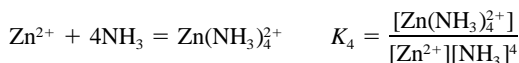
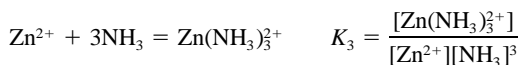
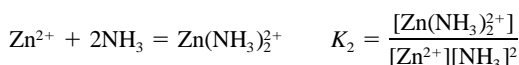
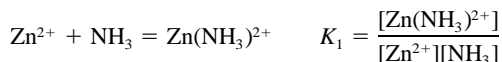


8.2.2 Formation Constants of Metal Complexes

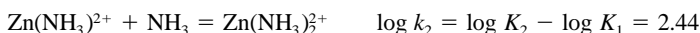
Each value listed in Tables 8.12 and 8.13 is the logarithm of the overall formation constant for the cumulative binding of a ligand L to the central metal cation M , viz.:

	Cumulative formation constant	Stepwise stability constants
$M + L = ML$	K_1	k_1
$M + 2L = ML_2$	K_2	$k_1 k_2$
.....		
$M + nL = ML_n$	K_n	$k_1 k_2 \cdots k_n$

As an example, the entries in Table 8.12 for the zinc ammine complexes represent these equilibria:



If the stepwise stability or formation constants of the reactions are desired, for the first step $\log K_1 = \log k_1 = 2.37$. For the second and succeeding steps the equilibria and corresponding constants are as follows:



The reverse of the association or formation reactions would represent the dissociation or instability constant for the systems, i.e., $-\log K_f = \log K_{\text{instab}}$.

The data in the tables generally refer to temperatures of about 20 to 25°C. Most of the values in Table 8.12 refer to zero ionic strength, but those in Table 8.13 often refer to a finite ionic strength.

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Ammonia						
Cadmium	2.65	4.75	6.19	7.12	6.80	5.14
Cobalt(II)	2.11	3.74	4.79	5.55	5.73	5.11
Cobalt(III)	6.7	14.0	20.1	25.7	30.8	35.2
Copper(I)	5.93	10.86				
Copper(II)	4.31	7.98	11.02	13.32	12.86	
Iron(II)	1.4	2.2				
Manganese(II)	0.8	1.3				
Mercury(II)	8.8	17.5	18.5	19.28		
Nickel	2.80	5.04	6.77	7.96	8.71	8.74
Platinum(II)						35.3
Silver(I)	3.24	7.05				
Zinc	2.37	4.81	7.31	9.46		
Bromide						
Astatine	2.51 [AtBr]					
Bismuth(III)	4.30	5.55	5.89	7.82		9.70
Bromine	1.24 [Br ₃ ⁻]					
Cadmium	1.75	2.34	3.32	3.70		
Cerium(III)	0.42					
Copper(I)		5.89				
Copper(II)	0.30					
Gold(I)		12.46				
Indium	1.30	1.88	2.48			
Iodine	2.64 [IBr]					
Iron(III)	-0.30	-0.50				
Lead	1.2	1.9		1.1		
Mercury(II)	9.05	17.32	19.74	21.00		
Palladium(II)				13.1		
Platinum(II)				20.5		
Rhodium(III)		14.3	16.3	17.6	18.4	17.2
Scandium	2.08	3.08				
Silver(I)	4.38	7.33	8.00	8.73		
Thallium(I)	0.93					
Thallium(III)	9.7	16.6	21.2	23.9	29.2	31.6
Tin(II)	1.11	1.81	1.46			
Uranium(IV)	0.18					
Yttrium	1.32					
Chloride						
Americium(III)	1.17					
Antimony(III)	2.26	3.49	4.18	4.72		
Bismuth(III)	2.44	4.7	5.0	5.6		
Cadmium	1.95	2.50	2.60	2.80		
Cerium(III)	0.48					
Copper(I)		5.5	5.7			
Copper(II)	0.1	-0.6				
Curium(III)	1.17					
Gold(III)		9.8				
Indium	1.42	2.23	3.23			
Iron(II)	0.36					
Iron(III)	1.48	2.13	1.99	0.01		
Lead	1.62	2.44	1.70	1.60		
Manganese(II)	0.96					
Mercury(II)	6.74	13.22	14.07	15.07		

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Palladium(II)	6.1	10.7	13.1	15.7		
Platinum(II)		11.5	14.5	16.0		
Plutonium(III)	1.17					
Silver(I)	3.04	5.04		5.30		
Thallium(I)	0.52					
Thallium(III)	8.14	13.60	15.78	18.00		
Thorium	1.38	0.38				
Tin(II)	1.51	2.24	2.03	1.48		
Tin(IV)						4
Uranium(IV)	0.8					
Uranium(VI)	0.22					
Zinc	0.43	0.61	0.53	0.20		
Zirconium	0.9	1.3	1.5	1.2		
Cyanide						
Cadmium	5.48	10.60	15.23	18.78		
Copper(I)		24.0	28.59	30.30		
Gold(I)		38.3				
Iron(II)						35
Iron(III)						42
Mercury(II)				41.4		
Nickel				31.3		
Silver(I)		21.1	21.7	20.6		
Zinc				16.7		
Fluoride						
Aluminum	6.10	11.15	15.00	17.75	19.37	19.84
Beryllium	5.1	8.8	12.6			
Cerium(III)	3.20					
Chromium(III)	4.41	7.81	10.29			
Gadolinium	3.46					
Gallium	5.08					
Indium	3.70	6.25	8.60	9.70		
Iron(III)	5.28	9.30	12.06			
Lanthanum	2.77					
Magnesium	1.30					
Manganese(II)	5.48					
Plutonium(III)	6.77					
Scandium						17.3
Thallium(I)	0.1					
Thallium(III) [TlO ⁺]	6.44					
Thorium	7.65	13.46	17.97			
Titanium(IV) [TiO ²⁺]	5.4	9.8	13.7	18.0		
Uranium(VI)	4.59	7.93	10.47	11.84		
Yttrium	4.81	8.54	12.14			
Zirconium	8.80	16.12	21.94			
Hydroxide						
Aluminum	9.27			33.03		
Antimony(III)		24.3	36.7	38.3		
Arsenic [as AsO ⁺]	14.33	18.73	20.60	21.20		
Beryllium	9.7	14.0	15.2			
Bismuth(III)	12.7	15.8		35.2		
Cadmium	4.17	8.33	9.02	8.62		
Cerium(III)	14.6					
Cerium(IV)	13.28	26.46				

