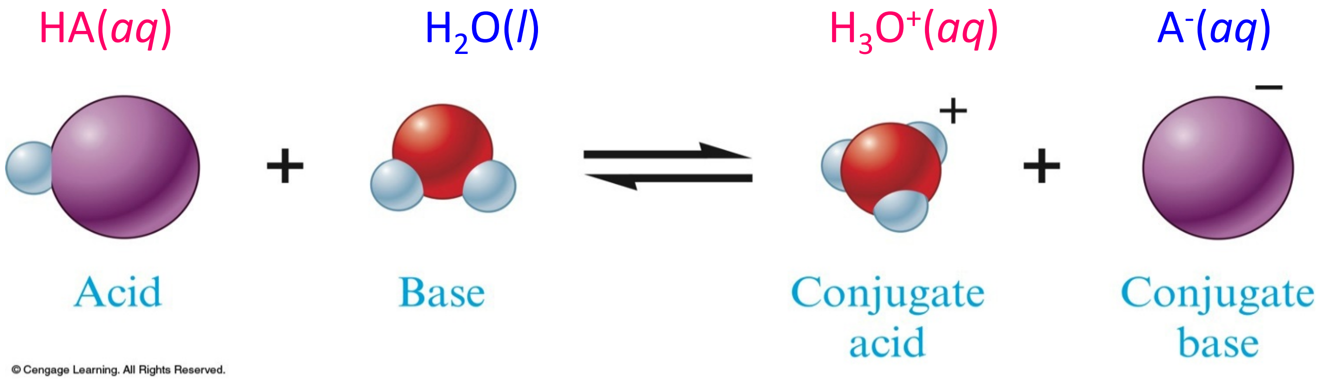
Acids and Bases

Properties	Acids	Bases
1. Taste	Sour	Bitter
2. Litmus paper	Turns Litmus paper	Turns Litmus paper
3. pH	pH 7 (high concentration of)	pH 7 (high concentration of)
4. Arrhenius	Yields excess H^+ in H_2O EX: $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$	Yields excess OH^- in H_2O EX: $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$
5. Brønsted–Lowry	Proton EX: $HCl_{(aq)} + H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$	Proton EX: $NH_{3(aq)} + H_2S \rightarrow NH_4^+_{(aq)} + SH^-_{(aq)}$

	Arrhenius acid base	Brønsted–Lowry acid base
Definition of acid	H^+ generator	H^+ provider
Definition of base	OH^- generator	H^+ receiver
Acid base reaction	Acid + Base → salt + H2O HCl + NaOH → NaCl + H2O	Proton transfer reaction, formation of H2O is no necessarily need $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$
Applicable system	Only for aqueous solution	Aqueous and non-aqueous solution

Conjugated Acids and Bases



1 acid-base reaction will have conjugated acid-base pair

How to judge conjugated acid and base: acid = conjugate base + H^+

$HClO_4 + H_2SO_4 \rightarrow ClO_4^- + H_3SO_4^+$

$HNO_3 + F^- \rightarrow NO_3^- + HF$

Which is more acidic: $HNO_3 > HF$
Which is more basic: $F^- > NO_3^-$

Stronger acid, its conjugate base will be a weak base
Weak strong
Stronger base, its conjugate acid will be a weak acid
Weak strong

EX: Which of the following species are NOT conjugated acid-base pair?

(A) H_3O^+, OH^-
(B) NH_4^+, NH_3
(C) HCO_3^-,CO_3^{2-}
(D) $HC_2H_3O_2$, $C_2H_3O_2^-$
(E) HCl, Cl^-

EX: with known acidity: HCL > HF>HNO_2>HClO>HCN, which one has the strongest conjugate base?

