Important points

- In their body cells, humans have 46 chromosomes, made up of 23 pairs. There are 44 chromosomes called *autosomes* that are numbered from 1 to 22 according to size from the smallest to the largest as well as the two sex chromosomes: X and Y
- Women's chromosomes are described as 46,XX; men's as 46,XY
- A mother passes 23 chromosomes to her child through her egg and a father passes 23 chromosomes through his sperm
- The chromosomes are made up of DNA
- Each chromosome consist of two very long thin strands of DNA chains twisted into the shape of a double helix and are located in the nucleus (the 'control centre') of our body cells
- The chromosomes can be thought of as long strings of genes
- Since the chromosomes in the cell's nucleus come in pairs, the genes in the nucleus also come in pairs
- Genes are also located in very small compartments called *mitochondria* that are randomly scattered in the cytoplasm of the cell outside the nucleus
- All of the DNA in the cell (in the nucleus and the mitochondria) make up the **genome**
  - Genes make up only about 1% of the genome
- Each of the approximate 20,000 genes in the cell contains a piece of genetic information which guides our growth, development and health.
  - The genetic information contained in the DNA is in the form of a chemical code, called the **genetic code**
- The DNA's genetic code is virtually identical across all living organisms and is like a recipe book for the body to make proteins and control how the genes work
- The DNA code is made up of very long chains of four chemical 'letters': Adenine (A), Guanine (G), Thymine (T) and Cytosine (C)
  - In the DNA information, each 'word' is a combination of three of these four chemical 'letters' A, G, C and T
  - Each three-letter word (*triplet*) tells the cell to produce a particular amino acid, the building blocks of proteins

    The sequence of three-letter words in the gene enables the cells to assemble the amino acids in the correct order to make up a protein
- We all have variations in the genetic code which is why we are all unique
- Most variations are harmless. However, variations to the genetic information can sometimes make the gene faulty which means that a particular protein is not produced properly, produced in the wrong amounts or not produced at all. Variations that make the gene faulty are called mutations.
  - Variations that make a gene faulty can result in a genetic condition, affecting our growth, development and how our bodies work
  - In other cases, the variation in the genetic code makes a person more susceptible to developing a genetic condition
- Different cell types, tissues and organs have specific roles and so produce specific proteins for that role. The genes that contain the information to make the necessary proteins are therefore 'switched on' in these cells while the remaining genes are 'switched off'
  - For example, the genes that are 'switched on' in liver cells are different to those that are 'switched on' in brain cells because the cells have different roles and make different proteins

Our (genetic) Book of Life

Our genetic information, sometimes described as the 'Book of Life', can be thought of as being made up of two volumes. Each volume of the book is contributed to a person by one of their parents (*Figures 1.1 & 1.2*).

For each of our '(genetic) Book of Life'

- One volume was inherited from your Mum and one from your Dad
- Both volumes contain 23 chapters each, equivalent to the 23 pairs of chromosomes present in your body cells that contain your genetic information (*Figure 1.1)*
- The 23 chapters (i.e. chromosomes) are made up of a different number of pages (i.e. genes)
- Some of the chapters contain many pages; others only a few. In your cells, some chromosomes contain many thousands of genes; others perhaps only a few thousand *Figure 1.2*)
- Careful examination of the words on the pages shows that all the words are made up of only three of the four possible letters (*triplets*): A, T, C & G. In your cells, these letters are the chemical components of DNA.

Just like we read the words on a page to understand what the author is telling us, the body reads the triplets of words in the DNA (our genetic information) to tell us to grow and develop and guide how our cells work in our bodies.

Also, we may read a book in different circumstances and similarly, our genetic information is 'read' by the cells in a background of our personal internal and external environments. This includes our diet, the chemicals that we are exposed to and the other genes in the cells.

Also, just as books get older and the pages become brittle or the words are harder to read, our genes are affected by the ageing process. It is important to remember however that our environment also plays a major role in how we develop and how our bodies work by interacting with the genetic information (see Genetics Fact Sheet 11).

