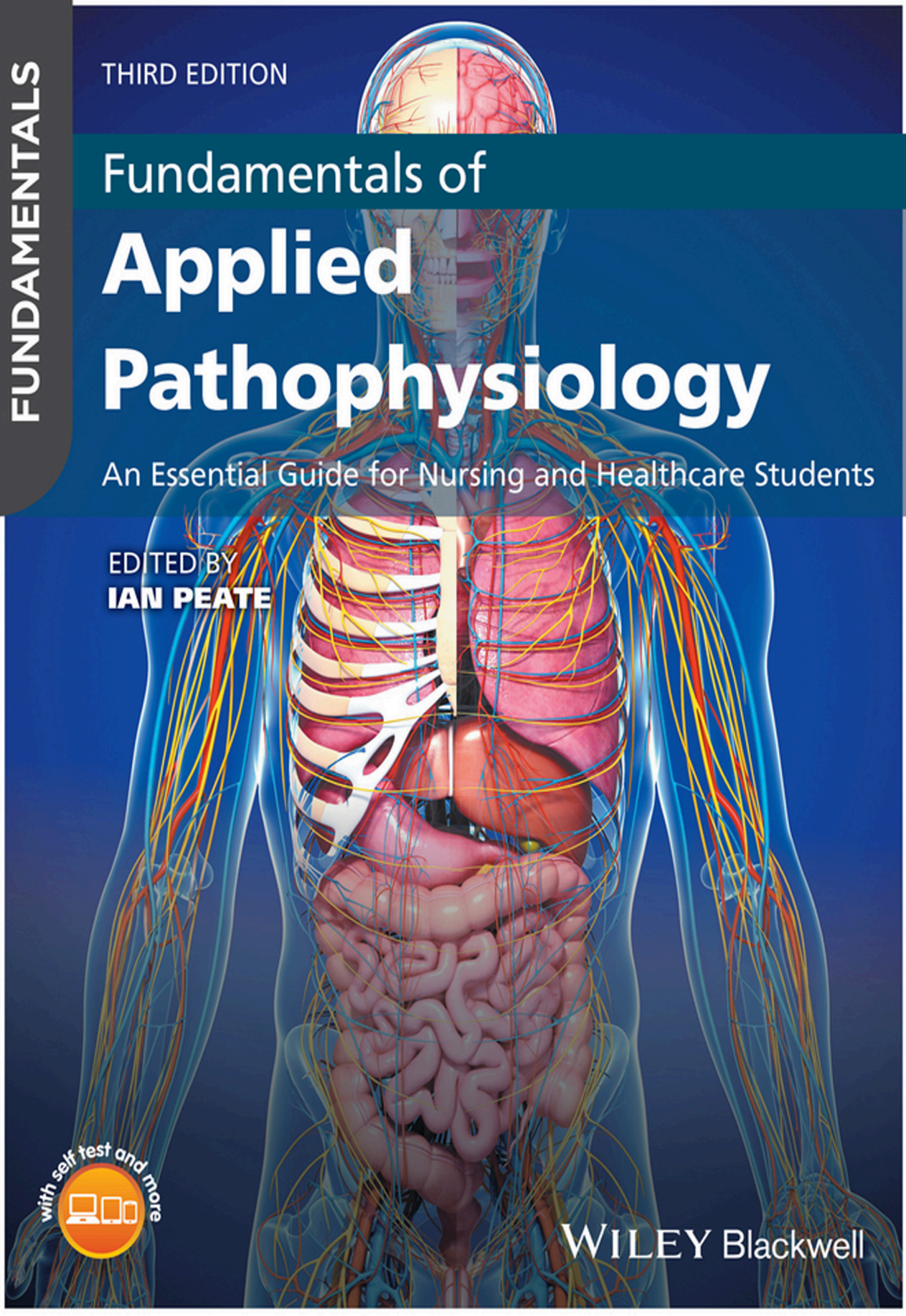
FUNDAMENTALS

THIRD EDITION

Fundamentals of Applied Pathophysiology

An Essential Guide for Nursing and Healthcare Students

EDITED BY
IAN PEATE



with self test and more

WILEY Blackwell

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Dedication

This text is dedicated to the life of Thomas Webster.
A brave young man who died far too early.

Contents

Preface

The third edition

I am delighted to be writing the preface to the third edition of this very popular text *Fundamentals of Applied Pathophysiology: An Essential Guide for Healthcare Students*. The new edition brings with it a number changes but at the same time it has aimed to preserve its user-friendly approach. Inviting and listening to feedback from readers has allowed me to retain features that have been seen as helpful, to introduce new features and to reorganise some of the chapters.

Illustrations are again used in abundance to assist in understanding and appreciating complex disease patterns that are being discussed. Applying a fundamental approach will provide readers with a crucial understanding of applied pathophysiology.

I have introduced a series of new activities that are intended to help you learn in an engaged way and to apply your learning when you are in the care setting, wherever this may be. This third edition provides you with an up-to-date overview of pathophysiology and important issues related to care.

This edition also considers the wider context of care provision supplementing a nursing focus by broadening the professional base to embrace all healthcare students. In providing care that is contemporary, safe and effective an integrated, multidisciplinary approach is an absolutely essential requirement for those who provide care as well those who manage it. The healthcare student is an important member of any multidisciplinary care team, and this edition also emphasises the multidisciplinary approach and acknowledges the fact that care is delivered in ever changing environments to a range of people and communities.

As with the first and second editions, this text has also been written with the intention of making the sometimes complex subject of pathophysiology accessible and exciting. Our bodies have an extraordinary ability to respond to disease in a number of physiological and psychological ways; we are able to compensate for the changes that occur as result of the disease process – the pathophysiological processes and the impact they can have on a person. This text will assist you in developing your critical thinking, encouraging innovation and creativity in relation to the health and well-being of the people that you have the privilege to care for.

The new features that have been added apply to most chapters and most chapters provide two case studies that are related to chapter content. At the end of each chapter there are questions that will trigger reflection and further thought. In all of the case studies, names that are used are pseudonyms, and these have been used in order to maintain confidentiality. Nurses owe a duty of confidentiality to all those who are receiving care (Nursing and Midwifery Council, 2015).