Type of acid

1. inorganic acid

1a. hydrogen halide: HCl, HBr,HI,HF

1b. Oxyacid: H_2SO_4, H_2SO_3,
HNO_3, HNO_2,
H_3PO_4, H_3PO_3, H_3PO_2,
$HClO_4$, $HClO_3$, $HClO_2$, HClO

2. Organic acid

2a. Carboxylic acid: CH_3COOH, C_6H_5COOH,$H_2C_2O_4$

Type of base

1. Metal hydroxide:

$Fe(OH)_3$, $Fe(OH)_2$
$Sn(OH)_4$, $Sn(OH)_2$
NaOH

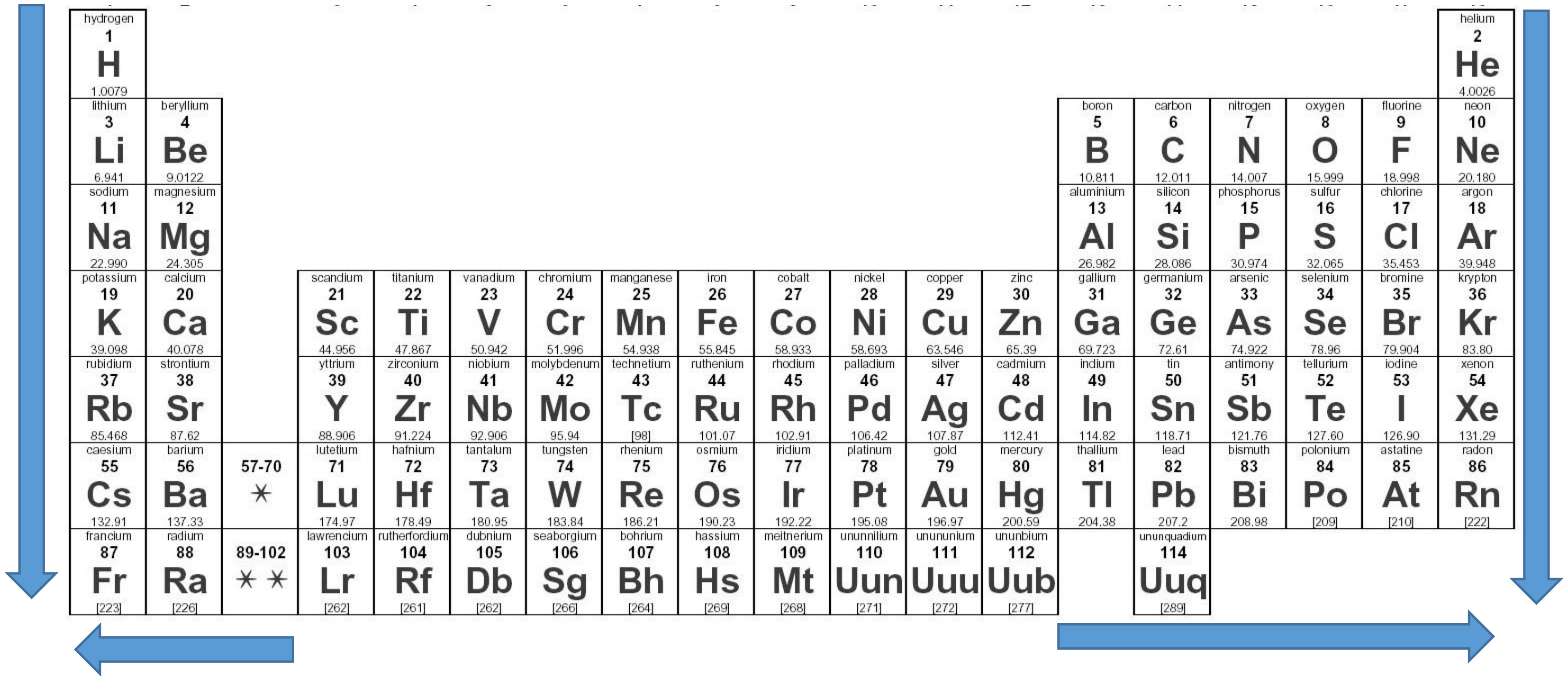
2. Metal oxide:

Na_2O

3. Metal Hydride:

NaH

Strong or weak acid/base ??



acidity of oxy acid: $n_O - n_H = 3, 2, 1, 0$

Basicity of metal hydroxide

acidity of hydrogen halide

strong base:

Quantify the acid and base strength: pH, pOH

$pH = -\log([H^+])$

$pOH = -\log([OH^-])$

→ Once you know $[H^+]$ and $[OH^-]$, you know the pH and pOH

How to know $[H^+]$ and $[OH^-]$? Use **equilibrium constant** !!

