CONCEPTUAL LIFE SCIENCE

CHEMISTRY OF LIFE

Chemistry is the study of matter

Life science involves the study of living things. Since living things are made of matter, knowledge of simple chemistry will help you to understand the principles underlying the structure and activities of living things.

ATOMS

The atom is the smallest quantity of an element that still possesses the properties of the element. The nucleus of the atoms contains the protons and the neutrons. The electrons are found in shells that surround the nucleus. Table III-1 contains information about the fundamental particles of the atom.

Table III-1. Fundamental particles of the atom.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Particle</th>
<th>Charge</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>☻</td>
<td>Proton</td>
<td>+1</td>
<td>1 AMU*</td>
</tr>
<tr>
<td>☼</td>
<td>Neutron</td>
<td>0</td>
<td>1 AMU</td>
</tr>
<tr>
<td></td>
<td>Electron</td>
<td>-1</td>
<td>5.5 x 10^{-4} AMU</td>
</tr>
</tbody>
</table>

*AMU = Atomic Mass Unit

Examples of atomic structure

Hydrogen

Hydrogen is the first and simplest element. In the nucleus it has one proton. In the electron shell is one electron. For hydrogen the atomic number is 1 and the mass is 1.
Hydrogen

<table>
<thead>
<tr>
<th>Chemical Symbol</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^1_1H$</td>
<td><img src="image" alt="Hydrogen Structure" /></td>
</tr>
</tbody>
</table>

Figure 3-1. Formula and structure of hydrogen. The atomic number is represented by the lower number and the atomic mass is represented by the upper number.

Helium

Helium is the second element. In the nucleus it has two protons and two neutrons. There are two electrons in the electron shell. For helium, the atomic number is 2 and the mass is 4.

<table>
<thead>
<tr>
<th>Chemical Symbol</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^4_2He$</td>
<td><img src="image" alt="Helium Structure" /></td>
</tr>
</tbody>
</table>

Figure 3-2. Formula and structure of helium.

Lithium

Lithium is the third element. Its nucleus has three protons and four neutrons. There are two electrons in the first shell and one electron in the second shell. This is because the first shell only holds two electrons. The capacity of the second shell is eight electrons.
Lithium

Chemical Symbol | Structure
---|---
\( ^7 \text{Li} \) | \( ^3 \text{P} ^4 \text{N} \)

Figure 3-3. Formula and structure of lithium. Lithium has two electron shells because the first shell only holds two electrons.

Carbon

Carbon is element number 6. It has six protons and six neutrons. There are six electrons, two in the first shell and four in the second shell. Its atomic number is 6 and its mass is 12.

Chemical Symbol | Structure
---|---
\( ^{12} \text{C} \) | \( ^6 \text{P} ^6 \text{N} \)

Figure 3-4. Formula and structure of carbon.

Oxygen

Oxygen is element number 8. It has eight protons and eight neutrons in its nucleus. It has eight electrons, two in the first shell and six in the second shell. Its atomic number is 8 and its mass is 16.
**Oxygen**

<table>
<thead>
<tr>
<th>Chemical Symbol</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{16}_8\text{O}$</td>
<td><img src="image" alt="Oxygen Structure" /></td>
</tr>
</tbody>
</table>

Figure 3-5. Formula and structure of oxygen. Note that the electrons in the outer shell are distributed unevenly. There are two pairs of electrons and two single electrons. This distribution is important in the way that oxygen bonds to other atoms.

Dot structures

The outer electrons are all that matter in chemical bonding. It is customary to represent them using dots.

![Dot Structures](image)

Figure 3-6. Dot structures. The electrons in the outer shell are represented using dots. These dot structures assist in understanding chemical bonding.

Elements

Elements are chemical substances composed of only one type of atom. There are over 100 elements. The elements are organized into the Periodic Table of the Elements.
Table III-2. Principal elements in protoplasm.

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>63</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>25.5</td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
<td>9.5</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>1.4</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Molecules

Molecules are electrically neutral aggregates of atoms bonded together. "Electrically neutral" means that the number of protons equals the number of electrons.

Compounds

Compounds are substances composed of a single kind of molecule. They can be broken down into simpler substances. For example, water (H₂O) can be decomposed into hydrogen and oxygen. Sodium chloride (NaCl) can be decomposed into sodium and chlorine atoms.

CHEMICAL BONDS

We are concerned with two kinds of bonds: ionic bonds and covalent bonds. Atoms behave in a way that gives them a complete outer shell. These bonding methods achieve that goal.

