1 Addition, substitution and elimination reactions

1.1 Addition reactions

An addition reaction occurs when two or more reactants combine to form a final product. This product will contain all the atoms that were present in the reactants. The following is a general equation for this type of reaction:

\[ A + B \rightarrow C \]  

(1)

Notice that C is the final product with no A or B remaining as a residue.

The following are some examples.

1. The reaction between ethene and bromine to form 1,2-dibromoethane (Figure 1). \( C_2H_4 + Br_2 \rightarrow C_2H_4Br_2 \)

Figure 1: The reaction between ethene and bromine is an example of an addition reaction

2. Polymerisation reactions In industry, making polymers is very important. A polymer is made up of lots of smaller units called monomers. When these monomers are added together, they form a polymer. Examples of polymers are polyvinylchloride (PVC) and polystyrene. PVC is often used to make piping, while polystyrene is an important packaging and insulating material. Polystyrene is made up of lots of styrene monomers which are joined through addition reactions (Figure 1). 'Polymerisation' refers to the addition reactions that eventually help to form the polystyrene polymer.

*Version 1.1: Jul 29, 2011 4:26 am -0500
†http://creativecommons.org/licenses/by/3.0/

http://cnx.org/content/m39090/1.1/
3. The **hydrogenation** of vegetable oils to form margarine is another example of an addition reaction. Hydrogenation involves adding hydrogen (H₂) to an alkene. An alkene is an organic compound composed of carbon and hydrogen. It contains a double bond between two of the carbon atoms. If this bond is broken, it means that more hydrogen atoms can attach themselves to the carbon atoms. During hydrogenation, this double bond is broken, and more hydrogen atoms are added to the molecule. The reaction that takes place is shown below. Note that the 'R' represents any side-chain or the rest of the molecule. A side-chain is simply any combination of atoms that are attached to the central part of the molecule. 

\[
RCHCH_2 + H_2 \rightarrow RCH_2CH_3
\]

4. The production of the alcohol ethanol from ethene. Ethanol (CH₃CH₂OH) can be made from alkenes such as ethene (C₂H₄), through a hydration reaction like the one below. A hydration reaction is one where water is added to the reactants.

\[
C_2H_4 + H_2O \rightarrow CH_3CH_2OH
\]  

A catalyst is needed for this reaction to take place. The catalyst that is most commonly used is phosphoric acid.

### 1.2 Elimination reactions

An elimination reaction occurs when a reactant is broken up into two products. The general form of the equation is as follows:

\[
A \rightarrow B + C
\]

The examples below will help to explain this:

1. The **dehydration of an alcohol** is one example. Two hydrogen atoms and one oxygen atom are eliminated and a molecule of water is formed as a second product in the reaction, along with an alkene.

\[
CH_3CH_2OH \rightarrow CH_2CH_2 + H_2O
\]
2. The elimination of potassium bromide from a bromoalkane. CH\textsubscript{3}CH\textsubscript{2}Br + KOH \rightarrow CH\textsubscript{2}CH\textsubscript{2} + KBr + H\textsubscript{2}O

\begin{center}
\[ \text{H} \quad \text{C} \quad \text{H} \quad \text{H} \quad + \quad \text{KOH} \quad \rightarrow \quad \text{C} \equiv \text{C} \quad + \quad \text{O} \quad + \quad \text{KBr} \]
\end{center}

Figure 3

3. Ethane cracking is an important industrial process used by SASOL and other petrochemical industries. Hydrogen is eliminated from ethane (C\textsubscript{2}H\textsubscript{6}) to produce an alkene called ethene (C\textsubscript{2}H\textsubscript{4}). Ethene is then used to produce other products such as polyethylene. You will learn more about these compounds in Grade 12. The equation for the cracking of ethane looks like this: C\textsubscript{2}H\textsubscript{6} \rightarrow C\textsubscript{2}H\textsubscript{4} + H\textsubscript{2}

1.3 Substitution reactions

A substitution reaction occurs when an exchange of elements in the reactants takes place. The initial reactants are transformed or 'swopped around' to give a final product. A simple example of a reaction like this is shown below:

\[ AB + CD \rightarrow AC + BD \] (4)

Some simple examples of substitution reactions are shown below:

\[ CH\textsubscript{4} + Cl\textsubscript{2} \rightarrow CH\textsubscript{3}Cl + HCl \] (5)

In this example, a chlorine atom and a hydrogen atom are exchanged to create a new product.

\[ Cu(H\textsubscript{2}O)\textsubscript{4}\textsuperscript{2+} + 4Cl\textsuperscript{−} \rightarrow Cu(Cl\textsuperscript{−})\textsubscript{4} + 4H\textsubscript{2}O \] (6)

In this example, four waters and four chlorines are exchanged to create a new product.

1.3.1 Addition, substitution and elimination reactions

1. Refer to the diagram below and then answer the questions that follow:
Figure 6

a. Is this reaction an example of substitution, elimination or addition?
b. Give a reason for your answer above.

2. The following diagram shows the reactants in an addition reaction.

Figure 6

a. Draw the final product in this reaction.
b. What is the chemical formula of the product?

3. The following reaction takes place:

Figure 6
Is this reaction a substitution, addition or dehydration reaction? Give a reason for your answer.

