6.1 The Molecular Basis of Inheritance

DNA (deoxyribonucleic acid) is the primary carrier of genetic information in all living organisms on Earth. From the simplest bacterium to the most complex animal, all organisms use DNA to pass information for their construction and operation from one generation to the next. Within an organism's DNA are the instructions necessary to build all the proteins it requires. DNA is responsible for ensuring the genetic continuity of the species, and therefore the continuity of life.

DNA is passed from generation to generation in the form of chromosomes. In eukaryotes, chromosomes may be visible in the cells during cell division. They appear as the familiar X-shaped objects that are split during mitosis or meiosis. The size and number of chromosomes in a cell are specific to each species. Humans, for example, have 46 chromosomes in each body cell, turkeys have 82, fruit flies have 8, sea stars have 36, and potatoes have 48. Most bacteria have only a single chromosome, while some plants contain many hundreds of chromosomes in each cell. The adder's tongue fern has the largest known number—about 1200. Following cell division, the chromosomes unravel to their functional form and spread throughout the new nucleus. They are no longer visible without powerful magnification.

Composed of amino acids, proteins are found throughout an organism. Some proteins are common to all forms of life, while others are specific to an individual species. Proteins have many roles, both physical and chemical. For example, proteins that are enzymes have the vital function of catalyzing all cellular reactions. When a particular protein is needed, the portion of DNA (the gene) that codes for this protein is activated. The nucleotide sequence is copied (transcribed) into a molecule of RNA (ribonucleic acid). The RNA then moves to the cytosol, where its sequence is translated by the ribosomes into amino acid chains called polypeptides. Elsewhere in the cell, polypeptides are further modified to form functional proteins. The entire process of protein synthesis will be covered in depth in Chapter 7.

Heredity and DNA

Figure 1 Researchers still use Mendel's hand pollination techniques to crossbreed plants such as this strawberry.

Our understanding of genes and the role of DNA in inheritance started with the simple experiments of an Austrian monk, Gregor Mendel. He spent his spare time breeding the pea plant *Pisum sativum*. Mendel developed techniques to pollinate selected flowers with the pollen from other selected flowers (**Figure 1**). Over seven years in the late 1800s, he statistically analyzed the inherited characteristics of over 28 000 plants. His analysis clearly showed how certain traits were expressed in the next generation from each cross-pollination experiment. He proposed that factors for a given trait were passed from parent to offspring, although at the time, he had no idea of how this actually happened. Because of the work that Mendel began, we now know that a hereditary molecule does exist. Over the past 100 years, numerous experiments, using increasingly sophisticated methods, have revealed that DNA is the carrier of the hereditary information.

All new cells arise from the division of existing cells, and all the information that is needed for optimal cell functioning is coded in a cell's DNA. In eukaryotes, the DNA is stored in the nucleus. In prokaryotes, it is stored in the cytosol. Regardless of the location, all forms of life use DNA in the same way to build proteins and grow new cells. How the message in DNA is decoded to make proteins is central to the development of all life.

Genes and Chromosomes

During his experiments, Mendel proposed a "factor" for each specific trait that is inherited by an organism. All the inherited and measurable characteristics of an organism, including its size, colour, and markings, are the result of these factors being passed from parents to offspring and expressed in the new organism. Today, we know that these factors are derived from our genes. Genes are the coding regions of DNA, which contain the instructions for building the proteins that are responsible for each inherited trait (**Figure 2**). In fact, there are several versions of each gene, called alleles, that give a trait more than one potential physical appearance. For example, different alleles of a certain gene give rise to round eyes or almond-shaped eyes, which are just two of the many alleles for the eye-shape characteristic.

Genes are scattered along an organism's DNA strands and can vary greatly in length. Within a species, the gene for a particular characteristic is always found in the same location on a particular chromosome. As scientists continue to study the genetic makeup of a great variety of organisms, they are discovering that many fundamental genes (such as those that direct the development of an embryo or the building of cell membranes) are shared by almost every form of life.

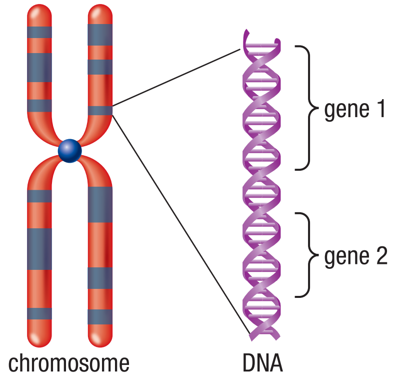

Figure 2 Genes make up the coding section of DNA. DNA strands are tightly coiled and compacted to form chromosomes, which are visible during cell division.

