Acids and Bases

Acids, bases and salts are terms used to describe chemical compounds with specific properties. The are formed from both ionic and covalent compounds

Acids

Acids are common around the home. The are in foods such as fruits like lemons (citric acid), vinegar (acetic acid), and in soft drinks (carbonic acid). Industrially acids are used extensively in the production of fertilizers, drugs, explosives and plastics. The are also used to clean the surfaces of metals before use.

The properties of acids have been well known since the 17th century. Some of these properties include

- They change the colour of some indicators
- They are corrosive
- They taste sour
- The react with bases
- They have a low pH
- Most are soluble in water
- They form hydrogen with active metals
- They form carbon dioxide with carbonates or bicarbonates
- They conduct electricity in solution

Some common acids and their uses are as follows

Name	Formula	Uses
Hydrochloric Acid	HCl	Stomach acid, cleaning brickwork
Sulfuric Acid	H_2SO_4	Car batteries, paint, detergent, fertiliser One of the most common chemicals made
Nitric Acid	HNO_3	Fertiliser, dye, explosives
Ethanoic (acetic) acid	CH_3COOH	Vinegar, preservative
Carbonic Acid	H_2CO_3	Soft drink, beer
Phosphoric Acid	H_3PO_4	Fertilisers, some soft drink
Citric Acid	$C_6H_8O_7$	Citrus fruits
Lactic Acid	$C_3H_6O_3$	Milk products, made in muscles during hard exercise
Ascorbic Acid	$C_6H_8O_7$	Vitamin C, citrus fruits

Bases

Bases are also very common around the home. Their main use is in cleaning agents whether it is cleaning the stove, the floor, your clothes or yourself.

Some of their properties include

- They change the colour of some indicators
- They are corrosive (caustic)
- They taste bitter
- The react with acids
- They have a high pH
- Most are soluble in water
- They feel slippery
- They conduct electricity in solution

Some common bases and their uses are as follows

Name	Formula	Uses
Sodium hydroxide (caustic soda)	$NaOH$	Drain and oven cleaners, soap making
Ammonia	NH_3	Household cleaners, fertilisers, explosives
Calcium hydroxide	$Ca(OH)_2$	Cement, garden lime, adjust soil pH
Magnesium hydroxide	$Mg(OH)_2$	Antacids
Sodium carbonate	Na_2CO_3	Washing powder, glass

Safety with Acids and Bases

Acids and bases are dangerous substances due to their corrosive property. These substances can be identified by the sign shown. Due care should be taken when using acids and bases, regardless of how strong or weak you think they are. These precautions include

- Always wearing safety glasses and aprons.
- Labelling all bottles and containers with the name of the substance and the concentration.
- When diluting acids , **<u>add the acid to the water</u>** not the other way.

The reason that we add acid to water is that the ionisation of concentrated acids is a highly exothermic reaction (releases a lot of energy). Therefore by when adding a bit of water to a lot of acid, it releases energy quickly causing the acid to boil and spit out of the container. Instead slowly add the acid to a larger amount of water, stopping every so often to allow the solution to cool down.

Spills of acids should be cleaned up with a weak base such as sodium bicarbonate. Spills of bases should be cleaned up with a weak acid such as vinegar.

Bronsted-Lowry Acids and Bases

According to the Bronsted-Lowry Theory two things can be said:

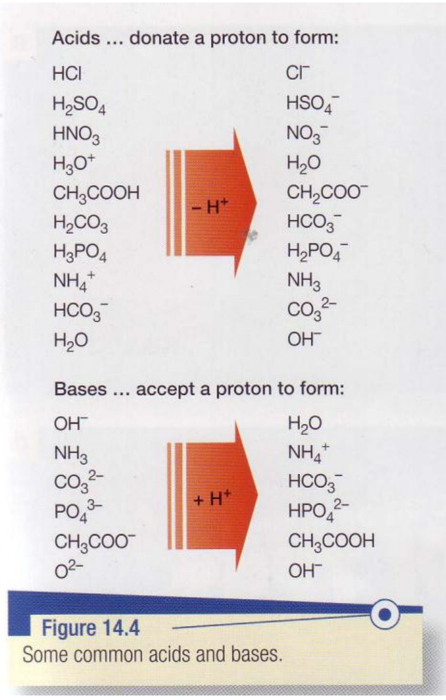


Figure 14.4
Some common acids and bases.

