Acids and Bases

CHEMISTRY • REACTIONS • ACIDS AND BASES

Section 1: Acids

• What are acids?

The term 'acid' comes from a Latin word meaning 'sour', and we encounter many acids in everyday life. Vinegar (literally 'sour wine') is a dilute solution of ethanoic (acetic) acid. Limes, lemons and oranges contain citric acid, tea contains tannic acid, vitamin C is ascorbic acid, and rainwater and fizzy drinks contain carbonic acid. Proteins are built out of long chains of amino acids, and even the DNA molecule itself is an acid (deoxyribonucleic acid).

• What makes an acid acidic?

Acid molecules all contain hydrogen atoms, and when they dissolve in water the acid molecules split up, or dissociate, making hydrogen ions H+(aq) and a negative ion. A good example is hydrochloric acid, which dissociates completely into hydrogen ions and chloride ions:

$$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

It is these hydrogen ions that give acids their characteristic properties, including:

- their sour taste
- turning blue litmus paper red
- turning Universal Indicator red, orange or yellow
- a pH less than 7.00
- reacting with magnesium metal, making hydrogen gas:

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

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow CO_2(g) + H_2O(l) + 2NaCl(aq)$$

- reacting with sodium carbonate, making carbon dioxide gas:

magnesium + hydrochloric acid
→ hydrogen + magnesium chloride

$$Mg(s) + 2HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$$

DIAGRAM 01:

Common Acids and Their Properties

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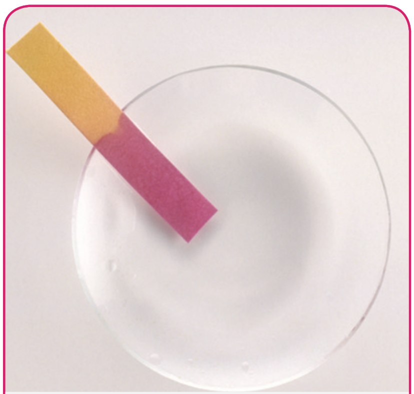
Name	Formula	Typical pH of the acid solution	Strong acid or weak?	Comments
Hydrochloric	HCl	1.0	Strong	Found in the stomach
Sulphuric	H_2SO_4	1.0	Strong	Use in car batteries and to make fertilisers
Nitric	HNO_3	1.0	Strong	Used to make fertilisers
Methanoic (formic)	$HCOOH$	2.1	Weak	Found in ant and nettle stings
Ethanoic (acetic)	CH_3COOH	2.4	Weak	Used in vinegar
Carbonic	H_2CO_3	3.8	Weak	In rainwater and fizzy drinks

• Worksheet Question

- Question 1



An acid will turn Universal Indicator red, orange or yellow

• Suggested Films

- Acids and Alkalis: Part 1
- Acids and Alkalis: Part 2
- Crystals in Caves

• What are indicators and what is the pH scale?

Indicators are substances that change colour in acids and alkalis. In the early days of chemistry, plant dyes such as litmus (made from a type of lichen) were used as indicators. Litmus is red in acids and blue in alkalis. Red cabbage can also be used to make a very good indicator, but the problem with plant dyes is that they tend to degrade in contact with air and sunlight. Later, more stable synthetic indicators such as phenolphthalein and methyl orange were discovered. Universal Indicator is a mixture of dyes, giving a range of different colours which allow us to distinguish strongly acidic solutions from those that are weakly acidic, and strongly alkaline solutions from those that are weakly alkaline.

Indicator	Colour in acidic solutions	Colour in neutral solutions	Colour in alkaline solutions
Litmus	Red	Purple	Blue
Methyl orange	Pink	Orange	Yellow
Phenolphthalein	Colourless	Colourless	Pink
Universal Indicator	Red/orange/yellow	Green	Blue/purple

The pH scale usually runs from 1 to 14, although it is possible to have pH values outside these limits. pH is a measure of the hydrogen ion concentration: low pH means a high concentration of hydrogen ions; high pH means a low concentration of hydrogen ions. Any solution with a pH below 7.00 will be acidic, a solution with a pH above 7.00 will be alkaline, and a solution with a pH exactly 7.00 (such as pure water) will be neutral.

We call an acid whose solutions have a low pH a strong acid. Strong acids are 100% dissociated in dilute solution: all the acid molecules are broken up to make hydrogen ions. A good example of a strong acid is nitric acid, which dissociates completely into hydrogen ions and nitrate ions:

$$HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$$

Weak acids will have a much higher pH, usually somewhere between 3 and 6. This is because although a few acid molecules dissociate into ions, most of the acid molecules do not dissociate, so the concentration of hydrogen ions is quite low. Weak acids are only slightly dissociated in dilute solution. For example, ethanoic acid dissociates into hydrogen ions and ethanoate ions, making the equilibrium:

Solutions of nitric acid and other strong acids typically have low pH values, below 3.0 and approaching 0.

