Chapter 1

Basic scientific principles of physiology

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Test your prior knowledge

- What is the difference between anatomy and physiology?
- Why is the process of osmosis essential for the functioning of the human body?
- What is an electrolyte?
- What is the process of external respiration in humans?
- Define homeostasis.

Learning outcomes

After reading this chapter you will be able to:

- Describe the levels of organisation of a body
- Describe the characteristics of life
- Understand and be able to explain an atom and how it relates to molecules
- Describe and understand the ways in which atoms can bind together
- Describe elements and their characteristics
- Understand how to read chemical equations
- Describe the pH scale and its importance to life
- List the differences between organic and inorganic substances
- List the various ways in which we measure things

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Introduction

Learning about the physiology of the body is very much like learning a foreign language – there are new vocabulary, grammar and concepts to learn and understand. This first chapter introduces you to this new language so that you can then use your knowledge to understand the physiology of the different parts of the body that are discussed in all the other chapters of this book.

First of all there are two terms to learn and understand:

- **anatomy**, the study of structure;
- **physiology**, the study of function.

However, structure is always related to function because the structure determines the function, which in turn determines how the body/organ, and so on, is structured – the two are interdependent.

Levels of organisation

The body is a very complex organism that consists of many components, starting with the smallest of them – the atom – and concluding with the organism itself (Figure 1.1). Starting from the smallest component and working towards the largest, the body is organised in the following way:

- The atom – for example, hydrogen, carbon.
- The molecule – for example, water, glucose.
- The macromolecule (large molecule) – for example, protein, DNA.
- The organelle (found in the cell) – for example, nucleus, mitochondrion.
- The tissues – for example, bone, muscle.
- The organs – for example, heart, kidney.
- The organ system – for example, skeletal, cardiovascular, respiratory, renal.
- The organism – for example, mouse, dog, elephant, and, of course, humans.

Characteristics of life

All living organisms have certain characteristics in common. Although these characteristics may differ from organism to organism, they are all important for the maintenance of life. These characteristics are:

- **Reproduction** – at both the micro- and the macrolevel, reproduction is an essential process. At the macrolevel is the reproduction of the organism, and at the microlevel is the reproduction of new cells to maintain the efficiency and growth of the organism.
- **Growth** – essential for the growth and development of an organism.
- **Movement** – changes in position as well as motion are parts of movement. This characteristic is essential to allow the organism to seek out nutrition, partners for reproduction, escape from predators, and so on
- **Respiration** – external respiration is important for obtaining oxygen and releasing carbon dioxide (or obtaining carbon dioxide and releasing oxygen if a green plant), while internal respiration releases energy from foods.

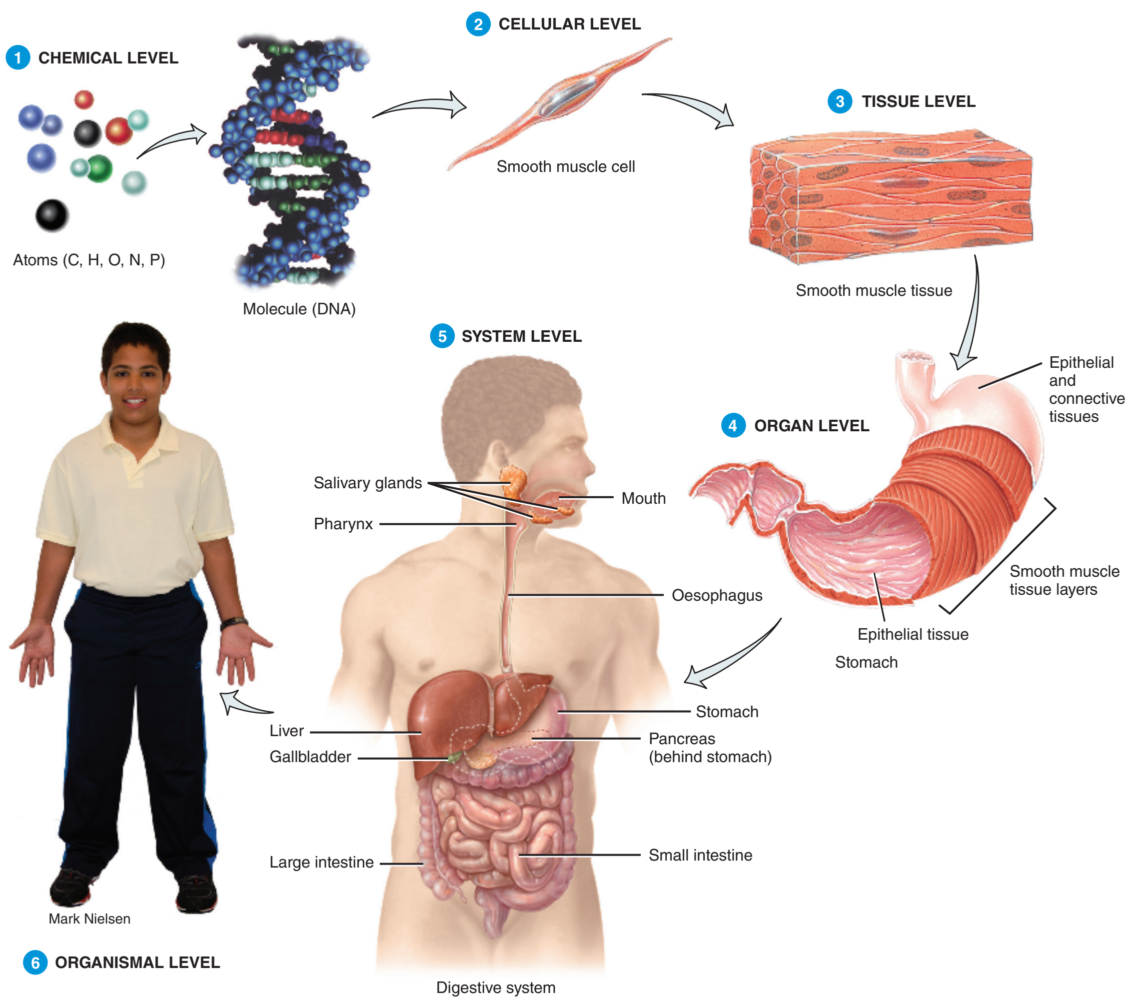

Figure 1.1 Levels of organisation of the body. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

- **Responsiveness** – organisms need to be able to respond to changes in the environment, for example, or to other stimuli such as predator danger.
- **Digestion** – this is the breakdown of food substances, so that the organism can produce the energy necessary for its life.
- **Absorption** – the movement of substances, such as digested food, through membranes and into body fluids, including blood and lymph, which then carry the substances to the parts of the organism requiring them.
- **Circulation** – the movement of substances through the body in the body fluids.
- **Assimilation** – the changing of absorbed substances into different substances, which can then be utilised by the tissues of the body.
- **Excretion** – the removal of waste substances from the body, either because they are of no use to the body or because they are harmful to the body.

Bodily requirements

There are five essential requirements that all organisms, including humans, require:

1. **Water**
   - Water is the most abundant substance found in the body. At birth, up to 78% of a baby's body is composed of water, at 1 year of age this has dropped to 65%. In adult males the figure has dropped to 60% and in adult females the figure is 55% (females have more fat than males as a percentage of their body, which accounts for the difference, although a fat adult male would also have a lower percentage than a thin adult male).
   - Water is required for the various metabolic processes that are necessary for an organism's survival.
   - Water is necessary to transport essential substances around the organism.
   - Water helps to regulate body temperature – a human operates within a very narrow temperature range and has an inability to cope with large temperature changes within the body. If body temperature exceeds this range – either below or above – then death will occur. Sweating is an example of water helping to reduce a high temperature – it cools the body surface as it evaporates (evaporative cooling).
2. **Food**
   - Food supplies the energy for the organism to fulfil all the essential characteristics mentioned above.
   - It also supplies the raw materials for these characteristics – particularly growth.
3. **Oxygen**
   - Oxygen forms 20% of air and is used in the release of energy from the assimilated nutrients.
4. **Heat**
   - Heat is a form of energy that partly controls the rate at which metabolic reactions occur.
5. **Pressure**
   - There are two types of pressure that are required by an organism:
     - atmospheric pressure, which is important in the process of breathing;
     - hydrostatic pressure, which keeps the blood flowing through the body.