Acids are proton donors
Bases are proton acceptors

But where does this proton come from? If we look at the table of common acids above we can see that all the acids have one element in common, hydrogen. By looking at the structure of hydrogen we can see that it is an element containing one proton and one electron. Therefore by removing the electron to from an hydrogen ion (H^+) we are left only with one proton that can be donated. Therefore acids are substances that donate a H^+ ion and bases are substances which accept a H^+ ion. ***The term hydrogen ion and proton can be used interchangeably.***

Let us take an example

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

Hydrochloric acid	Water	Hydronium ion	Chlorine ion

$$\mathbf{H}Cl + H_2O \rightarrow H_3O^+ + Cl^-$$

In this case as expected the hydrochloric acid is acting as the acid as it donates a proton to the water. This makes the water the base as it is accepting that proton.

Take another example with a base

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Ammonia	Water	Ammonium ion	Hydroxide ion

$$NH_3 + \mathbf{H}_2O \rightarrow NH_4^+ + OH^-$$

In this case as expected the ammonia is acting as a base as it is accepting a proton from the water. This makes the water an acid as it is donating protons.

The examples above demonstrate a very interesting property of water, in the first example it is acting as a base, in the second example it is acting as an acid. These types of substances are known as <u>amphoteric substances</u>. Amphoteric substances can donate or accept a proton, dependent on what they are reacting with. Another example of how this works is shown below.

$$HCO_3^- \quad + \quad H_2O \longrightarrow H_2CO_3 \quad + \quad OH^-$$

Here the water is acting as the acid

$$HCO_3^- \quad + \quad H_2O \longrightarrow CO_3^{2-} \quad + \quad H_3O^+$$

Here the water is acting as the base

The table below shows the different amphoteric substances and how they react as an acid and a base.

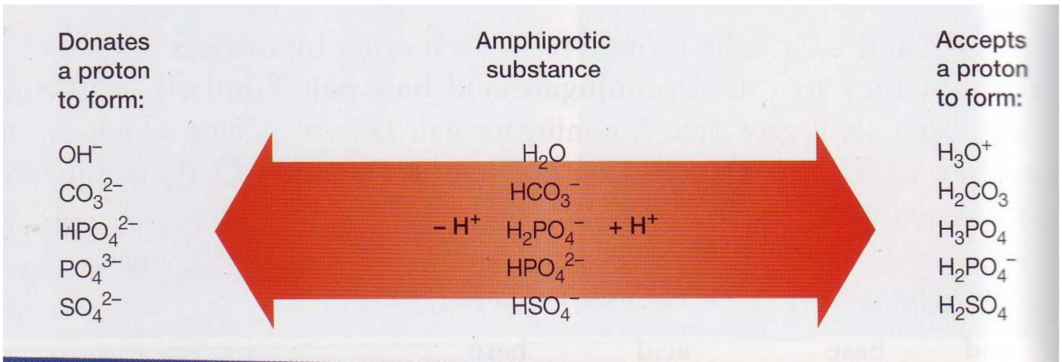


Figure 14.5
Substances that are amphiprotic.

Let us again consider the equation shown below

$$HCl \; + \; H_2O \longrightarrow H_3O^+ \quad + \quad Cl^-$$

In this case we know that HCl is the acid and can donate a proton to the water. However looking at the products side the Cl^- is able to accept a proton and is therefore a base. This HCl/Cl^- pair is known as a conjugate pair, every acid has a conjugate base and every base has a conjugate acid. Therefore in this case the base is water and it's conjugate acid is H_3O^+. It consists of an acidic form on one side and basic form on the other.