Where appropriate, we have included boxed information that will help you when you are providing care, which include red flags that contain significant information alerting you to be cautious in your approach, and information regarding the management of medicines as related to the chapter.

The case studies have been developed further and include data concerning the patient's vital signs and blood analysis. This can help you relate important concepts to care, offering you more insight into the patient's condition and therefore needs. One of the case studies includes a NEWS score (national early warning score) where applicable (Royal College of Physicians, 2016).

Many of the values cited are a range, and blood pressure in respect of the national early warning score is noted as systolic. Local policy and procedure should be adhered to when using the National Early Warning Score.

Although an elevated blood pressure is an important risk factor for cardiovascular disease, it is low or falling systolic blood pressure that is most significant in the context of assessing acute illness severity.

We have adopted Royal College of Physician's (2016) stance on this and parameters pertain to a range of systolic blood pressure.

Another new feature is the investigations box. One investigation will be chosen pertinent to one case study in the chapter. This will contain details about the test, the pre-, peri- and post-procedure care that is required.

Each chapter begins with and ends with questions that are there to test your pre- and post-knowledge. There are ten multiple choice questions at the end of each chapter along with varied learning activities such as word searches, ten true or false statements, and 'label the diagram' activities. Selected chapters provide a list of further resources that the reader may wish to access in order to increase and their advance learning. A glossary of terms is included at the end of each chapter.

Pathophysiology considers the cellular and organ changes that take place when disease is present, as well as the effects these changes have on the body's ability to function. When something interrupts the normal physiological functioning of the body, such as disease, this then becomes a pathophysiological issue. It must always be remembered that normal health is not and cannot be exactly the same in any two individuals and as such when using the term *normal* this has to be treated with caution. An understanding of pathophysiology 'normal' and 'abnormal' can assist the student to help the patient in a kind, compassionate, caring and safe way.

This text is a foundation text that can support the reader to grow personally and professionally in relation to the provision of care, and is primarily intended for nursing students who come into contact with those who may have a number of physically related healthcare problems such as coronary heart disease, asthma, dementia and many more diseases, in the hospital and community setting. The text focuses on the adult person. Illness and disease are discussed explicitly, highlighting the fact that people do become ill and they do experience disease.

It is not envisaged that you read the text from cover to cover, but you are encouraged to dip in and out of it. The aim is to entice and encourage you, whet the appetite, so you may read further and in so doing I hope to instill a sense of curiosity in you. The first four chapters however, set the scene and you may wish to read these first and the move on to a more specific area of interest.

References

Nursing and Midwifery Council (2015). *The Code. Professional Standards of Practice and Behaviour for Nurses and Midwives* https://www.nmc.org.uk/globalassets/sitedocuments/nmc-publications/nmc-code.pdf last accessed September 2016.

Royal College of Physicians (2016). *National Early Warning Score (NEWS)* https://www.rcplondon.ac.uk/projects/outputs/national-early-warning-score-news last accessed September 2016.

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Finally, thanks go to Muralitharan Nair, my co-editor for many years who has now decided to take a well earned retirement from editing. I have very much enjoyed working with you, thank you for all of your support.

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Carl began his nursing a career in 1990 as a Nursing Auxiliary. He later undertook 3 years student nurse training at Selly Oak Hospital (Birmingham), moving to The Royal Devon and Exeter Hospitals, then Northwick Park Hospital, and finally The Royal Brompton and Harefield NHS Trust as a Resuscitation Officer and Honorary Teaching Fellow of Imperial College (London). He has worked in nurse education since 2001. His key areas of interest are physiology, sociology, cardiac care and resuscitation. Carl has previously published work in cardiac care, resuscitation and pathophysiology.

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Karen qualified in 2000 from Sheffield Hallam University. She went on to work in various specialities including oncology and renal

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Muralitharan commenced his nursing a career in 1971 at Edgware General Hospital, becoming a Staff Nurse. In 1975, he commenced his mental health nurse training at Springfield Hospital and worked as a Staff Nurse for 1 year. He has worked at St Mary's Hospital Paddington and Northwick Park Hospital, returning to Edgware General Hospital to take up the post of Senior Staff Nurse and then Charge Nurse. He has worked in nurse education since 1989. His key interests include physiology, diabetes, surgical nursing and nurse education. Muralitharan has published widely in journals, and co-edited in a number of textbooks. He has now retired as full-time lecturer but is working as a Nursing Consultant.

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Ian began his nursing a career in 1981 at Central Middlesex Hospital, becoming an Enrolled Nurse working in an intensive care unit. He later undertook 3 years student nurse training at Central Middlesex and Northwick Park Hospitals, becoming a Staff Nurse and then a Charge Nurse. He has worked in nurse education since 1989. His key areas of interest are nursing practice and theory, men's health, sexual health and HIV. Ian has published widely; he is Professor of Nursing, Editor in Chief of the *British Journal of Nursing* and Head of School, School of Health Studies, Gibraltar. Ian was awarded an OBE in the Queen's 90th Birthday Honours List for his services to Nursing and Nurse Education. He was made a Fellow of the Royal College of Nursing in 2017 in recognition of his outstanding contribution to Nursing.

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Anthony began his nursing career at Barnet College of Nursing and Midwifery. After qualification in 1995, he worked as a staff nurse and senior staff nurse in the Respiratory Directorate at the Royal Brompton and Harefield NHS Trust in London. In 2000, he started teaching on post-registration cardio-respiratory courses before moving into full-time nurse education at Thames Valley University in 2002. Anthony has a wide range of nursing interests including cardio-respiratory nursing, anatomy and physiology, respiratory assessment, nurse education, and the application of bioscience in nursing practice. In 2006, Anthony joined the University of Hertfordshire where he has taught on both pre- and post-registration nursing courses. He is currently an Associate Subject Lead for Adult Nursing.