Atoms

It is now time to consider the smallest building block of the body (indeed of all matter), namely the atom. The word 'atom' comes from a Greek word which means 'incapable of being divided'. However, we now know that an atom consists of electrons, neutrons and protons.

The atom, as can be seen from Figure 1.2, is made up of even smaller matter, namely:

- protons
- neutrons
- electrons.

Protons carry a positive electrical charge and electrons carry a negative electrical charge, while the neutron, as its name implies, carries no electrical charge (it is neutral).

As can be seen from Figure 1.3, electrons move rapidly around the nucleus of the atom, which itself is made up of protons and neutrons. The electrons of an atom are bound to the nucleus by electromagnetic force.

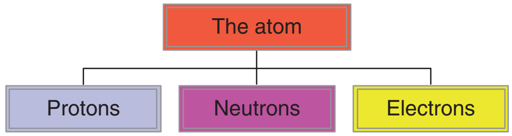

Figure 1.2 The atom.

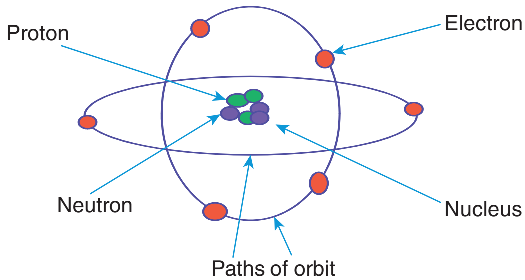

Figure 1.3 Schematic diagram of an atom.

Although there are many different types of atoms, they always have the same make-up – just different numbers of paths of orbit, **electrons, neutrons** and **protons** – and the same characteristics, while atoms of different elements (e.g. iron, carbon, sodium) have different numbers of electrons, protons and neutrons. For example:

- The nucleus is always central.
- The inner shell (path of orbit) always has a maximum of two electrons.
- The second shell can have a maximum of eight electrons.
- The third shell can have a maximum of 18 electrons, and so on.
- Of importance is the valence shell. This is the outermost shell of an atom and determines how the atom behaves in chemical reactions with other atoms. This can have a maximum of eight electrons (known as the octet rule). These **valence electrons** can participate in the formation of a **chemical bond**. See 'Covalent bonds' section.

Atomic number

All atoms are designated a number, known as the atomic number, and the atomic number of an atom is the same as the number of protons in that atom. Consequently, the atomic number of a carbon atom, which has six protons, is 6, while the sodium atom has 11 protons and therefore its atomic number is 11, and a chlorine atom has 17 protons and so has an atomic number of 17.

Carbon atom

Carbon, a very important atom for life forms because we are all carbon-based entities, will demonstrate the make-up of an actual atom.

As you can see from Figure 1.4, carbon has six electrons orbiting the nucleus, which is made up of six protons and six neutrons. Therefore, it has the same number of electrons, protons and neutrons. This is unusual, because while it is normal to have the same number of electrons and protons, usually the number of neutrons differs from the numbers of electrons and protons in an atom.

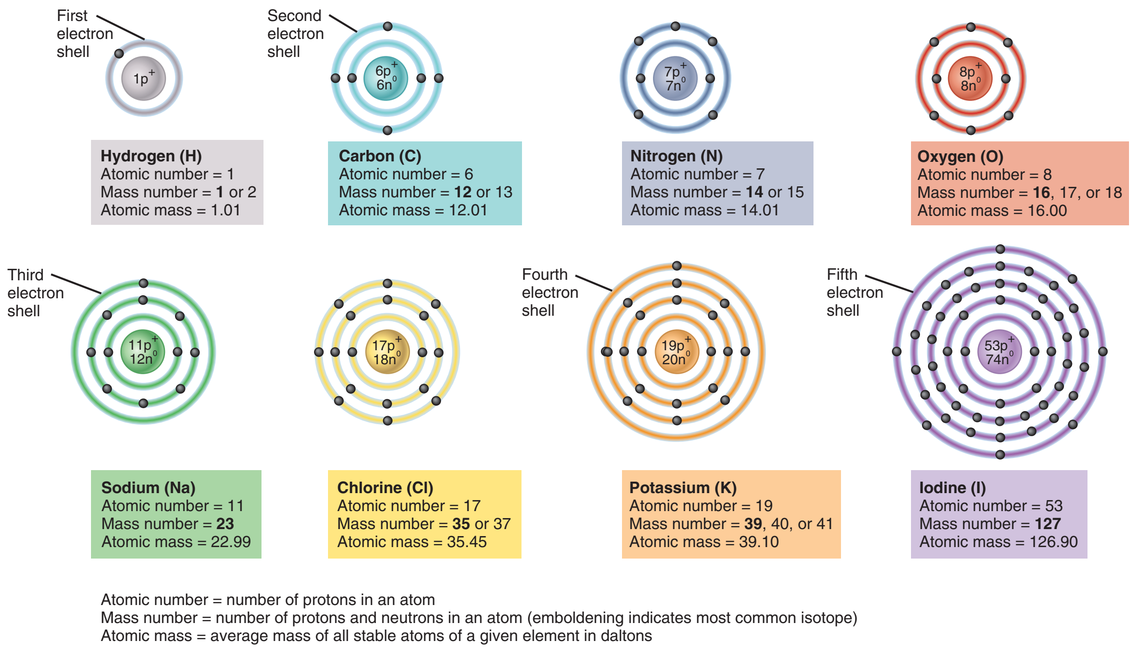

Figure 1.4 The carbon atom. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

A basic principle of the atom is that the number of electrons is equal to the number of protons in each atom, and this is all to do with electricity. As mentioned above, protons carry a positive electrical charge, electrons carry a negative electrical charge and neutrons carry a neutral charge (i.e. they carry no charge), and the aim of all atoms is to remain electrically stable (electrically neutral). Therefore, as neutrons carry no electrical charge, it is important that electrons and protons are equal in number to maintain the stability/neutrality.

Thus, as the carbon atom carries six electrons, six protons and six neutrons, the electrical charges of the electrons and protons cancel one another out. As a consequence, overall, the atom is neutrally charged and it is said to be in a state of equilibrium.

Molecules

This need for the atom to be in equilibrium is the driving force behind the combining of atoms to make molecules (the next stage in the building of life forms). A molecule is the smallest particle of an element or compound that exists independently. It contains atoms that have bonded together. For example, sodium chloride (NaCl) is a molecule containing one atom of sodium (also known as natrium, hence the symbol Na) which has bonded to one atom of chlorine (symbol Cl). Similarly, the molecule H_2O is made up of two atoms of hydrogen (H) bonded to one atom of oxygen (O). H_2O is better known as water.

Chemical bonds

A chemical bond is the way in which atoms bind to one another by the atoms attaining a lower energy state through losing, gaining or sharing their outer shell electrons with other atoms.

A chemical bond is the 'attractive' force that holds atoms together. This interaction results in the formation of atoms or ions that are in a lower energy state than the original atoms.

The formation of chemical bonds also results in the release of energy previously contained in the atoms, as shown in the formula

$$\text{atom} + \text{atom} \rightarrow \text{atom}\text{—}\text{atom} + \text{energy}$$

The combining power of atoms is known as **valence**. Because the only shell that is important in bonding is the outermost shell, this shell is known as the valence shell (Marieb, 2014).

There are several types of chemical bonds that occur between atoms, namely:

- ionic bonds
- covalent bonds
- polar bonds/hydrogen bonds.

Ionic bonding of atoms

Atoms always prefer to be in a state of electrical equilibrium. However, sometimes an atom that has a stable structure may lose an electron, in which case it becomes unstable. For example, a sodium (Na) atom is an atom that may lose an electron, and in this case, in order to become stable again, it must connect with an atom that can accept an electron – for example, chlorine (Cl). So, consequently, when sodium atoms and chlorine atoms are mixed together, one electron of each sodium atom will move to an equivalent atom of chlorine – as depicted in Figure 1.5 – thus forming the molecule sodium chloride (NaCl), also known as common salt. This is known as **ionic bonding**, because **ions** are involved.

