Demonstrate Understanding of Chemical reactivity

# ACIDS & BASES

**Brønsted-Lowry Theory** (one view of acids & bases)

Acids are proton donors. Bases are proton acceptors

When a substance dissolves in water, the solution may be acidic, neutral or alkaline. An acid is any substance which produces $H^+$ ions or $H_3O^+$ ions in water. In reality, $H^+$ is a single proton, and does not exist on its own. In water it joins to $H_2O$ to form $H_3O^+$ ions. We use either $H^+(aq)$ or $H_3O^+(aq)$ to mean acid in water.

**Types of Acid**

**Strong** – completely dissociate into ions eg HCl, $HNO_3$, $H_2SO_4$

$$HA + H_2O \rightarrow H_3O^+ + A^- \text{ (or more simply } HA + aq \rightarrow H^+ + A^-)$$

**Weak** – partially dissociate into ions

$$HA + H_2O \rightleftharpoons H_3O^+ + A^- \text{ (or more simply } HA + aq \rightleftharpoons H^+ + A^-)$$

The weaker the acid, the less it dissociates & the more the equilibrium lies to the left.

**Types of Base**

**Strong** – completely dissociate into ions eg NaOH, KOH, $Ca(OH)_2$

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

**Weak** – partially dissociate into ions

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

**Strong and weak are not the same as concentrated and dilute**.
The strength of an acid or alkali depends on how ionised or dissociated it is in water. A strong acid does not become a weak acid just because it is diluted. Concentrated hydrochloric acid and dilute hydrochloric acid are both strong acids because they are both completely ionised in water. Concentrated ethanoic acid and dilute ethanoic acid are both weak acids because they are only partly ionised in water.

**Further explanation**

A proton is a hydrogen ion, $H^+$. Hydrochloric acid is an acid because it is a proton donor. A proton donor is a substance which gives a hydrogen ion away.

A base is a proton acceptor. This means a base will gain a hydrogen ion. Water acts as a base when it is put with hydrochloric acid because water will gain a proton to become $H_3O^+$.

| $HCl(aq)$ | + | $H_2O(l)$ | $\rightarrow$ | $H_3O^+(aq)$ | + | $Cl^-(aq)$ |
|---|---|---|---|---|---|---|
| acid | | base | | acid | | base |

In the reaction below, ammonia acts as a base because it gains a hydrogen ion to become an ammonium ion. Water acts as the acid because it gives away a proton (to ammonia) to become a hydroxide ion.

| $NH_3(aq)$ | + | $H_2O(l)$ | $\rightleftharpoons$ | $NH_4^+(aq)$ | + | $OH^-(aq)$ |
|---|---|---|---|---|---|---|
| base | | acid | | acid | | base |

Be sure to note the distinction between **ammonia,** $NH_3$, and **ammonium**, $NH_4^+$.

**Amphiprotic Substances**

Some species such as water can act either as an acid *or* a base. Such species are called amphiprotic. Another example is the hydrogen carbonate ion, $HCO_3^-$. When dissolved in water, two possible reaction can occur:

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

or

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

## Conjugate Acids and Bases

An important feature of the Brønsted theory is the relationship it creates between acids and bases. Every Brønsted-Lowry acid has a conjugate base, and vice versa.

Acids are related to bases ACID $\rightleftharpoons$ PROTON + CONJUGATE BASE

Bases are related to acids BASE + PROTON $\rightleftharpoons$ CONJUGATE ACID

For an acid to behave as an acid, it must have a base present to accept a proton.

| HA | + | B | $\rightleftharpoons$ | $BH^+$ | + | $A^-$ |
|---|---|---|---|---|---|---|
| acid | | base | | conjugate acid | | conjugate base |
| HA | + | B | $\rightleftharpoons$ | $BH^+$ | + | $A^-$ |
| $acid_1$ | | $base_2$ | | $acid_2$ | | $base_1$ |

## Acidic & Basic Salts

Many salts dissolve in water to produce solutions which are not neutral. This is because the ions formed react with water

**NaCl**(aq) is neutral. $NaCl(s) + aq \rightarrow Na^+(aq) + Cl^-(aq)$, Since neither the $Na^+$ ion nor the $Cl^-(aq)$ ion react with water, the solution is neutral.

**$NH_4Cl$**(aq) is acidic. $NH_4Cl(s) + aq \rightarrow NH_4^+(aq) + Cl^-(aq)$. The $NH_4^+$ ion can act as a proton donor to water.

$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + \mathbf{H_3O^+(aq)}$. The $H_3O^+(aq)$ make the solution acidic.

