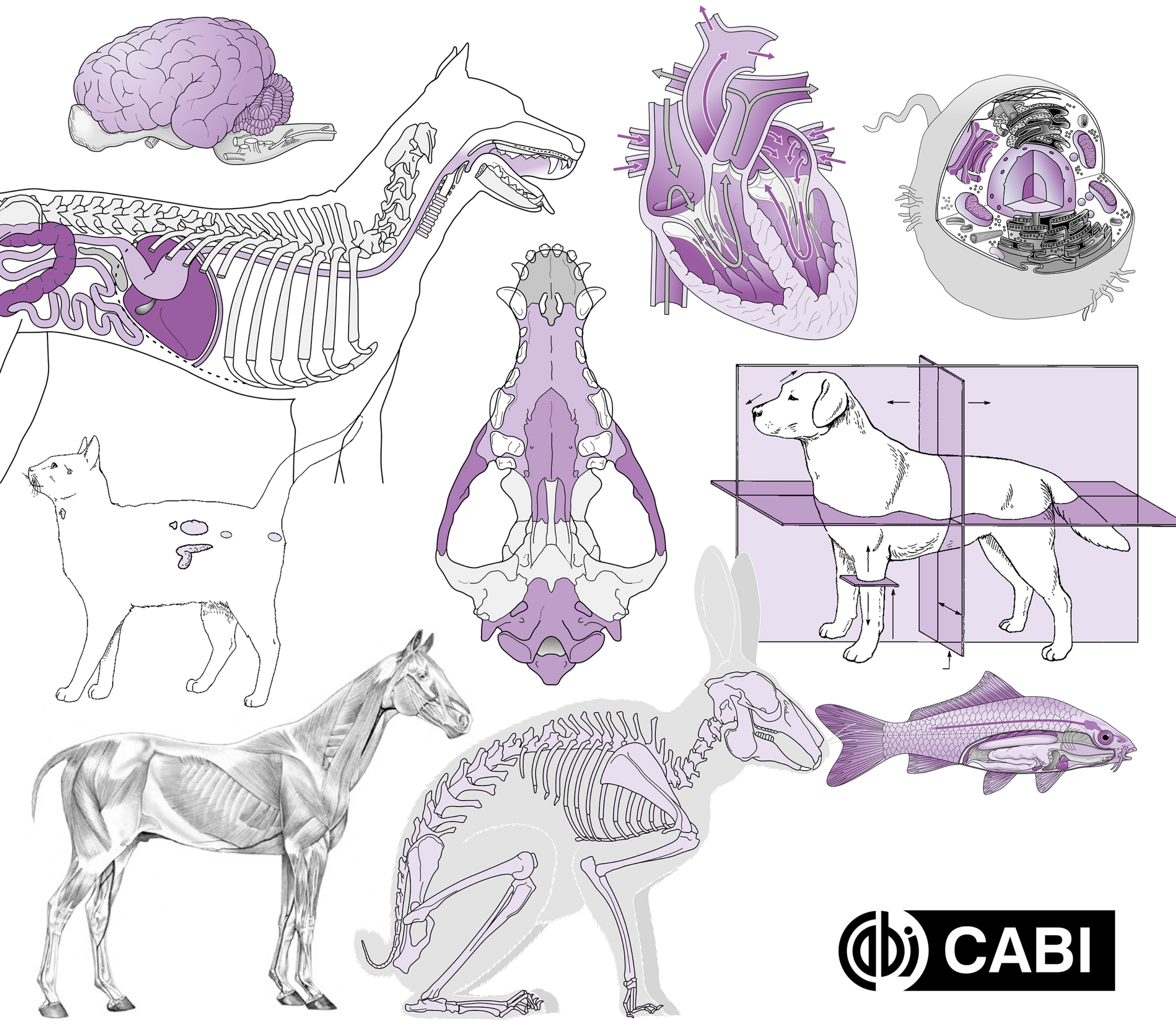
Victoria Aspinall and Melanie Cappello

INTRODUCTION TO

ANIMAL AND VETERINARY ANATOMY AND PHYSIOLOGY

5th edition



CABI

Introduction to Animal and Veterinary Anatomy and Physiology – 5th edition

INTRODUCTION TO Animal AND Veterinary Anatomy AND Physiology – 5th edition

Victoria Aspinall BVSc MRCVS
Retired veterinary surgeon and college lecturer

Melanie Capello BSc (Hons) PGCE (PCET)
Former veterinary nurse and clinical skills tutor

Contribution from:
Catherine Phillips MSc (Vet Ed) Cert Ed RVN REVN
Head of Department of Veterinary Nursing, Hartpury University, Gloucester

CABI

CABI is a trading name of CAB International

CABI
Nosworthy Way
Wallingford
Oxfordshire OX10 8DE
UK

Tel: +44 (0)1491 832111
E-mail: info@cabi.org
Website: www.cabi.org

CABI
200 Portland Street
Boston
MA 02114
USA

Tel: +1 (617)682-9015
E-mail: cabi-nao@cabi.org

A catalogue record for this book is available from the British Library, London, UK.

ISBN-13: 9781800624047 (paperback)
9781800624054 (ePDF)
9781800624061 (ePub)

DOI: 10.1079/9781800624061.0000

Commissioning Editor: Alexandra Lainsbury
Editorial Assistant: Emma McCann
Production Editor: James Bishop

Typeset by Straive, Pondicherry, India
Printed and bound in the UK by Bell and Bain Ltd, Glasgow

Contents

Preface

An understanding of anatomy and physiology is the basis of working with any species of animal. It does not matter whether you are dealing with a cat, a dog, a horse, an alpaca or an owl or a lizard, you must understand how they are made and how they work. An *Introduction to Animal and Veterinary Anatomy and Physiology* aims to provide students with comprehensive coverage of a range of commonly encountered domestic animals. Section 1 describes in detail the anatomy and physiology of the dog and cat. Section 2 applies the basic understanding gained from this study to a range of other common species. This is the fifth edition of what, we hope, has become a standard textbook at this level for those studying veterinary nursing and all those studying animal science at any level.

It is four years since the last edition was published and it was time for a rewrite. Every chapter has been reviewed and extra updated text has been added where appropriate. We have also added to many of the diagrams the ability to use augmented reality (AR). By means of an AR app it enables you, the reader, to bring the diagrams to 'life', allowing you to understand what you are seeing better and more clearly and to make it easier to remember the all-important scientific facts. We believe that, at the time of publication, this is one of the first anatomy textbooks to give access to this new aid to learning. The method of achieving this is explained on every relevant page. In addition to AR, we have also put a huge bank of questions and answers into an ancillary site. This provides you with a comprehensive means of self-assessment enabling you to keep track of your learning and to prepare you for whichever exam you are working towards. It will also be a useful inspiration to tutors when setting tests and exams. The answers are all within the text and the questions should make the students think harder when reading the book.

Melanie and I have tried to make sure that all the facts within the text are accurate and informative and we hope that this edition will continue to occupy a useful place in the scientific library.

Victoria Aspinall and Melanie Cappello

CABI Academy

To access the supporting content, you will need an account on the CABI Academy: https://academy.cabi.org – if you don't already have an account there is an option to create a new one. Once you are logged in, please go to: https://academy.cabi.org/course/index.php?categoryid=128

Select the relevant course and when prompted enter the enrolment key which is: Aspinal!

HOW TO USE LUDENSO

It's a simple two-step process

1 **Scan the QR code** with your phone or tablet and download the Ludenso Explore App. You will be automatically directed to this book.

2 **Use the app to scan pages** and access the list of enrichments. Click on the button "**Explore**" and scan the page with your phone and tablet to see the content coming to life.

Contact us

hello@ludenso.com
www.ludenso.com

Android & iOS
Download the App Now
Ludenso Explore

ENJOY THE
NEW GENERATION
OF BOOKS

SECTION 1

The dog and cat

This section describes the anatomy and physiology of the two most common species treated in small animal veterinary practice: the dog and cat. Following an introduction to cell biology, each body system is covered separately.

CHAPTER

1 Principles of cell biology

KEY POINTS

- All living organisms can be classified into different orders, classes and families linked by certain common characteristics. These groups can be further divided into a genus and species, which describes an individual type of organism.
- The body is made up of a number of systems, each of which has a specific function. These systems form the structural framework of the body or lie within one of the three body cavities.
- Each system consists of a collection of tissues and organs, which are composed of the smallest units of the body – the cells. Animals are multicellular organisms, comprised of eukaryotic cells which contain membrane-bound organelles, such as the nucleus.
- Cells can only be seen under the microscope and all have a basic structure with certain anatomical differences, which adapt them to their specific function within the body.
- Each structure within the cell plays a vital part in the normal function of the cell and therefore in the normal function of the body system that the cell is found in.
- Cells grow and divide by means of mitosis. Each mitotic division results in the production of two identical daughter cells containing the diploid (or normal) number of chromosomes.
- The healthy body contains 60–70% water, distributed into two principal fluid compartments: the extracellular fluid (ECF – surrounding the cells) and the intracellular fluid (ICF – within the cells).
- Body fluids move between these compartments and this movement is controlled by the chemical constituents of the fluid and the physical processes of diffusion and osmosis.
- Body fluids contain inorganic and organic compounds. The structure and percentage of all of these are fundamental to the balance and normal function of the body. Within the body there are many systems involved in maintaining a state of equilibrium – this is known as homeostasis.