Ions

An ion is an atom or a molecule in which the total number of electrons is not equal to the total number of protons – hence the atom or molecule has a net positive or negative electrical charge. It is no longer in an electrically neutral state. In the example above, sodium and chlorine have positive and negative electrical charges respectively due to the interchange of electrons, so they are now ions, and we depict them with a small positive or minus sign, as in the examples below:

- Na^+ (sodium positive)
- Cl^- (chlorine negative).

However, we can write the resultant sodium chloride molecule as NaCl because the positive (+) and the negative (–) have attracted each other and cancelled out the electrical charges, leaving us with a molecule that has a neutral electrical charge.

- Ions that carry a positive electrical charge are known as **cations**
- Ions that carry a negative electrical charge are known as **anions**.

To summarise, an ionic bond is a bond that is formed between ions, some of which are positively charged and some of which are negatively charged. These atoms are known as ions and are attracted to, and stabilise, each other, but they neither transfer nor share electrons between themselves. Consequently, this can be seen more as an interaction between atoms rather than as a bond between them (Fisher and Arnold, 2012).

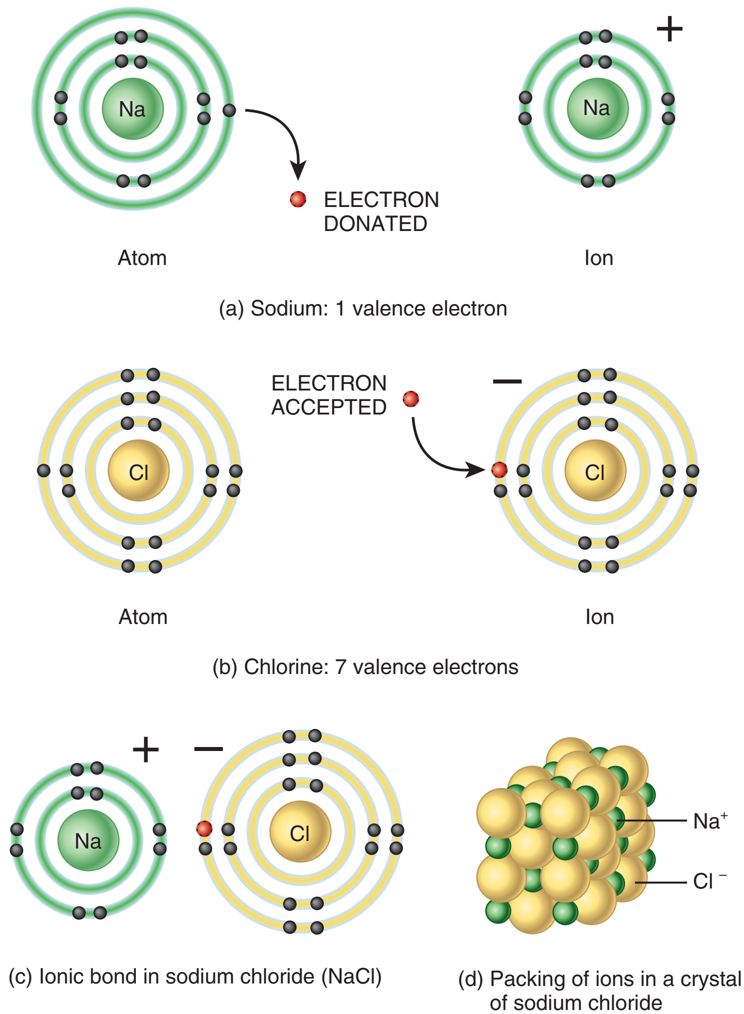

Figure 1.5 (a–d) Ionic bonding of a sodium and a chlorine atom to form a sodium chloride molecule. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

Covalent bonds

Unlike ionic bonding, covalent bonding does involve the sharing of valence electrons with compatible adjacent electrons. In this way, none of the atoms involved in this type of bonding actually loses or gains electrons. Instead, electrons are shared between them so that each of the atoms will have a complete valence shell (i.e. outermost shell) for at least part of the time (Marieb, 2014).

Covalent bonding occurs when two atoms are close to one another and so an overlapping of the outer shell electrons occurs. Following this overlapping, each outer shell becomes attracted to the nucleus of the other atom (Figure 1.6). This type of bonding does not require positive and negative electrical charges as ionic bonding does.

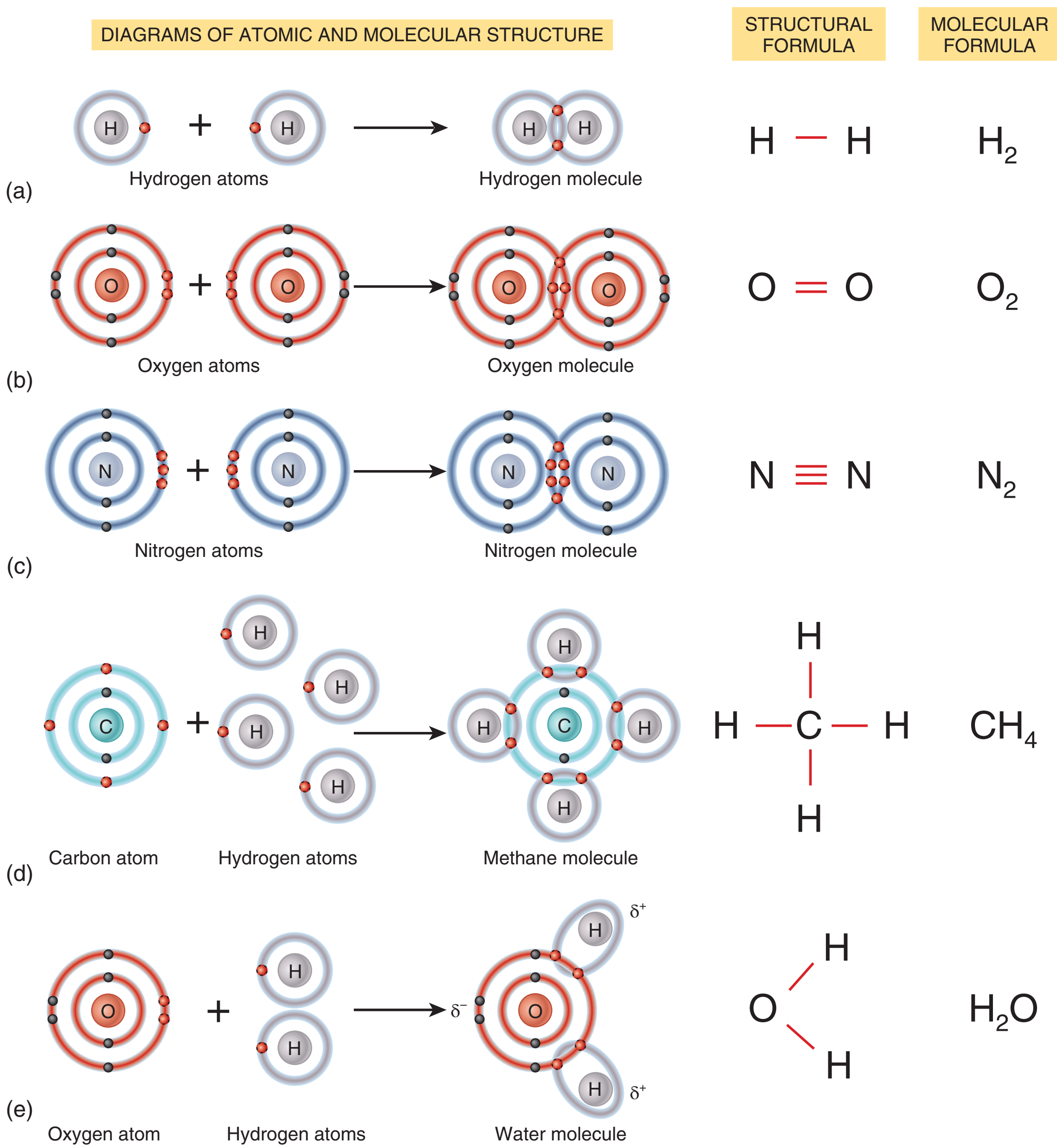

Figure 1.6 (a–e) Covalent bond. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

There are three types of covalent bonding, depending upon the number of electrons that are shared between the bonded atoms:

1. single covalent bonds (one electron from each atom is shared in the outermost shell, e.g. hydrogen molecule);
2. double covalent bonds (two electrons from each atom are shared, e.g. oxygen molecule);
3. triple covalent bonds (three electrons from each atom are shared, e.g. nitrogen molecule).

