8.1 Explaining the Properties of Acids & Bases

SCH4U – Chemistry, Gr. 12, University Prep

Equilibrium & Acids & Bases

- So far, we have looked at equilibrium of general chemical systems:
  - We learned about the equilibrium constant K, reversibility, factors that affect or shift equilibrium, using ICE charts and calculating K_c
- Now we are going to look at equilibrium, applying the concept to Acids & Bases
  - Calculating K_a and K_b
- Before we begin, we better review Acids & Bases from Grade 11!!!

Common Properties of Acids & Bases

Property	Acid	Base
Taste	Sour	Bitter
Texture of Solution	No characteristic texture	Slippery
Aqueous Property of Oxides	Non-metal oxides form acidic solutions: $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$	Metal oxides form basic solutions: $CaO_{(g)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)}$
Reaction with Phenolphthalein	Colourless	Pink
Reaction with litmus	Blue litmus → Red	Red litmus → Blue
Reaction with Metals	Acids react with metals above H in the activity series to displace $H_{2(g)}$	Bases react with certain metals (i.e. Al) to form $H_{2(g)}$
Reaction with CO_3^{2-}	Form $CO_{2(g)}$	No reaction
Reaction with NH_4Cl	No reaction	Form NH_3
Reaction with Fatty Acids	No reaction	React to form soap (saponification reaction)
Neutralization Reactions	Acid + Base → Water + Salt	

Arrhenius Theory of Acids & Bases

- Based on the ions produced when they are in water
  - ACID: dissociates in water to form $\mathbf{H^+}_{(aq)}$
    - $HCl_{(aq)} \rightarrow \mathbf{H^+}_{(aq)} + Cl^-_{(aq)}$
  - BASE: dissociates in water to form $\mathbf{OH^-}_{(aq)}$
    - $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + \mathbf{OH^-}_{(aq)}$
- LIMITATIONS:
  - does not explain some bases (i.e. ammonia, salt solutions)
  - does not explain acid-base reactions without water (i.e. gas)

Brønsted–Lowry Theory

- Defines acids and bases regarding protons (H^+)

proton = nucleus of a hydrogen atom (H^+ ion)

  - ACID: substance from which a proton can be removed
    - "proton-donor"
  - BASE: substance that can accept a proton
    - "proton-acceptor"

$$HCl_{(aq)} + H_2O_{(l)} \leftrightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

acid — base — conjugate acid — conjugate base

Conjugate Acid–Base Pairs

$$NH_{3(aq)} + H_2O_{(l)} \leftrightarrow NH^{+}_{4(aq)} + OH^{-}_{(aq)}$$

base — acid — conjugate acid — conjugate base

- dissociation is an equilibrium reaction because it proceeds in both directions
  - H_2O donates a proton in forward rxn → acid
  - NH_3 accepts a proton from H_2O → base
- If a substance acts as a proton donor and a proton accepter, it is termed "amphoteric" (i.e. water)

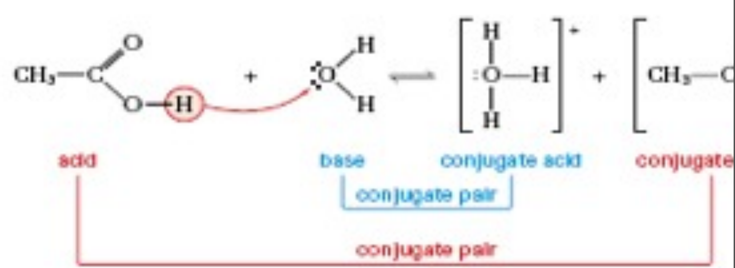
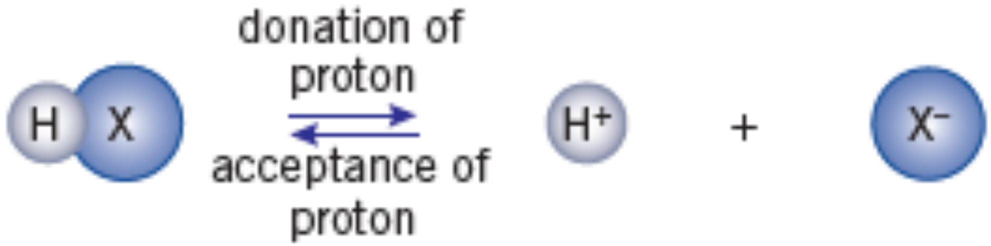