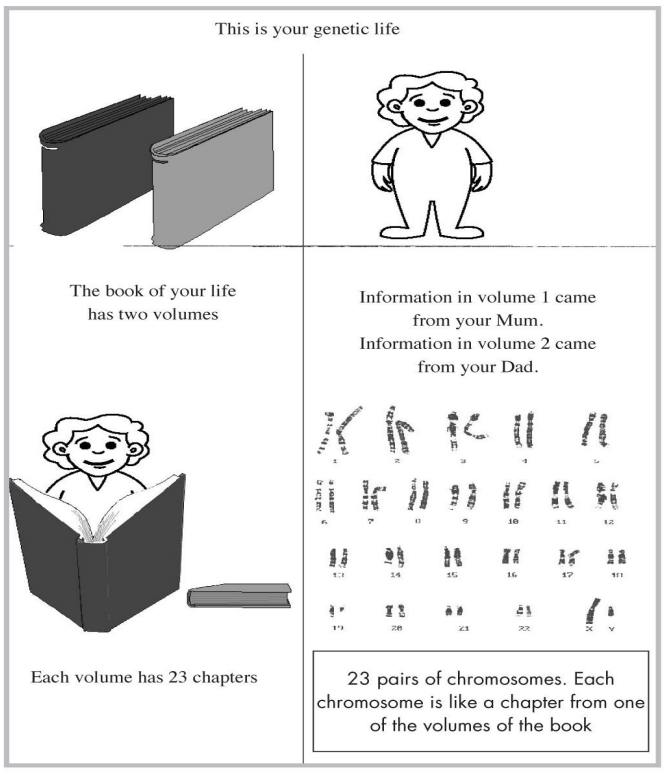

Figure 1.1: *Our (genetic) Book of Life—part 1*

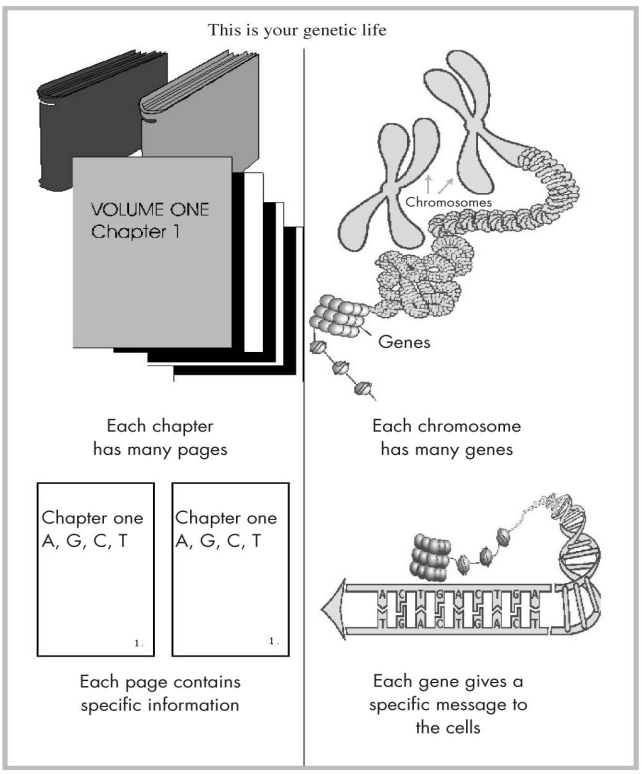

Figure 1.2: *Our (genetic) Book of Life—part 2*

Our genetic makeup in more detail

Our bodies are made up of millions of cells. Each cell contains a complete copy of a person's genetic plan or blueprint. This genetic plan is packaged in the cells in the form of genes.

Chromosomes can be thought of as being made up of strings of genes. The chromosomes, and therefore the genes, are made up of the chemical substance called DNA (**D**eoxyribo**N**ucleic **A**cid).

The chromosomes are very long thin strands of DNA, coiled up like a ball of string as shown in *Figure 1.3*.

The chromosomes containing the genes are located in the nucleus (or control centre) of our body cells *(Figure 1.4).* An exception is our red blood cells, which have no nucleus and so don't have any chromosomes.

Another place in the cell where DNA is found is in the cell in very small compartments called *mitochondria* that are found randomly scattered in the cytoplasm outside the nucleus (*Figure 1.4*).

The mitochondria are the energy centres of the cell.

- So mitochondria contain genes too, although the mitochondrial DNA is one long string of genes and is not arranged as chromosomes.
- The genes in bacterial DNA are also arranged in a long string, giving rise to the theory that the mitochondria originated from bacteria that invaded a human cell long ago in evolution. Further information on mitochondria can be found in Genetics Fact Sheet 12.

