EQUILIBRIUM CONSTANTS FOR TRACE ELEMENTS IN NATURAL WATERS

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INTRODUCTION

Much emphasis has recently been placed upon trace elements in natural waters, in the context of environmental research, geochemistry, hydrogeochemical exploration and geothermal water research. Hence, an increasing impetus exists to know the chemical nature of the processes that trace elements undergo in water, and to understand the chemical speciation of trace elements in natural waters.

Application of the relevant thermodynamic calculations is at present hampered because numerous published thermodynamic data are dispersed in the literature and often present in books, internal reports or less accessible journals, and are not always expressed in an obvious or similar form.

The aim of the present article is to provide, in a most user-friendly form, a homogeneous compilation of equilibrium constant values, gathered from over 50 literature sources, for trace element equilibria which are of interest in natural water studies.

SELECTION OF THE DATA

Evaluating all published thermodynamic data and choosing the "best" values is a task of such magnitude that most of the NBS publications /1/ on the topic, which comprise 7 volumes for the last decade, present selected data only. Therefore, the present compilation of equilibrium constants for trace elements in natural waters is partially extracted and adapted from existing critical reviews on thermodynamic data, including the four-volume series of Smith and Martell /5/, the two volumes of Sillen and Martell /9/, that of Naumov *et al.* /2/, of Baes and Mesmer /7/ for cation hydrolysis, of Barner and Scheuerman /3/ and of Robie *et al.* /6/ for numerous minerals. In addition, however, data were used from a number of less well-known publications, scattered throughout the literature.

The considered homogeneous and heterogeneous chemical equilibria are those that seemed relevant with respect to trace elements in natural waters.

The equilibria for major elements such as Na, Mg, Al, Si, K and Ca were not included explicitly, since these data are rather easy to find. The choice of the specific trace elements was determined by their importance from an environmental or geochemical point of view or their relevance for geothermal waters, and also partially based on our

experience with the detectable element range for natural waters of commonly applied trace analysis techniques such as neutron activation analysis, atomic absorption analysis, X-ray fluorescence, spark source mass spectrometry, and emission spectroscopy.

PRESENTATION OF THE DATA

For all the considered equilibria, the literature values for log K^0 are presented in Table 1, with reference to the literature source from which they were extracted. These K^0-data are for standard temperature and pressure, and for zero ionic strength. When relevant, different oxidation states are considered.

The elements are ordered according to their atomic number.

For each element, the reactions are given in the following order:

(1) Equilibria between the reference ion and solid phases, of which the mineral is mentioned if possible.

(2) Equilibria between the reference ion and inorganic ions in solution.

(3) Equilibria between solid phases and polynuclear complex ions.

Common ways of using the K^0-data in Table 1 to calculate chemical speciation, solubility and saturation index, and procedures for correcting the data for the influence of ionic strength and temperature, will be outlined below.

TABLE 1. Equilibrium constants for the reactions of ions and solid and dissolved compounds of 44 elements, that are of interest in natural waters.

Equilibrium reactions under consideration		Literature values of $\log K^0$ (and references)
Lithium		
$LiF(s)$ *	$= Li^+ + F^-$	-2.76 (2)
$Li_2CO_3(s)$	$= 2\ Li^+ + CO_3^{2-}$	-2.71 (2)
$LiAl(SiO_4)(s) + 4\ H^+$ Eucryptite	$= Li^+ + Al^{3+} + H_4SiO_4^\circ$	16.6 (2)
$LiAl(Si_2O_6)(s) + 2\ H_2O + 4\ H^+$ Spodumene.	$= Li^+ + Al^{3+} + 2\ H_4SiO_4^\circ$	10.2 (2)
$Li^+ + OH^-$	$= LiOH^\circ$	0.18 (9)
$+ F^-$	$= LiF^\circ$	-0.37 (3)
$+ SO_4^{2-}$	$= LiSO_4^-$	0.64 (5)(9)
$+ P_2O_7^{4-}$	$= LiP_2O_7^{3-}$	3.4 (5)
$+ HP_2O_7^{3-}$	$= LiHP_2O_7^{2-}$	2.0 (5)
$+ NO_3^-$	$= LiNO_3^\circ$	-1.45 (9)

* (s) refers to the solid phase.

Beryllium

$BeO(s) + H_2O$ Bromellite	$= Be^{2+} + 2\ OH^-$	-21.6 (1), -20.9 (2), -21.5 (3), -25.9 (4), -19.7 (11),
$Be(OH)_2(s)$	$= Be^{2+} + 2\ OH^-$	-21.4 (1), -21.3 (2), -21.4 (3), -26.0 (4), -21.3 (5), -21.1 (9), -21.3 (9), -25.7 (9), -21.6 (11),
$BeF_2(s)$	$= Be^{2+} + 2\ F^-$	-7.38 (1), -7.40 (3), -0.75 (11),
$BeCO_3(s)$	$= Be^{2+} + CO_3^{2-}$	-6.84 (2), -6.55 (11),
$BeSO_4(s)$	$= Be^{2+} + SO_4^{2-}$	5.34 (1), 5.45 (2), 5.42 (3), 2.18 (4),
$Be_3(PO_4)_2(s)$	$= 3\ Be^{2+} + 2\ PO_4^{3-}$	-37.7 (9),
$Be_2SiO_4(s) + 4\ H^+$ Phenacite	$= 2\ Be^{2+} + H_4SiO_4^\circ$	7.62 (1), 7.30 (2),
$Be(AlO_2)_2(s) + 8\ H^+$ Chrysoberyl	$= Be^{2+} + 2\ Al^{3+} + 4\ H_2O$	21.1 (1), 23.9 (2), 27.0 (11),

$Be^{2+} + OH^-$	$== BeOH^+$	8.60 (5)
$+ 2\ OH^-$	$== Be(OH)_2^\circ$	14.4 (5)
$+ 3\ OH^-$	$== Be(OH)_3^-$	18.6 (2)
$+ 4\ OH^-$	$== Be(OH)_4^{2-}$	18.4 (2)
$+ 2\ OH^-$	$== BeO_2^{2-} + 2\ H^+$	-3.73 (4)
$+ F^-$	$== BeF^+$	6.00 (2)
$+ 2\ F^-$	$== BeF_2^\circ$	9.94 (2)
$+ 3\ F^-$	$== BeF_3^-$	12.7 (2)
$+ 4\ F^-$	$== BeF_4^{2-}$	15.0 (2)
$+ OH^- + F^-$	$== Be(OH)F^\circ$	12.3 (40)
$+ 2\ OH^- + F^-$	$== Be(OH)_2F^-$	17.0 (40)
$+ OH^- + 2\ F^-$	$== Be(OH)F_2^-$	13.8 (40)
$+ Cl^-$	$== BeCl^+$	0.32 (29)
$+ 2\ Cl^-$	$== BeCl_2^\circ$	-0.54 (29)
$+ CO_3^{2-}$	$== BeCO_3^\circ$	5.13 (29)
$+ 2\ CO_3^{2-}$	$== Be(CO_3)_2^{2-}$	26.5 (44)
$+ OH^- + CO_3^{2-}$	$== Be(OH)CO_3^-$	24.0 (44)
$+ SO_4^{2-}$	$== BeSO_4^\circ$	1.95 (1)(5)
$+ 2\ SO_4^{2-}$	$== Be(SO_4)_2^{2-}$	3.56 (29)
$+ 3\ SO_4^{2-}$	$== Be(SO_4)_3^{4-}$	3.08 (29)
$+ NO_3^-$	$== BeNO_3^+$	-0.60 (5)
$2\ Be(OH)_2(s)$	$== Be_2O^{2+} + H_2O + 2\ OH^-$	-30.7 (4)
$2\ Be(OH)_2(s)$	$== Be_2O_3^{2-} + H_2O + 2\ H^+$	-27.1 (4)
$3\ Be(OH)_2(s)$	$== Be_3(OH)_3^{3+} + 3\ OH^-$	-30.7 (1)
$6\ Be(OH)_2(s)$	$== Be_6(OH)_8^{4+} + 4\ OH^-$	-41.9 (5)(1)

