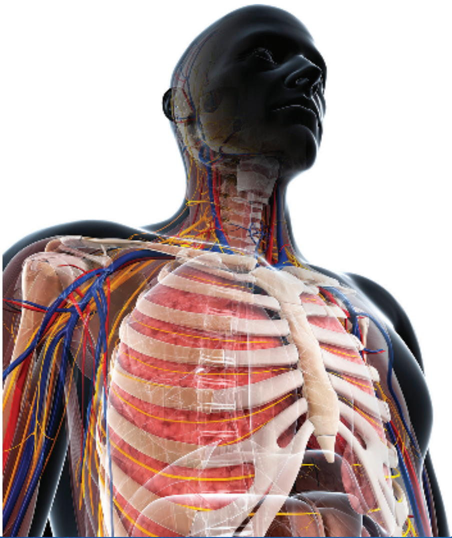

1

Basic Scientific Principles of Physiology

Suzanne Evans

Test Your Prior Knowledge

- **What is the difference between anatomy and physiology?**
- **What are atoms, ions and electrolytes?**
- **What is an element?**
- **How do we distinguish living things from non-living things?**
- **What is homeostasis?**

Learning Outcomes

After reading this chapter you will be able to:

- **Outline the levels of organisation of the body.**
- **Describe the characteristics and the requirements of all living things.**
- **Interpret chemical symbols and equations and understand the ways in which atoms can bind together.**
- **Describe the pH scale and its importance to life.**
- **List the differences between organic and inorganic substances.**

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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 operates, and can be studied, on the following levels:

- The chemical level – the atoms, molecules and macromolecules that we are made of.
- The cellular level – the smallest living units in our bodies.
- The tissue level – the groups of cells specialised to perform specific functions, e.g. nerve or muscle tissue.
- The organ level – a structure, consisting of many tissues, specialised to perform a specific function, e.g. the heart.
- The organ system level – a system, consisting of more than one organ, specialised to perform a range of functions, e.g. the cardiovascular system.
- The organism level – the whole individual.

Characteristics of Life

All living organisms have certain characteristics in common, which are considered essential for the maintenance of life. These characteristics are:

- **Sensitivity** – organisms need to be able to sense and respond to changes in their environment such as changes in light levels, temperature, chemical composition, presence of threats, etc.
- **Nutrition** – Seeking out, ingesting and using food to supply energy and the raw materials for growth and development is a very basic requirement.
- **Respiration** – This is the means by which an organism obtains and uses oxygen to release energy from food to power the other activities listed here.
- **Movement** – The ability to change position is essential if an organism is to be able to escape threats, find food, other members of the species, etc.
- **Growth** – This is essential for the development of an organism from birth to adulthood, but also for the renewal and repair of body parts during the life of an organism.
- **Reproduction** – This is an essential process, not for the survival of the individual, but for the survival of the species. Sexual reproduction has the added bonus of continually mixing and re-mixing genetic material to produce genetically unique individuals each time, which increases the ability of a species to adapt and survive over the very long term.
- **Excretion** – the removal of waste substances produced by metabolic processes from the body, to prevent them building up to harmful levels.

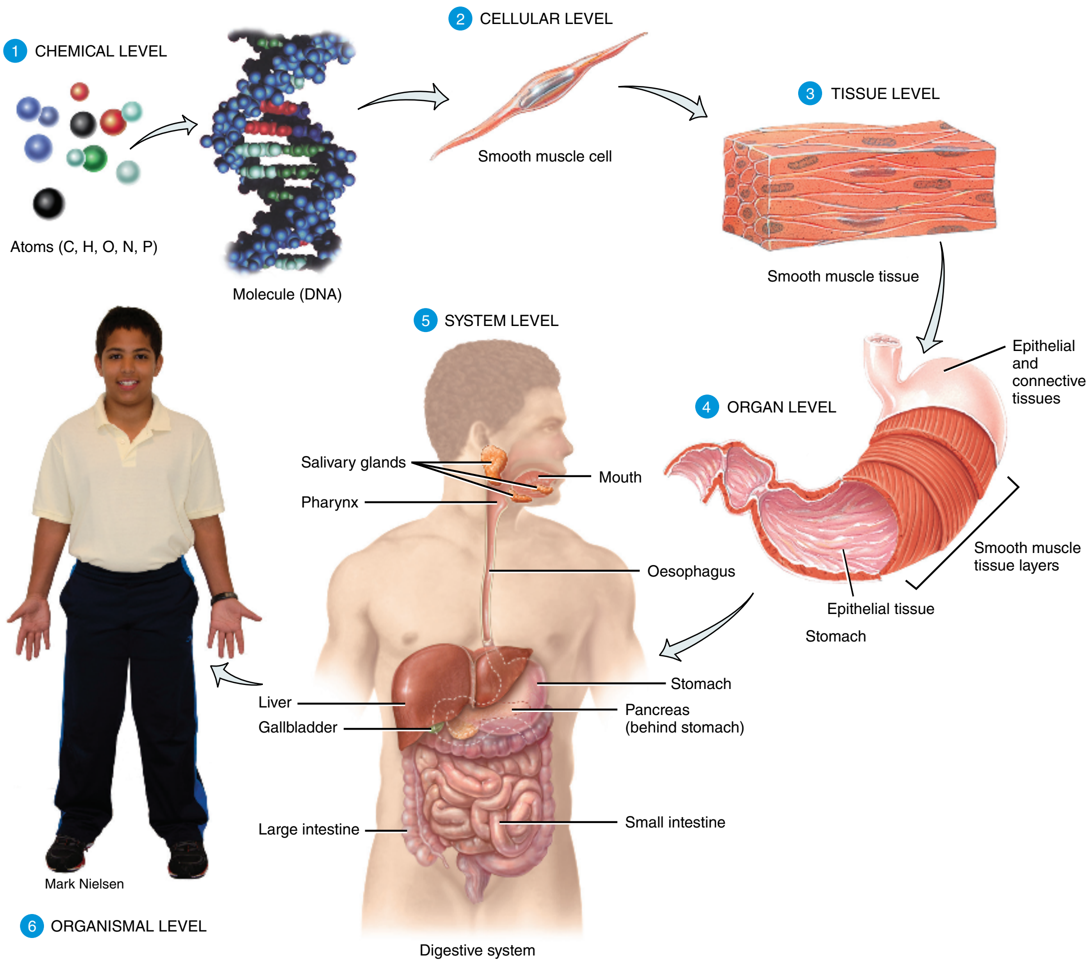

Figure 1.1 Levels of organisation of the body. ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

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, our bodies are approximately 78% water. This reduces to 65% at 1 year of age, and to 55–60% in adulthood. Our biochemistry evolved to operate in a watery (aqueous) environment; our cells are filled with a watery, salty solution, in which our cellular processes are carried out, and those cells are also bathed in a watery, salty solution. While it may not look like it, blood is also mainly water, making water important for the transport of substances around our large and complex bodies.
   Body water also helps regulate body temperature, since sweating is an important mechanism for evaporative cooling.
2. **Food:** Food supplies the energy and raw materials for the organism to fulfil all the essential activities of life.