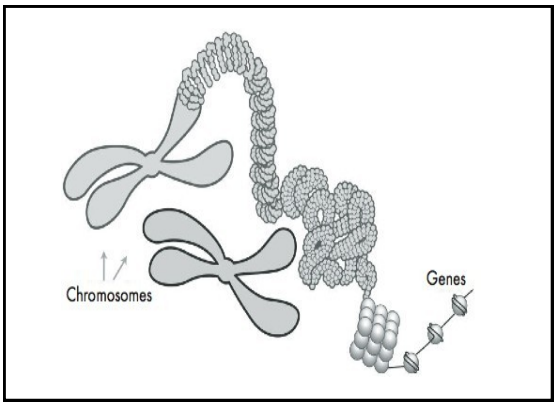

Figure 1.3: *Chromosomes are like strings of genes*

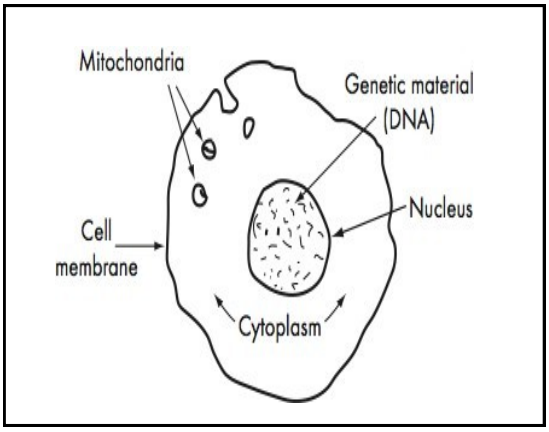

Figure 1.4: *Diagram of a human cell*

Our chromosomes

There are 46 chromosomes in the **nucleus** of our **body cells.**

- Of these, 23 came through our mother's egg and 23 came through our father's sperm.
- When the egg and the sperm join together at the time of conception (fertilised egg), the first cell of the baby is formed. This cell is copied to make all of the cells of the baby.
- The baby's body cells now have 46 chromosomes, made up of 23 pairs, just like the parents *(Figure 1.5).*

The genes in the **mitochondria** (*Figure 1.4*) are also important for the fertilised egg to divide and grow and for development to occur

- The vast majority of our mitochondria are in the egg from which we arise as the sperm contributes only a very small number of mitochondria to the fertilised egg.
- So the genetic information passed to a baby in the mitochondria largely comes from their mother only, while the genetic information in the nucleus comes from both their Mum and Dad.

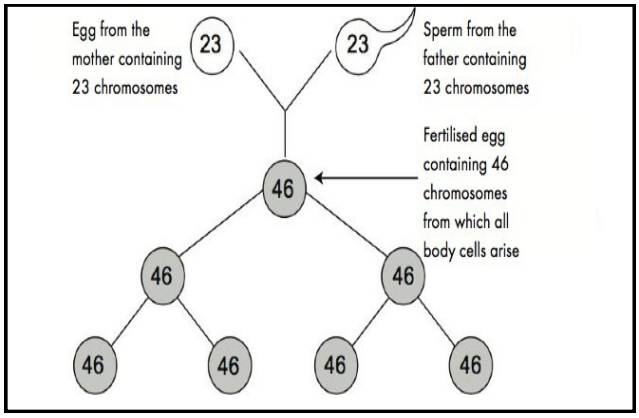

Figure 1.5: *At conception the sperm and egg combine*

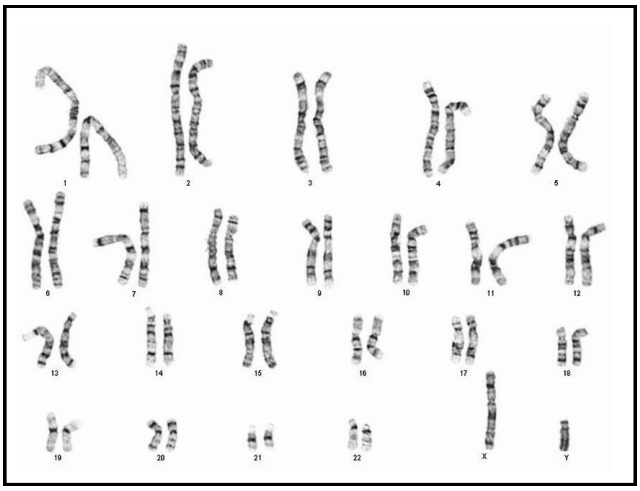

Figure 1.6: *Picture of chromosomes from a male as seen under a microscope and arranged in order of size (SEALS Genetics Prince of Wales Hospital, Randwick)*

