucleotides are connected by 3′, 5′-phosphate diester links.

(Reference: Chapter 25 from McMurry et al.)

25.3 The structure of Nucleic Acid Chains

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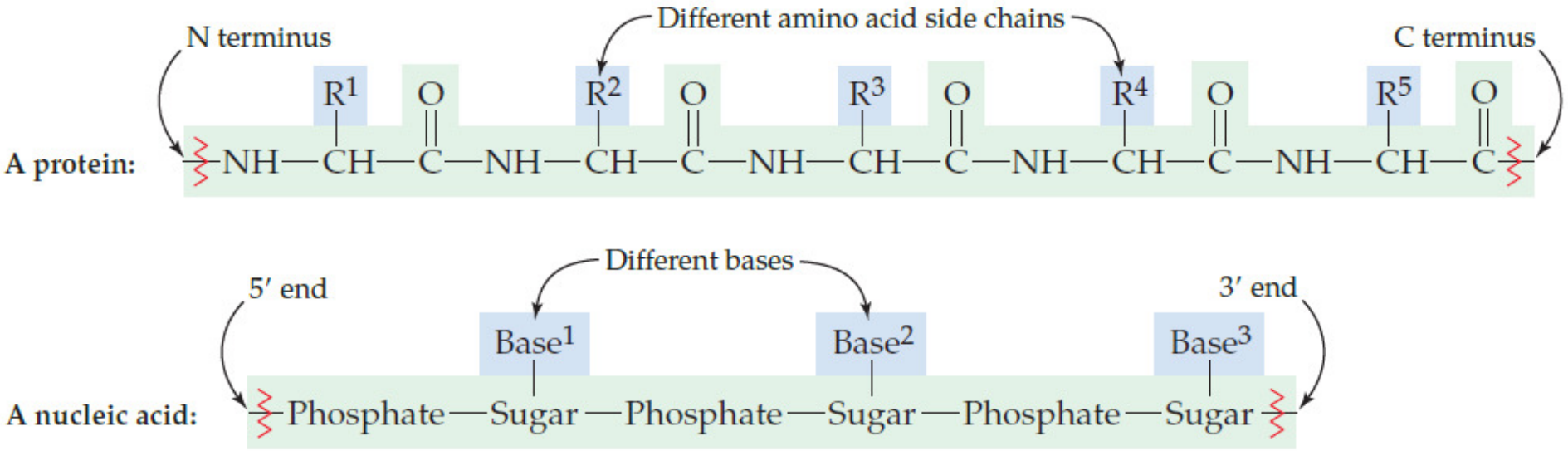
Comparison of protein and nucleic acid backbones and side chains



PROBLEM 25.6

Name the bases in the pentanucleotide with the sequence G-A-U-C-A. Does this come from RNA or DNA? Explain.

25.6 guanine–adenine–uracil–cytosine–adenine. The pentanucleotide comes from RNA because uracil is present.

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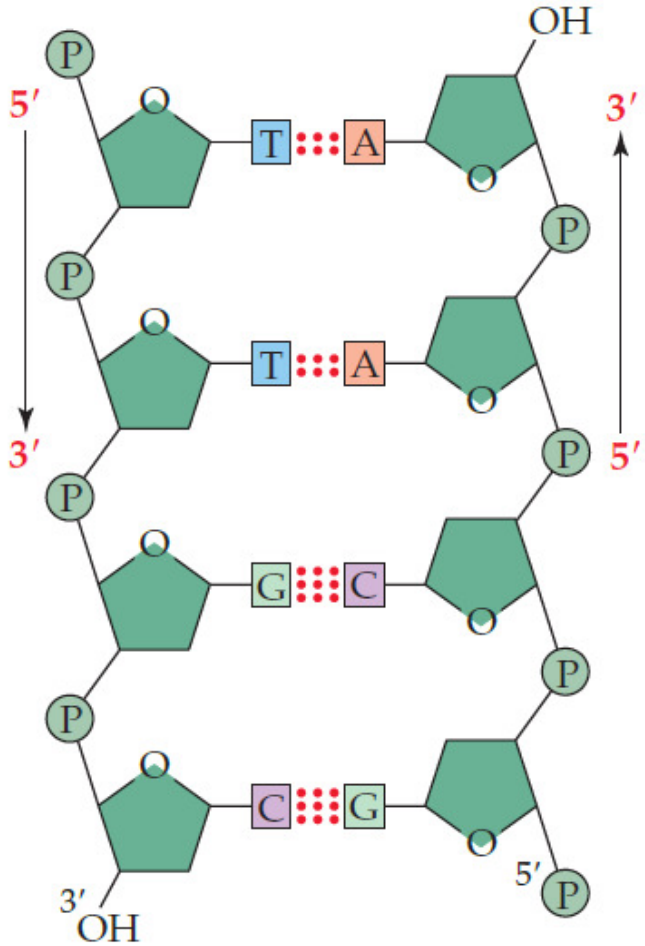
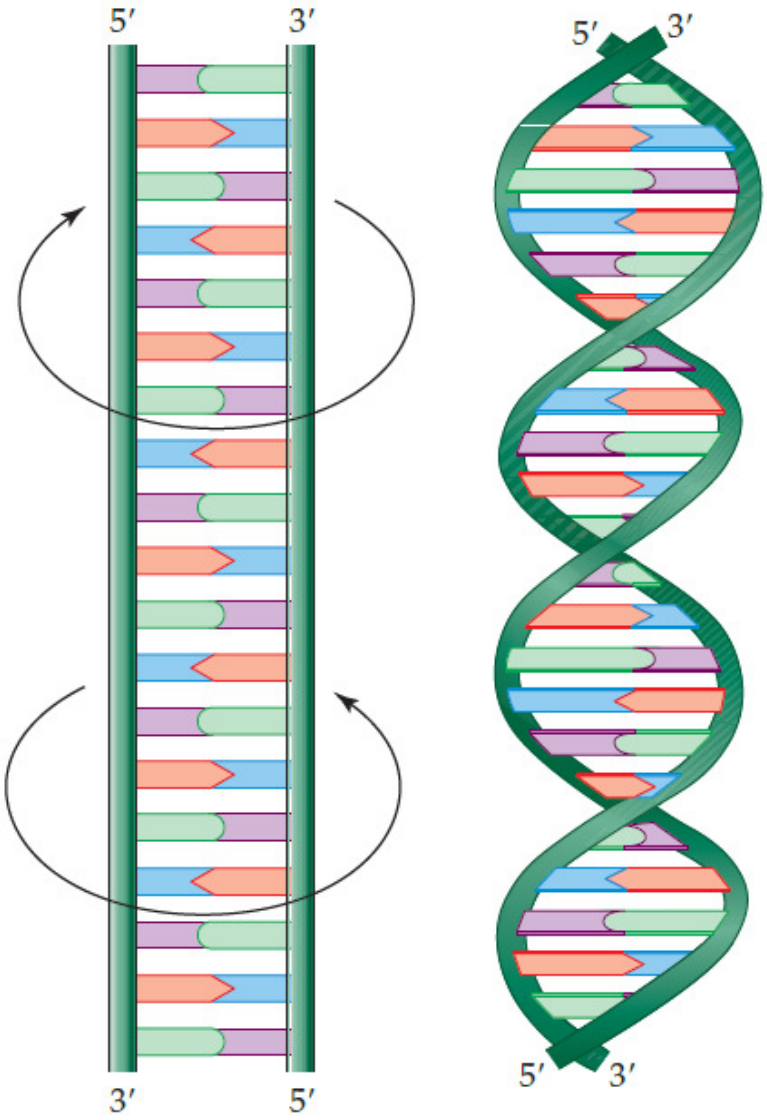
(Reference: Chapter 25 from McMurry et al.)

GPd6

25.4 Base Pairing in DNA: The Watson-Crick Model

GPd5





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(Reference: Chapter 25 from McMurry et al.)

