DP IB Chemistry: SL

Your notes

8.1 Theories & Reactions of Acids & Bases

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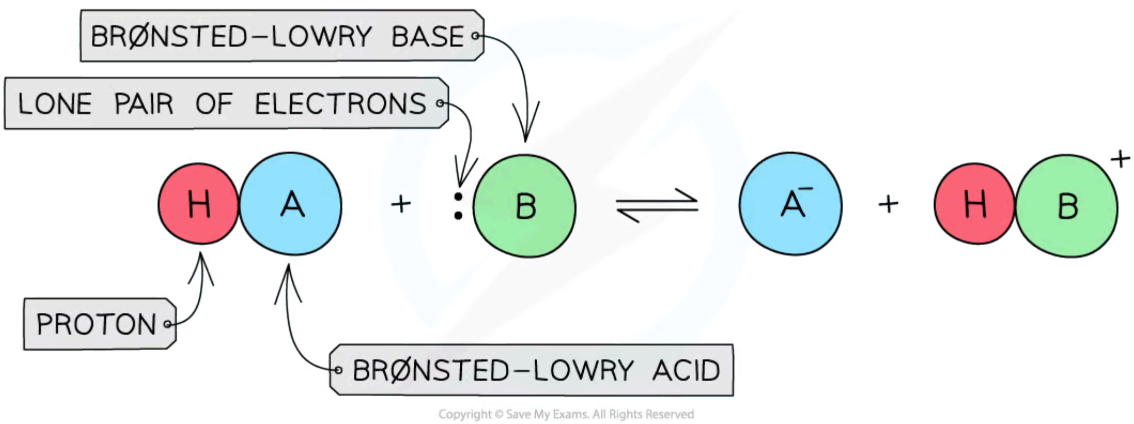
8.1.1 Brønsted–Lowry Acids & Bases

Your notes

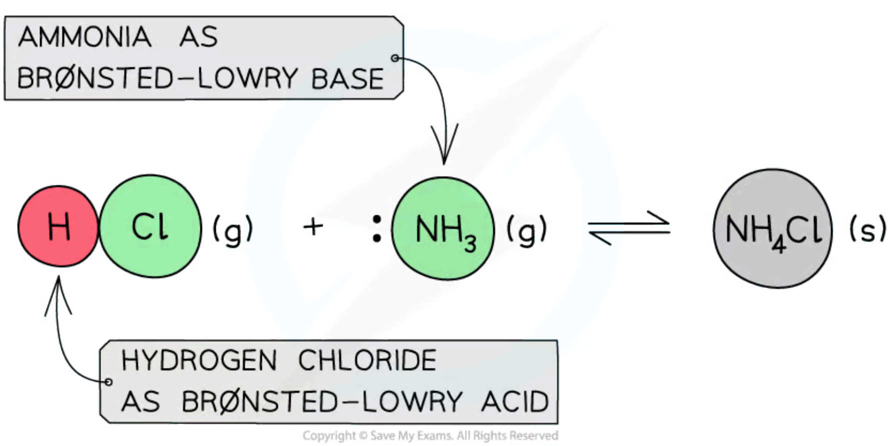
Brønsted–Lowry Acids & Bases

- **The Brønsted-Lowry Theory** defines acids and bases in terms of proton transfer between chemical compounds
- A **Brønsted-Lowry acid** is a species that **gives away** a **proton** (H^+)
- A **Brønsted-Lowry base** is a species that **accepts** a proton (H^+) using its **lone pair of electrons**



The diagram shows a Brønsted-Lowry acid which donates the proton to the Brønsted-Lowry base that accepts the proton using its lone pair of electrons

- The Brønsted-Lowry Theory is not limited to aqueous solutions only and can also be applied to reactions that occur in the gas phase



Example of a Brønsted-Lowry acid and base reaction in the gas state

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Worked example

Identify the correct role of the species in the following reaction:

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

	Brønsted–Lowry Acid	Brønsted–Lowry Base
A	$H_2PO_4^-$	H_2O
B	$H_2PO_4^{2-}$	$H_2PO_4^-$
C	$H_2PO_4^-$	H_3O^+
D	H_2O	$H_2PO_4^-$

Answer:

The correct option is **A**.

