ACID-BASE REACTIONS 11.1–11.3

Unit 2 Chemistry 2023

KEY KNOWLEDGE

- the Brønsted–Lowry theory of acids and bases, including polyprotic acids and amphiprotic species, and the writing of balanced ionic and full equations with states for their reactions in water
- the distinction between strong and weak acids and strong and weak bases, and between concentrated and dilute acids and bases, including common examples
- neutralisation reactions to produce salts:
  - reactions of acids with metal carbonates and hydroxides, including balanced full and ionic equations, with states
  - types of antacids and their use in the neutralisation of stomach acid
- use of the logarithmic pH scale to rank solutions from most acidic to most basic; calculation of pH for strong acid and strong base solutions of known concentration using the ionic product of water (K_w at a given temperature)
- accuracy and precision in measurement as illustrated by the comparison of natural indicators, commercial indicators, and pH meters to determine the relative strengths of acidic and basic solutions
- applications of acid–base reactions in society; for example, natural acidity of rain due to dissolved CO_2 and the distinction between the natural acidity of rain and acid rain, or the action of CO_2 in forming a weak acid in oceans and the consequences for shell growth in marine invertebrates.

11.1&2 OVERVIEW

All **Acids** have a sour taste, will turn litmus red and will neutralise bases.

Acids will donate proton/s (H^+) to a base

- All **bases** have a bitter taste, will turn litmus blue and will neutralise acids.

Bases will accept proton/s (H^+) from an acid

- **Alkalis** are bases that are soluble in water.
- Acids and bases react in **neutralisation** reactions to produce a **salt** and water.

COMMON ACIDS AND THEIR USES

Memorise names and formulas!

Name	Formula	Uses
Hydrochloric acid	HCl	Present in stomach acid. Used as a cleaning agent.
Sulphuric acid	H_2SO_4	Used in car batteries, to manufacture fertilisers and detergent
Nitric acid	HNO_3	Used in production of fertilisers, dyes and explosives
Ethanoic acid	CH_3COOH	Found in vinegar. Used as preservative.
Carbonic acid	H_2CO_3	Used in carbonated soft drinks and beer
Lactic acid	$C_3H_6O_3$	Occurs in milk products, produced in muscles during exercise
Ascorbic acid	$C_6H_8O_6$	Vitamin C – found in citrus fruits
Phosphoric acid	H_2PO_4	Used in some soft drinks and the manufacture of fertilisers
Citric acid	$C_6H_8O_7$	Found in citrus fruits

COMMON BASES AND THEIR USES

TABLE 11.2 Common bases and their uses

Base	Formula	Use
Ammonia	NH_3	Fertilisers and detergents
Sodium hydroxide (caustic soda)	$NaOH$	Soaps and detergents
Sodium carbonate	Na_2CO_3	Manufacture of glass; washing powder and detergents
Calcium oxide (quicklime)	CaO	Bricklayers' mortar
Lead(II) oxide	PbO	House paint (now phased out)
Calcium hydroxide (slaked lime)	$Ca(OH)_2$	Garden lime, plaster and cement
Ammonium hydroxide	NH_4OH	Cleaning agents
Magnesium hydroxide	$Mg(OH)_2$	Milk of magnesia (for treatment of indigestion)

SAFETY WITH ACIDS A
BASES

pH is a measure of the acidity of a solution. The lower the pH the more acidic the solution.

- Safety glasses
- Lab coats
- Label bottles and containers clearly

Acids	Bases
Tend to be corrosive	Are ‘caustic’ (corrosive toward organic matter)
Have a relatively low pH (1-7)	Have a relatively high pH (7-14)
Solutions conduct electricity	Conduct an electric current

When diluting acids, **add acid** to water, not the other way around

INDICATORS

Indicators can be used to view many acid base reactions that involve colourless solutions. Indicators are extracted from plant dyes. Solutions will change to different colours in the presence of an acid or base.