Boron

$BF_3(s) + 3\ H_2O$ == $B(OH)_3^\circ + 3\ H^+ + 3\ F^-$ -3.78 (2)

$NaBF_4(s) + 3\ H_2O$ == $B(OH)_3^\circ + 3\ H^+ + Na^+ + 4\ F^-$ -18.1 (2)
Ferrucite

$KBF_4(s) + 3\ H_2O$ == $B(OH)_3^\circ + 3\ H^+ + K^+ + 4\ F^-$ -22.9 (2)
Avogadrite

$Ca(BO_2)_2(s) + 2\ H_2O + 2\ H^+$ == $2\ B(OH)_3^\circ + Ca^{2+}$ 16.1 (2)
Calciborite

$Pb(BO_2)_2(s) + 2\ H_2O + 2\ H^+$ == $2\ B(OH)_3^\circ + Pb^{2+}$ 7.60 (2)

$CaB_4O_7(s) + 5\ H_2O + 2\ H^+$ == $4\ B(OH)_3^\circ + Ca^{2+}$ 13.2 (2)

$B(OH)_3^\circ$ == $H_2BO_3^- + H^+$ -9.18 (4)

== $HBO_3^{2-} + 2\ H^+$ -21.9 (4)

== $BO_3^{3-} + 3\ H^+$ -35.7 (4)

$B(OH)_3^\circ + OH^-$ == $B(OH)_4^-$ 4.75 (2)

$+ 2\ OH^-$ == $B(OH)_5^{2-}$ 6.45 (2)

$+ 3\ OH^-$ == $B(OH)_6^{3-}$ 7.04 (2)

$B(OH)_3^\circ$ == $BO_2^- + H_2O + H^+$ -2.84 (4)

$4\ B(OH)_3^\circ$	$== H_2B_4O_7^\circ + 5\ H_2O$	5.35 (1)
	$== HB_4O_7^- + 5\ H_2O + H^+$	-0.73 (1)
	$== B_4O_7^{2-} + 5\ H_2O + 2\ H^+$	-15.5 (1)
$B(OH)_3^\circ + F^-$	$== BF(OH)_3^-$	-0.29(41)
$+ 2\ F^-$	$== BF_2(OH)_2^- + OH^-$	-6.40 (41)
$+ 3\ F^-$	$== BF_3(OH)^- + 2\ OH^-$	-13.3 (41)
$+ 3\ F^-$	$== BF_3^\circ + 3\ OH^-$	-38.7 (1)
$+ 4\ F^-$	$== BF_4^- + 3\ OH^-$	-21.9 (41)

Scandium

$Sc_2O_3(s) + 3\ H_2O$	$== 2\ Sc^{3+} + 6\ OH^-$	-72.5 (1), -67.4 (2), -72.6 (7),
$ScO(OH)\ (s) + H_2O$	$== Sc^{3+} + 3\ OH^-$	-32.7 (5), -32.7 (7),
$Sc(OH)_3(s)$	$== Sc^{3+} + 3\ OH^-$	-30.7 (1), -29.7 (2), -27.1 (4), -29.7 (7), -33.0 (7), -27.0 (9), -29.7 (9),
$ScF_3(s)$	$== Sc^{3+} + 3\ F^-$	-23.2 (1),

$Sc^{3+} + OH^-$	$= Sc(OH)^{2+}$	9.24	(7)
$+ 2\ OH^-$	$= Sc(OH)_2^+$	18.3	(5)(7)
$+ 3\ OH^-$	$= Sc(OH)_3^\circ$	27.2	(7)
$+ 4\ OH^-$	$= Sc(OH)_4^-$	32.1	(7)
$+ F^-$	$= ScF^{2+}$	7.09	(2)(5)
$+ 2\ F^-$	$= ScF_2^+$	12.9	(2)(5)
$+ 3\ F^-$	$= ScF_3^\circ$	17.3	(2)
$+ 4\ F^-$	$= ScF_4^-$	20.2	(2)
$+ 6\ F^-$	$= ScF_6^{3-}$	15.7	(11)
$+ Cl^-$	$= ScCl^{2+}$	0.92	(29)
$+ 2\ Cl^-$	$= ScCl_2^+$	1.57	(9)
$+ Br^-$	$= ScBr^{2+}$	-1.72	(1)
$+ 2\ Br^-$	$= ScBr_2^+$	-1.47	(1)
$+ CO_3^{2-}$	$= ScCO_3^+$	10.1	(29)
$+ SO_4^{2-}$	$= ScSO_4^+$	4.40	(29)
$+ 2\ SO_4^{2-}$	$= Sc(SO_4)_2^-$	6.33	(29)
$+ NO_3^-$	$= ScNO_3^{2+}$	-1.40	(1)
$2\ Sc(OH)_3(s)$	$= Sc_2(OH)_2^{4+} + 4\ OH^-$	-39.3	(5)
$3\ Sc(OH)_3(s)$	$= Sc_3(OH)_5^{4+} + 4\ OH^-$	-38.2	(5)

Titanium IV

$TiO_2(s) + H_2O$ Rutile	$== TiO^{2+} + 2\ OH^-$	-41.1 (2), -40.9 (11
$TiO_2(s) + H_2O$ Anatase	$== TiO^{2+} + 2\ OH^-$	-39.9 (2), -35.9 (11
$TiO(OH)_2(s)$	$== TiO^{2+} + 2\ OH^-$	-29.0 (9), -29.0 (9) -29.2 (11),
$CaTiO(SiO_4)\ (s) + 4\ H^+$ Sphene - Titanite	$== TiO^{2+} + Ca^{2+} + H_4SiO_4^\circ$	-3.77 (2)
$TiO^{2+} +\ OH^-$	$== TiO(OH)^+$	11.7 (29)
$+ 2\ OH^-$	$== TiO(OH)_2^\circ$	23.2 (29)
$+ 3\ H_2O$	$== Ti(OH)_4^\circ + 2\ H^+$	-1.1 (9)
$+ 2\ OH^-$	$== HTiO_3^- + H^+$	11.2 (4)
$+ 6\ F^- + 2\ H^+$	$== TiF_6^{2-} + H_2O$	18.4 (11)
$+\ SO_4^{2-}$	$== TiOSO_4^\circ$	2.50 (5)

Vanadium III

$V_2O_3(s) + 3\ H_2O$ Karelianite	$== 2\ V^{3+} + 6\ OH^-$	-74.2 (2), -69.9 (4),
$V(OH)_3(s)$	$== V^{3+} + 3\ OH^-$	-33.1 (4),
$V^{3+} + OH^-$	$== V(OH)^{2+}$	11.1 (2)(4)
$+ 2\ OH^-$	$== V(OH)_2^+$	21.5 (2)

Vanadium IV

$V_2O_4(s) + 2\ H_2O$ Paramontrosite	$== 2\ VO^{2+} + 4\ OH^-$	-47.4 (1), -47.4 (2), -46.2 (4),
$VO(OH)_2(s)$ Duttonite	$== VO^{2+} + 2\ OH^-$	-21.6 (4),
$VO^{2+} + H_2O + OH^-$	$== V(OH)_3^+$	8.63 (2)
$+ F^-$	$== VOF^+$	3.29 (2)
$+ 2\ F^-$	$== VOF_2^+$	5.48 (2)
$+ 3\ F^-$	$== VOF_3^-$	7.15 (2)
$+ SO_4^{2-}$	$== VOSO_4^\circ$	2.48 (2)

Vanadium V

$V_2O_5(s) + 3\ H_2O$	$== 2\ VO_4^{3-} + 6\ H^+$	-58.3 (1), -57.0 (2),
Vanadiumochre		
$VO_4^{3-} + H^+$	$== HVO_4^{2-}$	13.3 (1)
$+ 2\ H^+$	$== H_2VO_4^-$	21.3 (1)
$+ 3\ H^+$	$== H_3VO_4^\circ$	24.6 (2)
$+ 4\ H^+$	$== V(OH)_4^+$	30.1 (1)
$+ 4\ H^+$	$== VO_2^+ + 2\ H_2O$	28.4 (1)
$+ 2\ H^+$	$== VO_3^- + H_2O$	21.3 (1)
$V_2O_5(s) + 2\ H_2O$	$== V_2O_7^{4-} + 4\ H^+$	-29.2 (1)
$+ 2\ H_2O$	$== HV_2O_7^{3-} + 3\ H^+$	-16.5 (1)
$+ 2\ H_2O$	$== H_3V_2O_7^- + H^+$	- 3.97 (1)
$5\ V_2O_5(s) + 3\ H_2O$	$== HV_{10}O_{26}^{5-} + 5\ H^+$	-18.7 (1)
$+ 3\ H_2O$	$== H_2V_{10}O_{28}^{4-} + 4\ H^+$	-15.1 (1)
$+ 3\ H_2O$	$== V_{10}O_{28}^{6-} + 6\ H^+$	-24.5 (7)
$3\ V_2O_5(s) + 3\ H_2O$	$== 2\ V_3O_9^{3-} + 6\ H^+$	-35.4 (7)

