# Section 2.1
# DNA Replication

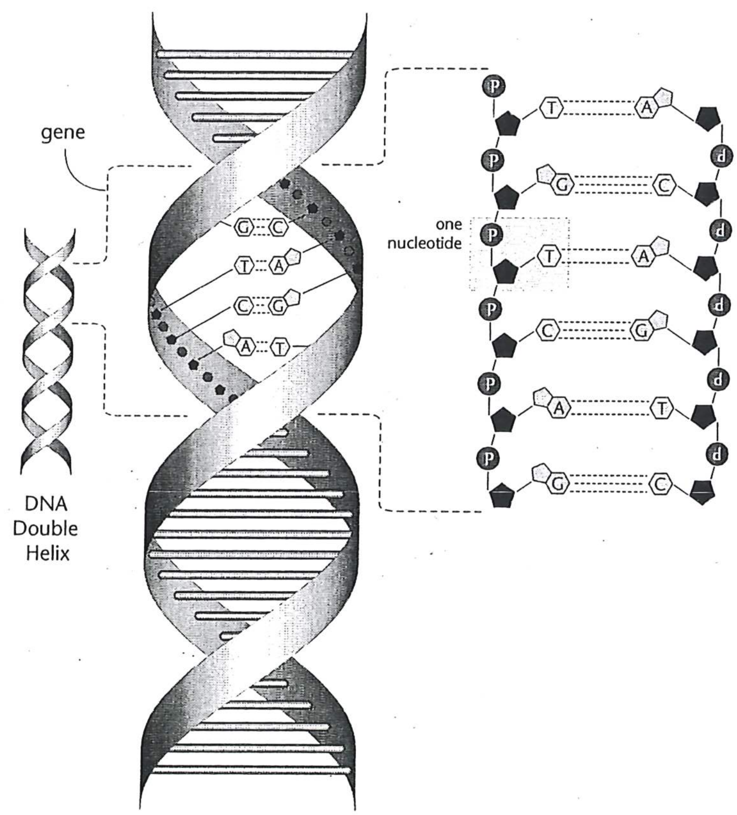
## Section Overview

You've undoubtedly seen a few episodes of CSI and know the importance of DNA to crime scene investigations. Its importance is simple: each human being has a unique DNA blueprint so determining a DNA profile at a crime scene can help detectives determine suspects.

In Module 1 you briefly learned about DNA structure and function. In this section your knowledge of DNA structure and function will be taken further along with new information relating to RNA structure and function, DNA replication, and recombinant DNA (or cloning).

It bears repeating—each person has a unique DNA blueprint—you are a unique human being with unique physical and mental characteristics provided by your parents. You are special... just don't get into trouble with the police!

Overview of DNA Structure



# Lesson 2.1A
# DNA/RNA Structure and Function

## Overview

Imagine that each of the trillions of cells in your body is an entire world all by itself. This cell can take in nutrients, produce energy and wastes, and even reproduce, all by using the built-in instructions contained in its DNA.

DNA stands for deoxyribonucleic acid. DNA is an organism's genetic blueprint and it resides in the nucleus of almost all body cells. DNA does not leave the nucleus. Instead, it creates a messenger to transfer information into the cytoplasm. The transfer of the genetic code from the nucleus sets in motion a chain of biochemical events that leads to the formation of a polypeptide. When many polypeptides are combined, the end result is a protein.

DNA contains enormous amounts of data, but its structure is elegantly simple, consisting of repeating units called nucleotides. A nucleotide is composed of a single sugar, a phosphate group, and one of four nitrogen-containing bases. It is the exact order in which these bases are arranged that determines the final structure of the protein that is to be made.

Module 1 introduced you to the structure of DNA. In this lesson you will look further at the structure of DNA and how that structure relates to its important role as the genetic blueprint, without which life would not exist.