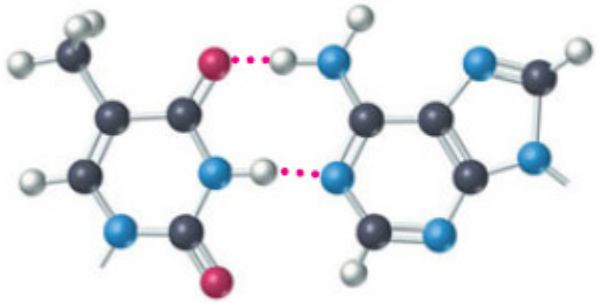
Slide 28

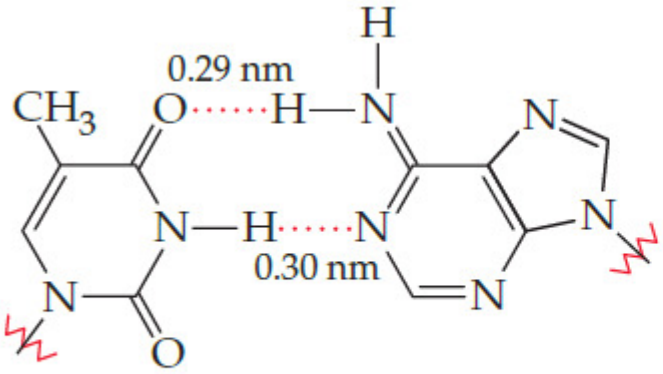
GPd5 1953: Watson & Crick
Groot Philip de; 23-10-2017

GPd6 strands are antiparallel
Groot Philip de; 23-10-2017

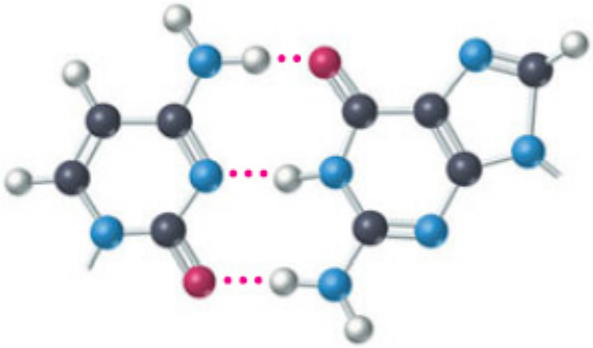
25.4 Base Pairing in DNA: The Watson-Crick Model

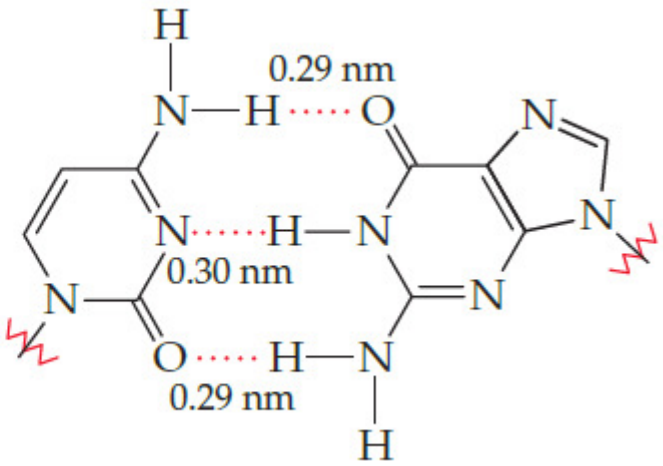
Thymine–Adenine

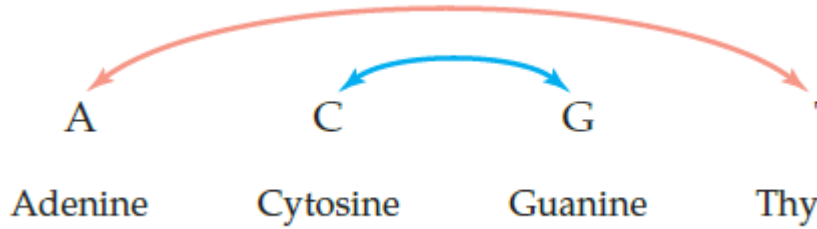




Cytosine–Guanine

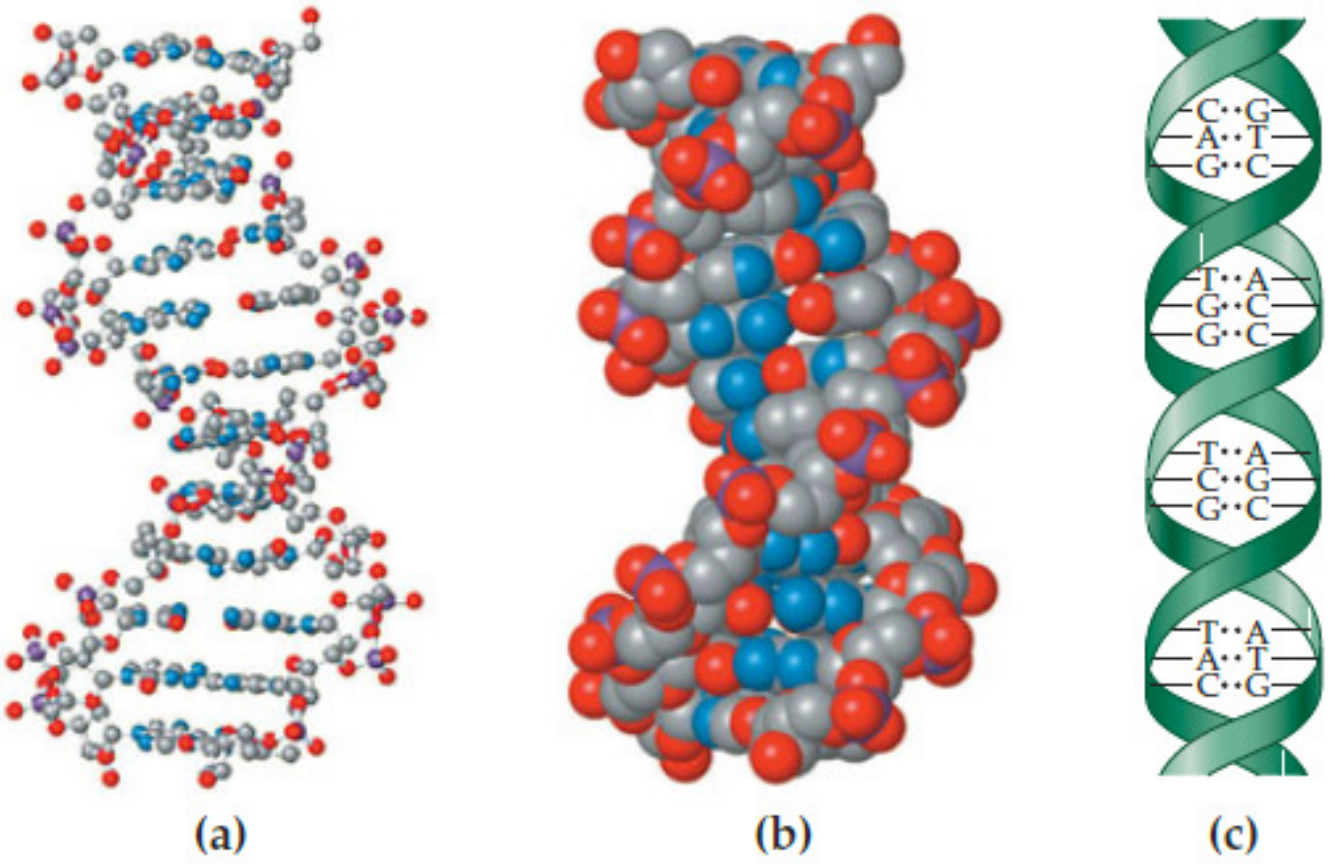






(Reference: Chapter 25 from McMurry et al.)