Anatomy is the study of the structure of organisms, and the relationship between their body parts. Physiology is the study of the function of the body parts, looking at the inner functions of the cells, tissues and organs that make up the body as a whole. In this section, we will study the anatomy and physiology of the dog and cat. In Section 2, we describe the comparative anatomy and physiology of the horse, the most common farm animals and some of the most commonly kept exotic species. We start by looking at the microscopic anatomy of an organism, i.e., the basic unit of the body, which is the cell. These can only be seen using microscopes. We then work our way through the tissues, organs and systems, or the macroscopic anatomy (meaning it can be seen with the naked eye), until the picture is complete.

Regional anatomy is where the focus is on a specific region of the body (e.g., the head and neck or the chest/thorax). It describes how different systems relate to each other in the function of that region (e.g., the organs, muscles, nerves and blood vessels, and how they work together to provide a functioning system in the abdomen). In this book we look at systemic anatomy, which focuses on a group of structures that work together to carry out a particular body function, such as the digestive, circulatory, nervous, endocrine and musculoskeletal systems.

Animal classification

When studying any aspect of biology, it is important to have a basic understanding of the classification system used to group animals. How the species that one may meet in a veterinary practice fit into this classification system should also be understood. Classification is the way in which we 'sort' species into orderly groups, depending on how closely they are related in terms of their evolution, structure and behaviour. The science of classification is known as *taxonomy*.

If organisms have certain basic features in common, they are grouped together into a *kingdom*. For example, if an organism is composed of more than one cell (i.e., it is multicellular) and obtains its food by ingestion, it is placed in the animal kingdom. Other kingdoms include plants and fungi. Animals, plants and fungi are all multicellular organisms, or eukaryotes. Eukaryotic cells contain membrane-bound organelles, such as the nucleus. In contrast to this are prokaryotic cells, such as bacteria, which do not contain membrane-bound organelles and are unicellular. For the purpose of this book we will only be considering eukaryotic cells.

The animal kingdom is then further subdivided, based upon similarities of organisms, into a hierarchical system (Table 1.1). This narrows the classification down until we eventually reach a

DOI: 10.1079/9781800624061.0001

particular *genus* and *species*. Most living organisms are identified by a genus and species – a method known as the binomial system, invented by the Swedish scientist Carl Linnaeus.

All the species within the animal kingdom are divided into those with backbones – the vertebrates – and those that do not have backbones – the invertebrates (e.g., insects, worms, etc.). The vertebrates are divided into eight *classes*. The classes that are of the most veterinary importance are:

- Amphibia: approximately 3080 species.
- Reptilia: approximately 6600 species.
- Aves or birds: approximately 8500 species.
- Fish: approximately 30,000 species.
- Mammalia: approximately 4070 species.

These classes are then further divided into *orders*, and so on, until a species is identified, as in Table 1.1.

Most of this section of the book concerns the mammals, because the majority of animals seen in veterinary practice will be from this class. The distinctive features of mammals are the production of milk by the mammary glands and the possession of hair as a body covering. Examples of mammalian orders include:

- Insectivores (e.g., shrews, moles).
- Rodents (e.g., mice, rats).
- Lagomorphs (e.g., rabbits, hares).
- Carnivores (e.g., cats, dogs, bears, seals).
- Ungulates (e.g., cows, sheep, horses).
- Cetaceans (e.g., whales, dolphins).
- Primates (e.g., monkeys, apes).

Generally speaking, all mammals have a similar basic structural plan in terms of anatomy and physiology, but each species has been modified to suit its specific lifestyle. In other words, mammals have become specialised for activities such as running, digging, gnawing, jumping and eating specific foods.

Table 1.1. Classification of the domestic dog and cat

Taxonomic group	Dog	Cat
Kingdom	Animal	Animal
Phylum	Chordata (vertebrate)	Chordata (vertebrate)
Class	Mammalia (mammal)	Mammalia (mammal)
Order	Carnivora	Carnivora
Family	Canidae	Felidae
Genus	*Canis*	*Felis*
Species	*familiaris*	*catus*
Common name	Domestic dog	Domestic cat

Anatomical definitions

When studying anatomy and physiology it is important to understand the terms that are used to describe where structures lie in relation to one another. These are illustrated in Fig. 1.1 and named as follows:

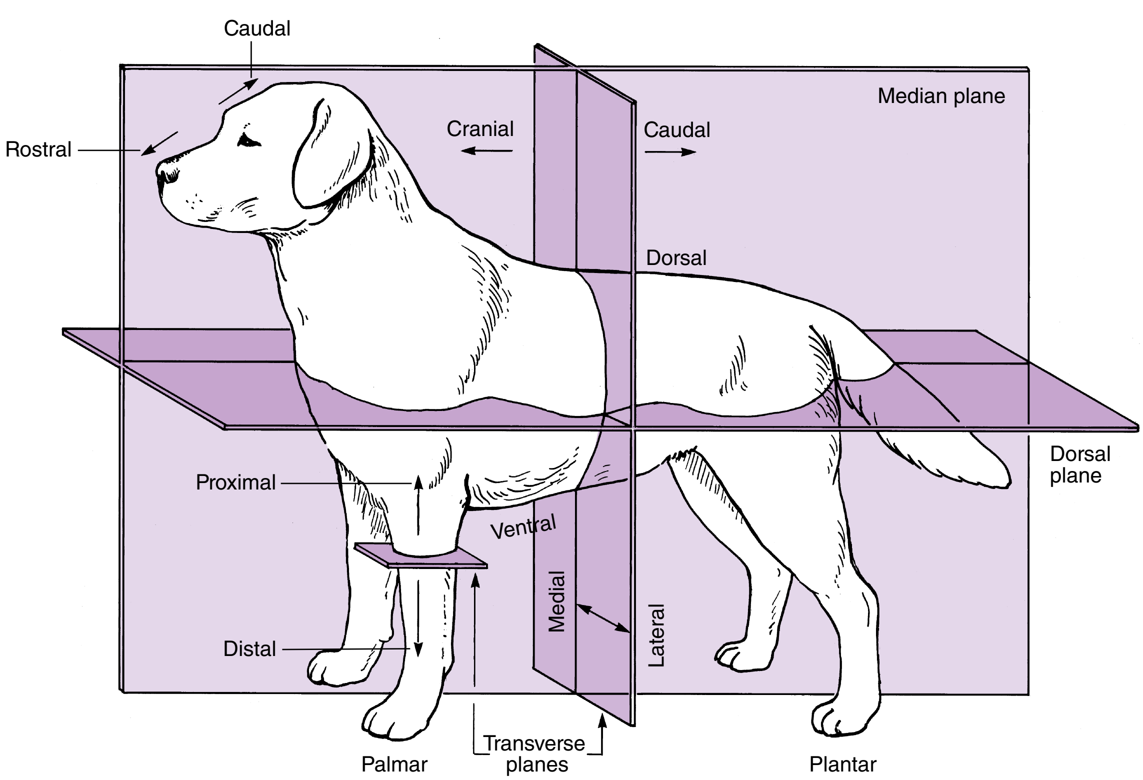


Fig. 1.1. Anatomical planes and directional terms used to describe the relative position of structures in the body. With permission from T Colville, JM Bassett, 2001. Clinical anatomy and physiology for veterinary technicians. St Louis, MO: Mosby, p. 3.

- *Median plane*: divides the body longitudinally into symmetrical right and left halves; can be described as 'the line down the middle of the animal' from nose to tail.
- *Superficial*: near to the surface of the body.
- *Deep*: closer to the centre of the body.
- *Cranial/anterior*: towards the front of the animal (i.e., towards the head).
- *Caudal/posterior*: towards the rear end or tail of the animal (i.e., away from the head).
- *Medial*: structures that lie towards or near the median plane (i.e., closer to the middle of the animal).
- *Lateral*: structures that lie towards the side of the animal (i.e., away from the median plane).
- *Dorsal:* towards or near the back or vertebral column of the animal and the corresponding surfaces of the head, neck and tail.
- *Ventral:* towards or near the belly or lowermost surface of the body and the corresponding surfaces of the head, neck and tail.
- *Rostral:* towards the nose; used to describe the position of structures on the head.
- *Proximal*: structures or part of the structure that lie close to the main mass of the body (e.g., the 'top' of the limb that attaches to the body); also used to describe parts that lie near the origin of a structure.
- *Distal*: structures or part of the structure that lie away from the main mass of the body or origin (e.g., the free end of the limb).
- *Palmar:* the rear surface of the fore paw that bears the footpads; the opposite surface (i.e., the front surface of the paw) is the dorsal surface.
- *Plantar:* the rear surface of the hind paw that bears the footpads; the opposite surface (as above) is the dorsal surface.

An understanding of anatomical terminology is useful when you are helping the vet in diagnostic imaging. For example, you may be asked to position the patient for a ventrodorsal chest X-ray and knowing the meaning of the words 'ventral' and 'dorsal' will help you position the animal correctly. It will also be helpful when being directed by other veterinary personnel in a number of situations; for example, the vet may ask you to place the animal in a right lateral position for a procedure.