Figure 8.3 Conjugate acid-base pairs in the dissociation of acetic acid in water

Conjugate Acid–Base Pairs

Conjugate Base – The species remaining after an acid has transferred its proton.

Conjugate Acid – The species produced after base has accepted a proton.



HX **acid**	**X–** **conjugate base**
HCl	Cl^-
H_2SO_4	HSO_4^-
HNO_3	NO_3^-
H_3O^+	H_2O
HSO_4^-	SO_4^{2-}
CH_3COOH	CH_3COO^-
NH_4^+	NH_3
H_2O	OH^-

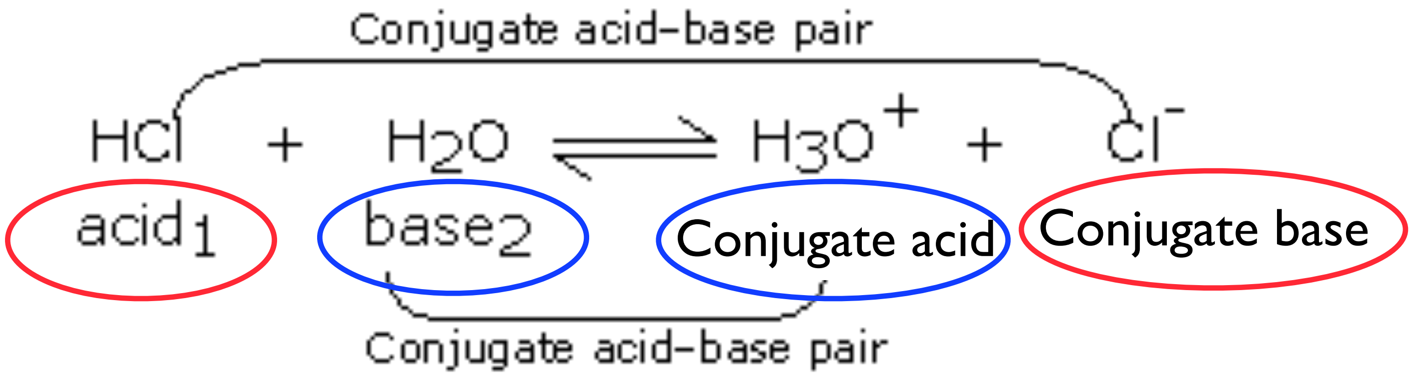
Amphoteric behaviour

Note: Water can act as acid or base (Amphoteric)

Acid		Base		Conjugate Acid		Conjugate Base
HCl	+	H_2O	$\leftrightarrow$	H_3O^+	+	Cl^-
$H_2PO_4^-$	+	H_2O	$\leftrightarrow$	H_3O^+	+	HPO_4^{2-}
NH_4^+	+	H_2O	$\leftrightarrow$	H_3O^+	+	NH_3

Base		Acid		Conjugate Acid		Conjugate Base
$:NH_3$	+	H_2O	$\leftrightarrow$	NH_4^+	+	OH^-
PO_4^{3-}	+	H_2O	$\leftrightarrow$	HPO_4^{2-}	+	OH^-

Identify the conjugate acid-base pairs. Connect as shown.



