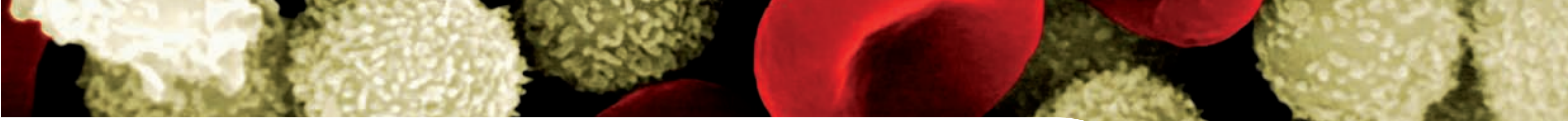


Chapter 17
DNA—the code for life

Unit
2B

Unit content

Cells, metabolism and regulation
Genes determine a cell's structure and function.

DNA:

- structure of DNA including base pair model
- locations in the cell including nucleus and mitochondria
- role of DNA in the cell
- DNA replication—base pair model

Inheritance
Pedigrees

- inheritance of mitochondrial DNA

Figure 17.1 A scientist examining a DNA profile. The bands on the profile are segments of DNA

How tall are you?
Are you a male or female?
What colour are your eyes?
Is your hair straight, wavy or curly?
Are you able to distinguish red and green colours?
Do you have normal vision, or are you short- or long-sighted?
Do you have the same allergic reactions as one of your parents?

All of these characteristics and a host of others are determined by your DNA. In this chapter we will examine how your characteristics are coded in the molecules of your DNA and how these molecules are able to make exact copies of themselves.

DNA, genes and chromosomes

DNA is short for **deoxyribonucleic acid**. It is a molecule found in the cells of all organisms—bacteria, single-celled plants and animals, and all complex plants and animals including humans. Most DNA molecules are found in the nucleus of each cell. They contain the genetic information that determines the structure of the cell and the way it functions.

Molecules of DNA are in the form of long strands. It is estimated that the length of the DNA molecules in a human cell is between two and three metres but the width is only two millionths of a millimetre. An average human hair is about 40 thousand times thicker! To give you some idea of the scale, suppose that a DNA molecule were as thick as a pencil (about 8 mm). The molecule would then be about 200 kilometres long. Think how difficult it would be to manage a pencil 200 km long without breaking it. The nuclei of human cells have 46 such DNA molecules.

How do such long molecules fit inside the cell nucleus? The DNA strands are bound to special proteins called **histones**. Each DNA strand is coiled around the histones so that these long molecules can fit into a small space. In a cell that is not dividing, the coiled DNA forms a tangled network called **chromatin** (Fig. 17.2).

Learn about the history of the discovery of DNA at:
- http://www.dnaftb.org
- http://www.dnai.org/index.htm

When a cell divides, exact copies of each DNA molecule in the tangled mass of chromatin must be distributed to the two daughter cells (see Chapter 5). How does the cell manage to keep the DNA intact during the process of cell division? When a cell is about to divide the coiled chromatin becomes even more tightly coiled. These 'super-coiled' structures are large enough to be seen with a light microscope and are called **chromosomes** (Fig. 17.3).

Sections of the DNA molecules make up the **genes**. The genes contain the **genetic code**, which is the stored information that determines the structure and activities of the cell.

Structure of DNA

Each DNA molecule in the cell nucleus consists of two strands of alternating sugars and phosphates with pairs of nitrogen bases forming cross-links between the sugar molecules in the two strands. The structure is twisted into a spiral shape, called a **double helix** (Fig. 17.4). Each phosphate group and sugar molecule with a nitrogen base attached is called a **nucleotide**. Nucleotides are the units that make up the DNA molecule. There are four different nitrogen bases in the DNA molecule, and they will pair only in a certain way: **adenine (A)** will pair only with **thymine (T)**, and **cytosine (C)** will pair only with **guanine (G)** (Fig. 17.4).

