6.3: Strength of acids and bases

The strength of acid HA is the extent to which the acid dissociates into H^+ and A^- ions, as illustrated in Fig. 6.3.1.

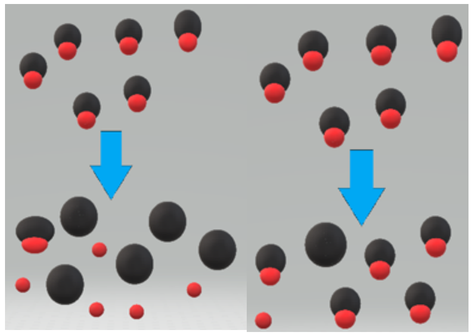

Figure 6.3.1: Image of strong acid mostly dissociating (left) and a weak acid partially dissociating into ions in water (right). Source: Cwszot / CC0

Strong acids

> Strong acids, like HCl, almost 100% dissociate into ions when they dissolve in water.

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

> One arrow is used to indicate that the reaction is nearly 100% complete.
>
> Strong acids include $HClO_4$, H_2SO_4, HI, HBr, HCl, and HNO_3

Weak acids

> Weak acids dissolve in water but partially dissociate into ions.

For example, acetic acid (CH_3COOH) is a weak acid, 1 M acetic acid dissolves in water, but only 0.4% of the dissolved molecules dissociate into ions, the remaining 99.6% remain undissociated, as illustrated in Fig. 6.3.2. and equation of the dissociation equilibrium below.

$$\mathrm{CH_3COOH(aq) + H_2O(I) \overset{\rightharpoonup}{\longleftarrow} H_3O^+(aq) + CH_3COO^-(aq)}$$

> Two arrows pointing in opposite directions are used for the dissociation of weak acids to indicate that the reaction is an equilibrium, i.e., two ways.

Often the arrows are not equal in size -the longer arrow points to acid-base pair that is weaker and present in a larger concentration at equilibrium than their conjugate pair.

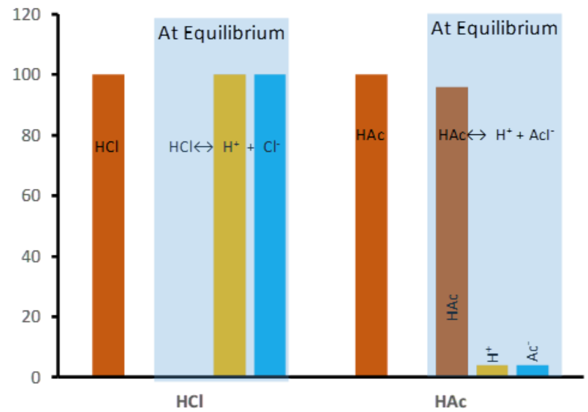

Figure 6.3.2: After dissolution in water. HCl –the strong acid is 100% dissociated into H^+ and Cl^- ions leaving no dissolved HCl molecules in water, but acetic acid (HAc) –the weak acid has a high concentration of HAc molecules and low concentration of H^+ and Ac^- ions.

Strong bases

Strong bases almost %100 dissociate into ions when dissolved in water. For example, NaOH is a strong base, and it dissociates almost 100% into ions in water.

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$$\mathrm{NaOH(s)} \xrightarrow{\text{Water}} \mathrm{Na^+(aq) + OH^-(aq)}$$

One arrow is used for the dissolution of strong bases to indicate that the reaction is almost complete.

Strong bases include hydroxides of alkali metals, i.e., LiOH, NaOH, KOH, RbOH, CsOH, and hydroxides of heavy alkaline earth metals, i.e., $Ca(OH)_2$, $Sr(OH)_2$, and $Ba(OH)_2$.

The last three, i.e., the hydroxides of heavy alkaline earth metals, have low solubility in water, but the dissolved fraction exists as ions.

Weak bases

Weak bases partially dissociate into ions when dissolved in water.

For example, ammonia is a weak base –only 0.42% of the dissolved ammonia molecules dissociate into ammonium ions and hydroxide ions in water from a 1 M solution of ammonia.

$$\mathrm{NH_3(aq) + H_2O(I) \rightleftharpoons NH_4{}^+(aq) + OH^-(aq)}$$

Weak bases in household use include ammonia (NH_3) in window cleaners, NaClO in bleach, Na_2CO_3 and Na_3PO_4 in laundry detergent, $NaHCO_3$ in tooth past, Na_2CO_3 in baking powder, $CaCO_3$ for use in lawns, $Mg(OH)_2$ and $Al(OH)_3$ in antacids and laxatives.