The basic plan of the body

The body is made up of a number of systems and each of them has a specific job, enabling the body to function effectively. These systems can be placed in one of three groups depending on their function:

- *Structural systems*: provide the basic 'framework' and transport system for the body.
- *Coordinating systems*: the control mechanisms of the body.
- *Visceral systems*: include all the basic functional systems, or organs, that do the general duties for the body; found within one of the three body cavities (i.e., thoracic, abdominal and pelvic).

Structural systems

- *Skeletal system*: the supporting frame upon which the body is built (i.e., the bones and joints).
- *Muscular system*: the mechanism by which the bones are moved to bring about locomotion (this relates to skeletal muscle only; the other categories of muscle are considered separately).
- *Integument*: the covering of the body (i.e., skin and hair).
- *Cardiovascular system*: transports the blood around the body.

Coordinating systems

- *Nervous system*: carries information to and from the central 'control station' of the body (i.e., the brain); controls and monitors the internal and external environment of the body.
- *Endocrine system*: controls the body's functions via a communication system of chemical messengers or hormones.

Visceral systems

- *Digestive system*: responsible for taking in food and breaking it down to its basic components so that the body can utilise them as required.
- *Respiratory system*: responsible for taking in oxygen and removing carbon dioxide.
- *Urinary system*: responsible for eliminating waste and toxic substances from the body.
- *Reproductive system*: responsible for producing offspring.

Each system of the body is made up of a collection of specific types of *tissue* arranged as *organs*. Each tissue is composed of a specialised type of *cell* (the smallest unit of the body).

The mammalian cell

Cells are the minute units of a tissue that can only be seen under a microscope. Cells are considered to be the basic structural and functional unit of an organism. In fact they are like 'little bodies' themselves because they carry out a number of basic functions such as taking in nutrients and excreting waste, respiring or 'breathing', and reproducing. These and other functions are carried out by various structures that make up the cell – mainly by the organelles, or 'little organs', that float within the cytoplasm of the cell.

Cell structure and function

The components of a cell are shown in Figs. 1.2 and 1.3 and are as follows:

- Cell membrane
- Nucleus
- Organelles:
  - Mitochondria
  - Ribosomes
  - Rough endoplasmic reticulum
  - Smooth endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Centrosome

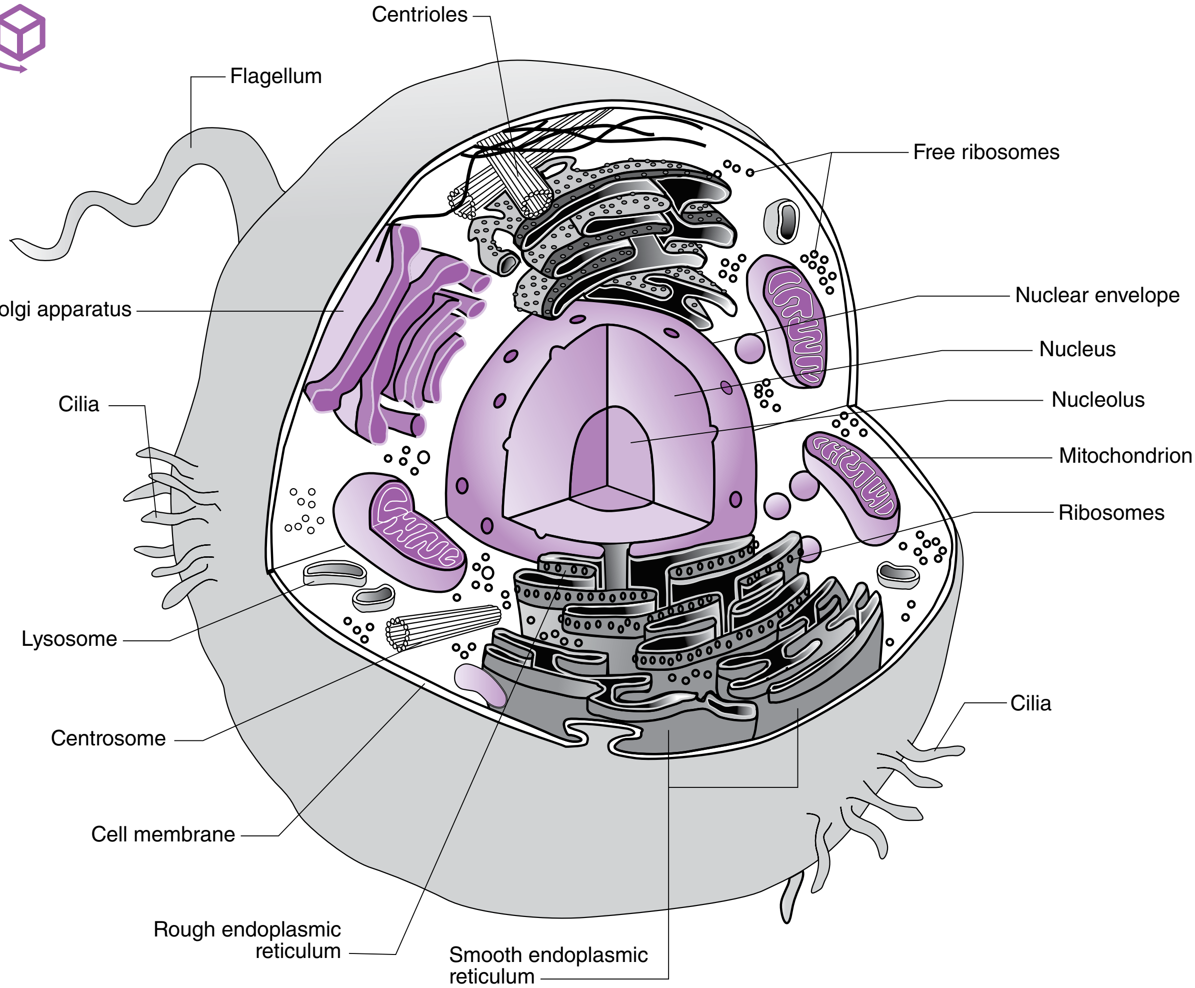


Fig. 1.2. Components of the mammalian cell.
With permission from T Colville, JM Bassett, 2001. Clinical anatomy and physiology for veterinary technicians. St Louis, MO: Mosby, p. 11.

Cell membrane

The cell membrane covers the surface of the cell and may also be called the plasma membrane. It is responsible for separating the cell from its environment and controls the passage of substances in and out of the cell. Carbohydrates are found on the surface of the cell membrane and it is believed that these help cell recognition, meaning that they enable a cell to recognise whether or not it is in contact with another cell of the same type. The cell membrane of a mammalian cell is composed of a *phospholipid bilayer* (Fig. 1.4). This is a double layer of phospholipid molecules with protein molecules embedded within it.

The nature of its structure means that the cell membrane is *selectively permeable*, allowing some substances to pass through it while others may either be excluded or must travel across the membrane by means of specialised transport systems. These include:

- *Pores in the cell membrane*: small molecules can pass through these pores.
- *Simple diffusion*: molecules that are soluble in lipids (or fats) will passively dissolve in the lipid part of the cell membrane and diffuse across it; oxygen and water enter the cell in this way.
- *Facilitated diffusion*: another type of passive diffusion, where the substance is moving down a concentration gradient, but the substance enlists the help of a carrier protein to help it across the membrane; glucose uses this method to enter the cell.
- *Active transport mechanisms*: substances are usually being moved from a region of low concentration to one of higher concentration (i.e., they are travelling against a concentration gradient). This is like going up a steep hill – it is hard work and therefore requires energy. Substances that require active transport mechanisms to cross the cell membrane use a carrier protein to transport them across. The 'cost' for this service is that energy is required and is supplied by the cell's 'energy currency' – molecules of adenosine triphosphate (ATP). Sodium enters the cell this way, for example.
    - *Examples of active transport mechanisms: endocytosis* is the mechanism by which some particles or substances are transported into the interior of the cell, by being engulfed by the cell membrane. The reverse of this process is *exocytosis*, whereby vesicles are formed that fuse with the phospholipid membrane, and the particles are released from the cell interior to the exterior. One type of endocytosis is *phagocytosis*, which is shown in Fig. 1.6. This is where solid particles, such as bacteria, are