The order in which the nitrogen bases occur in the DNA molecule determines the **genetic code**. A code of only four letters (A, T, C and G) would not seem to allow

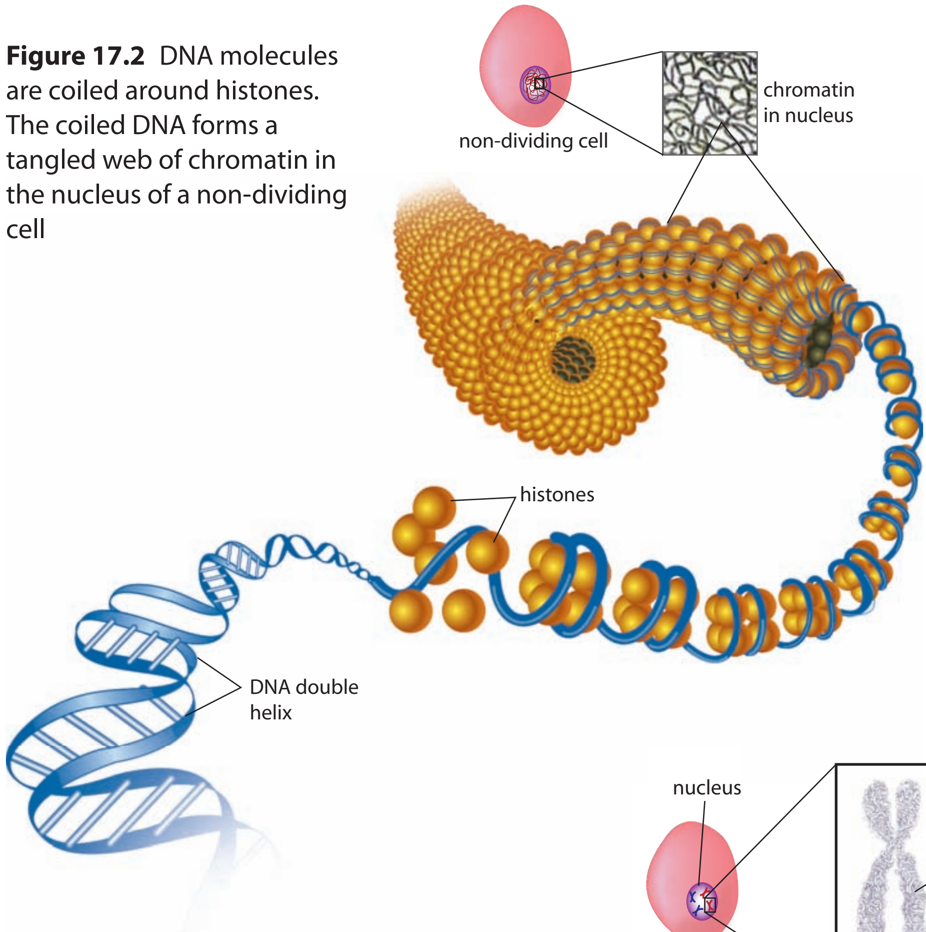


Figure 17.2 DNA molecules are coiled around histones. The coiled DNA forms a tangled web of chromatin in the nucleus of a non-dividing cell

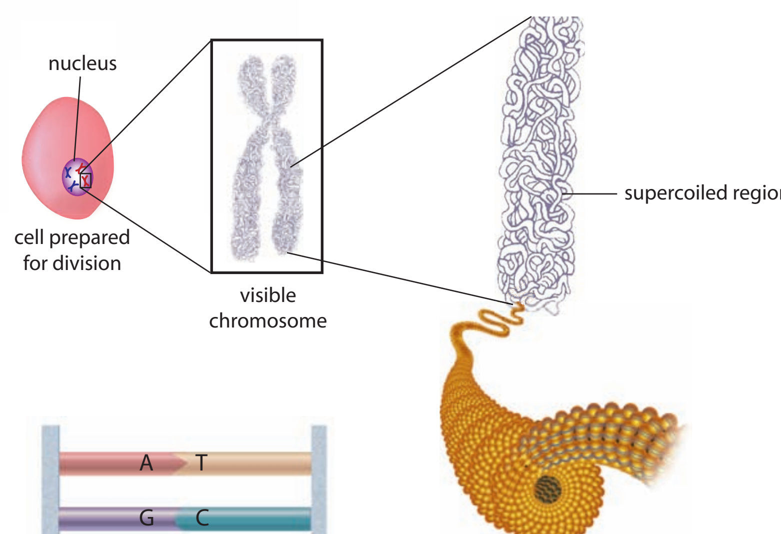


Figure 17.3 For cell division, coils of DNA become super-coiled to form chromosomes