Polar bonds

Sometimes molecules do not share electrons equally and so there is a separation of the electrical charge into positive or negative. This is called **polarity**, and because of this separation of electrical charge there is an additional weak bond. However, note that this bond is *not* between **atoms**, but is between the **molecules** themselves. Just as with ionic bonding, this polar bonding comes about because of the electrical rule that **opposites attract**. Thus, the small opposing charges from different polar molecules can be attracted to each other. Polar bonding only occurs with molecules that contain the atom hydrogen – so a polar bond is also known as a **hydrogen bond** (see Figure 1.7).

The fact that polar molecules can bond (albeit only weakly) is very important in determining the structure and function of physiologically active substances such as

- enzymes
- antibodies
- genetic molecules
- pharmacological agents (drugs).

Electrolytes

A further development of bonding is the production of electrolytes. Electrolytes are substances that move to oppositely charged electrodes in fluids. They occur in the following way: if molecules that are bonded together ionically (see 'Ionic bonding of atoms' section) are dissolved in water within the body cells, then they undergo a process where the ions separate; that is, they become dissociated. These ions are now known as electrolytes.

However, this does not apply to molecules that are produced by other types of bonding (e.g. covalent bonding). Molecules that are produced as a result of other types of bonding are called non-electrolytes, and these include most organic compounds, such as glucose, urea and creatinine.

Electrolytes are particularly important for three things within the body:

1. Many are essential minerals.
2. They control the process of osmosis.
3. They help to maintain the acid–base balance, which is necessary for normal cellular activity.

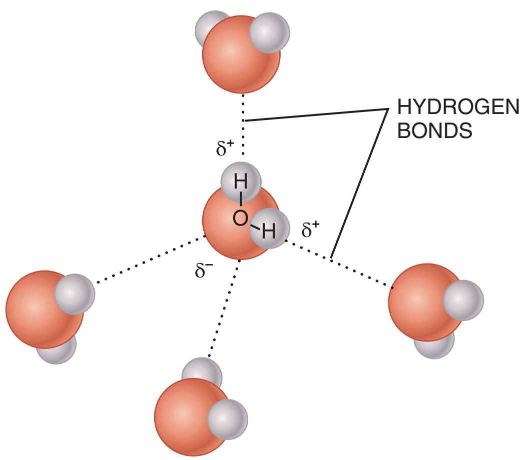

Figure 1.7 Hydrogen bonds and water. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

Elements

A chemical element is a pure chemical substance that cannot be broken down into anything simpler by chemical means. Each element consists of just one type of atom, which is distinguished by its atomic number (which in turn is determined by the number of protons in the nucleus of an atom – see earlier). If the number of protons in the nucleus of an atom changes, then we have a new element, not the original one. This differs from the case with electrons, the number of which can change but the atom remains basically the same – and it is now an **ion**. Some common examples of elements found in the body include

- iron
- hydrogen
- carbon
- nitrogen
- oxygen
- calcium
- potassium
- sodium
- chlorine
- sulphur
- phosphorus.

As of February 2015, a total of 118 elements have been confirmed; however, only the first 98 are known to occur naturally on Earth. These elements are usually presented as a **periodic table**. All chemical matter consists of these elements, although new elements of higher atomic number are discovered from time to time – but only as a result of artificial nuclear reactions, and so are not found in the body.

There are three classes of elements:

1. metals (e.g. iron – symbol 'Fe' from ferrum)
2. non-metals (e.g. oxygen – symbol 'O')
3. metalloids (e.g. arsenic – symbol 'As').

These three classes of elements all have certain characteristics that define them:

Metals	Non-metals	Metalloids
They conduct heat and electricity They donate electrons (to other atoms to make molecules) At normal temperatures they are all solids – with the exception of mercury (symbol 'Hg')	They are poor conductors of heat and electricity They accept electrons (from donor atoms) They may exist as a solid, a liquid or a gas	They are neither metals nor non-metals – they are sometimes referred to as semi metals They tend to have the physical properties of metals while having the chemical properties of both metals and non-metals depending upon their oxidation state. However, they are not relevant to biochemistry, so will not be discussed in this book

Usually metals bond with non-metals (i.e. electron donors with electron acceptors). The following are some examples of elements important for the body that are metals and non-metals:

Metals	Non-metals
Calcium (Ca)	Chlorine (Cl)
Potassium (K)	Nitrogen (N)
Sodium (Na)	Oxygen (O)
	Carbon (C)
	Sulphur (S)
	Phosphorus (P)

As well as sodium chloride – NaCl (met previously in this chapter) – some other important compounds that a nurse will need to know about include:

- sodium bicarbonate – $NaHCO_3$
- potassium chloride – KCl.

An interesting element is hydrogen (H), because hydrogen actually has properties of both metals and non-metals. As a consequence, water (H_2O) is an example of a substance that, although made up of two gases – oxygen (one atom) and hydrogen (two atoms) – becomes a liquid once these gases have bonded together.

Properties of elements

All substances have certain individual properties, particularly in the way that they react (i.e. behave):

- *physical properties* – these include such characteristics as colour, density, boiling point, melting point, solubility, hardness, and so on;
- *chemical properties* – these include whether or not a substance is a metal or non-metal (or even metalloid), whether it reacts with an acid or an alkaline substance, or whether it dissolves in water or alcohol.

Compounds

A 'compound' is a pure substance that is made up of two or more elements chemically bonded together. The properties of a compound are totally different from the individual properties of the elements that are bonded together to make that compound. In addition, compounds can be broken down chemically, while elements cannot. Examples of compounds include:

- water (H_2O)
- salt (NaCl)
- carbon dioxide (CO_2).

Note that when the symbol for an atom has a small lower number after it, then that denotes there are that number of that particular atom in the molecule. So, water (H_2O) is made up of two atoms of hydrogen and one atom of oxygen, while carbon dioxide (CO_2) consists of one atom of carbon and two atoms of oxygen. This will be discussed again later in this chapter.

Chemical equations/chemical reactions

Any mention of chemical equations and most non-chemists/non-scientists immediately start to panic and quickly turn the page. Not to worry, however, because if anyone is capable of doing simple addition sums, then they are capable of working through chemical equations. Everyone has worked through simple mathematical equations, such as

- $1+1=2$
- $2+2=4$
- $4+4=8$
- $1+1+2+2+2=8$
- $1+1+2+2+2=4+3+1$

and so on.

Chemical equations work on the same basic principles. When a chemical reaction occurs (which is portrayed as an equation), then a new substance is formed. This is called the **product** (as with a mathematical equation). However, in a chemical equation, this new substance (product) will have different properties from the individual substances involved in the reaction (called the reactants).

As discussed above, when atoms are combined they form elements or molecules, and symbols are used to describe this process. This look at chemical equations will start with a very simple example, namely the production of water (Figure 1.8).

As mentioned previously, two atoms of hydrogen (H) combined with one atom of oxygen (O) produce one molecule of water (H_2O). The chemical equation for this process is

$$H+H+O \rightarrow H_2O$$
$$\text{hydrogen}+\text{hydrogen}+\text{oxygen} \rightarrow \text{water}$$

In this equation (of a chemical reaction) there are two atoms of hydrogen and one atom of oxygen on the left-hand side, and there are two atoms of hydrogen and one atom of oxygen on the right-hand side. However, on the right, because of a chemical reaction, the same three atoms of gas have created water – a liquid.

