



FHSST Authors

**The Free High School Science Texts:
Textbooks for High School Students
Studying the Sciences
Chemistry
Grades 10 - 12**

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FHSST Core Team

Mark Horner ; Samuel Halliday ; Sarah Blyth ; Rory Adams ; Spencer Wheaton

FHSST Editors

Jaynie Padayachee ; Joanne Boule ; Diana Mulcahy ; Annette Nell ; René Toerien ; Donovan
Whitfield

FHSST Contributors

Rory Adams ; Prashant Arora ; Richard Baxter ; Dr. Sarah Blyth ; Sebastian Bodenstein ;
Graeme Broster ; Richard Case ; Brett Cocks ; Tim Crombie ; Dr. Anne Dabrowski ; Laura
Daniels ; Sean Dobbs ; Fernando Durrell ; Dr. Dan Dwyer ; Frans van Eeden ; Giovanni
Franzoni ; Ingrid von Glehn ; Tamara von Glehn ; Lindsay Glesener ; Dr. Vanessa Godfrey ; Dr.
Johan Gonzalez ; Hemant Gopal ; Umeshree Govender ; Heather Gray ; Lynn Greeff ; Dr. Tom
Gutierrez ; Brooke Haag ; Kate Hadley ; Dr. Sam Halliday ; Asheena Hanuman ; Neil Hart ;
Nicholas Hatcher ; Dr. Mark Horner ; Robert Hovden ; Mfandaidza Hove ; Jennifer Hsieh ;
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Andrew Kubik ; Dr. Marco van Leeuwen ; Dr. Anton Machacek ; Dr. Komal Maheshwari ;
Kosma von Maltitz ; Nicole Masureik ; John Mathew ; JoEllen McBride ; Nikolai Meures ;
Riana Meyer ; Jenny Miller ; Abdul Mirza ; Asogan Moodaly ; Jothi Moodley ; Nolene Naidu ;
Tyrone Negus ; Thomas O'Donnell ; Dr. Markus Oldenburg ; Dr. Jaynie Padayachee ;
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Riddle ; Evan Robinson ; Dr. Andrew Rose ; Bianca Ruddy ; Katie Russell ; Duncan Scott ;
Helen Seals ; Ian Sherratt ; Roger Sieloff ; Bradley Smith ; Greg Solomon ; Mike Stringer ;
Shen Tian ; Robert Torregrosa ; Jimmy Tseng ; Helen Waugh ; Dr. Dawn Webber ; Michelle
Wen ; Dr. Alexander Wetzler ; Dr. Spencer Wheaton ; Vivian White ; Dr. Gerald Wigger ;
Harry Wiggins ; Wendy Williams ; Julie Wilson ; Andrew Wood ; Emma Wormauld ; Sahal
Yacoob ; Jean Youssef

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this a continuously evolving resource!

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Chapter 15

Types of Reactions - Grade 11

There are many different types of chemical reactions that can take place. In this chapter, we will be looking at a few of the more common reaction types: acid-base and acid-carbonate reactions, redox reactions and addition, elimination and substitution reactions.

15.1 Acid-base reactions

15.1.1 What are acids and bases?

In our daily lives, we encounter many examples of acids and bases. In the home, vinegar (acetic acid), lemon juice (citric acid) and tartaric acid (the main acid found in wine) are common, while hydrochloric acid, sulfuric acid and nitric acid are examples of acids that are more likely to be found in laboratories and industry. Hydrochloric acid is also found in the gastric juices in the stomach. Even fizzy drinks contain acid (carbonic acid), as do tea and wine (tannic acid)! Bases that you may have heard of include sodium hydroxide (caustic soda), ammonium hydroxide and ammonia. Some of these are found in household cleaning products. Acids and bases are also important commercial products in the fertiliser, plastics and petroleum refining industries. Some common acids and bases, and their chemical formulae, are shown in table 15.1.

Table 15.1: Some common acids and bases and their chemical formulae

Acid	Formula	Base	Formula
Hydrochloric acid	HCl	Sodium hydroxide	NaOH
Sulfuric acid	H ₂ SO ₄	Potassium hydroxide	KOH
Nitric acid	HNO ₃	Sodium carbonate	Na ₂ CO ₃
Acetic (ethanoic) acid	CH ₃ COOH	Calcium hydroxide	Ca(OH) ₂
Carbonic acid	H ₂ CO ₃	Magnesium hydroxide	Mg(OH) ₂
Sulfurous acid	H ₂ SO ₃	Ammonia	NH ₃
Phosphoric acid	H ₃ PO ₄	Sodium bicarbonate	NaHCO ₃

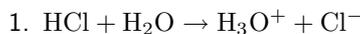
Most acids share certain characteristics, and most bases also share similar characteristics. It is important to be able to have a definition for acids and bases so that they can be correctly identified in reactions.