- $H_2PO_4^-$ is donating a proton to H_2O, so $H_2PO_4^-$ must be an acid and H_2O must be a base

Examiner Tip

An atom of hydrogen contains 1 **proton**, 1 electron and 0 neutrons. When hydrogen loses an electron to become **H^+** only a **proton** remains, which is why a H^+ ion is also called a proton.

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8.1.2 Conjugate Acid-Base Pairs

Conjugate Acid-Base Pairs

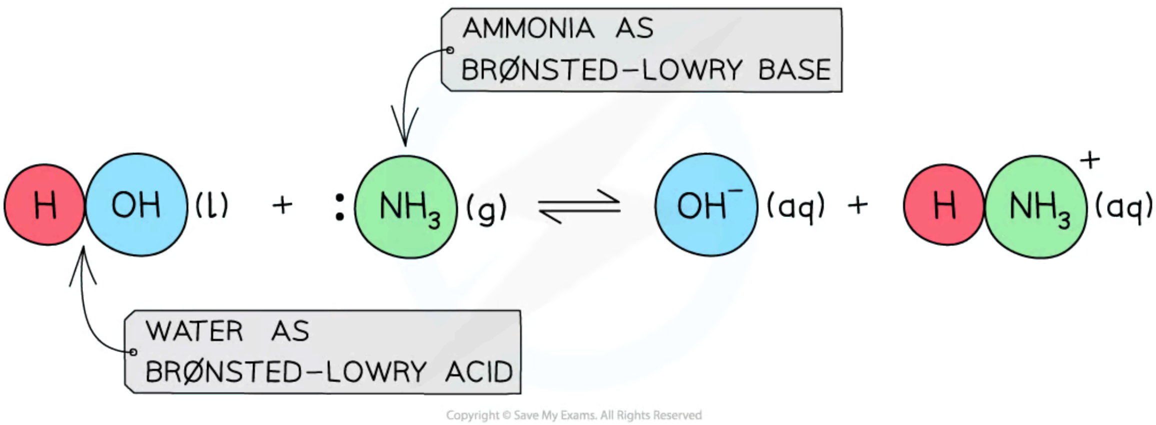
- A **Brønsted-Lowry acid** is a species that can donate a proton
- A **Brønsted-Lowry base** is a species that can accept a proton
- In a reaction at equilibrium, the products are formed at the same rate as the reactants are used

CH_3COOH (aq)	+ H_2O (l)	⇌ CH_3COO^- (aq)	+ H_3O^+ (aq)
acid	base	conjugate base	conjugate acid

- The reactant CH_3COOH is linked to the product CH_3COO^- by the transfer of a **proton** from the acid to the base
- Similarly, the H_2O molecule is linked to H_3O^+ ion by the transfer of a proton
- These pairs are therefore called **conjugate acid-base pairs**
- A **conjugate acid-base pair** is two species that are different from each other by a H^+ ion
  - **Conjugate** here means related
  - In other words, the acid and base are related to each other by one proton difference