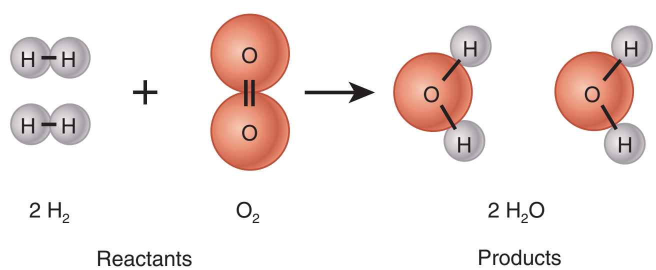

Figure 1.8 Pictorial depiction of the chemical equation (reaction) producing water. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

Thus, a chemical equation is just a shorthand way of describing a chemical reaction. Note that the equals sign in a mathematical equation is replaced by an arrow, meaning 'leads to', in a chemical equation. Basically, all chemical equations are as simple as this. There may be more reactants and products, but there are similar basic principles involved in chemical equations as in mathematical equations.

A very important basic principle is that when chemical reactions occur, the amount of each substance must be the same after the reaction has occurred as was present before the reaction. The two sides of a chemical reaction (and therefore a chemical equation) – the reactants and the products – must balance. In other words, no atoms/molecules are lost in a chemical reaction, they are just organised differently. Another thing to be aware of with chemical reactions is that although the numbers of atoms are the same before and after the reaction, during a chemical reaction, something extra is usually produced every time – namely, heat. This is known as an exothermic reaction, which is a process/reaction that gives out energy in the form of heat.

In a chemical equation, the reactants and the product may be separated by a single arrow (→) as in the earlier example of H_2O. This indicates that the reaction occurs only in one direction, namely in the direction that the arrow is pointing.

Sometimes the reactants and product may be separated by two arrows – one above the other and pointing in different directions ($\rightleftarrows$). This indicates that the chemical reaction can be reversed.

If the reactants and the products are separated by an equals sign '=' (which is a symbol used in mathematics to indicate a state of equality), instead of single or double arrows, this indicates that a state of chemical equilibrium exists.

Another important principle to be aware of, as regards chemical reactions and equations, is that a chemical equation has to be consistent. The elements cannot be changed into other elements by chemical means.

If electrical charges are involved (as occurs with the involvement of ions), the net charge on both sides of the equation must be equal – that is, they must balance.

So, to summarise, all equations must balance (i.e. the number of reactants and their electrical charges must equal the number of products and their electrical charges). However, balancing a chemical equation (and thus a reaction) may require the altering of the quantity of molecules.

Here is a more complicated chemical reaction/equation, but the principles will still hold for this:

$$\text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$$
$$\text{zinc} + \text{hydrogen chloride} \rightarrow \text{zinc chloride} + \text{hydrogen}$$

Note: mention has been made previously in this chapter of the principle that, when using the chemical symbols of substances (elements, compounds, molecules, etc.), if a small number comes after an atom as in H_2O, then that number applies to the atom immediately before it. In other words H_2O is composed of two atoms of hydrogen and one atom of oxygen. However, if an atom or molecule is preceded by a large number, then that applies to everything immediately afterwards until another mathematical symbol (e.g. +, →) occurs. For example, 2HCl means that there are two atoms of hydrogen and two atoms of chlorine bonded together to make two molecules of hydrogen chloride.

In this chemical reaction/equation, two molecules of hydrogen chloride (in the form of two ions of chloride, Cl^-, and two ions of hydrogen, H^+) along with one atom of zinc have been changed to one molecule of zinc chloride ($ZnCl_2$) and one molecule of hydrogen (H_2). So, even though the original atoms have now been combined differently following the chemical reaction, the balance between the two sides of the equation in terms of numbers and types of atoms and electrical charge has not been altered.

With this even more complicated chemical reaction/equation, it is a good idea to take some time and work out just what is going on here before reading on:

$$HCl + NaHCO_3 \rightleftarrows NaCl + H_2CO_3$$
$$\text{hydrochloric acid} + \text{sodium bicarbonate} \rightleftarrows \text{sodium chloride} + \text{carbonic acid}$$

Also in this reaction, H_2CO_3 can be broken down further:

$$H_2CO_3 \rightleftarrows CO_2 + H_2O$$

The reactants on the left-hand side are duplicated on the right-hand side (the products) but in different combinations. Note the double arrow – what does this mean?

The presence of the double-headed arrow means that the equation is capable of being reversed, so that the products become the reactants, and the reactants the products. Note that sodium bicarbonate ($NaHCO_3$) is made up of one atom each of sodium, hydrogen and carbon and three atoms of oxygen, while carbonic acid (H_2CO_3) is composed of two atoms of hydrogen, one atom of carbon and three atoms of oxygen. Counting the numbers and types of each atom on both sides demonstrates again that nothing is added and nothing deleted when the reaction takes place – everything is just rearranged in such a way that elements that can be used by the body are produced (along with any waste elements, which are then excreted).

This is the end of the section on chemical equations, and as can be seen, if someone can do simple arithmetic, then they can understand and work with chemical equations (remembering that the equations are a depiction of chemical reactions that are taking place within the body all the time).

Acids and bases (pH)

This section may initially appear complicated, but it is important to understand **pH** values, along with alkalinity and acidity, as our bodies (indeed our very lives) depend upon the relationship between acidity and alkalinity.

- An **acid** is any substance that donates hydrogen ions (H^+) into a solution.
- An **alkali** (also known as a **soluble base**) is any substance that donates hydroxyl ions (OH^-) into a solution or accepts H^+ ions from a solution.

The more OH^- ions that have been donated or H^+ ions accepted, the greater the alkalinity of a substance; conversely, the greater the number of H^+ ions that are released, the more acidic is the solution. Obviously, whenever the numbers of H^+ and OH^- ions are the same, then a **neutral** solution exists.

The chemical equation for the ionisation of water is shown as

$$H_2O \rightleftarrows H^+ + OH^-$$

In other words, water contains hydrogen and hydroxyl ions, and in one litre of pure water, 10^{-14} mol (**moles**) of water are dissociated into H^+ ions and OH^- ions. If there are 10^{-7} mol of H^+ ions and 10^{-7} mol of OH^- ions in one litre, then they are balanced and the water is neutral (neither acidic nor alkaline).

- Note that a **mole** in chemistry is a unit of amount of substance (it is a unit of measurement for chemicals) and is defined as the mass of substance that contains as many elements (atoms, molecules, etc.) as there are atoms in 12 g of carbon-12 (International Bureau of Weights and Measures, 2006).
  The concept of a mole in chemistry is quite complicated, but it is only necessary in this chapter to use it in relation to acid–base balance.
- The concept of 10^{-14} is an arithmetic one and denotes a very small number: $10^{-14} = 0.00000000000001$ of a mole.
- In biochemistry, **dissociation** is the separation of a substance into two or more simpler substances – such as a molecule into atoms or ions – by the action of heat or a chemical process. This process is usually reversible.

The properties of water are such that the minimum concentration of H^+ ions and OH^- ions is 10^{-14} mol L^{-1} (moles per litre), while the maximum concentration of H^+ ions and OH^- ions is 1 mol L^{-1} or 1.00 mol L^{-1}. Thus, the dissociation properties of water restrict the concentration of H^+ ions and OH^- ions to the range of 10^{-14} to 100 mol L^{-1}.

A scale of acidity and alkalinity has been devised that uses this range of 10^{-14} to 100 mol L^{-1} of H^+ and OH^- ions – known as the **pH scale** (see Figures 1.9 and 1.10). Consequently, the addition of H+ ions to pure water results in a proportionate decrease of OH^- ions from the initial concentration of 10^{-7} mol L^{-1}. Thus, an H^+ ion concentration of 10^{-8} mol L^{-1} results in an OH^- concentration of 10^{-6} mol L^{-1}. In this way, the combined totals of H^+ and OH^- molecules will always equal 10^{-14}. The pH scale represents the powers of 10 of H^+ ions from 10^{-14} to 10^0, but for convenience the scale uses positive numbers, so the scale is from pH 14 to pH 0.