25.4 Base Pairing in DNA: The Watson-Crick Model



(Reference: Chapter 25 from McMurry et al.)

25.4 Worked example 25.3

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Worked Example 25.3 Writing Complementary Nucleic Acid Sequences

What sequence of bases on one strand of DNA (reading in the 3′ to 5′ direction) is complementary to the sequence 5′ T-A-T-G-C-A-G 3′ on the other strand?

ANALYSIS Remembering that A always bonds to T and C always bonds to G, go through the original 5′ to 3′ sequence, replacing each A by T, each T by A, each C by G, and each G by C. Keep in mind that when a 5′ to 3′ strand is matched in this manner to its complementary strand, the complementary strand will be oriented 3′ to 5′ when read from left to right. (If the direction in which a base sequence is written is *not* specified, you can assume it follows the customary 5′ to 3′ direction when read left to right.)

SOLUTION

Original strand	5′ T-A-T-G-C-A-G 3′
Complementary strand	3′ A-T-A-C-G-T-C 5′

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25.5 Nucleic Acids and Heredity

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- Humans have 23 pairs of chromosomes
- Each pair contains one copy of your father and one copy of your mother
- Most cells in your body have copies of the chromosomes
- DNA is copied during cell division
- Duplication is possible because of the double DNA helix and the complementary base pairing.

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25.5 Nucleic Acids and Heredity
Replication, transcription, and translation

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- **Replication** (Section 25.6) is the process by which a replica, or identical copy, of DNA is made when a cell divides, so that each of the two daughter cells has the same DNA (Figure 25.4).
- **Transcription** (Section 25.8) is the process by which the genetic messages contained in DNA are read and copied. The products of transcription are specific ribonucleic acids, which carry the instructions stored by DNA out of the nucleus, to the sites of protein synthesis.
- **Translation** (Section 25.10) is the process by which the genetic messages carried by RNA are decoded and used to build proteins.

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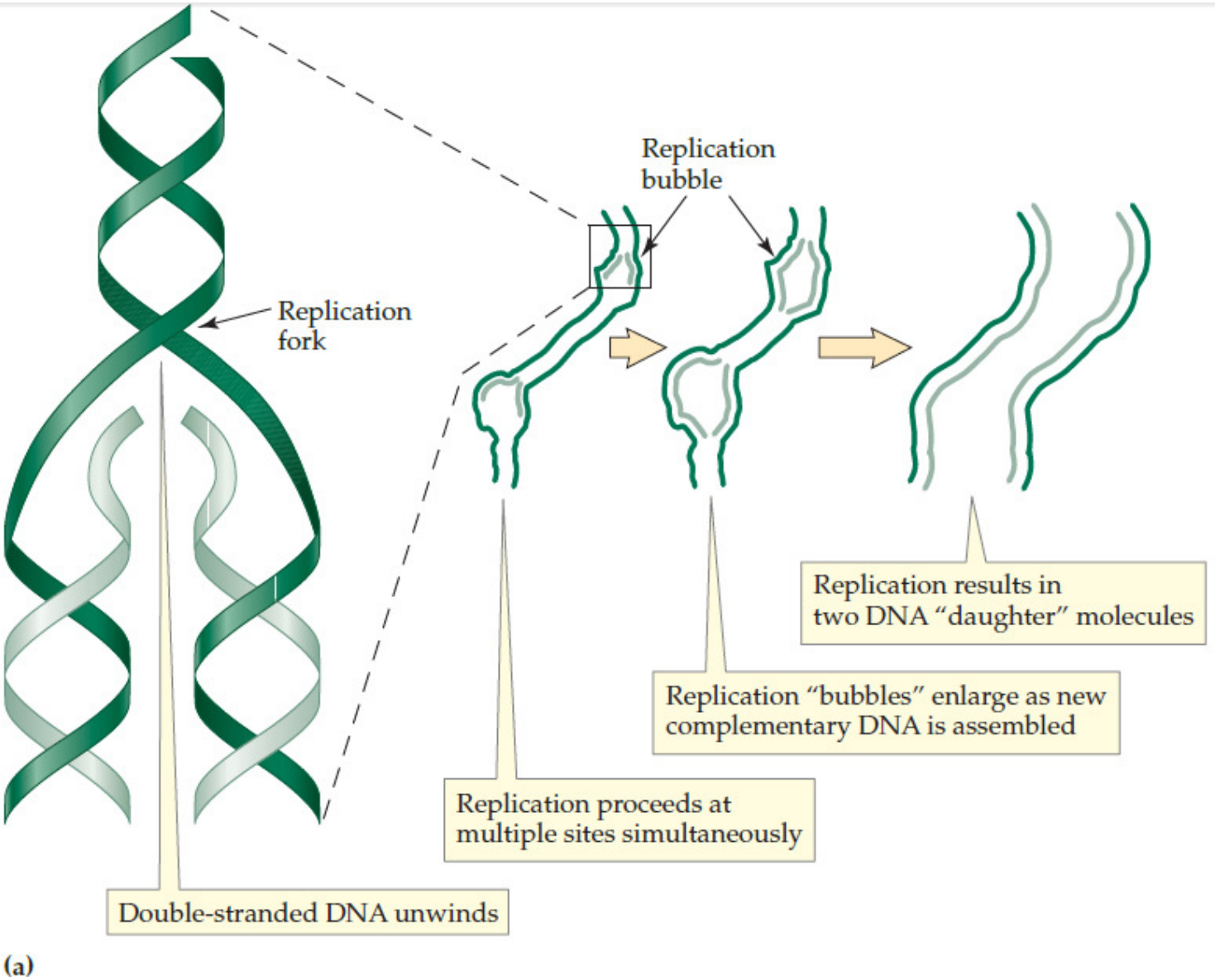
25.6 Replication of DNA



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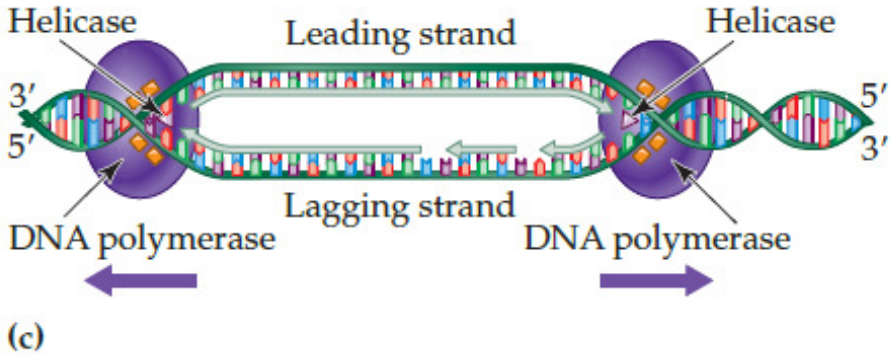
(Reference: Chapter 25 from McMurry et al.)

25.6 Replication of DNA



(c)

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(Reference: Chapter 25 from McMurry et al.)