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About the companion website

This book is accompanied by a companion website:

www.wiley.com/go/fundamentalsofappliedpathophysiology3e

The website includes:

- Interactive multiple choice questions
- Interactive true/false exercises
- Label the diagram activities
- Word searches
- Answers to the book's fill in the blank exercises
- Searchable glossary
- Further reading and resources

Chapter 1

Cell and body tissue physiology

Anthony Wheeldon

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Contents

Key words

- Plasma membrane
- Organelles
- Connective tissue
- Passive transport
- Nucleus
- Cell cycle
- Muscle tissue
- Active transport
- Cytoplasm
- Epithelial tissue
- Nervous tissue
- Bulk transport

Fundamentals of Applied Pathophysiology: An Essential Guide for Nursing and Healthcare Students, Third Edition. Edited by Ian Peate.

Companion website: www.wiley.com/go/fundamentalsofappliedpathophysiology3e

Test your prior knowledge

- What are the three main parts of a human cell?
- Describe the structure and function of a human cell.
- Describe the phases of a cell cycle.
- Make a list of the major cellular organelles.
- Name the four tissue types and explain the differences between them.

Learning outcomes

On completion of this chapter the reader will be able to:

- Outline the structure and function of a human cell.
- List and describe the functions of the organelles.
- Explain the phases of a cell cycle.
- Explain the cellular transport system.
- Describe the structure and function of epithelial tissue, connective tissue, muscle tissue and nervous tissue.
- Explain the process of tissue repair (inflammation).

Don't forget to visit to the companion website for this book (www.wiley.com/go/fundamentalsofappliedpathophysiology3e) where you can find self-assessment tests to check your progress, as well as lots of activities to practise your learning.

Introduction

To understand the human body and how it works (and also how it fails to work properly), it is important to understand the anatomy and physiology of the cell. Living organisms show a wide diversity as regards their size, shape, colour, behaviour and habitat. In spite of this, however, there are many similarities between organisms, and this fundamental similarity is known as the 'cell theory'. This cell theory states that all living organisms are composed of one or more cells and the products of cells. Despite the fact that the cells belong to different organisms, and cells within the same organism may have different functions, there are many similarities between them. For example, there are similarities in their chemical composition, their chemical and biochemical behaviour and in their detailed structure.

All cells have many characteristics, but these characteristics can differ from cell to cell, such as:

- Cells are able to carry out certain specific functions, i.e. they are active.
- Cells need to consume food to live and to carry out their functions. Although they do not have mouths, they are still able to 'catch' and digest their food and use it for growth and reproduction. The correct term for this is endocytosis – they surround and engulf organisms such as bacteria and digest them.
- Cells can grow and repair.

- Similarly, cells can reproduce themselves. They do this by a process known as simple fission. This means that they reproduce themselves by dividing into two, and then each new cell grows to full size before it divides by simple fission and so on. In other words, cells replicate themselves.
- Like humans, cells can become irritable if something upsets or stimulates them.
- The nutrition that cells take in is also used for the storage and release of energy (just like humans), thus enabling them to grow and repair themselves.
- Similarly, just as humans do not utilise all the food they eat – some of it cannot be used and so is excreted – cells excrete what they do not need or cannot use.
- Just as all humans will eventually die, so will cells. Some have a short life, whilst others survive many years – but eventually they will die.

So, cells are not all that different from humans in many respects. They do what humans do – albeit in different ways.

Anatomy of the cell

Each cell has a structure that is almost as complex as the human body (Figure 1.1). For example, each cell contains as many molecules as the body has cells. There is no such thing as a typical cell. However, each cell is surrounded by a membrane and contains protoplasm. This protoplasm consists of a nucleus, which is kept separate from the rest of the cell by a nuclear membrane (although the nuclear membrane disappears during the process of cell division), and an opaque substance called cytoplasm (Watson, 2005). The cells themselves consist of water, proteins, lipids, carbohydrates and various ions such as potassium (K^+) and magnesium (Mg^{2+}). Within the cytoplasm there are also many complex protein structures called organelles.

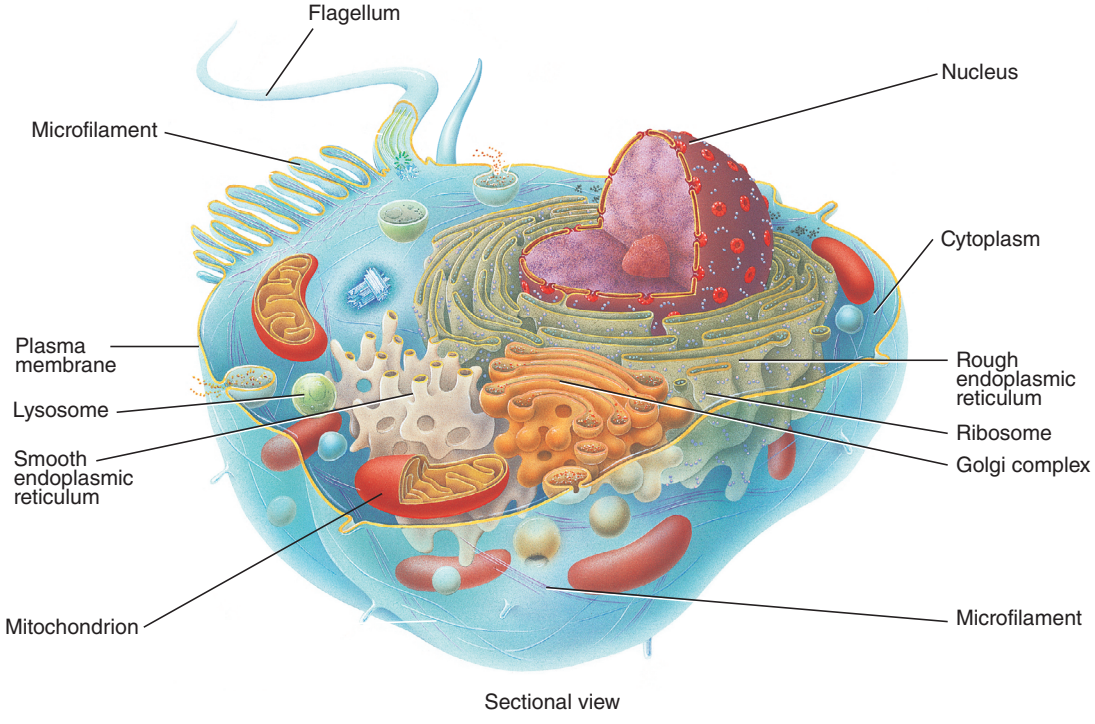

Figure 1.1 Simplified structure of a cell.

