3.2: Chemical Reactions

learning objectives

• Differentiate between substrate and product, and define chemical equation
• Define metabolism, synthesis (anabolic), decomposition (catabolic), and exchange reactions
• Differentiate between reversible reactions and irreversible reactions
• Explain dehydration synthesis and hydrolysis reactions
• Explain the relationship between monomers and polymers

Chemical reactions begin with one or more substances that enter into the reaction. The substances in our cells and body tissues that enter into the reaction are called substrates. The one or more substances produced by a chemical reaction are called products.

Chemical reactions are represented by chemical equations by placing the substrate(s) on the left and the product(s) on the right. Substrate(s) and product(s) are separated by an arrow (\(\rightarrow\)) which indicates the direction and type of the reaction. For example, lactose, the sugar found in milk, is broken down by our digestive system into two smaller sugars, glucose and galactose. In this reaction, lactose is the substrate, and glucose and galactose are the products. The chemical equation for this reaction is:

Lactose \(\rightarrow\) Glucose + Galactose

Concepts, terms, and facts check

Study Questions Write your answer in a sentence form (do not answer using loose words)

1. What is the difference between a substrate and a product?
2. What is a chemical equation?

**Metabolism** refers to the sum of all chemical reactions happening in a living organism. There are three main types of chemical reactions important in human physiology, synthesis (anabolic), decomposition (catabolic) and exchange.

1. **In a synthesis reaction** (syn- = together; -thesis = "put, place, set"), two or more substrates molecules covalently bond to form a larger product molecule. Synthesis reactions require energy to form the bond(s). A synthesis reaction is often symbolized as \( A + B \rightarrow AB \), where \( A \) and \( B \) are the substrates, and \( AB \) is the product. Synthesis reactions can also be called **anabolic** or constructive activities in a cell.

2. **In a decomposition reaction** (de- off, away= -composition = "putting together, arranging"), covalent bonds between components of a larger substrate molecule are broken down to form smaller product molecules. Decomposition reactions release energy when covalent bonds in the substrate are broken down. A decomposition reaction is often symbolized as \( AB \rightarrow A + B \); where \( AB \) is the substrate, and \( A \) and \( B \) are the products. Different types of decomposition reactions may also be referred to as digestion, hydrolysis, breakdown, and degradation reactions. Decomposition reactions are the basis of all **catabolic**, or breakdown activities in a cell.

3. **In an exchange reaction**, covalent bonds are both broken down and then reformed in a way that the components of the substrates are rearranged to make different products. An exchange reaction is often symbolized as \( AB + CD \rightarrow AC + BD \). In this exchange reaction, the covalent bonds between \( A \) and \( B \), and between \( C \) and \( D \) were broken; and new covalent bonds between \( A \) and \( C \), and \( B \) and \( D \) were formed.

![Figure](https://med.libretexts.org/Bookshelves/Anatomy_and_Physiology/Book%3A_Human_Anatomy_and_Physiology_Preparatory_...)

**Figure \( \PageIndex{1} \)**: Representation of three types of chemical reactions. From top to bottom: synthesis, decomposition, and exchange.

Concepts, terms, and facts check

**Study Questions** Write your answer in a sentence form (do not answer using loose words)

1. What is a synthesis reaction?
2. How can a synthesis reaction be represented by using letters?
3. What is an anabolic reaction?
4. What is a decomposition reaction?
5. How can a decomposition reaction be represented by using letters?
6. What is a catabolic reaction?
7. What is an exchange reaction?
8. How can an exchange reaction be represented by using letters?
9. What is a metabolism reaction?
10. What is metabolism?
Some metabolic reactions are called **irreversible reactions**. This means that the product(s) cannot be changed or "reversed" back into substrates. These reactions are represented with a single arrow as in \( A + B \rightarrow C \).

For example:

\[
\text{Glucose} + \text{Oxygen} \rightarrow \text{Carbon dioxide} + \text{Water}
\]

Note: This is a type of catabolic reaction (the larger glucose molecule is broken down to smaller carbon dioxide molecules) related to cellular energy production. In animal cells, such as humans, this is an irreversible reaction.