GPd8

25.6 Replication of DNA

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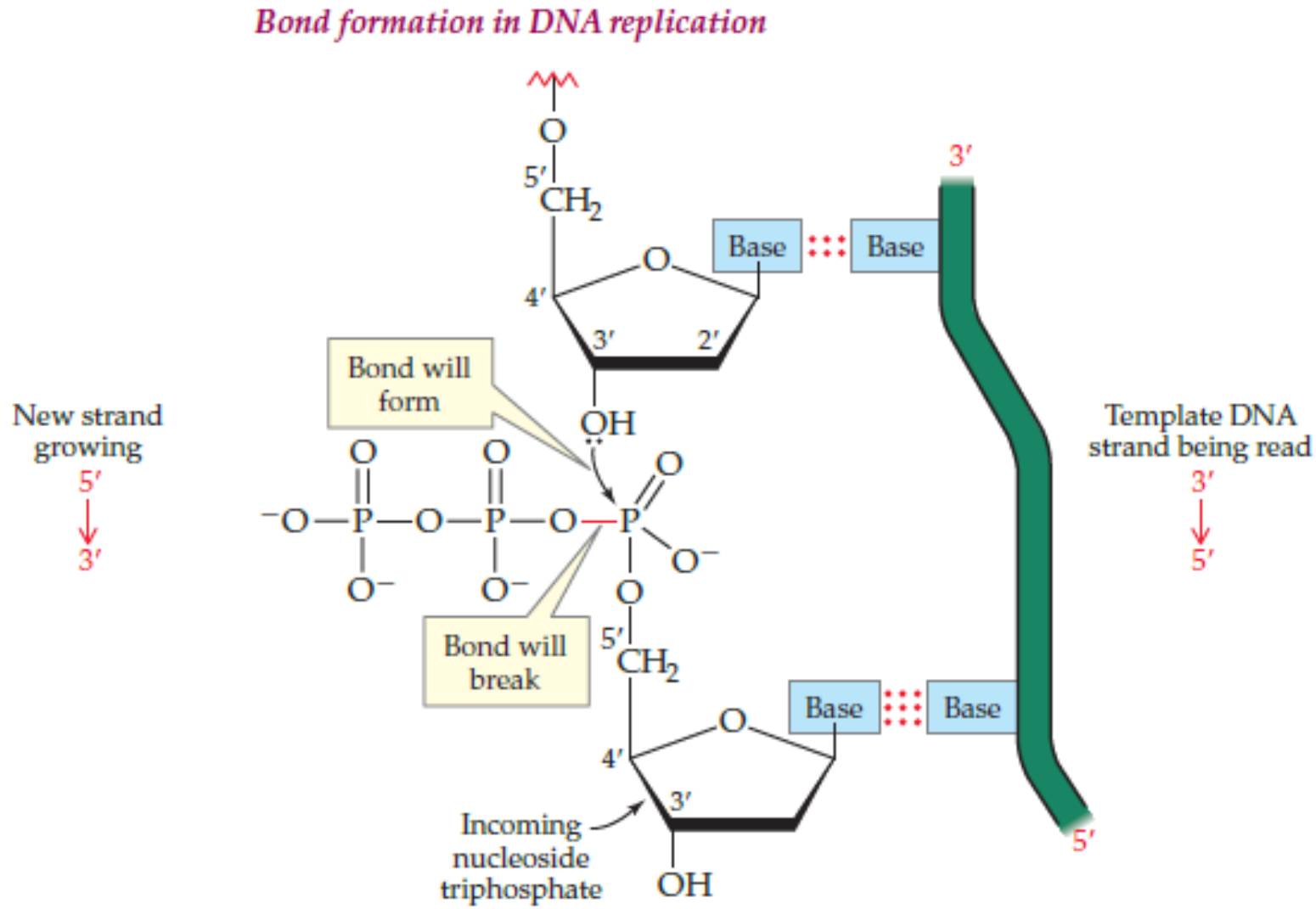

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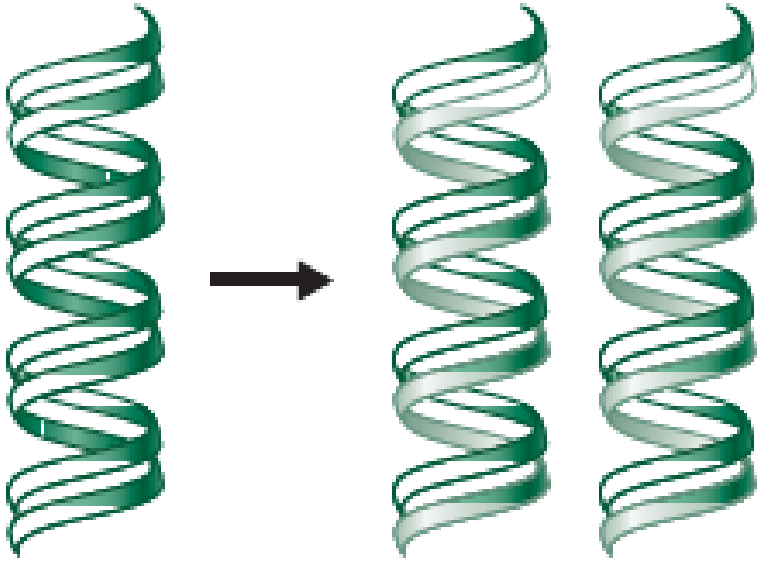
(Reference: Chapter 25 from McMurry et al.)

Slide 36

GPd8 Merk op dat de template strand is van 5'3'naar 5'. De nieuwe strand is juist andersom!
Groot Philip de; 25-10-2017

25.6 Replication of DNA



▲ Semiconservative replication produces a pair of DNA double helixes in which one strand (dark green) is the original strand and the other (light green) is the strand that has been copied from the original.

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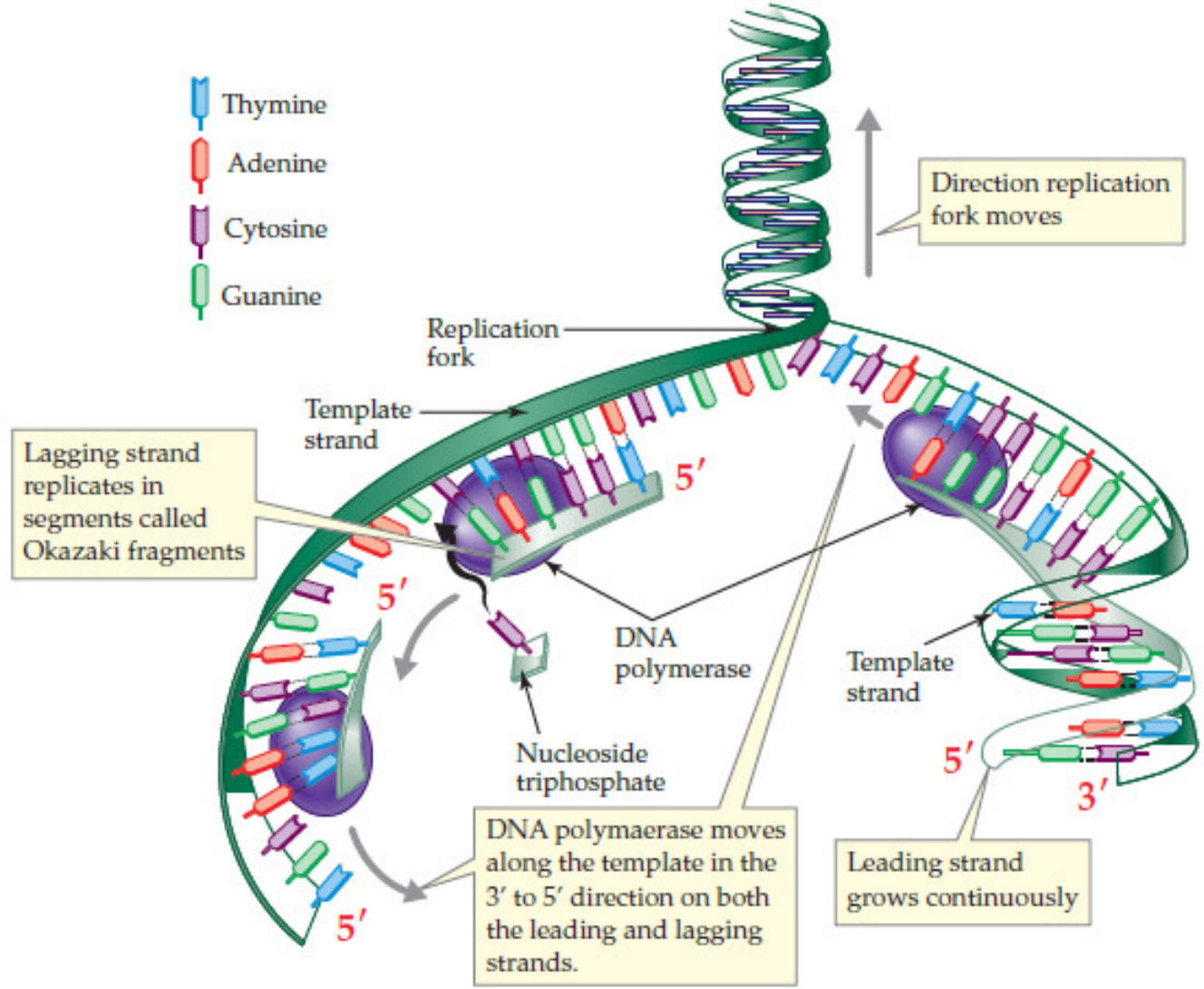
semiconservative replication: one of the two parent strands is conserved in each of the two new DNA molecules.

