**2.6 Acids, bases and neutralization reactions**

All substances are either **acidic, basic** or **neutral.** Acids and bases are some of the most common chemicals in both a laboratory and in our everyday lives. For example, vinegar and lemon juice are **acids** that we all know very well. Household ammonia is a **base** that we are familiar with mostly because of its pungent smell. Bases which are soluble in water are called **alkalis**. We can place many chemicals in one of these two groupings according to some rules that allow us to identify an acid and a base. These rules are presented in the following table. Chemicals which are neither acidic nor alkaline are called **neutral**.

|  |  |
| --- | --- |
| **Acids** | **Bases/Alkalis** |
| Acids taste sour e.g. lemon juice and vinegar | Bases have a bitter taste |
| Some acids are corrosive – they can kill living cells or stop them from working properly | Some bases can damage the eyes and the skin e.g. sodium hydroxide |
| Some acids are essential to health e.g. vitamin C is ascorbic acid | Bases have a slippery feel (because they change the fats in the skin to soaps!) |
| Acids react with metals (corrode metals) and give off hydrogen gas and a salt | Some bases are helpful e.g. milk of Magnesia as a laxative or to counteract acidity in the stomach. |
| Acids react with bases and become neutralised | Bases change the colour of indicators e.g. litmus paper turns blue |
| Acids react with carbonates and carbon dioxide is given off | Bases have pH values greater than 7 |
| Acids change the colour of indicators (and other dyes) e.g. litmus paper turns pink | Bases react with ammonium compounds to give ammonia gas, water and a salt. |
| Acids have a pH of less than 7 | Bases have a pH above 7 |
| Acids react with metal oxides, metal hydroxides and ammonia solution to give water and a salt |  |

Fig : The pH scale



Got it:

* The pH scale is a measure of the acidity or alkalinity of a substance.
* A neutral substance has a pH of 7.
* Basic substances have pH values greater than 7 (the higher the number the more strong the alkalinity).
* Acidic substances have pH values below 7 (the stronger the acid the lower the number).
* pH measures the hydrogen ion concentration.
* Indicators are also measures of pH – different colours indicating different hydrogen ion concentrations

Activity : Examining acids and bases

A student tested a number of substances in the laboratory. Each chemical was tested for its solubility (could it dissolve in water?). The resulting solutions were then tested by dipping a strip of litmus paper into the solution. Litmus paper is a rough measure of whether a substance is acidic or alkali. Acidic solutions turn litmus paper red/pink and alkaline solutions turn litmus paper blue.

The results were recorded as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Substance | Behaviour in water (soluble or insoluble) | Effect on red litmus paper | Effect on blue litmus paper | Classification (acidic, basic or neutral) |
| Sulfuric acid | Soluble | No effect | No effect | Neutral |
| Table salt | Slightly soluble | No effect | No effect | Neutral |
| Sodium hydroxide | Soluble | Turns blue | Remains blue | Basic (alkaline) |
| Hydrochloric acid | Soluble | Remains red | Turns red | Acidic |
| Potassium hydroxide | Soluble | Turns blue | Remains blue | Basic (alkaline) |

1. If you can, write down the chemical formulae of the pure chemicals that you are using. Put the acids and alkalis into separate groups.
2. What common element do you notice for all the acids? What common ion would be produced when an acidic substance is placed in water?
3. What do you notice to be common in the formulae for the alkalis? What common ion would be produced when a basic substance is dissolved in water?
4. The student then performed the following experiment:
 A small volume of the acid, HCl, was placed into a test tube and tested with blue and red litmus papers. Then a drop of the alkaline NaOH solution was added to the test tube , mixed and tested with litmus paper. This process was repeated, adding one drop more NaOH at a time. The student continued doing this until a change in the behaviour of the litmus paper was observed..
	1. Write down a balanced equation for the HCl and NaOH reaction. What do you see? How can you use this information to explain the student’s observations?

Answers:

1. Sulfuric acid: H2SO4Table salt: NaCl
Sodium hydroxide: NaOH
Hydrochloric acid: HCl
Potassium hydroxide: KOH
2. In acids H is the common element, The common ion would be H+
3. In bases O and H are common elements. The common ion would be OH-
4. HCl(aq) + NaOH(aq) → NaCl(aq) + H2O(l)
The acid and the base react with each other to produce salt and water. Water is neutral and so is salt. So, as more and more NaOH is added to the HCl the point will be reached where the solution is neutral. If still more NaOH is added it will become an excess which cannot be neutralised by the acid any longer and the solution will become basic, turning the litmus paper blue.