3. **Oxygen:** Oxygen is required for the release of energy from food, by the oxidation of high energy food substances. Oxygen is one of the gases that exists naturally in the air (oxygen makes up approximately 20% of the air).
4. **Sunlight:** All life on earth depends ultimately on sunlight, since plants need this to grow, and other organisms depend directly or indirectly on plants for food.

Life at the Chemical Level

Studying living things at a chemical level reveals a world of 'chemical machinery', carrying out millions of chemical reactions within our cells every minute, which keep us alive, functioning and growing. A living body depends for its continued survival on simple atoms and molecules and also some large and very complex molecules (macromolecules) to carry on the business of living, growing and reproducing. We will cover some of the most biologically important chemicals here.

The Elements

All matter on earth is made up of a range of approximately 100 chemical elements. A chemical element is a pure chemical substance that cannot be broken down into anything simpler by chemical means.

More than 100 elements are thought to exist, but only 98 are known to occur naturally on earth. All the elements are shown in the periodic table of the elements, which sets out the elements in terms of their unique atomic structures and their physical (colour, hardness, density, melting and boiling points) and chemical (the ways in which the element reacts chemically) properties. Based on physical and chemical properties, elements are classified as either metals, metalloids or non-metals. Those classed as metals share the following properties:

- They are solids at room temperature (apart from Mercury, which is liquid!).
- They conduct heat and electricity.
- They donate electrons when forming bonds (see chemical bonding).

Metalloids have some of the properties of metals and some of non-metals. Non-metals share the following properties:

- They may exist as a solid, a liquid or a gas.
- They are poor conductors of heat and electricity.
- They accept electrons from other atoms when forming bonds (see chemical bonding).

Below are some examples of metals and non-metals that are very important in biology:

METALS	NON-METALS
Calcium (Ca)	Chlorine (Cl)
Potassium (K)	Nitrogen (N)
Sodium (Na)	Oxygen (O)
Iron (Fe)	Carbon (C)
	Sulphur (S)
	Phosphorus (P)

The Smallest Unit of Matter: The Atom

Atoms are the building blocks of all matter. Each element in the periodic table consists of its own, unique atoms. The word 'atom' comes from a Greek word meaning 'incapable of being divided'. However, we now know that an atom consists of subatomic particles: electrons, neutrons and protons.

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 1.2, the protons and neutrons cluster together at the centre of the atom (forming the nucleus), while the electrons orbit constantly around the nucleus, and are kept in orbit by the electromagnetic force exerted by the nucleus.

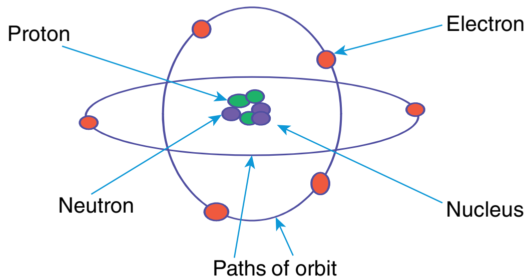

Figure 1.2 Schematic diagram of an atom. *Source:* Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

There are many different types of atoms, differing in the numbers of protons, neutrons and electrons they possess. It is these differences between the various types of atoms that give us the array of chemical elements you will see on the periodic table of the elements.

Regardless of the type of atom, the atomic structures all obey the following rules:

- The nucleus is always central.
- The number of protons an atom possesses in its nucleus is known as the atomic number of that atom.
- The total number of particles in the nucleus of an atom (i.e. the number of protons and neutrons added together) is the atomic mass number. The mass of an atom is almost all in its nucleus – the electrons orbiting around the nucleus have virtually no weight – they are really just electrical charges in motion, but they are extremely important to the behaviour of the atom, as you will see.
- As the number of electrons an atom possesses increases, the electrons form layers of orbits, or shells, which get larger and further from the nucleus. The inner shell can contain a maximum of two electrons and the second and third shells shell can contain a maximum of eight electrons. The electrons in the outermost shell of an atom determine whether and how the atom forms bonds with other atoms to make new chemicals. The electrons in the outermost shell are known as the valence electrons, as they are able to take part in bonding reactions with other atoms (see chemical bonds section).

Figure 1.3 shows the atomic structure of some of the most biologically important substances, or elements, with their atomic numbers and mass numbers.

If you look closely at the number of electrons in the various atoms shown in Figure 1.3, you will see that in each atom, the number of electrons is equal to the number of protons. Since each proton carries a positive charge and each electron carries a negative charge, having an equal number of each will mean that the atom has an overall neutral charge. For example, the carbon atom has six electrons, six protons and six neutrons. The equal and opposite electrical charges of the electrons and protons cancel each other out, so that the atom is electrically neutral and it is said to be in a state of equilibrium.

When referring to these different elements, we use symbols to represent each one, rather than writing out their names each time. For example, the symbol for sodium is Na (after its Latin name natrium), the symbol for potassium is K (after its Latin name kalium), Chlorine is Cl, and the symbol of Carbon is C.

Clinical Considerations Magnetic Resonance Imaging (MRI)

Health professional students often question what relevance subatomic particles have to the practice of health care. Magnetic resonance imaging, a widely used diagnostic imaging technique, is one example of how the behaviour of subatomic particles is harnessed for medical purposes. MRI, unlike CT or PET scans, does not involve exposing a patient to ionising radiation, and it is able to produce 3-dimensional images of all body structures, including soft tissue. It is an extremely versatile diagnostic imaging system, and it works by detecting the spin of protons in water molecules. Patients are placed into a powerful magnetic field, which forces the protons contained in the molecules of body water to align with the field (protons have a positive charge, so they will spin round and align when they find themselves in a charge field). When the magnetic field is turned off, those protons all return to their original alignment, but at different speeds, depending on what environment they are in. Capturing these signals released from protons as they realign in various different tissues allows the different tissues to be detected and visualised. Because of the very strong magnetic field, however, metal cannot be placed inside the MRI scanner, so patients with any implants that contain metal cannot be scanned.