15.1.2 Defining acids and bases

A number of definitions for acids and bases have developed over the years. One of the earliest was the **Arrhenius** definition. Arrhenius (1887) noticed that water dissociates (splits up) into hydronium (H₃O⁺) and hydroxide (OH⁻) ions according to the following equation:



Arrhenius described an acid as a compound that increases the concentration of H_3O^+ ions in solution, and a base as a compound that increases the concentration of OH^- ions in a solution. Look at the following examples showing the dissociation of hydrochloric acid and sodium hydroxide (a base) respectively:



Hydrochloric acid in water increases the concentration of H_3O^+ ions and is therefore an *acid*.



Sodium hydroxide in water increases the concentration of OH^- ions and is therefore a *base*.

However, this definition could only be used for acids and bases *in water*. It was important to come up with a much broader definition for acids and bases.

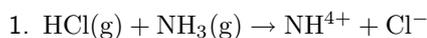
It was Lowry and Bronsted (1923) who took the work of Arrhenius further to develop a broader definition for acids and bases. The **Bronsted-Lowry model** defines acids and bases in terms of their ability to donate or accept protons.

For more information on *dissociation*, refer to chapter 20.

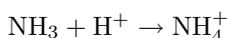
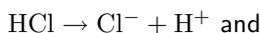
Definition: Acids and bases

According to the Bronsted-Lowry theory of acids and bases, an **acid** is a substance that gives away protons (H^+), and is therefore called a **proton donor**. A **base** is a substance that takes up protons, and is therefore called a **proton acceptor**.

Below are some examples:



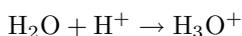
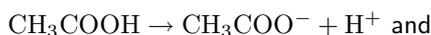
In order to decide which substance is a proton donor and which is a proton acceptor, we need to look at what happens to each reactant. The reaction can be broken down as follows:



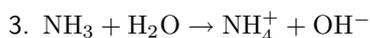
From these reactions, it is clear that HCl is a *proton donor* and is therefore an **acid**, and that NH_3 is a *proton acceptor* and is therefore a **base**.



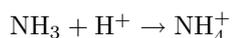
The reaction can be broken down as follows:



In this reaction, CH_3COOH (acetic acid) is a proton donor and is therefore the **acid**. In this case, water acts as a base because it accepts a proton to form H_3O^+ .



The reaction can be broken down as follows:



In this reaction, water donates a proton and is therefore an **acid** in this reaction. Ammonia accepts the proton and is therefore the **base**. Notice that in the previous equation, water acted as a base and that in this equation it acts as an acid. Water can act as both an acid and a base depending on the reaction. This is also true of other substances. These substances are called **ampholytes** and are said to be **amphoteric**.



Definition: Amphoteric

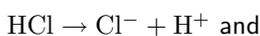
An amphoteric substance is one that can react as either an acid or base. Examples of amphoteric substances include water, zinc oxide and beryllium hydroxide.

15.1.3 Conjugate acid-base pairs

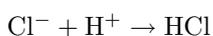
Look at the reaction between hydrochloric acid and ammonia to form ammonium and chloride ions:



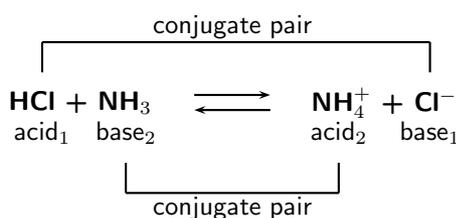
Looking firstly at the *forward reaction* (i.e. the reaction that proceeds from *left to right*), the changes that take place can be shown as follows:



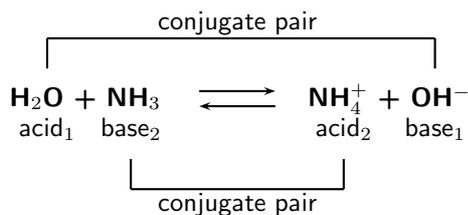
Looking at the *reverse reaction* (i.e. the reaction that proceeds from *right to left*), the changes that take place are as follows:



In the **forward reaction**, HCl is a proton donor (acid) and NH₃ is a proton acceptor (base). In the **reverse reaction**, the chloride ion is the proton acceptor (base) and NH₄⁺ is the proton donor (acid). A **conjugate acid-base pair** is two compounds in a reaction that change into each other through the loss or gain of a proton. The conjugate acid-base pairs for the above reaction are shown below.



The reaction between ammonia and water can also be used as an example:

**Definition: Conjugate acid-base pair**

The term refers to two compounds that transform into each other by the gain or loss of a proton.