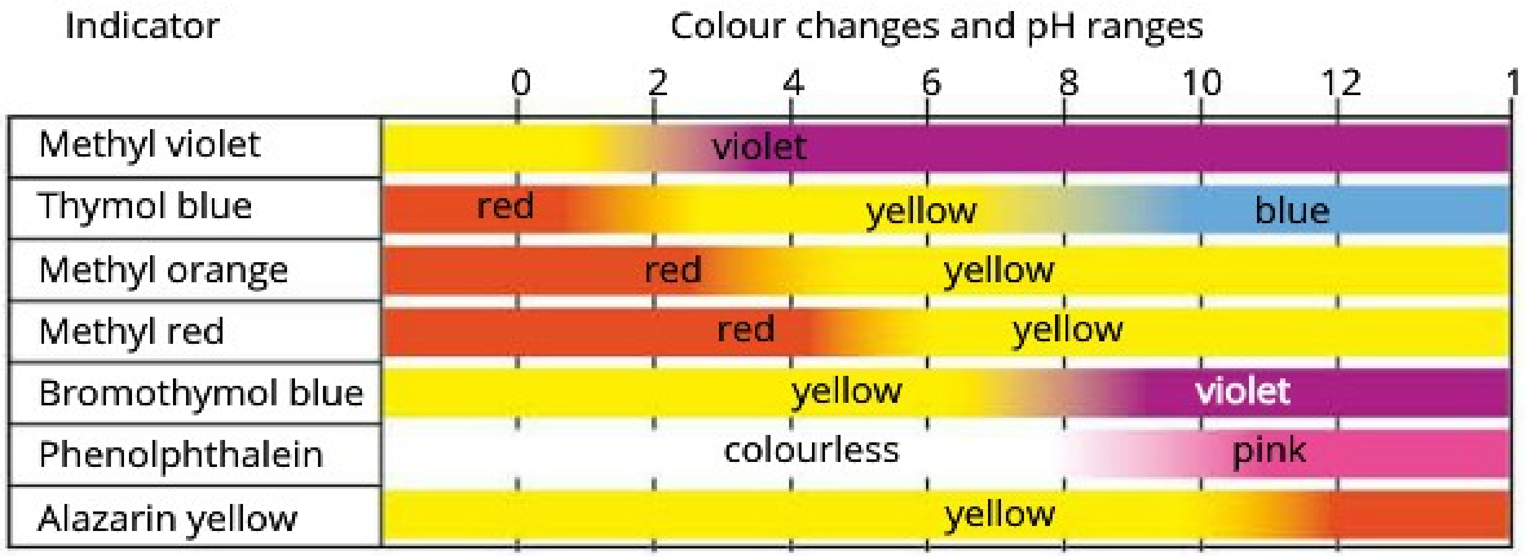


FIGURE 15.3.3 Common indicators and their pH ranges.

BRØNSTED–LOWRY THEORY OF ACIDS AND BASES

A substance behaves as an:

Acid – when it **donates** a proton/hydrogen ion (H^+) to a base

Base – when it **accepts** a proton/hydrogen ion from an acid

A hydrogen ion, H^+, is formed when an electron is removed from a hydrogen atom, H.

H+ is the same as a proton.