Chromium III

$Cr_2O_3(s) + 3\ H_2O$ Escolaite	$== 2\ Cr^{3+} + 6\ OH^-$	-73.2 (1), -73.5 (2), -69.2 (3), -67.2 (4), -68.5 (6),
$Cr(OH)_3(s)$	$== Cr^{3+} + 3\ OH^-$	-30.0 (2), -37.4 (4), -30.0 (7), -30.2 (9),
$Cr^{3+} + OH^-$	$== Cr(OH)^{2+}$	10.0 (2)
$+ 2\ OH^-$	$== Cr(OH)_2^+$	18.4 (2)
$+ 3\ OH^-$	$== Cr(OH)_3^\circ$	24.0 (7)
$+ 4\ OH^-$	$== Cr(OH)_4^-$	28.6 (7)
$+ 2\ OH^-$	$== CrO_2^- + 2\ H^+$	- 0.02 (2)
$+ 3\ OH^-$	$== CrO_3^{3-} + 3\ H^+$	-14.7 (4)
$+ F^-$	$== CrF^{2+}$	5.00 (1)
$+ 2\ F^-$	$== CrF_2^+$	9.31 (29)
$+ 3\ F^-$	$== CrF_3^\circ$	11.9 (29)
$+ Cl^-$	$== CrCl^{2+}$	0.60 (2)
$+ 2\ Cl^-$	$== CrCl_2^+$	- 0.11 (2)
$+ SO_4^{2-}$	$== CrSO_4^+$	4.61 (29)
$2\ Cr(OH)_3(s)$	$== Cr_2(OH)_2^{4+} + 4\ OH^-$	-37.0 (7)
$3\ Cr(OH)_3(s)$	$== Cr_3(OH)_4^{5+} + 5\ OH^-$	-42.1 (7)

Chromium VI

$CrO_3(s) + H_2O$ == $CrO_4^{2-} + 2\ H^+$ -4.83 (11),

$CrO_4^{2-} + H^+$ == $HCrO_4^-$ 6.50 (2)

$+ 2\ H^+$ == $H_2CrO_4^o$ 5.52 (2)

$+ Na^+$ == $NaCrO_4^-$ 0.70 (29)

$+ K^+$ == $KCrO_4^-$ 0.80 (29)

$2\ CrO_3(s) + H_2O$ == $Cr_2O_7^{2-} + 2\ H^+$ 7.13 (2)

$MnO(s) + H_2O$ Manganosite	$== Mn^{2+} + 2\ OH^-$	-10.1 (1), -9.70 (2), -10.0 (3), -10.2 (4), -10.1 (6), -9.60 (19),
$Mn(OH)_2(s)$ Pyrochroite	$== Mn^{2+} + 2\ OH^-$	-12.7 (1), -12.5 (2), -13.0 (4), -12.8 (5), -12.8 (7), -12.4 (9), -12.7 (9), -12.8 (9), -11.6 (11), -12.8 (19),
$MnCO_3(s)$ Rhodochrosite	$== Mn^{2+} + CO_3^{2-}$	-10.6 (1), -10.3 (2), -10.6 (3), -10.0 (4), -9.30 (5), -10.6 (6), -9.30 (9), -10.1 (19), -10.6 (48),
$MnS(s) + H^+$ Alabandite	$== Mn^{2+} + HS^-$	-0.43 (1), -0.04 (2), -0.44 (3), 1.09 (4), -0.40 (6), 0.06 (19),
$MnSO_4(s)$	$== Mn^{2+} + SO_4^{2-}$	2.67 (1), 2.77 (2), 2.71 (3), 2.39 (4), 2.42 (6), 2.25 (10), 2.87 (11), 3.43 (19),
$Mn_3(PO_4)_2(s)$	$== 3\ Mn^{2+} + 2\ PO_4^{3-}$	-21.7 (4), -27.3 (19),
$MnSiO_3(s) + H_2O + 2\ H^+$ Rhodonite	$== Mn^{2+} + H_4SiO_4^\circ$	11.7 (1), 10.9 (2), 10.3 (19),
$Mn_2SiO_4(s) + 4\ H^+$ Tephroite	$== 2\ Mn^{2+} + H_4SiO_4^\circ$	24.6 (1), 24.2 (2), 24.5 (19),

$Mn^{2+} + OH^-$	$== MnOH^+$	3.41 (2)
$+ 2\ OH^-$	$== Mn(OH)_2^\circ$	5.80 (7)
$+ 3\ OH^-$	$== Mn(OH)_3^-$	7.81 (2)
$+ 4\ OH^-$	$== Mn(OH)_4^{2-}$	7.70 (7)
$+ 2\ OH^-$	$== HMnO_2^- + H^+$	-6.37 (4)
$+ F^-$	$== MnF^+$	0.85 (1)
$+ Cl^-$	$== MnCl^+$	0.61 (1)
$+ 2\ Cl^-$	$== MnCl_2^\circ$	0.04 (1)
$+ 3\ Cl^-$	$== MnCl_3^-$	-0.30 (1)
$+ CO_3^{2-}$	$== MnCO_3^\circ$	4.10 (29)
$+ HCO_3^-$	$== MnHCO_3^+$	1.80 (5)
$+ S_2O_3^{2-}$	$== MnS_2O_3^\circ$	1.79 (4)
$+ SO_4^{2-}$	$== MnSO_4^\circ$	2.26(10)(37)
$+ NO_3^-$	$== MnNO_3^+$	0.20 (5)
$+ 2\ NO_3^-$	$== Mn(NO_3)_2^\circ$	0.60 (5)
$2\ Mn(OH)_2(s)$	$== Mn_2(OH)^{3+} + 3\ OH^-$	-22.2 (5)
$2\ Mn(OH)_2(s)$	$== Mn_2(OH)_3^+ + OH^-$	-7.50 (5)

Iron II

$FeO(s) + H_2O$ Wustite	$== Fe^{2+} + 2\ OH^-$	-13.2 (2), -15.6 (3), -14.4 (4), -16.6 (6), -14.3 (33), -14.5 (19),
$Fe(OH)_2(s)$	$== Fe^{2+} + 2\ OH^-$	-16.3 (1), -15.1 (2), -16.4 (3), -14.7 (4), -15.1 (5), -15.2 (7), -14.8 (9), -15.0 (9), -15.1 (9), -15.1 (36),
$FeCO_3(s)$ Siderite	$== Fe^{2+} + CO_3^{2-}$	-10.5 (1), -10.5 (2), -10.6 (3), -10.7 (4), -10.7 (5), -10.6 (6), -10.7 (10), -10.7 (36),
$FeS(s) + H^+$ Pyrrhotite	$== Fe^{2+} + HS^-$	-5.89 (1), -3.55 (2), -5.94 (3), -4.20 (5), -6.06 (6), -4.30 (9), -4.38 (9), -4.42 (9), -4.99 (10), -4.52 (19),
$FeSO_4(s)$	$== Fe^{2+} + SO_4^{2-}$	0.45 (1), 2.73 (2), 0.51 (3), -0.48 (4) 2.65 (19),
$Fe_3(PO_4)_2 \cdot 8H_2O$ Vivianite	$== 3\ Fe^{2+} + 2\ PO_4^{3-} + 8\ H_2O$	-36.0 (5), -36.0 (19),
$FeSiO_3(s) + H_2O + 2\ H^+$ Ferrosilite	$== Fe^{2+} + H_4SiO_4^\circ$	5.06 (4), 14.8 (19), 8.26 (33),
$Fe_2SiO_4(s) + 4\ H^+$ Fayalite	$== 2\ Fe^{2+} + H_4SiO_4^\circ$	16.7 (1), 20.1 (2), 15.5 (4), 19.8 (19), 19.7 (33),