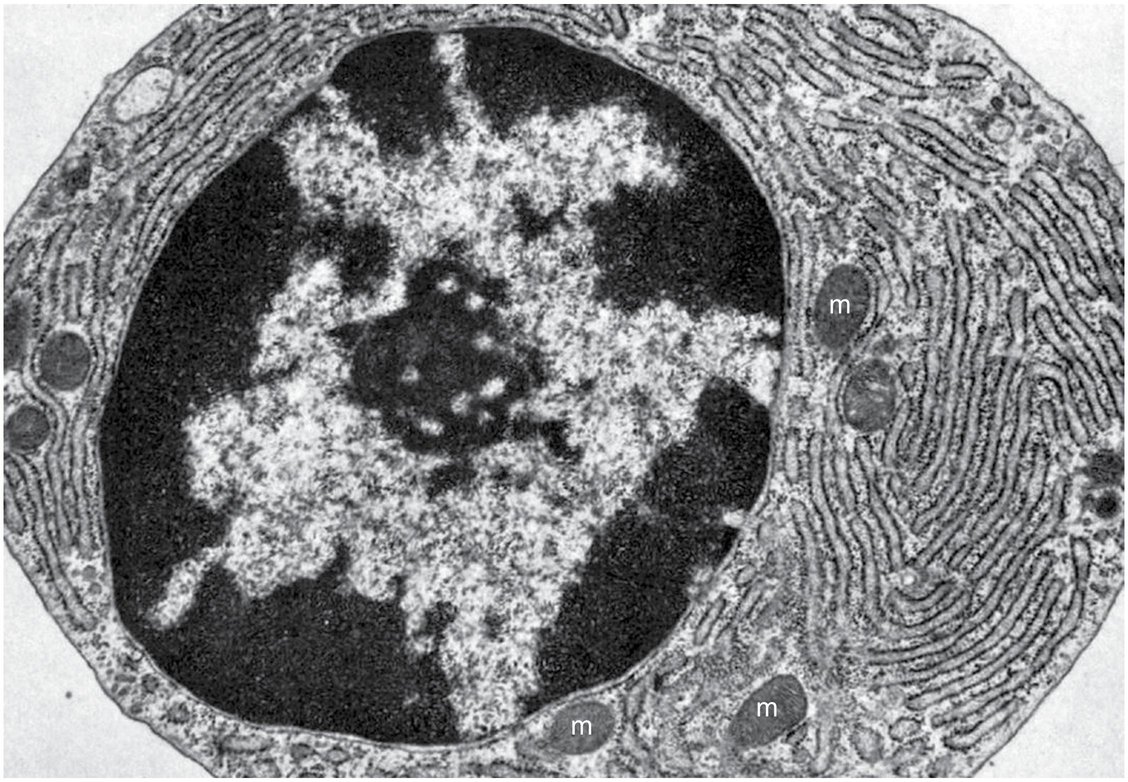


Fig. 1.3. Transmission electron micrograph of a plasma cell showing extensive rough ER and scattered mitochondria (m).
With permission from DA Samuelson, 2007. Textbook of veterinary histology. St Louis, MO: Saunders-Elsevier, p. 86.

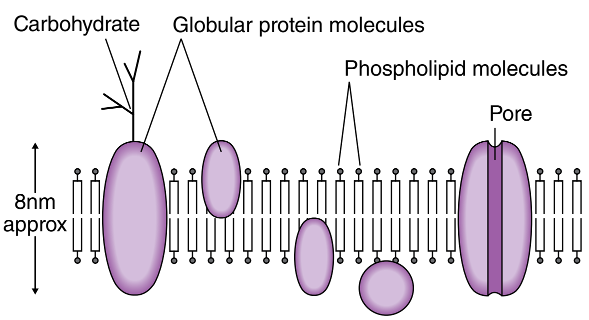


Fig. 1.4. Structure of the cell membrane showing the phospholipid bilayer. This structure is also known as the 'fluid mosaic model'.

transported into the cell. Another type of endocytosis is *pinocytosis*, where liquids with dissolved solutes, such as vitamins, are taken up by the cell. An example of exocytosis in the body is the release of neurotransmitter chemicals at a synapse (see Chapter 5).

The words *phago* and *pino* are derivatives of the Latin and Greek terms for 'eat' and 'drink', respectively. So phagocytosis can literally be translated into 'cell eating' and pinocytosis into 'cell drinking'.

Cytoplasm

This is the fluid that fills the interior of the cell, providing it with support. The nucleus and organelles are found within the cytoplasm, along with solutes such as glucose, proteins and ions.

Nucleus

The nucleus is the information centre of the cell. It is surrounded by a nuclear membrane and contains the *chromosomes*. Chromosomes are the bearers of the hereditary material, DNA (deoxyribonucleic acid), which carries the information for protein synthesis. DNA is the 'set of instructions' that tells the cell how to function, and these instructions are then passed on to the cell's descendants. The nucleus also contains several nucleoli, where the ribosomes (see below) are manufactured.

Organelles

- *Mitochondria*: these are responsible for cellular respiration and are the site where energy is extracted from food substances and stored in a form that the cell can use: ATP. Mitochondria have a smooth outer membrane and a highly folded inner membrane, which increases the surface area on which ATP production can take place (Figs. 1.2 and 1.3). Mitochondria are found in abundance in cells that are very active in terms of energy consumption (e.g., skeletal muscle). When a cell requires energy it uses its store of ATP molecules. The energy itself is stored in the bond that connects the phosphate group to the rest of the molecule (Fig. 1.5). If one of these phosphate groups is 'snapped off' the molecule, the bond is broken and energy is released. The remaining molecule is now called adenosine *di*phosphate (ADP), because it now has only two phosphate groups attached

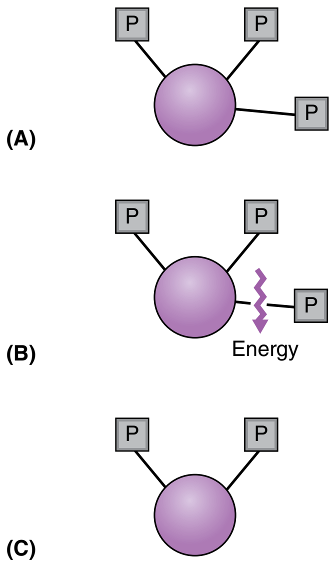


Fig. 1.5. The conversion of ATP to ADP to release energy. **(A)** The ATP molecule has three phosphate groups (P) attached by chemical bonds; energy is stored within the bonds. **(B)** One of the phosphate groups is 'snapped off', releasing energy. **(C)** The remaining molecule (ADP, with two phosphate groups) goes back into the metabolic cycle and has a phosphate group reattached, becoming ATP again.

to it (di = 2; tri = 3). However, the cell needs only to reattach another phosphate group (carried out as part of the cell's metabolic processes) and energy can be stored once more as ATP.

- *Ribosomes*: these float free in the cytoplasm and are the site for protein synthesis within the cell.
- *Endoplasmic reticulum (ER)*: this is a network of membrane-lined interconnected tubes and cavities within the cytoplasm of the cell. There are two types of ER:
    - *Rough ER* (Fig. 1.3) is so called because it has numerous ribosomes attached to its surface and thus appears 'rough' when viewed under a microscope. The function of rough ER is to transport the proteins that have been synthesised by ribosomes. Some of these proteins are not required by the cell in which they are made but are 'exported' outside the cell (e.g., digestive enzymes and hormones).
    - *Smooth ER* is so called because it does not have ribosomes on its surface; its functions include the synthesis and transport of lipids and steroids.
- *Golgi apparatus* or *body*: this is a stack of flattened sacs within the cytoplasm (Fig. 1.2). Its function includes the modification of some of the proteins produced by the cell (adding a carbohydrate component) and it plays a part in the formation of lysosomes.
- *Lysosomes*: these are membrane-bound sacs that contain lysozymes or digestive enzymes. Their function is to digest materials taken in by the cell during the process of phagocytosis or endocytosis (Fig. 1.6). Lysosomes also destroy worn-out organelles within the cell and, in some cases, the cell itself.

Lysosomal storage disease. This occurs if there is a dysfunction of the enzyme in the lysosomes resulting in the accumulation of waste substances. 'Lysosomal storage disease' is seen more commonly in cats. Storage diseases usually occur in young animals and present with clinical signs such as skeletal abnormalities, mental retardation, and neurological and ocular disorders.

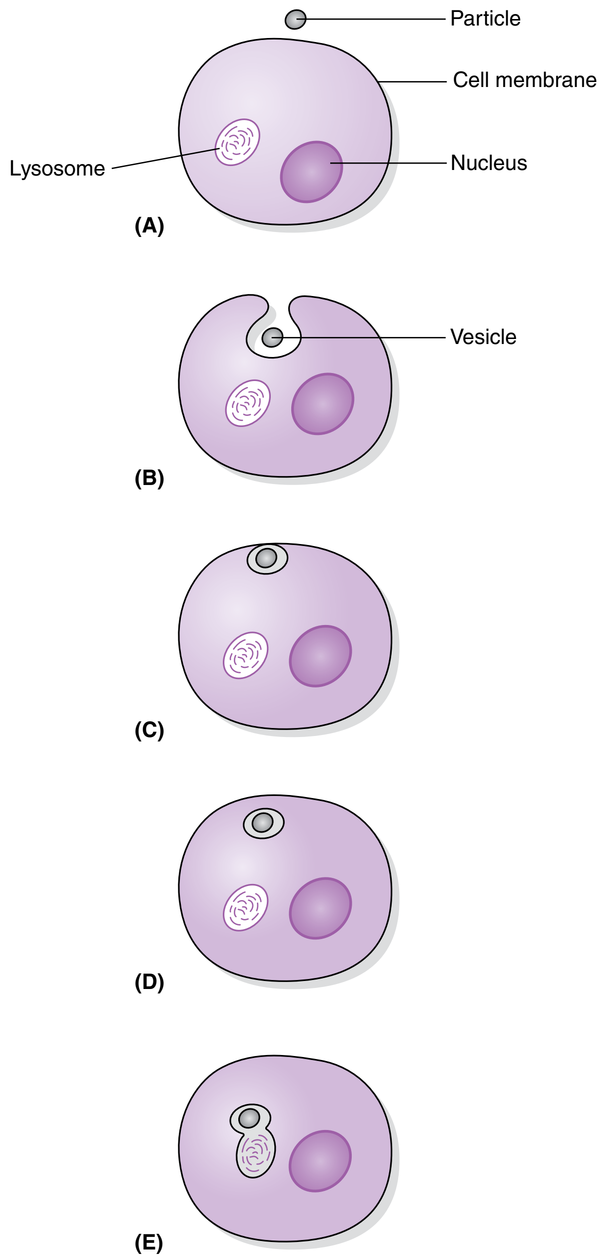


Fig. 1.6. Phagocytosis. **(A)** A small particle (e.g., bacterium) is present outside the cell. **(B)** The cell membrane invaginates and starts to enclose the particle. **(C)** The cell membrane completely surrounds the particle and seals it off in a vesicle. **(D)** The vesicle detaches from the membrane and enters the cell. **(E)** A lysosome, containing digestive enzymes, fuses with the phagocytic vesicle containing the particle and the particle is destroyed.