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Chromium(III)	10.1	17.8		29.9		
Copper(II)	7.0	13.68	17.00	18.5		
Dysprosium	5.2					
Erbium(III)	5.4					
Gadolinium	4.6					
Gallium	11.0	21.7		34.3	38.0	40.3
Indium	9.9	19.8		28.7		
Iodine	9.49	11.24				
Iron(II)	5.56	9.77	9.67	8.58		
Iron(III)	11.87	21.17	29.67			
Lanthanum	3.3					
Lead(II)	7.82	10.85	14.58			61.0
Lutetium	6.6					
Magnesium	2.58					
Manganese(II)	3.90		8.3			
Neodymium	5.5					
Nickel	4.97	8.55	11.33			
Praseodymium	4.30					
Plutonium(III)	7.0					
Plutonium(IV)	12.39					
Plutonium [as PuO_2^{2+}]	8.3	16.6	20.9			
Samarium(III)	4.8					
Scandium	8.9					
Tellurium(IV)			41.6	53.0	64.8	72.0
Thallium(III)	12.86	25.37				
Titanium(III)	12.71					
Uranium(IV)	13.3				41.2	
Uranium(VI) [as UO_2^{2+}]	9.5	22.80		32.4		
Vanadium(III)	11.1	21.6				
Vanadium(IV) [as VO^{2+}]	8.6		[25.8 for $\text{V}_2\text{O}_4(\text{OH})^-$]			
Vanadium(V) [as VO^{3+}]		25.2		46.2	58.5	
Yttrium	5.0					
Zinc	4.40	11.30	14.14	17.66		
Zirconium	14.3	28.3	41.9	55.3		
Iodide						
Bismuth	3.63			14.95	16.80	18.80
Cadmium	2.10	3.43	4.49	5.41		
Copper(I)		8.85				
Indium	1.00	2.26				
Iodine	2.89	5.79				
Iron(III)	1.88					
Lead	2.00	3.15	3.92	4.47		
Mercury(II)	12.87	23.82	27.60	29.83		
Silver	6.58	11.74	13.68			
Thallium(I)	0.72	0.90	1.08			
Thallium(III)	11.41	20.88	27.60	31.82		
Iodate						
Barium	1.05					
Calcium	0.89					
Magnesium	0.72					
Strontium	1.00					
Thorium	2.88	4.79	7.15			

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4	log K_5	log K_6
Nitrate						
Barium	0.92					
Beryllium	1.62					
Bismuth(III)	1.26					
Cadmium	0.40					
Calcium	0.28					
Cerium(III)	1.04	2.55				
Curium(III)	0.57					
Hafnium	0.92	2.43	4.32	6.40	8.48	10.29
Iron(III)	1.0					
Lanthanum	0.26	0.69	1.27			
Lead	1.18					
Mercury(II)	0.35					
Neodymium	0.52	1.18				
Neptunium(IV)	0.38					
Plutonium(III)	0.77	1.93	3.09			
Plutonium(IV)	0.54					
Strontium	0.82					
Thallium(I)	0.33					
Thallium(III)	0.92					
Thorium	0.78	1.89	2.89	3.63		
Uranium(IV)	0.20	0.37				
Uranium(VI)	0.34	0.45				
Ytterbium	0.45	1.30	2.42			
Zirconium [as ZrO^{2+}]		1.91		3.54		
Pyrophosphate						
Barium	4.6					
Calcium	4.6					
Cadmium	5.6					
Copper(II)	6.7	9.0				
Lead		5.3				
Magnesium	5.7					
Nickel	5.8	7.4				
Strontium	4.7					
Yttrium		9.7				
Zirconium		6.5				
Sulfate						
Cerium(III)	3.40					
Erbium	3.58					
Gadolinium	3.66					
Holmium	3.58					
Indium	1.78	1.88	2.36			
Iron(III)	2.03	2.98				
Lanthanum	3.64					
Neodymium	3.64					
Nickel	2.4					
Plutonium(IV)	3.66					
Praseodymium	3.62					
Samarium	3.66					
Thorium	3.32	5.50				
Uranium(IV)	3.24	5.42				
Uranium(VI)	1.70	2.45	3.30			

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Yttrium	3.47					
Ytterbium	3.58					
Zirconium	3.79	6.64	7.77			
Sulfite						
Copper(I)	7.5	8.5	9.2			
Mercury(II)		22.66				
Silver	5.30	7.35				
Thiocyanate						
Bismuth	1.15	2.26	3.41	4.23		
Cadmium	1.39	1.98	2.58	3.6		
Chromium(III)	1.87	2.98				
Cobalt(II)	-0.04	-0.70	0	3.00		
Copper(I)	12.11	5.18				
Gold(I)		23		42		
Indium	2.58	3.00	4.63			
Iron(III)	2.95	3.36				
Mercury(II)		17.47		21.23		
Nickel	1.18	1.64	1.81			
Ruthenium(III)	1.78					
Silver		7.57	9.08	10.08		
Thallium(I)	0.80					
Uranium(IV)	1.49	2.11				
Uranium(VI)	0.76	0.74	1.18			
Vanadium(III)	2.0					
Vanadium(IV)	0.92					
Zinc	1.62					
Thiosulfate						
Cadmium	3.92	6.44				
Copper(I)	10.27	12.22	13.84			
Iron(III)	2.10					
Lead		5.13	6.35			
Mercury(II)		29.44	31.90	33.24		
Silver	8.82	13.46				