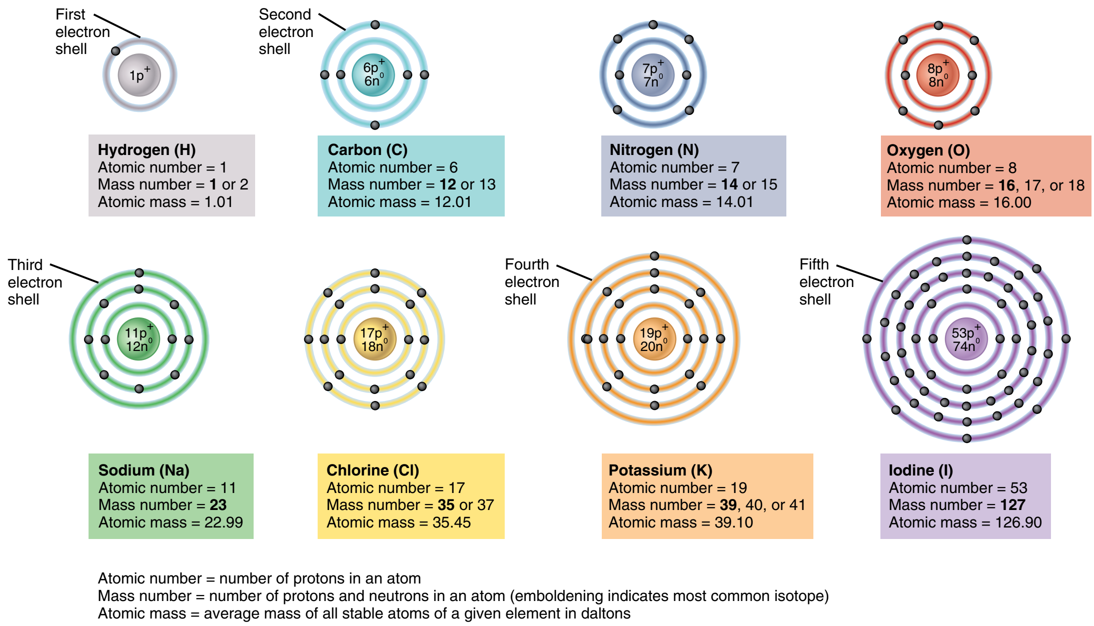

Figure 1.3 The structure of some biologically important atoms. ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

Chemical Reactions and Chemical Bonds

If atoms remained in their neutral state of equilibrium, then the world might be very different – it might contain only the 100 or so species of atom that are known to exist on earth. However, when the conditions are right, atoms react with other atoms to form molecules and compounds. A molecule, therefore, is formed when two or more of the same atoms bond chemically to each other, and a compound is formed when two or more different types of atoms bond chemically. This ability of different atoms to combine creates a huge variety of possible molecules and compounds, each of which possess their own physical and chemical properties. Why do these reactions occur? Remember that atoms achieve a lower energy, more stable state when they have a full outer shell of electrons. Accordingly, a joining together of two or more atoms that results in a more stable, lower energy state for all of them will be a reaction that will readily occur.

There are a couple of different types of chemical bonds:

Ionic Bonds

Ionic bonding involves the exchange of electrons from one atom to another. Because this exchange will alter the charge on any atom giving or receiving an electron (remember that the electron has a negative charge), it will create charged substances. Look for example, at the sodium atom depicted in Figure 1.4a. The sodium atom has a single electron in its outer shell. Since that shell needs 8 electrons to be full, then it must pick up another 7 electrons to achieve a lower energy state – a tall order! It could, however, lose that one electron, leaving the full second shell as the outer shell, thus achieving a full outer shell by 'donating' an electron to any atom that might be in need of an extra one. Of course, having donated its one electron, the number of protons in the sodium atom will exceed the number of electrons by one, giving the atom a net positive charge. At that point, it becomes known as a sodium ion (Na+), and since it has a net positive charge, it is a positive ion, also known as a cation.

You don't have to look far to find a suitable electron acceptor; chlorine has an outer shell containing 7 electrons, so accepting an extra electron would allow it to achieve a lower energy state:

By the same token, though, the chlorine atom now has one more electron than it has protons, and so gains a net negative charge, and is now known as a chloride ion (Cl^-), and is a negative ion, also known as an anion (Figure 1.4b).

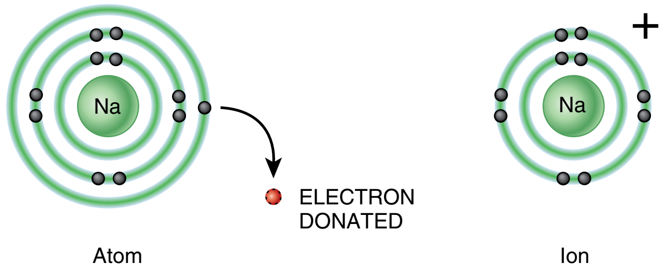

Figure 1.4a **The single electron in the outer shell of the sodium atom can be donated during a chemical reaction, leaving a positively charged, sodium ion.** ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

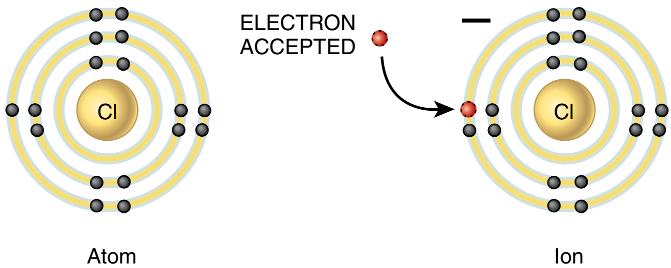

Figure 1.4b **A chlorine atom needs only one electron to complete its outer shell, so will readily react with electron donors like sodium, and accept the donated electron. This creates a negatively charged, chloride ion.** ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

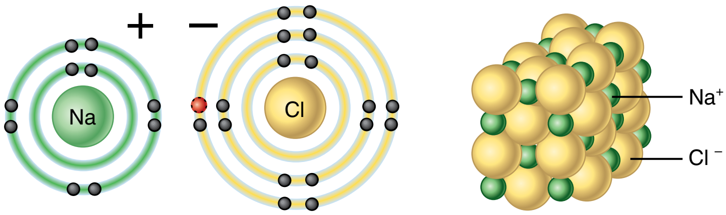

Figure 1.4c **The ionic bonding between a sodium and a chloride ion results in a neutral molecule, sodium chloride. Sodium chloride molecules pack together to form a regular, lattice, crystalline structure.** ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

Having exchanged electrons, the newly formed sodium and chloride ions are now oppositely charged. Opposite charges attract one another, while similar charges repel. The attractive forces between the two ions therefore 'bond' them together, since together, they form a neutral molecule, sodium chloride (NaCl) (Figure 1.4c).

Since the chemical bond is the result of the attractive force between the two ions, this bond is known as an ionic bond. Ionic bonds, therefore, are those that form between ions because of the attraction between opposite charges. These are not the strongest of chemical bonds because, in the presence of other ions, the individual components of an ionically bonded molecule may be more strongly attracted to other charged substances around them, thus breaking the ionic bond and freeing the two ions from each other. This often happens when ionically bonded substances are placed in water, since the water molecule, while not an ion, is a polar molecule, which can set up weak ionic bonds between itself and ions (see polar molecules section).

