

# Equilibrium Constants

TABLE A5.1 Ionization Constants of Selected Acids at 25°C

Acid	Step	Aqueous Equilibrium <sup>a</sup>	$K_a$	$pK_a$
acetic	1	$\text{CH}_3\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_3\text{COO}^-(aq)$	$1.76 \times 10^{-5}$	4.75
arsenic	1	$\text{H}_3\text{AsO}_4(aq) \rightleftharpoons \text{H}^+(aq) + \text{H}_2\text{AsO}_4^-(aq)$	$5.5 \times 10^{-3}$	2.26
	2	$\text{H}_2\text{AsO}_4^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{AsO}_4^{2-}(aq)$	$1.7 \times 10^{-7}$	6.77
	3	$\text{HAsO}_4^{2-}(aq) \rightleftharpoons \text{H}^+(aq) + \text{AsO}_4^{3-}(aq)$	$5.1 \times 10^{-12}$	11.29
ascorbic	1	$\text{H}_2\text{C}_6\text{H}_6\text{O}_6(aq) \rightleftharpoons \text{H}^+(aq) + \text{HC}_6\text{H}_6\text{O}_6^-(aq)$	$9.1 \times 10^{-5}$	4.04
	2	$\text{HC}_6\text{H}_6\text{O}_6^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{C}_6\text{H}_6\text{O}_6^{2-}(aq)$	$5 \times 10^{-12}$	11.3
benzoic	1	$\text{C}_6\text{H}_5\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{C}_6\text{H}_5\text{COO}^-(aq)$	$6.25 \times 10^{-5}$	4.20
boric	1	$\text{H}_3\text{BO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{H}_2\text{BO}_3^-(aq)$	$5.4 \times 10^{-10}$	9.27
	2	$\text{H}_2\text{BO}_3^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{HBO}_3^{2-}(aq)$	$<10^{-14}$	$>14$
bromoacetic	1	$\text{CH}_2\text{BrCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_2\text{BrCOO}^-(aq)$	$2.0 \times 10^{-3}$	2.70
butanoic	1	$\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-(aq)$	$1.5 \times 10^{-5}$	4.82
carbonic	1	$\text{H}_2\text{CO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{HCO}_3^-(aq)$	$4.3 \times 10^{-7}$	6.37
	2	$\text{HCO}_3^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{CO}_3^{2-}(aq)$	$4.7 \times 10^{-11}$	10.33
chloric	1	$\text{HClO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{ClO}_3^-(aq)$	$\sim 1$	$\sim 0$
chloroacetic	1	$\text{CH}_2\text{ClCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_2\text{ClCOO}^-(aq)$	$1.4 \times 10^{-3}$	2.85
chlorous	1	$\text{HClO}_2(aq) \rightleftharpoons \text{H}^+(aq) + \text{ClO}_2^-(aq)$	$1.1 \times 10^{-2}$	1.96
citric	1	$\text{HOC}(\text{CH}_2)_2(\text{COOH})_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{HOC}(\text{CH}_2)_2(\text{COOH})_2\text{COO}^-(aq)$	$7.4 \times 10^{-4}$	3.13
	2	$\text{HOC}(\text{CH}_2)_2(\text{COOH})_2\text{COO}^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{HOC}(\text{CH}_2)_2(\text{COOH})(\text{COO}^-)_2(aq)$	$1.7 \times 10^{-5}$	4.77
	3	$\text{HOC}(\text{CH}_2)_2(\text{COOH})(\text{COO}^-)_2(aq) \rightleftharpoons \text{H}^+(aq) + \text{HOC}(\text{CH}_2)_2(\text{COO}^-)_3(aq)$	$4.0 \times 10^{-7}$	6.40
dichloroacetic	1	$\text{CHCl}_2\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CHCl}_2\text{COO}^-(aq)$	$5.5 \times 10^{-2}$	1.26
ethanol	1	$\text{CH}_3\text{CH}_2\text{OH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_3\text{CH}_2\text{O}^-(aq)$	$1.3 \times 10^{-16}$	15.9
fluoroacetic	1	$\text{CH}_2\text{FCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_2\text{FCOO}^-(aq)$	$2.6 \times 10^{-3}$	2.59
formic	1	$\text{HCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{HCOO}^-(aq)$	$1.77 \times 10^{-4}$	3.75
germanic	1	$\text{H}_2\text{GeO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{HGeO}_3^-(aq)$	$9.8 \times 10^{-10}$	9.01
	2	$\text{HGeO}_3^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{GeO}_3^{2-}(aq)$	$5 \times 10^{-13}$	12.3
hydr(o)azoic	1	$\text{HN}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{N}_3^-(aq)$	$1.9 \times 10^{-5}$	4.72