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands

Temperature is 25°C and ionic strengths are approaching zero unless indicated otherwise: (a) At 20°C, (b) at 30°C, (c) 0.1 M uni-univalent salt, (d) 1.0 M uni-univalent salt, (e) 2.0 M uni-univalent salt present.

	log K_1	log K_2	log K_3	log K_4
Acetate				
Ag(I)	0.73	0.64		
Ba(II)	0.41			
Ca(II)	0.6			
Cd(II)	1.5	2.3	2.4	
Ce(III)	1.68	2.69	3.13	3.18
Co(II)	1.5	1.9		
Cr(III)	1.80	4.72		
Cu(II) <i>a</i>	2.16	3.20		
Fe(II) <i>c</i>	3.2	6.1	8.3	
Fe(III) <i>a,d</i>	3.2			
In(III)	3.50	5.95	7.90	9.08
Hg(II)		8.43		
La(III) <i>a,e</i>	1.56	2.48	2.98	2.95
Mg(II)	0.8			
Mn(II)	9.84	2.06		
Ni(II)	1.12	1.81		
Pb(II)	2.52	4.0	6.4	8.5
Rare earths <i>a,e</i>	1.6–1.9	2.8–3.0	3.3–3.7	
Sr(II)	0.44			
Tl(III)				15.4
UO ₂ (II) <i>a,e</i>	2.38	4.36	6.34	
Y(III) <i>a,e</i>	1.53	2.65	3.38	
Zn(II)	1.5			
Acetylacetonone				
Al(III) <i>b</i>	8.6	15.5		
Be(II)	7.8	14.5		
Cd(II)	3.84	6.66		
Ce(III)	5.30	9.27	12.65	
Cr(II)	5.9	11.7		
Co(II)	5.40	9.54		
Cu(II)	8.27	16.34		
Dy(III) <i>b</i>	6.03	10.70	14.04	
Er(III) <i>b</i>	5.99	10.67	14.09	
Eu(III) <i>b</i>	5.87	10.35	13.64	
Fe(II)	5.07	8.67		
Fe(III)	11.4	22.1	26.7	
Ga(III)	9.5	17.9	23.6	
Gd(III) <i>b</i>	5.90	10.38	13.79	
Hf(IV)	8.7	15.4	21.8	28.1
Ho(III)	6.05	10.73	14.13	
In(III)	8.0	15.1		
La(III) <i>b</i>	5.1	8.90	11.90	
Lu(III) <i>b</i>	6.23	11.00	13.63	
Mg(II)	3.65	6.27		
Mn(II)	4.24	7.35		
Mn(III)			3.86	
Nd(III)	5.6	9.9	13.1	
Ni(II) <i>a</i>	6.06	10.77	13.09	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Pd(II) <i>b</i>	16.2	27.1		
Pr(III) <i>b</i>	5.4	9.5	12.5	
Pu(IV) <i>c</i>	10.5	19.7	28.1	34.1
Sc(III) <i>b</i>	8.0	15.2		
Sm(III) <i>b</i>	5.9	10.4		
Tb(III) <i>b</i>	6.02	10.63	14.04	
Th(IV)	8.8	16.2	22.5	26.7
Tm(IV) <i>b</i>	6.09	10.85	14.33	
U(IV) <i>a,c</i>	8.6	17.0	23.4	29.5
UO ₂ (II) <i>b</i>	7.74	14.19		
VO(II)	8.68	15.79		
V(II)	5.4	10.2	14.7	
Y(III) <i>b</i>	6.4	11.1	13.9	
Yb(III) <i>b</i>	6.18	11.04	13.64	
Zn(II) <i>b</i>	4.98	8.81		
Zr(IV)	8.4	16.0	23.2	30.1
Alizarin red				
Cr(VI)	4.7			
Cu(II)	4.1			
Hf(IV)		10.4		
Mo(VI)		9.6		
Pb(II)	6.0			
Th(IV)		8.24		
UO ₂ (II)	4.22			
V(V)		8.6		
W(VI)		7.8		
Arsenazo				
Hf(IV)	10.07			
Zr(IV)	12.95			
Aurintricarboxylic acid				
Be(II)	4.54			
Cu(II)	4.1	8.81		
Fe(III)	4.68			
Th(IV)	5.04			
UO ₂ (II)	4.77			
Benzoylacetone (75% dioxane)				
Ba(II)		9.4		
Be(II)	12.59	24.01		
Cd(II)	7.79	14.36		
Ce(III)	10.09	19.42	27.04	
Co(II)	9.42	17.83		
Cu(II)	12.05	23.01		
La(III)	6.33	11.66	16.78	
Mg(II)	7.69	14.09		
Mn(II)	8.66	15.78		
Ni(II)	9.58	18.00		
Pb(II)	8.84	16.35		
Pr(III)	7.02	13.62	18.74	
UO ₂ (II)	12.15	23.27		
Y(III)	8.24	14.98	20.57	
Zn(II)	9.62	17.90		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1		log K_2		log K_3		log K_4	
Calmagite								
Ca	6.05							
Mg	8.05							
	Complex of HL ²⁻ Anion		Complex of L ³⁻ Anion		Complex of H ₂ L ⁻			
	log K_1	log K_2	log K_1	log K_2	log K_3			
Citric acid								
Ag	7.1							
Al	7.0		20.0					
Ba	2.98							
Be	4.52							
Ca	4.68							
Cd	3.98		11.3					
Ce(III)		6.18			9.65			3.2
Co(II)	4.8		12.5					
Cu(II)	4.35		14.2					
Eu(III)		6.46			9.80			
Fe(II)	3.08		15.5					
Fe(III)	12.5		25.0					
La		6.97			9.45			6.22
Mg	3.29							
Mn(II)	3.67							
Nd(III)		6.32			9.70			
Ni	5.11		14.3					
Pb	6.50							
Pr								3.4
Ra	2.36							
Sr	2.8							
Tl(I)	1.04							
UO ₂	8.5	10.8						
Y								3.6
Yb					8			
Zn	4.71		11.4					
	log K_1	log K_2	log K_3					
1,2-Diaminocyclohexane-<i>N,N,N',N'</i>-tetraacetic acid								
Al <i>c</i>	17.63							
Ba <i>c</i>	8.64							
Ca <i>c</i>	12.3							
Cd <i>c</i>	19.88							
Ce(III) <i>c</i>	16.76							
Co(II) <i>c</i>	19.57							
Cu(II) <i>c</i>	21.95							
Dy(III) <i>c</i>	19.69							
Er(III) <i>c</i>	20.20							
Eu(III) <i>c</i>	18.77							
Fe(III) <i>c</i>	27.48							
Ga <i>c</i>	22.91							