25.6 Replication of DNA



(Reference: Chapter 25 from McMurry et al.)

25.7 Structure and Function of RNA

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TABLE 25.3 Comparison of DNA and RNA

	Sugar	Bases	Shape and Size	Function
DNA	Deoxyribose	Adenine Guanine Cytosine Thymine	Paired strands in double helix; 50 million or more nucleotides per strand	Stores genetic information
RNA	Ribose	Adenine Guanine Cytosine Uracil	Single-stranded with folded regions; <100 to about 50,000 nucleotides per RNA	**mRNA**—Encodes a copy of genetic information ("blueprints" for protein synthesis) **tRNA**—Carries amino acids for incorporation into protein **rRNA**—Component of ribosomes (sites of protein synthesis)

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(Reference: Chapter 25 from McMurry et al.)

25.7 Structure and Function of RNA

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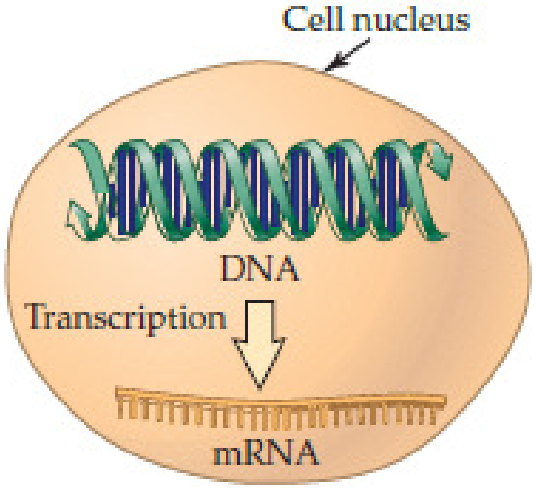
- **Ribosomal RNAs** Outside the nucleus but within the cytoplasm of a cell are the **ribosomes**—small granular organelles where protein synthesis takes place. (Their location in the cell is shown in Figure 20.3, p. 628.) Each ribosome is a complex consisting of about 60% **ribosomal RNA (rRNA)** and 40% protein, with a total molecular mass of approximately 5,000,000 amu.
- **Messenger RNAs** The **messenger RNAs (mRNA)** carry information transcribed from DNA. They are formed in the cell nucleus and transported out to the ribosomes, where proteins will be synthesized. They are polynucleotides that carry the same code for proteins as does the DNA.
- **Transfer RNAs** The **transfer RNAs (tRNA)** are smaller RNAs that deliver amino acids one by one to protein chains growing at ribosomes. Each tRNA carries only one amino acid.



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25.8 Transcription: RNA Synthesis

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DNA informational strand	5′	ATG	CCA	GTA	GGC	CAC	TTG	TCA 3′
DNA template strand	3′	TAC	GGT	CAT	CCG	GTG	AAC	AGT 5′
mRNA	5′	AUG	CCA	GUA	GGC	CAC	UUG	UCA 3′

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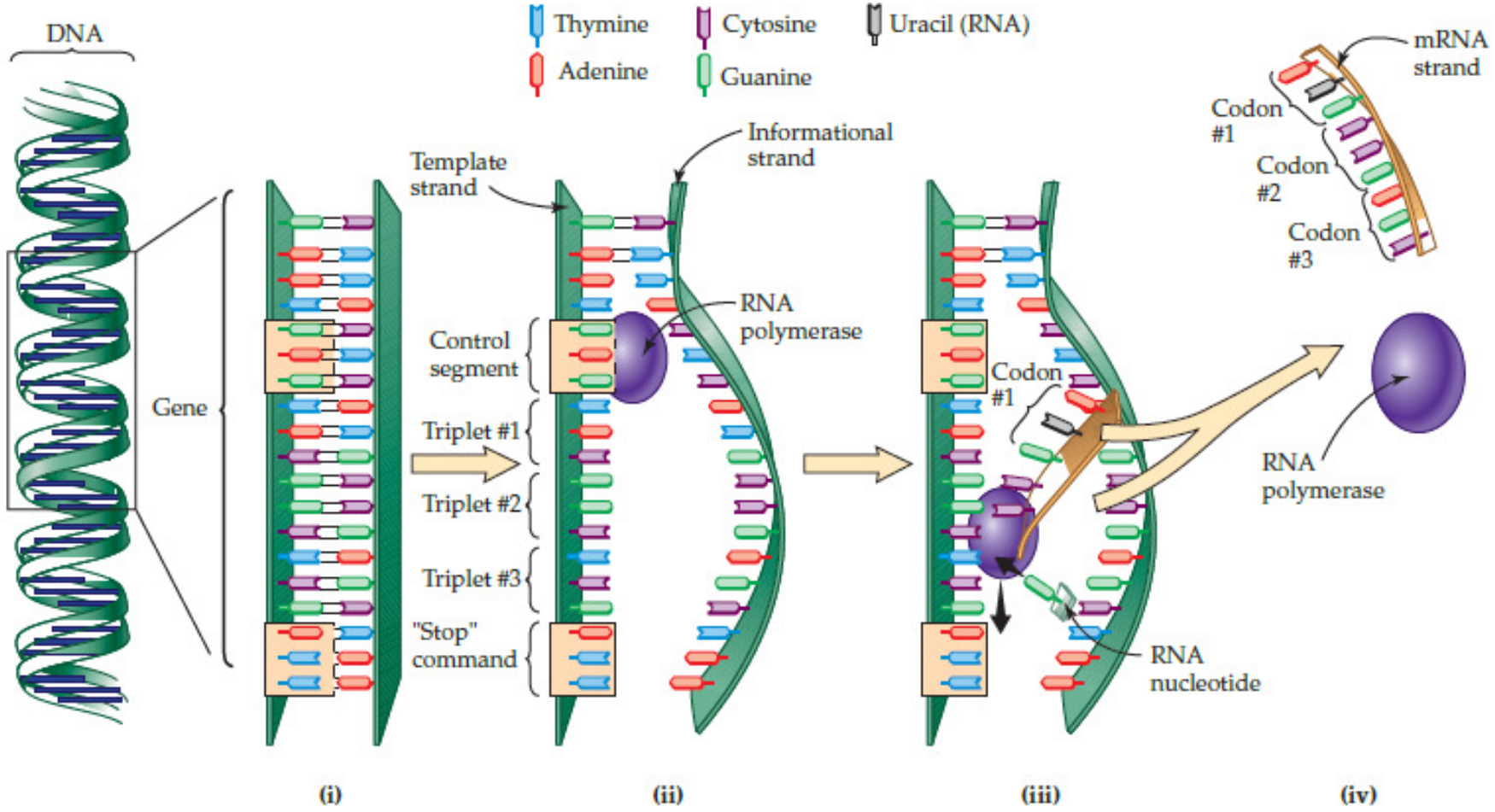
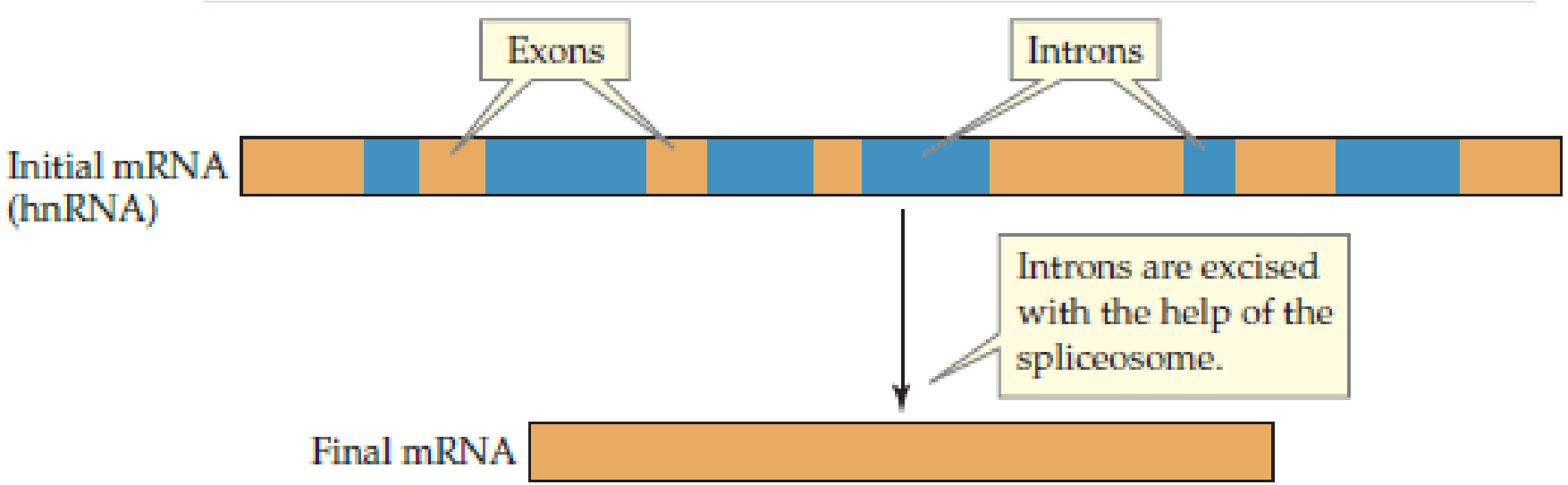
(Reference: Chapter 25 from McMurry et al.)