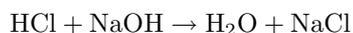
**Exercise: Acids and bases**

- In the following reactions, identify (1) the acid and the base in the reactants and (2) the salt in the product.
 - $\text{H}_2\text{SO}_4 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaSO}_4 + 2\text{H}_2\text{O}$
 - $\text{CuO} + \text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{H}_2\text{O}$
 - $\text{H}_2\text{O} + \text{C}_6\text{H}_5\text{OH} \rightarrow \text{H}_3\text{O}^+ + \text{C}_6\text{H}_5\text{O}^-$
 - $\text{HBr} + \text{C}_5\text{H}_5\text{N} \rightarrow (\text{C}_5\text{H}_5\text{NH}^+)\text{Br}^-$
- In each of the following reactions, label the conjugate acid-base pairs.
 - $\text{H}_2\text{SO}_4 + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{HSO}_4^-$
 - $\text{NH}_4^+ + \text{F}^- \rightleftharpoons \text{HF} + \text{NH}_3$
 - $\text{H}_2\text{O} + \text{CH}_3\text{COO}^- \rightleftharpoons \text{CH}_3\text{COOH} + \text{OH}^-$
 - $\text{H}_2\text{SO}_4 + \text{Cl}^- \rightleftharpoons \text{HCl} + \text{HSO}_4^-$

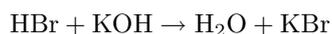
15.1.4 Acid-base reactions

When an acid and a base react, they neutralise each other to form a **salt**. If the base contains hydroxide (OH^-) ions, then *water* will also be formed. The word *salt* is a general term which applies to the products of all acid-base reactions. A salt is a product that is made up of the cation from a base and the anion from an acid. When an acid reacts with a base, they **neutralise** each other. In other words, the acid becomes less acidic and the base becomes less basic. Look at the following examples:

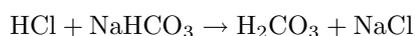
- Hydrochloric acid reacts with sodium hydroxide to form sodium chloride (the salt) and water. Sodium chloride is made up of Na^+ cations from the base (NaOH) and Cl^- anions from the acid (HCl).



- Hydrogen bromide reacts with potassium hydroxide to form potassium bromide (the salt) and water. Potassium bromide is made up of K^+ cations from the base (KOH) and Br^- anions from the acid (HBr).



3. Hydrochloric acid reacts with sodium hydrocarbonate to form sodium chloride (the salt) and hydrogen carbonate. Sodium chloride is made up of Na^+ cations from the base (NaHCO_3) and Cl^- anions from the acid (HCl).



You should notice that in the first two examples, the base contained OH^- ions, and therefore the products were a *salt* and *water*. NaCl (table salt) and KBr are both salts. In the third example, NaHCO_3 also acts as a base, despite not having OH^- ions. A salt is still formed as one of the products, but no water is produced.

It is important to realise how important these neutralisation reactions are. Below are some examples:

- **Domestic uses**

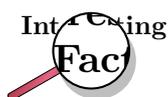
Calcium oxide (CaO) is put on soil that is too acid. Powdered limestone (CaCO_3) can also be used but its action is much slower and less effective. These substances can also be used on a larger scale in farming and also in rivers.

- **Biological uses**

Acids in the stomach (e.g. hydrochloric acid) play an important role in helping to digest food. However, when a person has a stomach ulcer, or when there is too much acid in the stomach, these acids can cause a lot of pain. **Antacids** are taken to neutralise the acids so that they don't burn as much. Antacids are bases which neutralise the acid. Examples of antacids are aluminium hydroxide, magnesium hydroxide ('milk of magnesia') and sodium bicarbonate ('bicarbonate of soda'). Antacids can also be used to relieve heartburn.

- **Industrial uses**

Alkaline calcium hydroxide (limewater) can be used to absorb harmful SO_2 gas that is released from power stations and from the burning of fossil fuels.



Bee stings are acidic and have a pH between 5 and 5.5. They can be soothed by using substances such as calomine lotion, which is a mild alkali based on zinc oxide. Bicarbonate of soda can also be used. Both alkalis help to neutralise the acidic bee sting and relieve some of the itchiness!

**Important: Acid-base titrations**

The neutralisation reaction between an acid and a base can be very useful. If an acidic solution of known concentration (a standard solution) is added to an alkaline solution until the solution is exactly neutralised (i.e. it has neither acidic nor basic properties), it is possible to calculate the exact concentration of the unknown solution. It is possible to do this because, at the exact point where the solution is neutralised, chemically equivalent amounts of acid and base have reacted with each other. This type of calculation is called **volumetric analysis**. The process where an acid solution and a basic solution are added to each other for this purpose, is called a **titration**, and the point of neutralisation is called the **end point** of the reaction. So how exactly can a titration be carried out to determine an unknown concentration? Look at the following steps to help you to understand the process.

Step 1:

A measured volume of the solution with unknown concentration is put into a flask.

Step 2:

A suitable indicator is added to this solution (bromothymol blue and phenolphthalein are common indicators).

Step 3:

A volume of the standard solution is put into a burette and is slowly added to the solution in the flask, drop by drop.

Step 4:

At some point, adding one more drop will change the colour of the unknown solution. For example, if the solution is basic and bromothymol blue is being used as the indicator in the titration, the bromothymol blue would originally have coloured the solution blue. At the end point of the reaction, adding one more drop of acid will change the colour of the basic solution from blue to yellow. Yellow shows that the solution is now acidic.

Step 5:

Record the volume of standard solution that has been added up to this point.

Step 6:

Use the information you have gathered to calculate the exact concentration of the unknown solution. A worked example is shown below.