As we age and grow, our cells are continually dividing to form new cells. During this division process, each of the long thin chromosomes coils up tightly, so that each of the 46 individual chromosomes in the nucleus become rod-shaped structures and can be seen when using a microscope *(Figure 1.6)*.

In the laboratory, the chromosomes are coloured (stained) with special dyes to produce distinctive banding patterns

- Each chromosome has been arranged in pairs and in order of size.
- At one point along their length, each chromosome has a constriction, called the *centromere.*
- The centromere divides the chromosomes into two 'arms': a long arm and a short arm.

Scientists have numbered the chromosomes from the largest (chromosome number 1) to the smallest (chromosome number 22): these numbered paired chromosomes are called ***autosomes***. *Figure 1.7* shows a drawing of one of these autosomes (chromosome number 7), illustrating its characteristic banding pattern and the centromere.

There are also two chromosomes that have been given the letters X and Y: these are the ***sex chromosomes***. The X chromosome is much larger than the Y chromosome.

Women have

- 46 chromosomes (44 autosomes plus two copies of the X chromosome) in their body cells and are described as 46,XX.
- 23 chromosomes (22 autosomes plus an X chromosome) in their egg cells.

Men have

- 46 chromosomes (44 autosomes plus an X and a Y chromosome) in their body cells and are described as 46,XY.
- 23 chromosomes (22 autosomes plus an X or Y chromosome) in their sperm cells.

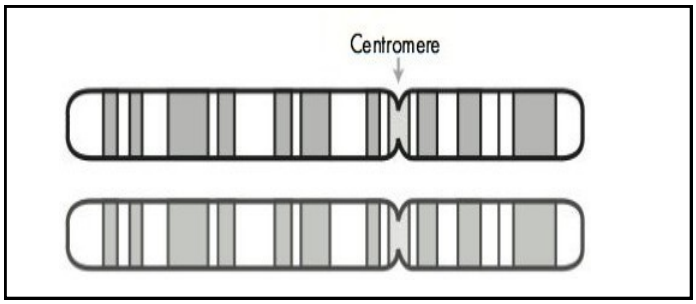

Figure 1.7: *The chromosome 7 pair showing the banding pattern*

Our genes

The DNA making up each chromosome is usually coiled up tightly. If we imagine it stretched out, it would look like beads on a string (*Figure 1.2*).

- Each of these beads is called a ***gene***
- Each gene is a piece of genetic information
- Thousands of genes make up each chromosome

Since the chromosomes come in pairs, there are two copies of the genes. The exception to this rule applies to the genes carried on the sex chromosomes: the X and Y.

- Since men have only one copy of the X chromosome, they have only one copy of all the genes carried on the X chromosome.
- Women have two copies of the X chromosome in their cells and so they have two copies of the genes carried on the X chromosome.
- So that men and women have the same number of X chromosome genes that are that are 'switched on' or active in their cells, in women one of the X chromosomes is 'switched off' or inactivated. process in more detail.
- The genes on the Y chromosome are responsible mainly for the development of 'maleness' only.

The human genome

All the DNA in the cell makes up for the ***human genome***.

There are about 20,000 genes located on one of the 23 chromosome pairs found in the nucleus or on long strands of DNA located in the mitochondria. The DNA in the genes make up only about 1% of the genome.

In recent years, knowledge about the location of each gene and the sequence of 'letters' it contains has been accumulating and is stored in a database that is publicly accessible. To date, about 12,800 genes have been mapped to specific locations (loci) on each of the chromosomes.