Hydronium ion H_3O^+, combination of a proton with a water molecule

Hydronium ion

- Can be represented as $H^+_{(aq)}$ or $H_3O^+_{(aq)}$

e.g. $HCl_{(g)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

is the same as $HCl_{(g)} \xrightarrow{H_2O} H^+_{(aq)} + Cl^-_{(aq)}$

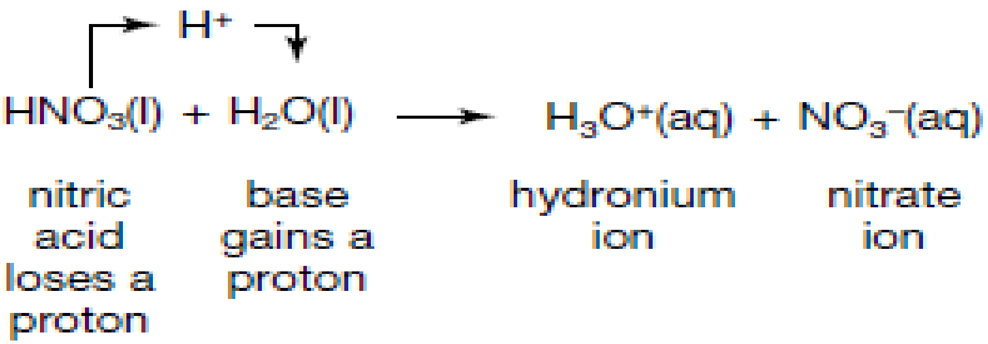
EXAMPLES OF ACID-BASE REACTIONS

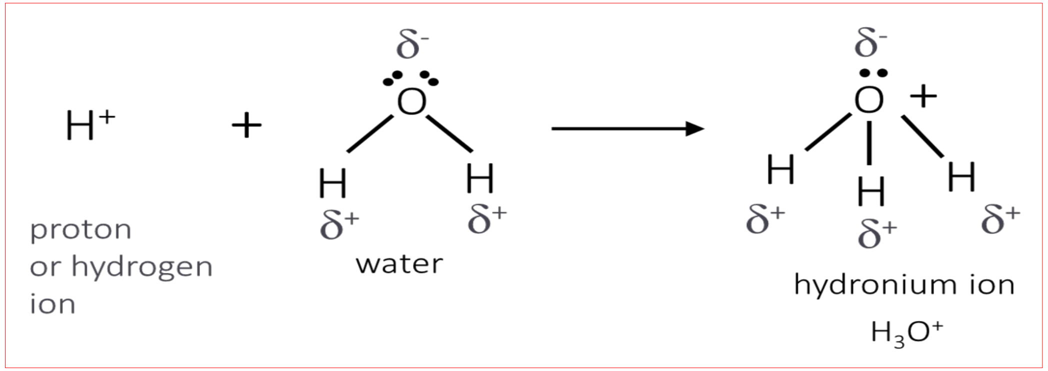
Acids are proton donors
Bases are proton acceptors

$$HCl_{(g)} + H_2O_{(l)} \rightarrow H_3O^+(aq) + Cl^-(aq)$$

acid

bas
e

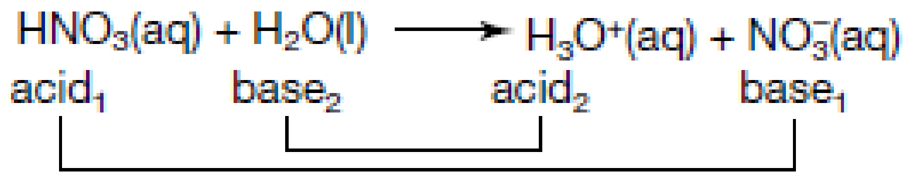


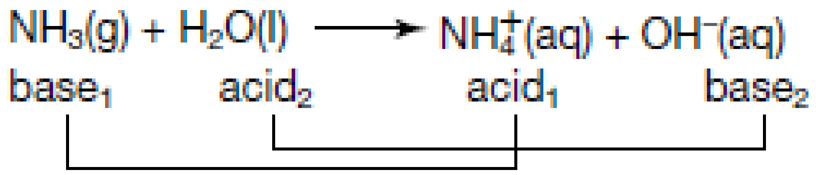


CONJUGATE ACID–BASE PAIRS

The **conjugate base** of an acid is the species formed after the proton is donated.

E.g. the conjugate base of the acid HNO_3 is NO_3^-.





Conjugate pairs are:

HNO_3/NO_3^- and H_3O^+/H_2O.

NH_4^+/NH_3 and H_2O/OH^-.

CONVENTION: CONJUGATE ACID/CONJUGATE BASE

$$\text{Acid} \underset{+H^+}{\overset{-H^+}{\rightleftharpoons}} \text{Base}$$

Conjugate Acid/Base Pairs Differ by a proton

conjugate acid **conjugate base**

$$H_3PO_4 \underset{-H^+}{\overset{+H^+}{\rightleftharpoons}} H_2PO_4^-$$

Identifying conjugate acid–base pairs

$$\text{Conjugate base} = \text{acid} - H^+$$

$$\text{Conjugate acid} = \text{base} + H^+$$

SAMPLE PROBLEM 1 Identifying conjugate pairs

Show that the following reaction is a proton transfer reaction and state the acid–base conjugate pairs: $HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$.