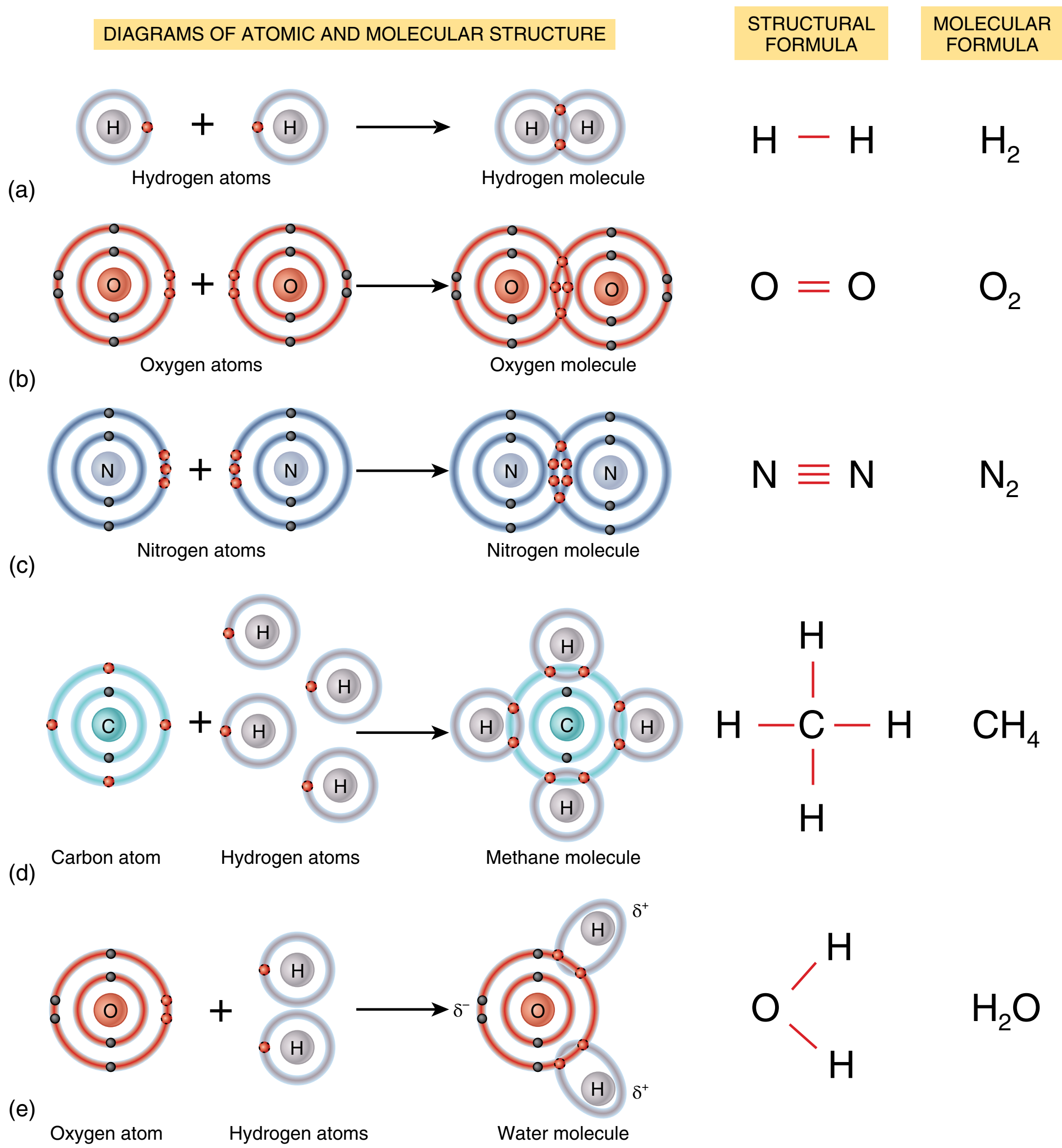

Figure 1.5 **(a–e) Some covalently bonded substances, showing the sharing of electrons between the atoms.**
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There is a second way in which atoms can bond, and this is known as covalent bonding. This form of bonding involves the sharing of valence electrons rather than the complete donation and accepting of electrons.

Electrons rapidly orbit the nucleus of an atom, and if two atoms are so close together that their electron outer shells overlap at the closest point, one electron can orbit both atomic nuclei (Figure 1.5).

Notice that some of the common covalent compounds shown in Figure 1.5 contain double and triple covalent bonds, in which four or six electrons are shared to create the bonds.

Polar Molecules

Sometimes, covalently bonded molecules do not share their electrons equally and the shared electron may spend more time orbiting one end of the covalent bond than the other, giving a more negative charge to that part of the molecule. This difference in charge between one end of a molecule and the other is called polarity, and a molecule that has a charge disparity between its two ends is known as a polar molecule. Water is a polar molecule because the two shared electrons that form each of the bonds between the oxygen atom and the hydrogen atoms spend more time orbiting the oxygen nucleus, thereby making the oxygen end of the molecule more negative than the hydrogen end. When we illustrate the molecule (Figure 1.6), the polarity is indicated by the Greek letter delta (δ) followed by a plus or minus sign to indicate the relative charge at each end of the molecule.

Because of this charge difference within the molecule, polar molecules can attract ions or other polar molecules of the opposite charge, just like ions, and this attraction forms weak bonds. Polar molecules will often swing round and line up with their more negative ends towards a positive charge, or away from a negative charge. The most important weak bond of this type occurs between water and other polar molecules or ions. Because the weak attraction is between the more positive hydrogen end of one water molecule and the more negative end of another water molecule, this type of bond is known as a hydrogen bond (Figure 1.7).

Electrolytes

When ionically bonded substances are placed in water, the ionic bonds break, and the ionically bonded substances 'dissociate' or fall apart, and the ions are released into the water as separate entities, no longer bound to each other. If you were to apply an electrical potential to a solution like this, by placing electrodes attached to a battery into the water, the ions in solution would respond by moving through the solution – the positively charged ions would move in one direction (towards the negatively battery pole) and the negatively charged

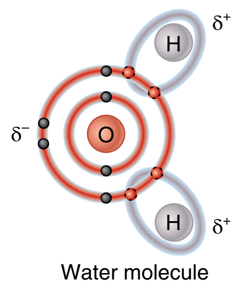

Figure 1.6 Water, a polar molecule, with its positive and negative poles shown. ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

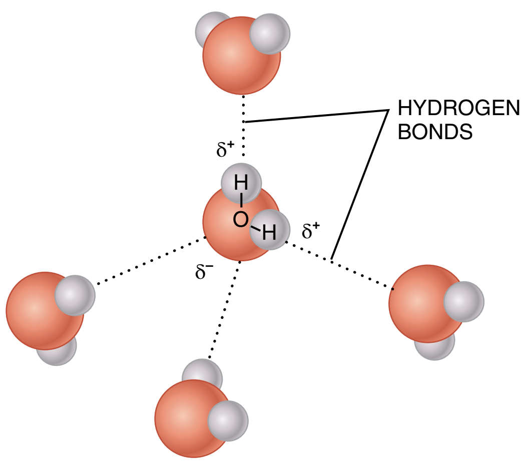

Figure 1.7 Hydrogen bonds and water. The weak bonds between the hydrogen of one water molecule and the oxygen of a neighbouring water molecule are known as hydrogen bonds, and account for the cohesion, or 'stickiness' of water, for surface tension effects and for its tendency to mix well with other polar molecules and ions. ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

ions in the other (towards the positively charged battery pole). By this movement, the ions would effectively carry their charge through the solution, thereby allowing electrical current to pass through the solution. Because of this, ions in solution are known as electrolytes, and an electrolyte solution will allow current to pass through it.