NH_2^- + H_2O ↔ NH_3 + OH^-

CN^- + H_2O ↔ HCN + OH^-

$HClO_4$ + CH_3COOH ↔ ClO_4^- + $CH_3COOH_2^+$

HCN + H_2O ↔ H_3O^+ + CN^-

HSO_4^- + HCl ↔ H_2SO_4 + Cl^-

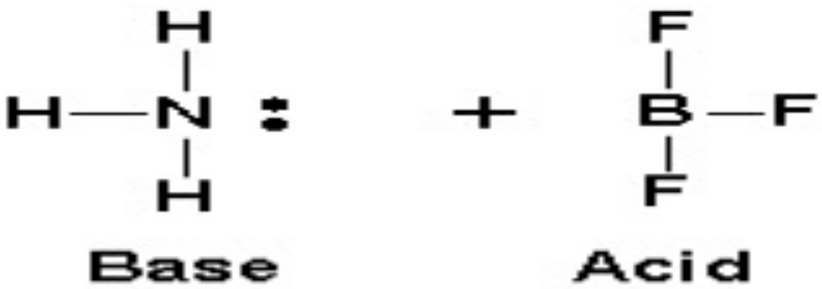
SO_4^{2-} + HNO_3 ↔ HSO_4^- + NO_3^-

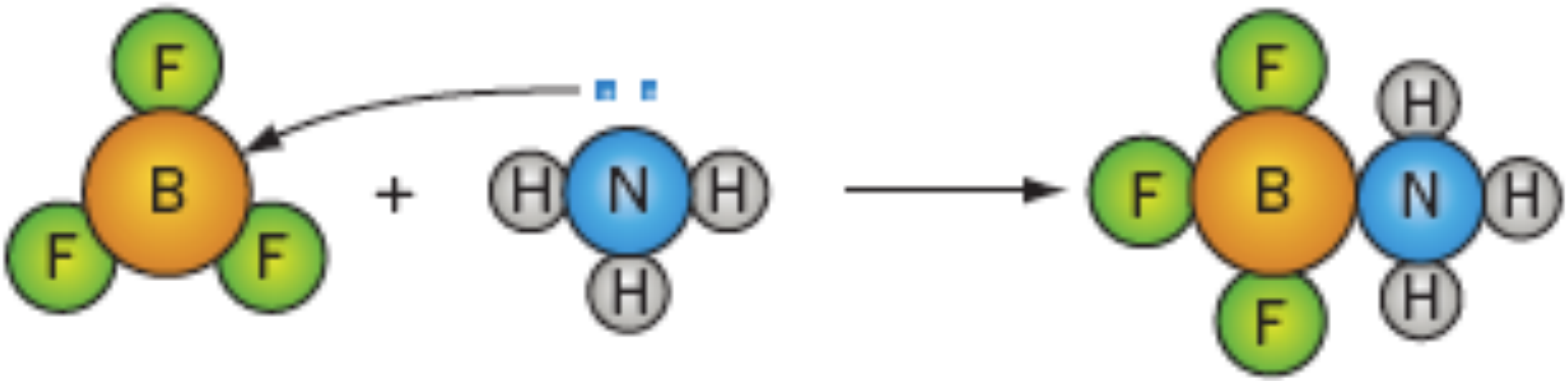
Lewis Acids & Bases

Lewis defined them as:

Acid – an electron pair acceptor

Base – an electron pair donor





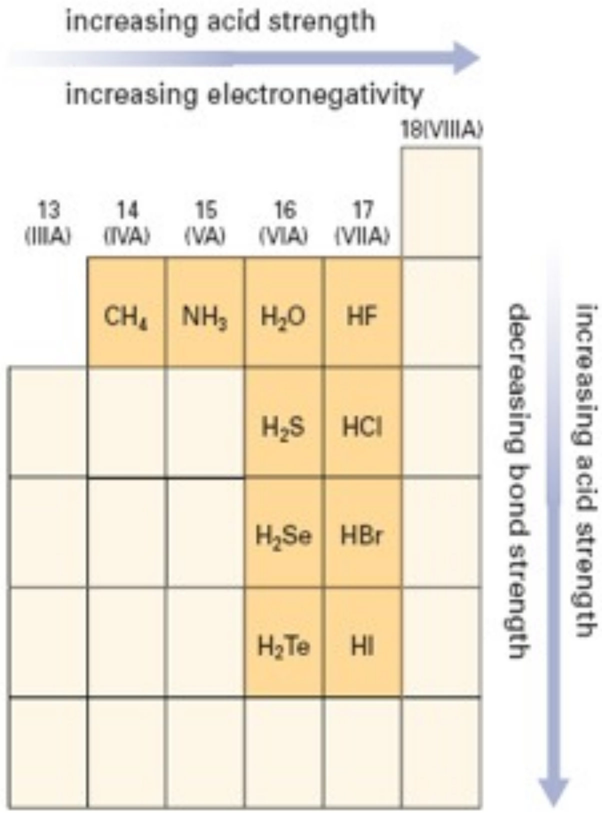
Strong Acids

- Examples of Strong acids:
  - Binary acids: HCl, HBr, HI
  - Oxoacids (contain polyatomics): HNO_3, H_2SO_4, $HClO_3$, H_3PO_4

- Strong acids **completely** dissociate in water (equilibrium favours products, lies to the right)

- This means 100% of the acid will turn into ions. So if you have 0.2 M HCl, it will turn into 0.2 M H_3O^+

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



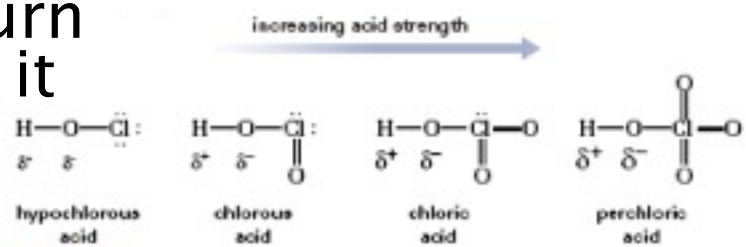
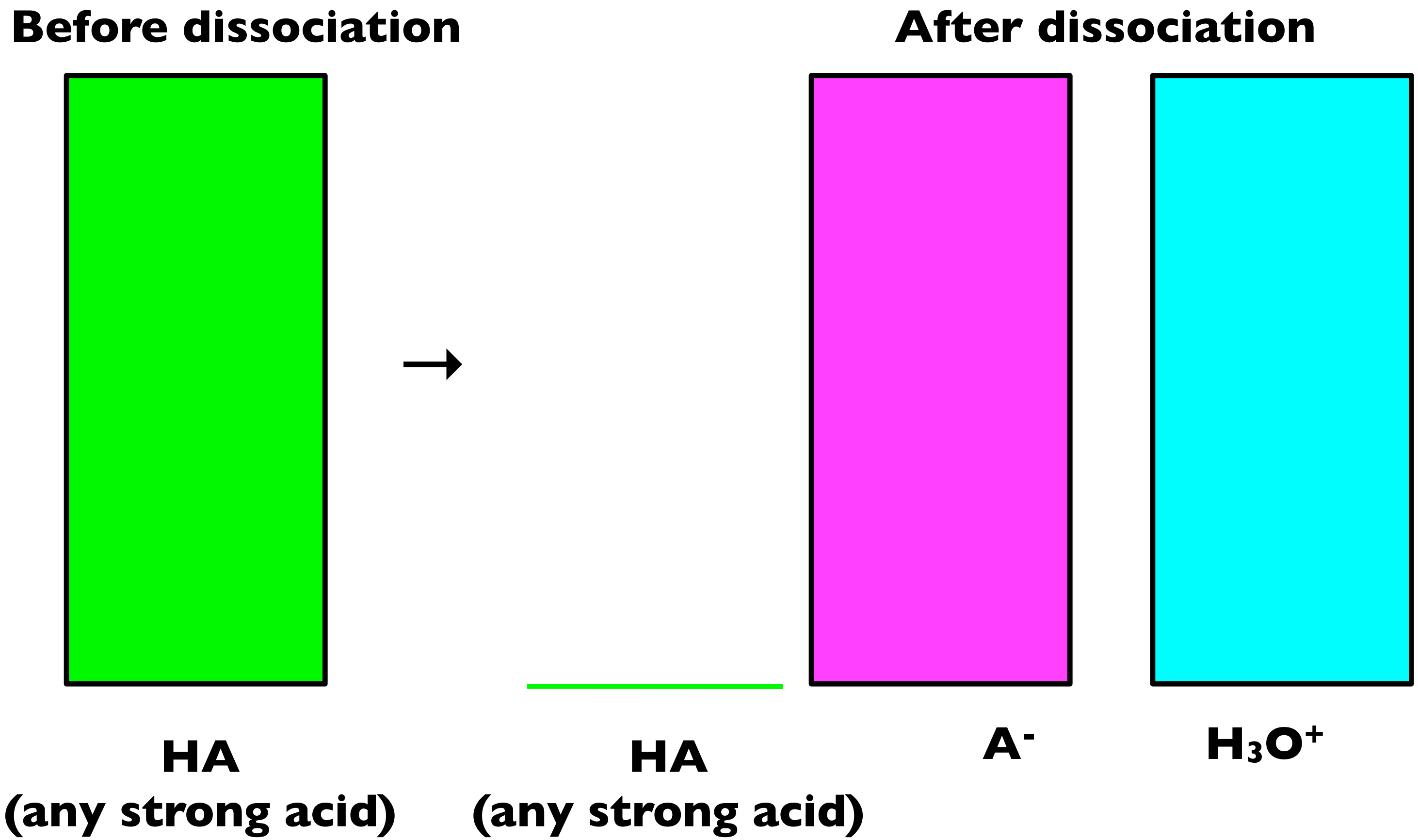