$CaFe(SiO_3)_2(s) + 2\ H_2O + 4\ H^+ == Fe^{2+} + Ca^{2+} + 2\ H_4SiO_4^\circ$ 20.3 (33),
Hedenbergite

$Fe_3Si_2O_5(OH)_4(s) + 6\ H^+ == 3\ Fe^{2+} + H_2O + H_4SiO_4^\circ$ 26.4 (27),
Greenalite

$Fe_3Si_4O_{10}(OH)_2(s) + 4\ H_2O + 6\ H^+ == 3\ Fe^{2+} + 4\ H_4SiO_4^\circ$ 16.0 (27),
Minnesotaite

$KFe_3(AlSi_3O_{10})(OH)_2(s) + 10\ H^+ == 3\ Fe^{2+} + K^+ + Al^{3+} + 3\ H_4SiO_4^\circ$
Annite 32.8 (27), 31.8 (33)

$CuFeS_2(s) + 2\ H^+ == Fe^{2+} + Cu^{2+} + 2\ HS^-$ -30.8 (2), -35.3 (3)
Chalcopyrite -33.7 (10),

$Fe^{2+} + OH^-$	$= Fe(OH)^+$	5.70 (10)(36)
$+ 2\ OH^-$	$= Fe(OH)_2^\circ$	7.40 (5)
$+ 3\ OH^-$	$= Fe(OH)_3^-$	10.0 (?)
$+ 4\ OH^-$	$= Fe(OH)_4^{2-}$	9.60 (2)
$+ 2\ OH^-$	$= HFeO_2^- + H^+$	-2.74 (1)
$+ 2\ OH^-$	$= FeO_2^{2-} + 2\ H^+$	-10.8 (1)
$+ F^-$	$= FeF^+$	1.42 (29)
$+ 2\ F^-$	$= FeF_2^\circ$	0.00 (1)
$+ Cl^-$	$= FeCl^+$	0.32 (29)
$+ 2\ Cl^-$	$= FeCl_2^\circ$	0.00 (1)
$+ 2\ Br^-$	$= FeBr_2^\circ$	0.00 (1)
$+ CO_3^{2-}$	$= FeCO_3^\circ$	4.73 (29)
$+ HCO_3^-$	$= FeHCO_3^+$	2.60 (53)
$+ 2\ HS^-$	$= Fe(HS)_2^\circ$	8.95 (?)
$+ 3\ HS^-$	$= Fe(HS)_3^-$	11.0 (?)
$+ S_2O_3^{2-}$	$= FeS_2O_3^\circ$	4.36 (1)
$+ SO_4^{2-}$	$= FeSO_4^\circ$	2.20 (2)
$+ H_2PO_4^-$	$= FeH_2PO_4^+$	2.70 (5)
$+ HPO_4^{2-}$	$= FeHPO_4^\circ$	3.60 (5)
$3\ Fe(OH)_2(s)$	$= Fe_3(OH)_4^{2+} + 2\ OH^-$	-34.7 (19)

Iron III

$Fe_2O_3(s) + 3\ H_2O$	$== 2\ Fe^{3+} + 6\ OH^-$	-87.7 (1), -83.1 (2),
Hematite		-87.7 (3), -85.4 (4),
		-85.4 (5), -87.9 (6),
		-85.4 (9), -83.6 (33),
		-83.8 (19),
$FeO(OH)(s) + H_2O$	$== Fe^{3+} + 3\ OH^-$	-41.7 (2), -41.5 (5),
Goethite		-43.7 (6), -42.0 (19),
$Fe(OH)_3(s)$	$== Fe^{3+} + 3\ OH^-$	-38.6 (1), -39.4 (2),
		-38.6 (3), -37.2 (4),
		-38.3 (5), -36.9 (9),
		-37.5 (9), -38.6 (9),
		-39.4 (9), -38.4 (19),
$Fe_2S_3(s) + 3\ H^+$	$== 2\ Fe^{3+} + 3\ HS^-$	-49.3 (2), -49.3 (19),
$Fe_2(SO_4)_3(s)$	$== 2\ Fe^{3+} + 3\ SO_4^{2-}$	3.58 (2), -3.44 (3),
		-1.92 (6), 2.89 (19),
$FePO_4(s)$	$== Fe^{3+} + PO_4^{3-}$	-26.0 (2), -17.9 (4),
Heterosite		-24.9 (19),
$FePO_4.H_2O(s)$	$== Fe^{3+} + PO_4^{3-} + H_2O$	-25.3 (1), -25.7 (2),
Strengite		-26.4 (5), -26.4 (19),

$Fe_2Si_4O_{10}(OH)_2(s) + 6\ H^+ + 4\ H_2O == 2\ Fe^{3+} + 4\ H_4SiO_4^\circ$ -9.11 (27)
Ferric Minnesotaite

$Ca_3Fe_2Si_3O_{12}(s) + 12\ H^+ == 2\ Fe^{3+} + 3\ Ca^{2+} + 3\ H_4SiO_4^\circ$ 34.1 (33),
Andradite

$Ca_2FeAl_2Si_3O_{12}(OH)(s) + 13\ H^+ == Fe^{3+} + 2\ Ca^{2+} + 2\ Al^{3+} + H_2O + 3\ H_4SiO_4^\circ$
Epidote 35.3 (33),

$Fe^{3+} + OH^-$	$== Fe(OH)^{2+}$	11.8 (2)
$+ 2\ OH^-$	$== Fe(OH)_2^+$	21.2 (2)
$+ 3\ OH^-$	$== Fe(OH)_3^\circ$	32.9 (2)
$+ 4\ OH^-$	$== Fe(OH)_4^-$	34.5 (2)
$+ F^-$	$== FeF^{2+}$	6.04 (2)
$+ 2\ F^-$	$== FeF_2^+$	10.9 (23)
$+ 3\ F^-$	$== FeF_3^\circ$	14.0 (23)
$+ Cl^-$	$== FeCl^{2+}$	1.48 (10)
$+ 2\ Cl^-$	$== FeCl_2^+$	2.13 (10)
$+ 3\ Cl^-$	$== FeCl_3^\circ$	1.13 (10)
$+ 4\ Cl^-$	$== FeCl_4^-$	-0.79 (10)
$+ Br^-$	$== FeBr^{2+}$	0.66 (3)
$+ 3\ Br^-$	$== FeBr_3^\circ$	0.04 (19)
$+ CO_3^{2-}$	$== FeCO_3^+$	9.72 (29)
$+ S_2O_3^{2-}$	$== FeS_2O_3^+$	17.4 (1)
$+ SO_4^{2-}$	$== FeSO_4^+$	4.15 (2)
$+ 2\ SO_4^{2-}$	$== Fe(SO_4)_2^-$	5.67 (1)
$+ H_2PO_4^-$	$== FeH_2PO_4^{2+}$	3.50 (12)
$+ HPO_4^{2-}$	$== FeHPO_4^+$	8.30 (12)
$+ NO_3^-$	$== FeNO_3^{2+}$	1.02 (1)

$2\ Fe(OH)_3(s)$	$== Fe_2(OH)_2^{4+} + 4\ OH^-$	-52.0 (1)
$3\ Fe(OH)_3(s)$	$== Fe_3(OH)_4^{5+} + 5\ OH^-$	-68.5 (5)
$2\ Fe(OH)_3(s) + 3\ SO_4^{2-}$	$== Fe_2(SO_4)_3^{\circ} + 6\ OH^-$	-78.4 (1)