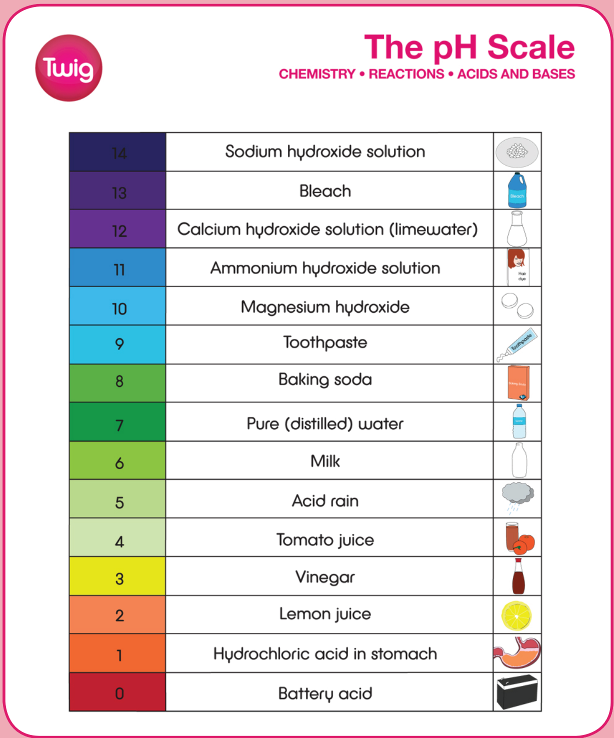
$$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$$

Highly concentrated, strong acids such as concentrated sulphuric acid are very dangerous. Concentrated sulphuric acid is a viscous, dense liquid which is highly corrosive if spilt on the skin. It should always be handled with great care, wearing appropriate safety clothing and eye protection.

However, not all acids are as dangerous as concentrated sulphuric acid. The nature of the hazard depends on three main factors:

- how the acid interacts with human tissue
- whether the acid is strong or weak – this depends on the chemical nature of the acid: we cannot change the nature of the acid
- how concentrated or dilute the acid is – we can decide how much acid to dissolve in a given volume of water.

DIAGRAM 02:



The pH Scale

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14	Sodium hydroxide solution
13	Bleach
12	Calcium hydroxide solution (limewater)
11	Ammonium hydroxide solution
10	Magnesium hydroxide
9	Toothpaste
8	Baking soda
7	Pure (distilled) water
6	Milk
5	Acid rain
4	Tomato juice
3	Vinegar
2	Lemon juice
1	Hydrochloric acid in stomach
0	Battery acid

Weak acids are therefore not necessarily safer to use than strong acids, as their chemical nature and their concentration can also affect how corrosive they are. Hydrofluoric acid HF is a weak acid but is highly corrosive, because it attacks human flesh and can cause serious injuries despite being technically 'weak'.

Our own bodies contain hydrochloric acid in the stomach, which has a pH between 1 and 2. We also add lemon juice and vinegar to our food, and drink fruit juices, all of which are acidic. The difference lies in their pH: the pH of the foods and drinks we consume are relatively high, so we are able to put them in our bodies safely. If we eat too much acidic food, however, we may suffer from painful acid indigestion, as the stomach is irritated by contents that have too low a pH.

Worksheet Question

- Question 2

• Suggested Films

- Acids and Alkalis: Part 1
- Acids and Alkalis: Part 2
- FactPack: pH Scale

Extension Questions

Q1. What is the difference between a 'strong' acid and a 'concentrated' acid?

Strong acids are 100% dissociated into hydrogen ions, for example, hydrochloric acid. Concentrated acids have a large mass of the acid dissolved in a small volume of water, for example, concentrated hydrochloric acid, concentrated sulphuric acid.

Q2. Are weak acids safe to handle without gloves?

Not necessarily. It will depend on the nature of the acid and how concentrated the acid is. Hydrofluoric acid HF is highly corrosive despite being a weak acid. Concentrated methanoic (formic) acid is a weak acid but is highly corrosive, and when it is used to remove limescale in showers, gloves and eye protection must be used

Section 2: Bases

• What is a base?

A base is a substance that neutralises an acid. There are three main types of base: metal oxides, metal hydroxides and metal carbonates. When they react with an acid, they all make a metal salt:

metal oxide + acid → metal salt + water
metal hydroxide + acid → metal salt + water
metal carbonate + acid → metal salt + water + carbon dioxide

See Section 3 for examples of these reactions.