At pH 7 an equal number of H^+ ions and OH^- ions occurs, while solutions with a pH that is lower than 7 are **acids** and those with a pH that is greater than 7 are **bases/alkaline**. The further away from a pH of 7 a solution becomes the more acidic or alkaline it is.

The pH scale is a logarithmic scale so consequently each whole pH value below 7 is 10 times more acidic than the next highest value. For example, a solution with a pH 3 value is 10 times more acidic than a solution with a pH 4 value. In addition, it is 100 times (i.e. 10 × 10) more acidic than solution with a pH 5, and 1000 times (i.e. 10 × 10 × 10) more acidic than a solution that has a

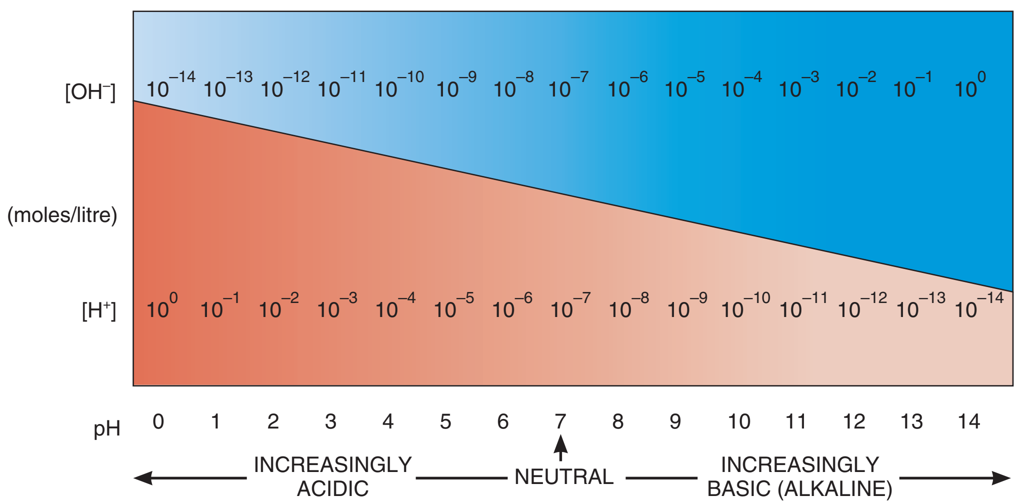

Figure 1.9 The pH scale. *Source*: Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

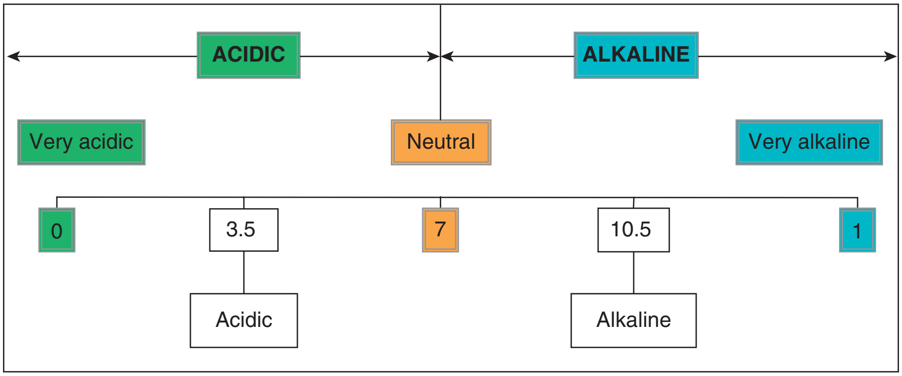

Figure 1.10 Simplified diagram of a pH scale.

pH value of 7 (i.e. a neutral solution). Exactly the same applies to pH values that are above 7 (i.e. alkaline solutions), in that each is 10 times more alkaline than the next lowest value. For example, a solution with a pH of 10 is 10 times more alkaline than one with a pH of 9, 100 times (10 × 10) more alkaline than a solution with a pH of 8, and so on.

This last concept of logarithmic values and pH is very important for us, as can be seen in the next section, which looks at pH values and blood.

Blood and pH values

In blood, the physiologically normal pH range is 7.35–7.45; that is, it is slightly alkaline. However, a blood pH lower than 7.35 is considered to be acidic, whereas a pH greater than 7.45 is alkaline, and when either of these events occurs it can have a serious effect on the body, as is discussed in other chapters within this book. The reason is that because the scale is a logarithm, then just a small change in pH indicates a very significant alteration in H^+ concentration. Every change in one pH unit represents a 10-fold change in H^+ ion concentration. Thus, an alteration of pH from pH 7.4 to pH 7.3 results in a doubling of the H^+ ion concentration. In other words:

- pH 8 contains 10^{-8} mol L^{-1} or 10 nmol L^{-1} (nanomoles per litre) of H^+
- pH 7 contains 10^{-7} mol L^{-1} or 100 nmol L^{-1} of H^+
- pH 6 contains 10^{-6} mol L^{-1} or 1000 nmol L^{-1} of H^+

and so on.

Homeostasis

Homeostasis is the body's attempt to maintain a stable internal environment by achieving some sort of balance. The body is normally able to achieve a relatively stable internal environment even though the external environment is constantly changing – from cold to hot, or from dry to wet, and so on. The body uses various homeostatic mechanisms to monitor and maintain a dynamic state of equilibrium within the body – that is, a balance in which the internal environment conditions can react to external environmental conditions by changing within quite narrow limits.

The homeostatic mechanisms include:

- **receptors** – the body has receptors that sense external and internal environmental changes and provide information on the changes to the control centre;
- **control centre** – the control centre determines what a particular value (e.g. pH value or blood pressure) should be and sends out a message to the effectors;
- **effectors** – once they have received the information from the control centre, the effectors cause responses to take place within the body's internal environment that hopefully will produce the changes that will enable the internal environment to return to normal values.

Organic and inorganic substances

All substances are classed either as organic or inorganic depending upon their molecules.

- **Organic** molecules:
  - contain carbon (C) and hydrogen (H);
  - are usually larger than inorganic molecules;
  - dissolve in water and organic liquids;
  - as a group include carbohydrates (sugars), proteins, lipids (fats) and nucleic acids (part of DNA) – see Chapter 3, Genetics.

- **Inorganic** molecules:
  - as a group include water (H_2O) and carbon dioxide (CO_2) and inorganic salts. It is true that H_2O and CO_2 do contain carbon atoms, but only in such small quantities that they are, at the moment, still classified as inorganic – although there is a lot of discussion around this within the scientific community
  - are usually smaller than organic molecules;
  - usually dissolve in water or they react with water and release ions;
  - as a group include water (H_2O) carbon dioxide (CO_2) and inorganic salts.

Examples of organic substances

Carbohydrates

Monosaccharides (one of the group of sugars known as carbohydrates) provide energy to cells as well as supplying the materials that allow for the building of the various structures of the cell (see Chapter 2). They contain carbon (C), hydrogen (H) and oxygen (O) and their structure has the chemical formula $C_6H_{12}O_6$. There are three types of carbohydrates:

- monosaccharides – glucose and fructose;
- disaccharides – sucrose, lactose;
- polysaccharides – glycogen, cellulose.

Fats (lipids)

Fats are lipids (known as triglycerides) and are soluble in organic solvents. They are mainly used to provide energy. Like carbohydrates, they consist of carbon (C), hydrogen (H) and oxygen (O), but because the numbers and proportions of these molecules are different from the carbohydrates, they have different properties. The chemical formula for stearin (one type of lipid) is $C_{57}H_{110}O_6$. Lipids can be either saturated or unsaturated. One important group of lipids is the steroid group, which is used to synthesise (produce/construct) hormones. Cholesterol is an important member of the steroid group of lipids.

Proteins

Proteins are built up from amino acids – this will be discussed in Chapter 3. Proteins are very important as they provide the structural material for the body, as well as being an energy source. They also help to form many other substances, including hormones, receptors, enzymes and antibodies.

Examples of inorganic substances

Water (H_2O)

As mentioned above, water is the most abundant compound found in all living material and is a major component of all body fluids. It has an important role to play in most metabolic reactions as well as in transporting chemicals around the body. Water can both absorb and transport heat, so it plays a crucial role in maintaining body temperature.