An enormous amount of information is stored in an organism's DNA, and it must fit inside every cell in the organism. Eukaryotes and prokaryotes handle this packing problem in different ways. In eukaryotes, the DNA is stored as chromosomes in the nucleus of each cell. In a eukaryotic chromosome, a DNA strand is wrapped around special proteins called **histones** to form a complex. Several of these complexes are bundled into coils to form thicker strands called chromatin fibres. This arrangement protects the DNA and reduces its volume so that it fits more easily into the nucleus. This DNA packing is discussed later, in Section 6.5. Eukaryotes also have very small amounts of DNA in their mitochondria and chloroplasts. The structure of this DNA is similar to the structure of the DNA found in prokaryotes.

histone a special protein molecule that is the core around which the DNA strand wraps

Archaea and bacteria do not have a membrane-bound nucleus, but they do have regions that are rich in DNA. Because these organisms are less complex, they contain less genetic material. Bacterial chromosomes are usually found in loops. The bacterial DNA is joined end to end to form one large ring. Smaller accessory loops of DNA, called **plasmids**, may also occur. Plasmids carry smaller amounts of genetic information—often only a few genes—and are sometimes copied and passed from one bacterium to another. The region of the cell that contains the looped DNA is called the nucleoid. Archaea also have circular chromosomes but, like eukaryotes, their DNA is associated with histone-like proteins. You will learn more about the organization of DNA in both eukaryotes and prokaryotes in Section 6.5.

plasmid a small circular section of DNA found in the cytosol of bacteria; replicates independently of the chromosomal DNA

The Genome

The entire complement of hereditary information that is contained in an organism is called its **genome**. The genome of a eukaryote is usually spread over many chromosomes, which often occur as pairs of homologous chromosomes. Each pair represents two copies of a particular set of genes. For example, humans have 23 homologous pairs of chromosomes of different sizes, two of which are special sex chromosomes (**Figure 3**). Each set of 23 chromosomes contains a total of more than 20 000 different genes, which are combined to form roughly 3 billion base pairs.

genome the complete set of an organism's hereditary information

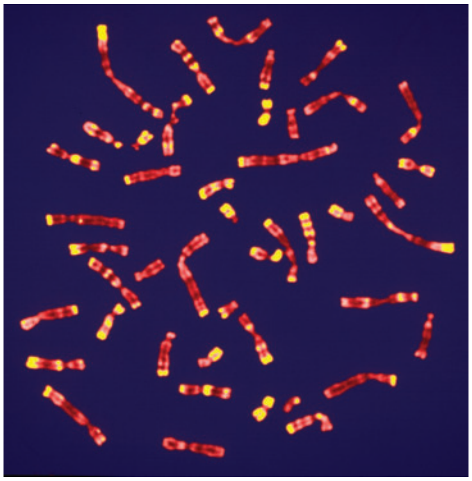

Figure 3 Micrograph of the human genome

Most eukaryotes are diploid (they have two sets of chromosomes), but there are many exceptions. Some large groups of species, such as bees, wasps, and ants, are haplodiploids. All the females are diploid, while all the males are haploid and contain only a single copy of each gene. Many plants are haploid, triploid, tetraploid, or even hexaploid. Different varieties of wheat, for example, have four or even six sets of chromosomes per cell.

6.1 Review

Summary

- DNA is the molecule that carries genetic information in all living things.
- A gene is a region of DNA that codes for the building of a particular polypeptide.
- Eukaryotic DNA is wound around histone proteins and organized into linear chromosomes. The chromosomes are found inside the nucleus of each cell.
- The genome of most eukaryotes is in the form of homologous sets of chromosomes in diploid organisms.
- Prokaryotic cells usually have a single chromosome, which is in the form of a loop of DNA and is not associated with histones. Most of the genome is stored in this chromosome, but smaller loops of DNA, called plasmids, may also be present.

Questions

1. Explain the difference between an allele and a gene. T/I
2. One base pair is about 3.3×10^{-10} m long. If the human genome contains roughly 3 billion base pairs, how long is our genome? T/I
3. Place the following terms in order of size, from smallest to largest: chromosome, genome, gene, nucleus. T/I
4. Differentiate between the following terms:
   (a) a factor (as described by Mendel) and an allele
   (b) a protein and a ribosome
   (c) DNA and a chromosome K/U
5. Create a concept map that includes the following terms: DNA, RNA, protein, nucleus, gene, allele. T/I C
6. Is there a difference between DNA in eukaryotes and DNA in prokaryotes? Explain. K/U
7. Species vary greatly in the number of chromosomes they possess. For example, the fruit fly has only eight chromosomes whereas the adder's tongue fern has about 1200 (**Figure 4**). Using online resources, find the number of chromosomes in three different species. T/I
   (a) What might the number of chromosomes suggest about the complexity of the organism?
   (b) Could a species with a small number of chromosomes have a larger genome, or more genes, than a species with a large number of chromosomes? Explain.

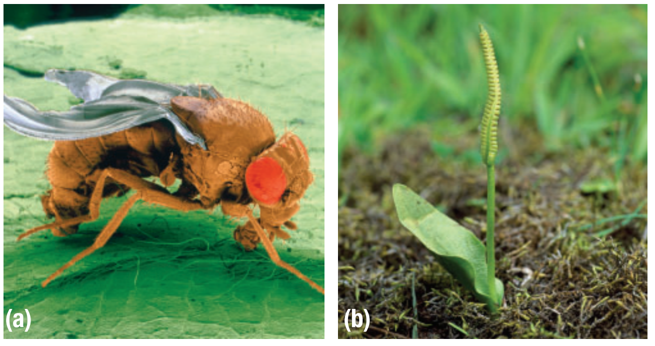

Figure 4 (a) fruit fly; (b) adder's tongue fern

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