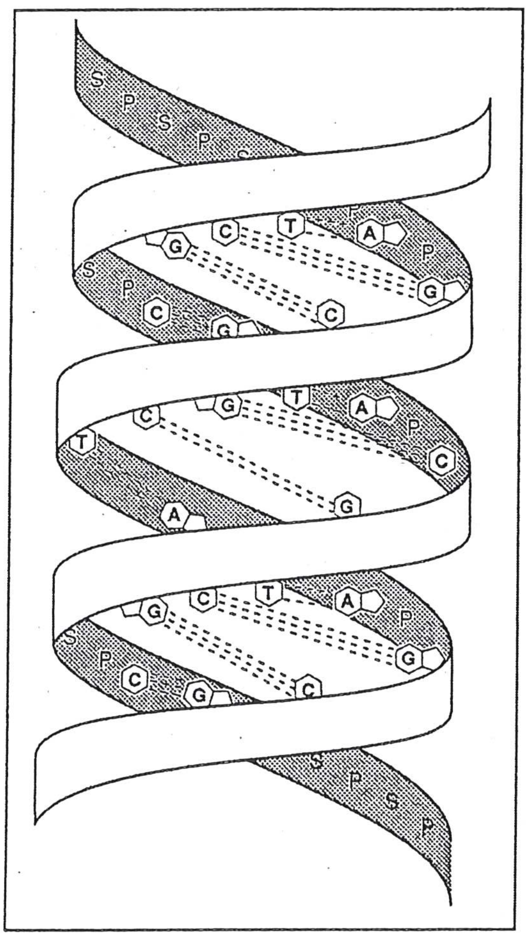
### Resource List

- *Inquiry Into Life*
- *Biology 12 Provincial Exam Preparation package*
- *Biology 12 Web site*
  http://www.openschool.bc.ca/courses/biology/bi12/mod2.html
- *Biology 12 Media CD*

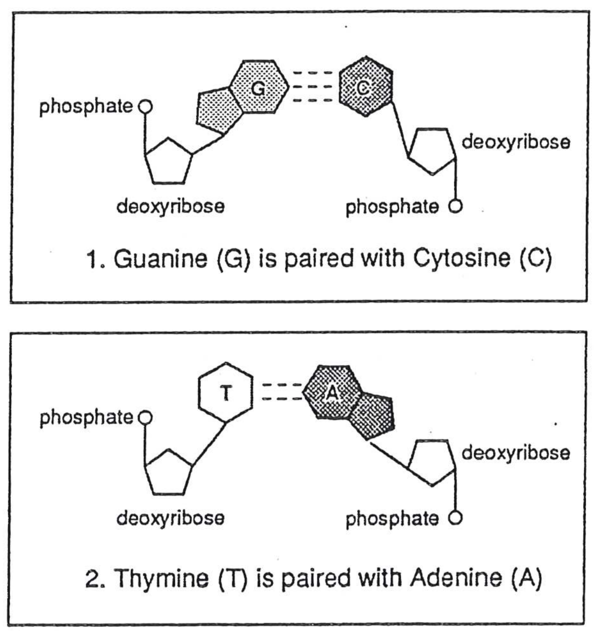
## The Structure of DNA

If you look under a microscope at a cell that is preparing to divide, you would see the cell's genetic material condensed into visible chromosomes. Each chromosome is a densely super-coiled mass of DNA, and it's there that the complex process of protein synthesis will begin.

DNA (deoxyribonucleic acid) is composed of polynucleotides (poly = many nucleotides). Each nucleotide is made up of three parts: a phosphate group, deoxyribose (a pentose sugar), and a base that contains nitrogen. The base may have a double ring structure (called purines) or a single ring structure (called a pyrimidine). The purine bases are adenine (A) and guanine (G); the pyrimidine bases are thymine (T) and cytosine (C). Adenine is always paired with thymine, and guanine is always bonded to cytosine. This is known as **complementary base pairing**.



