32 The pH Scale

Substances can be classified as acidic, basic or neutral according to their concentration of hydrogen ions in solution. To determine whether a substance is acidic, basic or neutral we measure their pH and observe how they change the colour of indicators.

pH and the pH scale

The **pH** of a substance tells us about its acidity or basicity. It indicates the concentration of hydrogen ions (H^+) in a solution, e.g. a low pH identifies an acidic substance with a high concentration of hydrogen ions. A pH of 7 is considered neutral, a pH below 7 is acidic and a pH above 7 is basic.

The pH (potential hydrogen) scale can be used to compare acids and alkalis. Figure 32.1 shows the approximate pH of some common substances, and their colour in universal indicator.

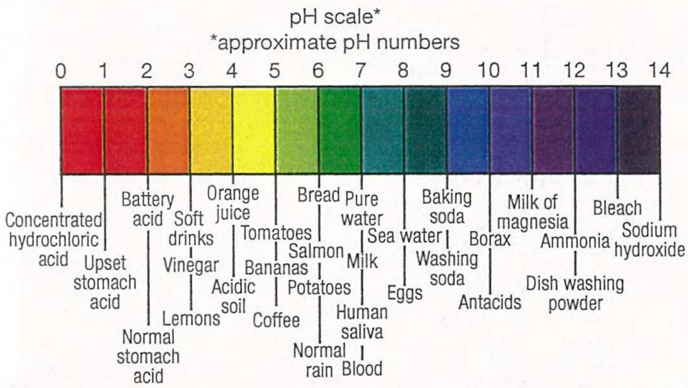


Figure 32.1 pH of common substances.

pH is a log scale, so a drop in pH of 1 indicates that the hydrogen ion concentration has increased 10 times. If we compare substances with a pH of 4 and 6, the substance with pH 6 has 100 times lower hydrogen ion concentration – it is 100 times less acidic than the substance with a pH of 4.

pH can be **measured** by using indicators and electronic probes. These will tell us the concentration of hydrogen ions in the solution – this depends on:

- If the solution is concentrated or dilute (how many moles of acid are present in each litre).
- The strength of the acid present (how readily it releases hydrogen ions).
- The number of protons (hydrogen ions) the acid has to donate (hydrochloric acid has 1; sulfuric acid has 2 per molecule).
- The temperature of the solution.

An **indicator** is a substance that changes colour if placed in an acid or a base.

Some plants contain dyes that are naturally occurring indicators. Many flower petals and also red cabbage leaves release an indicator dye when boiled in water. Lichens that grow on trees and rocks can be used to make the indicator, called litmus.

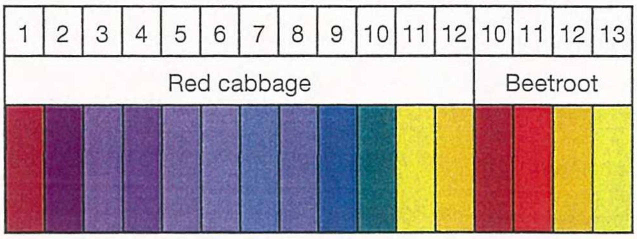


Figure 32.2 Colour changes of two natural indicators.

Commercial indicators can be sold as solutions or dried onto paper strips. Some common commercial indicators and the colour changes they undergo are shown in Table 32.1.

Table.32.1 Commercial indicators and colour change.

Indicator	Colour in acid	Colour in base
Litmus	Red (below pH = 5)	Blue (above pH = 7.6)
Phenolphthalein	Colourless (below pH = 8.3)	Red (above pH = 10.0)
Bromothymol blue	Yellow (below pH = 6.0)	Blue (above pH = 7.6)
Methyl orange	Red (below pH = 3.1)	Yellow (above pH = 4.4)

Universal indicator is a mixture of several dyes. It can show a range of colours as the pH changes, from red (acidic), orange, yellow (slightly acidic), green (neutral), blue-green (slightly basic), to purple (basic) as the pH changes (see Figure 32.1).