- *Centrosome and centrioles*: the centrosome contains a pair of rod-like structures called centrioles. These lie at right angles to each other and are involved in cell division (see mitosis).
- *Cilia and flagella*: these are extensions of the plasma membrane seen on some cells of the body. Cilia are found in large numbers on the outer surface of the cells and are responsible for creating a wave-like motion that moves fluid such as mucus and debris over the cell surface. Flagella are usually single and longer than cilia and move the cell along by undulating movements. The only example of a flagellum in mammals is the tail of a spermatozoon.

Materials can either be taken into the cell or exported out of it. These processes are called *endocytosis* and *exocytosis*, respectively. There are two types of endocytosis: phagocytosis or 'cell eating' and pinocytosis or 'cell drinking'. During both these processes the cell surface folds to make a small pocket that is lined by the cell membrane (Fig. 1.6). The pocket seals off, forming a vesicle that contains the material being brought into the cell. This separates from the cell surface, moves into the cell's interior and fuses with a lysosome, which contains lysozymes (a type of enzyme) that digest the vesicle contents. The process of phagocytosis is also used by some white blood cells to remove foreign particles such as invading bacteria (see Chapter 7 on blood cells).

Cell division

The cells of the body are classified into two types:

- *Somatic cells*: these include all the cells of the body except those involved in reproduction. Somatic cells divide by *mitosis* and contain the *diploid number* of chromosomes.
- *Germ cells*: these are the ova (within the ovaries) and the spermatozoa (within the testes). Germ cells divide by *meiosis* and contain the *haploid number* of chromosomes.

Mitosis

The tissues of the body grow, particularly when the animal is young, and are able to repair themselves when damaged. This is achieved by the process of mitosis in which the somatic cells of the body make identical copies of themselves. The cells replicate by dividing into two – a process called *binary fission*. However, before they can do this they must first make a copy of all the hereditary or genetic information that the new cell will need in order to function normally. This information is carried in the DNA (deoxyribonucleic acid) of the chromosomes within the nucleus of the parent cell. The normal number of chromosomes is described as the diploid number and before cell division takes place the chromosomes are duplicated (Fig. 1.7).

Mitosis can be divided into four active stages, followed by a 'resting' stage (called *interphase*), during which the new daughter cells grow and prepare for the next division. Interphase is not actually a resting stage because it is during this stage that the DNA replicates in preparation for the next mitosis. The centrioles have also replicated by the start of the new mitotic division. The four active stages of mitosis are:

1. *Prophase*: the nuclear membrane breaks down and the chromosomes contract and become shorter, fatter and more distinct. The identical pairs of chromosomes have not yet separated and are referred to as the *chromatids*. The chromatids are held together at a region called the centromere. The centrioles are now found at the opposite poles or ends of the cell and spindle fibres start to form. These are 'threads' passing from the centriole at one pole to the centriole at the other pole.
2. *Metaphase*: the chromosomes line up in the middle of the cell (known as the equator) and the chromatids draw apart at the centromere.
3. *Anaphase*: the chromosomes attach to the spindle fibres, which contract and move the chromatids towards the opposite poles of the cell.
4. *Telophase*: the chromatids will be the chromosomes of the daughter cells. The spindle fibres break down and the nuclear membrane reforms. The cell starts to constrict across the middle and continues until it is divided into two. Each of the new daughter cells is genetically identical to the original parent cell, and both contain the full set of chromosomes, known as the diploid number. The chromosomes then unravel and the cell returns to interphase.

> Mitosis results in the production of two identical daughter cells, each of which is identical to the parent cell and contains the diploid number of chromosomes.

Cancer is a mutation in cell division. The neoplastic (cancerous) cells have uncontrolled mitosis which results in a proliferation of cells forming a mass or tumour.

Meiosis

This is the process by which the germ cells divide within the ovary of the female and the testis of the male. Meiosis results in the production of ova or sperm containing *half* the normal number of chromosomes (the haploid number). Meiosis must occur before fertilisation, when a sperm penetrates the ovum and the two nuclei fuse. If those two nuclei had the diploid number of chromosomes then the nucleus of the resulting gamete would have twice the normal number and abnormalities would develop.

The resting cell is in interphase before meiosis begins. The eight stages are as follows (see also Fig. 1.8):

1. *Prophase I*: this takes longer than prophase in mitosis. The homologous (identical) chromosomes lie side by side and duplicate; each pair is joined at the centromere. These chromosomes may become entangled and pieces of one chromosome may become attached to another – this process is known as 'crossing over' and may influence the characteristics of the offspring.
2. *Metaphase I*: the homologous pairs of chromosomes come to lie along the line of the equator of the cell and the fibrous spindle starts to form.
3. *Anaphase I*: the pairs separate and the chromatids migrate along the spindle fibres towards the poles of the cell.
4. *Telophase I*: the cytoplasm begins to divide but the nuclear membrane does not reform. In some cells, the cytoplasm does not divide completely and a dumb-bell shaped cell is seen – this is known as a *syncytium*. Telophase I is the *first meiotic division*.
5. *Prophase II*: this may be transitory as there is no need to replicate the chromosomes.

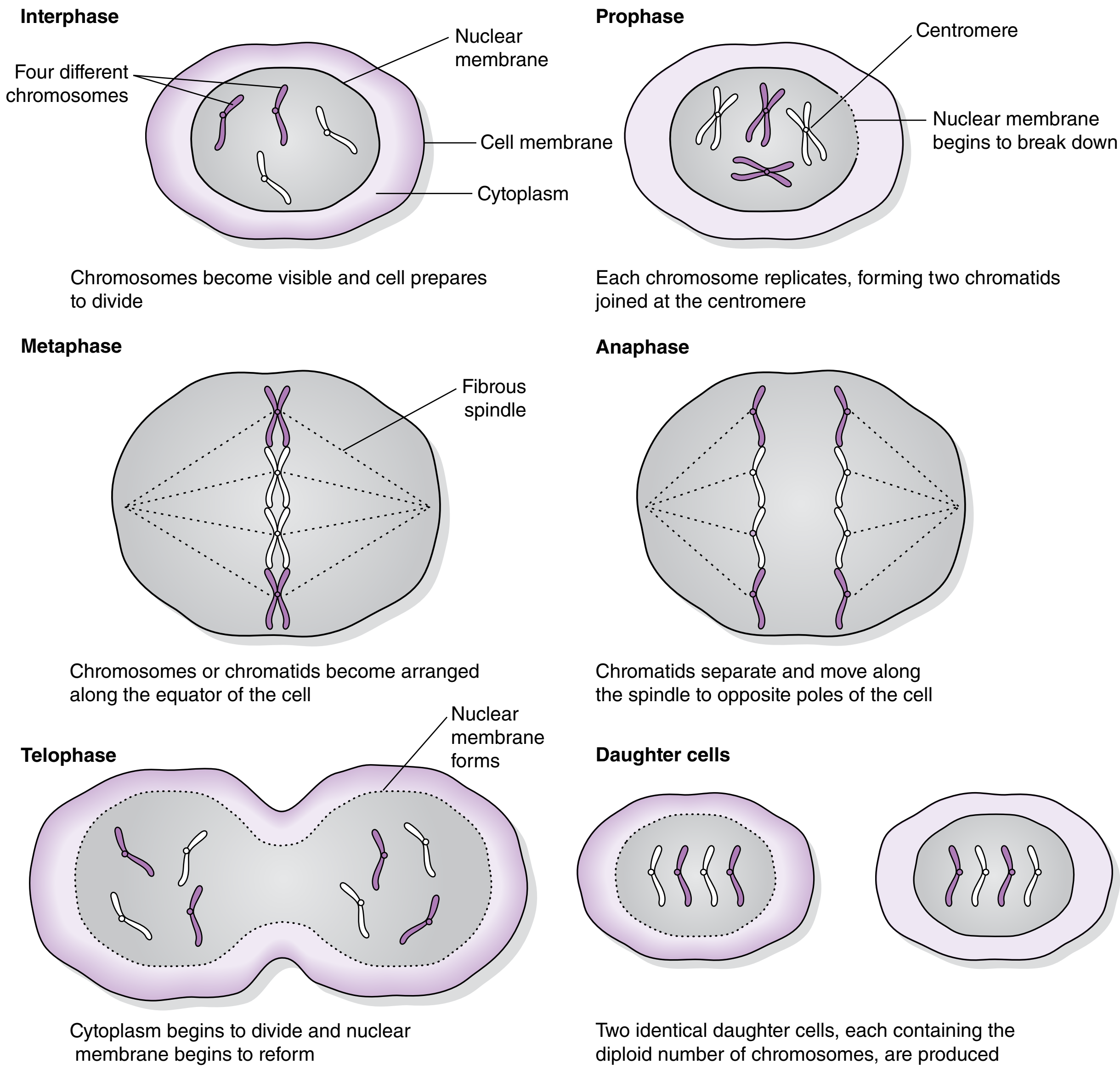


Fig. 1.7. Mitosis – the cell division seen in somatic cells.

