An introduction to

Human Embryology

for Medical Students

Inderbir Singh

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HUMAN EMBRYOLOGY

for Medical Students

International Edition

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Preface

This book on human embryology has been written keeping in mind the requirements of undergraduate medical students. The subject of embryology has traditionally been studied from imported textbooks of anatomy or of embryology. Experience has shown that the treatment of the subject in most of these books is well above the head of the average medical student in India. The difficulty has increased from year to year as there has been, and continues to be, progressive deterioration in the standards of the teaching of English in our schools and colleges. The combination of unfamiliar sophistications of language and of an involved technical subject, has very often left the student bewildered.

In this book care has been taken to ensure that the text provides all the information necessary for an intelligent understanding of the essential features of the development of various organs and tissues of the human body. At the same time, several innovations have been used to make the subject easy to understand.

Firstly, the language has been kept simple. Care has been taken not to compress too many facts into an involved sentence. New words are clearly explained.

Secondly, simultaneous references to the development of more than one structure have been avoided as far as possible. While this has necessitated some repetition, it is hoped that this has removed one of the greatest factors leading to confusion in the study of this subject.

Thirdly, almost every step in development has been shown in a simple, easy to understand, illustration. To avoid confusion, only structures relevant to the discussion are shown. As far as possible, the drawings have been oriented as in adult anatomy to facilitate comprehension.

Fourthly, the chapters have been arranged so that all structures referred to at a particular stage have already been adequately introduced.

In an effort of this kind it is inevitable that some errors of omission, and of commission, are liable to creep in. To obviate as many of these as possible a number of eminent anatomists were requested to read through the text (see Acknowledgements). Their suggestions have greatly added to the accuracy and usefulness of this book. Nevertheless, scope for further improvement remains, and the author would welcome suggestions to this end both from teachers and from students.

Rohtak
January 1976

INDERBIR SINGH

Acknowledgements

It is a pleasure to acknowledge with gratitude the help which I have received in the preparation of this book from many persons.

My former teacher, Prof. Indarjit Dewan (Chandigarh), has very kindly read through the text with characteristic attention to detail, and has brought to light many errors. His suggestions have greatly added to the accuracy of the book.

Prof. H S Sohal (Bikaner) agreed, in spite of frail health, to my request that he read through the manuscript. He offered many useful suggestions and materially improved upon punctuation and spellings.

My good friend Prof. V M Charnalia (New Delhi) also spared no pains while going through the manuscript. His suggestions have helped to make the text much more modern than it might otherwise have been.

Prof. S S Makhni (Patiala) has also offered numerous very useful suggestions in the light of his long and mature experience as a teacher.

I owe a very special debt of gratitude to Prof. N H Keswani (New Delhi) for his very kind encouragement and invaluable help.

Dr. S C Srivastava (Professor of Medicine, Rohtak) has read the section on the cardiovascular system, while Dr. P S Maini (Professor of Orthopaedic surgery, Rohtak) has read the section on the skeleton. They have made many valuable suggestions for improvement.

I would be failing in my duty if I do not thank my colleagues in the Department of Anatomy at Rohtak for their understanding help and suggestions. Dr. B S Pande, Dr. Usha Dhall and Dr. Maya Rathee have read through the manuscript and have offered very useful suggestions. I also wish to thank Mr. Harcharan Singh, Mr. V P Grover and Mr. Jagjit Singh Chowdhary of this department for their kind help.

I am highly indebted to Prof. W H Hollinshead and to Harper and Row for very kindly permitting me to reproduce a number of figures from *Anatomy for Surgeons.* These appear as Figs. 13.30, 14.16, 14.47, 16.9, 16.16 and 18.4 of this book.

I am equally grateful to Prof. W J Hamilton for permission to reproduce Figs. 12.7, 16.31, 18.3 and 21.8 from *Human Embryology* (Heffer, Cambridge).

The costs of publication of a book of this kind have risen very sharply in recent years, and this book would perhaps not have seen the light of day but for the generous help of the National Book Trust. The Trust has also offered many useful suggestions for the improvement of the book.

Contents

CHAPTER 1

Introduction

WHAT IS EMBRYOLOGY?