Uses of indicators include:

- Testing of soil acidity/basicity.
  When testing the pH of substances such as soil, the colour of the soil can hide the indicator colour change. To prevent this, a neutral white powder, such as barium sulfate can be added to the top layer of damp soil before adding the indicator.
- Testing aquarium water.
  Fish are sensitive to the pH of water so it must be maintained at a suitable level. Saltwater fish may need a pH of about 8.5.
- Finding the end point of an acid-base reaction.
  Indicators are used to do this in a quantitative technique called a titration.
- Checking the water in swimming pools.
  The pH of swimming pool water needs to be kept close to 7.4 to avoid skin and eye problems.

33 Oxides – Acidic, Basic or Neutral

In general the oxides of the elements on the left side of the periodic table (the metals) form basic oxides when dissolved in water and those on the right of the table (non-metals) form acidic oxides when dissolved in water. (See Figure 33.1.) However, there are some exceptions:

- The **inert gases** in group 8 do not form oxides.
- Some oxides are **amphoteric** – they have some acidic properties and some basic properties, e.g. Al_2O_3.
- Some only dissolve slightly in water and form **neutral** solutions, e.g. CO, NO, N_2O.

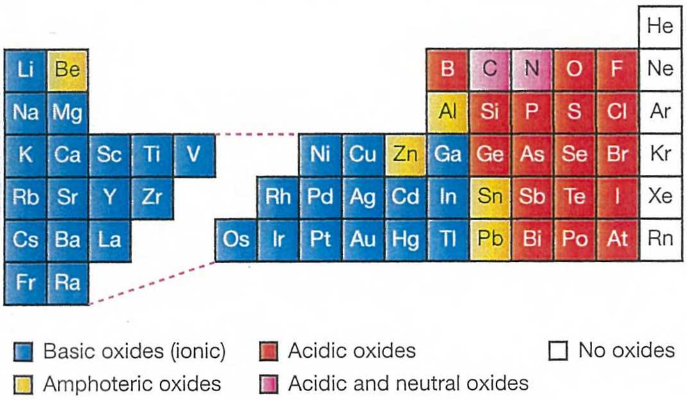


Figure 33.1 Acidic/basic oxides and the periodic table.

We can distinguish whether an oxide is acidic or basic by looking at its effect on an indicator and by seeing if it reacts with an acid or a base.

- Oxides of non-metals are acidic. They react with water to form acids so they turn litmus red.

  Non-metal oxide + water → acid
  Sulfur dioxide + water → sulfurous acid
  $$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

- Acidic oxides react with a base to form water.

  Acidic oxide + base → water + salt
  Sulfur dioxide + sodium hydroxide → water + sodium sulfite
  $$SO_2(g) + 2NaOH(aq) \rightarrow H_2O(l) + Na_2SO_3(aq)$$

  In the next few chapters we will look at the effects of acidic gases in the atmosphere.

- Oxides of metals are bases. They react with water to form an hydroxide and they turn litmus blue.

  Metal oxide + water → base
  Magnesium oxide + water → magnesium hydroxide
  $$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(aq)$$

- Basic oxides react with an acid to form water.

  Basic oxide + acid → water + salt
  Magnesium + hydrochloric acid → water + magnesium chloride
  $$MgO(s) + 2HCl(aq) \rightarrow H_2O(l) + MgCl_2(aq)$$

QUESTIONS

1. Define the following terms.
   (a) Acidic oxide.
   (b) Basic oxide.
2. Identify the acidic oxides in the following list and justify your decisions.
   Carbon dioxide; calcium oxide; nitrogen dioxide; potassium oxide.
3. Outline the relationship between position of elements in the periodic table and the acidity/basicity of their oxides.
4. When sulfur is burnt in air or oxygen an acidic oxide is formed.
   (a) Name the reactants and product.
   (b) Write the combustion equation.
5. Write equations in words and symbols to show the action of water on:
   (a) Sulfur dioxide.
   (b) Sulfur trioxide.
   (c) Diphosphorus pentoxide.
6. Complete the following table to summarise information about oxides formed from metals and non-metals.