If the acid is strong then the conjugate base is weak, if the base is strong the conjugate acid is weak.

In the examples I have shown only one proton has been transferred in each case. However there are acids that do not just donate one but two or three protons. These are known as **polyprotic acids**.

Monoprotic acids are ones that donate only one proton and they include hydrochloric (HCl), nitric (HNO_3), ethanoic (CH_3COOH) and hydrofluoric (HF) acids. Polyprotic acids can be classified as diprotic, donating two protons, and triprotic, donating three protons. Some common diprotic acids include carbonic (H_2CO_3) and sulfuric (H_2SO_4) acids whilst triprotic acids include phosphoric (H_3PO_4) and boric (H_3BO_3) acids.

It is important to note that the diprotic and triprotic acids do not donate all of their protons at once, instead it happens in a series of steps. Let us take the example of sulfuric acid

$$H_2SO_4 + H_2O \longrightarrow HSO_4^- + H_3O^+$$

$$HSO_4^- + H_2O \leftrightarrows SO_4^{2-} + H_3O^+$$

Here in the first equation sulfuric acid is a strong acid and therefore completely ionises in water to produce hydrogen sulfate ions and hydronium ions. In the second equation the hydrogen sulfate ions can act as a weak base and therefore partially ionises to sulfate ions and hydronium ions. Therefore a sulfuric acid solution contains sulfate, hydrogen sulfate and hydronium ions.

Another example is shown below with phosphoric acid. The first reaction has the highest ionisation the lowest is at the bottom.

$$H_3PO_4 + H_2O \leftrightarrows H_2PO_4^- + H_3O^+$$

$$H_2PO_4^- + H_2O \leftrightarrows HPO_4^{2-} + H_3O^+$$

$$HPO_4^{2-} + H_2O \leftrightarrows PO_4^{3-} + H_3O^+$$

Acid and Base Strength

The strength of an acid or base can be determined in two ways:

They can be concentrated or dilute - Concentrated acids have very little water added, there is a lot of substance in a small volume. For example concentrated sulfuric acid is about 98% acid and 2% water. Most laboratory solutions we use are much more dilute having concentrations of 10% or less

They can be strong or weak - Strong acids and bases are those that completely ionise in water. This means that when you add an acid such as HCl to water it is completely broken down into hydrogen ions and chlorine ions.

$$HCl \longrightarrow H^+_{(aq)} + Cl^-_{(aq)}$$

Weak acids and bases are those that only partially ionise in water. In the case of ethanoic acid only 4 out of 1000 or less than 1% of all the acid molecules ionise. In this case there is still a high amount of ethanoic acid in the solution and only very few hydrogen ions and ethanoate ions

$$CH_3COOH \rightleftarrows CH_3COO^-_{(aq)} + H^+_{(aq)}$$

From Bronsted-Lowry definitions we can say that:

Strong acids readily donate protons
Strong bases readily accept protons

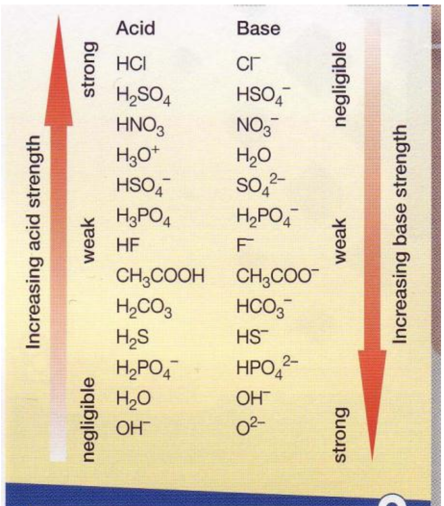
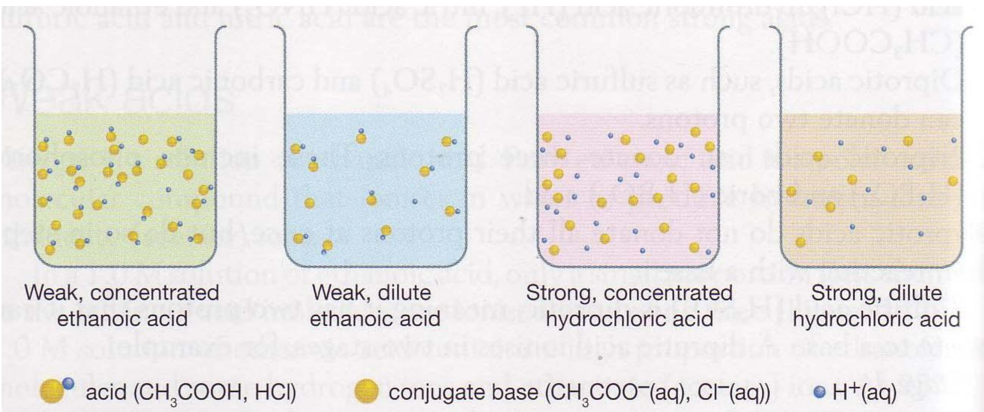


Figure 14.7 The relative strengths of some acid and base pairs. Note that the stronger the acid, the weaker its conjugate base.

Below is a diagram to help understand these differences



pH

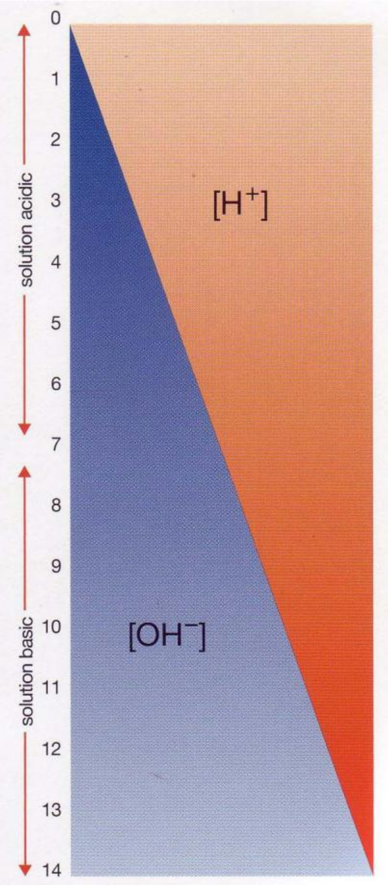
Experimental results have shown that in all aqueous solutions there is both H_3O^+ and OH^- ions. It was also found that the product of these concentrations is equal to 10^{-14} M^2. To put this mathematically it can be represented by.

$$[OH^-] \times [H_3O^+] = 10^{-14}$$

Water which is a neutral substance has equal concentrations of H_3O^+ and OH^- ions, therefore

$$[OH^-] = [H_3O^+] = 10^{-7}$$

Therefore if the concentration of H_3O^+ increases then the concentration of OH^- decreases. This is more clearly explained by the diagram opposite.



The pH scale is a useful way of showing the acidity of a solution. It is defined mathematically by the following equation

$$pH = -\log [H_3O^+]$$

Therefore since it is it is a logarithmic function for every decrease of 1 in the pH will decrease the concentration of H_3O^+ by a factor 10.

It is generally accepted that any substance with pH =7 is neutral, neither acidic or basic. Anything lower than 7 is acidic and higher than 7 is basic. However lets see if using the formula this holds true. For a neutral solution as shown above $[H_3O^+] = 10^{-7}$. Therefore using the pH formula we get:

$$\begin{aligned} pH &= -\log 10^{-7} \\ &= -(-7) \\ &= 7 \end{aligned}$$

For acidic solutions we would expect a higher concentration of H_3O^+ and therefore we can again calculate the pH as follows

$$\begin{aligned} pH &= -\log 10^{-6} \\ &= -(-6) \\ &= 6 \end{aligned}$$

We would get a similar result with a less concentrated solution take for example 10^{-8}, from the examples above you can clearly see this would have a pH = 8.
Therefore what we can confirm that acidic solutions have a pH less than 7 and basic ones a pH greater than 7, whilst a pH of exactly 7 indicates a neutral substance.