6. *Metaphase II*: the chromosomes arrange themselves along the equator and the spindle fibres appear.
7. *Anaphase II*: the chromatids pull apart and migrate towards the poles of the cells.
8. *Telophase II*: the cytoplasm begins to divide, the nuclear membrane reforms and four identical daughter cells are formed. Telophase II is the *second meiotic division*.

> Meiosis results in the production of four identical daughter cells, each of which is non-identical to the parent cell and contains the haploid number of chromosomes.

An *inherited* condition is one that has been passed on to the offspring from one or both of the parents in their DNA. Examples include progressive retinal atrophy (PRA), which causes a degeneration of the retina in dogs resulting in blindness, and von Willebrand disease which is a blood clotting disorder. Both these conditions can be screened for in a genetic test before breeding from male and female dogs (even if they are not apparently affected they may carry the gene) to prevent passing on these serious diseases to their puppies.

A *congenital* condition may have an inherited component but can also be as a result of an abnormality occurring during the development of the unborn puppy or kitten. This can be due to many factors; for example, as a result of the mother contracting a virus during pregnancy or due to malnutrition of the bitch or queen (see Chapter 11 for more detail).

The chemistry of the body

The cells, and therefore the tissues and organs, which are all made of cells, are composed of chemicals. It is important to be able to understand these chemicals and the reactions in which they take part within the body. Chemical compounds can be divided into two groups:

- *Organic* compounds are those that contain the element carbon.

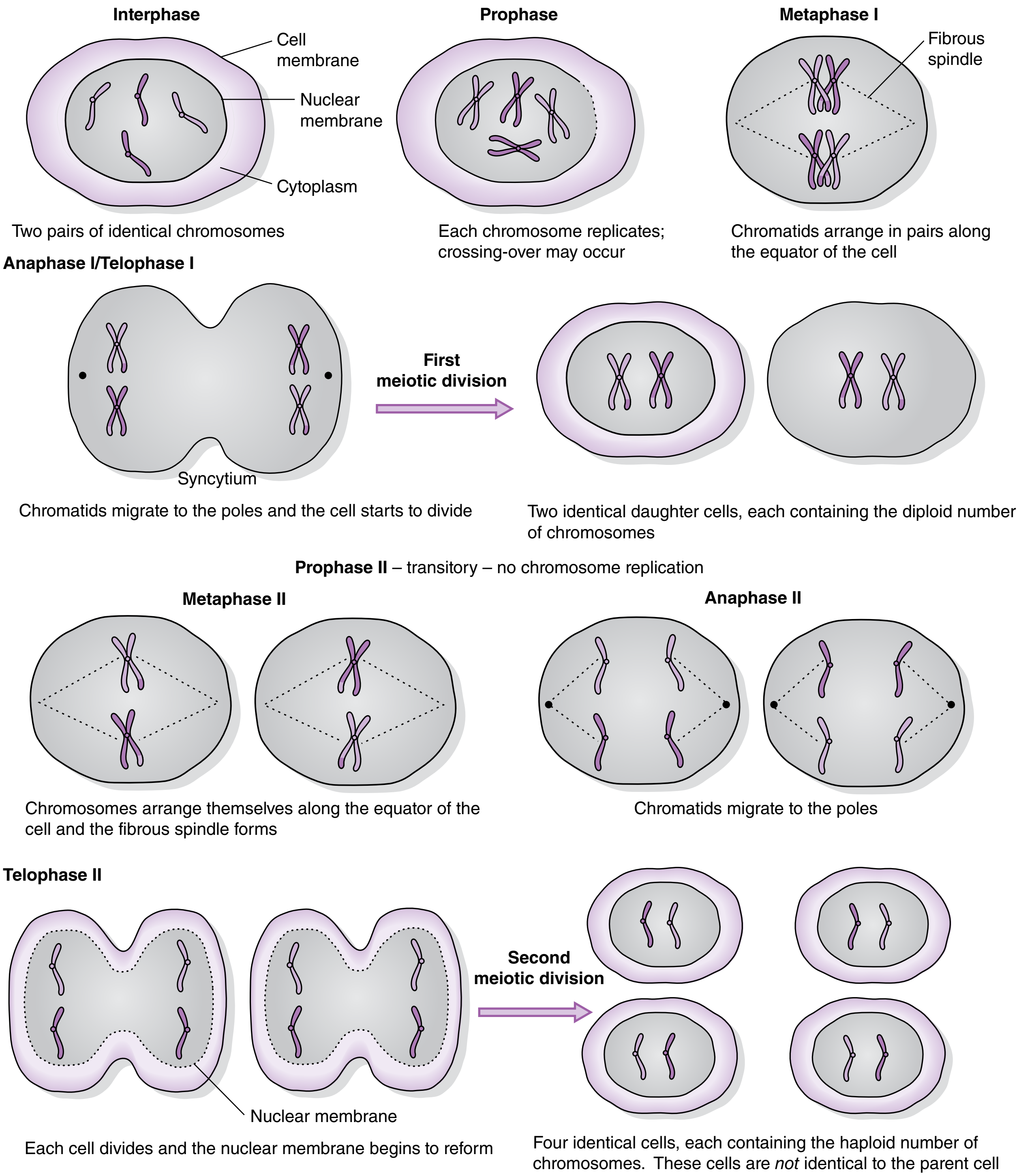


Fig. 1.8. Meiosis – the cell division seen in the germ cells.

- *Inorganic* compounds are all those compounds that do not contain carbon.

Both groups are found in the body but let us first look at the most biologically important inorganic compound of the body – water (H_2O).

Water content of the body

An individual mammalian cell contains ~ 80% water. In fact, 60–70% of the whole body's weight is water, which is divided into two main body compartments: *intracellular* (ICF) and *extracellular* (ECF) water.

ICF is that which is found inside the cells of the body and can be subdivided into the fluid within the blood cells and the fluid in all other cells. ICF takes up 40% of total body weight.

ECF is that which lies outside the cells (i.e., the surrounding environment of the cells). ECF takes up 20% of total body weight and includes the fluid in which the blood cells are suspended (the plasma), the fluid within the lymphatic system and the cerebrospinal fluid (the transcellular fluid), and the fluid that surrounds all the other cells of the body (the interstitial or tissue fluid).

Plasma takes up about 5% of body weight. It forms the medium in which the blood cells are transported within the blood vascular system. It is rich in proteins, termed plasma proteins.

Transcellular fluid is formed by active secretory mechanisms and its volume varies. It is considered to take up about 1% of body weight and it includes fluids such as cerebrospinal fluid, digestive juices and lymph. *Interstitial fluid* takes up 15% of body weight and lies outside the blood vascular system, surrounding the cells. It is formed from the blood by a process of ultrafiltration – small molecules and ions are separated from larger molecules and cells. The pressure in the blood vascular system forces the fluid through the walls of the capillaries. This acts like a sieve, holding back the large plasma protein molecules and the cellular components of the blood and allowing everything else to go through. Thus, interstitial fluid is similar to plasma but *without* the blood cells and protein molecules. Interstitial fluid is the medium in which the cells are bathed and from it the cells extract all that they need, such as oxygen and nutrients. They also get rid of all their unwanted waste products into the interstitial fluid.

Water or fluid provides the medium in which all the body's biochemical reactions take place and is thus essential to maintain the body's internal environment in a state of balance – this is a process known as *homeostasis*. Body water and the chemical substances within it constantly move around the body. The biological processes that are responsible for this movement are diffusion and osmosis.

Diffusion

Diffusion (Fig. 1.9A) is the movement of molecules of a liquid or a gas down a concentration gradient (i.e., from a region where they are at a high concentration to a region where they are at a lower concentration). Diffusion will occur until an equilibrium is reached (i.e., until the concentration equalises out). Diffusion takes place where there is no barrier to the free movement of molecules or ions and is very important in their movement in and out of cells. However, it can only occur if the particle size is small enough to pass through the cell membrane. If the molecules are too large, then another process takes place in order to achieve equilibrium – this is known as osmosis.

Osmosis

Osmosis (Fig. 1.9B) is the movement of water through a *semi-permeable membrane* from a fluid of low concentration to one of a higher concentration, which continues until the two concentrations are equal. The water is diffused along a concentration gradient. A semi-permeable membrane allows some substances through but not others. Osmosis is responsible for water movement from the interstitial fluid into the cells.