Cobalt

$CoO(s) + H_2O$	$== Co^{2+} + 2\ OH^-$	-14.1 (1), -14.3 (2), -14.4 (3), -13.0 (4), -14.5 (6), -14.6 (9), -15.2 (9), -15.5 (9), -14.0 (11),
$Co(OH)_2(s)$ Transvaalite	$== Co^{2+} + 2\ OH^-$	-15.0 (1), -15.0 (2), -15.4 (4), -14.9 (5), -14.9 (9), -15.4 (11), -14.9 (36),
$CoCO_3(s)$ Spherocobaltite	$== Co^{2+} + CO_3^{2-}$	-9.84 (2), -12.1 (4), -9.98 (5), -9.98 (9), -12.8 (9),
$CoS(s) + H^+$ Jaipurite	$== Co^{2+} + HS^-$	-7.09 (2), -7.04 (3), -7.34 (4), -5.35 (11),
$CoSO_4(s)$	$== Co^{2+} + SO_4^{2-}$	2.91 (1), 2.84 (2), 2.86 (3), 7.36 (4),
$CoSO_4.H_2O\ (s)$	$== Co^{2+} + SO_4^{2-} + H_2O$	-1.02 (2),
$CoSO_4.6H_2O(s)$	$== Co^{2+} + SO_4^{2-} + 6\ H_2O$	-2.18 (2),

$CoSO_4.7H_2O(s)$ Bieberite	$== Co^{2+} + SO_4^{2-} + 7\ H_2O$	-2.33 (2),
$Co_3(PO_4)_2(s)$	$== 3\ Co^{2+} + 2\ PO_4^{3-}$	-33.9 (1), -34.7 (9),
$Co^{2+} + OH^-$	$== Co(OH)^+$	4.35 (29)
$+ 2\ OH^-$	$== Co(OH)_2^\circ$	9.19 (2)(7)
$+ 3\ OH^-$	$== Co(OH)_3^-$	10.5 (2)(7)
$+ 4\ OH^-$	$== Co(OH)_4^{2-}$	9.70 (7)
$+ 2\ OH^-$	$== HCoO_2^- + H^+$	6.75 (1)
$+ F^-$	$== CoF^+$	1.02 (29)
$+ Cl^-$	$== CoCl^+$	-0.14 (2)
$+ 2\ Cl^-$	$== CoCl_2^\circ$	-0.03 (1)
$+ 2\ Br^-$	$== CoBr_2^\circ$	0.00 (1)
$+ CO_3^{2-}$	$== CoCO_3^\circ$	4.91 (29)
$+ HCO_3^-$	$== CoHCO_3^+$	1.39 (49)
$+ HS^-$	$== Co(HS)^+$	5.70 (2)
$+ 2\ HS^-$	$== Co(HS)_2^\circ$	8.76 (2)
$+ S_2O_3^{2-}$	$== CoS_2O_3^\circ$	2.04 (2)
$+ SO_4^{2-}$	$== CoSO_4^\circ$	2.36 (37)
$+ NO_3^-$	$== CoNO_3^+$	0.20 (5)
$+ 2\ NO_3^-$	$== Co(NO_3)_2^\circ$	-0.01 (1)
$2\ Co(OH)_2(s)$	$== Co_2(OH)^{3+} + 3\ OH^-$	-28.4 (5)
$4\ Co(OH)_2(s)$	$== Co_4(OH)_4^{4+} + 4\ OH^-$	-36.9 (5)

Nickel

$NiO(s) + H_2O$ Bunsenite	$= Ni^{2+} + 2\ OH^-$	-15.5 (1), -15.6 (2), -15.5 (3), -15.6 (4), -15.5 (6), -15.7 (7), -14.5 (11),
$Ni(OH)_2(s)$	$= Ni^{2+} + 2\ OH^-$	-15.3 (1), -17.4 (2), -15.8 (4), -15.2 (5), -14.9 (9), -15.0 (9), -15.2 (9), -15.5 (9), -15.1 (11),
$NiCO_3(s)$	$= Ni^{2+} + CO_3^{2-}$	-6.84 (1), -6.85 (2), -6.78 (4), -6.87 (5), -6.87 (9), -6.82 (11),
$NiS(s) + H^+$ Millerite	$= Ni^{2+} + HS^-$	-8.05 (1), -8.14 (2), -8.02 (3), -6.73 (4), -9.24 (6), -6.72 (11), -7.64 (11),
$NiSO_4(s)$	$= Ni^{2+} + SO_4^{2-}$	5.33 (1), 4.50 (2), 5.42 (3), 2.91 (4), 1.73 (11),
$Ni_3(PO_4)_2(s)$	$= 3\ Ni^{2+} + 2\ PO_4^{3-}$	-30.6 (1),
$Ni_2P_2O_7(s) + H_2O$	$= 2\ Ni^{2+} + 2\ H^+ + 2\ PO_4^{3-}$	-32.8 (1),
$Ni_2SiO_4(s) + 4\ H^+$	$= 2\ Ni^{2+} + H_4SiO_4^\circ$	14.5 (2),

$Ni^{2+} + OH^-$	$== Ni(OH)^+$	4.14	(7)
$+ 2\ OH^-$	$== Ni(OH)_2^\circ$	10.2	(2)
$+ 3\ OH^-$	$== Ni(OH)_3^-$	13.0	(2)
$+ 4\ OH^-$	$== Ni(OH)_4^{2-}$	12.0	(29)
$+ 2\ OH^-$	$== HNiO_2^- + H^+$	-2.39	(4)
$+ F^-$	$== NiF^+$	1.12	(29)
$+ 2\ F^-$	$== NiF_2^\circ$	0.01	(1)
$+ Cl^-$	$== NiCl^+$	0.18	(5)
$+ 2\ Cl^-$	$== NiCl_2^\circ$	-0.03	(1)
$+ CO_3^{2-}$	$== NiCO_3^\circ$	5.37	(29)
$+ S_2O_3^{2-}$	$== NiS_2O_3^\circ$	1.83	(1)
$+ SO_4^{2-}$	$== NiSO_4^\circ$	2.32	(10)
$+ 2\ SO_4^{2-}$	$== Ni(SO_4)_2^{2-}$	3.20	(29)
$+ NO_3^-$	$== NiNO_3^+$	0.40	(5)
$+ 2\ NO_3^-$	$== Ni(NO_3)_2^\circ$	0.06	(1)
$2\ Ni(OH)_2(s)$	$== Ni_2(OH)^{3+} + 3\ OH^-$	-31.5	(5)
$4\ Ni(OH)_2(s)$	$== Ni_4(OH)_4^{4+} + 4\ OH^-$	-41.3	(5)

Copper I

$Cu_2O(s) + H_2O$ Cuprite	$== 2\ Cu^+ + 2\ OH^-$	-29.5 (1), -29.9 (2), -29.6 (3), -29.7 (4), -29.6 (6), -29.6 (7), -29.1 (11), -30.2 (19),
$CuOH(s)$	$== Cu^+ + OH^-$	-14.7 (5), -14.7 (9), -14.7 (19),
$Cu_2S(s) + H^+$ Chalcocite	$== 2\ Cu^+ + HS^-$	-34.7 (1), -34.7 (2), -34.8 (3), -34.9 (4), -34.9 (6), -34.7 (10), -35.4 (11), -33.8 (11), -35.3 (11), -35.6 (19),
$Cu_2SO_4(s)$	$== 2\ Cu^+ + SO_4^{2-}$	-1.95 (4), -1.49 (11), -1.95 (19),
$Cu^+ + Cl^-$	$== CuCl°$	2.70 (5)
$+ 2\ Cl^-$	$== CuCl_2^-$	4.94 (10)
$+ 3\ Cl^-$	$== CuCl_3^{2-}$	5.14 (10)
$+ S_2O_3^{2-}$	$== CuS_2O_3^-$	10.4 (5)
$+ 2\ S_2O_3^{2-}$	$== Cu(S_2O_3)_2^{3-}$	12.3 (5)
$+ 3\ S_2O_3^{2-}$	$== Cu(S_2O_3)_3^{5-}$	13.7 (5)
$+ SO_3^{2-}$	$== CuSO_3^-$	7.81 (1)
$+ 2\ SO_3^{2-}$	$== Cu(SO_3)_2^{3-}$	8.61 (1)
$+ 3\ SO_3^{2-}$	$== Cu(SO_3)_3^{5-}$	9.35 (1)
$2\ Cu(OH)(s) + SO_3^{2-}$	$== Cu_2SO_3° + 2\ OH^-$	-29.4 (1)
$2\ Cu(OH)(s) + 4\ Cl^-$	$== Cu_2Cl_4^{2-} + 2\ OH^-$	-16.3 (5)
$2\ CuS(s) + S_3^{2-} + 3\ S_4^{2-}$	$== 2\ Cu(S_4)_2^{3-} + S^{2-}$	-1.30 (17)
$2\ CuS(s) + 3\ S_4^{2-} + S_5^{2-}$	$== 2\ CuS_4S_5^{3-} + S^{2-}$	-6.44 (17)