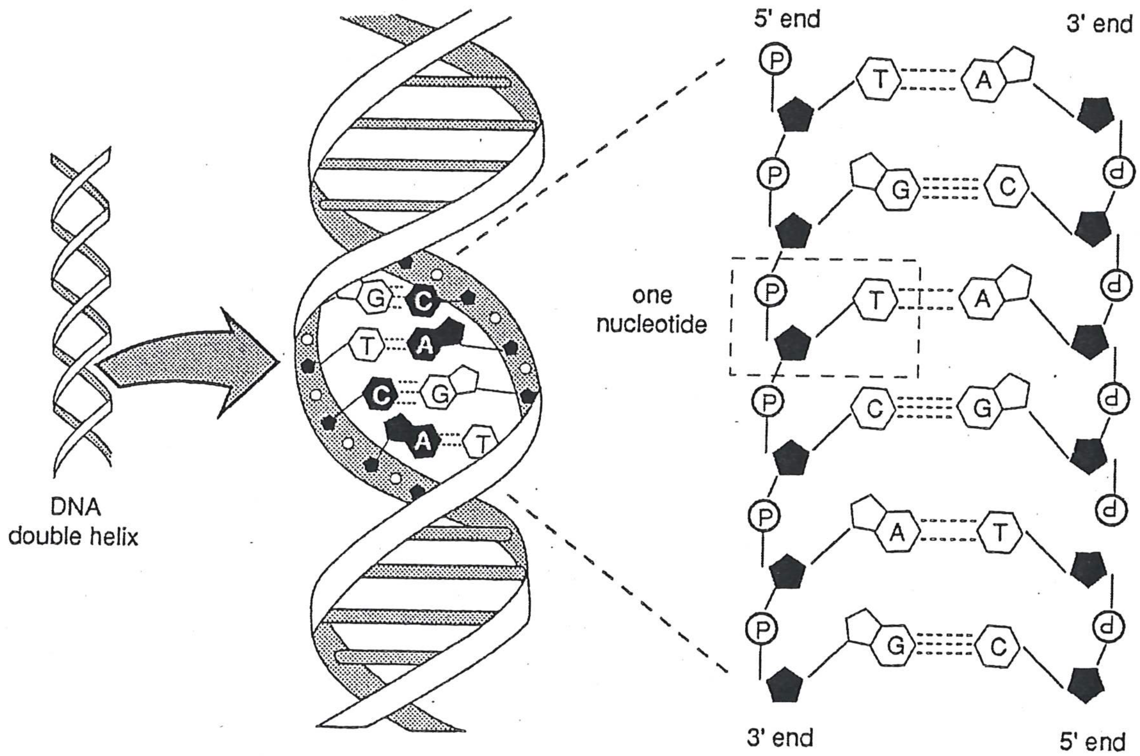

**Complementary pairing of nucleotides**




1. Guanine (G) is paired with Cytosine (C)

2. Thymine (T) is paired with Adenine (A)

Polynucleotides are joined to form long strands. Two of these strands, wound around each other and held together by hydrogen bonds, form the double helix shape of the DNA molecule. When unwound, DNA resembles a ladder. The phosphate groups and deoxyribose sugars form the sides, and weak hydrogen bonds between complementary base pairs complete the rungs of the ladder.




The nucleus of a cell is about 6 micrometres (0.000006 metres), yet it contains about 1.8 metres of DNA. This means that DNA is over 10 000 times longer than the nucleus into which it must fit. In order to accomplish this, DNA must be densely compacted into chromosomes.

## The Functions of DNA

DNA stores an organism's genetic information in the nuclei of cells. It also replicates (makes an exact copy of itself) when cells divide, so the nuclei of new cells contains the same DNA as the cells from which they originated. Finally, DNA provides a code or template for the particular sequencing of amino acids that ultimately bond together to form a protein.

In your *Inquiry Into Life* textbook, read the section on "Nucleic Acids" and focus on "Structure of DNA and RNA." Be sure you can recognize and identify the three parts of a nucleotide.

If you have access to the Internet, go to Mader Online Learning Centre's Essential Study Partner Version 2—Genetics on the *Biology 12 Web site* Lesson 2.1A DNA/RNA Structure and Function and read the section entitled DNA Structure.

## Guided Practice 2.1A 2
# DNA Structure Self-check

Correctly answer the following questions.