Every individual spends the first nine months of its life within the womb (uterus) of its mother. During this period it develops from a small one-celled structure to an organism having billions of cells. Numerous tissues and organs are formed and come to function in perfect harmony. The most spectacular of these changes occur in the first two months; the unborn baby acquires its main organs and just begins to be recognizable as human. During these two months we call the developing individual an *embryo*. From the third month until birth we call it a *foetus*.

Embryology is the study of the formation and development of the embryo (or foetus) from the moment of its inception upto the time when it is born as an infant. This subject tells us how the organs of the body develop. This knowledge in turn helps us to acquire a rational understanding of many facts of adult anatomy. Embryology also helps us to understand why some children are born with organs that are abnormal. Appreciation of the factors responsible for maldevelopment helps us to prevent, or treat, such abnormalities.

SUBDIVISIONS OF EMBRYOLOGY

The first step in the study of embryology is to obtain embryos and foetuses of various ages. The larger foetuses can be studied by dissection. Smaller foetuses and embryos are cut up into very thin slices, or sections, using a special machine called a microtome. These sections are studied under a microscope. In this way we come to know the structure of any particular organ at various stages of its development. Such studies constitute what is called *descriptive embryology*. Quite often the development of an organ becomes more clear if we study it in embryos of different animals, as certain stages of development are more clearly seen in some species than in others. Studies in more than one species are spoken of as *comparative embryology*.

Studies of descriptive embryology in man, and in other species, have taught us a great deal. However, it will be realised that in these studies we do not see the changes actually taking place. It is like seeing a series of 'stills' from a movie film. Further, these studies tell us nothing about the factors that cause or influence the changes we observe. Information of this kind can sometimes be obtained from experiments on living embryos of lower animals, like amphibians or chicks. Such studies are spoken of as *experimental embryology*.

The first few weeks of human development are concerned with preliminary

processes that are essential before the formation of individual organ systems can take place. Apart from the embryo itself, this period also sees the development of several accessory structures that protect the embryo and provide it with nutrition. The study of this phase of development is referred to as *general embryology*, while the study of the development of particular organs and organ systems is spoken of as *systemic* (or special) *embryology*.

For a proper understanding of general embryology a knowledge of cell structure, cell division, and the anatomy and histology of the male and female genital tracts, is essential. Similarly, a rational understanding of special embryology is possible only after the anatomy and histology of the region have been studied. The student will, therefore, do well to refresh his knowledge of these subjects before studying the relevant chapters.

CHAPTER 2

Germ Cells

Although the human body contains many millions of cells, a relatively small number carry out the special function of reproduction. These cells are located in the sex organs or *gonads*. The male gonad is the testis (plural = testes) and the female gonad is the ovary. The gonads produce highly specialized *germ cells*. The male germ cells are called spermatozoa (singular = spermatozoon) and the female germ cells are called ova (singular = ovum). The development of a new individual begins at the moment when one spermatozoon meets and fuses with one ovum. This process of fusion is called *fertilization*. The fused ovum and spermatozoon form the *zygote* (Fig. 2.1).

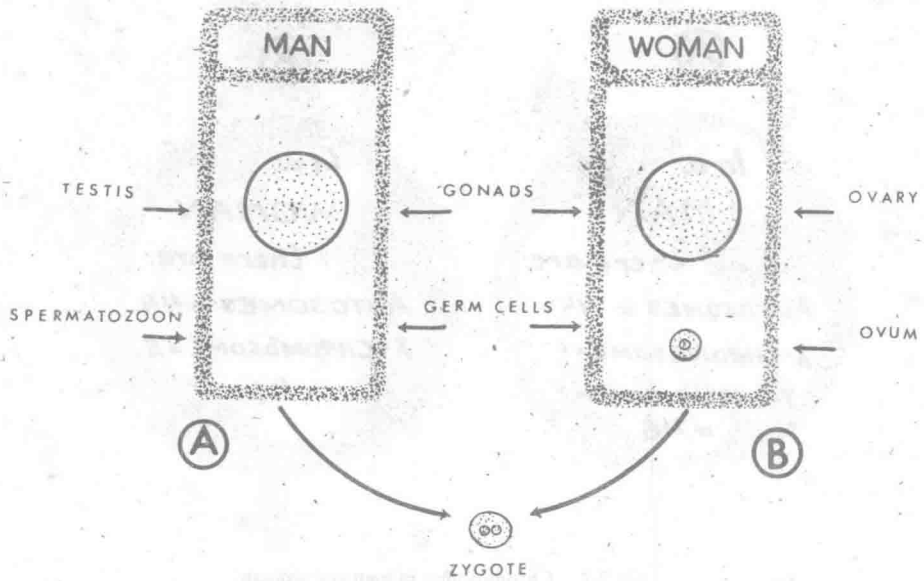

Fig. 2.1 Gonads and germ cells of man and woman.

