Topic 6.1

DNA and RNA Structure

Learning Objectives

- Learn about the transmission of heritable information by DNA and RNA
- Identify several important differences between the genomes of prokaryotes and eukaryotes
- Understand the role of nucleotide base pairing in DNA and RNA
- Learn about plasmids in eukaryotes and prokaryotes

Topic Questions

- What are the differences between eukaryotic and prokaryotic genomes?
- How does specific base pairing of nucleotides in nucleic acids make them well suited to carry heritable information?
- What are plasmids? Where are they found in cells, and how are they different from chromosomal DNA?

6.1.01 Transmission of Heritable Information through DNA and RNA

[IST-1.K.1 IST-1.K.2]

Genetic information is most often stored in **deoxyribonucleic acid (DNA)** (Figure 6.1). In living organisms, the order of nucleotides in DNA is used to store genetic information in **genes**. Groups of nucleotides make up genes, which typically encode proteins, and the order of nucleotides gives instructions for the expression of these genes. Genetic information is replicated (ie, copied) and passed from one generation to another through both sexual and asexual reproduction.

Some viruses also store genetic information in DNA, but others store it in **ribonucleic acid (RNA)**. Viral genetic information (ie, DNA or RNA, but not both) is typically replicated and passed on to future viruses using molecules within a host cell.

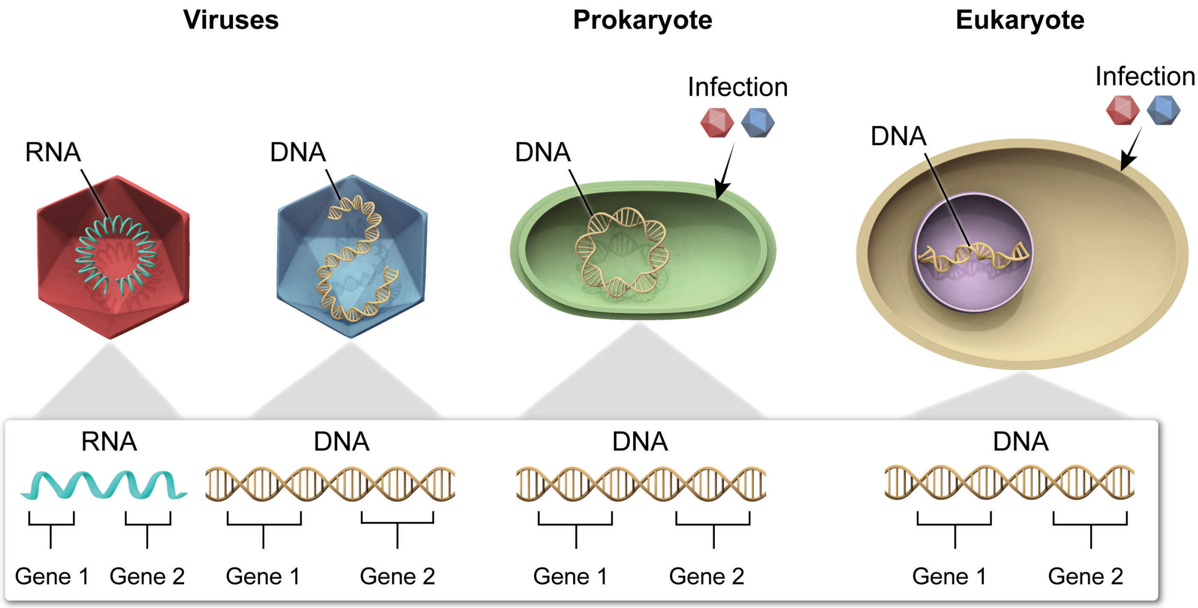


Figure 6.1 Genetic information is stored within the nucleic acids DNA and RNA.

Both DNA and RNA are made of nucleotide subunits (ie, monomers), but DNA and RNA have important structural differences that impact their behavior during the storage and transmission (ie, passing on) of genetic information. More detailed information about the structural components of DNA and RNA can be found in Unit 1.

The main differences between DNA and RNA are:

- DNA is double-stranded (ie, made of two strands of nucleotides joined by hydrogen bonding), while RNA is typically single-stranded (ie, made of a single strand of nucleotides).
- DNA nucleotides contain the sugar deoxyribose, while RNA nucleotides contain the sugar ribose.
- DNA contains the nucleotide thymine (T), while RNA contains the nucleotide uracil (U). Both DNA and RNA contain the nucleotides adenine (A), guanine (G), and cytosine (C).