A solution consists of the molecules of one substance (the solute) dissolved in another substance (the solvent). In the body, the solvent is water, so osmosis is a significant factor in the maintenance of the fluid volume within the body fluid compartments. A solution can be described as having an *osmotic pressure*. This is the pressure needed to prevent osmosis from occurring and is dependent on the number of particles, both dissolved and undissolved, in the solution; in other words, if the osmotic pressure of the plasma is high, water will flow into the blood to equalise the concentration; if the osmotic pressure of the plasma is low, water will flow out of the blood into the tissue spaces.

The osmotic pressure or tonicity of a rehydrating fluid is described relative to the osmotic pressure of blood plasma as follows:

Isotonic: fluid has the same osmotic pressure as plasma.
Hypotonic: fluid has a lower osmotic pressure than plasma.
Hypertonic: fluid has a higher osmotic pressure than plasma.

This is important in selecting fluids for rehydration therapy – most fluids used are isotonic. The replacement fluid must be as close as possible in tonicity and electrolyte content to that which has been lost from the body.

Fluid balance

Water is constantly moving within the body – from the interstitial fluid into the cells, from the plasma to the tissue fluid, and so on – but it is also continually lost from the body and must be replaced to ensure that the total fluid balance in the body is maintained. Water is lost through the respiratory system (expired air contains water vapour), and in the urine and faeces. Dogs and cats do not sweat appreciably but do lose heat and water through panting. Water is also lost in the tears, which are produced constantly to moisten the eye, and in vaginal secretions. Water is taken into the body through drinking fluids and from the water content of food.

Fluid losses may be increased in sick or injured animals, through vomiting, diarrhoea, vaginal discharge (as seen with an open pyometra) or blood loss. This can lead to dehydration, which may have serious consequences, such as reduction of the circulating blood volume, known as hypovolaemic shock. In a normal adult animal, about 60% of the total body weight is water. This percentage will be slightly lower if the animal is old or very obese (fatty tissue contains little water) and slightly higher in young or thin animals.

Typical daily water loss is: 20 ml/kg body weight in the urine; 10–20 ml/kg body weight in the faeces; and 20 ml/kg body weight through the loss of water vapour in expired air and panting and in body secretions – a total of 50–60 ml of water per kg of body weight daily. Thus an adult healthy animal should take in 50–60 ml of water per kg of body weight per day to balance the normal fluid loss (e.g., an animal weighing 20 kg will need 1000–1200 ml of water each day).

Inorganic compounds

A number of other inorganic compounds are also essential to the functions of the body: minerals, acids and bases. It is important to be familiar with some basic chemical definitions when considering these substances. Everything is composed of *atoms*, and an *element* is a substance that is composed of only one kind of atom (e.g., the element oxygen consists only of oxygen atoms). *Molecules* consist of two or more atoms linked by a chemical bond. A substance whose molecules contain more than one type of atom is called a *compound*.

When dissolved in water, the molecules of many substances break apart into charged particles, called *ions*. This charge may either be negative or positive: ions with one or more positive charges are called *cations* and ions with one or more negative charges are called *anions*.

An *electrolyte* is a chemical substance that, when dissolved in water, splits into ions and is thus capable of conducting an

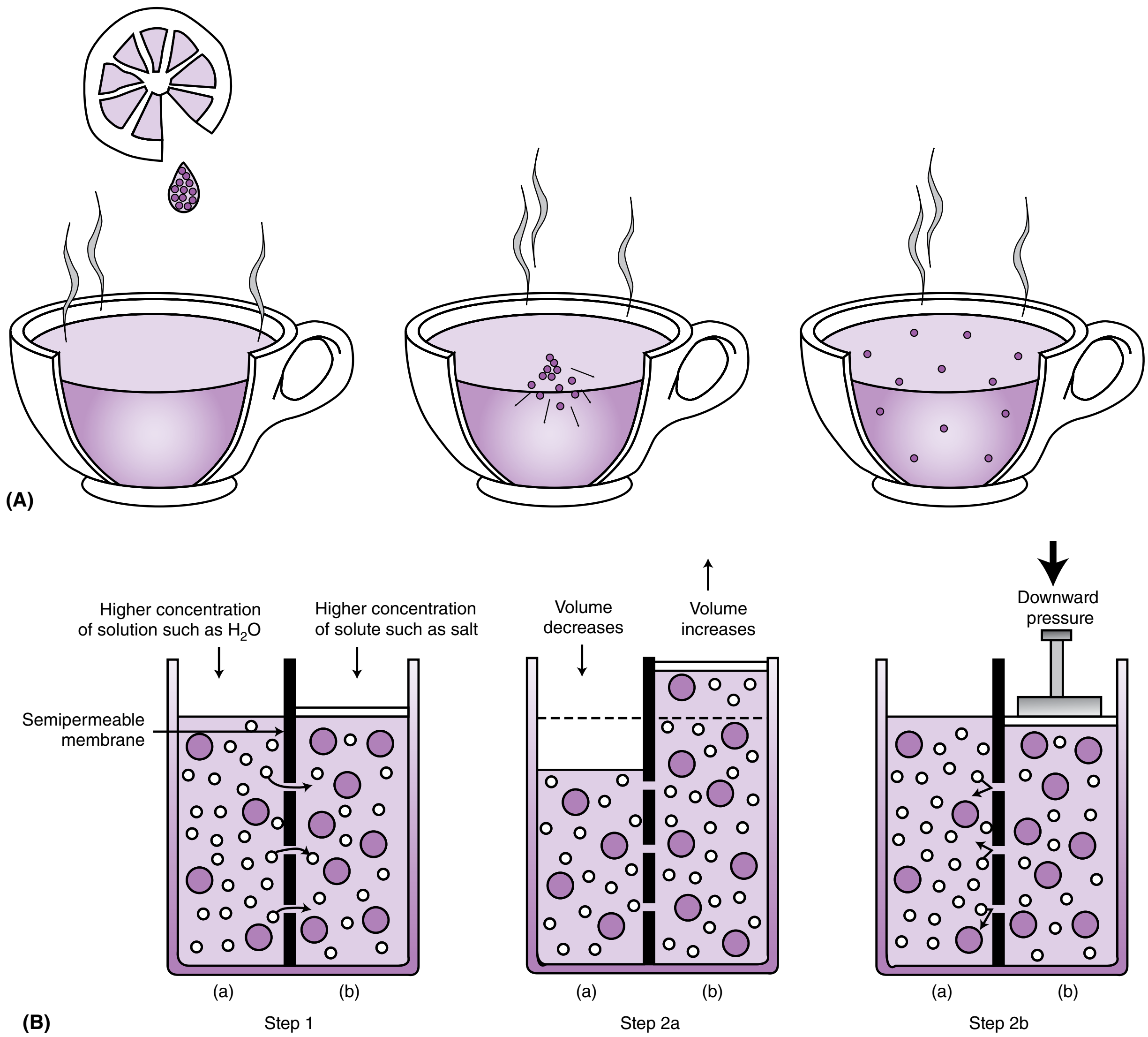


Fig. 1.9. **(A)** Diffusion. Molecules in solution are active and constantly collide into one another. With time, they become evenly distributed throughout the liquid, having moved down concentration gradients from areas of high concentration to those of low, until equilibrium is reached. Diffusion occurs when there is no barrier to free movement and it occurs more rapidly in hot liquids than in cold ones as molecules are more active at higher temperatures. (With permission from T Colville, JM Bassett, 2001. Clinical anatomy and physiology for veterinary technicians. St Louis, MO: Mosby, p. 24.) **(B)** Osmosis. Step 1: Smaller molecules of solution in side (a) can pass through the semi-permeable membrane into side (b), but the larger molecules of solute cannot. Step 2a: As solution moves from side (a) to side (b), the volume of side (b) increases until the concentration of solute is the same on both sides. Step 2b: Osmosis can be reversed by filtration, when hydraulic pressure is placed on side (b). This forces solution back through the semi-permeable membrane to side (a). (With permission from T Colville, JM Bassett, 2001. Clinical anatomy and physiology for veterinary technicians. St Louis, MO: Mosby, p. 25.)

electric current. Sodium chloride (NaCl) is an example of an electrolyte in the body, its ions being sodium (Na^+) and chloride (Cl^-) in solution.

Minerals

The principal cations in the body are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The principal anions include chloride (Cl^-) and bicarbonate (HCO_3^-). These ions are essential to the functions of the body and it is vital that they are present in sufficient and balanced quantities. Sodium and chloride are mainly found in the ECF, while potassium is mainly found in the ICF (i.e., inside the cells). The concentration of these ions is important in the regulation of fluid balance between the intracellular and extracellular fluids. This balance is maintained by special 'pumps' in the cell membrane. An imbalance will lead to significant problems; for example, sodium affects the osmotic pressure of the blood and so influences blood volume and pressure; a high concentration of potassium in the ECF can disrupt heart function.

Calcium, phosphorus and magnesium are important minerals that are found in storage in bone tissue. Calcium is essential for many processes in the body, such as muscle contraction, nerve conduction and blood clotting. Iron and copper are also essential to normal body function, iron being an essential component of the haemoglobin in red blood cells.

Hypocalcaemia is where there are insufficient calcium levels in the blood, resulting in muscle twitching and tremors, uncoordinated gait, panting, vomiting and seizures. There are a number of causes including endocrine dysfunction, kidney failure and neoplasia. It can also occur in dogs (and rarely cats) post-partum (after they have given birth). This is called eclampsia or 'milk fever' and can be life threatening if untreated.