Cells vary in size from 2 to 20 µm. For example, a lymphocyte (a type of blood cell) is about 8–10 µm in diameter.

All the cells in the body, apart from those on the surface of the body, are surrounded by a fluid that is known as extracellular fluid (i.e. fluid outside of the cell).

The cell membrane

The cell membrane can vary from 7.5 to 10 nm in thickness. It acts just like a 'skin' that protects the cell from the outside environment. In addition, it regulates the movement of water, nutrients and waste products into and out of the cell.

The cell membrane is made up of a double layer (bilayer) of phospholipid (fatty) molecules with protein molecules interspersed between them (Figure 1.2). A phospholipid molecule consists of a polar 'head' which is hydrophilic (water loving) and 'tails' which are hydrophobic (water hating). The hydrophilic 'heads' are attracted to water and are found on the inner and outer surfaces of the cell (water is the main component of both extracellular and intracellular environments), whilst the hydrophobic 'tails' are found in the middle of the cell membrane where they can avoid water. These phospholipid molecules are arranged as a bilayer with the heads facing outwards. This means that the bilayer is self-sealing. It is the central part of the plasma membrane, consisting of the hydrophobic 'tails', that makes the cell membrane impermeable to water-soluble molecules, and so prevents the passage of these molecules into and out of the cell (Marieb, 2015). However, if the membrane just consisted of these phospholipid molecules, then cells would not be able to function – within the cell membrane there are also plasma membrane proteins (PMPs), which can be either integral or peripheral.

Some of the integral PMPs are embedded amongst the tails of the phospholipid molecules, whilst others penetrate the membrane completely (Figure 1.2). Subunits of some of these integral proteins can form channels which allow for the transportation of materials into and out of the

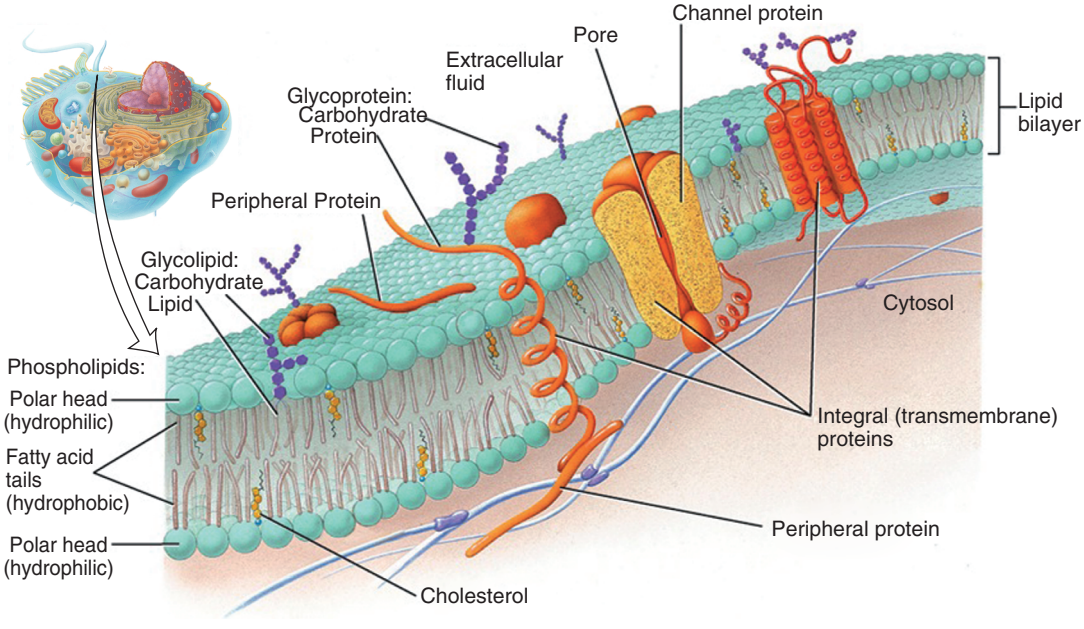

Figure 1.2 The cell membrane.

cell. Other subunits are able to bind to carbohydrates to form receptor sites. These receptor sites are important, as will be discussed in Chapter 3 – Inflammation, immune response and healing.

Peripheral PMPs bind loosely to the surface of the cell membrane and so can easily be separated from it. Some of them function as enzymes to catalyse cellular reactions, whilst others are receptors for hormones and other chemicals, or function as binding sites for attachment to other structures (Marieb, 2015).

Functions

- Endocytosis and exocytosis – the transport of fluids and other matter into and out of the cell.
- Endocytosis is the intake of extracellular fluid and particulate material (small particles) ranging in size from macromolecules to whole cells (e.g. the bacteria engulfed and destroyed by macrophage cells).
- Exocytosis is the bulk transport of material out of the cells.

There are three types of endocytosis:

1. Phagocytosis – involves the ingestion of large particles, even whole microbial cells.
2. Pinocytosis – involves the ingestion of small particles and fluids.
3. Receptor-mediated endocytosis – involves large particles, notably proteins, but also has the important feature of being highly selective.

Endocytosis involves part of the cell membrane being drawn into the cell along with the particles or fluid to be ingested (Figure 1.3). This membrane is then pinched off to form a membrane-bound vesicle within the cell, while at the same time the cell membrane as a whole reseals itself. Inside the cell, the fate of this vesicle depends upon the type of endocytosis involved as well as the material it contains. In some cases, the endocytic vesicle ultimately fuses with an organelle called a lysosome, after which processing of the ingested material can occur. Endocytosis is also the means by which many simple organisms obtain their nutrients.

Transport across the cell membrane

One of the key properties of the cell membrane with regards to transport is its selective permeability. This refers to its ability to let certain materials pass through, whilst preventing others from doing so. This selective permeability is based on the hydrophobicity (water hatred) of its component molecules. Because the phospholipid tails in the centre of the bilayer are composed entirely of hydrophobic fatty acid chains (lipids are fats), it is very difficult for water-soluble (hydrophilic) molecules to penetrate to the membrane interior. The result is a very effective permeability barrier.