# Reactions between acids and bases – Neutralisation reactions

Knowing what you do about acids and alkalis, what would you expect to see in a neutralisation reaction? Would you expect the products to be acidic, alkaline or neutral? What would it mean to be neutral?

As you have probably already realised, this type of reaction typically results in two neutral products: a salt and water.

 **A salt** is an ionic compound that does not involve –OH-1, O2- or H+ ions. The salt is composed of the anion from the acid and the cation from the base.

Remember: A cation is a positively charged ion and an anion is a negatively charged ion.

**Neutralisation reaction in everyday life**

Neutralisation reactions are often used to deal with situations that occur in our daily lives. Here are some examples:

1. In digestion
Your stomach contains HCl which is essential for digestion. However, if there is too much HCl present it can cause indigestion and even ulcers. So antacids are used to neutralize the stomach acid and relieve the pain and discomfort.

Did you know: Antacids have been around for as long as people have felt the need to deal with stomach discomfort. Originally, herbs and other plants and roots were used, and, in fact, they still are today. For example, ginger root, the liquorice plant, peppermint leaves and chamomile are often used. In South Africa the gel from the leaves of a plant called *Aloe arborescens* (inKalane or Krantz aloe) is still used with good effect.

Pics of antacids, both commercial and “traditional”?

The clinical word for acidity of the stomach is dyspepsia which gives you a clue for the original purpose of peppermints!

Other effective antacids include the sodium bicarbonate and calcium bicarbonate which act as simple acid-base neutralizations in the stomach.

1. Treating bee or ant stings
Insect stings often contain formic acid which is injected into your skin when you are stung or bitten. This causes pain. The pain can be eased by rubbing the area with moist baking soda (NaHCO3, sodium bicarbonate) to neutralize the formic acid. Another treatment is calamine lotion which contains zinc carbonate (ZnCO3) which also neutralises the acid.

Did you know: Many creatures use acids as part of their defence mechanisms and also for collecting food. For example, have you ever been bitten by an ant and felt the sting? That is because the ant injects formic acid into the wound. The amount of formic acid injected is very small, so the pain in a human being is limited, but in another insect such as a termite it is enough to immobilise it or kill it. Why do you think that we can use sodium bicarbonate to treat certain insect stings and bites? Wasps actually inject alkali into the skin when they sting you, so sodium bicarbonate would not be an effective antidote and an acid like vinegar would have to be used!

Pics of bees, ants and wasps

1. Treating acidic soil in agriculture.
Excessive use of fertilizers makes soils acidic, resulting in poor growth of crops. If a base such as calcium oxide (CaO, quick lime) or calcium hydroxide (Ca(OH)2, slaked lime) is added the acidity can be neutralised and the soil is again more suitable for the plants.

Soil can also become too basic in which case acid must be added to correct the pH and make it suitable for crops to grow.
2. Treating factory waste.
Much factory waste is very acidic. So, if this waste finds its way into our water systems it acidifies the water and makes it unsuitable for human, animals and plants. Such waste needs to be neutralised before being disposed of – but not into the water systems!

<http://www.fp.utm.my/projek/psm/webtlr/Neutralisation/learning2a.html>

<http://www.fp.utm.my/projek/psm/webtlr/Neutralisation/learning2b.html>

Activity : Write balanced equations for the following reactions. Decide whether they are neutralization reactions or not. Which products are salts.

1. Nitric acid (HNO3) and potassium hydroxide (KOH)
2. Zinc (Zn) and copper sulfate (CuSO4)
3. Sulfuric acid (H2SO4) and sodium hydroxide (NaOH)
4. Hydrochloric acid (HCl) and magnesium hydroxide (Mg(OH)2)
5. Methane (CH4) and oxygen (O2)

Answers:

1. HNO3(aq) + KOH (aq) → KNO3(aq) + H2O(l)
2. Zn(s) + CuSO4(aq) → ZnSO4(aq) + Cu(s)
3. H2SO4(aq) + 2NaOH (aq) → Na2SO4(aq) + 2H2O(l)
4. 2HCl(aq) + Mg(OH)2(s) → MgCl2(aq) + 2H2O(l)
5. CH4(g) + 2O2(g) → CO2(g) + 2H2O(g)

Reactions 1, 3 and 4 are neutralization reactions. Water is a product in each of these reactions.