Copper II

$CuO(s) + H_2O$ Tenorite	$== Cu^{2+} + 2\ OH^-$	-20.6 (1), -20.3 (2), -20.7 (3), -20.1 (4), -20.4 (5), -20.6 (6), -19.9 (9), -19.7 (9),
$Cu(OH)_2(s)$	$== Cu^{2+} + 2\ OH^-$	-18.8 (4), -19.3 (5), -18.2 (9), -18.3 (9), -19.3 (9), -19.8 (9), -19.9 (9), -19.3 (12),
$Cu_4Cl_2(OH)_6(s)$ Atacamite	$== 4\ Cu^{2+} + 2\ Cl^- + 6\ OH^-$	-35.2 (2),
$CuCO_3(s)$	$== Cu^{2+} + CO_3^{2-}$	-9.70 (2), -9.63 (9), -9.63 (19),
$Cu_2CO_3(OH)_2(s)$ Malachite	$== 2\ Cu^{2+} + CO_3^{2-} + 2\ OH^-$	-33.9 (2), -32.0 (3), -33.8 (5), -33.8 (9), -33.2 (19),
$Cu_3(CO_3)_2(OH)_2(s)$ Azurite	$== 3\ Cu^{2+} + 2\ CO_3^{2-} + 2\ OH^-$	-47.7 (2), -46.5 (3), -46.0 (5), -46.0 (9), -44.7 (19),
$CuS(s) + H^+$ Covellite	$== Cu^{2+} + HS^-$	-23.0 (1), -22.9 (2), -23.0 (3), -22.2 (4), -22.2 (6), -22.1 (10), -23.2 (19),
$CuSO_4(s)$ Chalcocyanite	$== Cu^{2+} + SO_4^{2-}$	3.01 (1), 2.95 (2), 3.01 (3), 2.65 (4), 2.72 (6), 3.72 (19),

$Cu_3SO_4(OH)_4(s)$ Antlerite	== 3 Cu^{2+} + SO_4^{2-} + 4 OH^-	-47.1 (2), -47.3 (3), -47.2 (9)
$Cu_4SO_4(OH)_6(s)$ Brochantite	== 4 Cu^{2+} + SO_4^{2-} + 6 OH^-	-68.5 (2), -69.4 (3), -68.6 (5), -68.5 (9), -68.6 (9), -69.0 (9), -69.4 (9), -68.6 (19),
$Cu_3(PO_4)_2(s)$	== 3 Cu^{2+} + 2 PO_4^{3-}	-36.1 (1), -36.9 (19),
$Cu_2P_2O_7(s)$ + H_2O	== 2 Cu^{2+} + 2 H^+ + 2 PO_4^{3-}	-35.2 (1), -32.5 (19),
$CuSiO_3(s)$ + H_2O + 2 H^+ Dioptase	== Cu^{2+} + $H_4SiO_4^\circ$	6.50 (2),
$CuFeS_2(s)$ + 2 H^+ Chalcopyrite	== Cu^{2+} + Fe^{2+} + 2 HS^-	-30.8 (2), -35.3 (3), -33.7 (10),

$Cu^{2+} + OH^-$	$== Cu(OH)^+$	6.03 (9)
$+ 2\ OH^-$	$== Cu(OH)_2^\circ$	11.8
$+ 3\ OH^-$	$== Cu(OH)_3^-$	15.0 (2)
$+ 4\ OH^-$	$== Cu(OH)_4^{2-}$	15.9 (2)
$+ 2\ OH^-$	$== HCuO_2^- + H^+$	1.66 (1)
$+ 2\ OH^-$	$== CuO_2^{2-} + 2\ H^+$	-11.5 (1)
$+ F^-$	$== CuF^+$	1.23 (2)(5)
$+ Cl^-$	$== CuCl^+$	0.01 (10)
$+ 2\ Cl^-$	$== CuCl_2^\circ$	0.69 (10)
$+ 3\ Cl^-$	$== CuCl_3^-$	-2.29 (10)
$+ 4\ Cl^-$	$== CuCl_4^{2-}$	-4.59 (10)
$+ CO_3^{2-}$	$== CuCO_3^\circ$	6.75 (5)
$+ 2\ CO_3^{2-}$	$== Cu(CO_3)_2^{2-}$	9.92 (5)
$+ HCO_3^-$	$== CuHCO_3^+$	2.10 (19)
$+ 3\ HS^-$	$== Cu(HS)_3^-$	25.9 (2)
$+ 4\ HS^-$	$== CuS(HS)_3^{3-} + H^+$	18.5 (43)
$+ NO_3^-$	$== CuNO_3^+$	0.50 (5)
$+ 2\ NO_3^-$	$== Cu(NO_3)_2^\circ$	-0.40 (5)
$+ H_2PO_4^-$	$== CuH_2PO_4^+$	1.59 (19)
$2\ Cu(OH)_2(s)$	$== Cu_2(OH)_2^{2+} + 2\ OH^-$	-21.3 (5)
$CuS(s) + 2\ HS^- + H_2S^\circ$	$== Cu(HS)_4^{2-}$	-3.20 (8)

Zinc

$ZnO(s) + H_2O$ Zincite	$== Zn^{2+} + 2\ OH^-$	-16.4 (1), -16.8 (2), -16.5 (3), -16.1 (4), -16.7 (5), -16.8 (6), -16.9 (9), -17.1 (9), -16.8 (19),
$Zn(OH)_2(s)$	$== Zn^{2+} + 2\ OH^-$	-16.2 (1), -15.5 (2), -15.7 (4), -16.5 (5), -15.7 (9), -16.5 (9), -16.7 (9), -15.5 (36), -15.5 (19),
$ZnCO_3(s)$ Smithsonite	$== Zn^{2+} + CO_3^{2-}$	-9.92 (1), -10.3 (2), -9.89 (3), -9.82 (4), -10.0 (5), -10.7 (9), -9.72 (10), -10.0 (36), -10.2 (19),
$ZnS(s) + H^+$ Sphalerite	$== Zn^{2+} + HS^-$	-11.6 (1), -12.0 (2), -11.6 (3), -11.2 (4), -11.8 (6), -11.8 (10), -11.8 (19),
$ZnSO_4(s)$ Zinkosite	$== Zn^{2+} + SO_4^{2-}$	3.01 (1), 3.93 (2), 3.01 (3), 3.09 (4),
$Zn_3(PO_4)_2 \cdot 4H_2O(s)$ Hopeite	$== 3\ Zn^{2+} + 2\ PO_4^{3-} + 4\ H_2O$	-32.0 (2), -35.3 (5), -32.0 (12), -35.2 (19),
$ZnSiO_3(s) + H_2O + 2\ H^+$	$== Zn^{2+} + H_4SiO_4^\circ$	2.93 (4),
$Zn_2SiO_4(s) + 4\ H^+$ Willemite	$== 2\ Zn^{2+} + H_4SiO_4^\circ$	15.3 (1), 13.4 (2), 13.2 (19),