The formation of spermatozoa in the testis is called *spermatogenesis*. The formation of ova in the ovary is called *oogenesis*. The two are collectively referred to as *gametogenesis*. Note that all these words end in 'genesis' which may be translated as 'formation of'. Thus 'formation of spermatozoa' is spermatogenesis. Later we will come across many other such words; e.g., formation of an organ is called 'organogenesis' while formation of the histological structure of a tissue or organ is referred to as 'histogenesis'.

HAPLOID AND DIPLOID CHROMOSOMES

When any cell is dividing, thread like structures called chromosomes can be seen in the nucleus. The number of chromosomes is fixed for a given species, and in man it is forty six. However, in a germ cell—spermatozoon or ovum—the number of chromosomes is only half that in other cells i.e., twenty three. The number of chromosomes in a germ cell is called the haploid (or half) number, whereas the number in other cells is called the diploid (or double) number.

AUTOSOMES AND SEX CHROMOSOMES

The 46 chromosomes in each cell can again be divided into 44 *autosomes* and two sex chromosomes. The sex chromosomes may be of two kinds—X or Y. In a man there are 44 autosomes, one X-chromosome and one Y-chromosome; while in a woman there are 44 autosomes and two X-chromosomes in each cell (Fig. 2.2).

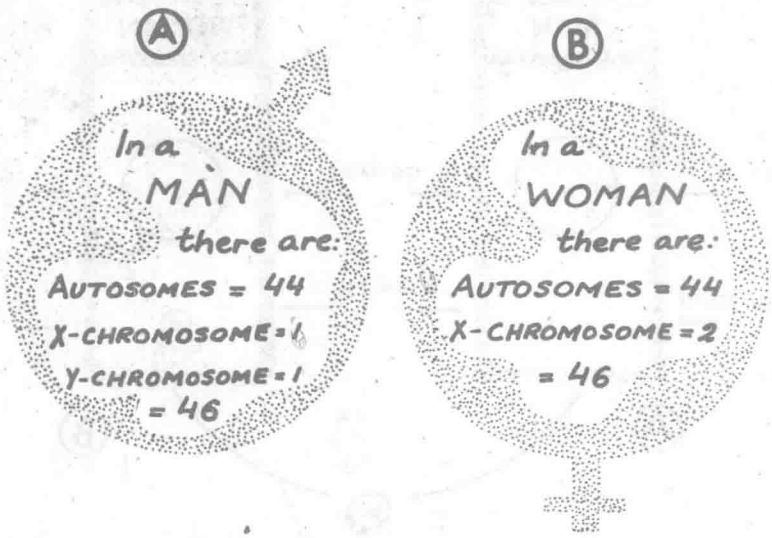

Fig. 2.2 Chromosomes in man and woman.

When we study the 44 autosomes, we find that they really consist of 22 pairs, the two chromosomes forming a pair being exactly alike. In a woman the two X-chromosomes form another such pair; in a man this pair is represented by one X- and one Y-chromosome. The X- and Y-chromosomes are dissimilar and, therefore, do not form a pair.

HOW A CONSTANT CHROMOSOME NUMBER IS MAINTAINED

One of the most important qualities of chromosomes is that they are able to duplicate themselves i.e., each chromosome can give rise to another one

exactly like it (See p. 11). During the process of cell division each of the 46 chromosomes duplicates itself so that the cell now has two sets of 46 chromosomes. As division proceeds, one set of chromosomes goes to each daughter cell. In this way the chromosomes in each daughter cell come to be exactly the same as they were in the mother cell. This kind of cell division is called *mitosis* (Fig. 2.3).

