Chapter 19 Acids and Bases

19.1 Introducing Acids and Alkalis

Acids and bases are common stuff in everyday life.

Domestic Acids and Alkalis

Common domestic acids

Many foods and drinks contain acids. For example

(1) Ascorbic acid (Vitamin C) and citric acid are found in lemon and oranges
(2) Tomato sauce contains ethanoic acid
(3) Soft drinks such as seven-up and coca cola contain carbonic acid and citric acid

Common domestic alkalis

(1) Drain cleaners and oven cleaners contain sodium hydroxide (removing grease and oil).
(2) Indigestion tablets contain a mild base (magnesium hydroxide) to neutralize excess acid in the stomach.

Testing Acidity and Alkalinity with Litmus

An acid dissolves in water to give an acidic solution, which turns blue litmus paper red.
An alkali dissolves in water to give an alkaline solution, which turns red litmus paper blue.

19.2 Acids in General

(1) Mineral acids
Derived from minerals, these include sulphuric acid (H_2SO_4), nitric acid (HNO_3) and hydrochloric acid (HCl).
(2) Organic acids
Composed of carbon, hydrogen and oxygen.
Citric acid $HOOC\text{-}CH_2\text{-}C(OH)COOH\text{-}CH_2\text{-}COOH$, ethanoic acid ($CH_3COOH$) and oxalic acid ($H_2C_2O_4$) are common examples.

Acids are usually found in the laboratory as dilute aqueous solutions. However there are concentrated acids.

Properties of Dilute Acids

(1) Taste
Most dilute acids taste sour.
(2) Effect on litmus paper
Aqueous acids turn blue litmus paper red.
(3) Electrical conductivity
Aqueous acids are electrolytes and conduct electricity.
(4) Reaction with metals
Acids react with metals higher than copper in the MRS to give hydrogen and salt.
Acid + Metal $\rightarrow$ Salt + Hydrogen
$2HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$
(5) Action on metal oxides and hydroxides
(a) Acid + Metal Oxide $\rightarrow$ Salt + Water
$2HCl(aq) + CuO(s) \rightarrow CuCl_2(aq) + H_2O(l)$
(b) Acid + Metal Hydroxide $\rightarrow$ Salt + Water
$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

(6) Action on carbonates and hydrocarbonates

(a) Acid + Carbonate → Salt + Carbon Dioxide + Water

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

(b) Acid + Hydrogencarbonate → Salt + Carbon Dioxide + Water

$HCl(aq) + NaHCO_3(s) \rightarrow NaCl(aq) + CO_2(g) + H_2O(l)$

Reagent to test for carbon dioxide

Lime water is $Ca(OH)_2(aq)$. It reacts with carbon dioxide to give $CaCO_3(s)$, which gives a milky appearance.

$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$

However, when excess CO_2 is bubbled into the milky solution, it turns to clear again due to the formation of soluble $Ca(HCO_3)_2(aq)$

$CaCO_3(s) + H_2O(l) + CO_2(g) \rightarrow Ca(HCO_3)_2(aq)$

Defining Acids

Aqueous solutions of acids must contain hydrated hydrogen ion, $H^+(aq)$

$H^+(aq)$ is the functional unit of acids.

An acid is a hydrogen containing covalent molecular compound, which when dissolved in water, forms hydrogen ions $H^+(aq)$ as the only positive ion.

Basicity of an acid

The Basicity of an acid is the number of ionizable hydrogen atoms in one molecule of the acid.

Acid	Ionization in water	Basicity of acid
Hydrochloric acid Nitric acid Nitrous acid Ethanoic acid	$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$ $HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$ $HNO_2(aq) \rightleftharpoons H^+(aq) + NO_2^-(aq)$ $CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$	1 (monobasic)
Sulphuric acid Sulphurous acid Carbonic acid Oxalic acid	$H_2SO_4(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$ $H_2CO_3(aq) \rightleftharpoons 2H^+(aq) + SO_3^{2-}(aq)$ $H_2CO_3(aq) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$ $H_2C_2O_4(aq) \rightleftharpoons 2H^+(aq) + C_2O_4^{2-}(aq)$	2 (dibasic)
Phosphoric acid	$H_3PO_4(aq) \rightleftharpoons 3H^+(aq) + PO_4^{3-}(aq)$	3 (tribasic)

Question 19.1

Write a full equation and an ionic equation for the reaction between aqueous sodium carbonate and

(a) dilute hydrochloric acid

(b) dilute nitric acid

(c) dilute sulphuric acid

Question 19.2

Rewrite each of the following as an ionic equation:

(a) $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

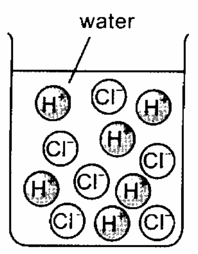
(b) $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
(Hint: $CaCO_3(s)$ is insoluble in water.)