It is also interesting to not that we can also go the other way from the pH to the concentration of H_3O^+. This formula is as shown below

$$[H_3O^+] = 10^{-pH}$$

Therefore the $[H_3O^+]$ of a solution with a pH = 2.5 would be as follows

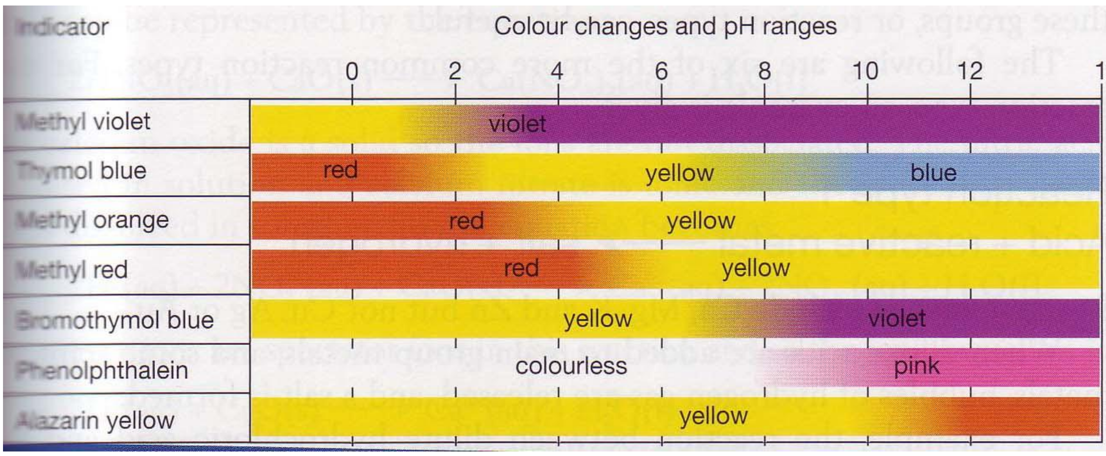
$$\begin{aligned}[H_3O^+] &= 10^{-2.5} \\ &= 3.16 \times 10^{-3} \text{ mol L}^{-1}\end{aligned}$$

Indicators

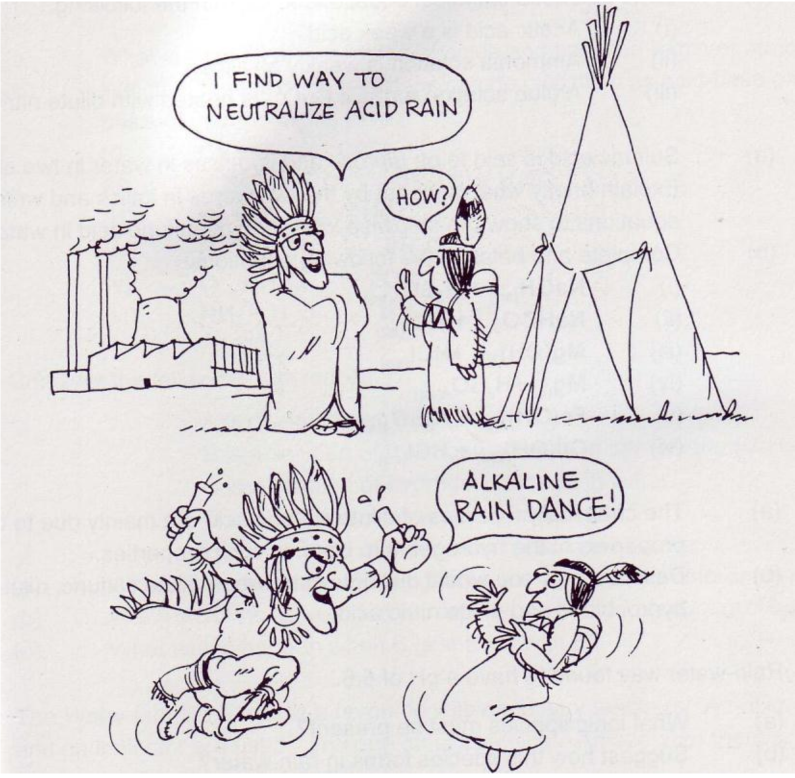
A chemist will use indicators rather than the speed of a reaction to determine how acidic or alkaline a solution is. Indicators show one colour in acidic Indicators are often extracted from plant dyes and are themselves acids or bases. Examples of these include litmus which is extracted from lichen, rose petals, blackberries, red cabbage, beetroot and to a lesser extent tea. They change according to the pH of the solution, not whether it is an acid or a base. So the colour change may occur within the acid or within the bases.