Acids and Bases

The concept of acidity is an extremely important one to understand, as maintaining acid-base balance in the body is essential for life. The acidity of a solution is a measure of the number of hydrogen ions in that solution; the more hydrogen ions in a solution, the more acidic it is. Acids are compounds, which when placed in water, dissociate into hydrogen ions and a second ion (which will vary depending on the acid). Any substance, therefore, which releases free hydrogen ions when it is put into a solution, is an acid. The more hydrogen ions it releases, the stronger the acid it is. Conversely, an alkali (or base), is a substance which removes hydrogen ions from solution, usually by releasing hydroxyl ions (OH^-), into a solution. Hydroxyl ions are attracted to and readily bind with H^+ ions, resulting in water.

A substance, therefore, which removes free hydrogen ions from a solution by providing another ion to bind them up, is an alkaline substance.

Acidity and alkalinity are measured on the pH scale, which extends between 0 and 14, the most acidic being 0 (many more hydrogen ions than hydroxyl ions in solution) and the most alkaline being 14 (many more hydroxyl ions than hydrogen ions in solution). Halfway between these two extremes, 7 on the pH scale, is the neutral point (an equal number of hydrogen ions and hydroxyl ions), as indicated on the pH scale accompanied by hydrogen and hydroxyl ion concentrations in Figure 1.8.

The pH scale is a logarithmic scale, which means that each unit on the scale corresponds to a 10-fold change in the concentration of hydrogen ions. For example, a solution with a pH 3 is 10 times more acidic than a solution of pH 4, 100 times (10 × 10) more acidic than solution of pH 5, and 1000 times (10 × 10 × 10) more acidic than a solution of pH 7. The same applies to pH values that are above 7 (i.e. alkaline solutions).

Blood and pH Values

The normal pH range in blood is slightly above 7 on the pH scale, it is therefore slightly alkaline. However, for the purposes of physiology, a blood pH lower (more acidic) than 7.35 is considered to be too acidic, and one greater than 7.45 is too alkaline, and when either of these events occurs it can have a serious effect on physiological function – as is discussed in other chapters within this book. The pH range for blood may seem very narrow, but because the scale is a logarithmic one, just a small change in pH indicates a very significant

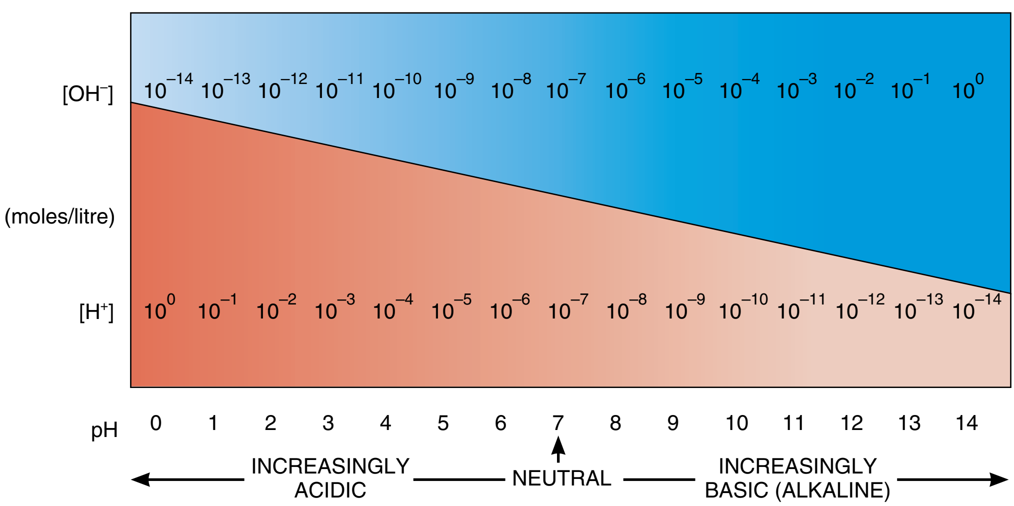

Figure 1.8 The pH scale. *Source:* Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.

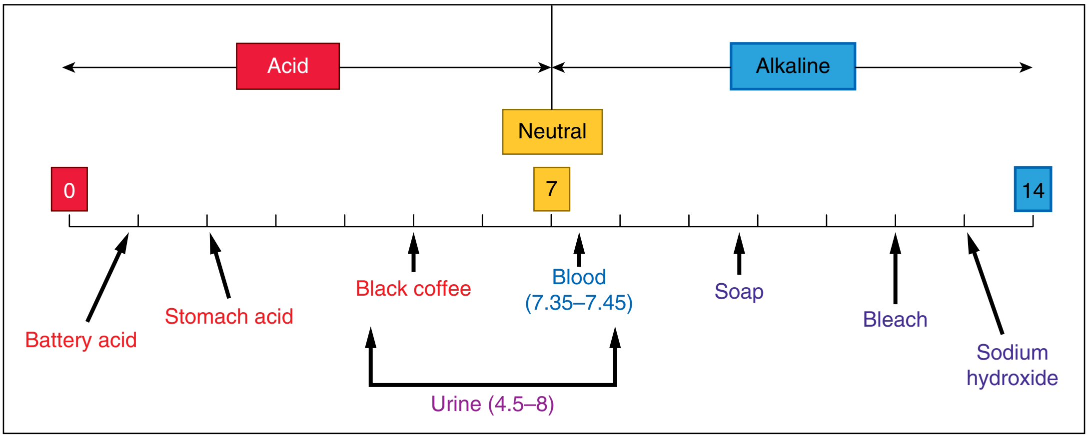

Figure 1.9 **The pH of some common household substances and some body fluids.**

alteration in H^+ concentration. An alteration of pH from pH 7.4 to pH 7.3 actually represents a doubling of the H^+ ion concentration (Figure 1.9).

Representing Chemical Reactions in Written Form: Chemical Equations

As already mentioned, to make writing chemistry quicker and easier, we use symbols to represent each element in the periodic table. When one element reacts with another to form a new compound, we can represent that reaction using the same symbols, showing the compounds reacting (the reactants) and the new compounds resulting from the reaction (the products).

As an example, let us look at a reaction which produces water, one of the most important and ubiquitous compounds on earth. We all know water as a liquid at room temperature, yet it is formed by the reaction between the gases hydrogen and oxygen. Two atoms of hydrogen bond with one atom of oxygen to create the new molecule we know as water. However, because in nature hydrogen gas exists as a hydrogen molecule (two hydrogen atoms bound together) as does oxygen gas (two oxygen atoms bound together), this means that two hydrogen molecules will actually react with one oxygen molecule, producing two water molecules. That equation is represented as:

$$2H_2 + O_2 \rightarrow H_2O$$

Since each water molecule contains two hydrogen atoms and only one oxygen atom, the chemical formula indicates this by placing a subscript 2 after the symbol for hydrogen, and since two hydrogen molecules are required for the reaction, a large 2 before hydrogen indicates this.

Chemical reactions can also be shown in a more graphical way, using not only the chemical symbols, but also diagrams of the atoms and molecules themselves, to give a better idea of their structure, as shown in Figure 1.10.

