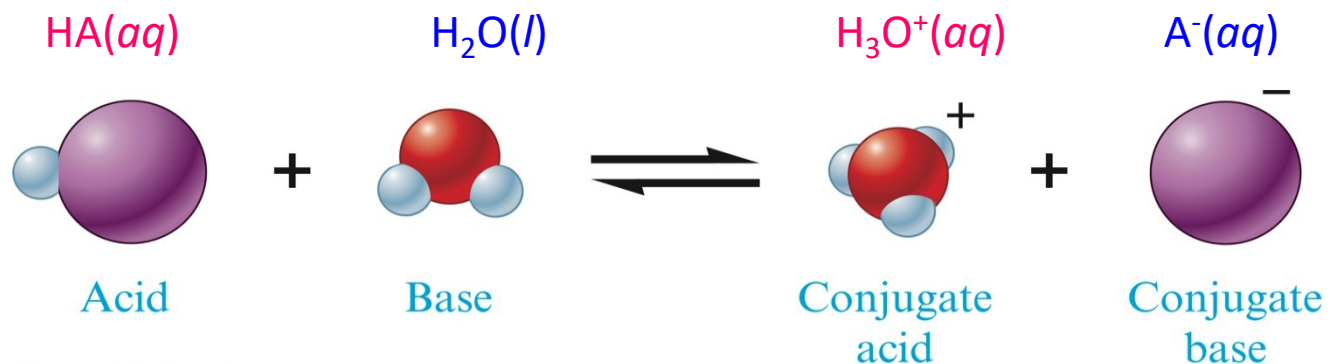


Acids and Bases

Properties	Acids	Bases
1. Taste	Sour	Bitter
2. Litmus paper	Turns Litmus paper	Turns Litmus paper
3. pH	pH < 7 (high concentration of H^+)	pH > 7 (high concentration of OH^-)
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 \rightarrow salt + H_2O $HCl + NaOH \rightarrow NaCl + H_2O$	Proton transfer reaction, formation of H_2O is not necessarily needed $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$
Applicable system	Only for aqueous solution	Aqueous and non-aqueous solution

Conjugated Acids and Bases



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

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



Which is more acidic: HNO₃ > HF

Which is more basic: F⁻ > NO₃⁻

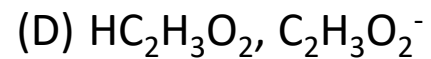
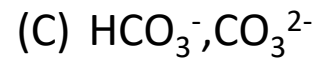
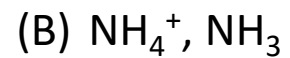
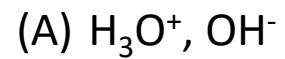
Stronger acid, its conjugate base will be a weak base

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?



EX: with known acidity: $\text{HCl} > \text{HF} > \text{HNO}_2 > \text{HClO} > \text{HCN}$, 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 , $\text{C}_6\text{H}_5\text{COOH}$, $\text{H}_2\text{C}_2\text{O}_4$

Type of base

1. Metal hydroxide:

$\text{Fe}(\text{OH})_3$, $\text{Fe}(\text{OH})_2$
 $\text{Sn}(\text{OH})_4$, $\text{Sn}(\text{OH})_2$
NaOH

2. Metal oxide:

Na_2O

3. Metal Hydride:

NaH

Strong or weak acid/base ??

hydrogen 1 H 1.0079																	helium 2 He 4.0026	
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180	
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948	
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80	
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29	
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [269]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]	ununquadium 114 Uuq [289]					

acidity of oxy acid: $n_{\text{O}} - n_{\text{H}} = 3, 2, 1, 0$

Basicity of metal hydroxide

strong base:

acidity of hydrogen halide

Quantify the acid and base strength: pH, pOH

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

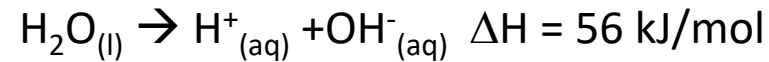
$$\text{pOH} = -\log([\text{OH}^-])$$



Once you know $[\text{H}^+]$ and $[\text{OH}^-]$, you know the pH and pOH

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

Neutral : H_2O



For 1L water, at 25C

$$[\text{H}_2\text{O}] = (1000/18)/1 = 55.56 \text{ M}$$

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

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

Acidic: strong acid, weak acid

Basic : strong base, weak base

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

$$\alpha = [\text{H}^+]/[\text{H}_2\text{O}] \times 100\% = 1.8 \times 10^{-7} \%$$

Temperature	K_{W}	α	$\text{p}K_{\text{W}}$ (= pH+pOH)	Neutral	
				$[\text{H}^+]$	pH
T = 25C	10^{-14}	$1.8 \times 10^{-7} \%$	14	10^{-7} M	7
T > 25C					
T < 25C					

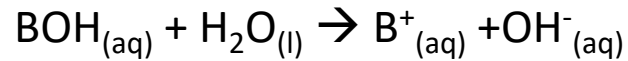
Acidic: strong acid, weak



$$K_a = K_c = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]} = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