19.4 The Role of Water for Acids

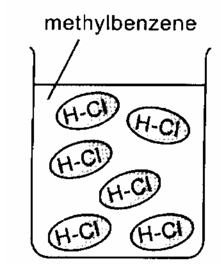
Solid citric acid crystals do not turn blue litmus paper red, conduct no electricity and have no reaction with magnesium nor solid sodium carbonate.
However, when citric acid crystals are dissolved in water to form an aqueous solution, the aqueous citric acid solution starts to exhibit all the typical acid properties.

Hydrogen chloride in water and methylbenzene
In water, hydrogen chloride dissolves to form $H^+(aq)$ and $Cl^-(aq)$. The $H^+(aq)$ ions account for the acidic behaviour.
In methylbenzene, there is absence of water and hydrogen chloride simply dissolves in methylbenzene and exist as molecules. There are no $H^+(aq)$ ions nor $Cl^-(aq)$ ions. Hence hydrogen chloride in methylbenzene does not behave as an acid.

Sketch two diagrams, one when hydrogen chloride molecules dissolve in water, and the other when hydrogen chloride molecules dissolve in methylbenzene.



HCl(g) in water



HCl(g) in methylbenzene

The following table compares the properties of HCl in water and in methylbenzene

Test	Hydrogen chloride in water (*hydrochloric acid)	Hydrogen chloride in dry methylbenzene
Effect on *dry* blue litmus paper	turns to red colour	no colour change
Electrical conductivity	good	none
Action on magnesium	bubbles of hydrogen evolved: $Mg(s) + 2H^+(aq) \longrightarrow Mg^{2+}(aq) + H_2(g)$	no gas evolved (no apparent reaction)
Action on *solid* sodium carbonate	*bubbles of carbon dioxide evolved:* $Na_2CO_3(s) + 2H^+(aq) \longrightarrow 2Na^+(aq) + CO_2(g) + H_2O(\ell)$	*no gas evolved* (no apparent reaction)

It is important to note that without water, solid acids and gaseous acid molecules cannot ionize to form $H^+(aq)$ and hence do not behave as typical acids.

Sulphuric acid and nitric acid in water

Pure sulphuric acid and nitric acid are colourless liquids. They both consist of covalent molecules. They do not show acidic properties without water.
However when they dissolve in water, hydrogen ions are formed.

$H_2SO_4(l) + water \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$
$HNO_3(l) + water \rightarrow H^+(aq) + NO_3^-(aq)$

Why Fizzy Drink tablets effervesce in water

Fizzy drink tablets contain a solid acid (usually citric acid) and solid sodium hydrogencarbonate. Without water, there is no reaction between the solids.
However, when water is present, the citric acid ionizes to form $H^+(aq)$ and the following reaction occurs, forming carbon dioxide:
$H^+(aq) + HCO_3^-(aq) \rightarrow CO_2(g) + H_2O(l)$

Question 19.3

What is the change in colour (if any) when a piece of dry blue litmus paper is put into
(a) liquid ethanoic acid (pure) [Hint: no water is present]

(b) aqueous ethanoic acid [$CH_3CO_2H(aq)$]

19.5 Concentrated Acids

Corrosive Nature of Concentrated Acids

Concentrated acids contain a lot of acid in a very small quantity of water. They are highly corrosive and would "eat away" metals, clothes, paper and human skin.

Oxidizing properties of concentrated nitric acid

Nitric acid behaves differently when the concentration differs.
(1) Concentrated nitric acid
$2H^+(aq) + NO_3^-(aq) + e^- \rightarrow NO_2(g) + H_2O(l)$
(2) Dilute or moderately concentrated nitric acid
$4H^+(aq) + NO_3^-(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$
(3) Nitric acid, in a **very dilute form**, reacts with metals to form hydrogen. (Concentrated and dilute nitric acid does not liberate hydrogen when react with metals, though)
$2H^+(aq) + 2e^- \rightarrow H_2(g)$

Question 19.4

For the reaction between silver and concentrated nitric acid, write
(a) a full equation

(b) an ionic equation

<u>Reactions of Concentrated Nitric acid with metals</u>
(a) Magnesium with concentrated nitric acid

(b) Magnesium with moderately concentrated nitric acid

Reactions of Concentrated Nitric acid with non-metals and compounds

(a) With sulphur

(b) With iron(II) chlorides and sulphates

(c) With sulphites [sulphate(IV)]

Concentrated Sulphuric acid

Chemical properties of sulphuric acid

(1) Affinity for water

Dilution of concentrated sulphuric acid

When concentrated sulphuric acid has to be diluted, a small amount of the conc. acid must be poured into a large amount of water in a beaker, with constant stirring.