Zn^{2+} + OH^-	== $Zn(OH)^+$	5.04	(2)
+ 2 OH^-	== $Zn(OH)_2^\circ$	12.9	(2)
+ 3 OH^-	== $Zn(OH)_3^-$	15.0	(2)
+ 4 OH^-	== $Zn(OH)_4^{2-}$	16.6	(2)
+ 2 OH^-	== $HZnO_2^-$ + H^+	-0.76	(1)
+ 2 OH^-	== ZnO_2^{2-} + 2 H^+	-13.5	(1)
+ F^-	== ZnF^+	1.26	(2)
+ 2 F^-	== ZnF_2°	0.02	(1)
+ Cl^-	== $ZnCl^+$	0.43	(10)
+ 2 Cl^-	== $ZnCl_2^\circ$	0.61	(10)
+ 3 Cl^-	== $ZnCl_3^-$	0.53	(10)
+ 4 Cl^-	== $ZnCl_4^{2-}$	0.20	(10)
+ OH^- + Cl^-	== $Zn(OH)Cl^\circ$	6.54	(1)
+ Br^-	== $ZnBr^+$	-0.56	(1)
+ 2 Br^-	== $ZnBr_2^\circ$	-0.96	(1)
+ 3 Br^-	== $ZnBr_3^-$	-1.73	(1)
+ CO_3^{2-}	== $ZnCO_3^\circ$	4.75	(29)
+ 2 HS^-	== $Zn(HS)_2^\circ$	14.9	(2)
+ 3 HS^-	== $Zn(HS)_3^-$	16.1	(2)
+ OH^- + HS^-	== $ZnSHOH^\circ$	19.0	(38)
+ $S_2O_3^{2-}$	== $ZnS_2O_3^\circ$	2.29	(2)
+ SO_4^{2-}	== $ZnSO_4^\circ$	2.38	(10)
+ 2 SO_4^{2-}	== $Zn(SO_4)_2^{2-}$	3.63	(29)
+ 3 SO_4^{2-}	== $Zn(SO_4)_3^{4-}$	2.70	(29)

$Zn^{2+} + NO_3^-$	$= ZnNO_3^+$	0.40 (5)
$+ 2\ NO_3^-$	$= Zn(NO_3)_2^\circ$	0.02 (1)
$+ H_2PO_4^-$	$= ZnH_2PO_4^+$	1.60
$+ P_2O_7^{4-}$	$= ZnP_2O_7^{2-}$	8.70 (5)
$+ 2\ P_2O_7^{4-}$	$= Zn(P_2O_7)_2^{6-}$	11.0 (5)
$2\ Zn(OH)_2(s)$	$= Zn_2(OH)^{3+} + 3\ OH^-$	-26.0 (5)
$ZnS(s) + HS^-$	$= ZnHS_2^-$	-2.96 (5)
$ZnS(s) + 2\ HS^- + H_2S^\circ$	$= Zn(HS)_4^{2-}$	-2.60 (8)

Gallium

$Ga_2O_3(s) + 3\ H_2O$	$= 2\ Ga^{3+} + 6\ OH^-$	-105.9 (2), -78.5 (3),
$GaO(OH)(s) + H_2O$	$= Ga^{3+} + 3\ OH^-$	-39.1 (5), -39.1 (7),
$Ga(OH)_3(s)$ Söhngeite	$= Ga^{3+} + 3\ OH^-$	-48.4 (2), -37.0 (5), -37.0 (7), -34.0 (9), -36.5 (9), -39.1 (9),
$GaPO_4(s)$	$= Ga^{3+} + PO_4^{3-}$	-20.6 (1), -20.4 (2), -21.0 (5),

Ga^{3+} + OH^-	== $Ga(OH)^{2+}$	11.2	(2)
+ 2 OH^-	== $Ga(OH)_2^+$	21.7	(2)
+ 3 OH^-	== $Ga(OH)_3^\circ$	31.7	(2)
+ 4 OH^-	== $Ga(OH)_4^-$	38.9	(2)
+ 5 OH^-	== $Ga(OH)_5^{2-}$	42.5	(2)
+ 6 OH^-	== $Ga(OH)_6^{3-}$	44.9	(2)
+ 3 OH^-	== $H_2GaO_3^-$ + H^+	19.9	(1)
+ 3 OH^-	== GaO_3^{3-} + 3 H^+	-2.04	(1)
+ F^-	== GaF^{2+}	6.19	(2)
+ 2 F^-	== GaF_2^+	10.7	(2)
+ 3 F^-	== GaF_3°	13.5	(2)
+ Cl^-	== $GaCl^{2+}$	-0.60	(2)
+ 4 Br^-	== $GaBr_4^-$	-4.32	(1)
+ CO_3^{2-}	== $GaCO_3^+$	8.79	(29)
+ SO_4^{2-}	== $GaSO_4^+$	2.77	(2)
+ 2 SO_4^{2-}	== $Ga(SO_4)_2^-$	5.06	(2)

Germanium

$GeO_2(s) + 2\ H_2O \quad == Ge^{4+} + 4\ OH^-$ -59.4 (2),

$GeS_2(s) + 2\ H^+ \quad == Ge^{4+} + 2\ HS^-$ -32.2 (2),

$Ge^{4+} +\ OH^-$	$== Ge(OH)^{3+}$	13.9	(2)
$+ 2\ OH^-$	$== Ge(OH)_2^{2+}$	27.6	(2)
$+ 3\ OH^-$	$== Ge(OH)_3^+$	41.1	(2)
$+ 4\ OH^-$	$== Ge(OH)_4^\circ$	54.4	(2)
$+ 5\ OH^-$	$== Ge(OH)_5^-$	59.7	(2)
$+ 6\ OH^-$	$== Ge(OH)_6^{2-}$	60.9	(2)
$+ 4\ OH^-$	$== H_3GeO_4^- + H^+$	45.1	(7)
$+ 4\ OH^-$	$== H_2GeO_4^{2-} + 2\ H^+$	32.5	(7)
$+ 3\ OH^-$	$== H_2GeO_3^\circ + H^+$	49.4	(4)
$+ 3\ OH^-$	$== HGeO_3^- + 2\ H^+$	40.9	(4)
$+ 3\ OH^-$	$== GeO_3^{2-} + 3\ H^+$	28.2	(4)
$+ 5\ F^-$	$== GeF_5^-$	21.8	(2)
$+ 6\ F^-$	$== GeF_6^{2-}$	25.6	(2)
$+ OH^- + 4\ F^-$	$== GeF_4(OH)^-$	31.1	(2)

Arsenic III

$As_2O_3(s) + 3\ H_2O \quad == 2\ AsO_3^{3-} + 6\ H^+$ -70.9 (2),
Claudetite

$As_2S_3(s) + 6\ H_2O \quad == 2\ AsO_3^{3-} + 3\ HS^- + 9\ H^+$ -115.5 (2), -114.7 (31),
Orpiment

$AsO_3^{3-} + H^+ == HAsO_3^{2-}$	13.4	(2)
$+ 2\ H^+ == H_2AsO_3^-$	25.5	(2)
$+ 3\ H^+ == H_3AsO_3^\circ$	34.5	(2)
$+ 2\ H^+ == AsO^+ + 2\ OH^-$	4.10	(2)
$+ H^+ == AsO_2^- + OH^-$	10.4	(1)
$+ 2\ H^+ == HAsO_2^\circ + OH^-$	19.7	(1)
$+ 2\ H^+ + H_2O == As(OH)_4^-$	25.5	(2+37)
$+ 3\ H^+ + H_2O == HAs(OH)_4^\circ$	34.7	(2+37)
$As_2S_3(s) + H_2S^\circ == H_2As_2S_4^\circ$	3.25	
$As_2S_3(s) + HS^- == HAs_2S_4^-$	1.27	
$As_2S_3(s) + HS^- + OH^- == As_2S_4^{2-} + H_2O$	-4.32	
$As_2S_3(s) + H_2S^\circ == 2\ HAsS_2^\circ$	-10.6	(8)
$As_2S_3(s) + S^{2-} == 2\ AsS_2^-$	2.00	(13)
$As_2S_3(s) + 2\ OH^- == AsS_2^- + AsS(OH)_2^-$	2.15	(13)
$As_2S_3(s) + 2\ S^{2-} == AsS_2^- + AsS_3^{3-}$	12.9	(13)

Arsenic V

$As_2O_5(s) + 3\ H_2O \quad == 2\ H_3AsO_4^\circ$ 8.15 (2), 6.71 (11)

$AsF_5(s) + 4\ H_2O \quad == H_3AsO_4^\circ + 5\ F^- + 5\ H^+$ 7.13 (2),

$AlAsO_4 \cdot 2H_2O(s) + H_2O == H_3AsO_4^\circ + Al^{3+} + 3\ OH^-$ -37.1 (2),

$H_3AsO_4^\circ \quad == H_2AsO_4^- + H^+$ -2.24 (7)