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Gd <i>c</i>	18.80			
Hg(II) <i>c</i>	24.4			
Ho <i>c</i>	19.89			
La <i>c</i>	16.35			
Lu <i>c</i>	21.51			
Mg <i>c</i>	10.41			
Mn(II) <i>c</i>	17.43			
Nd <i>c</i>	17.69			
Ni <i>c</i>	19.4			
Pb <i>c</i>	20.33			
Pr <i>c</i>	17.23			
Sm(III) <i>c</i>	18.63			
Sr <i>c</i>	8.92			
Tb <i>c</i>	19.30			
Tm <i>c</i>	20.46			
VO(II) <i>c</i>	19.40			
Y <i>c</i>	19.41			
Yb <i>c</i>	20.80			
Zn <i>c</i>	18.6			
Dibenzoylmethane (75% dioxane)				
Ba	6.10	11.50		
Be	13.62	26.03		
Ca	7.17	13.55		
Cd	8.67	16.63		
Ce(III)	10.99	21.53	30.38	
Co(II)	10.35	20.05		
Cu(II)	12.98	24.98		
Cs	3.42			
Fe(II)	11.15	21.50		
K	3.67			
Li	5.95			
Mg	8.54	16.21		
Mn(II)	9.32	17.79		
Na	4.18			
Ni	10.83	20.72		
Pb	9.75	18.79		
Rb	3.52			
Sr	6.40	12.10		
Zn	10.23	19.65		
	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_7$ [MHL]
4,5-Dihydroxybenzene-1,3-disulfonic acid (Tiron)				
Al	19.02	31.10	33.5	
Ba	4.10			14.6
Ca	5.80			14.8
Cd <i>d</i>	7.69	13.29		
Ce(III)		3.75		
Co(II) <i>d</i>	8.19	14.41		15.7
Cu(II) <i>d</i>	12.76	23.73		18.1