1. What are the three parts of a nucleotide?
2. What is meant by complementary base pairing?
3. Briefly describe the functions of DNA.

## The Structure of RNA

RNA (ribonucleic acid), like DNA, is a polynucleotide. However, its structure is somewhat different from that of DNA. RNA is single-stranded, so it does not form a double helix. Instead of deoxyribose sugar, RNA contains ribose sugar. And while DNA does not leave the nucleus, RNA does move out of the nucleus to perform its roles in protein synthesis. There'll be more on this in a later lesson. Finally, in RNA, adenine pairs with uracil, a different base that replaces thymine.

In the textbook, read the section on RNA only. Transcription and translation will be covered in later lessons. Be sure to note the structural differences between DNA and RNA.

## The Functions of RNA

There are three types of RNA and each is involved in protein synthesis. This topic will be explored in more depth in a future lesson. For now, it is important to know the basic functions of each type of RNA:

**Messenger RNA** (mRNA) —

- produced in the nucleus by transcription, using DNA as a template
- contains bases complementary to DNA (recall that uracil replaces thymine in RNA)
- carries DNA's message out of the nucleus to the ribosomes (the site of protein synthesis) in the cytoplasm

**Ribosomal RNA (rRNA) —**

- a component of ribosomes

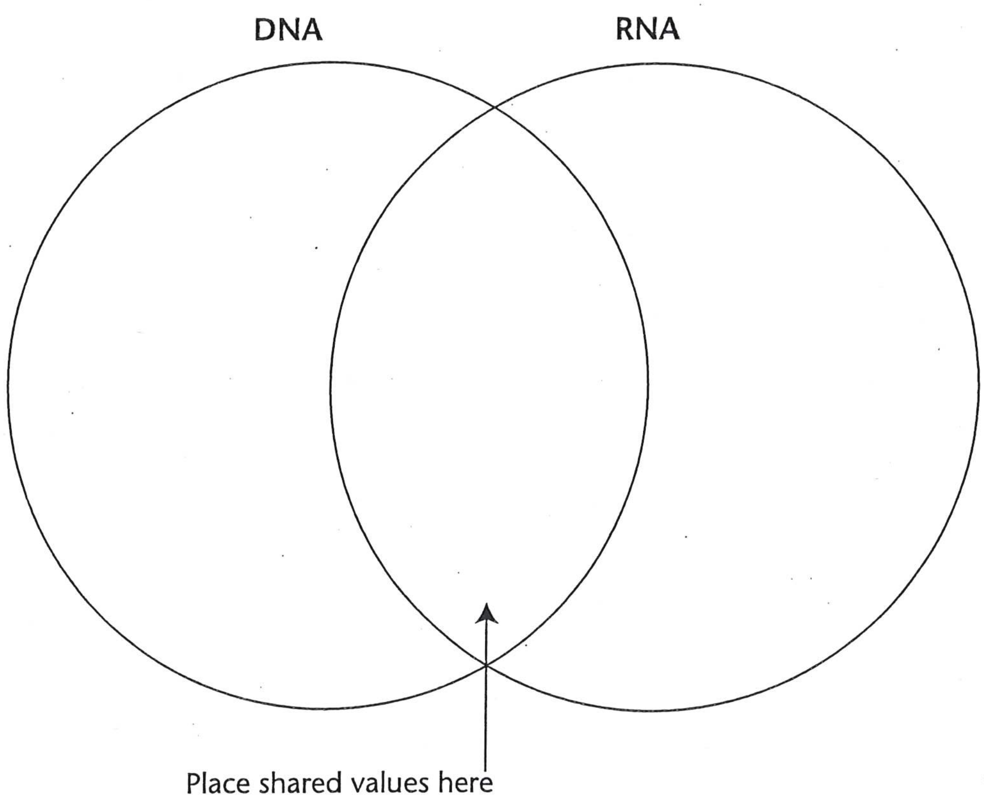
**Transfer RNA (tRNA) —**

- delivers individual amino acids to the ribosomes during protein synthesis

## Guided Practice 2.1A 3
# RNA Venn Diagram

Venn diagrams are a type of graphic organizer. They are useful when you want to show similarities and differences between two concepts.