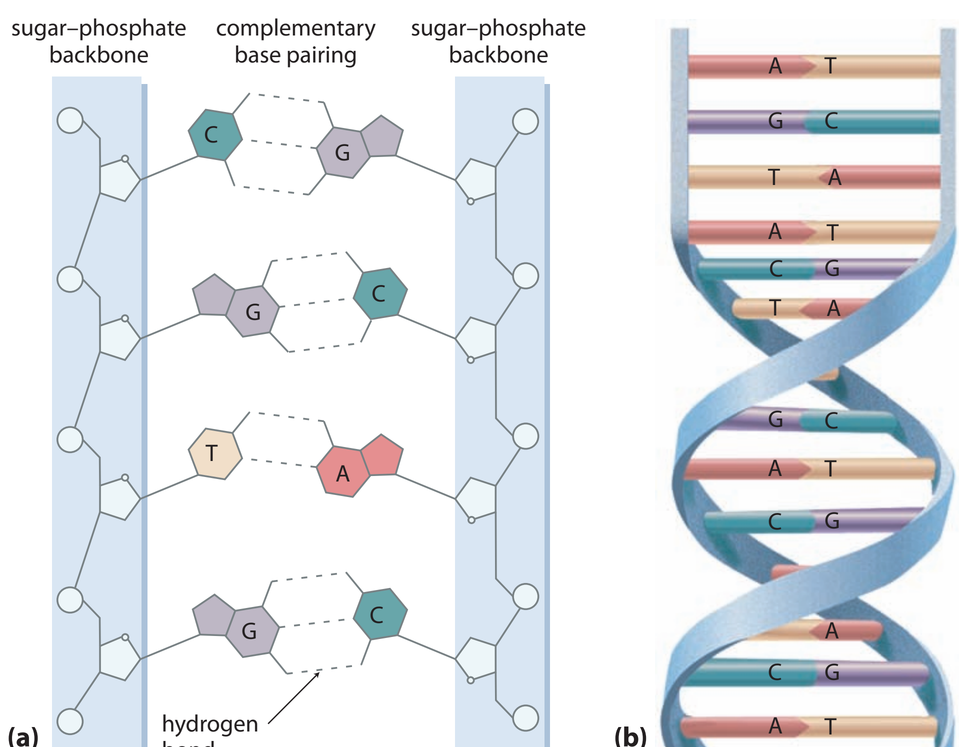


Figure 17.4 **(a)** DNA consists of two strands of alternating sugars and phosphates with pairs of nitrogen bases forming cross-links between the chains; **(b)** the two strands are twisted into a double helix

many different combinations, but each gene consists of up to 1000 pairs of bases. The number of possible combinations of base pairs is therefore enormous.

Replication of DNA

The formation of new DNA molecules that are identical, in every respect, to the original molecule ensures that inherited information is passed on unchanged when a cell reproduces. While a cell is in interphase (between cell divisions; see Chapter 5), the DNA molecules undergo **replication**: they form exact replicas of themselves. The two linked chains of the DNA molecule separate, and each separated section contains half of the original information. These then serve as a template for the nucleotides that will form the new half. As the base adenine can pair only with thymine, and cytosine can pair only with guanine, the new half that forms is identical to the original. Figure 17.5 shows how this process results in the formation of two identical DNA molecules.

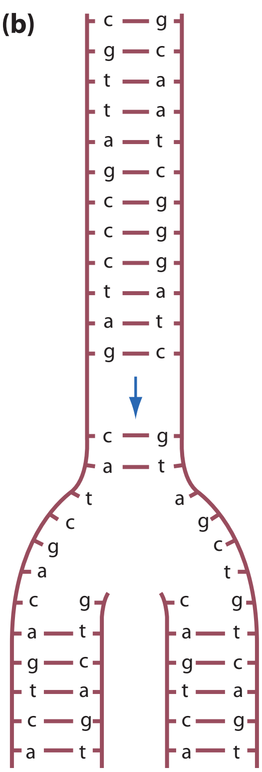
Role of DNA in the cell

The genetic code in the DNA provides the instructions for protein synthesis—making proteins in the cell. Synthesis is the combining of small molecules to make larger molecules. The example of energy transfer by ATP, illustrated in Figure 4.9 (page 49), shows how proteins are synthesised from amino acids. Synthesis requires both matter and energy—matter in the form of small molecules to be joined, and energy to form the chemical bonds that hold the smaller units together.