Larger K_a , higher $\text{p}K_a$, more acidic

Basic : strong base, weak base



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

Larger K_b , higher $\text{p}K_b$, 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	$\text{p}K_a$
Perchloric	HClO ₄	ClO ₄ ⁻	~10 ⁺⁸	~-8
Permanganic	HMnO ₄	MnO ₄ ⁻	~10 ⁺⁸	~-8
Chloric	HClO ₃	ClO ₃ ⁻	~10 ⁺³	~-3
Nitric	HNO ₃	NO ₃ ⁻		
Hydrobromic	HBr	Br ⁻		
Hydrochloric	HCl	Cl ⁻		
Sulfuric (1)	H ₂ SO ₄	HSO ₄ ⁻		
Hydrated proton or protonated solvent	H ⁺	H ₂ O(solvent)	1.00	0.00
Trichloroacetic	CCl ₃ COOH	CCl ₃ COO ⁻	2 × 10 ⁻¹	0.70
Oxalic (1)	HOOC—COOH	HOOC—COO ⁻	5.9 × 10 ⁻²	1.23
Dichloroacetic	CHCl ₂ COOH	CHCl ₂ COO ⁻	3.32 × 10 ⁻²	1.48
Sulfurous (1)	H ₂ SO 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 ₃ PO ₄	H ₂ PO ₄ ⁻	7.52 × 10 ⁻³	2.12
Bromoacetic	CH ₂ BrCOOH	CH ₂ BrCOO ⁻	2.05 × 10 ⁻³	2.69
Malonic (1)	HOOC—CH ₂ —COOH	HOOC—CH ₂ —COO ⁻	1.49 × 10 ⁻³	2.83
Chloroacetic	CH ₂ ClCOOH	CH ₂ ClCOO ⁻	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 ₆ H ₅ COOH	C ₆ H ₅ COO ⁻	6.46 × 10 ⁻⁵	4.19
Oxalic (2)	HOOC—COO ⁻	-OOC—COO ⁻	6.4 × 10 ⁻⁵	4.19
Acetic	CH ₃ COOH	CH ₃ COO ⁻	1.76 × 10 ⁻⁵	4.75
Propionic	CH ₃ CH ₂ COOH	CH ₃ CH ₂ COO ⁻	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 ₂ O	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 ₂ S	HS ⁻	9.1 × 10 ⁻⁸	7.04
Phosphoric (2)	H ₂ PO 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 ₂ O	AgOH	9.1 × 10 ⁻¹¹	10.04
Carbonic (2)	HCO ₃ ⁻	CO ₃ ²⁻	5.61 × 10 ⁻¹¹	10.25
Hydrogen peroxide	H ₂ O 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 ₂ O	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 1×10^{-10} M HCl

Weak acid, base:

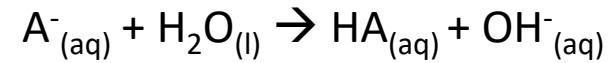
- Partially dissociate into $\text{H}^+ + \text{A}^-$ or $\text{B}^+ + \text{OH}^-$
- Small K_a or K_b (<1)

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:



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



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

$$K_a \times K_b = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} \times \frac{[\text{HA}][\text{OH}^-]}{[\text{A}^-]} = [\text{H}^+][\text{OH}^-] = K_w$$



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

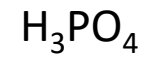
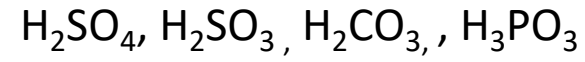
strong

$$\text{p}K_a + \text{p}K_b = \text{p}K_w = 14 \text{ at } 25\text{C}$$

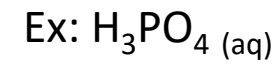
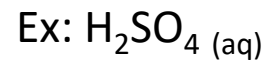
Acid	K_a	Base	K_b
HNO_3	(Strong acid)	NO_3^-	(Negligible basicity)
HF	6.8×10^{-4}	F^-	1.5×10^{-11}
$\text{HC}_2\text{H}_3\text{O}_2$	1.8×10^{-5}	$\text{C}_2\text{H}_3\text{O}_2^-$	5.6×10^{-10}
H_2CO_3	4.3×10^{-7}	HCO_3^-	2.3×10^{-8}
NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}
HCO_3^-	5.6×10^{-11}	CO_3^{2-}	1.8×10^{-4}
OH^-	(Negligible acidity)	O^{2-}	(Strong base)

Polyprotic acid

Acid with multiple dissociable protons :



Polyprotic acids dissociate in a stepwise manner



Major species:

Major species:

Minor species:

Minor species:

Calculate the concentrations at equilibrium of H_2CO_3 , HCO_3^- , CO_3^{2-} and H^+ in a saturated aqueous solution of H_2CO_3 in which the original concentration of H_2CO_3 is 0.034M ($K_{a1} = 4.3 \times 10^{-7}$, $K_{a2} = 4.8 \times 10^{-11}$)

Acid-base properties of Salts

Salts are also called ionic compounds (**cation** + **anion**)

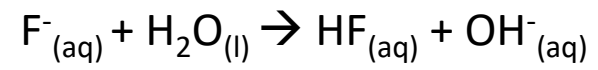
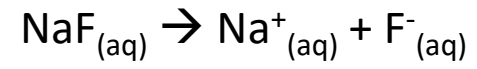
Salts can be either soluble or insoluble in water

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, $K_a = 6.6 \times 10^{-4}$.



Arrange the following 0.1M solutions in order of the most acidic to most basic : KOH, KCl, KCN, NH₄Cl, HCl