Acids and bases

An *acid* is a compound that can release hydrogen ions when dissolved in solution. Compounds that can accept or take in hydrogen ions are called *bases* or *alkalis*. The acidity of a solution is expressed as its pH, which is the measure of the hydrogen ion concentration. The pH scale is from 0 to 14, with a pH of 7 being neutral. A solution with a pH less than 7 is acidic (the lower the number the higher the acidity, i.e., the greater the concentration of hydrogen ions). A solution with a pH above 7 is basic or alkaline (the higher the number the more alkaline the solution).

The pH of body fluids is 7.35 and it is important that the body maintains this level. Within the respiratory system and kidneys there are homeostatic processes to maintain the correct acid–base balance.

Acid–base balance. When the normal pH of the body is disrupted, the animal may show an acidosis (i.e., a decreased blood pH) or an alkalosis (i.e., an increased blood pH).
A respiratory acidosis may develop if the animal holds its breath, allowing carbon dioxide levels to rise and oxygen levels to fall; a respiratory alkalosis occurs during rapid panting, which lowers carbon dioxide levels. A metabolic acidosis may occur as a complication of diabetes mellitus and a metabolic alkalosis as a result of excessive vomiting and diarrhoea.

Organic compounds

These are compounds that are based on the element carbon. The other main elements found in organic compounds are oxygen and hydrogen, and in some instances nitrogen. The principal organic compounds found in the body are carbohydrates, proteins and fats.

Carbohydrates

Carbohydrates contain carbon, hydrogen and oxygen and are also known as sugars. Sugars are an important source of energy and the most common simple sugar in the body is glucose (Fig. 1.10). Simple sugars can join together to form more complex carbohydrates; when many sugars join together they form a *polysaccharide* (e.g., glycogen, which is the form in which glucose is stored in the body). Carbohydrates are obtained from food and are then broken down during digestion into simple sugars so that they can be absorbed through the mucous membrane of the digestive system into the blood and utilised by the body.

Lipids

Lipids include the fats, which are compounds of fatty acids and glycerol (Fig. 1.11) and are also made up of carbon, hydrogen and oxygen. Fatty acids are the main form in which fats are transported in the blood after the breakdown of lipids obtained from food. Although carbohydrates provide the most direct source of energy for the body, fats can also yield a large amount of energy. They are an important means of energy storage for the body, to be used when required. Other functions of lipids include insulation of the body itself and of nerves, and in the formation of cell membranes and synthesis of steroids.

Proteins

Proteins are built up from subunits called *amino acids* (Fig. 1.12). Proteins differ from carbohydrates and lipids in that they always contain nitrogen in addition to carbon, hydrogen and oxygen. They may also contain other elements such as sulphur, phosphorus and iodine. When two amino acids are joined together by a peptide link they form a dipeptide. The addition of more amino acids (a process called *polymerisation*) leads to the formation of a polypeptide. A protein consists of one or more polypeptide chains, which are then coiled and folded to give the specific structure of a particular protein (Fig. 1.13).

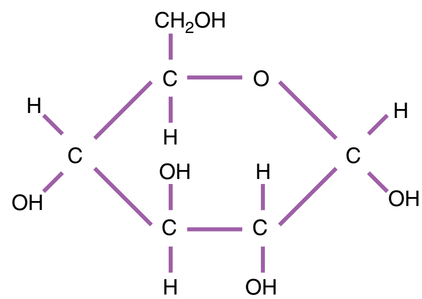


Fig. 1.10. Chemical structure of a simple carbohydrate – the sugar glucose.

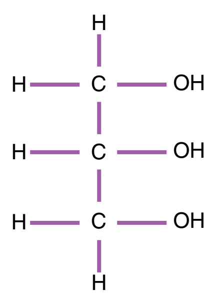


Fig. 1.11. Chemical structure of glycerol.

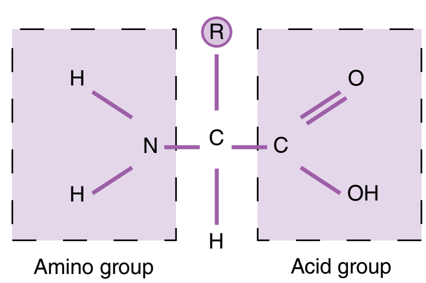


Fig. 1.12. General structure of an amino acid. The 'R' group varies from amino acid to amino acid.

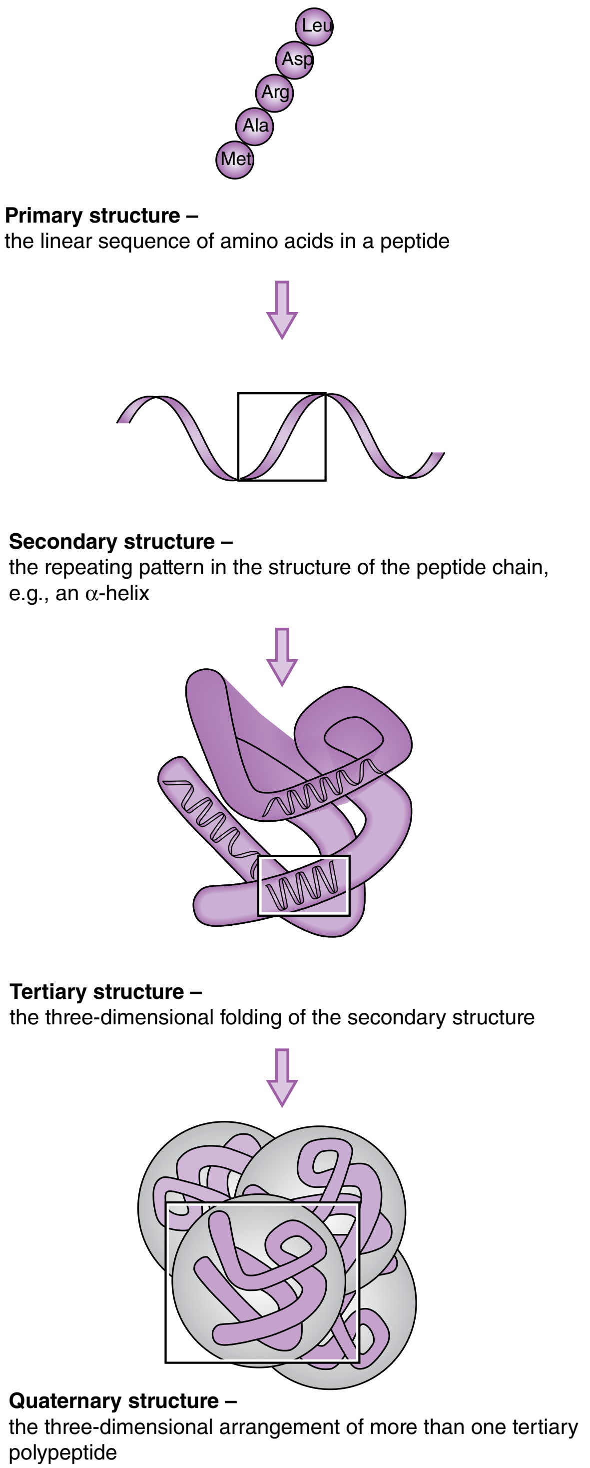


Fig. 1.13. The structure of a protein. It is not only the sequence of amino acids, but also the arrangement of the polypeptide chains, which determine the characteristics of a protein.

Proteins generally fall into one of two groups:

- *Globular*: the functional proteins. These are associated with cellular chemical reactions and include hormones and enzymes.
- *Fibrous*: the structural proteins. These are insoluble and are part of the composition of various structures in the body. They include keratin, collagen and elastin.

By means of digestive enzymes the body breaks down the proteins acquired from the diet into their constituent amino acids, which can then be absorbed through the mucous membrane of the digestive system into the blood.

> Taurine is an example of an amino acid found in the body, which most mammals are able to manufacture naturally. However, cats have a limited ability to do this and have to rely on obtaining this essential amino acid from their diet of animal-rich proteins. Taurine deficiency in cats can result in significant health problems, such as the degeneration of the retina and cardiomyopathy.

Chemical reactions in the body

Most of the chemical reactions that take place in the body require the presence of a functional protein compound called an *enzyme*. Enzymes are organic catalysts that speed up and control chemical reactions in the body. Enzymes are involved in the breakdown of food in the digestive system but are also involved in the many metabolic processes that are carried out within cells all around the body.

> A chemical reaction that requires an input of energy is called an *anabolic* reaction. A chemical reaction that releases energy is a *catabolic* reaction. The sum of the energy use (i.e., the gain and loss) is the *total metabolism*.

All animals require energy and this is provided by raw materials obtained from food. This is then converted by the body into a form that it can use – called ATP (adenosine triphosphate). Energy cannot be created or destroyed, it is just moved around or else changes its form; for example, electrical energy can be converted to heat energy, or it can be stored as potential energy that is released when the compound in which the energy is stored is broken down. In the body of an animal, energy comes from the oxidation of glucose (i.e., a reaction involving oxygen and glucose).

Digital enhancements are available via the Ludenso Explore App and CABI Academy - https://academy.cabi.org/course/view.php?id=439