TABLE A5.1 Ionization Constants of Selected Acids at 25°C (Continued)

Acid	Step	Aqueous Equilibrium <sup>a</sup>	$K_a$	$pK_a$
hydrobromic	1	$\text{HBr}(aq) \rightleftharpoons \text{H}^+(aq) + \text{Br}^-(aq)$	$\gg 1$ (strong)	<0
hydrochloric	1	$\text{HCl}(aq) \rightleftharpoons \text{H}^+(aq) + \text{Cl}^-(aq)$	$\gg 1$ (strong)	<0
hydrocyanic	1	$\text{HCN}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CN}^-(aq)$	$6.2 \times 10^{-10}$	9.21
hydrofluoric	1	$\text{HF}(aq) \rightleftharpoons \text{H}^+(aq) + \text{F}^-(aq)$	$6.8 \times 10^{-4}$	3.17
hydr(o)iodic	1	$\text{HI}(aq) \rightleftharpoons \text{H}^+(aq) + \text{I}^-(aq)$	$\gg 1$ (strong)	<0
hydrosulfuric	1	$\text{H}_2\text{S}(aq) \rightleftharpoons \text{H}^+(aq) + \text{HS}^-(aq)$	$8.9 \times 10^{-8}$	7.05
	2	$\text{HS}^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{S}^{2-}(aq)$	$\sim 10^{-19}$	$\sim 19$
hypobromous	1	$\text{HBrO}(aq) \rightleftharpoons \text{H}^+(aq) + \text{BrO}^-(aq)$	$2.3 \times 10^{-9}$	8.64
hypochlorous	1	$\text{HClO}(aq) \rightleftharpoons \text{H}^+(aq) + \text{ClO}^-(aq)$	$2.9 \times 10^{-8}$	7.54
hypoiodous	1	$\text{HIO}(aq) \rightleftharpoons \text{H}^+(aq) + \text{IO}^-(aq)$	$2.3 \times 10^{-11}$	10.64
iodic	1	$\text{HIO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{IO}_3^-(aq)$	$1.7 \times 10^{-1}$	0.77
iodoacetic	1	$\text{CH}_2\text{ICOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_2\text{ICOO}^-(aq)$	$7.6 \times 10^{-4}$	3.12
lactic	1	$\text{CH}_3\text{CHOHCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_3\text{CHOHCOO}^-(aq)$	$1.4 \times 10^{-4}$	3.85
maleic ( <i>cis</i> -butenedioic)	1	$\text{HOOCCH}=\text{CHCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{HOOCCH}=\text{CHCOO}^-(aq)$	$1.2 \times 10^{-2}$	1.92
	2	$\text{HOOCCH}=\text{CHCOO}^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{OOCCH}=\text{CHCOO}^-(aq)$	$4.7 \times 10^{-7}$	6.33
malonic	1	$\text{HOOCCH}_2\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{HOOCCH}_2\text{COO}^-(aq)$	$1.5 \times 10^{-3}$	2.82
	2	$\text{HOOCCH}_2\text{COO}^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{OOCCH}_2\text{COO}^-(aq)$	$2.0 \times 10^{-6}$	5.70
nitric	1	$\text{HNO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{NO}_3^-(aq)$	$\gg 1$ (strong)	<0
nitrous	1	$\text{HNO}_2(aq) \rightleftharpoons \text{H}^+(aq) + \text{NO}_2^-(aq)$	$4.0 \times 10^{-4}$	3.40
oxalic	1	$\text{HOCCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{HOCCOO}^-(aq)$	$5.9 \times 10^{-2}$	1.23
	2	$\text{HOCCOO}^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{OCCOO}^-(aq)$	$6.4 \times 10^{-5}$	4.19
perchloric	1	$\text{HClO}_4(aq) \rightleftharpoons \text{H}^+(aq) + \text{ClO}_4^-(aq)$	$\gg 1$ (strong)	<0
periodic	1	$\text{HIO}_4(aq) \rightleftharpoons \text{H}^+(aq) + \text{IO}_4^-(aq)$	$2.3 \times 10^{-2}$	1.64
phenol	1	$\text{C}_6\text{H}_5\text{OH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{C}_6\text{H}_5\text{O}^-(aq)$	$1.3 \times 10^{-10}$	9.89
phosphoric	1	$\text{H}_3\text{PO}_4(aq) \rightleftharpoons \text{H}^+(aq) + \text{H}_2\text{PO}_4^-(aq)$	$6.9 \times 10^{-3}$	2.16
	2	$\text{H}_2\text{PO}_4^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{HPO}_4^{2-}(aq)$	$6.4 \times 10^{-8}$	7.19
	3	$\text{HPO}_4^{2-}(aq) \rightleftharpoons \text{H}^+(aq) + \text{PO}_4^{3-}(aq)$	$4.8 \times 10^{-13}$	12.32
propanoic	1	$\text{CH}_3\text{CH}_2\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_3\text{CH}_2\text{COO}^-(aq)$	$1.4 \times 10^{-5}$	4.85
pyruvic	1	$\text{CH}_3\text{C}(\text{O})\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CH}_3\text{C}(\text{O})\text{COO}^-(aq)$	$2.8 \times 10^{-3}$	2.55
sulfuric	1	$\text{H}_2\text{SO}_4(aq) \rightleftharpoons \text{H}^+(aq) + \text{HSO}_4^-(aq)$	$\gg 1$ (strong)	<0
	2	$\text{HSO}_4^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{SO}_4^{2-}(aq)$	$1.2 \times 10^{-2}$	1.92
sulfurous	1	$\text{H}_2\text{SO}_3(aq) \rightleftharpoons \text{H}^+(aq) + \text{HSO}_3^-(aq)$	$1.7 \times 10^{-2}$	1.77
	2	$\text{HSO}_3^-(aq) \rightleftharpoons \text{H}^+(aq) + \text{SO}_3^{2-}(aq)$	$6.2 \times 10^{-8}$	7.21