4. Consider the following reaction: \( \text{Ca(OH)}_2 (s) + 2\text{NH}_4\text{Cl} (s) \rightarrow \text{CaCl}_2 (s) + 2\text{NH}_3 (g) + 2\text{H}_2\text{O} (g) \) Which one of the following best describes the type of reaction which takes place?
   a. Redox reaction
   b. Acid-base reaction
   c. Dehydration reaction

This media object is a Flash object. Please view or download it at
<http://static.slidesharecdn.com/swf/ssplayer2.swf?doc=typesofreactions-100512081352-phpapp02&stripped_title=types-of-reactions-4068567&userName=kwarme>

Figure 6

2 Summary

- There are many different **types of reactions** that can take place. These include acid-base, acid-carbonate, redox, addition, substitution and elimination reactions.
- The **Arrhenius** definition of acids and bases defines an acid as a substance that increases the concentration of hydrogen ions (\( \text{H}^+ \) or \( \text{H}_3\text{O}^+ \)) in a solution. A base is a substance that increases the concentration of hydroxide ions (\( \text{OH}^- \)) in a solution. However this definition only applies to substances that are in water.
- The **Bronsted-Lowry** definition is a much broader one. An **acid** is a substance that **donates protons** and a **base** is a substance that **accepts protons**.
- In different reactions, certain substances can act as both an acid and a base. These substances are called **amphotelytes** and are said to be **amphoteric**. Water is an example of an amphoteric substance.

  - A **conjugate acid-base pair** refers to two compounds in a reaction (one reactant and one product) that transform or change into the other through the loss or gain of a proton.
  - When an acid and a base react, they form a **salt** and water. The salt is made up of a cation from the base and an anion from the acid. An example of a salt is sodium chloride (NaCl), which is the product of the reaction between sodium hydroxide (NaOH) and hydrochloric acid (HCl).
  - The reaction between an acid and a base is a **neutralisation** reaction.
  - **Titrations** are reactions between an acid and a base that are used to calculate the concentration of one of the reacting substances. The concentration of the other reacting substance must be known.
  - In an **acid-carbonate reaction**, an acid and a carbonate react to form a salt, carbon dioxide and water.
  - A **redox reaction** is one where there is always a change in the oxidation numbers of the elements that are involved in the reaction.
  - **Oxidation** is the loss of electrons and **reduction** is the gain of electrons.
  - When two or more reactants combine to form a product that contains all the atoms that were in the reactants, then this is an **addition reaction**. Examples of addition reactions include the reaction between ethene and bromine, polymerisation reactions and hydrogenation reactions.
  - A reaction where the reactant is broken down into one or more product, is called an **elimination reaction**. Alcohol dehydration and ethane cracking are examples of elimination reactions.
  - A **substitution reaction** is one where the reactants are transformed or swopped around to form the final product.
2.1 Summary Exercise

1. Give one word/term for each of the following descriptions:
   a. A chemical reaction during which electrons are transferred
   b. The addition of hydrogen across a double bond
   c. The removal of hydrogen and halogen atoms from an alkane to form an alkene

2. For each of the following, say whether the statement is true or false. If the statement is false, re-write the statement correctly.
   a. The conjugate base of NH\textsuperscript{+} is NH\textsubscript{3}.
   b. The reactions \(C + O_2 \rightarrow CO_2\) and \(2KClO_3 \rightarrow 2KCl + 3O_2\) are examples of redox reactions.

3. For each of the following questions, choose the one correct statement from the list provided.
   a. The following chemical equation represents the formation of the hydronium ion: \(H^+(aq) + H_2O(l) \rightarrow H_3O^+(aq)\). In this reaction, water acts as a Lewis base because it...
      1. accepts protons
      2. donates protons
      3. accepts electrons
      4. donates electrons
   (IEB Paper 2, 2005)
   b. When chlorine water (Cl\textsubscript{2} dissolved in water) is added to a solution of potassium bromide, bromine is produced. Which one of the following statements concerning this reaction is correct?
      1. Br\textsuperscript{−} is oxidised
      2. Cl\textsubscript{2} is oxidised
      3. Br\textsuperscript{−} is the oxidising agent
      4. Cl\textsuperscript{−} is the oxidising agent
   (IEB Paper 2, 2005)

4. The stomach secretes gastric juice, which contains hydrochloric acid. The gastric juice helps with digestion. Sometimes there is an overproduction of acid, leading to heartburn or indigestion. Antacids, such as milk of magnesia, can be taken to neutralise the excess acid. Milk of magnesia is only slightly soluble in water and has the chemical formula Mg(OH)\textsubscript{2}.
   a. Write a balanced chemical equation to show how the antacid reacts with the acid.
   b. The directions on the bottle recommend that children under the age of 12 years take one teaspoon of milk of magnesia, whereas adults can take two teaspoons of the antacid. Briefly explain why the dosages are different.
   c. Why is it not advisable to take an overdose of the antacid in the stomach? Refer to the hydrochloric acid concentration in the stomach in your answer. In an experiment, \(25.0\) cm\textsuperscript{3} of a standard solution of sodium carbonate of concentration 0.1 mol.dm\textsuperscript{−3} was used to neutralise 35.0 cm\textsuperscript{3} of a solution of hydrochloric acid.
   d. Write a balanced chemical equation for the reaction.
   e. Calculate the concentration of the acid.
(DoE Grade 11 Exemplar, 2007)