Factor	Basic oxide	Acidic oxide
Consists of	Metal + oxygen	
Type of bonding		
State at room temperature		Gas

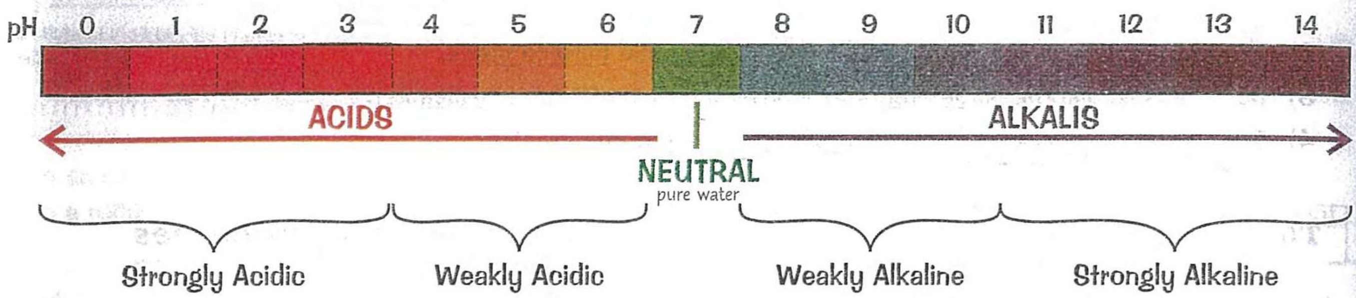
7. State whether each of the following oxides is acidic or basic.
   (a) A colourless gas that dissolves in water to form a solution with a pH of 2.
   (b) White pellets that dissolve in water to form a solution that turns universal indicator purple.
8. Check your knowledge with this quick quiz.
   (a) Is carbon dioxide acidic or basic?
   (b) Acidic oxides are formed by the combustion of ....
   (c) Identify two examples of basic oxides.
   (d) Identify the compound produced when carbon dioxide reacts with water.
   (e) Identify the products of the reaction between an acidic oxide and a base.

Acids and Alkalis

To test the pH of a solution, you can use an indicator — and that means colours...

The pH Scale Goes from 0 to 14

1) The strongest acid has pH 0. The strongest alkali has pH 14.
2) A neutral substance has pH 7 (e.g. pure water).

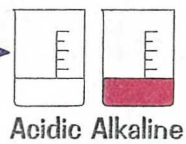


An Indicator is Just a Dye That Changes Colour

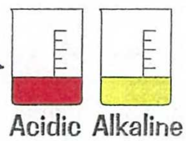
The dye in the indicator changes colour depending on whether it's above or below a certain pH. Indicators are very useful for estimating the pH of a solution. There are several different types:

1) Universal indicator is a very useful combination of dyes which gives the colours shown above. To find the pH of an aqueous solution, add the indicator to the solution you are testing and compare the colour formed to a chart.
2) Litmus paper tests whether a solution is acidic or alkaline because it changes colour at about pH 7. It's red in acidic solutions, purple in neutral solutions and blue in alkaline solutions.

3) Phenolphthalein will change from colourless in acidic solutions to bright pink in alkaline solutions.



4) Methyl orange changes from red in acidic solutions to yellow in alkaline solutions.



Acids can be Neutralised by Bases (or Alkalis)

An ACID is a source of hydrogen ions (H^+). They are proton donors. Acids have a pH of less than 7.

A BASE is a substance that can neutralise an acid. They are proton acceptors. ALKALIS are soluble bases. An alkali is a source of hydroxide ions (OH^-) and has a pH greater than 7.

The reaction between an acid and a base (or an acid and an alkali) is called neutralisation.