However, this barrier can be penetrated, but only by way of specific transport systems. These control what goes into and out of the cell, or what crosses from one subcellular compartment to another. Cell membranes control metabolism by restricting the flow of glucose and other water-soluble metabolites in and out of cells and between subcellular compartments. This is known as compartmentation. The cells store energy in the form of transmembrane ion gradients by allowing high concentrations of particular ions to accumulate on one side of the membrane.

Ions pass from inside to outside of the cell (or the other way round) so that there are more supplies of these ions just outside the cell or inside it and the membrane controls the speed/rate at which these ions pass through the membrane. The controlled release of such ion gradients can be used to:

- extract nutrients from surrounding fluids
- pass electrical messages (known as nerve excitability)
- control cell volume and stop cells bursting from excess fluid.

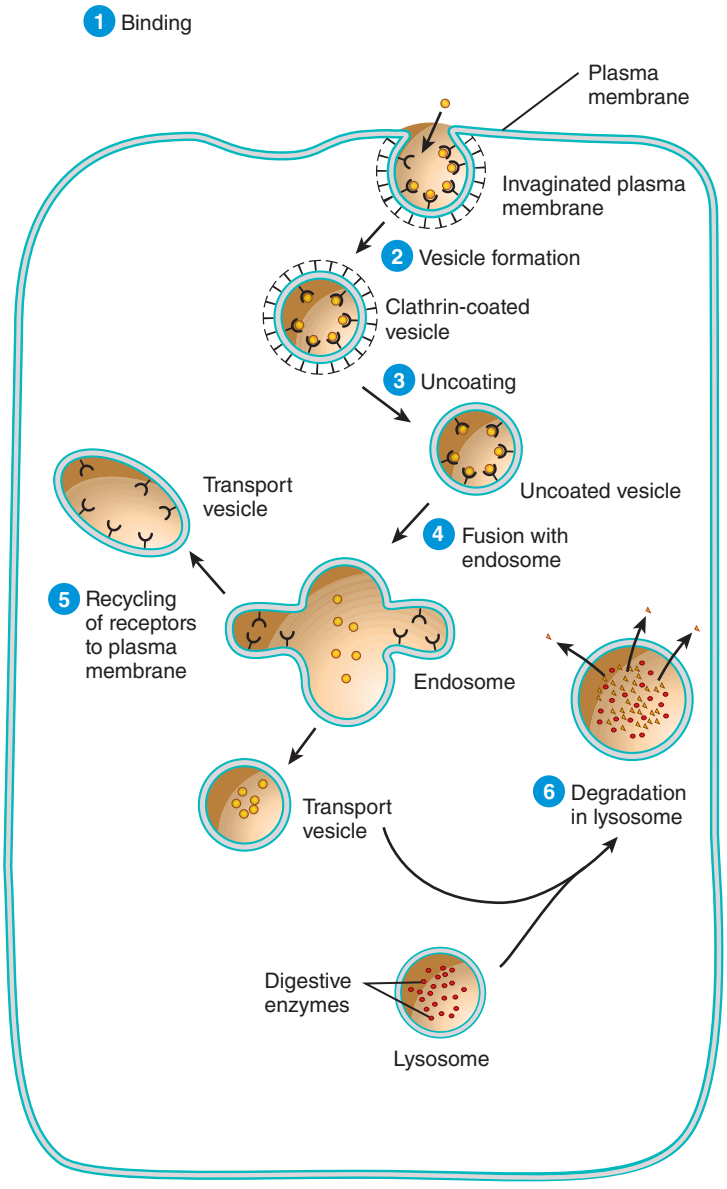

Figure 1.3 Endocytosis.

To return to the cell membrane itself, there are four factors that decide the degree of permeability of a membrane:

1. Size of molecules – large molecules cannot pass through the integral membrane proteins, but small ones such as water and amino acids can.
2. Solubility in lipids (fats) – substances that easily dissolve in lipids can pass through the membrane more easily than non–lipid-soluble substances. Lipid-soluble substances include oxygen, carbon dioxide and steroid hormones.

3. If an ion has an electrical charge opposite to that of the membrane, then it is attracted to the membrane and can more easily pass through it.
4. Carrier integral proteins can carry substances across the membrane, regardless of their size, ability to dissolve in lipids or membrane electrical charge.

There are two ways in which substances can move across the membrane: passive or active. Passive processes are:

- diffusion
- facilitated diffusion
- osmosis
- filtration.

Active processes are:

- active transport pumps
- endocytosis
- exocytosis.

A passive process is one in which the substances move on their own down a concentration gradient from an area of higher to one of lower concentration. The cell does not expend any energy on the process. Think of it as rolling down a hill from an area of high altitude to one of lower altitude. Little energy is expended just rolling down a hill.

Diffusion is the most common form of passive transport in which a substance of higher concentration moves to an area where there is a lower concentration of that substance (Colbert *et al*., 2011). This difference between the areas of high concentration and of low concentration is known as a concentration gradient. This process of diffusion is essential for respiration. It is through diffusion that oxygen is transported from the lungs to the blood and carbon dioxide makes the opposite journey from the blood to the lungs (Colbert *et al*., 2011).

Facilitated diffusion is similar to diffusion, but with one exception. For this process to take place, there needs to be a substance that helps – a facilitator. Glucose is moved using this process. Although glucose can move part of the way through the membrane on its own, it needs something else (a carrier/transport protein) to give it that extra push to get it completely through the membrane (Colbert *et al.*, 2011; McCance *et al.*, 2014).

Osmosis is the process in which water travels through a selectively permeable membrane so that concentrations of a substance that is soluble in water (known as a solute) are the same on both sides of that membrane. This is known as osmotic pressure (Figures 1.4 and 1.5). The higher the concentration of the solute on one side of the membrane, the higher the osmotic pressure available for the movement of the water (Colbert *et al*., 2011).

Filtration is similar to osmosis, except that pressure is applied in order to 'push' water and solutes across that membrane. The heart is a major supplier of the force that can lead to one type of filtration (renal filtration) as it pushes blood into the kidneys where filtration of the blood can take place (Colbert *et al*., 2011).