Protein synthesis

Synthesis of proteins is a very important part of cell metabolism. Proteins make up much of the structural material of cells, and chemical reactions are controlled by enzymes that are also proteins.

(b)



(a)

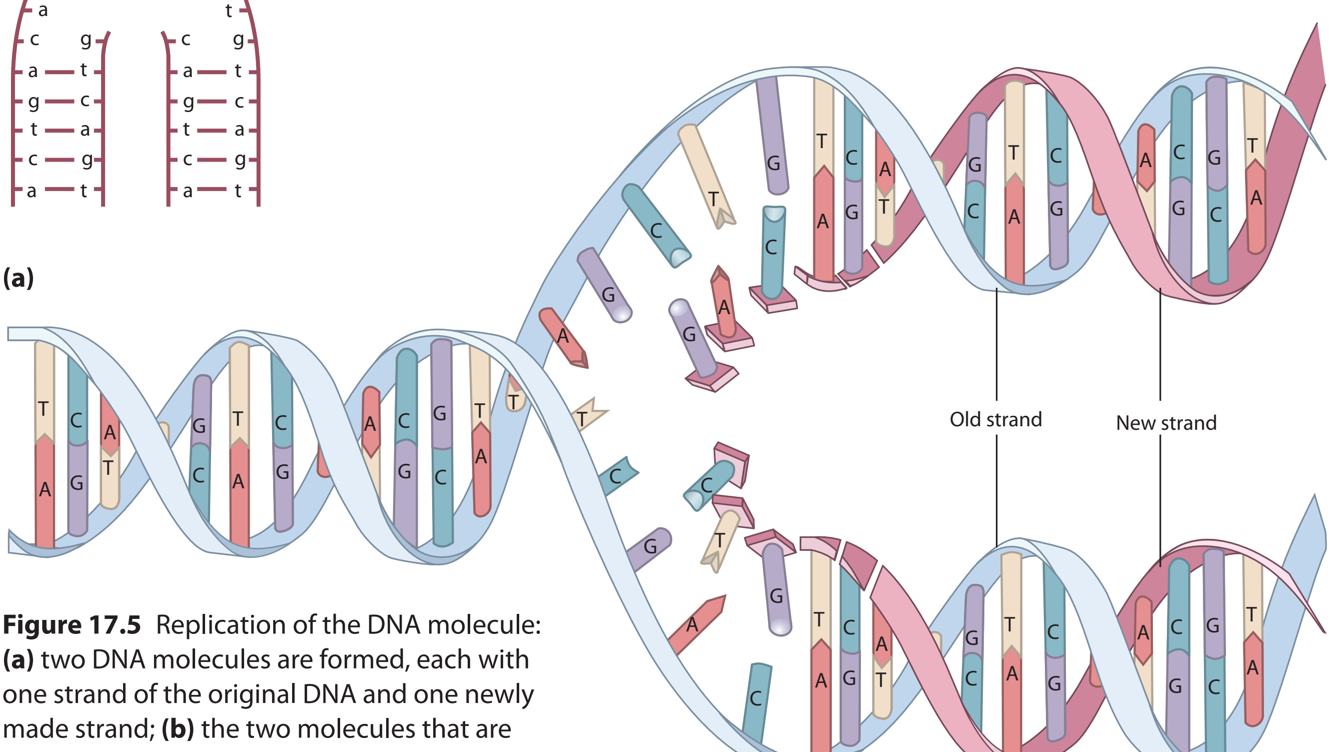


Figure 17.5 Replication of the DNA molecule: **(a)** two DNA molecules are formed, each with one strand of the original DNA and one newly made strand; **(b)** the two molecules that are produced are identical to the original

The types of proteins a cell can make are determined by the **genes**, which are parts of the DNA molecules in the nucleus. The order in which the four bases (adenine, thymine, cytosine and guanine) occur in a DNA molecule is the genetic code. Each sequence of three bases is the code for a particular amino acid. For example, the sequence CAG (cytosine–adenine–guanine) is a code for the amino acid valine; CGA is a code for alanine; and TTC is a code for lysine. Thus, if the bases in part of a DNA molecule occurred in the order CAG CGA TTC, then the amino acids valine, alanine and lysine would be assembled in that order in any protein made using instructions from that part of the DNA molecule.

Amino acids are actually assembled at the ribosomes (see Fig. 17.6) in the cytoplasm of the cell. Instructions contained in the DNA in the nucleus must be accurately transferred to the ribosomes.