**$CH_3COONa$**(aq) and **$NaCO_3$**(aq) are both alkaline due to formation of the $OH^-$(aq) ion.

$CH_3COONa(s) + aq \rightarrow Na^+(aq) + CH_3COO^-(aq)$: $CH_3COO^-$ acts as a base.

$CH_3COO^-(aq) + H_2O(l) \rightleftharpoons CH_3COOH(aq) + \mathbf{OH^-(aq)}$

$Na_2CO_3(aq) + aq \rightarrow 2Na^+(aq) + CO_3^{2-}(aq)$: $CO_3^{2-}$ acts as a base.
$CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + \mathbf{OH^-(aq)}$

## Comparing a weak and strong acid of the same concentration eg 2 mol $L^{-1}$ HCl & 2 mol $L^{-1}$ $CH_3COOH$

Hydrochloric acid, HCl, is a strong acid that fully dissociates in water. Therefore, it will have a high concentration of $H_3O^+$ and a lower pH, and a high concentration of ions overall, resulting in a high electrical conductivity. Reaction rate of acid depends on concentration of hydrogen / hydronium ions - the higher the concentration, the faster the reaction. HCl has the lowest pH and therefore highest hydrogen / hydronium ion concentration. It will react rapidly with magnesium ribbon or calcium carbonate (marble chips).

Ethanoic acid, $CH_3COOH$, is a weak acid which only partially dissociates in water. Therefore, it will have a relatively low concentration of $H_3O^+$, resulting in a higher pH, and a low concentration of ions overall, resulting in low electrical conductivity. It will react slowly with magnesium ribbon or calcium carbonate (marble chips).

A weak acid and a strong acid of the same concentration and volume will produce the same amount of product from the same amount of reactant but the weak acid will take longer to do it.

The ionisation of a strong acid is complete.

$HCl + H_2O \rightarrow H_3O^+ + Cl^-$

A weak acid is only partly ionised.

$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$

The number of $H_3O^+$ ions produced by a weak acid is small. When they have reacted with (for example) magnesium more of the ethanoic acid molecules ionise to produce more hydrogen ions and $CH_3COO^-$, ethanoate ions (Le Chatelier's Principle).

Eventually all of the ethanoic acid molecules ionise to react with the magnesium and so the same amount of product (hydrogen gas) will be produced.

## At A Glance

**Brønsted-Lowry Theory** Acids are proton donors. Bases are proton acceptors. $H^+$ = a proton. $H^+(aq)$ or $H_3O^+(aq)$ means acid in water.

- **Strong Acid**– completely dissociate into ions / completely ionise / react completely with water eg HCl: $HCl + H_2O \rightarrow H_3O^+ + Cl^-$
- **Weak Acid** – partially dissociate into ions / incompletely ionise / don't react completely with water eg $CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$
- **Strong Base** – completely dissociate into ions eg $NaOH + aq \rightarrow Na^+ + OH^-$
- **Weak** Base – partially dissociate into ions eg $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

**Strong and weak are not the same as concentrated and dilute**. Strong & weak = how ionised, Concentrated & dilute = how much water.

**Amphiprotic substances** - species such as water or $HCO_3^-(aq)$ that can act either as an acid *or* a base. Eg

(actino as acid) $HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$ or (actino as base) $HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$

**Conjugate Acids and Bases.** Each B-L acid has a conjugate base, and vice versa.

Acids are related to bases ACID $\rightleftharpoons$ PROTON + CONJUGATE BASE and

Bases are related to acids BASE + PROTON $\rightleftharpoons$ CONJUGATE ACID

$$\underset{acid_1}{HA} + \underset{base_2}{B} \rightleftharpoons \underset{acid_2}{BH^+} + \underset{base_1}{A^-}$$

**Acidic & Basic Salts** – some salts dissolve in water to produce solutions which are not neutral because the ions formed when they are dissolved react with water. Eg ammonium chloride solution – acidic, sodium ethanoate solution and sodium hydrogen carbonate solution – alkaline.

**Comparing a weak and strong acid of the same concentration eg HCl & $CH_3COOH$.**

| | HCl – strong acid - fully ionised | $CH_3COOH$ – weak acid – partially ionised |
|---|---|---|
| pH | Low pH eg 1 due to high concentration of $H_3O^+$ | High pH eg 4-5 due to low concentration of $H_3O^+$ |
| Rate of reaction with Mg or $CaCO_3$ | Rapid due to high concentration of $H_3O^+$ | Slow due to low concentration of $H_3O^+$ |
| Electrical conductivity | high electrical conductivity due to overall high concentration of ions | poor electrical conductivity due to overall low concentration of ions |

A weak acid and a strong acid of the same concentration and volume will react with same amount of reactant (or make the same amount of product from the same amount of reactant) because the total number of potential $H_3O^+$ ions are the same. All that will be different is the rate of the reaction.