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_f [MHL]
Fe(III) <i>a,c</i>	20.7	35.9	46.9	22.6
La	12.9			18.6 [La(OH)L]
Mg <i>a,c</i>	6.86			14.6
Mn(II) <i>c</i>	8.6			
Ni <i>a,c</i>	8.56	14.90		15.6
Pb <i>d</i>	11.95	18.28		
Sr <i>c</i>	4.55			
UO ₂ (II) <i>c</i>	15.90			
VO(II)	15.88			
Zn <i>d</i>	9.00	16.91		15.9
	log K_1	log K_2	log K_f [M ₂ L ₃]	
2,3-Dimercaptopropan-1-ol (BAL)				
Fe(II)	15.8			
Fe(III)	30.6 [Fe(OH)L]			28
Mn(II)	5.23	10.43		
Ni		22.78		
Zn	13.48	23.3		40.6
	log K_1	log K_2	log K_3	log K_4
Dimethylglyoxime (50% dioxane)				
Cd	5.7	10.7		
Co(II)	9.80	18.94		
Cu(II)	12.00	33.44		
Fe(II)		7.25		
La	6.6	12.5		
Ni	11.16			
Pb	7.3			
Zn	7.7	13.9		
2,2'-Dipyridyl				
Ag	3.65	7.15		
Cd	4.26	7.81	10.47	
Co(II)	5.73	11.57	17.59	
Cr(II)	4.5	10.5	14.0	
Cu(I)		14.2		
Cu(II)	8.0	13.60	17.08	
Fe(II)	4.36	8.0	17.45	
Hg(II)	9.64	16.74	19.54	
Mg	0.5			
Mn(II) <i>d</i>	4.06	7.84	11.47	
Ni	6.80	13.26	18.46	
Pb	3.0			
Ti(III)			25.28	
V(II)	4.9	9.6	13.1	
Zn	5.30	9.83	13.63	
Eriochrome Black T				
Ca	5.4			
Mg	7.0			
Zn	13.5	20.6		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Ethanolamine				
Ag	3.29	6.92		16.48
Cu(II)		6.68		
Hg(II)	8.51	17.32		
Ethylenediamine				
Ag	4.70	7.70		
Cd <i>a</i>	5.47	10.09	12.09	
Co(II)	5.91	10.64	13.94	
Co(III)	18.7	34.9	48.69	
Cr(II)	5.15	9.19		
Cu(I)		10.8		
Cu(II)	10.67	20.00	21.0	
Fe(II)	4.34	7.65	9.70	
Hg(II)	14.3	23.3		
Mg	0.37			
Mn(II)	2.73	4.79	5.67	
Ni	7.52	13.84	18.33	
Pd(II)		26.90		
V(II)	4.6	7.5	8.8	
Zn	5.77	10.83	14.11	
Ethylenediamine-<i>N, N, N', N'</i>-tetraacetic acid				
Ag	7.32			
Al	16.11			
Am(III)	18.18			
Ba	7.78			
Be	9.3			
Bi	22.8			
Ca	11.0			
Cd	16.4			
Ce(III)	16.80			
Cf(III)	19.09			
Cm(III)	18.45			
Co(II)	16.31			
Co(III)	36			
Cr(II)	13.6			
Cr(III)	23			
Cu(II)	18.7			
Dy	18.0			
Er	18.15			
Eu(III)	17.99			
Fe(II)	14.33			
Fe(III)	24.23			
Ga	20.25			
Gd	17.2			
Hg(II)	21.80			
Ho	18.1			
In	24.95			
La	16.34			
Li	2.79			
Lu	19.83			
Mg	8.64			
Mn(II)	13.8			
Mo(V)	6.36			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Na	1.66			
Nd	16.6			
Ni	18.56			
Pb	18.3			
Pd(II)	18.5			
Pm(III)	17.45			
Pr	16.55			
Pu(III)	18.12			
Pu(IV)	17.66			
Pu(VI)	17.66			
Ra	7.4			
Sc	23.1			
Sm	16.43			
Sn(II)	22.1			
Sr	8.80			
Tb	17.6			
Th	23.2			
Ti(III)	21.3			
TiO(II)	17.3			
Tl(III)	22.5			
Tm	19.49			
U(IV)	17.50			
V(II)	12.70			
V(III)	25.9			
VO(II)	18.0			
V(V)	18.05			
Y	18.32			
Yb	18.70			
Zn	16.4			
Zr	19.40			
Glycine				
Ag	3.41	6.89		
Ba	0.77			
Be		4.95		
Ca	1.38			
Cd	4.74	8.60		
Co(II)	5.23	9.25	10.76	
Cu(II)	8.60	15.54	16.27	
Dy		12.2		
Er		12.7		
Fe(II) <i>a</i>	4.3	7.8		
Fe(III) <i>a,d</i>	10.0			
Gd		11.9		
Hg(II)	10.3	19.2		
La		11.2		
Mg	3.44	6.46		
Mn(II)	3.6	6.6		
Ni	6.18	11.14	15	
Pb	5.47	8.92		
Pd(II)	9.12	17.55		
Pr		11.5		
Sm		11.7		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Sr	0.91			
Y		12.5		
Yb		13.0		
Zn	5.52	9.96		
<i>N'</i>-(2-Hydroxyethyl)ethylenediamine-<i>N,N,N'</i>-triacetic acid				
Ba <i>c</i>	5.54			
Ca <i>c</i>	8.43			
Cd <i>c</i>	13.0			
Ce(III) <i>c</i>	14.11			
Co(II) <i>c</i>	14.4			
Cu(II) <i>c</i>	17.40			
Dy <i>c</i>	15.30			
Er <i>c</i>	15.42			
Eu(III) <i>c</i>	15.35			
Fe(II) <i>c</i>	11.6			
Fe(III) <i>c</i>	19.8			
Gd <i>c</i>	15.22			
Hg(II) <i>c</i>	20.1			
Ho <i>c</i>	15.32			
La <i>c</i>	13.46			
Lu <i>c</i>	15.88			
Mg <i>c</i>	5.78			
Mn(II) <i>c</i>	10.7			
Nd <i>c</i>	14.86			
Ni <i>c</i>	17.0			
Pb <i>c</i>	15.5			
Pr <i>c</i>	14.61			
Sm <i>c</i>	15.28			
Sr <i>c</i>	6.92			
Tb <i>c</i>	15.32			
Th <i>c</i>	18.5			
Tm <i>c</i>	15.59			
Y <i>c</i>	14.65			
Yb <i>c</i>	15.88			
Zn <i>c</i>	14.5			
8-Hydroxy-2-methylquinoline (50% dioxane)				
Cd	9.00	9.00	16.60	
Ce(III)	7.71			
Co(II)	9.63	18.50		
Cu(II)	12.48	24.00		
Fe(II)	8.75	17.10		
Mg	5.24	9.64		
Mn(II)	7.44	13.99		
Ni	9.41	17.76		
Pb	10.30	18.50		
UO ₂ (II)	9.4	17		
Zn	9.82	18.72		
8-Hydroxyquinoline-5-sulfonic acid				
Ba	2.31			
Ca	3.52			
Cd	7.70	14.20		
Ce(III)	6.05	11.05	14.95	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Co(II)	8.11	15.05	20.41	
Cu(II)	11.92	21.87		
Er	7.16	13.34	18.56	
Fe(II)	8.4	15.7	21.75	
Fe(III)	11.6	22.8	35.65	
Gd	6.64	12.37	17.27	
La	5.63	10.13	13.83	
Mg	4.79	8.19		
Mn(II)	5.67	10.72		
Nd	6.3	11.6	16.0	
Ni	9.57	18.27	22.9	
Pb	8.53	16.13		
Pr	6.17	11.37	15.67	
Sm	6.58	12.28	17.04	
Sr	2.75			
Th	9.56	18.29	25.92	32.04
UO ₂ (II)	8.52	15.67		
Zn	8.65	16.15		
Lactic acid				
Ba	0.64			
Ca	1.42			
Cd	1.70			
Ce(III) <i>a,c</i>	2.76	4.73	5.96	
Co(II)	1.90			
Cu(II)	3.02	4.85		
Er	2.77	5.11	6.70	
Eu(III)	2.53	4.60	5.88	
Fe(III)	7.1			
Gd	2.53	4.63	5.91	
Ho	2.71	4.97	6.55	
La <i>a,c</i>	2.60	4.34	5.64	
Li	0.20			
Mg	1.37			
Mn(II)	1.43			
Nd	2.47	4.37	5.60	
Ni	2.22			
Pb	2.40	3.80		
Pr <i>a,c</i>	2.85	4.90	6.10	
Rare earths <i>a,c</i>	2.8–3.0	4.9–5.4	6.1–7.8	
Sm	2.56	4.58	5.90	
Sr	0.98			
Tb	2.61	4.73	6.01	
Y	2.53	4.70	6.12	
Yb	2.85	5.27	7.96	
Zn	2.20	3.75		
Nitrilotriacetic acid				
Al	>10			
Ba <i>a</i>	5.88			
Ca	7.60	11.61		
Cd <i>c</i>	9.80	15.2		
Ce(III) <i>c</i>	10.83	18.67		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Co(II) <i>c</i>	10.38	14.5		
Cr(III)	>10			
Cu(II) <i>c</i>	13.10			
Dy <i>c</i>	11.74	21.15		
Er <i>c</i>	12.03	21.29		
Eu(III) <i>c</i>	11.52	20.70		
Fe(II) <i>c</i>	8.84			
Fe(III) <i>c</i>	15.87	24.32		
Gd <i>c</i>	11.54	20.80		
Hg(II)	12.7			
Ho <i>c</i>	11.90	21.25		
In	15			
La <i>c</i>	10.36	17.60		
Li <i>a</i>	3.28			
Lu <i>c</i>	12.49	21.91		
Mg <i>c</i>	5.36	10.2		
Mn(II)	8.60	11.1		
Na	2.15			
Nd <i>c</i>	11.26	19.73		
Ni	11.26	16.0		
Pb <i>a,c</i>	11.8			
Pr <i>c</i>	11.07	19.25		
Sm(III) <i>c</i>	11.53	20.53		
Sr	6.73			
Tb <i>c</i>	11.59	20.97		
Tl(I)	3.44			
Th <i>c</i>	12.4			
Tm <i>c</i>	12.22	21.45		
Y <i>c</i>	11.48	20.43		
Yb <i>c</i>	12.40	21.69		
Zn <i>c</i>	10.45	13.45		
Zr <i>c</i>	20.8			