6.1.02 Differences between Eukaryotic and Prokaryotic Genomes

[IST-1.K.2]

All organisms are composed of one or more cells. Cells can be categorized as prokaryotic or eukaryotic based on different structural and functional characteristics. One major difference between eukaryotic cells (eg, plants, animals, fungi) and prokaryotic cells (ie, bacteria, archaea) is that eukaryotic cells contain membrane-bound organelles. One of the largest membrane-bound organelles is the **nucleus**, which separates most of the genetic information from the rest of the cell. Prokaryotic genetic information is located in the cytosol because prokaryotes *lack* a nucleus.

There are also differences in the structural features of prokaryotic and eukaryotic chromosomes (Figure 6.2). Prokaryotic cells typically have one circular chromosome, while eukaryotes have a genome with many linear chromosomes. In addition, prokaryotic genomes are smaller and typically need only one origin of DNA replication to replicate (ie, copy) their genomes, while many origins of replication are needed to replicate the larger eukaryotic genome.

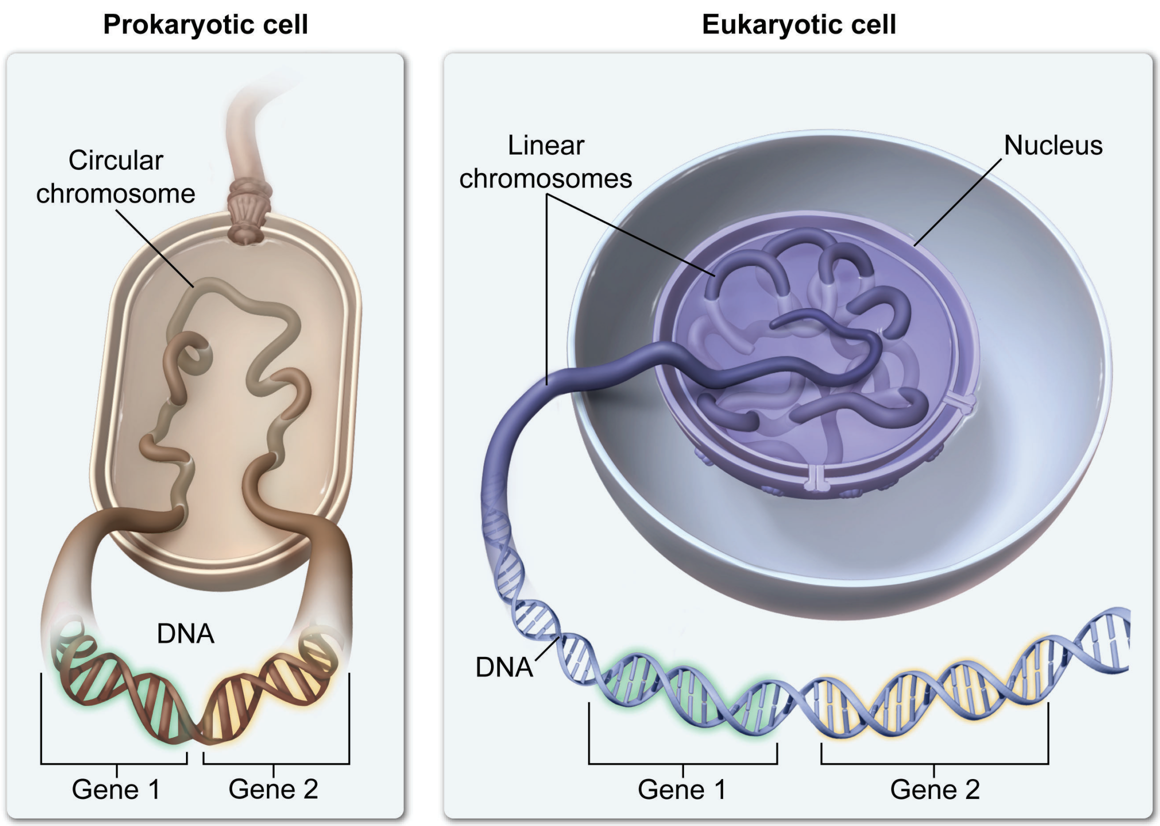


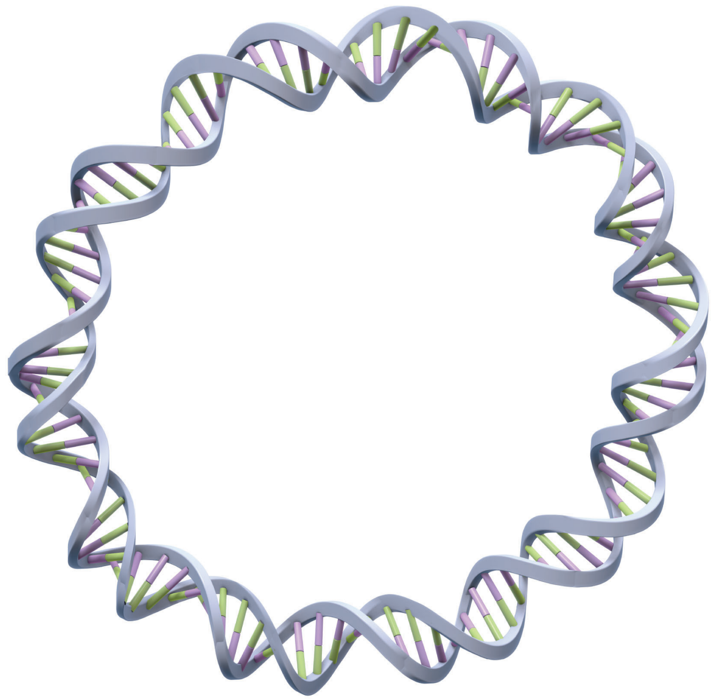
Figure 6.2 Prokaryotic versus eukaryotic chromosomes.

6.1.03 Plasmids in Eukaryotes and Prokaryotes

[IST-1.K.3]

Many prokaryotes and some eukaryotes have genes located within small, circular double-stranded DNA molecules called **plasmids** (Figure 6.3). Plasmids are extrachromosomal, which means that they are separate from the organism's chromosomal DNA.

Plasmids replicate separately from chromosomal DNA, and there may be more than one plasmid copy per cell. Plasmids can range in size from about one thousand to hundreds of thousands of base pairs. Because plasmid size varies, the number of genes plasmids carry also varies. Although plasmid genes are usually not needed for organism survival, plasmids often give an evolutionary advantage to organisms in specific conditions (eg, harsh environments).



- Small, circular pieces of DNA that are separate from chromosomal DNA
- May be found in **both** prokaryotic and eukaryotic cells

Figure 6.3 Plasmid structure and features.

Plasmids can be experimentally engineered to insert specific genes scientists are interested in studying (ie, gene of interest) into cells. Restriction enzymes (ie, enzymes that cut DNA at specific places) can be used to cut sections out of a plasmid so the gene being studied (ie, gene of interest) can be inserted into a plasmid. After the plasmid is taken up by the cell, the new gene can be expressed.