Place each feature from the following bulleted list into the correct location on the blank Venn diagram. To do this, you need to determine if each feature is unique to DNA or RNA, or if the feature is present in both molecules.




- nucleotides contain phosphate group
- located in nucleus
- deoxyribose sugar
- double-stranded
- ribose sugar
- adenine pairs with thymine
- adenine pairs with uracil
- cytosine pairs with guanine
- located in nucleus and cytoplasm
- single-stranded
- monomers contain nitrogen

# Lesson 2.1B
# DNA Replication

## Overview

How fast can our cells make exact copies of the large amount of genetic information they contain? The human genome copies itself relatively slowly, at a rate of about 50 bases per second. In some bacteria, this rate is much faster, up to thousands of pairs per second. This is the rough equivalent of driving three hundred miles per hour while at the same time spinning your car in tight circles!

In this lesson you will learn about the essential process of **replication** in cells—how, when, and why DNA makes exact copies of itself.

### Resource List

- *Inquiry Into Life*
- *Biology 12 Provincial Exam Preparation package*
- *Biology 12 Web site*
  http://www.openschool.bc.ca/courses/biology/bi12/mod2.html
- *Biology 12 Media CD*

## Why Is Replication Necessary?

**DNA replication** must occur in a eukaryotic cell before the cell undergoes either mitosis or meiosis. For this reason, before we discuss replication itself, it is important to review the two processes that make replication necessary.

The number of chromosomes in a cell varies by species. Humans have 46 chromosomes, arranged in 23 pairs, in each body cell. Sperm and egg cells are the exception—each of those cells has 23 chromosomes.

In organisms produced by sexual reproduction, one member of each pair of chromosomes comes from the female parent and the other from the male. Each parent must therefore have a means of dividing its genetic material in half—creating a haploid or half cell—in order to contribute half of its offspring's DNA. This division is achieved by meiosis.

A cell spends about 90% of its life performing a function according to its location and specialization in the body—cardiac cell, muscle cell, etc. This period is termed interphase. The prefix inter- means between, so the cell is between divisions.

Since a cell continues to grow, it must divide at some point during its life cycle. Otherwise it will become too large to allow efficient exchange of nutrients, gases and wastes across the cell membrane, and it will die. In other words, the volume of the cell becomes too large to be accommodated by the cell membrane surface area.

Cell division occurs by mitosis (nuclear division) and cytokinesis (cytoplasm and organelle division). Before meiosis or mitosis can occur, the number of chromosomes in the cell must be exactly duplicated. This is accomplished by DNA replication, which occurs at the end of interphase.

Find the diagram titled "The Cell Cycle" in the section on cell division in your *Inquiry Into Life* textbook. Notice that the cell spends most of its life cycle in interphase and a very short time undergoing mitosis. Also note that replication takes place during interphase, not during mitosis.

If you have access to the Internet, go to the *Biology 12 Web site* Lesson 2.1B DNA Replication to view a short animation of the cell cycle. Observe how the cells in the centre of the cycle change as the cycle itself progresses through interphase and mitosis.

## DNA Replication and Mitosis

Mitosis, the division of a cell's nucleus, occurs during tissue growth and repair. It is one of two types of cell division. The other is cytokinesis—division of the cytoplasm and organelles. Mitosis produces two cells from one. Each daughter cell has the same number of chromosomes as the original cell. Therefore, DNA replication must occur before cell division so the number of chromosomes is doubled. It will then be halved during mitosis.

Locate the section titled "Overview of Mitosis" in your *Inquiry Into Life* textbook's section on cell division and take a few moments to review mitosis.

If you have access to the Internet, go to the *Biology 12 Web site* Lesson 2.1B DNA Replication to see an excellent animation of mitosis.

Remember that DNA replication must occur before mitosis. Focus on Interphase, in which chromosomes replicate. You will examine this process in more detail during this lesson. Although this animation only shows two chromosomes, a human cell duplicates all 46 of its chromosomes.