THINK	WRITE
1. Decide whether each of the reactants has donated or gained a proton.	HCl has become Cl^-; it has lost a proton (H^+). H_2O has become H_3O^+; it has gained a proton, (H^+).
2. The substance that has donated a proton is the acid.	HCl is an acid.
3. The substance that has gained a proton is the base.	H_2O is a base in this reaction.
4. Conjugate base = acid – H^+. Conjugate acid = base + H^+. TIP: Remember that the acid should be put first in each pair.	Conjugate base is Cl^-. Conjugate acid is H_3O^+. Conjugate pairs are HCl/ Cl^- and H_3O^+/ H_2O.

PRACTISE ACID/BASE PAIRS

Identify the acids and bases in the following equation and their conjugate pairs:

- NH_3 (aq) + HF (aq) → F^- (aq) + NH_4^+ (aq)
- H_2O (l) + CN^- (aq) → OH^- (aq) + HCN (aq)
- NH_4^+ (aq) + CH_3COO^- (aq) → NH_3 (aq) + CH_3COOH (aq)

State the formula of the conjugate acid of:

- Cl^-
- CO_3^{2-}
- HSO_4^-

State the formula of the conjugate base of:

- HF
- HCO_3^-
- HSO_4^-

ANSWERS – ACID/BASE PAIRS

Identify the acids and bases in the following equation and their conjugate pairs:

- NH_3 (aq) + HF (aq) → F^- (aq) + NH_4^+ (aq)
- H_2O (l) + CN^- (aq) → OH^- (aq) + HCN (aq)
- NH_4^+ (aq) + CH_3COO^- (aq) → NH_3 (aq) + CH_3COOH (aq)

State the formula of the conjugate acid of:

- Cl^- HCl (after receiving H^+)
- CO_3^{2-} HCO_3^-
- HSO_4^- H_2SO_4

State the formula of the conjugate base of:

- HF F^- (after donating H^+)
- HCO_3^- CO_3^{2-}
- HSO_4^- SO_4^{2-}

AMPHIPROTIC SPECIES

Amphiprotic species can donate as well as accept a proton, H^+

$$\underset{\text{acid}}{HCO_3^-} + \underset{\text{base}}{H_2O} \longrightarrow \underset{\text{acid}}{H_3O^+} + \underset{\text{base}}{CO_3^{2-}}$$

$$\underset{\text{base}}{HCO_3^-} + \underset{\text{acid}}{NH_4^+} \longrightarrow \underset{\text{acid}}{H_2CO_3} + \underset{\text{base}}{NH_3}$$

POLYPROTIC ACIDS

- A **monoprotic** acid- can donate only one proton, H^+
- A **polyprotic** acid is one that can donate more than one proton, H^+
- A **diprotic** acid can donate two protons
- A **triprotic** acid can donate three protons

TABLE 11.3 Common monoprotic and polyprotic acids (acidic protons in bold)

	Polyprotic acids	
Monoprotic acids	Diprotic acids	Triprotic acids
*Ethanoic acid, $CH_3CO\mathbf{OH}$	Ascorbic acid, $\mathbf{H_2}C_6H_6O_6$	Citric acid, $\mathbf{H_3}C_6H_5O_7$
Hydrochloric acid, $\mathbf{H}Cl$	Carbonic acid, $\mathbf{H_2}CO_3$	Boric acid, $\mathbf{H_3}BO_3$
Hydrocyanic acid, $\mathbf{H}CN$	Sulfuric acid, $\mathbf{H_2}SO_4$	Phosphoric acid, $\mathbf{H_3}PO_4$
Hydrofluoric acid, $\mathbf{H}F$	Tartaric acid, $\mathbf{H_2}C_4H_4O_6$	
Nitric acid, $\mathbf{H}NO_3$		

*Contains four hydrogen atoms, but can only donate one proton.