The instructions get from the DNA in the nucleus to the ribosomes in the cytoplasm via RNA (ribonucleic acid), which carries the message. RNA differs from DNA in that it is usually only a single strand of sugars and phosphates, and the bases thus occur singly. Another difference is that RNA has the base uracil (U) instead of thymine.

To transfer the coded information from the nucleus to the ribosomes, part of the DNA molecule breaks apart. A segment of RNA, called **messenger RNA (mRNA)**, is formed. The bases in the messenger RNA are complementary to those of the DNA—that is, where cytosine occurs in the DNA, the messenger RNA will have the base guanine; thymine in the DNA will correspond to adenine in the RNA; and so on. The messenger RNA then passes out of the nucleus and attaches to a ribosome (see Fig. 17.7). At the ribosome the amino acids are joined together in a sequence determined by the messenger RNA. Another form of RNA, **transfer RNA (tRNA)**, brings the amino acids from the cytoplasm to the ribosomes. Each transfer RNA molecule has three bases, and when these bases complement those of the messenger RNA the amino acid attached to the transfer molecule is included in the chain being assembled (Fig. 17.7). In this way, amino acids are joined together in the order originally determined by the DNA in the nucleus. Each gene has the coded instructions for synthesising a particular protein.

(a)

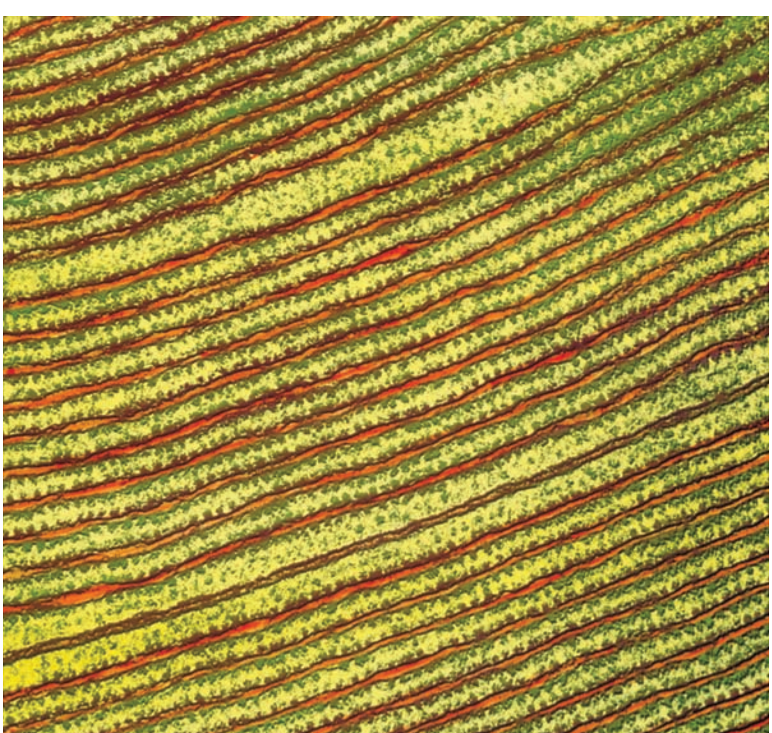
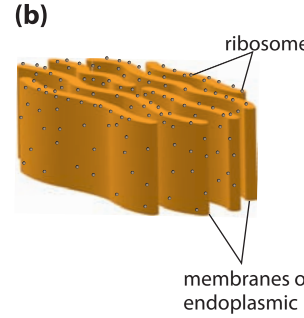
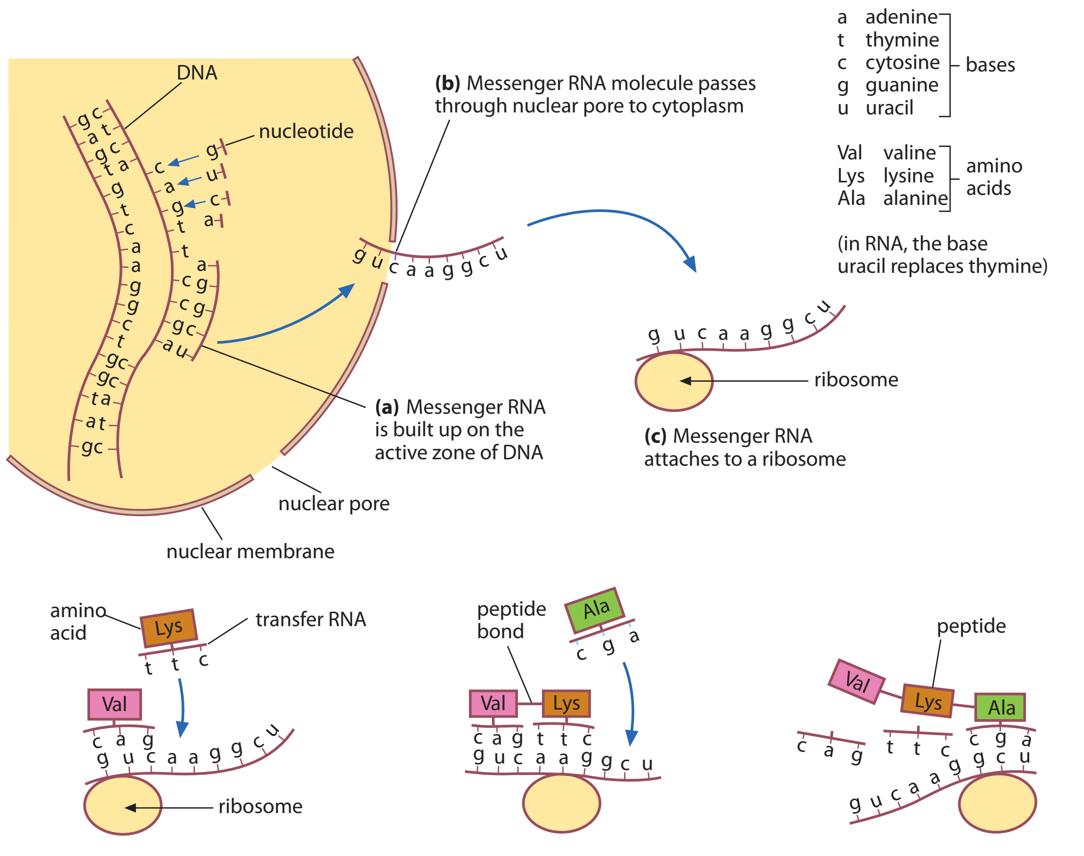