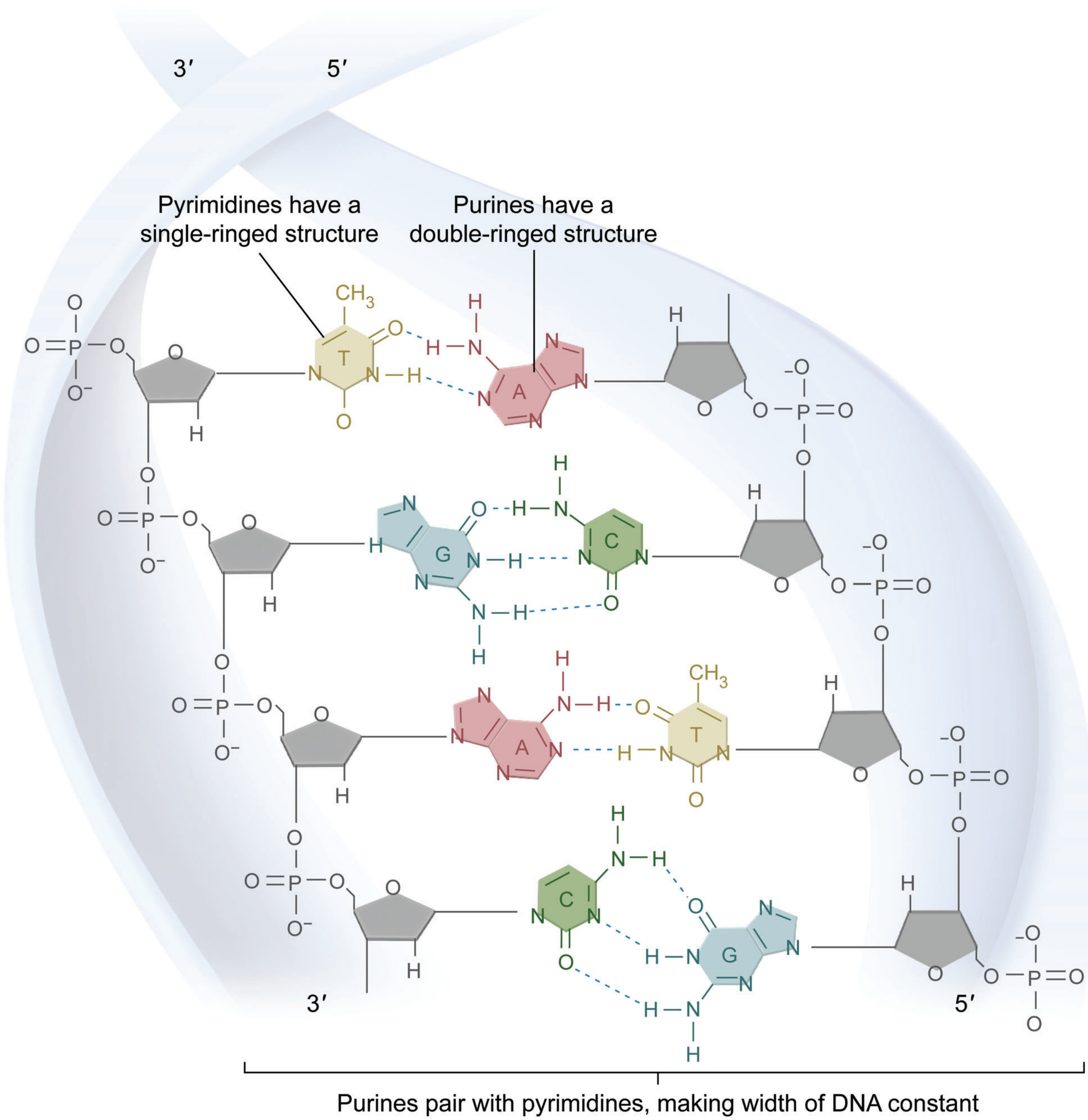
In addition to having a gene of interest, most plasmids contain at least one gene that codes for antibiotic resistance. When an antibiotic resistance gene is expressed in a bacterium, the antibiotic should not affect the bacterium (ie, slow its growth or kill it). After being grown in the presence of the antibiotic, only bacteria that take up the plasmid survive, allowing researchers to identify bacterial cells with the antibiotic resistance gene (ie, the plasmid).

6.1.04 Nucleotide Base Pairing in DNA and RNA

[IST-1.L.1]

Nucleotides can be classified as either purines or pyrimidines. The purine nucleotides guanine (G) and adenine (A) have a double-ringed structure, and the pyrimidine nucleotides cytosine (C), thymine (T), and uracil (U) have a single-ringed structure. Base pairing between nucleotides in DNA and RNA is **complementary**, and a purine always pairs with a pyrimidine. Complementary base pairing between purines and pyrimidines in DNA is *specific* in that C always pairs with G, and A always pairs with T. In RNA, C always pairs with G, but A always pairs with U (instead of T).

Usually, DNA is found as a double-stranded polymer (ie, large molecule made up of many similar subunits) in the shape of a double helix. The two strands of the double helix are antiparallel (ie, oriented in opposite directions) and are held together by hydrogen bonds between complementary base pairs (Figure 6.4).



A = adenine; **C =** cytosine; **G =** guanine; **T =** thymine.

Figure 6.4 Complementary base pairing in DNA.

Complementary base pairing is important for the processes of replication and transcription. When DNA is replicated (ie, copied), its two strands are separated and an enzyme called DNA polymerase builds two new strands using nucleotides that are complementary to those on the original template DNA strands. Likewise, during transcription the two strands of a DNA molecule separate so an enzyme called RNA polymerase can make a new RNA strand using complementary base pairing with the DNA template strand. These processes are discussed in more detail in Topic 6.2-6.3.

Topic 6.1 DNA and RNA Structure
Check for Understanding Quiz

1. Which of the following is true about prokaryotic genomes?
   A. They contain circular chromosomes.
   B. They usually contain more than one chromosome.
   C. They do not contain plasmids.
   D. They contain many origins of replication.

2. Which of the following best represents two nucleotides that would undergo complementary base pairing in both DNA and RNA molecules?
   A. A and U
   B. G and A
   C. T and A
   D. G and C

Note: Answers to this quiz are in the back of the book (appendix).