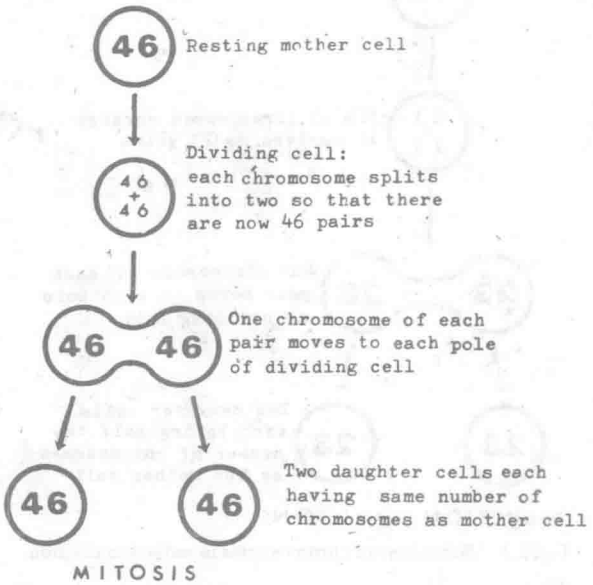

Fig. 2.3 Behaviour of chromosomes in mitosis.

BEHAVIOUR OF CHROMOSOMES IN GAMETOGENESIS

During gametogenesis, we have a special kind of cell division called *reduction division* (also called the *first meiotic division*). In this process the chromosomes do not duplicate themselves. We have seen that the 46 chromosomes in a cell really consist of 23 pairs. During reduction division, one chromosome of each pair goes to each daughter cell. Thus each of the daughter cells resulting from such a division has only 23 chromosomes (haploid number) (Fig. 2.4).

Each of these daughter cells again divides into two *(second meiotic division)*, but this time there is no further reduction in chromosome number, so that each of the resulting cells again has 23 chromosomes. Ova and spermatozoa are formed from these cells, and hence they also contain 23 chromosomes each.

SIGNIFICANCE OF CHROMOSOMES

The entire human body develops from one cell, the fertilized ovum. It is, therefore, obvious that the fertilized ovum contains all the information necessary for formation of the numerous tissues and organs of the body, and

for their orderly assembly and function. Each cell of the body inherits from the ovum, all the directions that are necessary for it to carry out its functions throughout life. This tremendous volume of information is stored within the chromosomes of each cell. Each chromosome bears on itself a very large number of structures called genes, that are regarded as the units, which guide

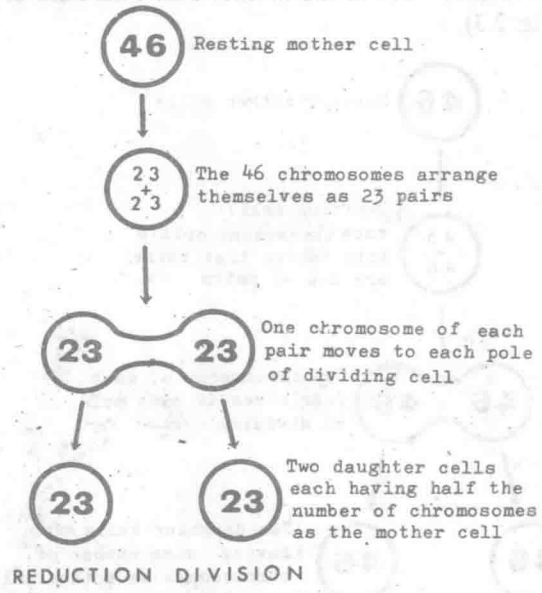

Fig. 2.4 Behaviour of chromosomes in reduction division.

the performance of particular cellular functions, which may in turn lead to the development of particular features of a species or of an individual. Recent researches have told us a great deal about the way in which chromosomes and genes store and use information.

The nature and functions of a cell depend on the proteins synthesized by it. Proteins are the most important constituents of our body. They make up the greater part of each cell and of intercellular substances. Enzymes, hormones and antibodies are also proteins. It is, therefore, not surprising that one cell differs from another because of the differences in the proteins that constitute it. Individuals and species also owe their distinctive characters to their proteins. We now know that chromosomes control the development and functioning of cells, by determining what types of proteins will be synthesized within them.

Chromosomes are made up predominantly of a nucleic acid called *deoxyribonucleic acid (or DNA),* and all information is stored in molecules of this substance. When the need arises this information is used to direct the activities of the cell by synthesizing appropriate proteins. To understand how this becomes possible we must consider the structure of DNA in some detail.

STRUCTURE OF DNA

DNA in a chromosome is in the form of very fine fibres. If we look at one such

fibre it has the appearance shown in Fig. 2.5. It is seen that each fibre consists of two parallel strands that are together twisted spirally to form what is called a *double helix*. The two strands are linked to each other at regular intervals.