Oxygen (O_2)

Oxygen is necessary for survival. It is used by the organelles of the nucleus to release energy from nutrients (see Chapter 2).

Units of measurement

To conclude this chapter, which introduces certain bioscientific concepts and prepares the reader for the remaining chapters, just some brief notes about units of measurement. This is an important section because the ability to identify and understand units of measurement will enhance the understanding of the complex human organism.

A unit is a standardised, descriptive word that specifies the dimension of a number. Traditionally there have been seven properties of matter that have been measured independently of each other, namely:

- **time** – measures the duration that something occurs;
- **length** – measures the length of an object;
- **mass** – measures the mass (commonly taken to be the weight) of an object;
- **current** – measures the amount of electric current that passes through an object;
- **temperature** – measures how hot or cold an object is;
- **amount** – measures the amount of a substance that is present;
- **luminous intensity** – measures the brightness of an object.

Originally, each country/society had its own units of measurement. In the UK, for example, there were such units as furlongs, miles, poles, gallons, quarts, bushels, pecks, and so on. This made it difficult for people, particularly scientists, from other countries to work with each other, so several years ago an international system of units was agreed upon by most major countries (however, a notable exception to this agreement is the USA). This new agreed system became known as the Système International d'Unités (or SI units for short). It is a system of units that relates present scientific knowledge to a unified system of units. Tables 1.1, 1.2, 1.3, 1.4, 1.5, 1.6 and 1.7 give the SI units, unit prefixes and some Imperial unit equivalents that will be useful as reference while working through this book.

Table 1.1 The fundamental SI units

Quantity	Name	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Current	ampere	A
Temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Table 1.2 Other common SI units

Physical quantity	Name	Symbol
Force	Newton	N
Energy	joule	J
Pressure	pascal	Pa
Potential difference	volt	V
Frequency	hertz	Hz
Volume	litre	L

Table 1.3 Multiples of SI units

Prefix	Symbol	Meaning	Scientific notation
tera	T	one million million	10^{12}
giga	G	one thousand million	10^{9}
mega	M	one million	10^{6}
kilo	k	one thousand	10^{3}
hecto	h	one hundred	10^{2}
deca	da	ten	10^{1}
deci	d	one tenth	10^{-1}
centi	c	one hundredth	10^{-2}
milli	m	one thousandth	10^{-3}
micro	μ	one millionth	10^{-6}
nano	n	one thousandth of a millionth	10^{-9}
pico	p	one millionth of a millionth	10^{-12}
femto	f	one thousandth of a pico	10^{-15}
atto	a	one millionth of a pico	10^{-18}

Table 1.4 Measures of weight

1 kg = 1000 g
1 g = 1000 mg
1 mg = 10^{-3} g
1 μg = 10^{-6} g
1 pound = 0.454 kg/454 g
1 ounce = 28.35 g
25 g = 0.9 ounce
1 ounce = 8 dram

Table 1.5 Measures of volume

1 L = 1000 mL
100 mL = 1 dL
1 mL = 1000 μL
1 UK gallon = 4.5 L
1 pint = 568 mL
1 fluid ounce = 28.42 mL
1 teaspoon = 5 mL
1 tablespoon = 15 mL

Table 1.6 Measures of length

1 m = 10^{-3} km
1 cm = 10^{-2} m
1 mm = 10^{-3} m
1 m = 39.37 inches
1 mile = 1.6 km
1 yard = 0.9 m
1 foot = 0.3 m
1 inch = 25.4 mm

Table 1.7 Measures of energy

1 calorie = 4.184 J
100 calories = 1 dietary Calorie or kilocalorie
1 dietary Calorie = 4184 J or 4.184 kJ
1000 Calorie = 4184 kJ
1 kJ = 0.238 Calories

Conclusion

This concludes this introduction to the very basics of the biochemistry of physiology. As you can now appreciate, biochemistry and physiology are really quite complicated – but also very interesting, and indeed exciting. After all, as you work through this book, you are learning about yourself – how your body works and functions – both in good times (when you are fit and healthy) and in bad times (when you are sick or have had an accident). Everyone is interested in how they function and what happens when they eat and drink, or exercise, or go to the toilet, and so on – not just you, but also your patients. So this is important knowledge for you to have when you are talking to patients. This first chapter is just the beginning of a journey – think of it as a map to help you to complete this journey. This journey is one of self-knowledge and awareness that will lead you to your ultimate goal – a good knowledge of the human body and its functioning. Good luck.

Glossary

Acid A chemical substance with a low **pH**. The opposite of an **alkaline** substance.

Acid–base balance The relationship between an **acidic** environment and an **alkaline** one. This is essential for maintaining our good health. See **pH**.

Alkali A chemical substance with a high **pH**. The opposite of an **acidic** substance.

Anatomy The study of the structures of the body.

Antibody Antibodies are proteins that can recognise and attach to infectious agents in the body, and so provoke an immune response to these infectious agents.

Atomic number Relates to the number of **protons** to be found in any one **atom**.

Atoms The base of all life, atoms are extremely minute and consist of different numbers of protons, neutron and electrons.

Base Another name for an **alkaline** substance.

Bonds The joining together of various substances, particularly atoms and molecules. See **chemical bond**, **covalent bonds**, **ionic bonds**, and **polar bonds**.

Chemical bond The 'attractive' force that holds **atoms** together.

Chemical reaction A process in which chemical substances are transformed into something completely different. This is usually depicted in a chemical equation.

Compounds A pure substance that is made up of two or more **elements** that are **chemically bonded** together.

Covalent bonds Bonds between **atoms** caused by the sharing of **electrons** between the **atoms**.

Electrolyte Substance that is able to move to opposite electrically charged electrodes in fluids.

Electrons The parts of an **atom** that carry a negative electrical charge. See **neutrons** and **protons**.

Elements A pure chemical substance which cannot be broken down into anything simpler by chemical means (e.g. iron, hydrogen).

Enzymes Proteins that are produced by cells and can cause very rapid biochemical reactions in the body.

Homeostasis The name given to processes in which both negative and positive controls are given over variables; they usually involve negative feedback, and the aim is to maintain a stable internal environment.

Inorganic substances Substances that do not contain carbon **molecules** (e.g. water).

Ionic bonds Bonding that takes place when atoms lose or gain **electrons**. This alters the electrical charge of the **atoms**.

Ions Ions are **atom**s that are no longer in a stable state (i.e. they are no longer electrically neutral but are either positively or negatively electrically charged).

Mole The unit of measurement for the amount of a substance.

Molecules The smallest part of an **element** or **compound** that can exist on its own (e.g. sodium chloride).

Neutral substance A chemical substance that is neither **acidic** nor **alkaline**.

Neutron The parts of an **atom** that carry a neutral electrical charge (i.e. they have no electrical charge). See **electrons** and **protons**.

Organelle Structural and functional parts of a cell.

Organic substances Substances that contain carbon **molecules** (e.g. carbohydrates, lipids (fats) and proteins).

Osmosis The movement of water across a semi permeable membrane from an area of low solute concentration to an area of high solute concentration; this allows for equilibrium of solute and water density on both sides of the semi permeable membrane.

pH A measure of the acidity or alkalinity of a solution. See **acid–base balance**.

Physiology The study of the way in which the body structures function.

Polar bonds Polar bonds occur when atoms of different electronegativities form a bond. Consequently, the **molecules** that are then formed also carry a weak negative electrical charge, which allows molecules to **ionically bond**, just like **atom**s. They are also known as hydrogen bonds because hydrogen molecules have to be present for polar bonding to exist. Examples of such **molecules** include hydrochloric acid and water.

Product (chemical reactions) The new substance formed following a **chemical reaction**.

Protons The parts of an **atom** that carry a positive electrical charge. See **electrons** and **neutrons**.

Reactant (chemical reactions) The individual substances involved in a **chemical reaction**.

Shell (of an atom) The name that is given to the orbits of **electrons** moving around the nucleus (containing **protons** and **neutrons**) of an **atom**.

Valency A measure of the combining power of **atoms**.