An active process is one in which substances move against a concentration gradient from an area of lower to one of higher concentration. To do this, the cell must expend energy; this is released by splitting adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and phosphate. ATP is a compound of a base, a sugar and three phosphate groups (triphosphate). These phosphate groups are held together by high-energy bonds, which when broken release a high level of energy. Once one of these phosphate bonds has been broken and a phosphate group has been released, that compound now has only two phosphate groups (diphosphate). The released phosphate group in turn joins up with another ADP group, so forming another molecule of ATP (with energy stored in the phosphate bonds), and the whole process continues to recur.

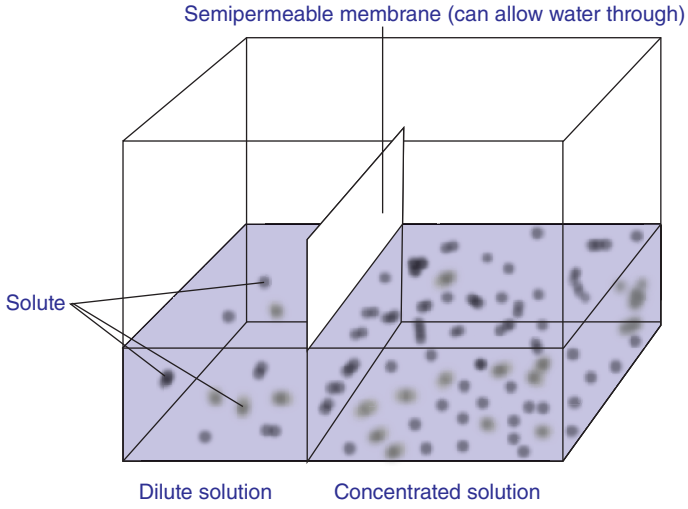

Figure 1.4 Osmosis.

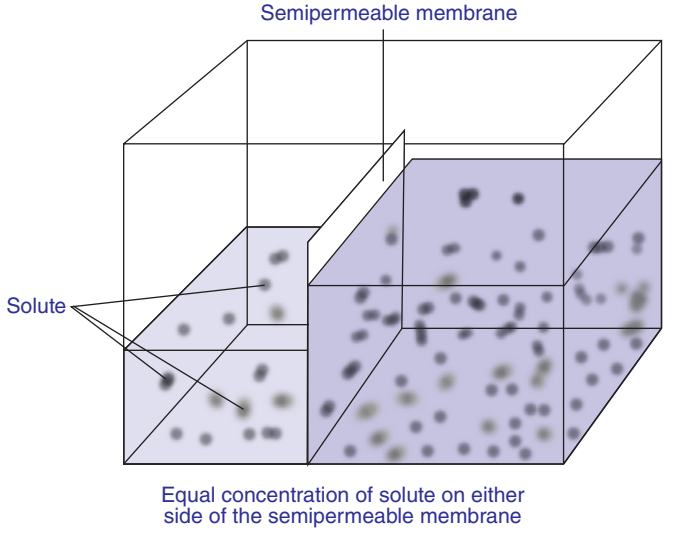

Figure 1.5 Osmosis and movement of solute.

The energy is required because the cell is attempting to move a substance to an area that already has a high concentration of that substance. Think again of a hill. When walking up a hill, a lot of energy is expended. Obviously, the higher the concentration already present, the more energy required to move further molecules of the particular substance into that area – the steeper the hill, the more energy is used. For example, cells contain a lot of potassium (K^+); therefore, energy is required to transport more potassium through the membrane and into the cell.

Now, to turn to what is inside the cell membrane, starting with the cytoplasm.

Cytoplasm

Cytoplasm is a ground substance (also known as a matrix) in which various cellular components are found. 'Cyto' means cell, so any word that has 'cyto' in it is to do with cells.

Cytoplasm, itself, is a thick, semitransparent, elastic fluid containing suspended particles and the cytoskeleton. The cytoskeleton provides support and shape to the cell. In addition, it is involved in the movement of structures in the cytoplasm because some cells can change shape, e.g. phagocytic cells (see Figure 1.3).

Role of cytoplasm

- Chemically, cytoplasm is 75–90% water plus solid compounds – mainly carbohydrates, lipids and inorganic substances, and it is the substance in which chemical reactions occur.
- The cytoplasm receives raw materials from the external environment (such as from digested food) and converts them into usable energy by decomposition reactions.
- As well as the breakdown of raw materials to make energy, the cytoplasm is also the site where new substances are synthesised (produced) for the use of the cell.
- It is the place where various chemicals are packaged for transport to other parts of the cell, or to other cells in the body.
- It is in the cytoplasm that various chemicals facilitate the excretion of waste materials.

Nucleus

When considering the nucleus, a simple analogy is to think of it as the brain of the cell.

Prokaryotic cells do not have a nucleus, but eukaryotic cells do. Eukaryotic cells are found in animals and plants, whilst prokaryotic cells are very typical of bacteria. In many ways, prokaryotic cells are less complex and often smaller than eukaryotes.

However, not all human cells possess a nucleus. An example of a cell without a nucleus is the red blood cell. Chapter 7 describes the concave shape of the mature red blood cells. This is because the lack of a nucleus means the red blood cell 'collapses in' on itself. Also, just to make it more confusing, some cells can have more than one nucleus, e.g. some muscle fibre cells (see Figure 1.12).

Some facts about the nucleus are:

- The nucleus is the largest structure in the cell.
- It is surrounded by a nuclear membrane. This nuclear membrane has two layers and, like the cell membrane, is selectively permeable.
- The protoplasm within the nucleus is not called cytoplasm – it is called nucleoplasm.
- The nucleus assumes a great responsibility for both mitosis and meiosis (see later).
- Inside the nucleus is found the genetic material, consisting principally of deoxyribonucleic acid (DNA). When a cell is not reproducing, the genetic material is a threadlike mass called chromatin.
- Before cell division, the chromatin shortens, and coils into rod-shaped bodies called chromosomes.
- The basic structural unit of a chromosome is a nucleosome – composed of DNA and protein.
- DNA has two main functions:
  1. It provides the genetic blueprint which ensures that the next generation of cells is identical to existing ones.
  2. It provides the plans for the synthesis of protein by the cell.