This information was initiated by the work done as part of the Human Genome Project (see Genetics Fact Sheet 24). Although the project's completion was celebrated in April 2003, and understanding how the letters are arranged in the genes (sequencing) is essentially finished, the exact number of genes in our genome is still unknown. Moreover, it will still take many years to find out what the information in all our genes tells our cells to do, and understanding how the non-coding DNA and the environment regulates the gene expression (epigenetics – see Genetics Fact Sheets 14 & 15).

The genetic Code

Each gene has its own specific location on the chromosome or on the mitochondrial DNA and is a piece of the genetic material that does one particular job.

All of the 20,000 or so genes contain a different `packet' of information necessary for our bodies to grow and work. Our genes also contain the information for how we look: the colour of our eyes, how tall we are, the shape of our nose, etc.

The genetic information is in the form of a chemical (DNA) code (the ***genetic code***) (see Genetics Fact Sheet 4).

- The DNA code is made up of very long chains of four basic building blocks (*nucleotide bases*): **A**denine (A) and **G**uanine (G), and **T**hymine (T) and **C**ytosine (C).
- A chromosome consists of two of these DNA chains running in opposite directions; the bases pair up to form the rungs of a ladder twisted into the now famous double helix *(Figures 1.8 & 1.9.)*
- Pairing of the bases follows strict rules: base A can only pair with base T, and vice versa; and base G can only pair with base C, and vice versa. Roughly three billion of these base pairs of DNA make up the human genome.
- In the DNA information, each 'word' is a combination of three of these four chemical 'letters' A, G, C and T (a triplet)

In summary, genes can be defined as segments of DNA that issue chemically coded 'messages' to the cells to make a product (protein) that the cells can use.

There may be hundreds, or even thousands, of three-letter words in the information in a gene coding for a particular protein *(Figure 1.8)*.

- So the DNA that makes up the genes is often called '***coding DNA***'.

The DNA 'string' between each of the genes in a chromosome is often called '***non-coding DNA'***. It was originally referred to as 'junk DNA' as it appeared that this DNA did not contain the information for gene products that the cells use and produce.

- It is increasingly clear that the non-coding DNA has a very important role to play.
- That role is still largely unknown but is likely to include regulating which genes are 'switched on' or 'switched off' in each cell.
- Studies of this non-coding DNA are useful for forensic investigations and determining biological relationships (see Genetics Fact Sheet 22).

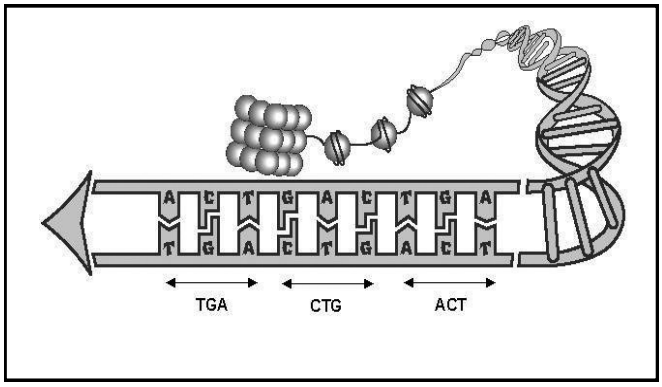

Figure 1.8: *The information in the genes*

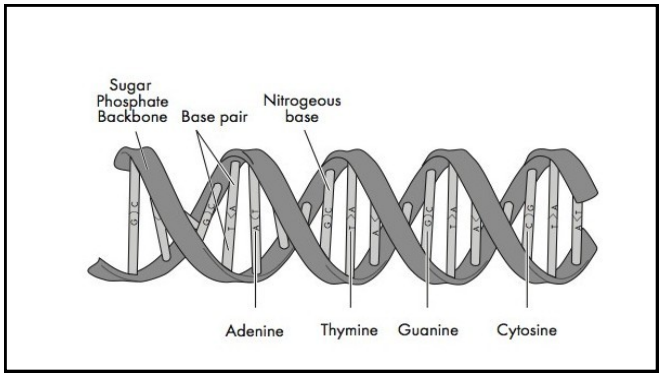

Figure 1.9: *The DNA helix*

Variations in our genetic code

We all have small variations in our genetic code. That is why we are all unique. Even identical twins have some variations in their DNA by the time they are born. Because we inherit our genes from our parents, members of the same family share their DNA, and its variations.

There may be a variation in the sequence of letters in the message, a deletion or insertion of individual letters into the code or the deletion or insertion of one or more whole words within the message. Even a deletion of the whole gene can occur.