Universal indicator is a mixture of many different indicators. As shown in the table below the colour change may occur anywhere from pH 1 to pH 12 depending on the indicator. By mixing the indicators we get a full range of colour changes which helps us to gauge the pH more accurately. For an even more accurate calculation of pH a pH meter is used.

The table below shows some common laboratory indicators, the range they change at and their respective colour changes.



Reactions of Acids and Bases



Acids and Bases undergo many reactions, these reactions one ones that are very important and that you need to know for next year.

Reaction 1

Acid + Reactive Metal $\longrightarrow$ Salt + Hydrogen

Reactive metals include Ca, Mg, K and Zn but not Cu, Ag, Au. Dilute acid will reaction with the main group and some of the transition metals. Let us consider the example below

$$2HCl_{(aq)} + Zn_{(s)} \longrightarrow ZnCl_{2(aq)} + H_{2(g)}$$

Or by simply showing the ionic equation we get

$$2H^{+}_{(aq)} + Zn_{(s)} \longrightarrow Zn^{2+}_{(aq)} + H_{2(g)}$$

Reaction 2

Acid + Metal Hydroxide $\longrightarrow$ Salt + Water

This reaction is more commonly known as an acid-base reaction, however not all bases will react in this way and therefore the above is a more accurate way of defining it. Metal hydroxides include NaOH, KOH, $Ca(OH)_2$, $Mg(OH)_2$. Let us consider the following example

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Or by simply showing the ionic equation we get

$$H^{+}_{(aq)} + OH^{-}_{(aq)} \longrightarrow H_2O_{(l)}$$

Reaction 3

Acid + Metal Carbonate $\longrightarrow$ Salt + Carbon dioxide + Water

Metal Carbonates include Na_2CO_3, $CaCO_3$, $MgCO_3$. When adding an acid to any of these substances an clear reaction will occur shown bubbles of carbon dioxide gas.

$$2HCl_{(aq)} + MgCO_{3(s)} \longrightarrow MgCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Or by simply showing the ionic equation we get

$$2H^{+}_{(aq)} + MgCO_{3(s)} \longrightarrow Mg^{2+}_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Reaction 4

Acid + Metal Hydrogen Carbonate $\longrightarrow$ Salt + Carbon dioxide + Water

Metal hydrogen Carbonates include $NaHCO_3$, $KHCO_3$, $Mg(HCO_3)_2$. When adding an acid to any of these substances an clear reaction will occur shown bubbles of carbon dioxide gas.

$$HNO_{3(aq)} + KHCO_{3(s)} \longrightarrow KNO_{3(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Or by simply showing the ionic equation we get

$$H^{+}_{(aq)} + KHCO_{3(s)} \longrightarrow K^{+}_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$