- All this information is stored in genes.
- Inside the nucleus are little spherical bodies called nucleoli and these are responsible for the production of ribosomes from ribosomal ribonucleic acid (rRNA).
- In humans, there are 23 pairs of chromosomes in each cell with a nucleus, with the exception of the spermatozoa and ova (sperm and eggs).
- Sperm and ova only have 23 single chromosomes (i.e. one of each).
- The chromosomes are the same for males and females except for one pair – the X and Y chromosomes. It is these chromosomes that determine whether a baby is going to be male or female.

Mitosis and meiosis

These are the processes by which the cell reproduces itself. Most human cells reproduce asexually by mitosis, but the spermatozoa and ova reproduce by meiosis. Whereas the cells reproducing by mitosis finish up as exact copies of the parent cells with a pair of each of the 23 chromosomes, the cells reproducing by meiosis just finish up with one each of the 23 chromosomes.

Mitosis

In order for the body to grow, and also for the replacement of body cells that die, cells must be able to reproduce themselves, and in order for genetic information not to be lost, they must be able to reproduce themselves accurately. They do this by cloning themselves. In some organisms, this can occur by simple fission, where the nucleus in a single cell becomes elongated and then divides to form two nuclei in the same cell, each new nucleus carrying identical genetic information. The cytoplasm then divides in the middle between the two nuclei, and so two identical daughter cells result, each with its own nucleus and other essential organelles.

In humans, cell reproduction is a complex process called mitosis, in which the number of chromosomes in the daughter cells has to be the same as in the original parent cell.

Mitosis can be divided into four stages:

1. prophase
2. metaphase
3. anaphase
4. telophase.

- Before and after it has divided, the cell enters a stage known as interphase – this was thought to be a resting period for the cell, but the cell is actually very busy during this period because it has to get ready for replication.
- Extra organelles are manufactured by the replication of existing organelles.
- Also, the cell builds up a store of energy which is required for the process of division.

Prophase

The first stage after interphase is prophase:

- During prophase (Figure 1.6), the chromosomes become shorter, fatter and more easily visible, and each chromosome now consists of two chromatids, each containing the same genetic information (i.e. the DNA has replicated itself during interphase).
- The nucleolus and nuclear membrane disappear, leaving the chromosomes in the cytoplasm.

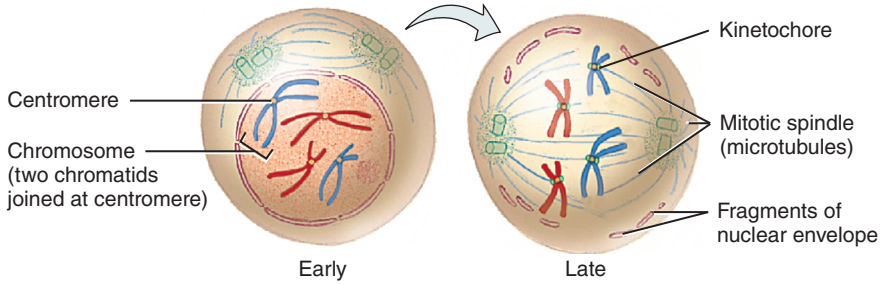

Figure 1.6 Prophase.

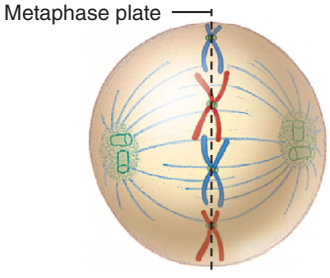

Figure 1.7 Metaphase.

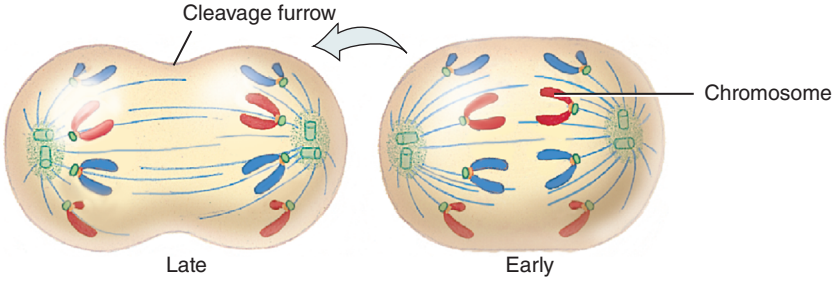

Figure 1.8 Anaphase.

Metaphase

- During metaphase (Figure 1.7), the 46 chromosomes (two of each of the 23 chromosomes), each consisting of two chromatids, become attached to the spindle fibres.

Anaphase

- During anaphase (Figure 1.8), the chromatids in each chromosome are separated.
- One chromatid from each chromosome then moves towards each pole of the spindle.

Telophase

- There are now 46 chromatids at each pole, and these will form the chromosomes of the daughter cells.
- The cell membrane constricts in the centre of the cell, dividing it into two cells.

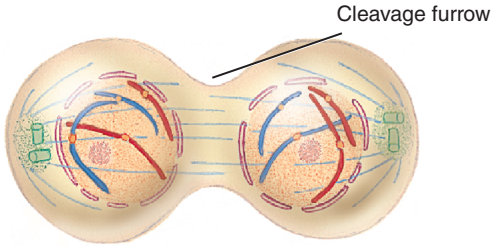

Figure 1.9 Telophase.

- The nuclear spindle disappears, and a nuclear membrane forms around the chromosomes in each of the daughter cells (Figure 1.9).
- The chromosomes become long and threadlike again, and are very difficult to see.

Cell division is now complete, and the daughter cells themselves enter the interphase stage in order to prepare for their replication and division.

Cell cycle

Looking now at the cell cycle (Figure 1.10) and supposing that one full cycle represents 24 hours, then the actual process of replication (mitosis) would only last for about 1 hour out of those 24 hours. The rest of the time, the cell is undertaking the replication of its DNA. It also has to produce two of everything that is in the cell. In addition, it has to go through the process of obtaining and digesting nutrients so that it has the raw materials for this duplication, as well as the energy required in order to carry out various functions of the cell.