Neutral : H_2O

Acidic: strong acid, weak acid

Basic : strong base, weak base

$H_2O_{(l)} \rightarrow H^+_{(aq)} + OH^-_{(aq)}$ $\Delta H = 56$ kJ/mol

$K_{eq} = K_W = [H^+][OH^-] = 10^{-14}$ at 25C

For 1L water, at 25C

$[H_2O] = (1000/18)/1 = 55.56$ M

$pH = -\log([H^+]) = -\log(10^{-7}) = 7$

$pOH = -\log([OH^-]) = -\log(10^{-7}) = 7$

$\alpha = [H^+]/[H_2O]$ x100% = 1.8×10^{-7} %

Temperature	K_W	α	pK_W (= pH+pOH)	Neutral	
				$[H^+]$	pH
T = 25C	10^{-14}	1.8×10^{-7} %	14	10^{-7} M	7
T > 25C					
T < 25C					

Acidic: strong acid, weak

$$HA_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + A^-_{(aq)}$$

$$K_a = K_c = \frac{[H_3O^+][A^-]}{[HA]} = \frac{[H^+][A^-]}{[HA]}$$

Larger K_a, higher , more acidic

Basic : strong base, weak base

$$BOH_{(aq)} + H_2O_{(l)} \rightarrow B^+_{(aq)} + OH^-_{(aq)}$$

$$K_b = K_c = \frac{[B^+][OH^-]}{[BOH]}$$

Larger K_b, higher , more basic

K_a and K_b is a good indication of acid and base strength

Dissociation Constants of Some Acids at 25 °C[a]

Acid[b]	HA	A^-	K_a	pK_a
Perchloric	$HClO_4$	ClO_4^-	$\sim 10^{+8}$	~ -8
Permanganic	$HMnO_4$	MnO_4^-	$\sim 10^{+8}$	~ -8
Chloric	$HClO_3$	ClO_3^-	$\sim 10^{+3}$	~ -3
Nitric	HNO_3	NO_3^-		
Hydrobromic	HBr	Br^-		
Hydrochloric	HCl	Cl^-		
Sulfuric (1)	H_2SO_4	HSO_4^-		
Hydrated proton or protonated solvent	H^+	H_2O(solvent)	1.00	0.00
Trichloroacetic	CCl_3COOH	CCl_3COO^-	2×10^{-1}	0.70
Oxalic (1)	$HOOC-COOH$	$HOOC-COO^-$	5.9×10^{-2}	1.23
Dichloroacetic	$CHCl_2COOH$	$CHCl_2COO^-$	3.32×10^{-2}	1.48
Sulfurous (1)	H_2SO_3	HSO_3^-	1.54×10^{-2}	1.81
Sulfuric (2)	HSO_4^-	SO_4^{2-}	1.20×10^{-2}	1.92
Phosphoric (1)	H_3PO_4	$H_2PO_4^-$	7.52×10^{-3}	2.12
Bromoacetic	$CH_2BrCOOH$	CH_2BrCOO^-	2.05×10^{-3}	2.69
Malonic (1)	$HOOC-CH_2-COOH$	$HOOC-CH_2-COO^-$	1.49×10^{-3}	2.83
Chloroacetic	$CH_2ClCOOH$	CH_2ClCOO^-	1.40×10^{-3}	2.85
Nitrous	HNO_2	NO_2^-	4.6×10^{-4}	3.34
Hydrofluoric	HF	F^-	3.53×10^{-4}	3.45
Formic	$HCOOH$	$HCOO^-$	1.77×10^{-4}	3.75
Benzoic	C_6H_5COOH	$C_6H_5COO^-$	6.46×10^{-5}	4.19
Oxalic (2)	$HOOC-COO^-$	$^-OOC-COO^-$	6.4×10^{-5}	4.19
Acetic	CH_3COOH	CH_3COO^-	1.76×10^{-5}	4.75
Propionic	CH_3CH_2COOH	$CH_3CH_2COO^-$	1.34×10^{-5}	4.87
Malonic (2)	$HOOC-CH_2-COO^-$	$^-OCC-CH_2-COO^-$	2.03×10^{-6}	5.69
Carbonic (1)	$CO_2 + H_2O$	HCO_3^-	4.3×10^{-7}	6.37
Sulfurous (2)	HSO_3^-	SO_3^{2-}	1.02×10^{-7}	6.91
Hydrogen sulfide (1)	H_2S	HS^-	9.1×10^{-8}	7.04
Phosphoric (2)	$H_2PO_4^-$	HPO_4^{2-}	6.23×10^{-8}	7.21
Ammonium ion	NH_4^+	NH_3	5.6×10^{-10}	9.25
Hydrocyanic	HCN	CN^-	4.93×10^{-10}	9.31
Silver ion	$Ag^+ + H_2O$	$AgOH$	9.1×10^{-11}	10.04
Carbonic (2)	HCO_3^-	CO_3^{2-}	5.61×10^{-11}	10.25
Hydrogen peroxide	H_2O_2	HO_2^-	2.4×10^{-12}	11.62
Hydrogen sulfide (2)	HS^-	S^{2-}	1.1×10^{-12}	11.96
Phosphoric (3)	HPO_4^{2-}	PO_4^{3-}	2.2×10^{-13}	12.67
Water[c]	H_2O	OH^-		