**Important: Titration calculations**

When you are busy with these calculations, you will need to remember the following:

$1\text{dm}^3 = 1\text{ litre} = 1000\text{ml} = 1000\text{cm}^3$, therefore dividing cm^3 by 1000 will give you an answer in dm^3 .

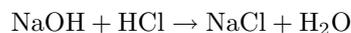
Some other terms and equations which will be useful to remember are shown below:

- Molarity is a term used to describe the concentration of a solution, and is measured in $\text{mol}\cdot\text{dm}^{-3}$. The symbol for molarity is M. Refer to chapter 13 for more information on molarity.
- Moles = molarity ($\text{mol}\cdot\text{dm}^{-3}$) \times volume (dm^3)
- Molarity ($\text{mol}\cdot\text{dm}^{-3}$) = mol / volume



Worked Example 74: Titration calculation

Question: Given the equation:



25cm³ of a sodium hydroxide solution was pipetted into a conical flask and titrated with 0.2M hydrochloric acid. Using a suitable indicator, it was found that 15cm³ of acid was needed to neutralise the alkali. Calculate the molarity of the sodium hydroxide.

Answer

Step 1 : Write down all the information you know about the reaction, and make sure that the equation is balanced.

NaOH: $V = 25 \text{ cm}^3$

HCl: $V = 15 \text{ cm}^3$; $C = 0.2 \text{ M}$

The equation is already balanced.

Step 2 : Calculate the number of moles of HCl that react according to this equation.

$$M = \frac{n}{V}$$

Therefore, $n(\text{HCl}) = M \times V$ (make sure that all the units are correct!)

$M = 0.2 \text{ mol} \cdot \text{dm}^{-3}$

$V = 15 \text{ cm}^3 = 0.015 \text{ dm}^3$

Therefore

$$n(\text{HCl}) = 0.2 \times 0.015 = 0.003$$

There are 0.003 moles of HCl that react

Step 3 : Calculate the number of moles of sodium hydroxide in the reaction

Look at the equation for the reaction. For every mole of HCl there is one mole of NaOH that is involved in the reaction. Therefore, if 0.003 moles of HCl react, we can conclude that the same quantity of NaOH is needed for the reaction. The number of moles of NaOH in the reaction is 0.003.

Step 4 : Calculate the molarity of the sodium hydroxide

First convert the volume into dm³. $V = 0.025 \text{ dm}^3$. Then continue with the calculation.

$$M = \frac{n}{V} = \frac{0.003}{0.025} = 0.12$$

The molarity of the NaOH solution is 0.12 mol.dm³ or 0.12 M



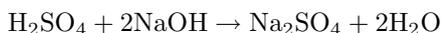
Worked Example 75: Titration calculation

Question: 4.9 g of sulfuric acid is dissolved in water and the final solution has a volume of 220 cm³. Using titration, it was found that 20 cm³ of this solution was

able to completely neutralise 10 cm³ of a sodium hydroxide solution. Calculate the concentration of the sodium hydroxide in mol.dm⁻³.

Answer

Step 1 : Write a balanced equation for the titration reaction.



Step 2 : Calculate the molarity of the sulfuric acid solution.

$$M = n/V$$

$$V = 220 \text{ cm}^3 = 0.22 \text{ dm}^3$$

$$n = \frac{m}{M} = \frac{4.9\text{g}}{98\text{g}\cdot\text{mol}^{-1}} = 0.05\text{mols}$$

Therefore,

$$M = \frac{0.05}{0.22} = 0.23\text{mol}\cdot\text{dm}^{-3}$$

Step 3 : Calculate the moles of sulfuric acid that were used in the neutralisation reaction.

Remember that only 20 cm³ of the sulfuric acid solution is used.

$$M = n/V, \text{ therefore } n = M \times V$$

$$n = 0.23 \times 0.02 = 0.0046\text{mol}$$

Step 4 : Calculate the number of moles of sodium hydroxide that were neutralised.

According to the balanced chemical equation, the mole ratio of H₂SO₄ to NaOH is 1:2. Therefore, the number of moles of NaOH that are neutralised is 0.0046 × 2 = 0.0092 mols.

Step 5 : Calculate the concentration of the sodium hydroxide solution.

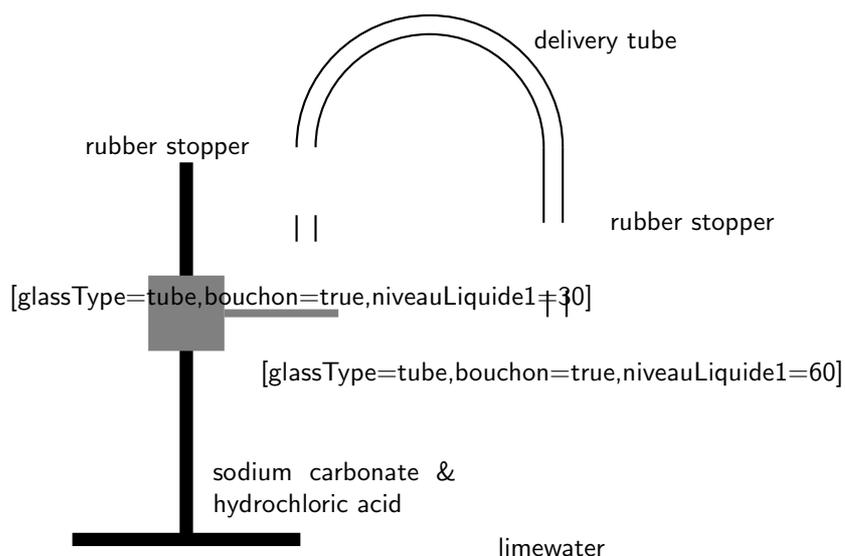
$$M = \frac{n}{V} = \frac{0.0092}{0.01} = 0.92M$$