Figure 17.6 **(a)** Electron micrograph showing endoplasmic reticulum with ribosomes attached; **(b)** ribosomes may be free in the cytoplasm or bound to the endoplasmic reticulum, as shown

(b)





(d) Amino acids are brought in sequence by transfer RNA to messenger RNA on the ribosome

(e) Amino acids are assembled to make part of a protein molecule

Figure 17.7 Synthesis of proteins at the ribosomes using the information from the DNA code in the nucleus

An animation of protein synthesis may be seen at http://www.wisc-online.com/objects/index_tj.asp?objID=AP1302

The process of copying information from DNA onto messenger RNA and then translating the message into a series of amino acids is called **gene expression**.

One ribosome can make a protein containing 400 amino acids in about 20 seconds. Each messenger RNA molecule may be attached to 10 or 20 ribosomes, all reading the code and joining amino acids. There may be 300 000 identical messenger RNA molecules in a cell. This means that a cell may produce more than 150 000 protein molecules each second!

Lipid and carbohydrate synthesis

There are no genes that carry instructions for the manufacture of lipids or carbohydrates. However, the synthesis of these substances requires enzymes, and enzymes are proteins. As we have seen, the DNA in the genes carries the code for protein manufacture. Thus, indirectly, the genes control the synthesis of lipids and carbohydrates.

Mitochondrial DNA

Mitochondria are the organelles in the cell where the aerobic phase of respiration occurs to release energy for use by the cell (see Chapter 4). Most of a cell's DNA is located in the nucleus but a small amount is in the mitochondria. This is called **mitochondrial DNA** or **mtDNA**.

Unlike the DNA in the nucleus, which is in the form of very long strands, mitochondrial DNA is in the form of small circular molecules. There are about five to ten of these molecules in each mitochondrion. The mitochondrial DNA has 37 genes, all of which are essential for the mitochondrion to function normally. Twenty-four of the genes contain the code for making transfer RNA molecules which are involved in protein synthesis. The other 13 genes have instructions for making some of the enzymes necessary for the reactions of cellular respiration. Some rare diseases may be caused by mutations in the mitochondrial DNA.