Variations in the code can occur during our life for a variety of reasons including exposure to radiation or certain chemicals. However, ageing is one of the most common causes of genetic variation. As our body's age, our cells need to be continually replaced: the cells (and their genetic make-up) are copied over and over again as time goes by. Sometimes mistakes occur in this copying process, and variations in the genes build up in our cells.

Some variations in the genetic information do not seem to make any difference to the way the message is read or the protein that is produced by the cell. These types of variations in genes are quite common.

Other gene variants can sometimes be associated with an increased susceptibility to a genetic condition, for example, schizophrenia (see Genetics Fact Sheet 58).

Some gene variants mean make the gene faulty so that the message is not read correctly or is not read at all. A variation in a gene that makes it faulty is called a ***mutation*****.** A faulty (mutated) gene may cause a problem with the development and functioning of different body systems or organs and result in a genetic condition (see Genetics Fact Sheets 2, 4 & 5).

We are all born with several faulty gene copies that usually cause no problem

We have two copies of each gene. If one of the gene copies is faulty (mutated), and the other copy is working as it should, 'carrying' the faulty gene copy may not cause any problem. We are all born with several faulty gene copies. Indeed having a faulty gene copy can be beneficial as discussed in Genetics Fact Sheet 5.

When faulty gene copies are contained in the egg or sperm cells, they can be passed on to children (inherited). The faulty gene copy may be in these cells because that person inherited it from one or both parents.

However, sometimes a variation in a gene copy that makes the gene faulty can occur for unknown reasons in an egg or sperm cell. This is called a *de novo* mutation. The person arising from that egg or sperm cell will be the first in the family to have the mutation which may then be passed down to his or her children and future generations. Inheriting a faulty gene copy may or may not cause a genetic condition. Genetics Fact Sheets 8, 9, 10 & 11 discuss the patterns of inheritance of these faulty genes in more detail. Fact sheets 4 & 5 discuss changes to the genetic code in more detail.

Genes contain recipes for the body to make proteins - the Book of Life is like a recipe book for our bodies!

The DNA message in the genes is like a recipe for an essential component of the body, such as a protein. Chains of the protein building blocks (*amino acids)* form structures known as *polypeptides*.

- Sometimes proteins are made up of a number of different polypeptides.
- That can mean that a number of different genes are concerned with coding for that protein.

The (genetic) Book of Life is made up of recipes for proteins - it is like a recipe book for our bodies. In this Book, each three-letter word (triplet) tells the cell to produce a particular amino acid; other words tell the cell to start or stop reading the message.

- The sequence of three-letter words in the gene enables the cells to assemble the amino acids in the correct order to make up the protein or polypeptide.
- The genetic code for each amino acid is virtually identical across all living organisms.
- When the information in a gene is to be 'read' because the cell needs to make a particular protein, the DNA making up the gene unwinds and the message is 'translated' into a chain of amino acids.
- When the whole message has been translated, the long chain of amino acids folds itself up into a distinctive shape that depends upon its sequence, and is now known as a 'protein'.

Some of the proteins form building blocks for structures within the cells such as the protein called *keratin*, from which hair is made; others are called enzymes which help carry out chemical reactions, such as digesting food. Others form communication networks within and between cells.

- Each gene message can be 'read' by the cell in a number of different ways.
- Each gene can provide a message to the cell to make two or three different proteins.
- That is why the number of proteins known to exist in the cells is more than the number of genes.

Not all our genes are 'switched on' all the time

Our bodies have many different types of cells such as those in the skin, muscle, liver and brain.

- While all of these different types of cells contain the same genes, each cell requires particular proteins to function correctly.
- Therefore, different genes are active in different cell types, tissues and organs, producing the necessary specific proteins.
- Not all the genes in the cell are 'switched on' (active) in every cell.

For example, the genes that are active in a liver cell are different from the genes that are active in a brain cell. This is because these cells have different functions and therefore require different genes to be active.

Some genes are only switched on during the development of the baby. After birth they are no longer needed to be active as their 'job' has been completed.

Other Genetics Fact Sheets referred to in this Fact Sheet: 2, 4, 5, 8, 9, 10, 11, 12, 14, 15, 22, 24, 58