15.1.5 Acid-carbonate reactions

Activity :: Demonstration : The reaction of acids with carbonates

Apparatus and materials:

Small amounts of sodium carbonate and calcium carbonate (both in powder form); hydrochloric acid and sulfuric acid; retort stand; two test tubes; two rubber stoppers for the test tubes; a delivery tube; lime water. The demonstration should be set up as shown below.

**Method:**

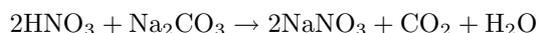
1. Pour limewater into one of the test tubes and seal with a rubber stopper.
2. Pour a small amount of hydrochloric acid into the remaining test tube.
3. Add a small amount of sodium carbonate to the acid and seal the test tube with the rubber stopper.
4. Connect the two test tubes with a delivery tube.
5. Observe what happens to the colour of the limewater.
6. Repeat the above steps, this time using sulfuric acid and calcium carbonate.

Observations:

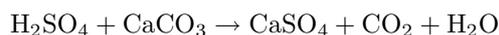
The clear lime water turns milky meaning that carbon dioxide has been produced.

When an acid reacts with a carbonate a salt, carbon dioxide and water are formed. Look at the following examples:

- Nitric acid reacts with sodium carbonate to form sodium nitrate, carbon dioxide and water.



- Sulfuric acid reacts with calcium carbonate to form calcium sulphate, carbon dioxide and water.

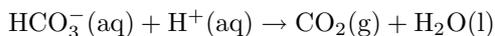


- Hydrochloric acid reacts with calcium carbonate to form calcium chloride, carbon dioxide and water.

**Exercise: Acids and bases**

1. The compound NaHCO_3 is commonly known as baking soda. A recipe requires 1.6 g of baking soda, mixed with other ingredients, to bake a cake.

- (a) Calculate the number of moles of NaHCO_3 used to bake the cake.
- (b) How many atoms of oxygen are there in the 1.6 g of baking soda?
During the baking process, baking soda reacts with an acid to produce carbon dioxide and water, as shown by the reaction equation below:



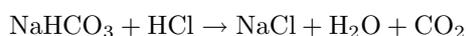
- (c) Identify the reactant which acts as the Bronsted-Lowry base in this reaction. Give a reason for your answer.
- (d) Use the above equation to explain why the cake rises during this baking process.

(DoE Grade 11 Paper 2, 2007)

2. Label the acid-base conjugate pairs in the following equation:



3. A certain antacid tablet contains 22.0 g of baking soda (NaHCO_3). It is used to neutralise the excess hydrochloric acid in the stomach. The balanced equation for the reaction is:



The hydrochloric acid in the stomach has a concentration of $1.0 \text{ mol}\cdot\text{dm}^{-3}$. Calculate the volume of the hydrochloric acid that can be neutralised by the antacid tablet.

(DoE Grade 11 Paper 2, 2007)

4. A learner is asked to prepare a *standard solution* of the weak acid, oxalic acid $(\text{COOH})_2\cdot 2\text{H}_2\text{O}$ for use in a titration. The volume of the solution must be 500 cm^3 and the concentration $0.2 \text{ mol}\cdot\text{dm}^{-3}$.
- (a) Calculate the mass of oxalic acid which the learner has to dissolve to make up the required standard solution. The learner titrates this $0.2 \text{ mol}\cdot\text{dm}^{-3}$ oxalic acid solution against a solution of sodium hydroxide. He finds that 40 cm^3 of the oxalic acid solution exactly neutralises 35 cm^3 of the sodium hydroxide solution.
- (b) Calculate the concentration of the sodium hydroxide solution.
5. A learner finds some sulfuric acid solution in a bottle labelled 'dilute sulfuric acid'. He wants to determine the concentration of the sulphuric acid solution. To do this, he decides to titrate the sulphuric acid against a standard potassium hydroxide (KOH) solution.
- (a) What is a standard solution?
- (b) Calculate the mass of KOH which he must use to make 300 cm^3 of a $0.2 \text{ mol}\cdot\text{dm}^{-3}$ KOH solution.
- (c) Calculate the pH of the $0.2 \text{ mol}\cdot\text{dm}^{-3}$ KOH solution (assume standard temperature).
- (d) Write a balanced chemical equation for the reaction between H_2SO_4 and KOH.
- (e) During the titration he finds that 15 cm^3 of the KOH solution neutralises 20 cm^3 of the H_2SO_4 solution. Calculate the concentration of the H_2SO_4 solution.