Amphiprotic Species

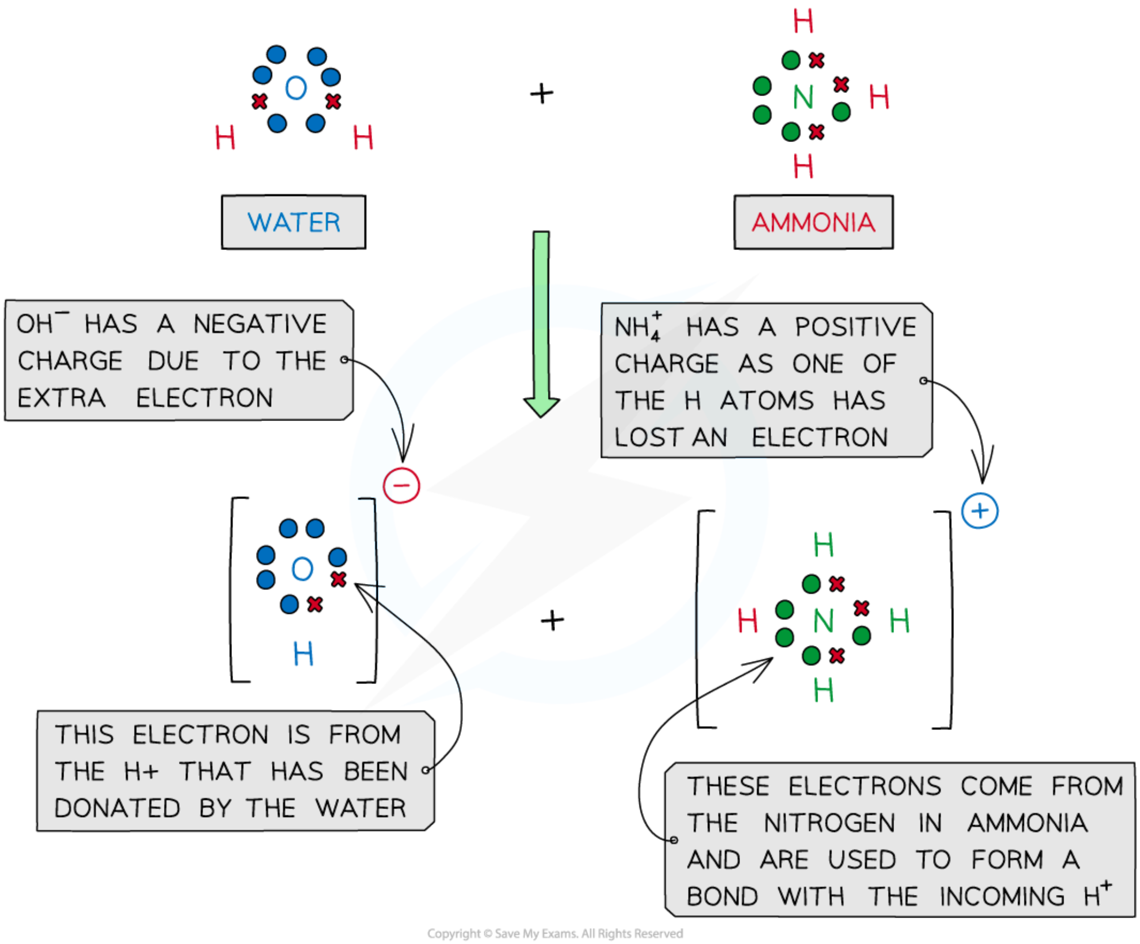
- Species that can act both as proton donors and acceptors are called **amphiprotic**
  - Eg. water as a Brønsted-Lowry acid



The diagram shows water acting as a Brønsted-Lowry acid by donating a proton to ammonia which accepts the proton using its lone pair of electrons

Your notes

Your notes



The Lewis diagram for the reaction of water with ammonia to show how water acts as a Brønsted-Lowry acid and ammonia as a Brønsted-Lowry base