Strong acid, base:

- ~100% dissociate into $H^+ + A^-$ or $B^+ + OH^-$
- Very big K_a or K_b

Ex: calculate the pH of 0.1M and $1x10^{-10}$M HCl

Weak acid, base:

- Partially dissociate into $H^+ + A^-$ or $B^+ + OH^-$
- Small K_a or K_b (<1)

Ex: calculate the pH and percent dissociation of 1M acetic acid CH_3COOH, $K_a = 1.8 \times 10^{-5}$

K_a and K_b of conjugated acid and base:

$HA_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + A^-_{(aq)}$

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

$A^-_{(aq)} + H_2O_{(l)} \rightarrow HA_{(aq)} + OH^-_{(aq)}$

$$K_b = \frac{[HA][OH^-]}{[A^-]}$$

$$Ka \times Kb = \frac{[H^+][A^-]}{[HA]} \times \frac{[HA][OH^-]}{[A^-]} = [H^+][OH^-] = K_W$$

K_a is inversely proportional to K_b

Stronger acid, its conjugate base will be a weak base
Weak strong
Stronger base, its conjugate acid will be a weak acid
Weak strong

$pK_a + pK_b = pK_w = 14$ at 25C

Acid	K_a	Base	K_b
HNO_3	(Strong acid)	NO_3^-	(Negligible basicity)
HF	6.8×10^{-4}	F^-	1.5×10^{-11}
$HC_2H_3O_2$	1.8×10^{-5}	$C_2H_3O_2^-$	5.6×10^{-10}
H_2CO_3	4.3×10^{-7}	HCO_3^-	2.3×10^{-8}
NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}
HCO_3^-	5.6×10^{-11}	CO_3^{2-}	1.8×10^{-4}
OH^-	(Negligible acidity)	O^{2-}	(Strong base)

Polyprotic acid

Acid with multiple dissociable protons :

H_2SO_4, H_2SO_3 , H_2CO_3, , H_3PO_3

H_3PO_4

Polyprotic acids dissociate in a stepwise manner

Ex: H_2SO_4 $_{(aq)}$

Major species:

Minor species:

Ex: H_3PO_4 $_{(aq)}$

Major species:

Minor species:

Calculate the concentrations at equilibrium of H_2CO_3, HCO_3^-,CO_2^{2-} and H^+ in a saturated aqueous solution of H_2CO_3 in which the original concentration of H_2CO_3 is 0.034M (K_{a1}= 4.3 x10^{-7},K_{a2}= 4.8x10^{-11})

Acid-base properties of Salts

Salts are also called ionic compounds (cation + anion)

Salts can be either soluble or insoluble in water

Soluble salts: can act as acid, base or neutral in water

2 step process: dissociation of salt, interaction with water

	cation	anion
acidic	Conjugate acid of base NH_4^+	
neutral	Group 1 and 2	Conjugate base of acid ClO_4^-, ClO_3^-, I^-,Br^-,Cl^-,NO_3^- SO_4^{2-}
basic		Conjugate base of acid HS^-, HCO_3^-,HPO_4^{2-},CH_3COO^-

Calculate the pH of a 0.30M NaF solution, $K_a = 6.6 \times 10^{-4}$.

$NaF_{(aq)} \rightarrow Na^+_{(aq)} + F^-_{(aq)}$

$F^-_{(aq)} + H_2O_{(l)} \rightarrow HF_{(aq)} + OH^-_{(aq)}$

Arrange the following 0.1M solutions in order of the most acidic to most basic : KOH, KCl, KCN,NH_4Cl, HCl