Water should never be poured into concentrated sulphuric acid, otherwise serious spillage would occur.

Hygroscopic properties

A hygroscopic substance is a compound which absorbs water vapour from air.

Concentrated sulphuric acid absorbs water vapour if left to stand in air, diluting itself.

Dehydrating properties

Concentrated sulphuric acid can remove water of crystallization (w.o.c.) from hydrated salts, for example:

(a) Reaction with copper(II) sulphate-5-water

$$CuSO_4.5H_2O(s) \xrightarrow{\text{conc. } H_2SO_4} CuSO_4(s) + 5H_2O(l)$$

blue white

(b) Reaction with sugars

$$C_{12}H_{22}O_{11}(s) \xrightarrow{\text{conc. } H_2SO_4} 12C(s) + 11H_2O(l)$$

crystal clear black

(a) and (b) show that concentrated sulphuric acid is a strong dehydrating (remove water) agent.

Question 19.5

Write an equation for the reaction between glucose (a sugar with molecular formula $C_6H_{12}O_6$) and concentrated sulphuric acid.

(2) Oxidizing properties

Conc. sulphuric acid is a strong oxidizing agent, especially when hot.

The following ionic half equation is used to describe the oxidizing property of conc. H_2SO_4:

$2H_2SO_4(l) + 2e^- \rightarrow SO_4^{2-}(aq) + SO_2(g) + 2H_2O(l)$

(a) Hot concentrated sulphuric acid reacting with metals:
(i) With copper

(ii) With zinc

(b) Hot concentrated sulphuric acid reacting with non-metals
(i) carbon

(ii) sulphur

Question 19.6
When concentrated sulphuric acid is added to solid sodium chloride, the following reaction takes place:
$NaCl(s) + H_2SO_4(l) \rightarrow NaHSO_4(s) + HCl(g)$
Does concentrated sulphuric acid act as an oxidizing agent in this reaction? Explain.

Question 19.7
Write an equation for each of the following (if applicable):
(a) Heat dilute sulphuric acid with copper.

(c) Heat concentrated sodium sulphate solution with carbon.

19.6 A brief comparison of Three Mineral Acids

Molarities

	Hydrochloric acid	Nitric acid	Sulphuric acid
Dilute	2 M	2 M	1 M
Concentrated	11 M	16 M	18 M

Oxidizing properties
1. Dilute and concentrated hydrochloric acid behave as typical acids.
2. Concentrated sulphuric acid, concentrated nitric acid and moderately concentrated nitric acid possess strong oxidizing properties.
3. Dilute sulphuric acid and very dilute nitric acid are both typical acids, liberating hydrogen when react with metals.

Reducing properties

Acid	Action on	
	magnesium	copper
Bench dilute HCl Concentrated HCl	H_2 evolved H_2 evolved	no reaction no reaction
Very dilute nitric acid (0.1M) Bench dilute HNO_3 Concentrated HNO_3	H_2 evolved NO evolved NO_2 evolved	no reaction NO evolved NO_2 evolved
Bench dilute H_2SO_4 Hot concentrated H_2SO_4	H_2 evolved SO_2 evolved	no reaction SO_2 evolved

Question 19.8

Which acid is used to acidify potassium permanganate solution? Why?

19.7 Bases and Alkalis

Bases

A base is a compound which reacts with an acid to form a salt and water only.

acid + base → salt + water

Alkalis

Bases that are soluble in water are called alkalis.

e.g. CuO(s) is not soluble in water, CuO(s) is a base only

NaOH is soluble in water, NaOH(aq) is an alkali.

Properties of Aqueous Alkalis

(1) Taste

Aqueous alkalis taste bitter.

(2) Feel

Dilute solutions of alkalis have a soapy and slippery feel to the skin.

(3) Effect on litmus

Alkalis turn red litmus paper to blue.

(4) Electrical conductivity

Alkalis, like acids, are electrolytes. The OH^-(aq) ions account for the electrical conductivity.