Inheritance of mitochondrial DNA

When a sperm penetrates an egg at fertilisation the mitochondria in the sperm are rapidly destroyed. This means that we inherit nuclear DNA from both parents but we inherit mitochondrial DNA only from our mothers.

Since mitochondrial DNA is passed to the next generation only through the mother it has been very useful in tracing the ancestry of people. For example, through studying mitochondrial DNA it has been possible to trace the migration routes of ancient peoples. Such studies have shown that most Europeans are descended from hunter-gatherers who migrated into Europe during the last Ice Age, rather than from farmers coming from the Middle East.

Table 17.1 Types of nucleic acids

Deoxyribonucleic acid (DNA)	Very large molecule made of two strands of nucleotides that are joined by bonds between the nucleotide bases. The two strands are twisted into a double helix. Found in the nucleus and mitochondria of cells.
Nuclear DNA (nDNA)	DNA found in the nucleus of cells.
Mitochondrial DNA (mtDNA)	DNA found in the mitochondria.
Ribonucleic acid (RNA)	Large molecule composed of a single strand of nucleotides.
Messenger RNA (mRNA)	RNA molecule that carries the code for protein synthesis from the DNA in the nucleus to the ribosomes where the protein is made.
Transfer RNA (tRNA)	A small RNA molecule that transfers the correct amino acid to the ribosome for inclusion in the protein molecule being made.

Working scientifically

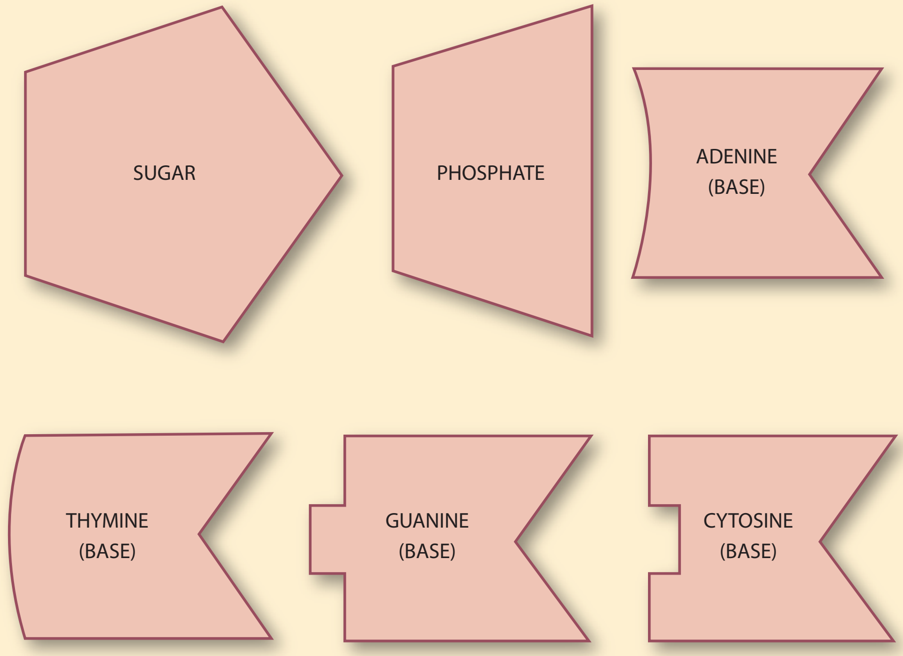
Activity 17.1 Modelling DNA structure and replication

A scientific model is a simplified representation of an idea or process. In this activity you will build a simple model of a DNA molecule and use it to demonstrate how the model can form an exact replica of itself.

You will need

Shapes (cut out of cardboard or plastic) to represent sugar, phosphate, adenine, thymine, guanine and cytosine. Note: The edges of the shapes must fit together perfectly for this activity so keep this in mind when cutting them out. Suitable shapes are shown in Figure 17.8.

Figure 17.8



What to do

The DNA molecule

DNA is made up of thousands of units called nucleotides. Each nucleotide consists of a sugar (deoxyribose), a phosphate and a base containing the element nitrogen. The nucleotides are arranged so that the molecule has two frameworks of alternating sugars and phosphates. The two backbones are joined by the bases of the nucleotides.

1. Arrange the shapes for the sugars, phosphates and bases to form the structure of a DNA molecule. Include at least 12 nucleotides in your DNA molecule.
2. Using the letters A, T, G and C, write down the order of the base pairs in the molecule you have made (list the pairs from top to bottom).

