

Freem

[Science](#), [Genetics](#)



Freeman, Biological Science, 4e, Chapter 4 Chapter 4 - Nucleic Acids and the RNA World Learning Objectives: Students should be able to... - Sketch a nucleotide, label its three basic parts, and identify the 2', 3', and 5' carbons. - Make another sketch showing the primary and secondary structures of DNA. - Describe the primary, secondary, tertiary, and quaternary structures of RNA, and explain in what ways RNA differs from DNA. - Explain why and how the secondary structure of DNA allows organisms to store and copy information. - Explain why RNA, and not DNA, was probably the first self-replicating molecule, and describe at least one piece of experimental evidence that supports this hypothesis.

Lecture Outline I. What Is a Nucleic Acid? A. What is a nucleic acid made of? 1. A nucleic acid is a polymer that is made up of monomers called nucleotides. 2. One nucleotide consists of a phosphate group, a sugar, and a nitrogenous base. (Fig. 4. 1a) 3. The sugar can be either ribose or deoxyribose. (Fig. 4. 1b) a. Ribonucleotides contain the sugar ribose; deoxyribonucleotides contain the sugar deoxyribose. b. On the 2' carbon, ribose has an -OH group; deoxyribose has an -H . 4. The nitrogenous bases: (Fig. 4. 1c) a. There are two classes of nitrogenous bases: purines and pyrimidines. (1) Adenine (A) and guanine (G) are purines. (2) Cytosine (C), uracil (U), and thymine (T) are pyrimidines. b. Ribonucleotides can have the bases A, G, C, and U. c. Deoxyribonucleotides can have the bases A, G, C, and T. 5. Students should be able to sketch a nucleotide using a ball, pentagon, and hexagon to depict the phosphate group, sugar, and nitrogenous base. Students should also be able to label the 2', 3', and 5' carbons on the sugar molecule, and add the atoms that are bonded to the 2' carbon. B. Could chemical evolution result in the production of

nucleotides? 1. No one has yet observed the formation of a nucleotide via chemical evolution. 2. The ribose problem: a. On early Earth, sugars could have been easily synthesized from heated formaldehyde molecules. b. But, it is not clear how ribose became the predominant sugar. © 2011 Pearson Education, Inc. Freem an, Biological Science, 4e, Chapter 4 3. The pyrimidine problem: a. On early Earth, purines could have been readily synthesized from HCN molecules. b. But, no one has yet discovered a plausible mechanism for pyrimidine production via chemical evolution. C. How do nucleotides polymerize to form nucleic acids? 1. Nucleic acids form when nucleotides polymerize. a. The polymerization occurs via a condensation reaction that forms a phosphodiester linkage, linking the 5' carbon of one nucleotide to the 3' carbon of the sugar of the next nucleotide. (Fig. 4. 2) b. A polymer of ribonucleotides is ribonucleic acid (RNA); a polymer of deoxyribonucleotides is deoxyribonucleic acid (DNA). c. The sequence of nitrogenous bases forms the primary structure of the RNA or DNA molecule. 2. DNA and RNA strands are directional. (Figs. 4. 2 and 4. 3) a. One end has an unlinked 5' carbon with a free phosphate group. b. The other end has an unlinked 3' carbon with a free OH group, where new nucleotides can be added. c. The sequence of bases of a strand of DNA or RNA is conventionally written from the 5' to the 3' end. d. Students should be able to draw a simplified diagram of a phosphodiester linkage between two nucleotides, mark the 3' and 5' ends, and indicate where the next nucleotide would be added. 3. Polymerization is an endergonic process that requires energy. a. The free energy of the nucleotides is first raised by the addition of two phosphate groups to each nucleotide. (Fig. 4. 4) b. This raises the potential energy of the substrate

molecules enough to make the polymerization reaction possible. c.

Phosphorylation is used in many other cellular reactions to make endergonic reactions possible. 4. Could nucleic acids form in the prebiotic soup? a.

During chemical evolution, activated nucleotides may have polymerized on the surfaces of clay-sized mineral particles. b. In one experiment,

researchers added fresh activated nucleotides to clay particles every day for two weeks. This resulted in RNA molecules up to 40 nucleotides long. c. If

nucleotides managed to form in the prebiotic soup, they could then probably have polymerized to form DNA and RNA. II. DNA Structure and Function A.

DNA's primary structure 1. DNA has a sugar-phosphate backbone with four types of nitrogenous bases. 2. DNA's primary structure is the sequence of nitrogenous bases. © 2011 Pearson Education, Inc. Freem an, Biological

Science, 4e, Chapter 4 B. What is the nature of DNA's secondary structure?

1. The discovery of DNA's secondary structure by Watson and Crick (1953) was one of the greatest scientific breakthroughs of the twentieth century. 2.