(5) Reaction with acids

Alkalis neutralize acids to form salt and water only.

acid + base → salt + water

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

(6) Action on non-metal oxides

(a) Sodium hydroxide reacting with carbon dioxide

(b) Lime water ($CaCO_3$) reacting with carbon dioxide (This is also a test for CO_2)

(7) Action on ammonium compounds

When the presence of an ammonium compound is suspected, the suspected compound can be heated with a dilute alkali (e.g. NaOH). The liberated gas, if shown to be ammonia, proves the suspected compound to contain the ammonium (NH_4^+) ion.

$NH_4^+(aq) + OH^-(aq) \rightarrow NH_3(g) + H_2O(l)$

(8) Reaction with metal ions in aqueous solution

For details, refer to p.117 Book 1B Table 19.5

Corrosive Nature of concentrated alkalis

Concentrated sodium hydroxide (NaOH) and potassium hydroxide (KOH) solutions are severely corrosive. They attack the skin readily and stain it yellow or even black. If any of the alkalis is split on the skin, wash the affected area immediately with plenty of water, then with very dilute ethanoic acid solution.

19.8 Acidity and Alkalinity

The pH scale is a convenient method to indicate the acidity or alkalinity of a solution.
(1) An acidic solution has a pH value less than 7.
(2) A neutral solution has a pH value of exactly 7.
(3) An alkaline solution has a pH value of greater than 7.

Question 19.10

(a) Given the pH values of four solutions at room temperature:
A: 5.5 B: 1.7 C: 8.0 D: 7.0
Describe each of the above solutions, using terms such as "strongly acidic", "weakly alkaline" and so on.

(b) State whether the pH value increases or decreases in each of the following cases:
(i) Dilute 2 M sulphuric acid to 0.2 M

(ii) Add excess potassium carbonate to concentrated nitric acid.

Common Acid-Base Indicators

An acid-base indicator is a special dye (usually either a weak acid or a weak base) added to the solution to test for its pH.
It changes colour with different H^+(aq) ion concentrations.

Measuring pH of a solution

(1) By pH paper (litmus paper)
(2) By liquid indicators, e.g. Universal indicator, phenolphthalein, methyl orange, etc.
(3) By pH meter, and instrument usually reporting pH by digital outputs.

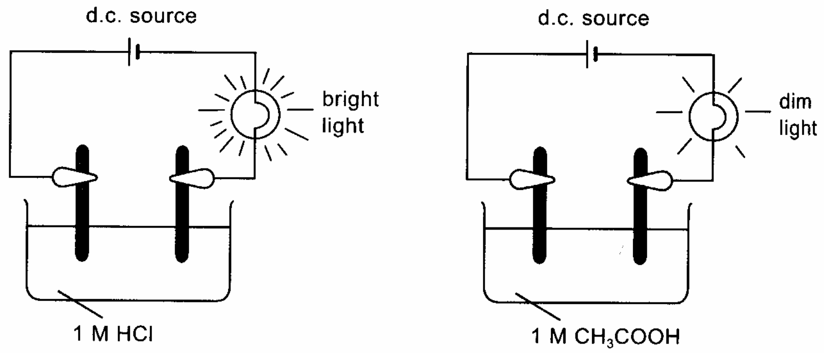
Effect of Solutions with different pH values on hair

Each hair strand is made up of a large number of fibres. The strand maintains a rigid texture because the fibres within are cross-linked with each other.
Highly acidic and highly alkaline solutions can damage hair, and experiments have shown that highly alkaline solutions are more damaging. As hair is weakly acidic by its nature, the cross links between fibres are easily broken down by alkaline solutions.

Experimental results showed that hair soaked in alkaline solutions looks duller, feels coarser (rough texture) and breaks more easily. However, alkaline solutions can effectively curl hair and the curled hair could be kept for a longer period of time.

19.9 Strengths of Acids and Alkalis

Strong and weak electrolyte
The electrical conductivity of hydrochloric acid and ethanoic acid, of the same concentration, is compared by the following set-up.



The electrical conductivity of 1 M HCl is much higher than that of 1 M CH_3COOH, this result could be explained by the different degree of ionization of HCl and CH_3COOH

(a) Strong electrolyte (HCl)