EXAMPLES:

Monoprotic acids:

Write the reaction : Ethanoic acid + water → Hydronium ion + ethanoate ion

$$CH_3COOH\ (aq) + H_2O\ (l) \rightarrow H_3O^+\ (aq) + CH_3COO^-\ (aq)$$

Diprotic acids:

Write the reaction: sulphuric acid + water.

In

$$\text{Stage 1: } H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$$

$$\text{Stage 2: } HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$$

double arrow indicates only partial ionisation, because hydrogen sulfate is only a weak acid

EXAMPLES:

Triprotic acids:

Write the reactions for phosphoric acid

Stage 1: $H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + H_3O^+(aq)$

Stage 2: $H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$

Stage 3: $HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$

SOME COMMON ACID-BASE CONJUGATE PAIRS

Acids ... donate a proton to form:

Acid	$- H^+$
HCl	Cl^-
H_2SO_4	HSO_4^-
HNO_3	NO_3^-
HSO_4^-	SO_4^{2-}
H_3O^+	H_2O
CH_3COOH	CH_3COO^-
H_2CO_3	HCO_3^-
H_3PO_4	$H_2PO_4^-$
NH_4^+	NH_3
HCO_3^-	CO_3^{2-}
H_2O	OH^-

Bases ... accept a proton to form:

Base	$+ H^+$
OH^-	H_2O
NH_3	NH_4^+
CO_3^{2-}	HCO_3^-
PO_4^{3-}	HPO_4^{2-}
CH_3COO^-	CH_3COOH
O^{2-}	OH^-

AMPHIPROTIC SUBSTANCES

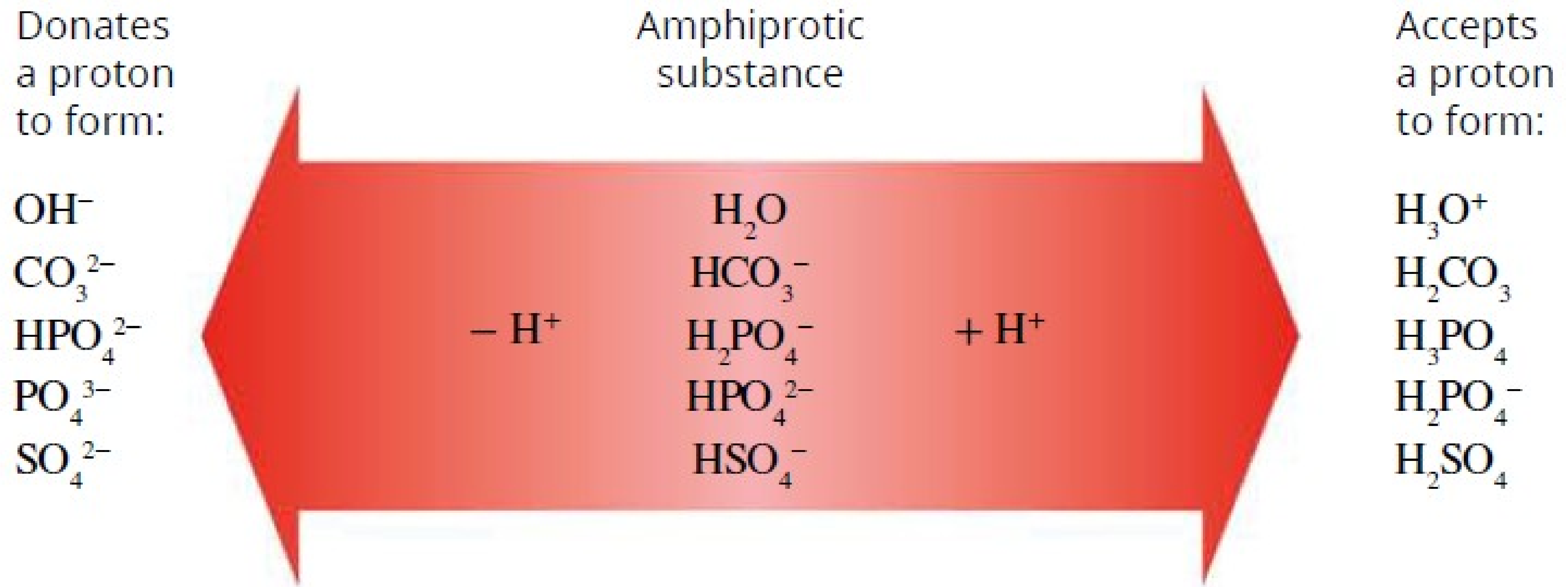


FIGURE 15.1.11 Substances that are amphiprotic.

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$$

base acid

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$$

acid base

COMPLETE EXERCISES

Exercise 11.1 and 11.2- pg 414

11.3 CONCENTRATION AND STRENGTH OF ACIDS AND BASES

Concentrated solutions have a large number of solute particles in a given volume.

Dilute solutions have a small number of solute particles in a given volume.

Molarity concentration measured in units of moles of solute per litre of solution, with units M or mol/L.

$c = n/V$ (mol/L)

CALCULATING THE CONCENTRATION AND THE NUMBER OF MOLES

$$c = \frac{n}{V}$$

$$n = c \times V$$

where:

n is the number of moles of solute

c is the concentration or molarity (mol L^{-1} or M)

V is the volume (L).

TIP: Remember that uppercase M represents the molar concentration of a solution in mol L^{-1}. Uppercase *M* (in italics) is molar mass in g mol^{-1}.

SAMPLE PROBLEM 2 Calculating the number of moles in a solution

Calculate the number of moles present in 250 mL of 3.00 M HCl.

THINK	WRITE
1. Identify the given information and compare units given to units required. The volume of the solution is given in mL, while the concentration is calculated in L. Convert from mL to L.	$c(\mathrm{HCl}) = 3.00\mathrm{M}$ $V(\mathrm{HCl}) = \frac{250\ \mathrm{mL}}{1000}$ $= 0.250\ \mathrm{L}$
Identify the unknown quantity.	$n(\mathrm{HCl}) = ?$
2. Use the formula to calculate the number of moles: $n = c \times V$ **TIP:** Remember to check significant figures and units.	$n(\mathrm{HCl}) = 3.00 \times 0.250$ $= 0.750\ \mathrm{mol}$

PRACTICE PROBLEM 2

Calculate the number of moles present in 100 mL of 1.35 M NaOH.

11.3.2 STRENGTH OF ACIDS AND BASES

- Strength of an acid or base is related to the ease with which it donates or accepts a proton, H^+.

  A strong acid donates protons readily. A strong base accepts protons readily.
- Strong acids fully ionise in water – shown by using just one arrow.
- Strong bases fully dissociate in water.
- Ionisation reaction - reaction in which a substance reacts with water to form ions
- Electrolyte solution or liquid that can conduct electricity.

E.G STRONG ACID AND STRONG BASES

A few strong acids fully ionise in water, producing many ions. Their solutions, therefore, are strong electrolytes. All protons are donated to water, forming hydronium ions and the anion of the acid.

$$\underset{\text{strong acid}}{HCl(g)} + H_2O(l) \xrightarrow{\text{virtually complete}} H_3O^+(aq) + Cl^-(aq)$$

Strong bases fully dissociate in water.

$$NaOH(s) \xrightarrow{H_2O(l)} Na^+(aq) + OH^-(aq)$$

Strong base

STRONG ACIDS

… are acids which ionise completely (readily donate protons)

Examples:

$$HCl_{(g)} + H_2O(l) \rightarrow H_3O^+{}_{(aq)} + Cl^-{}_{(aq)}$$

$$H_2SO_4(l) + H_2O(l) \rightarrow H_3O^+{}_{(aq)} + HSO_4^-{}_{(aq)}$$

$$HNO_3(l) + H_2O(l) \rightarrow H_3O^+{}_{(aq)} + NO_3^-{}_{(aq)}$$

HCl, H_2SO_4, HNO_3 completely ionise in water until there are hardly any HCl, H_2SO_4, HNO_3 covalent molecules remaining

