

RELATIVE STRENGTHS OF SELECTED WEAK ACIDS AND WEAK BASES

The fundamental relationship between acid strengths and base strengths in H₂O is that for a conjugate acid-base pair, $K_a K_b = K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ at 25°C.

Note that the hydronium ion, H₃O⁺, is very often written simply as H⁺, for short.

HYDROLYSIS of WEAK ACIDS Acid + H ₂ O ⇌ Conjugate Base + H ₃ O ⁺	$K_a = \frac{[\text{Base}][\text{H}_3\text{O}^+]}{[\text{Acid}]}$
$\text{HSO}_4^- + \text{H}_2\text{O} \rightleftharpoons \text{SO}_4^{2-} + \text{H}_3\text{O}^+$	$K_a = 1.2 \times 10^{-2}$
$\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+$	$K_a = 1.8 \times 10^{-5}$
$\text{H}_2\text{S} + \text{H}_2\text{O} \rightleftharpoons \text{HS}^- + \text{H}_3\text{O}^+$	$K_a = 1.0 \times 10^{-7}$
$\text{NH}_4^+ + \text{H}_2\text{O} \rightleftharpoons \text{NH}_3 + \text{H}_3\text{O}^+$	$K_a = 5.7 \times 10^{-10}$
$\text{HCN} + \text{H}_2\text{O} \rightleftharpoons \text{CN}^- + \text{H}_3\text{O}^+$	$K_a = 4.9 \times 10^{-10}$
$\text{HCO}_3^- + \text{H}_2\text{O} \rightleftharpoons \text{CO}_3^{2-} + \text{H}_3\text{O}^+$	$K_a = 4.7 \times 10^{-11}$

HSO₄⁻ (bisulfate ion, or hydrogen sulfate ion) is the *strongest weak acid* listed above.

HCO₃⁻ (bicarbonate ion, or hydrogen carbonate ion) is the *weakest weak acid* listed above.

CO₃²⁻ (carbonate ion) is the *strongest weak base* listed above, because $K_a K_b = K_w$.

SO₄²⁻ (sulfate ion) is the *weakest weak base* listed above, because $K_a K_b = K_w$.

HYDROLYSIS of WEAK BASES Base + H ₂ O ⇌ Conjugate Acid + OH ⁻	$K_b = \frac{[\text{Acid}][\text{OH}^-]}{[\text{Base}]}$
$\text{CO}_3^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{OH}^-$	$K_b = 2.1 \times 10^{-4}$
$\text{CN}^- + \text{H}_2\text{O} \rightleftharpoons \text{HCN} + \text{OH}^-$	$K_b = 2.0 \times 10^{-5}$
$\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-$	$K_b = 1.8 \times 10^{-5}$
$\text{HS}^- + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{S} + \text{OH}^-$	$K_b = 1.0 \times 10^{-7}$
$\text{CH}_3\text{COO}^- + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COOH} + \text{OH}^-$	$K_b = 5.7 \times 10^{-10}$
$\text{SO}_4^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{HSO}_4^- + \text{OH}^-$	$K_b = 8.3 \times 10^{-13}$

Observe that the conjugate base of a **weak acid** is a **weak base** (*not* a strong base), and the conjugate acid of a **weak base** is a **weak acid** (*not* a strong acid), as shown in the examples given above. The strength of the weak acid and the strength of the weak base in each conjugate acid-base pair are related by the fundamental relation $K_a K_b = K_w$. These tables contain the same information.

The anions ClO₄⁻, Cl⁻, Br⁻, I⁻, NO₃⁻, and HSO₄⁻, conjugate bases of the six **strong acids** HClO₄, HCl, HBr, HI, HNO₃, and H₂SO₄, respectively, do not combine at all with H⁺ from water or any other source. The basic character of these anions in aqueous solution is so extremely weak as to be totally negligible: they are not considered to be bases at all.

ACID	K_a	CONJUGATE BASE
<p>VERY STRONG ACIDS: more acidic than H^+ $HNO_3, HCl...$ never found associated in water</p>	> 1	<p>NOT BASIC at all in water: do not react as bases with <i>water</i> NO_3^-, Cl^-</p>
H_3O^+	1	H_2O
<p>WEAK ACIDS</p> <p style="text-align: right;">Stronger</p> <p style="text-align: center;">HNO_2</p> <p style="text-align: center;">CH_3COOH</p> <p style="text-align: center;">HCO_3^-</p> <p style="text-align: center;">HS^-</p> <p style="text-align: right;">Weaker</p> <p style="text-align: center;">↑</p>		<p>WEAK BASES:</p> <p style="text-align: right;">Weaker</p> <p style="text-align: center;">NO_2^- slightly basic</p> <p style="text-align: center;">CH_3COO^-</p> <p style="text-align: center;">CO_3^{2-}</p> <p style="text-align: center;">S^{2-} quite basic (ET-1)</p> <p style="text-align: right;">Stronger</p> <p style="text-align: center;">↓</p>
H_2O	10^{-14}	OH^-
<p>NOT ACIDIC at all in water do not react as acids with <i>water</i>: CH_3OH, OH^- in other solvents, can donate H^+</p>	$< 10^{-14}$	<p>VERY STRONG BASES: more basic than OH^- CH_3O^-, O^{2-} never found as ions in water</p>