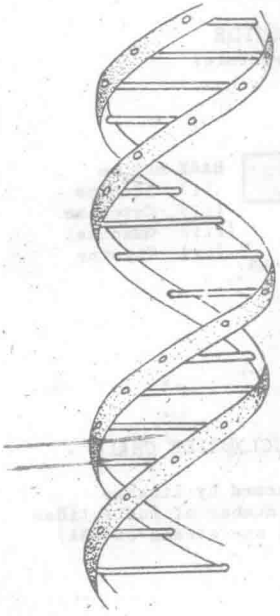

Fig. 2.5 Diagram showing part of a DNA molecule arranged in the form of a double helix. The two strands are united together at regular intervals.

Each strand of the DNA fibre consists of a chain of *nucleotides*. Each nucleotide consists of a sugar, deoxyribose, a molecule of phosphate and a base (Fig. 2.6A). The phosphate of one nucleotide is linked to the sugar of the next nucleotide (Fig. 2.6B). The base which is attached to the sugar molecule may be adenine, guanine, cytosine or thymine. The two strands of a DNA fibre are joined together by the linkage of a base on one strand with a base on the opposite strand (Fig. 2.6 C). This linkage is peculiar in that adenine on one strand is always linked to thymine on the other strand, while cytosine is always linked to guanine. Thus the two strands are complementary and the arrangement of bases on one strand can be predicted from the other.

The order in which these four bases are arranged along the length of a strand of DNA determines the nature of the proteins that can be synthesized under its influence. Every protein is made up of a series of amino acids; the nature of the protein, depending upon the amino acids present, and the sequence in which they are arranged. Amino acids may be obtained from food or may be synthesized within the cell. Under the influence of DNA these amino acids are linked together in a particular sequence to form proteins.

RIBONUCLEIC ACID

In addition to DNA, cells contain another important nucleic acid called *ribonucleic acid* or RNA. The structure of a molecule of RNA corresponds

fairly closely to that of one strand of a DNA molecule, with the following important differences:

(i) RNA contains the sugar ribose instead of deoxyribose.
(ii) Instead of the base thymine it contains uracil.

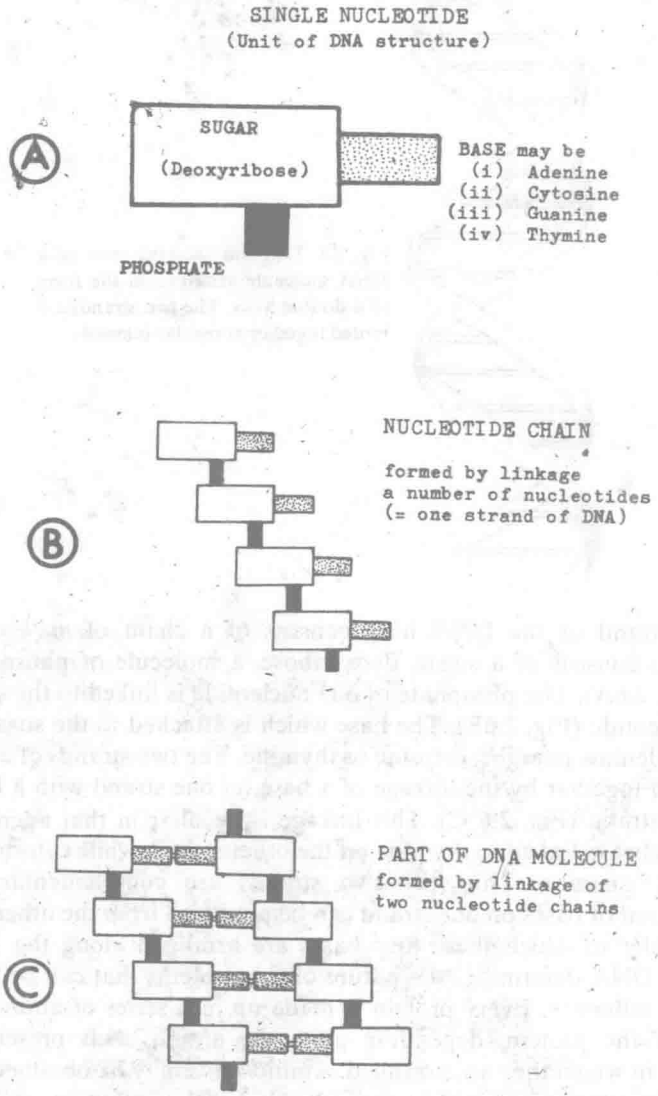

Fig. 2.6 (A) Composition of a nucleotide (B) Linkage of nucleotides to form one strand of a DNA molecule (C) Linkage of two chains of nucleotides to form part of a DNA molecule.