Early data provided three clues: a. Chemists already knew that DNA must have a sugar-phosphate backbone. b. Chargaff found that nucleotides seem

to be "paired" in some way: (1) The total numbers of purines and pyrimidines are equal in any given nucleic acid molecule. (2) The amount of

adenine is always equal to the amount of thymine, and cytosine is always equal to guanine. c. Franklin's and Wilkins's X-ray crystallography studies

suggested that DNA had a helix, with a regular, repeating structure, with certain spacing. 3. Watson and Crick put the pieces together: a. Antiparallel

strands: By building models, Watson and Crick deduced that the two DNA strands must run in opposite directions (antiparallel) with the nitrogenous

bases in the middle. (Fig. 4. 5) b. Complementary base pairing: To maintain the correct distance between the two strands, a purine must always pair with a pyrimidine. This allows hydrogen bonds to form between A and T and between G and C. (Fig. 4. 6a, b) c. The double helix: The hydrogen bonds cause the backbone to twist, forming a double helix with a major groove and a minor groove. (Figs. 4. 7 and 4. 8) C. DNA functions as an information-containing molecule. 1. In all cells studied, DNA carries the information required for the organism's growth and reproduction. 2. This information is contained in the sequence of nucleotides. 3. The double helix allows the information to be copied, by using one strand as a template for the synthesis of a complementary strand. (Fig. 4. 9) D. Is DNA a catalytic molecule? 1. DNA is highly stable because it exists as a double-stranded structure with few exposed functional groups. 2. DNA is so stable, and so simple in structure, that it cannot catalyze any reactions. E. Students should be able to sketch a DNA molecule, labeling the sugar-phosphate backbone, the hydrogen bonds, and the orientation of each strand. III. RNA Structure and Function A. Structurally, RNA differs from DNA. (Table 4. 1) 1. RNA's primary structure © 2011 Pearson Education, Inc. Freem an, Biological Science, 4e, Chapter 4 a. Like DNA, RNA has a sugar-phosphate backbone with phosphodiester linkages between nucleotides, with a sequence of four nitrogenous bases. b. Unlike DNA, RNA contains ribose instead of deoxyribose. This makes RNA more reactive and less stable than DNA. c. Unlike DNA, RNA contains uracil instead of thymine. Uracil pairs with adenine. 2. RNA's secondary structure a. Unlike DNA, a single RNA strand tends to fold and form complementary base pairs with itself, resulting in structures such as hairpin loops. (Fig. 4. 10) 3.

RNA's tertiary and quaternary structures a. Unlike DNA, RNA molecules can have tertiary structure and quaternary structure, resulting in very different shapes and chemical properties. (Fig. 4. 11, Table 4. 1) B. RNA's structure makes it an extraordinarily versatile molecule. 1. RNA is not as good at information storage as DNA or as good at catalysis as protein, but it can do " a little of everything." 2. RNA has recently been found to perform many diverse and important functions in cells. C. RNA is an information-containing molecule. 1. RNA's sequence of base pairs can carry information, just as in DNA. 2. Unlike DNA, the template RNA molecule is a single strand rather than a double strand. 3. Students should be able to draw the steps involved in synthesizing a complementary strand of RNA, analogous to the steps described for DNA in Figure 4. 9. D. RNA can function as a catalytic molecule. 1. Due to RNA's structural complexity, RNA is capable of stabilizing a few transition states and can catalyze some chemical reactions. 2. RNA catalysts are called ribozymes. 3. Altman and Kech (1989 Nobel Prize) found that ribozymes catalyze important reactions in living cells, such as the formation of phosphodiester bonds. (Fig. 4. 11) 4. If a ribozyme could catalyze its own replication, it could make a copy of itself. Such a ribozyme could have been the first living entity. IV. The First Life-Form A. The first living molecule had to do two things: 1. Provide a template that can be copied. 2. Catalyze polymerization reactions that link monomers into a copy of that template. B. RNA is the only molecule that is capable of both processes. Therefore, most researchers think that the first life-form was made of RNA. C. Johnston and Bartel's research 1. Their goal: To produce, from scratch, an RNA molecule that can catalyze the addition of nucleotides to an existing RNA strand. ©

2011 Pearson Education, Inc. Freem an, Biological Science, 4e, Chapter 4 2. Their strategy: a. Synthesize many RNA molecules. b. Select those that can catalyze the addition of the most nucleotides. c. Copy the selected RNA molecules in a way that introduces " mutations." 3. Their results: After 18 rounds of selection, a ribozyme evolved that was very effective at adding ribonucleotides to a growing RNA strand. 4. Other scientists have produced other ribozymes capable of catalyzing many of the key reactions needed for life. Chapter Vocabulary To emphasize the functional meanings of these terms, the list is organized by topic rather than by first occurrence in the chapter. It includes terms that may have been introduced in earlier chapters but are important to the current chapter as well. It also includes terms other than those highlighted in bold type in the chapter text. RNA world hypothesis nucleic acid nucleotide phosphate group sugar nitrogenous base ribose 5' carbon 3' carbon deoxyribose ribonucleotide deoxyribonucleotide purine pyrimidine adenine (A) thymine (T) cytosine (C) guanine (G) uracil (U) ribose problem polymerization phosphodiester linkage phosphorylation sugar-phosphate backbone ribonucleic acid (RNA) deoxyribonucleic acid (DNA) template strand © 2011 Pearson Education, Inc. complementary strand gel electrophoresis autoradiography X-ray crystallography antiparallel complementary base pairing double helix major groove minor groove stem-and-loop structure hairpin ribozyme