Hydrochloric acid (HCl), sulphuric acid (H_2SO_4) and

STRONG BASES

Just like strong acids, strong bases dissociate completely in water

Take Na_2O:

$$Na_2O_{(aq)} + H_2O_{(l)} \rightarrow 2Na^{+}{}_{(aq)} + O^{2-}{}_{(aq)}$$

$$\text{then} \quad O^{2-}{}_{(aq)} + H_2O_{(l)} \rightarrow OH^{-}{}_{(aq)} + OH^{-}{}_{(aq)}$$

Here the O^{2-} ion is an example of a strong base

- Strong bases accept protons easily
- Reaction is complete

NaOH is also a strong base

- It is more correct to say that NaOH is a source of the strong base OH^- $NaOH_{(s)} \xrightarrow{H_2O} Na^{+}{}_{(aq)} + OH^{-}{}_{(aq)}$

WEAK ACIDS AND BASES

Weak acids and bases

Weak acids partially ionise in water. Weak bases partially dissociate in water.

Examples of weak acids are ethanoic acid, lactic acid and citric acid.

$$CH_3COOH(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

Use double arrows in reaction

Weak bases are ammonia.

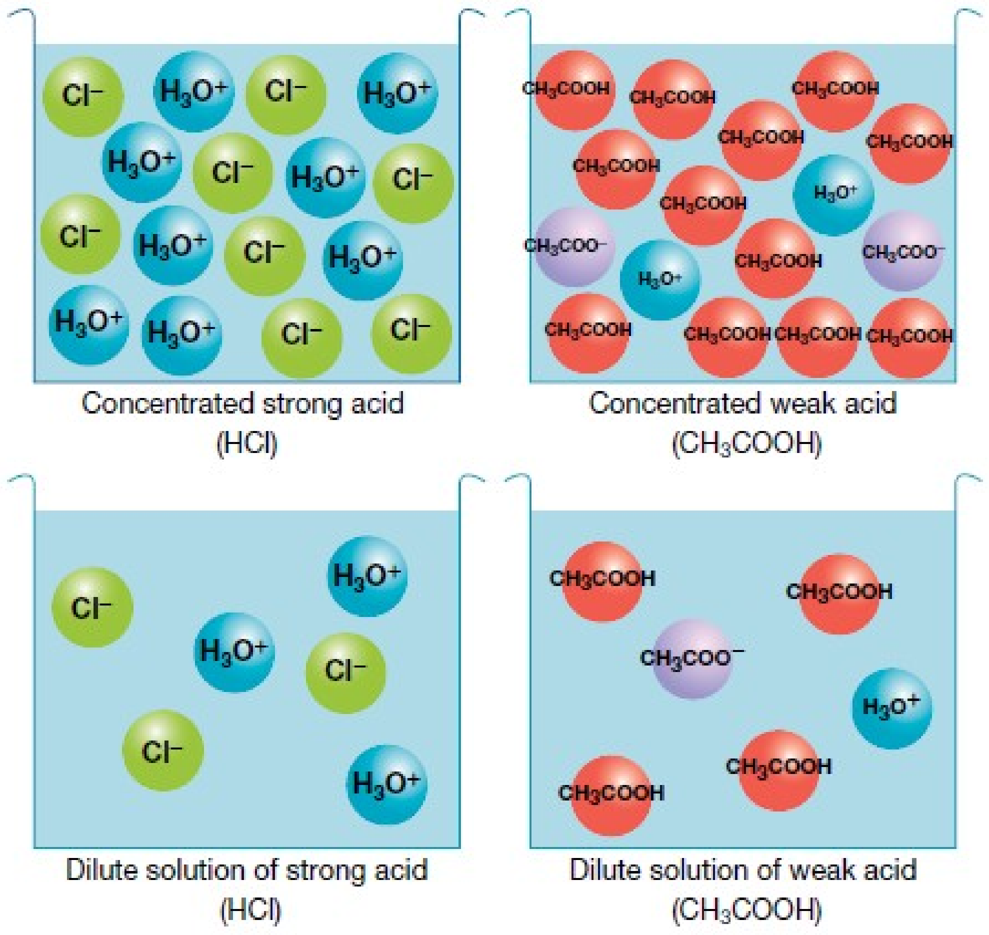
$$NH_{3\,(g)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

11.3.3 CONCENTRATION VERSUS STRENGTH

The concentration of an acid or base refers to the quantity of solute in a given volume of solution, whereas the strength of a solution refers to the extent of ionisation or dissociation of the acid or base.