- Eg. water as a Brønsted-Lowry base

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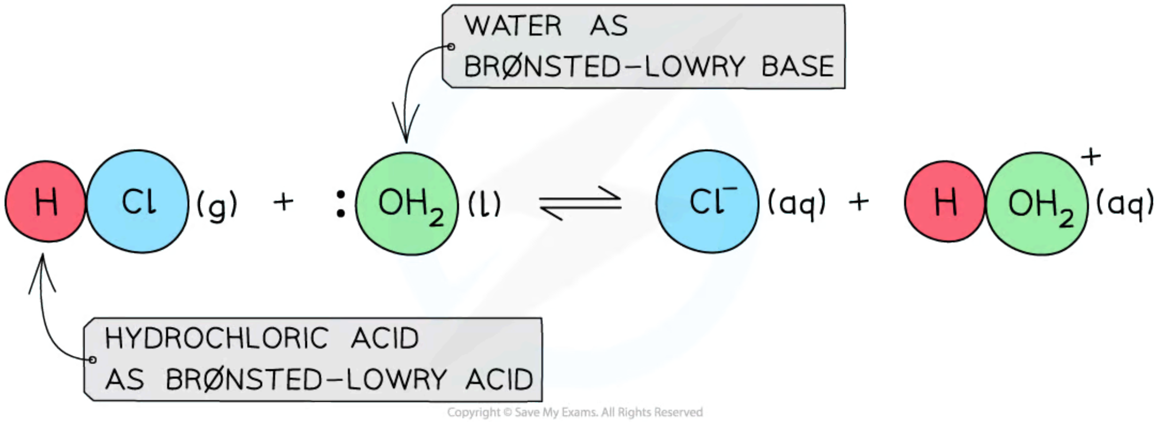
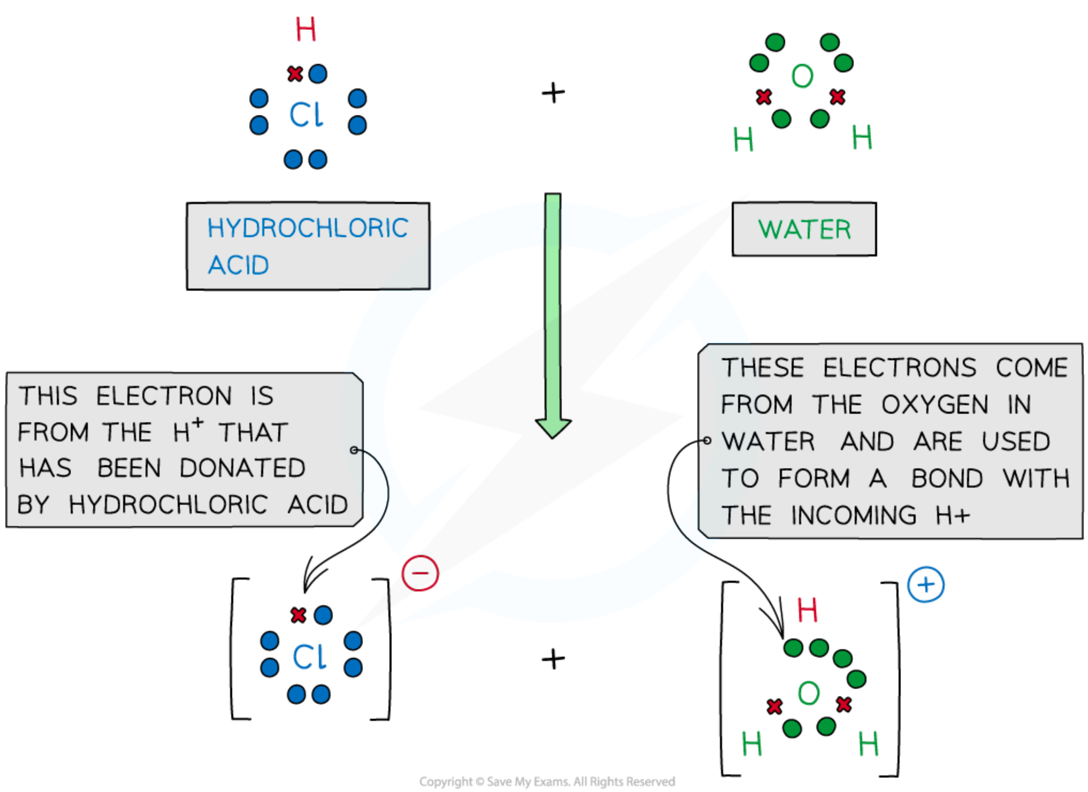


The diagram shows water acting as a Brønsted-Lowry base by accepting a proton from hydrochloric acid proton using its lone pair of electrons



The Lewis diagram for the reaction of water with hydrochloric acid to show how water acts as a Brønsted-Lowry base and ammonia as a Brønsted-Lowry acid

Your notes

What is the difference between amphiprotic and amphoteric?