RNA is present both in the nucleus and in the cytoplasm of a cell. It is present in three distinct forms namely, *messenger RNA* (mRNA), *transfer RNA* (tRNA) and *ribosomal RNA*. Messenger RNA acts as an intermediary between

the DNA of the chromosome and the amino acids in the cytoplasm and plays a vital role in the synthesis of proteins from amino acids.

HOW PROTEIN IS SYNTHESIZED

We have seen that a protein is made up of amino acids that are linked together in a definite sequence. This sequence is determined by the order in which the bases are arranged in a strand of DNA. Each amino acid is represented in the DNA molecule by a sequence of three bases (triplet code). It has been mentioned earlier that there are four bases in all in DNA, namely adenine, cytosine, thymine and guanine. These are like letters in a word. They can be arranged in various combinations so that as many as sixty-four code words can be formed from these four bases. There are only about twenty amino acids that have to be coded so that each amino acid often has more than one code. The code words for some amino acids are shown in Fig. 2.7. The code for a complete polypeptide chain is formed when the codes for its constituent amino

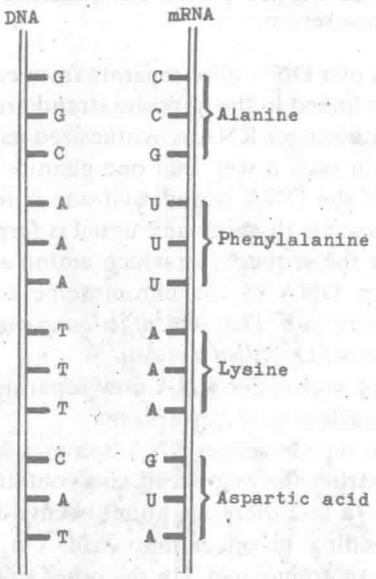

Fig. 2.7 Code words for some amino acids made up of the bases adenine(A), cytosine(C), guanine(G), and thymine(T) on a DNA molecule. When this code is transferred to messenger RNA, cytosine is formed opposite guanine (and vice versa), adenine is formed opposite thymine, while uracil(U) is formed opposite adenine.

acids are arranged in proper sequence. That part of a DNA molecule that bears the code for a complete polypeptide chain constitutes a *structural gene* or *cistron.*

At this stage it must be emphasized that each chromosome is a long structure containing a very large number of DNA molecules. Only a few of these molecules may be involved in protein synthesis at a particular time (See Chapter 21).

The steps in the synthesis of a protein may now be summarized as follows (See Fig. 2.8).

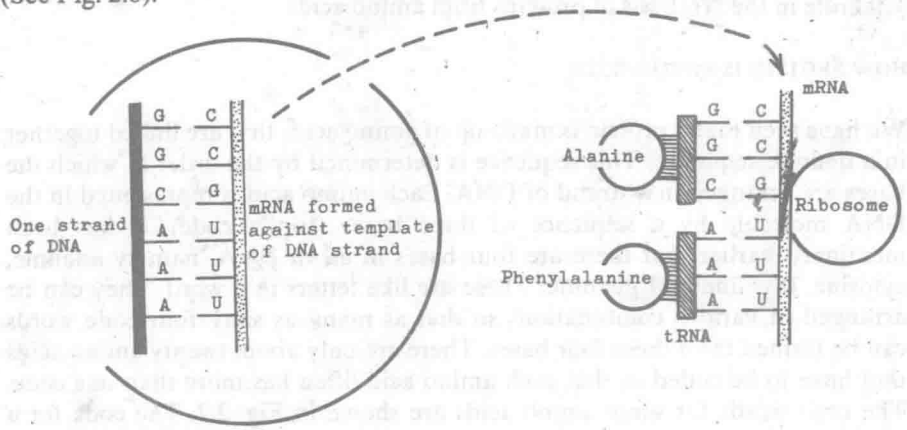

Fig. 2.8 Scheme showing how proteins are synthesized under the influence of DNA. For explanation see text.