Another good mitosis resource can be found at the *Biology 12 Web site* Lesson 2.1B DNA Replication. Read the review of mitosis in Section 2.9, and then watch the animated film clip to see the process in action. As you watch, be sure you understand why DNA replication must precede mitosis.

## Meiosis

Meiosis can be thought of as double cell division because it results in four new cells, rather than the two produced by mitosis. The main difference is that each new cell will have only half the number of chromosomes as the original cell. In humans, meiosis produces sperm and egg cells, which have 23 chromosomes rather than 46.

In both mitosis and meiosis:

- DNA replication occurs in the nucleus at the end of interphase
- replication results in the doubling of chromosomes within the nucleus

Locate the section in your *Inquiry Into Life* textbook titled "Reducing the Chromosome Number" and study the "Overview of Meiosis" diagram. In the 11th edition, see Figure 5.9 on page 90. Although a complete review of the process of meiosis is not necessary, it is important to note that DNA replication occurs just prior to meiosis.

Although a complete review of meiosis is not necessary, an animation of the process is useful. If you have access to the Internet, go to the *Biology 12 Web site* Lesson 2.1B DNA Replication and focus on the interphase stage. Recall that DNA replication is identical in both mitosis and meiosis.

Alternately, for a brief review of meiosis, go to the *Biology 12 Web site* to the online Mader Essential Study Partner Version 2 and read Sections 2.19, "Ultimate Goal of Meiosis," and watch the animation of meiosis in Section 2.23.

Now that you have reviewed why DNA replication is necessary, and when it occurs, we will examine how the process of replication is carried out.

Guided Practice 2.1B 2

## DNA Replication—What You Know Already

Write the letter of the term in Column A beside the correct definition in Column B. Not all definitions will be used, and some may be used more than once.

| Column A | Column B | |
|---|---|---|
| A. cell cycle | 1. results in four haploid cells (e.g., human sperm and egg) | |
| B. interphase | 2. the process of duplicating the DNA in a cell's nucleus | |
| C. mitosis | 3. phase in which a cell grows, conducts its normal processes, and replicates its DNA | |
| D. cytokinesis | 4. describes the four stages in the life of a cell | |
| E. meiosis | 5. division of a cell's nucleus; occurs as part of cell division | |
| F. DNA replication | 6. required in order for both mitosis and meiosis to occur | |

## How Does DNA Replication Occur?

DNA Replication is the process of exactly copying one DNA double helix to produce two identical helices. The process is **semi-conservative**, meaning that each of the two strands from the original double helix provides a template for the formation of a complementary new strand. After replication, each new double helix will contain one original and one newly made strand.

**Step 1: DNA unzips —**

```
A---T
T---A
G---C
T---A
C---G
G---C
T---A
A---T
G---C
```

Recall that two DNA strands are held together by weak hydrogen bonding between base pairs—adenine is paired with thymine, cytosine with guanine). There are two hydrogen bonds, or H-bonds, between A and T and three between C and G. An enzyme, **DNA helicase** (enzyme names end in -ase), targets certain sections of DNA that contain a large proportion of A–T bonds. DNA helicase breaks the H-bonds, causing the DNA to unzip and unwind into two separate strands. This happens simultaneously in a number of locations.

**Step 2: Complementary base pairing —**

```
A-T         T
T-A         A
G-C       ↑ C
T ↓       T-A
C         C-G
G         G-C
  \      /
   T---A
   A---T
   G---C
```

The action of DNA helicase results in two separated DNA strands with exposed bases that are no longer paired. Free-floating nucleotides in the nucleus pair up with the exposed bases on each strand (recall that adenine pairs with thymine, and cytosine pairs with guanine). These nucleotides are joined together by **DNA polymerase** to form a new sugar-phosphate backbone and create a new DNA strand.

| | |
|---|---|
| A-T | A-T |
| T-A | T-A |
| G-C | G-C |
| T-A | T-A |
| C-G | C-G |
| G-C | G-C |
| T-A | T-A |
| A-T | A-T |
| G-C | G-C |

**Step 3: Replication is completed —**

After the unattached nucleotides become attached to an unzipped DNA strand, **DNA ligase** seals any remaining breaks in the sugar-phosphate backbone. Two DNA double helices have then been created from one original DNA helix. Each new double helix contains one original and one newly made strand of DNA.