SELECTED ACIDS IN ORDER OF THEIR ACIDITY
CHEMISTRY BC2001x

ACID FORMULA	NAME OF ACID	K_a	CONJUGATE BASE
HClO₄	Perchloric acid	← The six acids on the left are all VERY STRONG. In aqueous solution they dissociate 100%, forming H ₃ O ⁺ and the conjugate base on the right. None is ever found as acid in water. These six anions on the right → are not at all basic in water.	ClO₄⁻
HI	Hydroiodic acid		I⁻
HBr	Hydrobromic acid		Br⁻
H₂SO₄	Sulfuric acid		HSO₄⁻
HCl	Hydrochloric acid		Cl⁻
HNO₃	Nitric acid		NO₃⁻
H₃O⁺	HYDRONIUM ION	1.0	H₂O
H₂C₂O₄	Oxalic acid	5.9×10^{-2}	HC₂O₄⁻
H₂SO₃	Sulfurous acid (= SO ₂ + H ₂ O)	1.2×10^{-2}	HSO₃⁻
HSO₄⁻	Hydrogen sulfate ion (bisulfate ion)	1.2×10^{-2}	SO₄²⁻
HClO₂	Chlorous acid	1.1×10^{-2}	ClO₂⁻
H₃PO₄	Phosphoric acid (orthophosphoric acid)	7.5×10^{-3}	H₂PO₄⁻
H₃AsO₄	Arsenic acid (orthoarsenic acid)	6.0×10^{-3}	H₂AsO₄⁻
ClCH₂COOH	Monochloroacetic acid	1.4×10^{-3}	ClCH₂COO⁻
HF	Hydrofluoric acid	7.2×10^{-4}	F⁻
HNO₂	Nitrous acid	4.5×10^{-4}	NO₂⁻
HCOOH	Formic acid	1.8×10^{-4}	HCOO⁻
HC₂O₄⁻	Hydrogen oxalate ion	6.4×10^{-5}	C₂O₄²⁻
C₆H₅COOH	Benzoic acid	6.3×10^{-5}	C₆H₅COO⁻
CH₃COOH	Acetic acid	1.8×10^{-5}	CH₃COO⁻
H₂CO₃	Carbonic acid (= CO ₂ + H ₂ O)	4.3×10^{-7}	HCO₃⁻
HCrO₄⁻	Hydrogen chromate ion	3.0×10^{-7}	CrO₄²⁻
H₂AsO₄⁻	Dihydrogen arsenate ion	1.0×10^{-7}	HasO₄²⁻
H₂S	Hydrosulfuric acid (hydrogen sulfide)	1.0×10^{-7}	HS⁻
H₂PO₄⁻	Dihydrogen phosphate ion	6.2×10^{-8}	HPO₄²⁻
HSO₃⁻	Hydrogen sulfite ion (bisulfite ion)	6.2×10^{-8}	SO₃²⁻
HOCl	Hypochlorous acid	3.5×10^{-8}	OCl⁻
HOBr	Hypobromous acid	2.5×10^{-9}	OBr⁻
H₃BO₃	Boric acid	5.8×10^{-10}	B(OH)₄⁻

ACID FORMULA	NAME OF ACID		K_a	Conjugate BASE
NH_4^+	Ammonium ion		5.7×10^{-10}	NH_3
HCN	Hydrocyanic acid (hydrogen cyanide)		4.9×10^{-10}	CN^-
$\text{C}_6\text{H}_5\text{OH}$	Phenol		1.3×10^{-10}	$\text{C}_6\text{H}_5\text{O}^-$
HCO_3^-	Hydrogen carbonate (bicarbonate) ion		4.7×10^{-11}	CO_3^{2-}
CH_3NH_3^+	Methylammonium ion		2.4×10^{-11}	CH_3NH_2
HOI	Hypoiodous acid		1.0×10^{-11}	OI^-
HAsO_4^{2-}	Hydrogen arsenate ion		4.0×10^{-12}	AsO_4^{3-}
HPO_4^{2-}	Hydrogen (monohydrogen) phosphate ion		4.0×10^{-13}	PO_4^{3-}
HS^-	Hydrosulfide (bisulfide) ion		1.3×10^{-13}	S^{2-}
H_2O	WATER		1.0×10^{-14}	OH^-
$\text{C}_2\text{H}_5\text{OH}$	Ethanol	Each of the anions on the right \rightarrow is a VERY STRONG base. Each reacts 100% with water, forming OH^- and the conjugate negligibly weak acid on the left. The conjugate acids are thus not considered to be acidic in water.	$\text{C}_2\text{H}_5\text{O}^-$	
NH_3	Ammonia		NH_2^-	
H_2	Hydrogen		H^-	
OH^-	Hydroxide ion		O^{2-}	

- Nomenclature:** Gaseous molecules containing hydrogen that dissolve in water and act as acids in solution are named hydrogen (Q)-ide as molecules and hydro(Q)-ic acid in water. Examples: HCl (hydrogen chloride, hydrochloric acid); HCN (hydrogen cyanide, hydrocyanic acid); H_2S (hydrogen sulfide, hydrosulfuric acid).
- Note the **leveling effect of water** on the acid strengths of strong acids and on the base strengths of strong bases. The strong acids are given in order of their intrinsic acid strengths, but they are equally acidic in water, because the strongest acid that can exist as such in water is the hydronium ion, H_3O^+ . The strong bases are given in order of their intrinsic base strength, but they are equally basic in water, because the strongest base that can exist as such in water is the hydroxide ion, OH^- . Differences in intrinsic strength among such strong acids and such strong bases can be observed only in various protic solvents other than water.
- Note the following trends:
 - Acidity in an acid series increases as the degree of oxygenation of a central atom increases. Examples: HOCl , HClO_2 , HClO_4 ; HNO_2 , HNO_3 ; H_2SO_3 , H_2SO_4 .
 - Acidity in the following two acid series increases with halogen identity in opposite directions as follows: HOI , HOBr , HOCl ; HF , (HCl , HBr , HI).
 - Increasing halogen substitution on the hydrocarbon portion makes an acid stronger. Example: monochloroacetic acid, ClCH_2COOH , is stronger than acetic acid, CH_3COOH .