Ionic bonds

**Ionic bonding: Before**

\[ \text{Na}^+ \leftrightarrow \text{Cl}^- \]

**Ionic bonding: After**

\[ \text{Na}^+ \leftrightarrow \text{Cl}^- \]

Figure 3-7. Formation of an ionic bond.
Ionic bonds are formed by complete transfer of one or more electrons from one atom to another. An example is the formation of sodium chloride (table salt).

Covalent bonds are formed by sharing of electrons between atoms. A bond is formed when a pair of electrons is shared. Each atom gets to share enough electrons to give it a complete outer shell.

**Some Biologically Important Compounds**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>H–O–H</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>O = C = O</td>
</tr>
<tr>
<td>Oxygen (a diatomic molecule)</td>
<td>O = O</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>NaCl</td>
</tr>
</tbody>
</table>

Water and salts are examples of inorganic compounds.
THE pH SCALE

Ionization

Molecules of ionic compounds contain ions. Ions are formed by complete transfer of electrons from one atom to another. You will recall that in the formation of sodium chloride (NaCl), one electron was transferred from sodium to chlorine. The result was formation of a sodium ion (Na\(^+\)) and a chloride ion (Cl\(^-\)).

When salt is dissolved in water, the ions separate from each other. The result is that the positive sodium ions and the negative chloride ions move around among the water molecules as separate charged particles.

Water can ionize. Despite being a covalent compound, water can dissociate to a slight extent to form ions. The result is that the water molecule (H\(_2\)O) forms hydrogen ions (H\(^+\)) and hydroxide ions (OH\(^-\)).

Neutralization

Acids form hydrogen ions. When an acid compound ionizes, it will form hydrogen ions. For example, hydrochloric acid (HCl):

\[ \text{HCl} \rightarrow \text{H}^+ + \text{Cl}^- \]

Bases form hydroxide ions. When a basic compound ionizes, it will form hydroxide ions. For example, sodium hydroxide (NaOH):

\[ \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- \]

Neutralization is a reaction between an acid and a base. When an acid and a base react, the hydrogen and hydroxide ions combine to produce water. The other ions combine to produce a salt. A salt is formed by the positive ion of the base and the negative ion of the acid. For example:

\[ \text{NaOH} + \text{HCl} \rightarrow \text{HOH} + \text{NaCl} \]

Neutralization has some important applications. You use vinegar (a weak acid) or boric acid to partly neutralize oven cleaner (a strong base). It can be used if lye (NaOH) is spilled on the skin while cleaning a drain. Farmers will add limestone to the soil if it is too acidic. Many over-the-counter products contain sodium bicarbonate (a weak base) to neutralize "excess stomach acid". Sodium bicarbonate is produced in the digestive system for the same reason.
The pH scale

The pH scale shows the strength of an acid or a base. The pH scale ranges from 0 to 14 as shown in figure 3-9. The number 7, in the middle, represents the neutral point between an acid and a base. Here, at pH 7, the concentration of hydrogen ions (H⁺) equals the concentration of hydroxide ions (OH⁻).

![Figure 3-9. The pH scale.](image)

The pH 7 value is the neutral point. The smaller than 7 a number is, the more acid there is in the solution. The scale is logarithmic. Stomach acid (pH 1.1) is over 10,000 times stronger than boric acid (pH 5.2). The larger than 7 a number is, the stronger base it is. Therefore, lye (pH 13.0) is approximately 100,000 times stronger than sodium bicarbonate solution (pH 8.4).
ORGANIC CHEMISTRY

*Organic chemicals contain carbon.* There are many organic compounds that are important in biology. They may be used for biological structures or as nutrients. Some of the more important ones are carbohydrates, lipids, proteins and nucleic acids.

CARBOHYDRATES

Carbohydrates contain carbon (C), hydrogen (H), and oxygen (O). The ratio of hydrogen to oxygen is 2:1 in carbohydrates. This means that there is twice as much hydrogen as there is oxygen.

Simple sugars (monosaccharides)

Simple sugars contain from three to seven carbon atoms. Some of the larger ones such as glucose can form rings.

Glucose

\[
\begin{align*}
\text{H} & \text{C} = \text{O} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\end{align*}
\]

Glyceraldehyde

\[
\begin{align*}
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\text{H} & \text{C} - \text{OH} \\
\end{align*}
\]

Figure 3-10. Examples of monosaccharides.
Condensation reactions

A condensation reaction occurs between two molecules when an enzyme removes water from them and joins them together with a single bond. This process is known as dehydration synthesis. The water is always removed in the form of H from one molecule and OH from the other molecule.