The salts are potassium nitrate, KNO3, sodium sulfate, Na2SO4 and magnesium chloride, MgCl2

Activity : Answer the following questions:

1. Define the following terms:
	1. An acid
	2. A base
	3. An alkali
	4. A salt
	5. A neutral solution (5)
2. Explain the following:
	1. How to test whether a substance is basic, acidic or neutral.
	2. What happens when an alkaline solution is slowly added to an acidic solution. (5)

Answers:

1. 1. An acid is a substance that releases hydrogen (H+) ions when placed in water
	2. A base is a substance that releases hydroxide (OH-) ions when placed in water
	3. An alkali is a base which is soluble in water
	4. A salt is the product of a reaction between an acid and a base
	5. A neutral solution is one which is neither acidic nor alkaline (5)
2. 1. One can use litmus paper. Place red and blue litmus paper into the solution/liquid. If the red paper turns blue and the blue paper remains blue, the solution is a base. If the blue paper turns red and the red paper remains red, the solution is an acid. Litmus papers are not really suitable for measuring neutral solutions. (2)
	2. The alkaline solution and the acidic solution start to react with each other. Initially there is too little alkaline solution to neutralise all the acid so the litmus paper would stay reddish in colour. As more alkaline solution is added more and more of the acid is neutralised until there is neither acid nor base in the mixture. As more alkaline solution is added the solution will become more alkaline because there is no acid left to neutralise it and the litmus paper will turn blue. (3)

### The Arrhenius and Brønsted-Lowry theories of acids and bases

The Arrhenius theory is based on the following:

* Acids are substances that produce hydrogen ions in solution.
* Bases are substances that produce hydroxide ions in solution.
* Neutralization happens because hydrogen ions and hydroxide ions react to produce water.

H+(aq) + OH−(aq) → H2O(l)

The examples you have looked at so far described the reactions of

Arrhenius acids and bases.

However, there is another theory of acids and bases.

### The Brønsted-Lowry theory is based on the following:

* Acids are a proton (hydrogen ion, H+) donors.
* Bases are proton (hydrogen ion, H+) acceptors.

The Brønsted-Lowry theory does not go against the Arrhenius theory in any way - it just broadens it. Hydroxide ions are still bases because they accept hydrogen ions from acids and form water. An acid produces hydrogen ions in solution because it reacts with the water molecules by giving a proton to them.

Consider the following reaction:

HCl(aq)  +   H2O(l)  →    H3O+(aq)   +   Cl-(aq)

* According to Arrhenius, hydrochloric acid is an acid because it produces hydrogen ions (H+) in water
The hydrogen ions in water become [*hydroxonium ions*](http://www.gcsescience.com/aa1.htm) *(H3O+)*.
* According to the Brønsted-Lowry theory hydrochloric acid is an acid because it is a proton donor.
*A* [*proton*](http://www.gcsescience.com/a1-atom-electron-neutron-proton.htm) *is a* [*hydrogen ion*](http://www.gcsescience.com/aa1.htm) *(H+).*
A proton donor is a substance which gives a hydrogen ion away.
If you look at the reaction above hydrochloric acid gives a hydrogen ion to water.

In the Arrhenius theory the base is a substance that produces –OH- ions when dissolved in water, as you saw with NaOH → Na+ + OH-.

Remember: You can identify an Arrhenius acid because it contains H atoms which can form H+ ions. And an Arrhenius base contains OH atoms which can form OH- ions.

A Brønsted [base](http://www.gcsescience.com/aa20.htm) is a proton acceptor.
This means that a base will gain a hydrogen ion (H+).
Water acts as a base when it is added to hydrochloric acid
because water will gain a hydrogen ion to become H3O+.

 HCl(aq)  +   H2O(l)  →   H3O+(aq)   +   Cl-(aq)

 acid     +    base     →       acid        +     base

On the right side of the arrow, H3O+ is an acid because it can give away a hydrogen ion to become H2O.
Cl- is a base because it can gain a hydrogen ion to become HCl.