1-Nitroso-2-naphthol (75% dioxane)				
Ag	7.74			
Cd	6.18	11.38		
Co(II)	10.67	22.81		
Cu(II)	12.52	23.37		
Mg	6.2	10.60		
Nd	9.5	17.7	25.6	
Ni	10.75	21.29	28.09	
Pb	9.73	17.31		
Pr	9.04	17.06	23.85	
Th <i>c</i>	8.50	16.13	24.03	30.29
Y	9.02	17.74	25.04	
Zn	9.32	17.02		
Zr	3.6			
Oxalate				
Ag	2.41			
Al	7.26	13.0	16.3	
Am(III)		9.8		[Am(HL) ₄] 11.0]
Ba	2.31			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Be	4.90			
Ca	3.0			
Cd	3.52	5.77		
Ce(III)	6.52	10.5	11.3	
Co(II)	4.79	6.7	9.7	
Co(III)			~20	
Cu(II)	6.16	8.5		
Er	4.82	8.21	10.03	
Fe(II)	2.9	4.52	5.22	
Fe(III)	9.4	16.2	20.2	
Gd	7.04			
Hg(II)		6.98		
Mg	3.43	4.38		
Mn(II)	3.97	5.80		
Mn(III) <i>e</i>	9.98	16.57	19.42	
Mo(III)	3.38			
Mo(VI)				[MoO ₃ (L) ²⁻ 13.0]
Nd	7.21	11.5	> 14	
Ni	5.3	7.64	~8.5	
NpO ₂ (II)	3.30	7.07		
Pb		6.54		
Pu(III)	9.31	18.70	28	
Pu(IV)	8.74	16.91	23.39	27.50
PuO ₂ (II)		11.4		
Sr	2.54			
Th				24.48
TiO(II)	2.67			
Tl(I)	2.03			
UO ₂ (II)		10.57		
VO(II)		9.80		
V(II)	~2.7			
Y	6.52	10.10	11.47	
Yb	7.30	11.7	> 14	
Zn	4.89	7.60	8.15	
Zr	9.80	17.14	20.86	21.15
1,10-Phenanthroline				
Ag	5.02	12.07		
Ca	0.7			
Cd	5.93	10.53	14.31	
Co(II)	7.25	13.95	19.90	
Cu(II)	9.08	15.76	20.94	
Fe(II)	5.85	11.45	21.3	
Fe(III)	6.5	11.4	23.5	
Hg(II)		19.65	23.35	
Mg	1.2			
Mn(II)	3.88	7.04	10.11	
Ni	8.80	17.10	24.80	
Pb	4.65	7.5	9	
VO(II)	5.47	9.69		
Zn	6.55	12.35	17.55	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Phthalic acid				
Ba	2.33			
Ca	2.43			
Cd	2.5			
Co(II)	1.81	4.51		
Cu(II)	3.46	4.83		
La		7.74		
Ni	2.14			
Pb <i>d</i>	3.4			
UO ₂ (II)	4.38			
Zn	2.2			
Piperidine				
Ag	3.30	6.48		
Hg(II)	8.70	17.44		
Pt(II)			$\log K_5$ 5.7	$\log K_6$ 8.2
Propylene-1,2-diamine				
Cd <i>b,c</i>		9.97	12.12	
Co(II) <i>d</i>	5.42	11.47	14.72	
Cu(II) <i>c</i>	6.41	20.06		
Hg(II) <i>c</i>	10.78	23.53	23.25	
Ni <i>d</i>	7.43	13.62	17.89	
Zn <i>b,c</i>	5.89	10.87	12.57	
Pyridine				
Ag	1.97	4.35		
Cd	1.40	1.95	2.27	2.50
Co(II)	1.14	1.54		
Cu(I)		3.34	4.51	5.44
Cu(II)	2.59	4.33	5.93	$\log K_6$ 6.89
Fe(II)	0.71		$\log K_5$ 7.00	6.54
Hg(II)	5.1	10.0	10.4	$\log K_6$ 10.2
Mn(II)	1.92	2.77	3.37	3.50
VO(II)	-1.70			
Zn	1.41	1.11	1.61	1.93
Pyridine-2,6-dicarboxylic acid				
Ba <i>a,d</i>	3.46			
Ca <i>a,d</i>	4.6	7.2		
Cd <i>a,d</i>	5.7	10.0		
Ce(III) <i>a,d</i>	8.34	14.42	18.80	
Co(II) <i>a,d</i>	7.0	12.5		
Cu(II) <i>a,d</i>	9.14	16.52		
Dy <i>a,d</i>	8.69	16.19	22.14	
Er <i>a,d</i>	8.77	16.39	22.14	
Eu(III) <i>a,d</i>	8.84	15.98	21.00	
Fe(II) <i>a,d</i>	5.71	10.36		
Fe(III) <i>a,d</i>	10.91	17.13		
Gd <i>a,d</i>	8.74	16.06	21.83	
Ho <i>a,d</i>	8.72	16.23	22.08	
La <i>a,d</i>	7.98	13.79	18.06	
Lu <i>a,d</i>	9.03	16.80	21.48	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Hg(II) <i>a,d</i>	20.28			
Mg <i>a,d</i>	2.7			
Mn(II) <i>a,d</i>	5.01	8.49		
Nd <i>a,d</i>	8.78	15.60	20.66	
Ni <i>a,d</i>	6.95	13.50		
Pb <i>a,d</i>	8.70	10.60		
Pr <i>a,d</i>	8.63	15.10	19.94	
Sm <i>a,d</i>	8.86	15.88	21.23	
Sr <i>a,d</i>	3.89			
Tb <i>a,d</i>	8.68	16.11	22.03	
Tm <i>a,d</i>	8.83	16.54	22.04	
Y <i>a,d</i>	8.46	15.73	21.34	
Yb <i>a,d</i>	8.85	16.61	21.83	
Zn <i>a,d</i>	6.35	11.88		
1-(2-Pyridylazo)-2-naphthol (PAN)				
Co(II)	> 12			
Cu(II)	16			
Mn(II)	8.5	16.4		
Ni	12.7	25.3		
Tl(III)	2.29			
Zn	11.2	21.7		
		log K_f [ML]	log K_f [MHL]	log K_f [M(HL) ₂]
4-(2-Pyridylazo)resorcinal (PAR)				
Co(II)			> 12	
Cu(II)		10.3		
Mn(II)			9.7	18.9
Ni			13.2	26.0
Sc		4.8		
Tl(III)		4.23		
Zn			12.4	23.5
		log K_f [ML]	log K_f [M ₂ L]	log K_f [MHL]
Pyrocatechol-3,5-disulfonate (Pyrocatechol Violet)				
Al		19.13	4.95	
Bi		27.07	5.25	
Cd		8.13		5.86
Co(II)		9.01		6.53
Cu(II)		16.47		11.18
Ga		22.18	4.65	
In		18.10	4.81	
Mg		4.42	4.6	3.66
Mn(II)		7.13		5.36
Ni		9.35	4.38	6.85
Pb		13.25		10.19
Th		23.36	4.42	
Zn		10.41	6.21	7.21
Zr		27.40	4.18	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
8-Quinolinol				
Ba	2.07			
Be	3.36			
Ca (75% dioxane)	7.3	13.2		
Cd	7.2	13.4		
Ce(III) (50% dioxane)	9.15	17.13		
Co(II)	9.1	17.2		
Cu(II)	12.2	23.4		
Fe(II)	8.58	16.93	22.23	
Fe(III)	12.3	23.6	33.9	
La	5.85	16.95		
Mg (50% dioxane)	6.38	11.81		
Mn(II) (50% dioxane)	8.28	15.45		
Ni (50% dioxane)	11.44	21.38		
Pb (50% dioxane)	10.61	18.70		
Sm	6.84		19.50	
Sr	2.89	6.08		
Th	10.45	20.40	29.85	38.80
UO ₂ (II) (50% dioxane)	11.25	20.89		
V(II)	12.8	23.6		
VO(II)	10.97	20.19		
Y	8.15	14.90	20.25	
Zn (50% dioxane)	9.96	18.86		
	$\log K_f [\text{MHL}^+]$		$\log K_f [\text{M}(\text{HL})_2]$	
Salicylaldoxime				
Ba		0.53		3.72
Be		<7		
Ca		0.92		3.72
Cd		<4.4		
Co(II)				8.13
Cu(II)				8.13
Mg		0.64		4.10
Ni				3.77
Sr				3.77
Zn		<5.2		
	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Salicylic acid				
Al	14.11			
Be	17.4			
Cd	5.55			
Ce(III)	2.66			
Co(II)	6.72	11.42		
Cr(II)	8.4	15.3		
Cu(II)	10.60	18.45		
Fe(II)	6.55	11.25		
Fe(III) <i>a, c</i>	16.48	28.12	36.80	
La	2.64			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Mg (75% dioxane)	4.7			
Mn(II)	5.90	9.80		
Nd	2.70			
Ni	6.95	11.75		
Pr	2.68			
Th	4.25	7.60	10.05	11.60
TiO(II)	6.09			
UO ₂ (II)	13.4			
V(II)	6.3			
Zn	6.85			
Succinic acid				
Ba	2.08			
Be	3.08			
Ca	2.0			
Cd	2.2			
Co(II)	2.22			
Cu(II)	3.33			
Fe(III)	7.49			
Hg(II)		7.28		
La	3.96			
Mg	1.20			
Mn(II)	2.26			
Nd	8.1			
Ni	2.36			
Pb	2.8			
Ra	1.0			
Sr	1.06			
Zn	1.6			
5-Sulfosalicylic acid				
Al <i>c</i>	13.20	22.83	28.89	
Be <i>c</i>	11.71	20.81		
Cd <i>c</i>	16.68	29.08		
Co(II) <i>c</i>	6.13	9.82		
Cr(II) <i>c</i>	7.1	12.9		
Cr(III) <i>c</i>	9.56			
Cu(II) <i>c</i>	9.52	16.45		
Fe(II) <i>c</i>	5.90			
Fe(III) <i>c</i>	14.64	25.18	32.12	
La <i>c</i>	9.11			
Mn(II) <i>c</i>	5.24	8.24		
NbO(III) <i>c</i>	4.0	7.7		
Ni <i>c</i>	6.42	10.24		
UO ₂ (II) <i>c</i>	11.14	19.20		
Zn <i>c</i>	6.05	10.65		
Tartaric acid				
Ba		1.62		
Bi			8.30	
Ca	2.98	9.01		
Cd	2.8			
Co(II)	2.1			
Cu(II)	3.2	5.11	4.78	6.51
				$\log K_f$ 19.14 [Cu(OH) ₂ L ²⁻]