Figure 8.6 The relative strength of oxoacids increases with the number of oxygen atoms.

Strong Acids

- Strong acids dissociate 100%
- $HA + H_2O \rightarrow A^- + H_3O^+$



Strong Bases

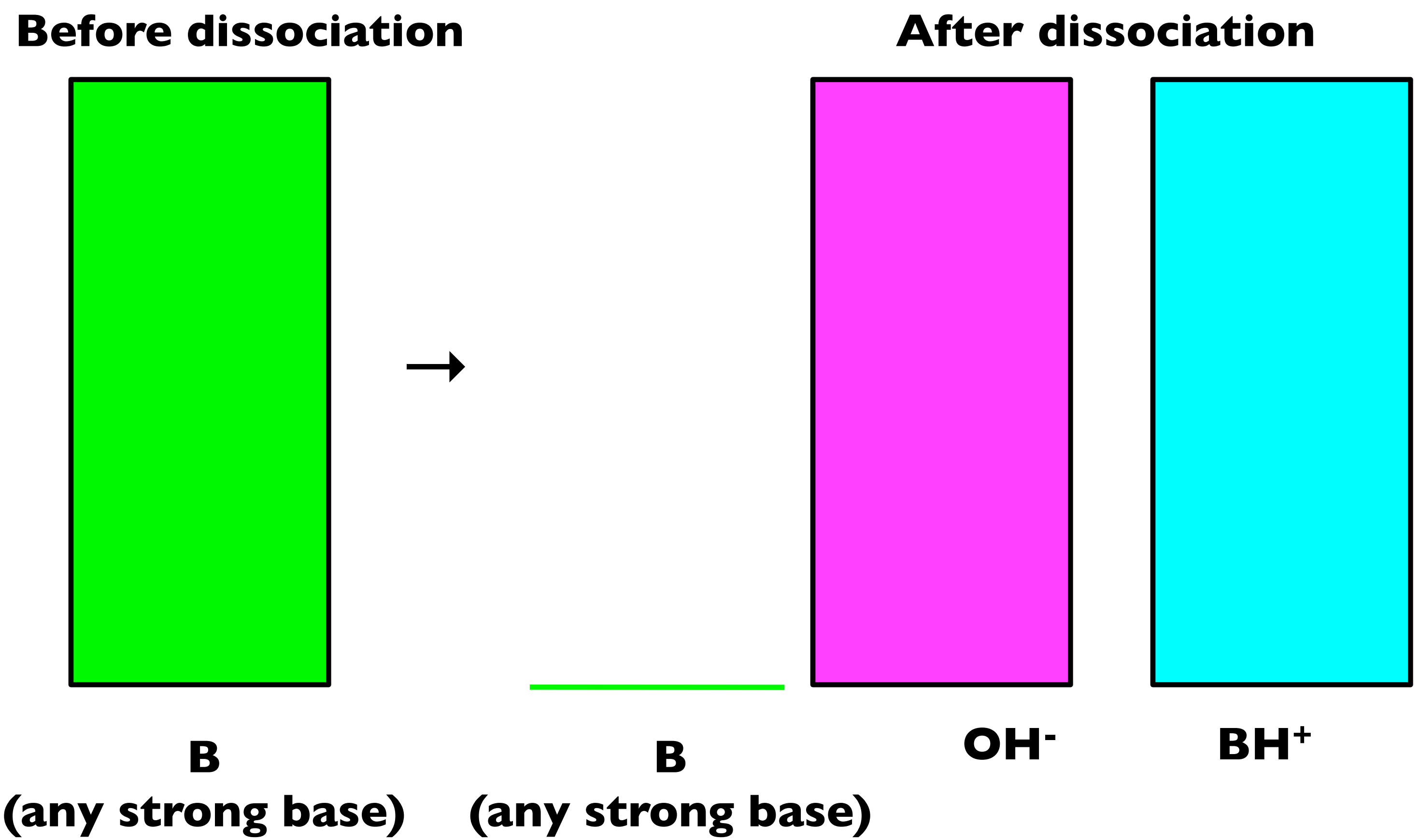
- Examples of strong bases:
  - Oxides & Hydroxides of alkali metals (Group 1) and of of alkali earth metals (Group 2) below beryllium [e.g. NaOH sodium hydroxide, MgO magnesium oxide, Na_2O sodium oxide]