Neutralisation can be seen in terms of H^+ and OH^- ions like this:

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

These reactions are sometimes called acid-base reactions.

The reaction can also be seen in terms of proton transfer.

The acid donates protons which are then accepted by the base.

When an acid neutralises a base (or vice versa), the products are neutral, i.e. they have a pH of 7.

This page should have all bases covered...

pHew, you got to the end of the page, so here's an interesting(ish) fact — your skin is slightly acidic (pH 5.5).

Q1 The pH of an unknown solution is found to be 2. Is the solution acidic or alkaline? [1 mark]

Reactions of Acids

Acids are an enthusiastic bunch — they get involved in loads of reactions. For example, they can react with metals (see page 41), metal oxides and metal carbonates.

Salts Form When Acids React with Bases

1) A salt, an ionic compound, is formed during a neutralisation reaction (a reaction between an acid and a base). This is a general equation for a neutralisation reaction: acid + base → salt + water
2) The type of salt depends on the acid used. In general, hydrochloric acid produces chloride salts, sulfuric acid produces sulfate salts and nitric acid produces nitrate salts.
3) You need to be able to remember what happens when you add acids to various bases...

Acid + Metal Oxide → Salt + Water

Examples:
- $2HCl + CuO \rightarrow CuCl_2 + H_2O$ (Copper chloride)
- $H_2SO_4 + ZnO \rightarrow ZnSO_4 + H_2O$ (Zinc sulfate)
- $2HNO_3 + MgO \rightarrow Mg(NO_3)_2 + H_2O$ (Magnesium nitrate)

Acid + Metal Hydroxide → Salt + Water

Examples:
- $HCl + NaOH \rightarrow NaCl + H_2O$ (Sodium chloride)
- $H_2SO_4 + Zn(OH)_2 \rightarrow ZnSO_4 + 2H_2O$ (Zinc sulfate)
- $HNO_3 + KOH \rightarrow KNO_3 + H_2O$ (Potassium nitrate)

These are the same as the acid/alkali neutralisation reaction you met on page 46.

Acid + Ammonia → Ammonium Salt

Examples:
- $HNO_{3(aq)} + NH_{3(aq)} \rightarrow NH_4NO_{3(aq)}$ (ammonium nitrate)
- $H_2SO_{4(aq)} + 2NH_{3(aq)} \rightarrow (NH_4)_2SO_{4(aq)}$ (ammonium sulfate)

When ammonia dissolves in water it forms NH_4^+ and OH^- ions. So this reaction is actually: $NH_4^+ + OH^- + HNO_3 \rightarrow NH_4NO_3 + H_2O$ as the reactant is aqueous ammonia.

Salts Also Form When Acids React With Metals or Metal Carbonates

You also need to know what happens when you react an acid with a metal or a metal carbonate. The reaction of acids and metals is covered on page 41 in more detail.

Examples:
- $2HCl + Mg \rightarrow MgCl_2 + H_2$ (Magnesium chloride)
- $H_2SO_4 + Mg \rightarrow MgSO_4 + H_2$ (Magnesium sulfate)

The reaction of nitric acid with metals can be more complicated — y[illegible] a nitrate salt, but instead of hydrogen gas, the other products are usually a mixture of water, NO and NO_2.

Acid + Metal Carbonate → Salt + Water + Carbon Dioxide

Examples:

hydrochloric acid + sodium carbonate → sodium chloride + water + carbon dioxide

$$2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$$

sulfuric acid + calcium carbonate → calcium sulfate + water + carbon dioxide

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$$

nitric acid + calcium carbonate → calcium nitrate + water + carbon dioxide

$$2HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$$

Nitrates — much cheaper than day-rates...

What a lot of reactions. Better take a peek back at page 23 for help with writing and balancing chemical equations.

Q1 Write a balanced chemical equation for the reaction of hydrochloric acid with calcium carbonate. [2 marks]