(IEB Paper 2, 2003)

15.2 Redox reactions

A second type of reaction is the **redox** reaction, in which both **oxidation** and **reduction** take place.

15.2.1 Oxidation and reduction

If you look back to chapter 4, you will remember that we discussed how, during a chemical reaction, an exchange of electrons takes place between the elements that are involved. Using *oxidation numbers* is one way of tracking what is happening to these electrons in a reaction. Refer back to section 4.11 if you can't remember the rules that are used to give an oxidation number to an element. Below are some examples to refresh your memory before we carry on with this section!

Examples:

1. **CO₂**

Each oxygen atom has an oxidation number of -2. This means that the charge on *two* oxygen atoms is -4. We know that the molecule of CO₂ is neutral, therefore the carbon atom must have an oxidation number of +4.

2. **KMnO₄**

Overall, this molecule has a neutral charge, meaning that the sum of the oxidation numbers of the elements in the molecule must equal zero. Potassium (K) has an oxidation number of +1, while oxygen (O) has an oxidation number of -2. If we exclude the atom of manganese (Mn), then the sum of the oxidation numbers equals +1+(-2×4)=-7. The atom of manganese must therefore have an oxidation number of +7 in order to make the molecule neutral.

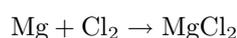
By looking at how the oxidation number of an element changes during a reaction, we can easily see whether that element is being **oxidised** or **reduced**.



Definition: Oxidation and reduction

Oxidation is the *loses* of an electron by a molecule, atom or ion. Reduction is the *gain* of an electron by a molecule, atom or ion.

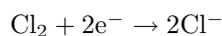
Example:



As a *reactant*, magnesium has an oxidation number of zero, but as part of the *product* magnesium chloride, the element has an oxidation number of +2. Magnesium has *lost* two electrons and has therefore been *oxidised*. This can be written as a **half-reaction**. The half-reaction for this change is:



As a *reactant*, chlorine has an oxidation number of zero, but as part of the *product* magnesium chloride, the element has an oxidation number of -1. Each chlorine atom has *gained* an electron and the element has therefore been *reduced*. The half-reaction for this change is:



Definition: Half-reaction

A half reaction is either the oxidation or reduction reaction part of a redox reaction. A half reaction is obtained by considering the change in oxidation states of the individual substances that are involved in the redox reaction.



Important: Oxidation and reduction made easy!

An easy way to think about oxidation and reduction is to remember:

'OILRIG' - **O**xidation **I**s **L**oss of electrons, **R**eduction **I**s **G**ain of electrons.

An element that is **oxidised** is called a **reducing agent**, while an element that is **reduced** is called an **oxidising agent**.

15.2.2 Redox reactions



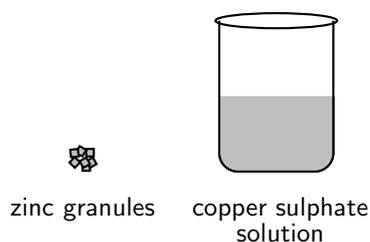
Definition: Redox reaction

A redox reaction is one involving oxidation and reduction, where there is always a change in the oxidation numbers of the elements involved.

Activity :: Demonstration : Redox reactions

Materials:

A few granules of zinc; 15 ml copper (II) sulphate solution (blue colour), glass beaker.



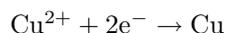
Method:

Add the zinc granules to the copper sulphate solution and observe what happens. What happens to the zinc granules? What happens to the colour of the solution?

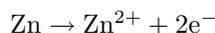
Results:

- Zinc becomes covered in a layer that looks like copper.
- The blue copper sulphate solution becomes clearer.

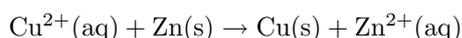
Cu^{2+} ions from the CuSO_4 solution are **reduced** to form copper metal. This is what you saw on the zinc crystals. The reduction of the copper ions (in other words, their removal from the copper sulphate solution), also explains the change in colour of the solution. The equation for this reaction is:



Zinc is **oxidised** to form Zn^{2+} ions which are clear in the solution. The equation for this reaction is:



The overall reaction is:

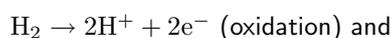


Conclusion:

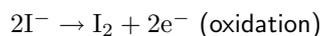
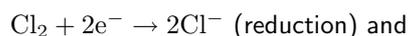
A redox reaction has taken place. Cu^{2+} ions are reduced and the zinc is oxidised.

Below are some further examples of redox reactions:

- $\text{H}_2 + \text{F}_2 \rightarrow 2\text{HF}$ can be re-written as two half-reactions:



- $\text{Cl}_2 + 2\text{KI} \rightarrow 2\text{KCl} + \text{I}_2$ or $\text{Cl}_2 + 2\text{I}^- \rightarrow 2\text{Cl}^- + \text{I}_2$, can be written as two half-reactions:



In Grade 12, you will go on to look at electrochemical reactions, and the role that electron transfer plays in this type of reaction.