So, a chemical equation is just a shorthand way of showing a chemical reaction.

It is important to understand that chemical reactions involve a rearrangement of atoms and molecules to form different molecules and compounds – nothing can be created and nothing destroyed in these reactions, so the total number of atoms and molecules must be the same on each side of a chemical equation. Remember that chemical bonds form in the first place to allow atoms and molecules to achieve a lower energy, more stable, state, so it follows that if a chemical rearrangement is to take place, then the rearranged form of the chemicals must be a still lower energy state. When these reactions occur, therefore, energy is released as heat when chemical bonds are broken and different ones formed. This means that heat is one of the products of the reaction, along with the chemical products. Chemical reactions which

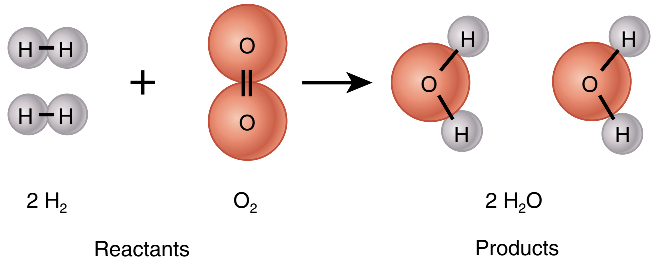

Figure 1.10 Pictorial depiction of the reaction between two hydrogen molecules and one oxygen molecule to produce two water molecules. ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

produce heat as a by-product of the reaction are known as exothermic reactions. Humans often put exothermic reactions to good use – the best example being the crackling fire that keeps us warm in winter – the heat from the fire is in fact the heat produced by the exothermic chemical reaction between the cellulose (in the fire wood) and oxygen (in the air). The arrow in the middle of the chemical equation indicates the direction of the reaction; in other words, it points towards the products of the reaction. This is not to say that the reaction cannot also reverse and proceed from right to left as written, but it does mean that if the reaction from left to right is exothermic, then energy will need to be supplied in order to get it to go back the other way. Take the example shown earlier, of the gases hydrogen and oxygen combining to form water; that reaction is exothermic. It is also possible for the reaction to proceed in the opposite direction, and water to break apart to yield hydrogen and oxygen, but energy would have to be supplied to drive this reaction, so it would not happen spontaneously.

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 the direction that the arrow is pointing. If a reaction can proceed in either direction, it is known as a reversible reaction, and is written with arrows pointing in both directions.

An example of a reversible reaction, and one which is a very important reaction in the control of acid-base balance in the body, is the reaction between carbon dioxide and water to form carbonic acid.

$$CO_2 + H_2O \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{Bicarbonate ion}}{HCO_3^-} + \underset{\text{Hydrogen ion}}{H^+}$$

Not only does the reaction take place in two stages, but, as the arrows indicate, the reactions can also proceed in both directions, with bicarbonate and hydrogen ions combining to form carbonic acid, which then rearranges to produce carbon dioxide and water. Reactions like this, which can proceed in either direction, will create an equilibrium, a point at which there is a mix of products and reactants. This means that changes in the balance between the reactants and the products would therefore be expected to 'tip' the reaction in one direction or the other. This behaviour is very important in the rapid buffering of acids and alkalis in the blood, to help maintain normal blood pH.

Organic Molecules

Chemicals can be classified as being either organic or inorganic. These terms derive from the observation that the molecules that make up living things are large, carbon-containing compounds, and these became known as organic compounds, because they formed living (organic) material. Organic molecules contain carbon, often in long chains, with hydrogen, and are usually very large molecules. Inorganic molecules, on the other hand, do not contain carbon and hydrogen atoms arranged in long chains, although some do contain carbon (carbon dioxide, for example, is an inorganic compound) and some contain hydrogen (water, for example). Inorganic molecules tend to be much smaller.

There are other characteristics which set organic and inorganic compounds apart:

- **Organic** molecules:
  - contain carbon (C) and hydrogen (H);
  - are usually larger than inorganic molecules;
  - dissolve in water and organic liquids;
  - include carbohydrates (sugars), proteins, lipids (fats) and nucleic acids (part of DNA) – see Chapter 3, Genetics. Organic molecules are sometimes known as the 'molecules of life' for this reason.
- **Inorganic** molecules:
  - include water (H_2O), carbon dioxide (CO_2) and inorganic salts.
  - are usually smaller than organic molecules;
  - usually dissolve in water or react with water to produce ions;

Examples of Organic Substances

Carbohydrates

This group of organic molecules, also known as saccharides, makes up one of our major food groups, and includes sugars, starch and cellulose. The smallest and simplest members of the group, the monosaccharides, provide energy to cells as well as forming part of some of the structures in cells (see Chapter 2). They contain carbon (C), hydrogen (H) and oxygen (O), usually in the proportion CH_2O; that is, with two hydrogen atoms to every one oxygen and carbon atom.

Carbohydrates are classified into three groups based on their molecular size:

Monosaccharides
- Glucose (dextrose), formula $C_6H_{12}O_6$
- Fructose (fruit sugar), formula also $C_6H_{12}O_6$

Disaccharides
- Sucrose (table sugar), formula $C_{12}H_{22}O_6$
- Lactose (milk sugar), formula $C_{12}H_{22}O_{11}$

Polysaccharides
- Starch (amylose), formula $(C_6H_{10}O_5)n$
- Glycogen, formula $(C_6H_{10}O_5)n$
- Cellulose, formula $(C_6H_{10}O_5)n$

Monosaccharides and disaccharides can be referred to collectively as simple sugars or simple carbohydrates. Disaccharides, as the name suggests, consist of two monosaccharides bonded together – a sucrose molecule is one molecule of glucose bound to one molecule of fructose. The much larger polysaccharides are referred to as complex sugars or complex carbohydrates. It is the foods containing complex carbohydrates that are often listed as having a low glycaemic index, since, as larger sugars that require digestion before they can be absorbed, they arrive in the bloodstream more gradually.

Fats

Fats are one part of a larger group of chemicals known as lipids. They form another major food group, and are used in the diet to provide energy, but cell membranes are made of lipids and the group of hormones known as the steroids are also lipids, so this group plays a range of important roles in human function. Like carbohydrates, they consist of carbon (C), hydrogen (H) and oxygen (O), but because the relative proportions of these atoms are different from the carbohydrates, the lipids have different properties. They are only soluble in non-polar solvents like alcohol, for example, and not in water.

There are several types of lipids, but some of the most common are the following:

Fatty acids. These molecules are the 'building blocks' of larger, more complex lipids, and do not often exist on their own. They consist of long chains of carbon and hydrogen, with an organic acid group at the end (Figure 1.11). There are many different types of fatty acid, three common examples being oleic acid – found in olive, sunflower, peanut and palm oil, palmitic acid – found in palm oil, meat and dairy and stearic acid – found most commonly in animal fats.

Triglycerides (triacylglycerols). These molecules consist of three fatty acid molecules attached to a glycerol molecule (Figure 1.12). The long chains of the fatty acid molecules anchored to the glycerol molecule make the triglycerides look a little like three ties on a hanger.