25.8 Transcription: RNA Synthesis



25.8 Transcription: RNA Synthesis



Heterogeneous nuclear RNA (hnRNA) The initially synthesized mRNA strand containing both introns and exons.

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(Reference: Chapter 25 from McMurry et al.)

25.8 Transcription: RNA Synthesis

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Worked Example 25.4 Writing Complementary DNA and RNA Strands from Informational DNA Strands

The nucleotide sequence in a segment of a DNA informational strand is given below. What is the nucleotide sequence in the complementary DNA template strand? What is the sequence transcribed from the template strand into mRNA?

5′AAC GTT CCA ACT GTC 3′

ANALYSIS Recall:

1. In the informational and template strands of DNA, the base pairs are A-T and C-G.
2. Matching base pairs along the informational strand gives the template strand written in the 3′ to 5′ direction.
3. The mRNA strand is identical to the DNA informational strand except that it has a U wherever the informational strand has a T.
4. Matching base pairs along the template strand produces the mRNA strand written in the 5′ to 3′ direction.

SOLUTION

Applying these principles gives

DNA informational strand	5′AAC GTT CAA ACT GTC 3′
DNA template strand	3′TTG CAA GTT TGA CAG 5′
mRNA	5′AAC GUU CAA ACU GUC 3′

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(Reference: Chapter 25 from McMurry et al.)

25.9 The Genetic Code

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TABLE 25.4 Codon Assignments of Base Triplets in mRNA

First Base (5′ end)	Second Base	Third Base (3′ end) U	C	A	G
U	U	Phe	Phe	Leu	Leu
	C	Ser	Ser	Ser	Ser
	A	Tyr	Tyr	*Stop*	*Stop*
	G	Cys	Cys	*Stop*	Trp
C	U	Leu	Leu	Leu	Leu
	C	Pro	Pro	Pro	Pro
	A	His	His	Gln	Gln
	G	Arg	Arg	Arg	Arg
A	U	Ile	Ile	Ile	Met
	C	Thr	Thr	Thr	Thr
	A	Asn	Asn	Lys	Lys
	G	Ser	Ser	Arg	Arg
G	U	Val	Val	Val	Val
	C	Ala	Ala	Ala	Ala
	A	Asp	Asp	Glu	Glu
	G	Gly	Gly	Gly	Gly

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(Reference: Chapter 25 from McMurry et al.)

25.9 The Genetic Code

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DNA informational strand	5′	ATG	CCA	GTA	GGC	CAC	TTG	TCA 3′
DNA template strand	3′	TAC	GGT	CAT	CCG	GTG	AAC	AGT 5′
mRNA	5′	AUG	CCA	GUA	GGC	CAC	UUG	UCA 3′
Protein		Met	Pro	Val	Gly	His	Leu	Ser

Worked Example 25.5 Translating RNA into Protein

In Worked Example 25.4, we derived the mRNA sequence of nucleotides shown below. What is the sequence of amino acids coded for by the mRNA sequence?

5′ AAC GUU CAA ACU GUC 3′

ANALYSIS The codons must be identified by consulting Table 25.4. They are

5′	AAC	GUU	CAA	ACU	GUC	3′
	Asn	Val	Gln	Thr	Val	

SOLUTION

Written out in full, the protein sequence is

asparagine-valine-glutamine-threonine-valine

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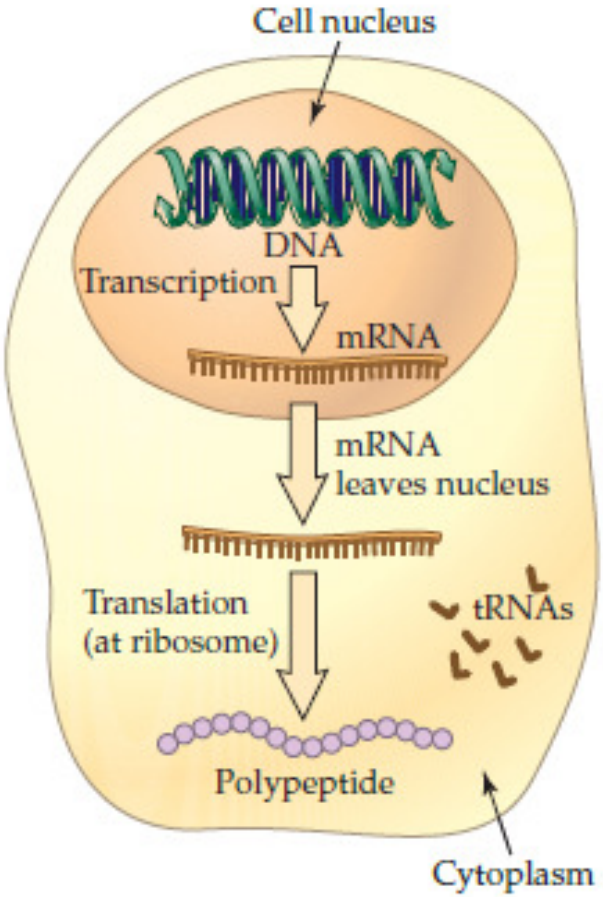
25.10 Translation: Transfer RNA and Protein Synthesis



▲ **Overview of protein synthesis. The codons of mature mRNA are translated in the ribosomes, where tRNAs deliver amino acids to be assembled into proteins (polypeptides).**

(Reference: Chapter 25 from McMurry et al.)