Strong acids	Weak acids	Strong bases	Weak bases
Hydrochloric acid, HCl	Ethanoic acid, CH_3COOH	Sodium hydroxide, $NaOH$	Ammonia, NH_3
Sulfuric acid, H_2SO_4	Carbonic acid, H_2CO_3	Potassium hydroxide, KOH	
Nitric acid, HNO_3	Phosphoric acid, H_3PO_4	Calcium hydroxide, $Ca(OH)_2$	

CONCENTRATED AND DILUTE WEAK AND STRONG ACIDS



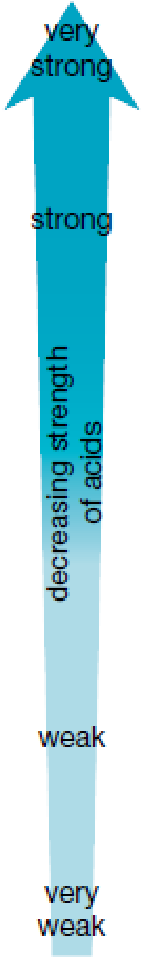
Strength

- **Strong acid or base solutions**, will have the ionised products because it is completely ionised.
- **Weak acid or base solutions**, will have both the reactants and products because it is only partially ionised.

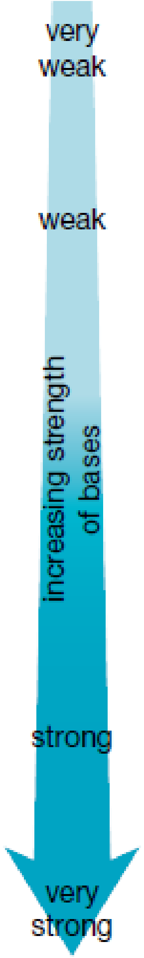
Concentration

- **Concentrated solutions** will have a large number of solute particles.
- **Dilutes solutions** will have fewer solute particles.

TABLE 11.4 Relative strengths of common acids and their conjugate bases



	Name of acid	Formula	Conjugate base	Name of base	
COMMON STRONG ACIDS	Hydrochloric	HCl	Cl^-	Chloride ion	
	Nitric	HNO_3	NO_3^-	Nitrate ion	
	Sulfuric	H_2SO_4	HSO_4^-	Hydrogen sulfite ion	
	Hydronium ion	H_3O^+	H_2O	Water	
COMMON WEAK ACIDS	Phosphoric	H_3PO_4	$H_2PO_4^-$	Dihydrogen phosphate ion	
	Hydrofluoric	HF	F^-	Fluoride ion	
	Ethanoic (acetic)	CH_3COOH	CH_3COO^-	Ethanoate (acetate) ion	
	Carbonic	H_2CO_3	HCO_3^-	Hydrogen carbonate ion	
	Hydrogen sulfide	H_2S	HS^-	Hydrogen sulfide ion	
	Ammonium ion	NH_4^+	NH_3	Ammonia	COMMON WEAK BASES
	Hydrogen carbonate ion	HCO_3^-	CO_3^{2-}	Carbonate ion	
	Hydrogen sulfide ion	HS^-	S^{2-}	Sulfide ion	
	Water	H_2O	OH^-	Hydroxide ion	COMMON STRONG BASES
	Hydroxide ion	OH^-	O^{2-}	Oxide ion	
	Hydrogen	H_2	H^-	Hydride ion	



The stronger the acid, the **weaker its conjugate base.**

HOMEWORK

11.3 Exercises and Exams