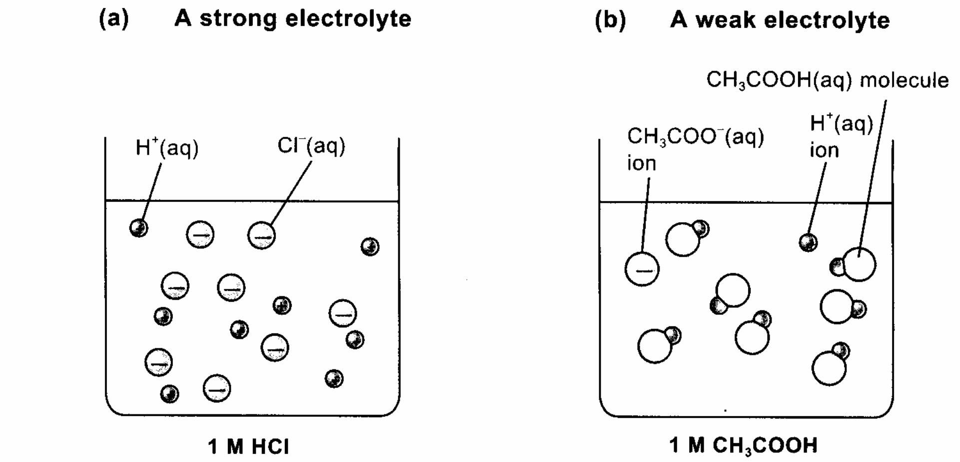
HCl completely ionizes in water according to the following equation:

$$\underset{\text{molecules}}{HCl(g) + \text{water}} \xrightarrow{\text{100\% ionization}} \underset{\text{ions}}{H^+(aq) + Cl^-(aq)}$$

(b) Weak Electrolyte (CH_3COOH)

CH_3COOH ionizes only weakly in water

$$CH_3COOH(aq) \underset{}{\overset{\text{slight ionization}}{\rightleftharpoons}} CH_3COO^-(aq) + H^+(aq)$$



Hydrochloric acid is *completely* ionized in water.

Ethanoic acid is only *slightly* ionized in water; the solution contains mainly *un*ionized $CH_3COOH(aq)$ molecules and a very small proportion of $H^+(aq)$ and $CH_3COO^-(aq)$ ions.

A strong electrolyte is one which fully ionizes in an aqueous solution.
A weak electrolyte is one which slightly ionizes in an aqueous solution.

Strong and Weak Acids

A strong acid is one which fully ionizes in water to give hydrogen ions.
A weak acid is one which slightly ionizes in water to give little hydrogen ions.

Strong Acids	Weak acids
Hydrochloric acid, HCl Sulphuric acid, H_2SO_4 Nitric Acid, HNO_3	Ethanoic acid, CH_3COOH Carbonic acid, H_2CO_3 Ethanedioic acid, $H_2C_2O_4$

Question 19.11

Name all the particles present in each of the following. Underline the name(s) of the most plentiful particles (apart from water molecules).

(a) Pure sulphuric acid

(b) 2 M nitric acid

(c) 2 M citric acid

(d) 1 M aqueous ammonia solution

Strong and weak alkalis

A strong alkali is one which fully dissociates in water (to give hydroxide ions).
A weak alkali is one which slightly ionizes in water (to give little hydroxide ions).

(1) Group I hydroxide solutions, example NaOH and KOH, are strong alkalis.

$$NaOH(s) + water \xrightarrow{\text{complete dissociation}} Na^+(aq) + OH^-(aq)$$

non-mobile ions → mobile ions

(2) Group II hydroxides are less soluble in water and if they can dissolve well in water, they form strong alkalis, too.

(3) Ammonia, NH_3, an molecular compound, ionizes only slightly in water, to form few OH^- ions. Ammonia is a weak alkali.

$$NH_3(aq) + H_2O(l) \underset{}{\overset{\text{slight ionization}}{\rightleftharpoons}} NH_4^+(aq) + OH^-(aq)$$

molecules → mobile ions

Strength and concentration of acids and alkalis

Strength is concerned with the degree of dissociation (or ionization) of an acid or alkali in the solution. When an acid fully ionizes in water, it is a strong acid.
Concentration refers to the amount of solute per unit volume of solution. A concentrated acid has a huge amount of acid molecules in water. A concentrated acid (e.g. 20 M) can be a weak acid.

The concentration of an acid (or alkali) has nothing to do with its strength.

Question 19.12

Fills in the blanks:

(a) 10 M NH_3 is a ________________________ solution of a __________________ alkali.

(b) (b) 0.1 M NH_3 is a ____________________ solution of a __________________ alkali.

(c) 0.2 M NaOH is a _____________________ solution of a __________________ alkali.

(d) 5 M NaOH is a _______________________ solution of a __________________ alkali

Question 19.13

Write a full equation and an ionic equation for each of the following reactions.

(a) The reaction between dilute sulphuric acid and sodium carbonate solution.

(b) The reaction between ethanoic acid solution and potassium hydrogencarbonate solution.