- Strong bases completely dissociate in water (equilibrium favours products, lies to the right)
- This means 100% of the base will turn into ions. So if you have 0.2 M NaOH, it will turn into 0.2 M OH^-

- ie) $NaOH + H_2O \rightarrow Na^+ + OH^-$

Strong Bases

- Strong bases dissociate 100%
- $B + H_2O \rightarrow OH^- + BH^+$



Calculations that involve strong acids & bases

- Strong acids/bases (and strong electrolytes) completely dissociates into ions in water
  - $[H_3O]^+_{(aq)}$ is equal to the [strong acid]
  - $[OH]^-_{(aq)}$ is equal to the [strong base]
- You cannot determine the concentrations of ions of weak acids/bases/electrolytes this way because they do not completely dissociate in solution (which means we will have use the concept of EQUILIBRIUM!!!)

Example

- Find the concentration of hydronium ions in 4.5 mol/L HCl
  - Since HCl is a strong acid, it will completely dissociate into ions
  - $HCl + H_2O \rightarrow H_3O^+ + Cl^-$
  - 4.5 M 4.5 M
  - So, the $[H_3O^+]$ is 4.5 M

Example

- Is this solution acidic or basic: 31.9 mL of 2.75 M HCl added to 125 mL of 0.05 M $Mg(OH)_2$?
  - Find the moles of H_3O^+ (since HCl is strong)
  - $HCl + H_2O \rightarrow H_3O^+ + Cl^-$ (1:1 ratio)
  - n = cv = (2.75 M)(0.0319 L) = 0.0877 mol
  - Find the moles of OH^- ($Mg(OH)_2$ is strong)
  - $Mg(OH)_2 + H_2O \rightarrow Mg^{2+} + 2OH^-$ (1:2 ratio)
  - n = cv = (0.05 M)(0.125L) = 0.00625 mol x 2 = 0.0125 mol of hydroxide ion
  - Combine the two! 0.0877 mol H_3O^+ – 0.0125 mol OH^- leaves us with 0.0752 mol H_3O^+
  - c = n/v = 0.0752 / 0.1569 L = 0.479 M [H_3O^+]

Homework

- p. 24 in workbook