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Activities

Multiple choice questions

1. The characteristics of life include:
   - **(a)** digestion, excretion, irritation
   - **(b)** absorption, bleeding, circulation
   - **(c)** excretion, perspiration, reproduction
   - **(d)** intelligence, growth, responsiveness
2. There are five essential requirements for all organisms. These are:
   - **(a)** carbon dioxide, water, mouths, rectums, oxygen
   - **(b)** oxygen, pressure, heat, water, food
   - **(c)** food, low temperatures, carbon dioxide, oxygen, pressure
   - **(d)** pressure, spatial awareness, sight, water, food
3. Protons possess:
   - **(a)** a stable electrical charge
   - **(b)** no electrical charge
   - **(c)** a negative electrical charge
   - **(d)** a positive electrical charge
4. Which of the following is not a type of chemical bond?
   - **(a)** polar
   - **(b)** equatorial
   - **(c)** ionic
   - **(d)** covalent
5. There are three classes of elements, namely:
   - **(a)** metals, non-metals, metalloids
   - **(b)** metals, oxidants, electrons
   - **(c)** carbons, non-metals, metalloids
   - **(d)** metalloids, non-metals, atomic
6. Which of the following are organic substances?
   - **(a)** carbohydrates, proteins, lipids
   - **(b)** carbohydrates, water, oxygen
   - **(c)** water, proteins, lipids
   - **(d)** lipids, oxygen, proteins
7. Homeostasis is:
   - **(a)** the effective use of receptors
   - **(b)** a measurement of acidity in the body
   - **(c)** the body's attempt to maintain a stable environment
   - **(d)** a combination of physical properties

8. A molecule of water is a combination of which atoms:
   - (a) 1 × hydrogen, 1 × oxygen, 1 × carbon atoms
   - (b) 2 × oxygen, 1 × carbon atoms
   - (c) 2 × oxygen, 1 × hydrogen atoms
   - (d) 1 × oxygen, 2 × hydrogen atoms
9. In biochemistry, a 'mole' is a unit of:
   - (a) intensity
   - (b) luminosity
   - (c) pH values
   - (d) substance
10. Water is a requirement for the body in order to help:
    - (a) release energy
    - (b) regulate body temperature
    - (c) provide energy
    - (d) keep blood flowing through the body

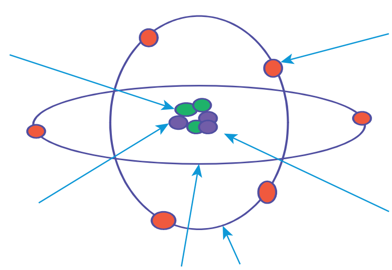
True or false

1. An ion is an atom that is in an electrically neutral state.
2. Molecules are combinations of atoms.
3. Polar bonds occur between molecules.
4. Many electrolytes are essential minerals.
5. Reactions with an acid or alkaline substance are physical properties of elements.
6. Salt is not a compound.
7. There are always more atoms and molecules present following a chemical reaction.
8. Organic substances contain carbon and hydrogen.
9. Lipids are examples of inorganic substances.
10. Proteins are built up from amino acids and provide the structural material for the body.

Label the diagram 1

Label the diagram using the following list of words:

Proton, Neutron, Paths of orbit, Nucleus, Electron



Fill in the blanks 1

Using words from the following list, fill in the missing blanks:

body effectors environmental external feelers homeostatic internal mechanisms messages physical pressure problems receptors response stable stimuli type unstable

Homeostasis is the body's attempts to maintain a __________ internal environment. To do this, it has to be able to change in response to both __________ (e.g. environmental temperature) and internal __________ (e.g. blood pressure) changes. Various __________ are utilised by the body to maintain homeostasis, including __________ to sense external and internal __________ changes. Receptors then send out messages to the __________ control centre, which determines the particular value – for example, the correct temperature or blood __________ required for the essential functioning of the body. This then sends a __________ to the body's __________, which, in turn, cause the body's __________ environment to counteract the effects of the various stimuli/changes.

Word search 1

Find the words listed in the following grid.

A	C	O	Z	E	J	I	R	O	N	K	P	A
N	A	J	O	Z	Y	O	F	Q	I	U	R	N
A	T	O	M	I	P	N	E	U	T	R	O	N
T	O	J	M	O	R	T	I	O	N	B	T	L
O	C	H	E	R	L	S	N	T	R	H	O	E
M	A	Y	B	G	S	E	D	A	H	A	N	Y
Y	E	D	A	A	H	T	C	Q	O	J	E	K
E	N	R	Y	N	E	X	T	U	R	N	I	P
P	R	O	T	E	I	N	S	A	L	T	C	H
S	I	G	P	L	I	P	I	D	F	E	V	L
U	V	E	B	L	Y	I	F	R	U	K	L	O
Z	E	N	Y	E	L	E	M	E	N	T	O	X
E	S	S	T	I	M	A	B	L	E	Q	U	E

Anatomy, Atom, Carbon, Element, Hydrogen, Ion, Iron, Lipid, Molecule, Neutron, Organelle, Protein, Proton

Test your learning

1. What is the importance of respiration for the body?
2. Why is water essential for all organisms, including humans?

3. How is the atomic number of an atom calculated?
4. What is an ion, and what is its importance for us?
5. Make a list of some of the common elements found in the body.
6. Explain what is happening in the chemical reaction as depicted by this chemical equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP\ (\text{cellular energy})$$

7. Discuss the importance of the pH of blood.
8. Discuss the importance of carbohydrates to the body.

Find out more

1. Look at a copy of the periodic table of elements and mark off the ones you have come across in this chapter and that are important for humans.
2. Many electrolytes are essential minerals for the body. Find out which these are.
3. Find out about, and make notes on, the process of osmosis and its importance for human functioning and health.
4. Discuss the acid–base balance and its importance for maintaining good health – and, indeed, for life itself.
5. Discuss what is happening in these two equations – you will need to have access to chemical abbreviations to help you understand the symbols:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

6. Find out the normal range of human pH and then discuss why it is important for the nurse to alert medical staff if a patient's pH is found to be outside the normal range.
7. Find out more about the importance of homeostasis to health.
8. Lipids/fats can be either saturated on unsaturated – find out from the foodstuffs that you normally eat which of them contain either or both of these types of lipids and their role(s) in healthy nutrition.
9. Take one day, and on that day look at your breakfast, lunch and tea/dinner (as well as snacks, etc.) and try to find out the contents of them all in terms of carbohydrates, lipids and proteins.
10. How can a nurse help to provide a healthy diet for their patients while they are in hospital and/or the community?

Fill in the blanks 2

Using words from the following list fill in the missing blanks:

atom chemical electrical electron electrons equal to greater than ion less than minus molecule negative neutron organ organelle physical plus positive protein protons

An _______ is an atom or _______ in which the total number of _______ is not _______ _____ the total number of protons. Hence the _______ or molecule has a net _______ or negative _______ charge.

Word search 2

Find the following words below in the grid, and then write something about each of them:

Alkali, Atom, Calcium, Covalent, Fats, Hydrogen, Ion, Mass, Mercury, Metal, Organ, pH, Physiology, Polar Bonds, Sodium

P	O	L	A	R	B	O	N	D	S	U	Z	K
P	H	R	E	M	O	Z	I	A	X	Y	N	X
S	A	Y	G	O	N	I	L	A	K	L	A	V
T	M	A	S	S	T	T	Q	U	E	R	G	H
C	H	R	M	I	G	M	E	R	C	U	R	Y
A	O	V	O	U	O	H	Z	W	R	D	O	D
L	O	V	T	X	E	L	E	I	P	U	S	R
C	S	I	A	O	R	S	O	D	I	U	M	O
I	N	F	V	L	T	I	O	G	L	X	A	G
U	Q	A	Y	Z	E	I	N	L	Y	A	Z	E
M	E	T	A	L	X	N	Z	A	S	I	O	N
P	W	S	R	E	A	C	T	I	O	N	G	H
Q	U	E	R	T	Y	U	I	O	P	L	K	J

Label the diagram 2

Fill in the missing words in the three lower boxes.

THE ATOM