25.10 Translation: Transfer RNA and Protein Synthesis

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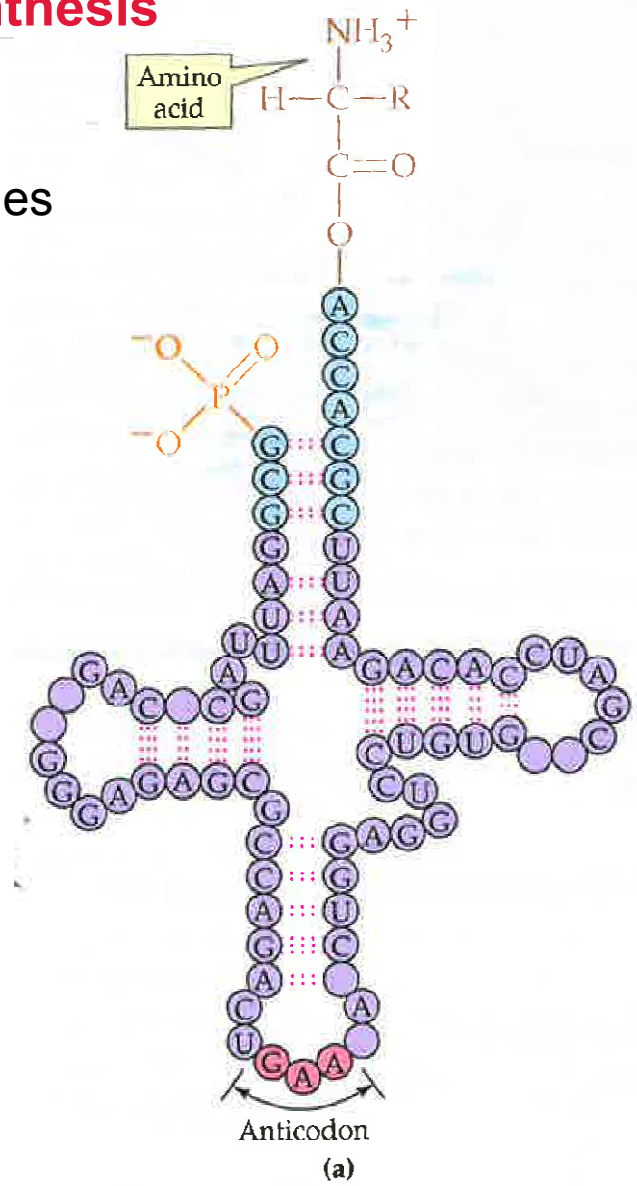
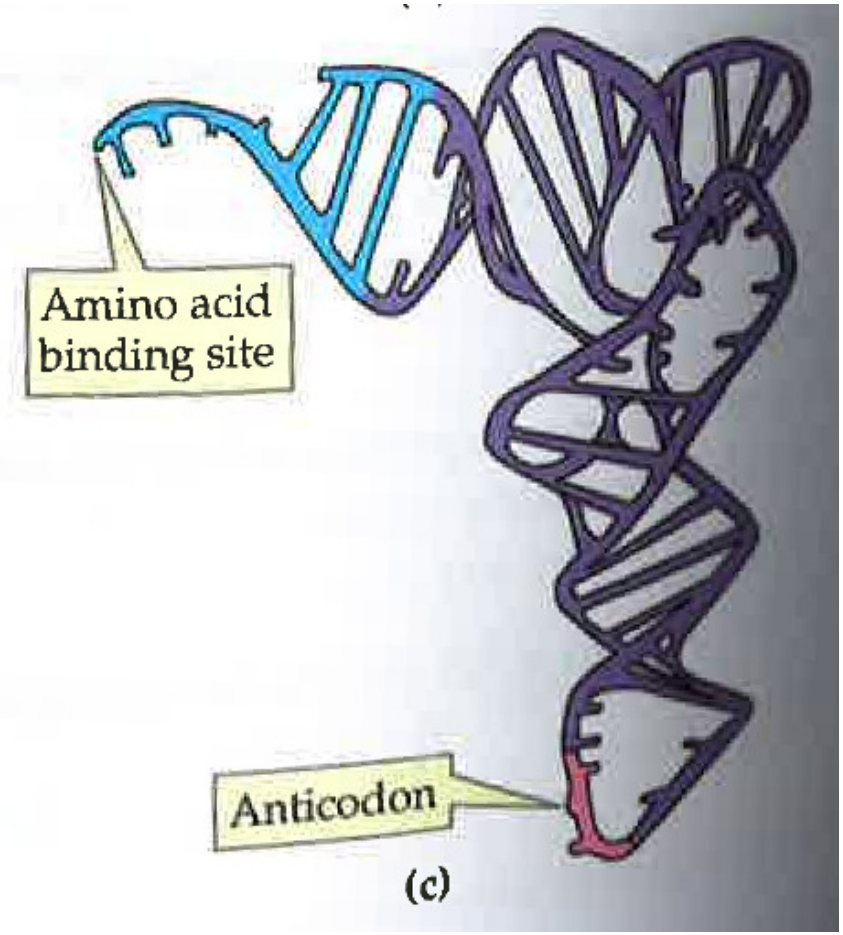
t-RNA molecules
(a) schematic
(c) 3D-view





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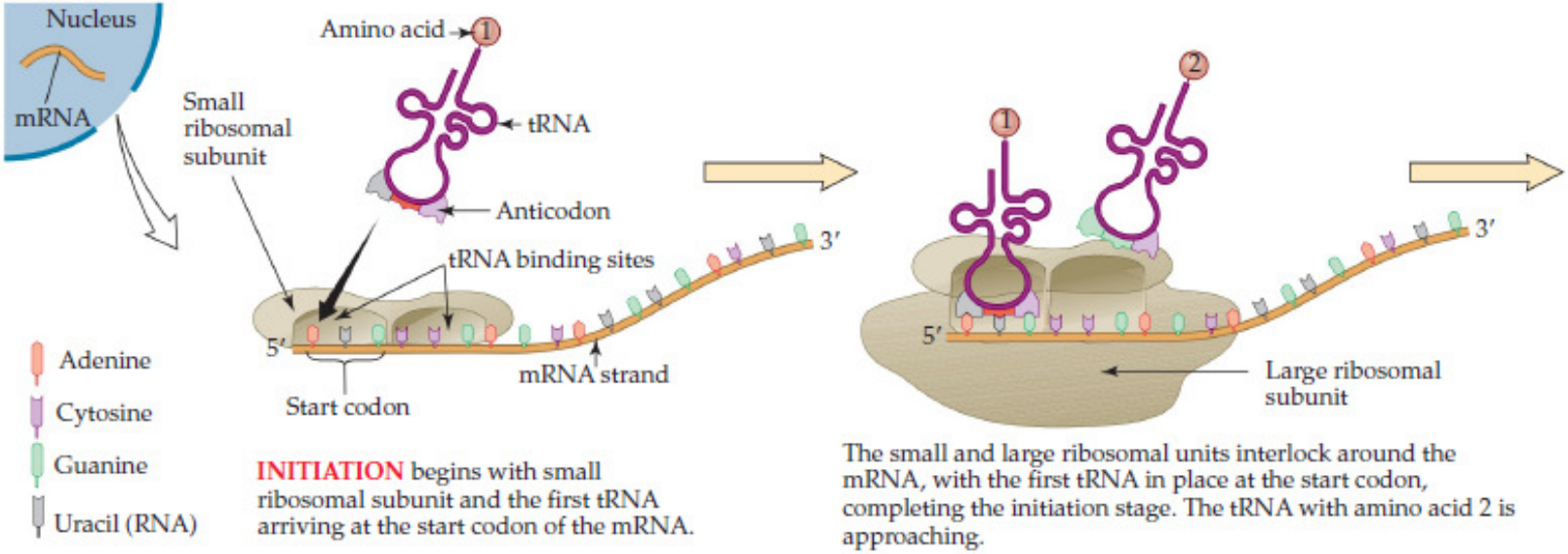
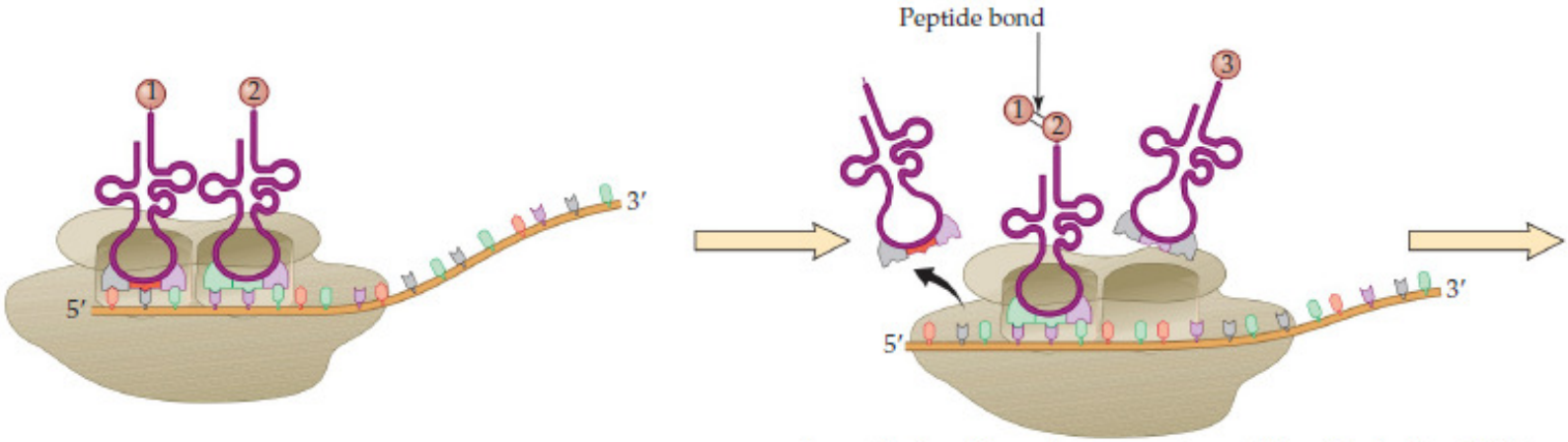
(Reference: Chapter 25 from McMurry et al.)