If you have access to a computer and the *Biology 12 Media CD*, go to DNA Replication in Motion now to view an animation of these steps.

Go to your:

*Biology 12 Media CD* > Module 2 > **DNA Replication in Motion.**

## Errors in Replication

Although replication is an intricate process involving the unzipping of DNA and the pairing of millions of bases, errors rarely occur. DNA polymerase basically proofreads the newly made DNA strand, compares it to the original, and corrects mismatched base pairs. If an error is missed, it can result in a **mutation**. The role of mutations in protein synthesis will be discussed in a later lesson.

## Guided Practice 2.1B 3
# Replication Self-check

Before you complete the following guided practice, read the section titled "DNA Replication" in your *Inquiry Into Life* text and be sure you are familiar with the three steps involved in replication.

Before you move on, check your understanding of DNA replication by answering the following questions.

1. An enzyme begins the process of DNA replication by unzipping the two DNA strands. This requires:
   - A. ion transfer between nitrogenous bases
   - B. water
   - C. breaking of covalent bonds
   - D. breaking of hydrogen bonds
2. In DNA replication, the term "unzipping" refers to:
   - A. unwinding the mRNA from the DNA after transcription
   - B. denaturing the DNA helix
   - C. breaking the bonds between the sugar and phosphate molecules
   - D. breaking the bonds between complementary DNA strands
3. Which of the following is the second step of replication?
   - A. the formation of two new DNA molecules
   - B. complementary base pairing of nitrogenous bases
   - C. the breaking of hydrogen bonds between nitrogenous bases
   - D. the joining of bonds between the sugar and phosphate backbone
4. Where does replication take place?
   - A. the nucleus
   - B. the ribosome
   - C. the nucleolus
   - D. the Golgi body

# Lesson 2.1C
# Recombinant DNA

## Overview

What is **recombinant DNA**?

If you asked the next ten people you meet to answer that question, most probably couldn't. However, you might get a better reaction if you ask, "What do you think of cloning?" **Genetic engineering**, genetically modified foods, and cloning are controversial issues in our society, largely because of the wide range of possibilities provided by these technologies. Will genetic engineering cure diseases, hunger, and environmental disasters during your lifetime? Will the technologies outlast the controversies they create?

In this lesson you will learn about a method of cloning DNA, and you'll have a chance to investigate some of the many uses of rDNA in biotechnology.

To understand some of the far-reaching implications of genetic engineering, it's important to have a basic knowledge of rDNA.

### Resource List

- *Inquiry Into Life*
- *Biology 12 Provincial Exam Preparation package*
- *Biology 12 Web site*
  http://www.openschool.bc.ca/courses/biology/bi12/mod2.html

## What Is Recombinant DNA?

By knowing the structure and replication process of DNA, scientists are able to manipulate the genetic material of an ever-increasing number and variety of organisms. Genetic engineering is defined in your textbook as "the alteration of genomes for medical or industrial purposes." Recombinant DNA (rDNA) is said to be "genetically modified." Creating rDNA is therefore one example of genetic engineering.

You might remember the sheep named Dolly—the world's first cloned mammal—that was introduced to the world in 1997. DNA technology has been developing since the early 1900s, even before the structure of DNA itself was discovered. The birth of the biotechnology industry really began in 1972 with the first creation of recombinant DNA.

Recombinant DNA contains DNA from two or more different sources.

Segments of DNA from one organism are inserted into the chromosomes of another host organism. Bacteria are commonly-used as hosts, mainly because they multiply quickly, so rDNA can be mass-produced in a fairly short time.

## How Recombinant DNA Technology Works

Genetic engineering is a term synonymous with recombinant DNA technology, and producing rDNA is one way for scientists to **clone** DNA. But how, exactly, can the DNA from one organism be added to that of another?