Ask yourself: [Is water always a base according to Lowry and Brønsted?](http://www.gcsescience.com/aa3.htm)

Let’s look at the Brønsted-Lowry theory a bit closer. Consider the following reaction

NH3(aq)  +  H2O(l)   ⇌   NH4+(aq)   +    OH-(aq)

Ammonia (NH3) is the [base](http://www.gcsescience.com/aa2.htm) because it gains a [hydrogen ion](http://www.gcsescience.com/aa2.htm) (H+)
to become an ammonium [ion](http://www.gcsescience.com/a-what-is-the-difference-between-an-atom-and-an-ion.htm) (NH4+).
Water is the [acid](http://www.gcsescience.com/aa2.htm) because it gives away a hydrogen ion (H+) to ammonia
and becomes a hydroxide ion (OH-).

Now we can see that the reaction can be described like this:

NH3(aq)  +  H2O(l)   ⇌   NH4+(aq)   +    OH-(aq)

 base + acid ⇌    acid   +    base

Got it: According to the Brønsted-Lowry theory, water can be an acid or a base depending on the substance reacting with it.

Water is a base when it is put with hydrochloric acid because water will gain a hydrogen ion to become H3O+. However, water will be an acid when it reacts with ammonia (NH3) because water will lose a hyrdrogen ion (H+) and become the base hydroxide ion, (OH-).

**Strong and weak acids and bases

Acids**

Strong acids are those that ionize completely in solution and therefore release all the H+ possible. Examples of strong acids are hydrochloric acid, sulfuric acid and nitric acid which ionize as follows:

 HCl → H+ + Cl–

H2SO4 → 2H+ + SO42–

HNO3 → H+ + NO3–

Weak acids ionize partially in solution. Instead, they form a n equilibrium reaction. As a result not all of the possible H+ ions are released into the solution. Strong acids have a lower pH (are more acidic) than weak acids even when they are at the same concentration.

An example of a weak acid is ethanoic acid (acetic acid or vinegar) as follows:

CH3COOH ⇌ CH3COO– + H+

## Acid strength and acid concentration

The strength of an acid is a measure of the degree of its ionization. Strong acids are fully ionised but weak acids are only partly ionised. An acid that is not strong is called a weak acid.

The concentration of an acid is a measure of the number of [moles](http://www.bbc.co.uk/schools/gcsebitesize/science/triple_ocr_gateway/how_much/strong_weak_acids/revision/1/) of acid in 1 dm3 of acid solution. For example, 2 mol.dm3 hydrochloric acid is twice as concentrated as 1 mol.dm3 hydrochloric acid or 1 mol.dm3 ethanoic acid. An acid that is not concentrated is called a dilute acid.

**Base strength and base concentration**

A strong base is one that ionizes completely in solution.The reaction is not reversible and the total number of OH- ions are released. Some examples of strong bases are sodium hydroxide and potassium hydroxide:

 NaOH(s) + H2O(l) → Na+(aq) + OH-(aq)

 KOH(s) + H2O(l) → K+(aq) + OH-(aq)

A weak base ionizes only partially in solution. It is a reversible reaction and an equilibrium is established. An example of a weak base is an ammonia solution:

NH3(aq) + H2O(l) ⇌ NH4+(aq) + OH-(aq)

The equilibrium favours the left hand reaction so only a few hydroxyl ions (OH-) form, resulting in a weak base.

The concentration of an base is a measure of the number of [moles](http://www.bbc.co.uk/schools/gcsebitesize/science/triple_ocr_gateway/how_much/strong_weak_acids/revision/1/) of base in 1 dm3 of base solution. For example, 2 mol.dm3 sodium hydroxide solution is twice as concentrated as 1 mol.dm3 sodium hydroxide solution or ammonia solution. A base that is not concentrated is called a dilute base.

Got it: **Strong** and **weak** refer to the ability of an acid or base to ionise. **Concentrated** and **dilute** refer to the quantity of acid or base present in the aqueous solution. **Chemical indicators**

A chemical indicator is a substance that gives a visible sign, usually by a **colour change**, of the presence or absence an acid or an alkali in a solution. (Note: indicators can be used for other types of reactions, but for your purposes only neutralization reactions are being considered).

You have already met a simple indicator, litmus paper, which is red in acidic conditions and blue in alkaline conditions.

Here are a few other indicators that are quite common in a chemistry laboratory:

|  |  |  |  |
| --- | --- | --- | --- |
| **Indicator** | **Acidic** | **Neutral** | **Alkaline** |
| Methyl orange | red | yellow | yellow |
| Phenolphthalein | colourless | colourless | pink |
|  |  |  |  |

A universal indicator is a mixture of a different indicators and can be used to measure the approximate pH of a solution across the whole pH range from 1-14. The range of colours is similar to the rainbow, with reds being very acidic, greens being closer to neutral and the purples being very basic. Universal indicators give estimates of the pH – the values are not very accurate.