These are the lipids that our cells can use for energy, and we often measure triglycerides circulating in the blood when checking a person's blood lipid profile.

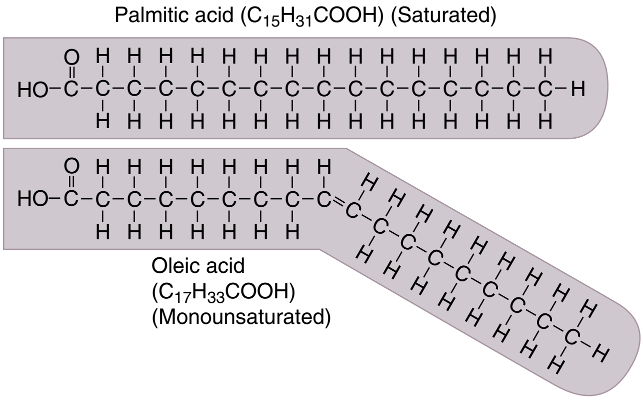

Figure 1.11 **The fatty acids palmitic acid and oleic acid, indicating the general structure of fatty acids.** ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

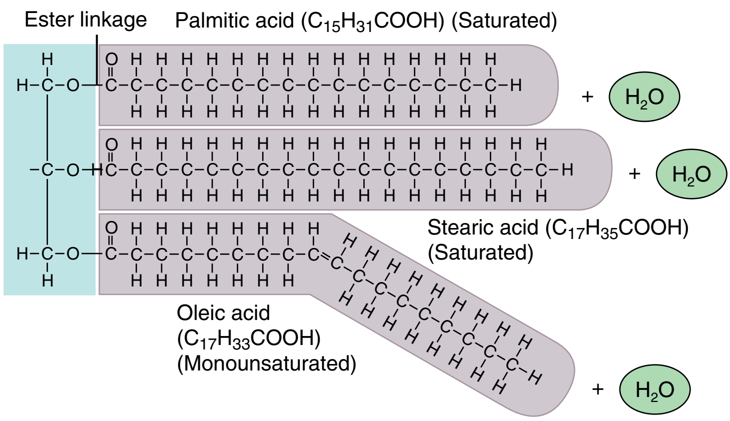

Figure 1.12 **Triglyceride molecule.** ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

Clinical Considerations Cholesterol, Blood Lipids and Health

Routine measurement of blood lipids includes measurement of a number of lipids carried in the blood stream, and usually includes triglycerides, low density lipoprotein (LDL), high density lipoprotein (HDL) and total cholesterol. While fats are an excellent source of energy, excessively high levels of triglycerides, LDL and total cholesterol are linked with an increased risk of cardiovascular disease. High levels of HDL, on the other hand, are associated with reduced risk of cardiovascular disease. Improving blood lipid profiles to improve health can be achieved by dietary changes and increasing physical activity, but the use of drugs known as statins has a more powerful effect on cholesterol levels, and these drugs have been widely prescribed for this purpose. As with any drug, the benefits of taking it have to be carefully weighed against the risks. The data seem to suggest that raising HDL to provide a protective effect is just as, or perhaps more, important than reducing LDL, so refinements to the way the problem of high blood lipids are managed are on the way.

Phospholipids. As the name suggests, these lipids have a phosphate group as a component of their molecules. A double layer of these molecules makes up the basis of our cell membranes, as will be discussed in Chapter 2 (Figure 1.13).

Steroids. Steroids are substances that are quite different chemically from lipids, but are considered lipids because they are insoluble in water. A number of very important hormones are steroids, as is cholesterol, which is a vital component of cell membranes. The names of these substances usually indicate the chemical group they belong to, by including -sterol or -sterone in the name, e.g. cholesterol, corticosterone, aldosterone, progesterone, testosterone.

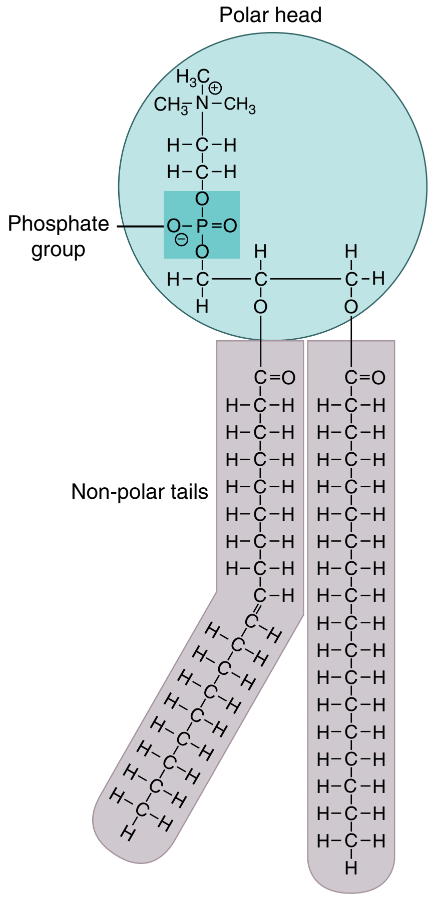

Figure 1.13 **Phospholipid molecule. This molecule has a 'head', where the phosphate group is located, and two 'tails', consisting of two fatty acid molecules.** ***Source:*** **Tortora and Derrickson (2014). Reproduced with permission of John Wiley & Sons.**

Proteins

Proteins are large molecules built from amino acids strung together to form long chains. The body makes many different proteins, each one with a different sequence and number of amino acids strung together. The structural material that makes up the body is protein, and many vital molecules such as hormones receptors, enzymes and antibodies are proteins. It is useful to think of protein function in two major categories: structural proteins (make up our structures) and functional proteins (part of our biochemical machinery, including receptors, enzymes and antibodies). Proteins will be discussed in much greater depth in Chapter 3.

Homeostasis

Homeostasis is the maintenance of a relatively stable internal environment in the face of a constantly changing external environment – from cold to hot, from dry to wet, from acid to alkaline and so on. Homeostatic mechanisms are continuously monitoring and controlling variables in the body such as blood pH, core temperature, blood pressure, blood glucose levels and many others. Regardless of the variable being controlled, homeostatic systems all follow a general scheme:

1. A detector system to monitor changes in the variable. These detectors are collectively known as receptors, and we have many types – each one specialised to detect a particular variable, e.g. baroreceptors detect pressure changes in blood vessels, chemoreceptors detect changes in the concentration of some chemicals and thermoreceptors detect temperature changes.

2. A control centre to receive the messages from the detectors about changes, and to organise a response to counteract the change, thereby maintaining stability.
3. Effectors, to bring about the response, e.g. shivering and 'goosebumps' when a drop in temperature is detected, increased insulin when blood glucose level increases or an increase in heart rate when a drop in blood pressure is detected.