25.10 Translation: Transfer RNA and Protein Synthesis



INITIATION begins with small ribosomal subunit and the first tRNA arriving at the start codon of the mRNA.

The small and large ribosomal units interlock around the mRNA, with the first tRNA in place at the start codon, completing the initiation stage. The tRNA with amino acid 2 is approaching.

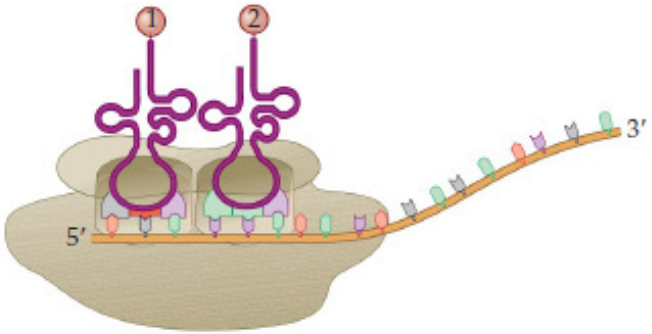


ELONGATION begins as the tRNA with amino acid 2 binds to its codon at the second site within the ribosome.

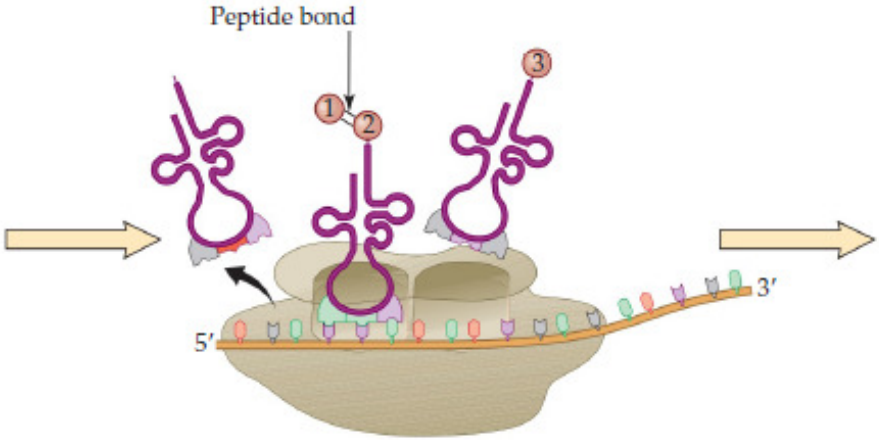
A peptide bond forms between amino acid 1 and 2, the first tRNA is released, the ribosome moves one codon to the right, and the tRNA with amino acid 3 is arriving.

(Reference: Chapter 25 from McMurry et al.)

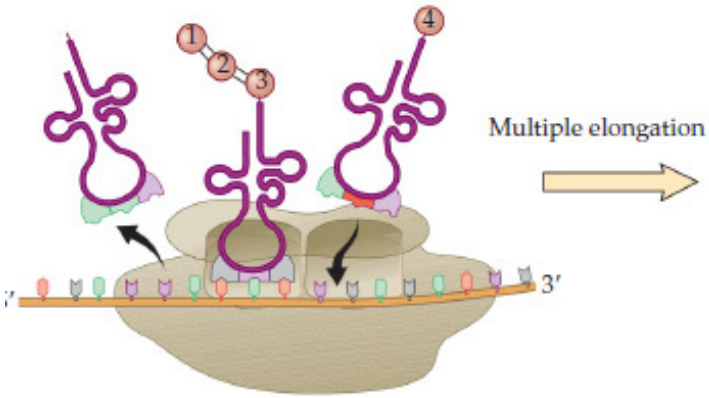
25.10 Translation: Transfer RNA and Protein Synthesis



ELONGATION begins as the tRNA with amino acid 2 binds to its codon at the second site within the ribosome.

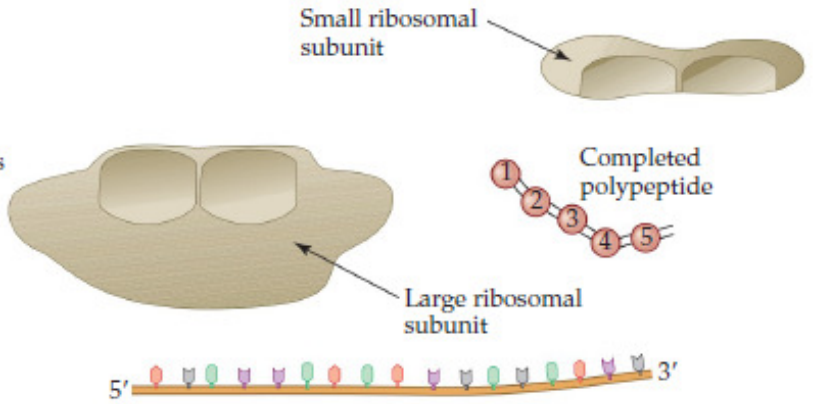


A peptide bond forms between amino acid 1 and 2, the first tRNA is released, the ribosome moves one codon to the right, and the tRNA with amino acid 3 is arriving.



Elongation continues with three amino acids in the growing chain and the fourth one arriving with its tRNA.

Multiple elongation steps



TERMINATION occurs after the elongation steps have been repeated until the stop codon is reached. The ribosomal units, the mRNA, and the polypeptide separate.

(Reference: Chapter 25 from McMurry et al.)

Questions?

(Reference: Chapter 25 from McMurry et al.)