1. The two strands of a DNA fibre separate from each other so that the ends of the bases that were linked to the opposite strand are now free.

2. A molecule of messenger RNA is synthesized using one DNA strand as a guide (or template), in such a way that one guanine base is formed opposite each cytosine base of the DNA strand, cytosine is formed opposite guanine, adenine is formed opposite thymine and uracil is formed opposite adenine. In this way the code for the sequence in which amino acids are to be linked has been passed on from DNA of the chromosome to messenger RNA. This process is called *transcription. That part of the messenger RNA strand that bears the code for one amino acid is called a codon.*

3. This molecule of messenger RNA now separates from the DNA strand and moves from the nucleus to the cytoplasm.

4. In the cytoplasm the messenger RNA becomes attached to a ribosome.

5. As mentioned earlier the cytoplasm also contains another form of RNA called transfer RNA. In fact there are about twenty different types of transfer RNA each corresponding to one amino acid. On one side transfer RNA becomes attached to an amino acid. On the other side it bears a code of three bases (anticodon) that are complementary to the bases coding for its amino acid on messenger RNA. Under the influence of the ribosome several units of transfer RNA, along with their amino acids become arranged alongside the strand of messenger RNA in the sequence determined by the code on messenger RNA. This process is called *translation.*

6. The amino acids now become linked to each other to form a polypeptide chain. From the above it will be clear that the amino acids have been linked up exactly in the order in which their codes were arranged on messenger RNA, which in turn was an exact replica of the code on the DNA molecule. Proteins are formed by union of polypetide chains.

DUPLICATION OF CHROMOSOMES

It was stated in an earlier section that one of the most remarkable properties of chromosomes is that they are able to duplicate themselves. From the foregoing discussion on the structure of chromosomes it is clear that duplication of chromosomes involves the duplication of DNA. This takes place as follows (Fig. 2.9):

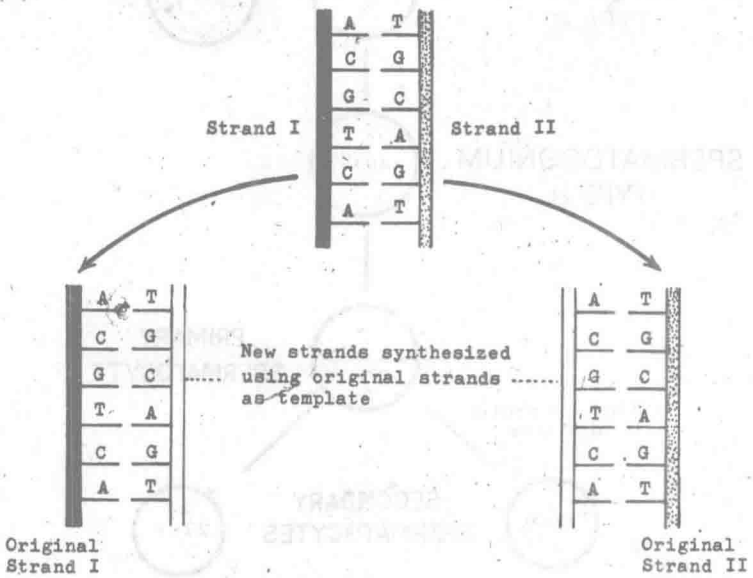

Fig. 2.9 Scheme showing how a DNA molecule is duplicated.

1. The two strands of the DNA molecule to be duplicated unwind and separate from each other so that their bases are free.

2. A new strand is now synthesized opposite each original strand of DNA in such a way that adenine is formed opposite thymine, guanine is formed opposite cytosine, and vice versa. This new strand becomes linked to the original strand of DNA to form a new molecule. As the same process has taken place in relation to each of the two original strands we now have two complete molecules of DNA. It will be noted that each molecule has one strand that belonged to the original molecule and one strand that is new. It will also be noted that the two molecules formed are absolutely alike to each other and to the original molecule.

The importance of the process of protein synthesis in relation to developmental processes is discussed in Chapter 21.

SPERMATOGENESIS

Spermatozoa are formed in the wall of the seminiferous tubules of the testes. If we look at one of these tubules under a microscope, we find that there are many cells of different sizes and shapes. Most of these represent stages in the