You can build a DNA molecule in a similar way on the Genetic Science Learning Center website at **http://learn.genetics.utah.edu/units/basics/builddna**

Replication of DNA

3. Separate the DNA molecule that you have made into two halves by separating the two chains of nucleotides. Using extra shapes, form new molecules from each of your 'halves' by adding sugars, phosphates and bases to them.
4. Write down the order of the base pairs in your two new molecules.

After completing this activity, answer the following questions:

1. How does the order of the base pairs of your two new molecules compare with the original that you wrote down?
2. How can you explain this result?

Studying your observations

3. Why are the numbers of adenine and thymine bases in a DNA molecule always equal?
4. Would there be equal numbers of thymine and cytosine bases? Explain your answer.

5. Explain how, when a cell divides, the two daughter cells contain exactly the same genetic information as the parent cell.

James Watson and Francis Crick, using information discovered by other scientists, were the first to work out the structure of DNA. In 1953, using molecular shapes cut out of cardboard, they suggested how the components could fit together to form the DNA molecule. You can see a photograph of Watson and Crick's model at **http://osulibrary.oregonstate.edu/specialcollections/coll/pauling/dna/pictures/dna-model.html**

Activity 17.2 Extracting DNA

In this activity you will extract DNA from plant or animal material.

You will need

Plant or animal material such as wheat germ, split peas, onion or chicken liver; food blender or processor; salt; liquid detergent; methylated spirits; fine kitchen sieve; clean beakers; wooden skewer

What to do

1. Place one quarter of a cup (about 100 mL) of the plant or animal material in the blender.
2. Dissolve half a teaspoon of salt in 150 mL of warm water (about body temperature) and add to the material in the blender.
3. Blend on high for about 30 seconds.
4. Separate the liquid from the solid material by pouring the contents of the blender into a fine kitchen sieve and catching the liquid in a 250 mL beaker.
5. Add a teaspoon of liquid detergent and stir gently every minute for five minutes.
6. Tilt the beaker and slowly pour methylated spirits down the side until it forms a 1 cm layer on top of the solution in the beaker. Make sure the methylated spirits does not mix with the solution.
7. Allow the mixture to stand and you should see white, stringy DNA form at the interface between the watery solution and the methylated spirits.
8. Twist a wooden skewer in the layer of DNA and you may be able to lift some of it out of the solution.

For further investigation

Design investigations to find out whether:

- all plant or animal material has DNA that appears the same
- you can extract more DNA from some plant or animal materials than from others.

You may be able to carry out your investigations by using fruit such as bananas, vegetables such as silver beet, meat, seaweed or mushrooms.

REVIEW QUESTIONS

1. What is the difference between a gene and a chromosome?
2. Explain how molecules of DNA that may be a metre or more long can fit inside the microscopic nucleus of a cell.
3. What is the genetic code?
4. Draw a diagram to illustrate the structure of DNA.
5. Explain how a DNA molecule is able to form an exact replica of itself.
6. What is the role of the ribosomes in protein synthesis?
7. What is the difference between
   (a) DNA and RNA?
   (b) messenger RNA and transfer RNA?
8. How does DNA control the synthesis of carbohydrates and lipids in a cell?
9. What is mitochondrial DNA?

APPLY YOUR KNOWLEDGE

1. Table 17.2 shows the results of analysing the nucleotides found in the cells of humans, chickens and wheat plants. What do these percentages tell us about the structure of DNA?

Table 17.2 Proportion of nucleotides in the cells of some organisms

	Percentage of nucleotides containing:			
Cells	**Adenine**	**Guanine**	**Cytosine**	**Thymine**
Human	30.9	19.9	19.8	29.4
Chicken	28.8	20.5	21.5	29.2
Wheat	27.3	22.7	22.8	27.2

2. Approximately how many bases would there be in a messenger RNA molecule that coded for a protein 250 amino acids long?
3. DNA is found in all organisms from bacteria to complex plants and animals. What does this suggest about the origin of life?
4. Suppose that part of a DNA molecule has the following sequence of bases:
   CTC CCC TTA GTC GAT AGT
   (a) What would be the sequence of bases on the complementary strand of the DNA molecule?
   (b) What sequence of bases would be found in a complementary strand of messenger RNA?
5. When new DNA is made we say that the DNA replicates. Why is it incorrect to say that the DNA splits or divides?