To create rDNA, several steps are required.

First, DNA is removed from cells of two different organisms, for example, human and bacterial DNA. The bacterium provides a **vector**—a piece of host organism DNA to which foreign DNA can be added. Bacteria are often used as vectors because they have DNA in **plasmids** as well as in their chromosomes, making them easier to work with.

Restriction enzymes cut DNA in specific locations, and DNA ligase pastes human DNA to the gap in the plasmid.

This creates recombinant DNA, but it is only useful if it can be mass-produced as the host cell multiplies.

Before you move on, locate and read the section in your *Inquiry to Life* textbook titled "Using Recombinant DNA Technology" and explore the resources listed for this lesson.

If you have access to the Internet, go to the *Biology 12 Web site* Lesson 2.1C Recombinant DNA to view an interactive piece on how genes are transferred. Move your mouse over each picture to see how recombinant DNA is made. Read the steps and view simple animations by clicking each diagram.

Also go to the *Biology 12 Web site* Lesson 2.1C Recombinant DNA to explore more information on genetic engineering. The site contains useful, readable information on Genetic Engineering. Focus on "Recombinant DNA: How Genes Are Transferred."

## Guided Practice 2.1C 2
# Checking Your Understanding of rDNA

Using what you have read in your *Inquiry Into Life* textbook about recombinant DNA, complete the following questions and check your answers.

1. What is recombinant DNA?
2. Name and describe the functions of two enzymes required to produce rDNA.
3. At which stage in the production of rDNA does cloning occur?

## How rDNA Is Used in Biotechnology

All life forms—both extinct and living—store their genetic material in DNA molecules. The potential uses of biotechnology in our everyday lives are limited only by our imaginations. Would you want to clone your favourite pet? Would you change your eye, hair, or skin colour? Does the world need square corn on the cob so that butter doesn't drip off it? Should your life span be 200 years or more?

Today, rDNA technology seems to raise more questions than answers because the potential applications are almost endless. Biotechnology is both a science and an industry. It manipulates naturally-occurring processes to meet a growing wish list of human needs and desires. Transgenic organisms—those with foreign DNA added to their own—include bacteria, plants, and animals. You'll recall that a major function of DNA is to code for proteins. Therefore, recombinant DNA codes for altered versions of those proteins.

Read the following examples of current applications of rDNA in agriculture and pharmaceuticals. Keep in mind that there are many more applications of rDNA technology in medicine, industry, environmental science, and other fields of study!

### Pharmaceuticals: Insulin Production

Our bodies normally produce insulin in response to increased blood glucose levels. Type 1 diabetes results when the pancreas does not produce insulin. Individuals affected by this type of diabetes require treatment that includes insulin injections. Before rDNA, cow and pig insulin was given to diabetic patients. However, some patients' immune systems reacted against it, because it is not identical to human insulin. Now, rDNA technology is used to mass produce human insulin by using the bacteria E. coli—a bacterium found in, among other habitats, the human intestinal tract. The insulin gene is injected into an E. coli vector, where it combines with bacterial plasmid DNA. The insulin produced by rapidly reproducing E. coli is identical to what our bodies normally produce.

Similarly, rDNA technology is used to make parathyroid hormone, blood proteins for the treatment of anemia and hemophilia, and human growth hormones.

By using rDNA to add foreign genes to plant genomes, plant crops can be improved in a number of ways. For example, genetically engineered bacteria can be sprayed on strawberries to protect them from freezing. Other agricultural uses of rDNA include delayed ripening, increased crop yields (the potential to grow more food on less land), and herbicide, insect, fungus, and disease resistance.

For more details, read the section in your *Inquiry to Life* textbook titled "Biotechnology." It provides more examples of applications of rDNA technology in bacteria, plants, and animals.

Now do Section Assignment 2.1 Parts A and B.

## Summary

**Completing this lesson has helped you to:**

- describe how rDNA is made from the DNA of two or more different organisms
- identify some of the applications of biotechnology