Other metabolic reactions are called **reversible reactions**. This means that the reaction can proceed from substrates to product(s) or from product(s) back to substrates. The product(s) can be changed back into or "reversed" into substrates. They are represented with a double arrow as in \( A + B \leftrightarrow C + D \).

For example:

\[
\text{Glycogen} + \text{Water} \leftrightarrow \text{Glucose}
\]

Note: When cells need energy, glycogen (a larger molecule used as an energy store in some cells) can be catabolized to smaller glucose molecules, which can then be further catabolized to provide energy for cell functions. When cells do not need as much energy, or when glucose levels are very high, glycogen is synthesized from the smaller glucose molecules. For example, muscle cells synthesize glycogen when resting and catabolize glycogen when contracting. Which way this reversible reaction proceeds depends on body needs.

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**Study Questions** Write your answer in a sentence form (do not answer using loose words)

1. What is a reversible reaction?
2. What is an irreversible reaction?

In the body, synthesis reactions (smaller molecules to larger molecule, requires energy) and decomposition reactions (larger molecule to smaller molecules, releases energy) are often associated with the formation and breakdown of water molecules, respectively. A **dehydration synthesis** reaction is a type of synthesis reaction that makes water as a byproduct. A **hydrolysis** reaction is a type of decomposition reaction that uses water.

In the dehydration synthesis (de- = "off, remove"; hydrate = "water") shown in figure \( \PageIndex{2} \), two monomers are covalently bonded in a reaction in which one gives up a hydroxyl ion (-OH\(^-\)) and the other a hydrogen ion (-H\(^+\)). Monomer 1 and monomer 2 are the substrates on the left, and the "monomers linked by a covalent bond" is the product on the right. The product shown here is also called a dimer (di- = two, mer = part). OH\(^-\) and H\(^+\) combine to form a molecule of water, which is released as a byproduct. This can be confusing because water is made during dehydration synthesis. The larger product has been dehydrated (lost the water).
Example of dehydration synthesis: two glucose molecules (substrates on the left of the arrow) form a covalent bond to form a maltose molecule (product on the right of the arrow). The OH- and H+ shown in red combine with each other to form H2O (shown in red too).

In the hydrolysis reaction shown in figure (PageIndex{3}), (hydro- = “water”; -lysis = “breaking down, a loosening, a dissolution”) the covalent bond between two monomers is split by the addition of a hydrogen ion (H\(^+\)) to one and a hydroxyl ion (OH\(^-\)) to the other. These two ions come from splitting a water molecule, H\(_2\)O, into H\(^+\) and OH\(^-\). The dimer (monomers linked by a covalent bond on the left) is the substrate, and monomer 1 and monomer 2 on the right are the products.

Concepts, terms, and facts check

**Study Questions** Write your answer in a sentence form (do not answer using loose words)

1. What is a dehydration synthesis reaction?
2. What is a hydrolysis reaction?

Large molecules composed of hundreds or thousands of atoms are called macromolecules. Many macromolecules are composed of repetitive units of the same building block, similar to a pearl necklace that is composed of many pearls. **Polymers** (poly- = “many”; meros = “part”) are long chain, large organic molecules (macromolecules) assembled from many covalently bonded smaller molecules called **monomers**. Polymers consist of many repeating monomer units in long chains, sometimes with branching or cross-linking between the chains.

Three of the four classes of organic molecules previously identified, i.e. carbohydrates, lipids, proteins, and nucleic acids are often polymers made of smaller monomer subunits (lipids are not). For example, proteins are polymers made of many covalently bonded smaller molecules, monomers, called amino acids. Each of these classes is considered in more detail below.
Figure \(\PageIndex{3}\) Two-dimensional view of the protein insulin. Insulin is a polymer made of covalently linked monomers called amino acids (shown as green balls).

Concepts, terms, and facts check

**Study Questions** Write your answer in a sentence form (do not answer using loose words)

1. What is a polymer?
2. What is a monomer?