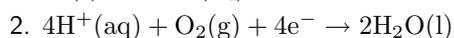
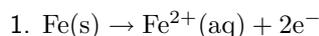
Exercise: Redox Reactions

1. Look at the following reaction:



- (a) What is the oxidation number of the oxygen atom in each of the following compounds?
 - i. H_2O_2
 - ii. H_2O
 - iii. O_2
- (b) Does the hydrogen peroxide (H_2O_2) act as an oxidising agent or a reducing agent or both, in the above reaction? Give a reason for your answer.

2. Consider the following chemical equations:

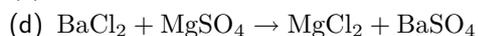
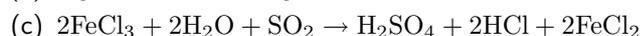
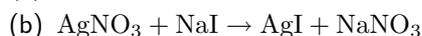


Which one of the following statements is correct?

- (a) Fe is oxidised and H^+ is reduced
- (b) Fe is reduced and O_2 is oxidised
- (c) Fe is oxidised and O_2 is reduced
- (d) Fe is reduced and H^+ is oxidised

(DoE Grade 11 Paper 2, 2007)

3. Which one of the following reactions is a redox reaction?



15.3 Addition, substitution and elimination reactions

15.3.1 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:



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 15.1).

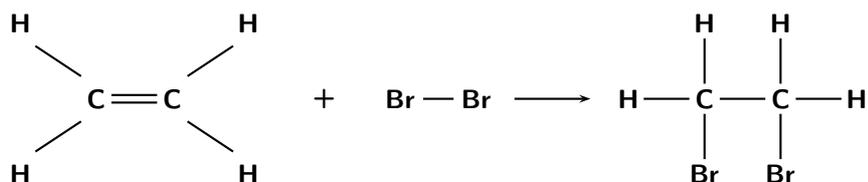
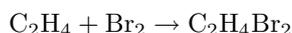


Figure 15.1: The reaction between ethene and bromine is an example of an addition reaction

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 15.2). 'Polymerisation' refers to the addition reactions that eventually help to form the polystyrene polymer.

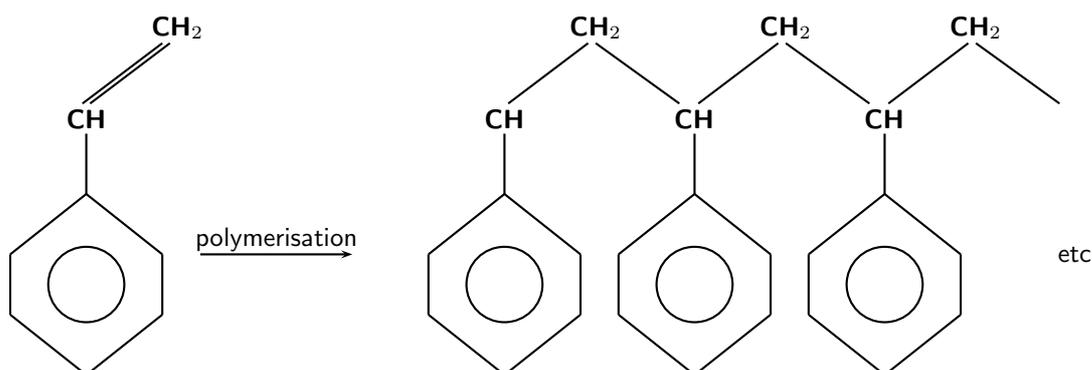
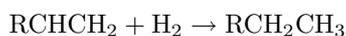
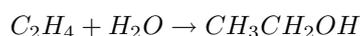


Figure 15.2: The polymerisation of a styrene monomer to form a polystyrene polymer

3. The **hydrogenation** of vegetable oils to form margarine is another example of an addition reaction. Hydrogenation involves adding hydrogen (H_2) 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. A side-chain is simply any combination of atoms that are attached to the central part of the molecule.



4. The production of the alcohol ethanol from ethene. Ethanol (CH_3CH_2OH) can be made from alkenes such as ethene (C_2H_4), through a hydration reaction like the one below. A hydration reaction is one where water is added to the reactants.



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

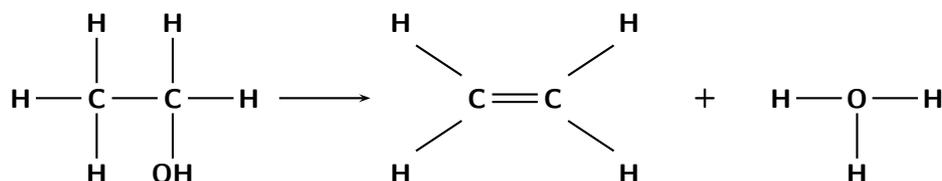
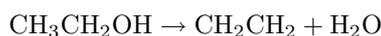
15.3.2 Elimination reactions

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

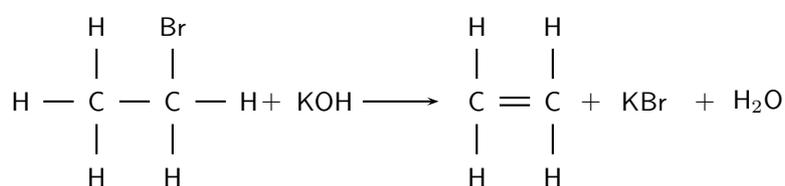
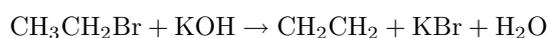


The examples below will help to explain this:

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.