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TABLE A5.1 Ionization Constants of Selected Acids at 25°C (Continued)

Acid	Step	Aqueous Equilibrium <sup>a</sup>	$K_a$	$pK_a$
thiocyanic	1	$\text{HSCN}(aq) \rightleftharpoons \text{H}^+(aq) + \text{SCN}^-(aq)$	$\gg 1$ (strong)	$< 0$
trichloroacetic	1	$\text{CCl}_3\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CCl}_3\text{COO}^-(aq)$	$2.3 \times 10^{-1}$	0.64
trifluoroacetic	1	$\text{CF}_3\text{COOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{CF}_3\text{COO}^-(aq)$	$5.9 \times 10^{-1}$	0.23
water	1	$\text{H}_2\text{O}(aq) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq)$	$1.0 \times 10^{-14}$	14.00

<sup>a</sup>The formulas of most carboxylic acids are written in an RCOOH format to highlight their molecular structures.

TABLE A5.2 Acid Ionization Constants of Hydrated Metal Ions at 25°C

Free Ion	Hydrated Ion	$K_a$
$\text{Fe}^{3+}$	$\text{Fe}(\text{H}_2\text{O})_6^{3+}$	$3 \times 10^{-3}$
$\text{Sn}^{2+}$	$\text{Sn}(\text{H}_2\text{O})_6^{2+}$	$4 \times 10^{-4}$
$\text{Cr}^{3+}$	$\text{Cr}(\text{H}_2\text{O})_6^{3+}$	$1 \times 10^{-4}$
$\text{Al}^{3+}$	$\text{Al}(\text{H}_2\text{O})_6^{3+}$	$1 \times 10^{-5}$
$\text{Cu}^{2+}$	$\text{Cu}(\text{H}_2\text{O})_6^{2+}$	$3 \times 10^{-8}$
$\text{Pb}^{2+}$	$\text{Pb}(\text{H}_2\text{O})_6^{2+}$	$3 \times 10^{-8}$
$\text{Zn}^{2+}$	$\text{Zn}(\text{H}_2\text{O})_6^{2+}$	$1 \times 10^{-9}$
$\text{Co}^{2+}$	$\text{Co}(\text{H}_2\text{O})_6^{2+}$	$2 \times 10^{-10}$
$\text{Ni}^{2+}$	$\text{Ni}(\text{H}_2\text{O})_6^{2+}$	$1 \times 10^{-10}$