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Eu(III)	4.98	8.11		
Fe(III)	7.49			
La	3.06			
Mg		1.36		
Nd	9.0			
Pb	3.78		4.7	$\log K_f$ 14.1 [Pb(OH) ₂ L ²⁻]
Ra	1.24			
Sr	1.60			
Zn	2.68	8.32		
Thioglycolic acid				
Ce(III) <i>a,c</i>	1.99	3.03		
Co(II)	5.84	12.15		
Fe(II)		10.92		
Hg(II)		43.82		
La <i>a,c</i>	1.98	2.98		
Mn(II)	4.38	7.56		
Pb	8.5			
Ni	6.98	13.53		
Rare earths <i>a,c</i>	1.9–2.1	3.0–3.3		
Y <i>a,c</i>	1.91	3.19		
Zn	7.86	15.04		
Thiourea				
Ag	7.4	13.1		
Bi				$\log K_6$ 11.9
Cd	0.6	1.6	2.6	4.6
Cu(I)			13	15.4
Hg(II)		22.1	24.7	26.8
Pb	1.4	3.1	4.7	8.3
Ru(III)	1.21		0.72	
Thoron				
Th		10.15		
Triethanolamine				
Ag	2.30	3.64		
Co(II)	1.73			
Cu(II)	4.30			
Hg(II)	6.90	13.08		
Ni	2.7			
Zn	2.00			
Triethylenetetramine (Trien)				
Ag	7.7			
Cd	10.75	13.9		
Co(II)	11.0			
Cu(II)	20.4			
Fe(II)	7.8			
Fe(III)	21.9			
Hg(II)	25.26			
Mn(II)	4.9			
Ni	14.0			
Pb	10.4			
Zn	11.9			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
1,1,1-Trifluoro-3-2'-Thenoylacetone (TTA)				
Ba		10.6		
Cu(II)	6.55	13.0		
Fe(III)	6.9			
Ni	10.0			
Pr	9.53			
Pu(III)	9.53			
Pu(IV)	8.0			
Th	8.1			
U(IV)	7.2			
Zr	3.03 [as ZrL ³⁺]			
Xylenol orange				
Bi	5.52			
Fe(III)	5.70			
Hf	6.50			
Tl(III)	4.90			
Zn	6.15			
Zr	7.60			
Zincon				
Zn	13.1			