• Suggested Films

- Acids and Alkalis: Part 1
- Acids and Alkalis: Part 2

• Worksheet Question

- Question 3

• What is an alkali?

There are no simple chemical tests which can be used for all bases, as some bases are insoluble in water (iron(III) oxide, copper(II) oxide) and other bases are soluble in water. Soluble bases are called alkalis. The hydroxides of the Group 1 elements (the alkali metals) are all strong alkalis; the hydroxides of Group 2 (alkaline-earth metals) are also alkalis, but are somewhat weaker. Alkalis have the following properties:

- turn red litmus blue
- turn Universal Indicator blue or purple
- have a pH greater than 7
- taste bitter
- feel 'soapy' when on the skin

Strong alkalis are 100% dissociated in dilute solution, making positive ions and hydroxide ions, for example:

sodium hydroxide sodium ions + hydroxide ions

$$NaOH(aq) \rightarrow Na^{+}(aq) + OH^{-}(aq)$$

Strong alkalis have very high pH values, approaching pH 14. Strong, concentrated alkalis are highly corrosive when in contact with the skin, and must be handled at least as carefully as strong, concentrated acids, hence the terms 'caustic soda' and 'caustic potash' – 'caustic' means 'burning'.

DIAGRAM 03:

Common Alkalis and Their Properties

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Name	Formula	Typical pH of the solution	Strong or weak?	Comments	
Sodium hydroxide	$NaOH$	14.0	Strong	Known as lye or caustic soda. Used in making soaps and detergents, cleaning drains, making paper	
Potassium hydroxide	KOH	14.0	Strong	Known as caustic potash. Used in making soaps and biodiesel	
Calcium hydroxide	$Ca(OH)_2$	12.3	Strong	As a solid, also known as 'slaked lime'. As a solution, known as 'limewater'	
Ammonium hydroxide	NH_4OH	11.0	Weak	Also called ammonia solution. Used as cleaning agent	

• Suggested Films

- Acids and Alkalis: Part 1

- Acids and Alkalis: Part 2

• Why are alkalis used for cleaning?

Alkalis are used for cleaning because they can break down the molecules in fats and oils. This creates an emulsion, which allows the oil to be washed away. Fats and oils are triesters of glycerol, known as triglycerides. Alkalis react with triglycerides to make a sodium or potassium salt and glycerol:

sodium hydroxide + (vegetable oil) triglyceride → sodium salt + glycerol

Alkalis are used in cleaning products

• Suggested Films

- Acids and Alkalis: Part 1

- Acids and Alkalis: Part 2

- Why Do Leaves Change Colour?

The sodium salt is soluble in water and also acts as an emulsifier, thus cleaning the fat or oil. Soaps are salts of sodium or potassium made by this reaction with vegetable oils.

Section 3: Neutralisation and Salts

• What is a salt?

A salt is a compound made when a base neutralises an acid. The type of salt made will depend on the acid:

Acid	Type of salt it makes
hydrochloric	chloride
sulphuric	sulphate
nitric	nitrate
methanoic	methanoate
ethanoic	ethanoate
carbonic	carbonate

metal oxide + acid → metal salt + water copper oxide + sulphuric acid → copper sulphate + water

$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$

The first part of the name of the salt comes from the base; the second part from the acid.

metal hydroxide + acid → metal salt + water

sodium hydroxide + hydrochloric acid → sodium chloride + water

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

metal carbonate + acid → metal salt + water + carbon dioxide

copper carbonate + sulphuric acid → copper sulphate + water + carbon dioxide

$CuCO_3(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l) + CO_2(g)$

Salts are always 100% dissociated into ions in dilute solution, for example sodium chloride solution consists entirely of sodium ions and chloride ions. There are no 'sodium chloride molecules':

$NaCl(aq) \rightarrow Na^+ (aq) + Cl^-(aq)$

• Suggested Films

- Acids and Alkalis: Part 1
- Acids and Alkalis: Part 2
- First Synthetic Pigment

• Worksheet Question

- Question 4

• What is neutralisation?