Disaccharides

Disaccharides consist of two monosaccharides connected by a condensation reaction. An example of a disaccharide is maltose which is formed by reaction between two glucose molecules.

Figure 3-12. Formation of maltose
Polysaccharides

Polysaccharides contain many monosaccharides linked together by condensation reactions. These consist of long chains called polymers. The three polymers of glucose are starch, cellulose and glycogen.

![Figure 3-13. The Hydrolysis-Synthesis Cycle.](image)

![Figure 3-14. The Carbohydrate Pyramid.](image)
LIPIDS

Lipids contain carbon, hydrogen and oxygen. There is much less oxygen in a lipid than in a carbohydrate. The types of lipids are triglycerides, waxes, phospholipids and steroids.

Fats and Oils

Fats and oils are examples of triglycerides. Fat is solid at room temperature. Oil is liquid at room temperature. The building blocks of triglycerides are fatty acids and glycerol. Molecules of triglycerides each contain one glycerol and three fatty acids.

Saturated fats do not have double bonds between the carbon atoms. Saturated fats have at least one double bond between the carbon atoms.

\[
\text{O}==\text{C}-%\text{CH}_2-%\text{CH}_2-%\text{CH}_2-%\text{CH}_3 \quad \text{O}==\text{C}-%\text{CH}_2-%\text{CH}=%\text{CH}-%\text{CH}_2-%\text{CH}_3 \\
\text{OH} \quad \text{OH}
\]

A. Saturated \hspace{1cm} B. Unsaturated

Figure 3-15. Saturated and unsaturated fatty acids.

Waxes

Waxes are formed by condensation reactions between long-chain fatty acids and long-chain alcohols. They are found in various places, such as the surfaces of leaves.

Phospholipids

Phospholipids are lipids that contain glycerol, two fatty acids, phosphorus and sometimes nitrogen. The phosphorus is derived from phosphoric acid. Molecules of phospholipids have a polar head and non-polar tails. The end with the polar head attracts water and is called hydrophilic. The end with the non-polar tails repels water and is known as hydrophobic. Phospholipids are the major component of the membranes found in all cells.

Figure 3-16. Diagram of a phospholipids molecule.
Steroids

Steroid molecules have a complicated structure of interlocking carbon rings. This is an important type of lipid. It includes the sex hormones, cortisone, cholesterol, and related molecules.

PROTEINS

Proteins are long-chain polymers of amino acids which are linked together by condensation reactions (dehydration synthesis). They are the fundamental structural molecules in biology.

Amino acids

There are 20 different types of amino acids. They can combine in a variety of ways.

![Structure of an amino acid]

**Figure 3-17. Structure of an amino acid.**

Formation of Proteins by Condensation Reactions

When two amino acids are joined together, water is removed from the amino group of one amino acid and the acid group of the other. The result is a dipeptide (two amino acids) joined by a peptide bond, and the water molecule which was removed.
Functions of proteins

Structural proteins. Structural proteins hold biological structures together or form body structures. An example is keratin. Keratin is the protein found in hair, skin, nails, and the corresponding parts of other animals such as fur, hooves, claws, as well as fish and reptile scales.

Enzymes. An enzyme is a catalyst that allows the occurrence of a chemical reaction at body temperature. All enzymes are proteins. Condensation reactions are examples of biological reactions that are catalyzed by enzymes. There is also an enzyme called catalase. Catalase is another example of an enzyme.

NUCLEIC ACIDS

There are two types of nucleic acids. These are known as:

- Deoxyribonucleic acid (DNA), and,
- Ribonucleic acid (RNA).

Nucleotides

Nucleotides are the building blocks of nucleic acids. They have three components: a base, a sugar and a phosphate. The bases are rings of carbon and nitrogen atoms and are
sometimes called nitrogenous bases. The phosphate is derived from phosphoric acid. The sugar found in DNA is called deoxyribose while the sugar found in RNA is called ribose.

**Formation of nucleic acids**

The phosphate from one nucleotide becomes joined to the sugar of another nucleotide by a condensation reaction. This process results in the formation of very long chains of nucleotides.

**Figure 3-19. The nucleic acid pyramid.**

**Functions of the nucleic acids**

**Deoxyribonucleic acid (DNA).** DNA is found in the chromosomes of the nucleus of the cell. It directs all aspects of cell function. It is organized into genes which determine the properties of the organism.

**Ribonucleic acid (RNA).** There are three kinds of RNA. Each is associated in some way with protein synthesis. The structure of proteins (the sequence of the amino acids in the protein) is ultimately determined by the DNA of the cell.