TABLE A5.3 Ionization Constants of Selected Bases at 25°C

Base	Aqueous Equilibrium	$K_b$	$pK_b$
ammonia	$\text{NH}_3(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)$	$1.76 \times 10^{-5}$	4.75
aniline	$\text{C}_6\text{H}_5\text{NH}_2(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{C}_6\text{H}_5\text{NH}_3^+(aq) + \text{OH}^-(aq)$	$4.0 \times 10^{-10}$	9.40
diethylamine	$(\text{CH}_3\text{CH}_2)_2\text{NH}(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons (\text{CH}_3\text{CH}_2)_2\text{NH}_2^+(aq) + \text{OH}^-(aq)$	$8.6 \times 10^{-4}$	3.07
dimethylamine	$(\text{CH}_3)_2\text{NH}(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons (\text{CH}_3)_2\text{NH}_2^+(aq) + \text{OH}^-(aq)$	$5.9 \times 10^{-4}$	3.23
methylamine	$\text{CH}_3\text{NH}_2(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{CH}_3\text{NH}_3^+(aq) + \text{OH}^-(aq)$	$4.4 \times 10^{-4}$	3.36
nicotine (1)		$1.0 \times 10^{-6}$	6.0
nicotine (2)		$1.3 \times 10^{-11}$	10.9
pyridine	$\text{C}_5\text{H}_5\text{N}(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{C}_5\text{H}_5\text{NH}^+(aq) + \text{OH}^-(aq)$	$1.7 \times 10^{-9}$	8.77
quinine (1)		$3.3 \times 10^{-6}$	5.48
quinine (2)		$1.4 \times 10^{-10}$	9.9
urea	$\text{H}_2\text{NCONH}_2(aq) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{NCONH}_3^+(aq) + \text{OH}^-(aq)$	$1.3 \times 10^{-14}$	13.9

Table 2.2  
Hydrolysis Constants for Metal Cations

Electronegativity < 1.5				Electronegativity > 1.5				
Ion	Radius	(a)	pK <sub>a</sub>	Ion	Radius	(a)	(b)	pK <sub>a</sub>
+1 Ions								
K	152	0.007	14.5	Tl	164	0.006	0.016	13.2
Na	116	0.009	14.2	Ag	129	0.008	0.049	12.0
Li	90	0.011	13.6					
+2 Ions								
Ba	149	0.027	13.5	Pb	133	0.030	0.066	7.7
Sr	132	0.030	13.3	Sn				3.4
Ca	114	0.035	12.8	Hg	116	0.034	0.082	3.4
				Cd	109	0.037	0.055	10.1
				Cr	94	0.043	0.043	10.0
				Mn	97	0.041	0.046	10.6
				Fe	92	0.043	0.075	9.5
				Co	88	0.045	0.082	9.6
Mg	86	0.047	11.4	Ni	83	0.048	0.088	9.9
				Zn	88	0.045	0.060	9.0
				Be	59	0.068	0.074	6.2
+3 Ions								
Pu	114	0.079	7.0	Bi	117	0.077	0.127	1.1
La	117	0.077	8.5	Tl	102	0.088	0.140	0.6
Lu	100	0.090	7.6	Au	99	0.091	0.191	-1.5
Y	104	0.086	7.7	In	94	0.096	0.123	4.0
Sc	88	0.102	4.3	Ti	81	0.111	0.115	2.2
				Ga	76	0.118	0.148	2.6
				Fe	78	0.115	0.147	2.2
				Cr	75	0.120	0.135	4.0
				Al	67	0.134	0.145	5.0
+4 Ions								
Th	108	0.148	3.2					
Pa	104	0.154	-0.8					
U	103	0.155	0.6					
Np	101	0.158	1.5					
Pu	100	0.160	0.5					
Ce	101	0.158	-1.1					
Hf	85	0.188	0.2	Sn	83	0.193	0.222	-0.6
Zr	86	0.186	-0.3	Ti	74	0.216	0.220	-4.0

SOURCES: Values of hydrolysis constants (pK<sub>a</sub>) taken from C. F. Baes and R. E. Mesmer, *The Hydrolysis of Cations*, Wiley-Interscience, New York, 1976; and from J. Burgess, *Metal Ions in Solution*, Ellis Horwood, Chichester, UK, 1978; pp. 264-267.

<sup>a</sup> The  $Z^2/r$  ratio for the cation.

<sup>b</sup> The  $Z^2/r + 0.096 (\chi_P - 1.50)$  for the cation, as in Eq. (2.12).