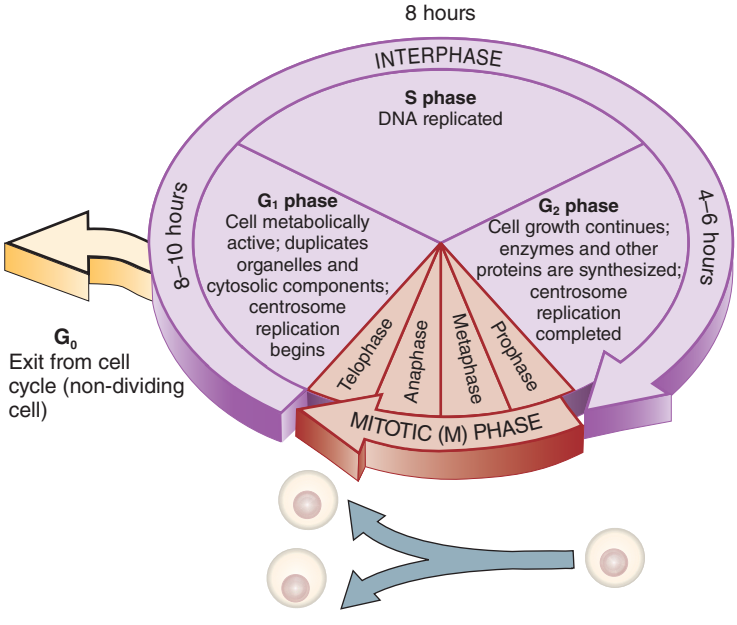

Figure 1.10 Cell cycle.

Table 1.1 Stages of meiosis.

First meiotic stage	Second meiotic stage
Prophase I	Prophase II
Metaphase I	Metaphase II
Anaphase I	Anaphase II
Telophase I	Telophase II

Meiosis

During the reproduction of humans, the egg is penetrated by a sperm, which then releases its DNA to combine with the DNA of the egg, so that the resulting embryo has two copies of each of the 23 chromosomes in nucleated cells. If the sperm and eggs had two copies of each chromosome (like other cells), the resulting fusion and developing embryo would have four copies of each chromosome. This means that the next generation would have four copies of each chromosome. The generation after that would have eight copies, and so on. This is obviously not practical, so the sperm and eggs undergo a process known as meiosis to ensure that the resulting embryo will only carry two copies of each chromosome in each cell with a nucleus.

For descriptive purposes, meiosis can be divided into eight stages (not the four of mitosis). However, they have the same names, but are known as either I or II (Table 1.1). As with mitosis, these phases are continuous with one another. However, there are differences as well as similarities between mitosis and meiosis.

First meiotic stage

Prophase I

- This is similar to prophase in mitosis.
- However, instead of being scattered randomly, the chromosomes are arranged in 23 pairs. For example, the two chromosome number ones will pair up, as will the two chromosome number twos.
- Within each pair of chromosomes, genetic material may be exchanged between the two chromosomes.
- It is these exchanges that are partly responsible for the differences between children of the same parents.
- This process is called 'gene cross-over'.

Metaphase I

As in mitosis, the chromosomes become arranged on the spindles at the equator. However, they remain in pairs.

Anaphase I

One chromosome from each pair moves to each pole, so that there are now 23 chromosomes at each end of the spindle.

Telophase I

The cell membrane now divides the cell into two halves, as in mitosis. Each daughter cell now has half the number of chromosomes that each parent cell had.

Second meiotic stage

- The cells produced by the first meiotic division now divide again.
- Prophase II, metaphase II, anaphase II and telophase II are all similar to their equivalent stage in mitosis, with the exception that the DNA has not been replicated before prophase II, so there are only 23 single chromosomes in each of the granddaughter cells.

Fusion of the gametes

- When the gametes, each with 23 chromosomes, fuse together, a cell known as a zygote with 23 paired chromosomes (i.e. 46 in all) is formed.
- One chromosome in each pair comes from the mother and one from the father.
- The zygotic cell then divides (by mitosis) many times to form the embryo.

The organelles

All cells contain many organelles (little organs).

Endoplasmic reticulum

It is believed that the endoplasmic reticulum (ER; Figure 1.11) is formed from the nuclear membrane.

The ER consists of membranes that form a series of channels (called cisternae) dividing the cytoplasm into compartments. The cisternae are concerned with the transport of materials, primarily proteins. The alteration or addition of proteins for export from the cell can occur within the cisternae. They also contain a number of enzymes of importance in cell metabolism, such as digestive enzymes, enzymes involved in the synthesis of steroids, and enzymes responsible for a variety of reactions leading to the removal of toxic substances from the cell (McCance *et al*., 2014). The ER present in liver cells has a role in drug detoxification.

There are two types of cisternae:

1. granular (rough) ER – associated with ribosomes
2. agranular (smooth) ER – free of ribosomes.

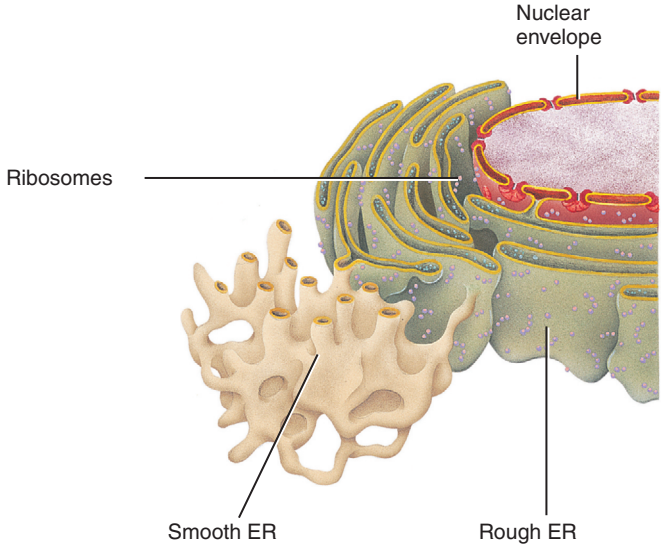

Figure 1.11 Endoplasmic reticulum (ER).