Neutralisation is a chemical reaction in which a base reacts with an acid. For example, when sodium hydroxide neutralises hydrochloric acid:

(I) sodium hydroxide + hydrochloric acid → sodium chloride + water

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Since sodium hydroxide is a strong alkali it is 100% dissociated:

$$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$$

Hydrochloric acid is 100% dissociated:

$$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

Sodium chloride is also 100% dissociated:

$$NaCl(aq) \rightarrow Na^+(aq) + Cl^-(aq)$$

If we substitute all these ions into equation (I) we get

$$\text{(II) } Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)$$

The sodium ions and chloride ions 'cancel out' on both sides of the equation, because they are not actually involved in the reaction: we say they are 'spectator ions'. This gives the overall equation for neutralisation:

$$\text{(III) } OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$$

Equation (III) shows that the neutralisation reaction involves a hydrogen ion reacting with a hydroxide ion to make a water molecule. Neutralisation reactions are always exothermic, because a new O-H covalent bond is being made when the water molecule is formed from the hydroxide ion and the hydrogen ion. Pure water can also break up into hydrogen ions and hydroxide ions to a very small extent:

$$\text{(IV) } H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$$

Soft drinks contain carbonic acid

• Suggested Films

- Acids and Alkalis: Part 1
- Acids and Alkalis: Part 2

This is called the self-ionisation of water. Equation (IV) tells us that in water the number of hydrogen ions and hydroxide ions must be equal, which is why pure water is neutral with pH 7.00.

• When is neutralisation a useful reaction?

Neutralisation has many practical applications. If we have acid indigestion because the concentration of the acid in our stomach is too high, we can take an antacid, which is a base, to neutralise the acid. Commonly used antacids are: calcium carbonate, sodium hydrogencarbonate (bicarbonate of soda), magnesium hydroxide, aluminium hydroxide and magnesium carbonate.

The pH of soil is of crucial importance in order for crops to grow well. If land is farmed intensively, the soil tends to become more acidic (its pH drops) and crop yields tend to fall. As plants can't take in nutrients, such as nitrogen and phosphorus compounds, if the pH is too low, farmers add alkaline calcium hydroxide (slaked lime) to the soil to neutralise the soil acidity. This makes the soil pH rise to a level at which the crops can absorb these vital nutrients.

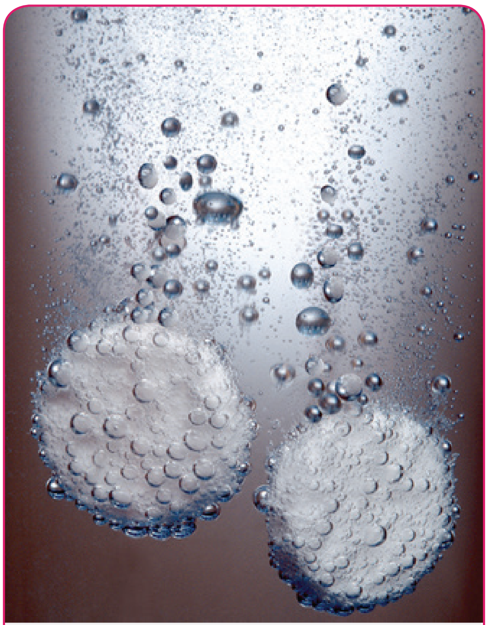
Acids are also made by the action of bacteria in the mouth, breaking down sugary foods into acids which dissolve tooth enamel and cause tooth decay. Toothpaste is alkaline and so neutralises the acid and slows down the attack on the enamel.

• Suggested Activity

Ask students to research 4 or 5 commercial antacids and find out what chemicals they contain. Identify the bases in each antacid

• Suggested Films

- **Acids and Alkalis: Part 1**
- **Acids and Alkalis: Part 2**



Antacids can be used to neutralise stomach acid

Extension Question

Q3. What problem may be caused by the use of calcium carbonate as an antacid?

The carbon dioxide gas generated during the reaction may cause discomfort in the stomach.

• Worksheet

Q1. Sort the following substances into acids and alkalis:
toothpaste, baking powder, vinegar, milk, human blood, saliva, tomato juice, lemonade, soap, detergent, pure water, bleach

Acids: ____________________

Alkalis: ____________________

Q2. Put the following substances in order of decreasing acidity, starting with the MOST acidic:
human blood 7.4, vinegar 3.0, milk 6.6, tomato juice 4.5, pure water 7.0, bleach 12.0, wine 4.0, toothpaste 9.0, oven cleaner 13.0, lemon juice 2.0, window cleaner 10.0

Most Acidic												Most Alkaline

Q3. Which of these substances are NOT bases? Why?
NaCl, KOH, CCl_4, $Mg(OH)_2$, BaO, Na_2CO_3, CuO, HCl, $CuCO_3$

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Q4. Complete and (if necessary) balance these word and symbol equations to show the neutralisation reactions:

(a) magnesium oxide + sulphuric acid →
$MgO(s) + H_2SO_4(aq) \rightarrow$
____

(b) calcium hydroxide + hydrochloric acid →
$Ca(OH)_2(aq) + HCl(aq) \rightarrow$
____

(c) sodium carbonate + nitric acid
$Na_2CO_3(s) + HNO_3(aq) \rightarrow$
____

• Worksheet Answers

Q1. Sort the following substances into acids and alkalis:
toothpaste, baking powder, vinegar, milk, human blood, saliva, tomato juice, lemonade, soap, detergent, pure water, bleach

Acids: vinegar, milk, tomato juice, lemonade

Alkalis: toothpaste, baking powder, human blood, bleach, soap, detergent

Q2. Put the following substances in order of decreasing acidity, starting with the MOST acidic:
human blood 7.4, vinegar 3.0, milk 6.6, tomato juice 4.5, pure water 7.0, bleach 12.0, wine 4.0, toothpaste 9.0, oven cleaner 13.0, lemon juice 2.0, window cleaner 10.0

Most Acidic	Lemon juice 2.0	Vinegar 3.0	Wine 4.0	Tomato juice 4.5	Milk 6.6	Pure water 7.0	Human blood 7.4	Tooth-paste 9.0	Window cleaner 10.0	Bleach 12.0	Oven cleaner 13.0	Most Alkaline

Q3. Which of these substances are NOT bases? Why?
NaCl, KOH, CCl4, Mg(OH)2, BaO, Na2CO3, CuO, HCl, CuCO3

NaCl, CCl_4 - are NOT bases because they are not metal oxides, hydroxides or carbonates

KOH, $Mg(OH)_2$ - are metal hydroxides

BaO and CuO are metal oxides

Na_2CO_3, and $CuCO_3$ are metal carbonates

HCl is an acid

Q4. Complete and (if necessary) balance these word and symbol equations to show the neutralisation reactions:

(a) magnesium oxide + sulphuric acid → magnesium sulphate + water
$MgO(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l)$

(b) calcium hydroxide + hydrochloric acid → calcium chloride + water
$Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H2O(l)$

(c) sodium carbonate + nitric acid → sodium nitrate + water + carbon dioxide
$Na_2CO_3(s) + 2HNO_3(aq) \rightarrow 2NaNO_3(aq) + H_2O(l) + CO_2(g)$

• Quizzes

Acids and Alkalis: Part 1

Basic

• Which of these substances is NOT acidic?

A – lemon juice
B – vinegar
C – distilled water
D – fizzy drinks

• Which of these pH values does NOT indicate an acid?

A – 7.1
B – 6.9
C – 4.0
D – 3.4

• Tea is acidic, but it is safe to consume because the acid is...

A – weak
B – soluble in water
C – corrosive
D – an irritant

• Which of these pH values indicates a strong alkali?

A – 1.0
B – 5.9
C – 8.2
D – 13.9

Advanced

• Which of these substances is NOT a base?

A – copper oxide
B – sodium hydroxide
C – calcium carbonate
D – magnesium chloride

• If a solution of sugar is tested with Universal Indicator, what colour will the indicator be?

A – green
B – red
C – yellow
D – blue

• If you are handling a corrosive acid, you should wear all the following EXCEPT for...

A – gloves
B – lab coat
C – goggles
D – trainers

• Hydrochloric acid can be neutralised by all the following EXCEPT for...

A – sodium oxide
B – sodium carbonate
C – sodium chloride
D – sodium hydroxide

Acids and Alkalis: Part 2

Basic

• The reaction between an acid and a base is called...

A – oxidation

B – reduction

C – combustion

D – neutralisation

• Indigestion tablets are made of...

A – an alkali

B – an acid

C – a salt

D – sugar

• When a base reacts with an acid it makes...

A – a salt

B – a salt and water

C – an alkali

D – an acid

• Carbon dioxide can be absorbed by soda lime in a 'rebreather' because carbon dioxide is...

A – a greenhouse gas

B – corrosive

C – acidic

D – alkaline

Advanced

• Exhaled air contains a lot of...

A – argon

B – carbon dioxide

C – nitrogen

D – oxygen

• If a solution has pH7 it will turn Universal Indicator...

A – red

B – purple

C – blue

D – green

• A neutralisation reaction could be used to make all the following compounds EXCEPT...

A – sodium chloride

B – sodium sulphate

C – sodium nitrate

D – sodium oxide

• Sodium hydroxide is NOT suitable for use in treating stomach indigestion because sodium hydroxide is...

A – corrosive

B – acidic

C – toxic

D – insoluble in water

• Answers

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Basic

• Which of these substances is NOT acidic?

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