8.3 BUFFER SOLUTIONS

8.3.1 Standard Reference pH Buffer Solutions

The assigned values of pH_s , according to the Bates-Guggenheim convention [*Pure Applied Chem.* **1**:163 (1960)], for the primary standard solutions prepared from salts issued by the National Institute for Science and Technology (NIST, US) (U.S.) are given in Table 8.14. These are smoothed values. The ionic strength of these reference solutions is 0.1 or less. Strictly speaking the NIST scale uses a molality concentration system; however, values are given in molarity units for convenience.

As a result of a variable liquid-junction potential, the measured pH may be expected to differ seriously from the $\text{p}a_{\text{H}}$ determined from cells without a liquid junction in solutions of high acidity or high alkalinity. Merely to affirm the proper functioning of the glass electrode at the extreme ends of the pH scale, two secondary standards are included in Table 8.14. In addition, values for a 0.1 *m* solution of HCl are given to extend the pH scale up to 275°C [see R. S. Greeley, *Anal. Chem.* **32**:1717 (1960)]:

$t, ^\circ\text{C}$:	25	60	90	125	150	175	200	225–275
pH:	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.2

Uncertainties in the values are ± 0.03 pH unit from 25 to 90°C, ± 0.05 pH unit from 125 to 200°C, and ± 0.1 pH unit from 225 to 275°C.