- A compound that is **amphoteric** means it has both basic and acidic character
  - When the compound reacts with an acid, it shows that it has basic character
  - When it reacts with a base, it shows that it's acidic
  - An example of this is aluminum oxide which reacts with both hydrochloric acid and sodium hydroxide:

$$Al_2O_3\,(s) + 6HCl\,(aq) \rightarrow 2AlCl_3\,(aq) + 3H_2O\,(l)$$

$$Al_2O_3\,(s) + 2NaOH\,(aq) + 3H_2O\,(l) \rightarrow 2NaAl(OH)_4\,(aq)$$

- When a compound is **amphiprotic**, it means it can act as a proton donor and as a proton acceptor
- Aluminium oxide is not amphiprotic, even though it is amphoteric

Amphiprotic versus Amphoteric Table

Amphiprotic	Amphoteric
The term amphiprotic describes a substance that can both accept and donate a proton or H^+	The term amphoteric refers to the ability to act as both an acid and a base
Amphiprotic substances can both accept or donate protons	Amphoteric substances can act as both an acid and a base
All amphiprotic substances are amphoteric	Not all amphoteric substances are amphiprotic

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Worked example

In the equilibrium reaction shown below, which species are a conjugate acid-base pair?

$CH_3CH_2CH_2COOH\,(aq) + H_2O\,(l) \rightleftharpoons CH_3CH_2CH_2COO^-\,(aq) + H_3O^+\,(aq)$

A. $CH_3CH_2CH_2COOH$ and H_2O

B. H_2O and H_3O^+

C. H_2O and $CH_3CH_2CH_2COO^-$

D. $CH_3CH_2CH_2COO^-$ and H_3O^+

Answer

The correct option in **B**

- A conjugate acid-base pair differ only by an H^+ ion

Your notes

8.1.3 Characteristic Reactions of Acids

Characteristic Reactions of Acids

Metals and acids

- The typical reaction of a metal and an acid can be summarized as

acid + metal → salt + hydrogen

- For example:

$2HCl (aq) + Zn (s) \rightarrow ZnCl_2 (aq) + H_2 (g)$

hydrochloric acid + zinc → zinc chloride + hydrogen

- Clearly, the extent of reaction depends on the **reactivity** of the metal and the **strength** of the acid
- Very reactive metals would react dangerously with acids and these reactions are not usually carried out
- Metals low in **reactivity** do not react at all, for instance copper does not react with dilute acids
- **Stronger acids** will react **more vigorously** with metals than weak acids. What signs of reaction would be expected to be different between the two?
  - Faster reaction, seen as
    - more effervescence
    - the metal dissolves faster
  - More exothermic

Metals and oxides

- The reaction of an acid with a metal oxide forms two products:

acid + metal oxide → salt + water

- For example:

$2HCl (aq) + CaO (s) \rightarrow CaCl_2 (aq) + H_2O (l)$

hydrochloric acid + calcium oxide → calcium chloride + water

Metals and hydroxides

- The reaction with a metal hydroxide and an acid follows the same pattern as an oxide:

acid + metal hydroxide → salt + water

- A suitable example might be:

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H_2SO_4 (aq) + $Mg(OH)_2$ (s) → $MgSO_4$ (aq) + $2H_2O$ (l)

sulfuric acid + magnesium hydroxide → magnesium sulfate + water

Metals and carbonates

- The reaction between a metal carbonate and an acid produces three products:

acid + metal carbonate → salt + water + carbon dioxide

- For example:

$2HNO_3$ (aq) + $CuCO_3$ (s) → $Cu(NO_3)_2$ (aq) + H_2O (l) + CO_2 (g)

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

Metals and hydrogencarbonates

- The reaction between a metal hydrogencarbonate and an acid is the same as the carbonate reaction with a slight difference in stoichiometry:

acid + metal hydrogencarbonate → salt + water + carbon dioxide

- An example of this would be:

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

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

Examiner Tip

Make sure you learn the formulae of the common acids and bases and that you can write examples of balanced equations of their characteristic reactions

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Making Salts

- The acids and bases needed to make different salts can be deduced using the principles covered in the previous section
- The table below summarises these reactions

Making Salts Table

Type of salt	Ion	Acid needed	Formula	Base needed
Sulfates	SO_4^{2-}	sulfuric	H_2SO_4	metal oxide, hydroxide, carbonate or hydrogencarbonate
Nitrates	NO_3^-	nitric	HNO_3	
Chlorides	Cl^-	hydrochloric	HCl	
Ethanoates	CH_3COO^-	ethanoic	CH_3COOH	
Ammonium	NH_4^+	any	–	aqueous ammonia

- Note that although some metals can be used to make salts, they are not classified as bases as water is not a product of the reaction

Worked example

Which are the products of the reaction between zinc oxide and hydrochloric acid?

A. zinc chloride and carbon dioxide

B. zinc chloride, hydrogen gas and water

C. zinc, hydrogen gas and water

D. zinc chloride and water

Answer:

The correct option is **D**.

- Metal oxides when reacting with acids produce a salt and water as the only products

Your notes

8.1.4 Neutralization

Your notes

Neutralization

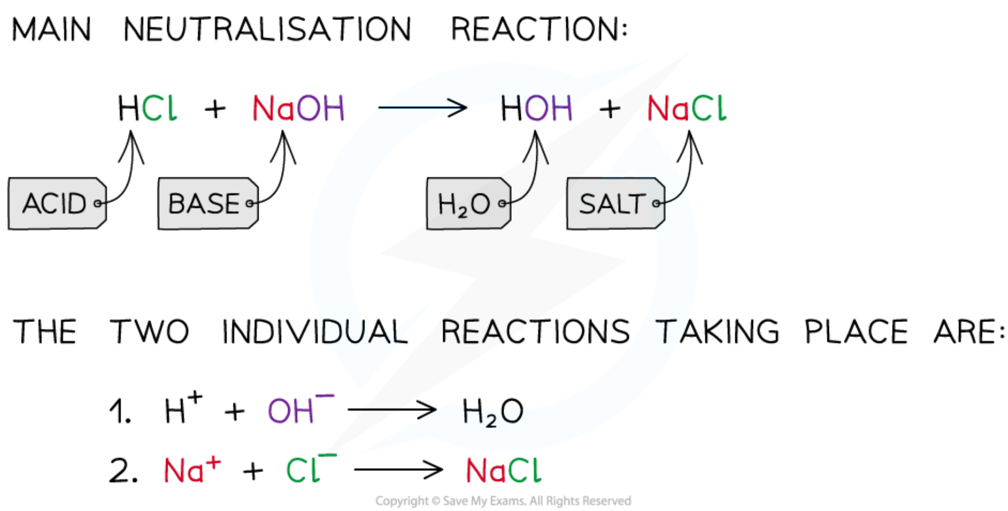
- A neutralisation reaction is one in which an acid (pH <7) and a base/alkali (pH >7) react together to form water (pH = 7) and a salt

$$\text{ACID} + \text{BASE (ALKALI)} \longrightarrow \text{SALT} + \text{WATER}$$

- The proton of the acid reacts with the hydroxide of the base to form water

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

- The spectator ions which are not involved in the formation of water, form the salt



The diagram shows a neutralisation reaction of HCl and NaOH and the two individual reactions that take place to form the water and salt

- The name of the salt produced can be predicted from the acid that has reacted

Acid Reacted & Salt Table

Your notes

Acid Reacted	Salt produced
Hydrochloric Acid	A Chloride
Nitric Acid	A Nitrate
Sulfuric Acid	A Sulfate

Examiner Tip

The enthalpy of neutralisation is the enthalpy change that occurs when an acid reacts with a base to form one mole of water. Since the reaction between strong acids and strong bases is the same regardless of the acid or base, it should be no surprise the enthalpy change is the same and is approximately -57 $kJ\ mol^{-1}$