The weak bases mentioned above are all ionic compounds except ammonia. Ionic compounds are strong electrolytes, i.e., they dissociate into ions almost 100% upon dissolution in water. It appears to contradict the fact that these ionic compounds are weak bases. It does not actually contradict, because the base properties do not refer to these ionic compounds, the base properties refer to the reactions of their polyatomic anions, i.e., ClO^-, $CO_3{}^{2-}$, and $PO_4{}^{3-}$ with water, as shown in the reactions below:

$$\mathrm{ClO^- + H_2O \rightleftharpoons HClO + OH^-}$$
$$\mathrm{CO_3^{2-} + 2H_2O \rightleftharpoons H_2CO_3 + 2OH^-}\text{, and}$$
$$\mathrm{PO_4{}^{3-} + 3H_2O \rightleftharpoons H_3PO_4 + 3OH^-}$$

The above reactions are equilibrium reactions that are more favored in the revers than the forward direction, producing a small number of OH^- ions compared to the anion on the reactant sides. The last two examples, i.e., $Mg(OH)_2$ and $Al(OH)_2$ are classified as weak bases because they are considered insoluble in water. The solubility of $Mg(OH)_2$ is 0.00064 g/100 mL (25 °C), and the solubility of $Al(OH)_3$ is 0.0001 g/100 mL, which are in the range of insoluble ionic compounds.

> The solubility and the strength of acids and bases are two different things. A strong base may be less soluble, and a weak base may be more soluble or vice versa, but a dissolved strong base exists as ions only, and a dissolved weak base exists both as molecules and ions.

The relative strength of acid-conjugate base pair

> A general rule is that the stronger the acid, the weaker the conjugate base, and vice versa.

The conjugate bases of strong acids have negligible base strength, and the conjugate acids of strong basses have negligible acid strength. Fig. 6.3.3. illustrates the relative strengths of some acids and their conjugated bases.

Acid Strength	Acid		Conjugate base		Base Strength
Strong acids	Perchloric acid	$HClO_4$	ClO_4^-	Perchlorate ion	Very week bases
	Sulfuric acid	H_2SO_4	HSO_4^-	Hydrogen sulfate ion	
	Hydroiodic acid	HI	I^-	Iodide ion	
	Hydrobromic acid	HBr	Br^-	Bromide ion	
	Huydrochloric acid	HCl	Cl^-	Chloride ion	
	Nitric acid	HNO_3	NO_3^-	Nitrate ion	
	Hydronium ion	H_3O^+	H_2O	Water	
Weak acids	Hydrogensulfate	HSO_4^-	SO_4^{2-}	Sulfate ion	Weak bases
	Phosphoric acid	H_3PO_4	$H_2PO_4^-$	Dihydrogen phosphate ion	
	Hydrofluoric acid	HF	F^-	Fluoride ion	
	Nitrous acid	HNO_2	NO_2^-	Nitrite ion	
	Acetic acid	CH_3COOH	CH_3COO^-	Acetate ion	
	Carbonic acid	H_2CO_3	HCO_3^-	Hydrogen carbonate ion	
	Hydrogen sulfide	H_2S	HS^-	Hydrogen sulfide ion	
	Ammonium ion	NH_4^+	NH_3	Ammonia	
	Hydrogen cyanide	HCN	CN^-	Cyanide ion	
	Hydrogen carbonate	HCO_3^-	CO_3^{2-}	Carbonate ion	
	Water	H_2O	HO^-	Hydroxide ion	
Very weak acid	Hydrogen sulfide ion	HS^-	S^{2-}	Sulfide ion	Strong Bases
	Ethanol	$CH_3CH_2\text{-}OH$	$CH_3CH_2\text{-}O^-$	Ethoxide ion	
	Ammonia	NH_3	NH_{2-}	Amide ion	
	Hydrogen	H_2	H^-	Hydride ion	
	Methane	CH_4	CH_3^-	Methide ion	

Figure 6.3.3: Strength of acid-conjugate base pairs relative to water as a reference.

> **Direction of acid-base equilibrium**
>
> In any Brønsted–Lowry acid-base reaction, the general rule is that a stronger acid and a stronger base tend to form a weaker acid and a weaker base.

For example, a dissociation reaction between HCl and H_2O is almost 100% complete because HCl is a stronger acid than H_3O^+ and H_2O is a stronger base than Cl^-:

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

The dissolution of acetic acid (CH_3COOH) and ammonia (NH_3) are equilibrium reactions because all the acids, bases, and their conjugates are in the weak acids or weak bases category. However, acetic acid and water dominate over their conjugates H_3O^+ and CH_3COO^- by 99.6:0.4 ratio (in 1 M acetic acid solution) because the conjugate acid H_3O^+ is a stronger acid than CH_3COOH, and conjugate base CH_3COO^- is a stronger base than H_2O.

$$\mathrm{CH_3COOH(aq) + H_2O(l) \overset{\rightharpoonup}{\longleftarrow} H_3O^+(aq) + CH_3COO^-(aq)}$$

> The longer arrow, in the unbalanced equilibrium arrows, points to the acid-base pair in the reaction that exists in a higher concentration relative to their conjugates.

Similarly, ammonia (NH_3) and water (H_2O) dominate over their conjugates NH_4^+ and OH^- by ~99.6:0.4 ratio (1M ammonia solution) because the conjugate acid NH_4^+ is a stronger acid than H_2O and conjugate base OH^- is a stronger base than NH_3.

$$\mathrm{NH_3(aq) + H_2O(I)) \overset{\rightharpoonup}{\longleftarrow} NH_4^+(aq) + OH^-(aq)}$$