**Some common types of reactions with acids**

1. Acids will react with metal oxides, such as copper oxide, to make a salt and water.
The general equation is as follows:
 acid + metal oxide → salt + water

For example the reaction between copper oxide and hydrochloric acid:

 CuO(s) + HCl(aq) → CuCL2(aq) + H2O(l)
 metal oxide + acid → salt + water

1. Acids will react with metal hydroxides, such as calcium hydroxide, to make a salt and water.
The general equation is as follows:
 acid + metal hydroxide → salt + water

For example the reaction between calcium hydroxide and hydrochloric acid:

 Ca(OH)2(s) + 2HCl (aq) → CaCl2(aq) + 2H2O(l)

 metal hydroxide + acid → salt + water
2. Acids will react with metal carbonates, such as, to make a salt, water and carbon dioxide.
The general equation is as follows:

 acid + metal carbonate → salt + water + carbon dioxide

For example, the reaction between calcium carbonate (found in chalk, limestone and marble) and hydrochloric acid:

 CaCO3(aq) + HCl(aq) → CaCl2(aq) + CO2(g) + H2O(l)
 metal carbonate + acid → salt + carbon dioxide + water

Again you would see bubbling during this reaction. Can you see why? Yes, it is because of carbon dioxide gas being released. This gas can be identified as CO2 by passing it through a solution of limewater and seeing the formation of a white solid (called a precipitate).

The damage caused to rocks and buildings by acid rain is due to this reaction.
3. Acids will react with reactive metals, such as magnesium and zinc, to make a salt and hydrogen.
The general equation is as follows:
 acid + metal → salt + hydrogen

For example, the reaction between zinc and hydrochloric acid:

Zn(s) + HCl(aq) → ZnCl2(aq) + H2(g)

metal + acid → salt + hydrogen

If you did this reaction you would see it bubbling. This is because the hydrogen is released as a gas. A simple test for hydrogen gas is that it stops a lighted piece of wood (called a splint in the laboratory) from burning.

**Asessment :**

**Answer the following multiple choice questions:**

1. Which of these acids is most likely to be dangerous?
	1. Nitric acid
	2. Acetic acid
	3. Hydrochloric acid
2. Which statement about bases is true?
	1. All bases are soluble
	2. Bases can neutralize acids
	3. All bases are alkalis
3. Which statement about alkalis is true
	1. All alkalis are not bases
	2. All alkalis are soluble
	3. Alkalis cannot neutralize acids
4. Litmus paper that is placed in an acidic solution
	1. Turns red litmus paper blue
	2. Turns yellow litmus paper green
	3. Turns blue litmus paper red
5. A liquid is tested for pH using a universal indicator. The colour shown is green. This means that the liquid is
	1. neutral
	2. acidic
	3. basic
6. A liquid that has a pH of 6.5 is
	1. Neutral
	2. Weakly acidic
	3. Weakly basic
7. The contents of your stomach have a pH of 1. What does this mean?
	1. The stomach is a strongly alkaline environment
	2. The stomach is a neutral environment
	3. The stomach is a strongly acidic environment.
8. When an acid reacts with a metal hydroxide the products formed are:
	1. A salt and water
	2. A salt and hydrogen
	3. A salt, carbon dioxide and water
9. The products of a reaction with acid are A salt, carbon dioxide and water. What is the substance reacting with the acid?
	1. A metal oxide
	2. A metal carbonate
	3. A metal
10. Which acid could be used to manufacture a fertilizer called ammonium nitrate?
	1. Sulfuric acid
	2. Citric acid
	3. Nitric acid
11. What gas is produced when magnesium reacts with sulfuric acid?
	1. Oxygen
	2. Carbon dioxide
	3. Hydrogen
12. What salt is formed when copper oxide reacts with nitric acid?
	1. Copper sulfate
	2. Copper nitrate
	3. Copper chloride
13. A Brønsted-Lowry base is
	1. A proton donor
	2. A proton acceptor
	3. An electron acceptor
14. Which of the following statements is true?
	1. If you mix an acid with a base the base becomes stronger
	2. If you mix an acid with a base they neutralize each other
	3. If you mix an acid with a base no reaction takes place
15. A hydrogen ion (H+) is the same as a
	1. Proton
	2. Neutron
	3. Electron