2. The elimination of **potassium bromide from a bromoalkane**.

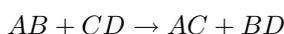


3. Ethane cracking is an important industrial process used by SASOL and other petrochemical industries. Hydrogen is eliminated from ethane (C_2H_6) to produce an alkene called ethene (C_2H_4). Ethene is then used to produce other products such as polyethylene. You will learn more about these compounds in chapter 23. The equation for the cracking of ethane looks like this:

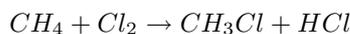


15.3.3 Substitution reactions

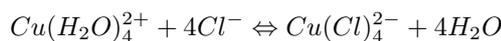
A substitution reaction occurs when an exchange of reactants takes place. The initial reactants are transformed or 'swapped around' to give a final product. A simple example of a reaction like this is shown below:



Some simple examples of substitution reactions are shown below:

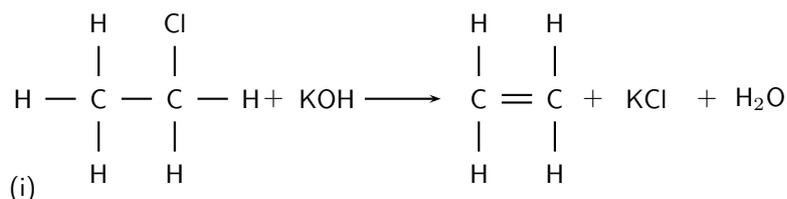


In this example, a chlorine atom and a hydrogen atom are exchanged to create a new product.

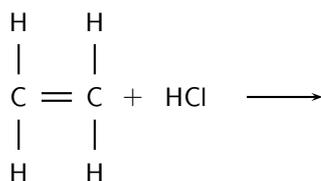


Exercise: Addition, substitution and elimination reactions

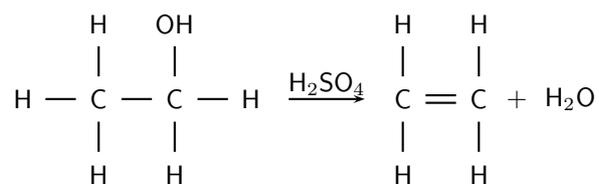
1. Refer to the diagram below and then answer the questions that follow:



- (a) Is this reaction an example of substitution, elimination or addition?
 (b) Give a reason for your answer above.
 (c) What type of compound is the reactant marked (i)?
2. The following diagram shows the reactants in an addition reaction.

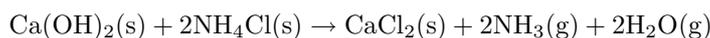


- (a) Draw the final product in this reaction.
 (b) What is the chemical formula of the product?
3. The following reaction takes place:



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

4. Consider the following reaction:



Which one of the following best describes the type of reaction which takes place?

- (a) Redox reaction
- (b) Acid-base reaction
- (c) Dehydration reaction

15.4 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 (H^+ or H_3O^+) in a solution. A base is a substance that increases the concentration of hydroxide ions (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 **ampholytes** 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 that change into 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.

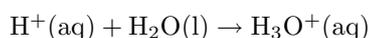
- When two or more reactants combine to form a product that contains all the atoms that were in the reactants, then this is an **addition reaction**. Examples of addition reactions include the reaction between ethene and bromine, polymerisation reactions and hydrogenation reactions.
- A reaction where 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 swapped around to form the final product.



Exercise: 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_4^+ is NH_3 .
 - (b) The reactions $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$ and $2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2$ 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:



In this reaction, water acts as a Lewis base because it...

- i. accepts protons
 - ii. donates protons
 - iii. accepts electrons
 - iv. donates electrons
- B What is the concentration (in $\text{mol}\cdot\text{dm}^{-3}$) of H_3O^+ ions in a NaOH solution which has a pH of 12 at 25°C ?
- i. 1×10^{12}
 - ii. 1×10^2
 - iii. 1×10^{-2}
 - iv. 1×10^{-12}
- (IEB Paper 2, 2005)
- C When chlorine water is added to a solution of potassium bromide, bromine is produced. Which one of the following statements concerning this reaction is correct?
- i. Br^- is oxidised
 - ii. Cl_2 is oxidised
 - iii. Br^- is the oxidising agent
 - iv. Cl^- 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 $\text{Mg}(\text{OH})_2$.

- 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^3 of a standard solution of sodium carbonate of concentration 0.1 mol.dm^{-3} was used to neutralise 35.0 cm^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)
-

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