Since the tendency of homeostatic control is therefore to resist, or at least limit, the size of changes occurring within the internal environment, the mechanism which achieves this is often referred to as a negative feedback loop, since the response of the system is opposite to (a negative of) the change that triggered it. For example, if the blood pressure drops slightly, the homeostatic mechanism that controls blood pressure will respond by producing an increase in blood pressure – the response is therefore opposite to the change, hence the feedback to the change is negative to it. Systems that work like this are inherently stable, as they tend to resist change within the system.

Much of the study of human function is the study of these complex homeostatic control mechanisms, and the maintenance of good health depends on their effectiveness. It is important to remember that homeostasis does not 'lock' a variable at one setting, but limits the degree to which a variable can change, so that our systems are flexible enough to adapt to changing demands and conditions, but stable enough to maintain an internal environment that is consistent with healthy function of our body systems.

Units of Measurement

To conclude this chapter, which introduces certain scientific 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 measured property. 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 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 brief introduction to some of the basics of chemistry and biology. As you will appreciate, the study of body function at any level, whether it be at the level of molecules reacting or at the level of the whole person, is extremely complicated, but also fascinating.

Learning something about how bodies function and how they respond to the challenges placed upon them in both health and disease can equip you with power to save lives in your future practice. It is only through gaining an understanding of the wonderful machines we inhabit that we can learn how to best care for them. Enjoy the discoveries that await you.

Glossary

Acid: A chemical substance with a pH below 7.
Acid-base balance: The maintenance of pH within controlled limits. This is essential for good health. See pH.
Alkali: A chemical substance with a pH above 7.
Anatomy: The study of the structures of the body.
Anion: An ion with a negative charge.
Antibody: Proteins that recognise and attach to specific infectious agents in the body.
Atomic number: The number of protons in the nucleus of an atom.
Atoms: The smallest unit of matter.
Base: An alkaline substance.
Bonds: The joining together of various substances, particularly atoms and molecules. See chemical bond, covalent bonds, ionic bonds, and polar bonds.
Cation: An ion with a positive charge.
Chemical bond: The 'attractive' force that holds atoms together.
Chemical reaction: A process in which chemical substances react together to produce a different chemical form. This is usually expressed by a chemical equation.
Compound: A substance that is made up of two or more elements chemically bonded together.
Covalent bonds: Bonds between atoms formed by the sharing of electrons between the atoms.
Electrolyte: Substance that produces a solution that conducts electricity when placed in water. Physiologically important electrolytes include sodium and potassium ions.

Electrons: The parts of an atom that orbit the atomic nucleus and carry a negative electrical charge. See also neutrons and protons.
Elements: A chemical substance that cannot be broken down into anything simpler by chemical means.
Enzymes: Proteins produced by cells that increase the rate of biochemical reactions in the body.
Homeostasis: The maintenance of a stable internal environment by the use of systems of detectors, control centres and effectors.
Inorganic substances: Substances that do not contain long chains of carbon and hydrogen molecules (although they may contain carbon and hydrogen).
Ionic bonds: Bonds that form between ions with opposite charges.
Ions: The entities formed when atoms lose or gain electrons, thereby becoming positively or negatively charged.
Mole: The unit of measurement of the amount of a substance.
Molecules: Electrically neutral group of two or more atoms bonded together.
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 also electrons and protons.
Organelles: Structural and functional parts of a cell.
Organic substances: Substances that contain carbon molecules (e.g. carbohydrates, lipids, proteins).
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: Bonds that form between polar molecules, in which the increased negativity of one pole of a polar molecule is attracted to the increased positivity of the opposite pole of another molecule. Hydrogen bonds are polar bonds.
Product (chemical reactions): The new substance/s formed following a chemical reaction.
Protons: Subatomic particles found in the atomic nucleus which carry a positive electrical charge. See also electrons and neutrons.
Reactant (chemical reactions): The individual substances involved in a chemical reaction.
Shell (of an atom): The name given to the orbits of electrons moving around the nucleus of an atom.
Valency: The number of hydrogen atoms an element is able to combine with. This is the bond-forming power of an element, and depends on the number of electrons in its outermost shell.

References

Tortora, G.J. and Derrickson, B.H. (2014) *Principles of Anatomy and Physiology*, 14th edn. Hoboken, NJ: John Wiley & Sons.

Activities

Multiple Choice Questions

1. The characteristics of life include:
   (a) digestion, excretion, irritation
   (b) absorption, bleeding, circulation
   (c) excretion, perspiration, reproduction
   (d) respiration, growth, responsiveness
2. The four essential requirements for all organisms are:
   (a) respiration, digestion, excretion and circulation
   (b) oxygen, water, sunlight, food
   (c) food, low temperatures, carbon dioxide, oxygen.
   (d) pressure, 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. An atom contains five electrons in its outermost shell. Which of the following is it most likely to do when it reacts?
   (a) donate 5 electrons to another atom, becoming a more stable, neutral atom
   (b) donate three electrons to another atom, becoming a negatively charged ion
   (c) accept three electrons from another atom, becoming a negatively charged ion
   (d) accept one electron from another atom, becoming a neutral, more stable atom
5. Which of the following is not a type of chemical bond?
   (a) polar
   (b) equatorial
   (c) ionic
   (d) covalent
6. 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
7. Which of the following is both an anion and a compound?
   (a) NaCl
   (b) Cl^-
   (c) Na^+
   (d) HCO_3^-
8. Which of the following are organic substances?
   (a) carbohydrates, proteins, lipids
   (b) carbohydrates, water, oxygen
   (c) water, proteins, lipids
   (d) lipids, oxygen, proteins
9. Which of these pH values is the least acidic?
   (a) 1.0
   (b) 0.8
   (c) 11
   (d) 6.5
10. Homeostasis is:
   (a) the effective use of receptors
   (b) a measurement of acidity in the body
   (c) maintenance of a stable internal environment
   (d) a combination of physical properties
11. A molecule of water is a combination of these atoms:
   (a) 1 × hydrogen, 1 × oxygen, 1 × carbon
   (b) 2 × oxygen, 1 × carbon
   (c) 2 × oxygen, 1 × hydrogen
   (d) 1 × oxygen, 2 × hydrogen
12. In biochemistry, a ‘mole’ is a unit of:
   (a) intensity of radiation
   (b) luminosity of light
   (c) pH of a solution
   (d) amount of a substance
13. The pH of a solution depends on:
   (a) the number of ions in the solution
   (b) the number of electrolytes in the solution
   (c) the number of hydrogen ions in the solution
   (d) the number of organic ions in the solution
14. Which of the following is a complex carbohydrate?
   (a) a polysaccharide
   (b) a protein
   (c) a monosaccharide
   (d) a triglyceride

15. An atom has an atomic number of 20. That means it has:
    (a) 10 electrons
    (b) 10 protons and 10 neutrons
    (c) 20 protons
    (d) 10 protons and 10 electrons

True or False

1. An ion is an atom that is in an electrically neutral state.
2. Molecules are combinations of atoms.
3. Many electrolytes are essential minerals.
4. Organic substances contain carbon and hydrogen.
5. Lipids are examples of inorganic substances.
6. Proteins are built up from amino acids and provide the structural material for the body.

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:

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

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?