$== HAsO_4^{2-} + 2\ H^+$ -9.20 (7)

$== AsO_4^{3-} + 3\ H^+$ -20.7 (7)

$+ F^- \quad == HAsO_3F^- + H_2O$ 44.4

$+ F^- \quad == AsO_3F^{2-} + H_2O + H^+$ 38.5

Selenium IV

$SeO_2(s) + H_2O \quad == SeO_3^{2-} + 2\ H^+$ -7.87 (2), -6.49 (4),
Selenolite -7.17 (11), -7.39 (11),

$SeO_3^{2-} + H^+ \quad == HSeO_3^-$ 8.32 (2)(9)

$+ 2\ H^+ \quad == H_2SeO_3^\circ$ 10.9 (2)(9)

Selenium VI

$SeO_3(s) + H_2O$	$== SeO_4^{2-} + 2\ H^+$	21.0 (2),
$SeO_4^{2-} + H^+$	$== HSeO_4^-$	1.66 (2)(9)(29)

Rubidium

$RbCl(s)$	$== Rb^+ + Cl^-$	1.31 (2),
$RbBr(s)$	$== Rb^+ + Br^-$	1.17 (2),
$Rb_2SO_4(s)$	$== 2\ Rb^+ + SO_4^{2-}$	-0.99 (2),
$Rb^+ + OH^-$	$== Rb(OH)°$	0.00 (4)
$+ Cl^-$	$== RbCl°$	-0.66
$+ I^-$	$== RbI°$	0.04

Strontium

$Sr(OH)_2(s)$	$== Sr^{2+} + 2\ OH^-$	0.43 (4),
$SrF_2(s)$	$== Sr^{2+} + 2\ F^-$	-8.36 (1), -8.60 (2), -8.43 (3), -9.12 (4), -8.54 (5), -8.54 (9), -8.61 (9),
$SrCO_3(s)$ Strontianite	$== Sr^{2+} + CO_3^{2-}$	-9.25 (1), -9.28 (2), -9.24 (3), -9.15 (4), -9.03 (5), -9.03 (9), -9.28 (9),
$SrSO_4(s)$ Celestine	$== Sr^{2+} + SO_4^{2-}$	-6.46 (1), -6.67 (2), -6.38 (3), -6.13 (4), -4.62 (5), -6.46 (9), -6.49 (9), -6.53 (9),
$Sr_3(PO_4)_2(s)$	$== 3\ Sr^{2+} + 2\ PO_4^{3-}$	-31.0 (4),
$SrHPO_4(s)$	$== Sr^{2+} + HPO_4^{2-}$	-3.66 (4), -6.92 (5), -6.38 (9), -6.92 (9), -7.06 (9),
$SrSiO_3(s) + H_2O + 2\ H^+$	$== Sr^{2+} + H_4SiO_4^\circ$	15.6 (1), 14.5 (2), 19.1 (4),
$Sr_2SiO_4(s) + 4\ H^+$	$== 2\ Sr^{2+} + H_4SiO_4^\circ$	42.8 (1), 41.6 (2), 52.0 (4),

$Sr^{2+} + OH^-$	$== Sr(OH)^+$	0.82 (37)
$+ 2\ Cl^-$	$== SrCl_2^\circ$	0.00 (1)
$+ 2\ Br^-$	$== SrBr_2^\circ$	0.00 (1)
$+ CO_3^{2-}$	$== SrCO_3^\circ$	0.00 (1)
$+ S_2O_3^{2-}$	$== SrS_2O_3^\circ$	2.04 (5)
$+ SO_4^{2-}$	$== SrSO_4^\circ$	2.31 (5)
$+ NO_3^-$	$== SrNO_3^+$	0.82 (5)
$+ 2\ NO_3^-$	$== Sr(NO_3)_2^\circ$	0.80 (5)
$+ P_2O_7^{4-}$	$== SrP_2O_7^{2-}$	5.40 (5)

Yttrium

$Y_2O_3(s) + 3\ H_2O$	$== 2\ Y^{3+} + 6\ OH^-$	-34.5 (1), -37.1 (2), -35.3 (11),
$Y(OH)_3(s)$	$== Y^{3+} + 3\ OH^-$	-22.0 (1), -24.5 (2), -23.2 (5), -22.2 (6), -24.2 (9), -24.5 (9), -23.0 (11),
$YF_3(s)$	$== Y^{3+} + 3\ F^-$	-20.1 (1), -21.1 (2), -21.7 (11),
$Y_2(CO_3)_3(s)$	$== 2\ Y^{3+} + 3\ CO_3^{2-}$	-30.6 (5), -30.6 (9),
$Y_2(SO_4)_3(s)$	$== 2\ Y^{3+} + 3\ SO_4^{2-}$	-0.95 (1),

Y^{3+} + OH^-	== $Y(OH)^{2+}$	6.30	(5)
+ 2 OH^-	== $Y(OH)_2^+$	11.6	(7)
+ 3 OH^-	== $Y(OH)_3^\circ$	16.0	(7)
+ 4 OH^-	== $Y(OH)_4^-$	19.5	(7)
+ F^-	== YF^{2+}	4.82	(2)
+ 2 F^-	== YF_2^+	8.55	(2)
+ 3 F^-	== YF_3°	12.1	(2)
+ Cl^-	== YCl^{2+}	1.27	(2)
+ Br^-	== YBr^{2+}	0.70	(1)
+ CO_3^{2-}	== YCO_3^+	6.94	(29)
+ SO_4^{2-}	== YSO_4^+	3.24	(2)
+ 2 SO_4^{2-}	== $Y(SO_4)_2^-$	3.99	(2)
+ NO_3^-	== YNO_3^{2+}	-0.01	(1)
+ $H_2PO_4^-$	== $YH_2PO_4^{2+}$	2.65	(5)
2 $Y(OH)_3(s)$	== $Y_2(OH)_2^{4+}$ + 4 OH^-	-30.3	(1)
3 $Y(OH)_3(s)$	== $Y_3(OH)_5^{4+}$ + 4 OH^-	-27.6	(5+1)

Zirconium

$ZrO_2(s) + 2\ H_2O$ Baddeleyite	$== Zr^{4+} + 4\ OH^-$	-63.7 (2), -54.1 (5), -51.1 (11),
$ZrO(OH)_2(s) + H_2O$	$== Zr^{4+} + 4\ OH^-$	-56.3 (11),
$Zr(OH)_4(s)$	$== Zr^{4+} + 4\ OH^-$	-58.6 (2), -56.9 (4), -54.0 (9), -57.5 (9), -57.2 (11), -57.6 (11),
$ZrF_4(s)$	$== Zr^{4+} + 4\ F^-$	-29.0 (2), -13.7 (11),
$ZrSiO_4(s) + 4\ H^+$	$== Zr^{4+} + H_4SiO_4^\circ$	-7.31 (2)

Zircon

$Zr^{4+} + OH^-$	$= Zr(OH)^{3+}$	14.0	(2)
$+ 2\ OH^-$	$= Zr(OH)_2^{2+}$	27.8	(2)
$+ 3\ OH^-$	$= Zr(OH)_3^{+}$	41.3	(2)
$+ 4\ OH^-$	$= Zr(OH)_4^{\circ}$	54.5	(2)
$+ 5\ OH^-$	$= Zr(OH)_5^{-}$	54.0	(7)
$+ OH^-$	$= ZrO^{2+} + H^+$	16.1	(4)
$+ 3\ OH^-$	$= HZrO_3^- + 2\ H^+$	24.1	(4)
$+ F^-$	$= ZrF^{3+}$	8.89	(2)
$+ 2\ F^-$	$= ZrF_2^{2+}$	16.4	(2)
$+ 3\ F^-$	$= ZrF_3^{+}$	22.2	(2)
$+ 4\ F^-$	$= ZrF_4^{\circ}$	27.2	(2)
$+ 5\ F^-$	$= ZrF_5^{-}$	31.8	(2)
$+ 6\ F^-$	$= ZrF_6^{2-}$	35.9	(2)
$+ Cl^-$	$= ZrCl^{3+}$	1.57	(29)
$+ 2\ Cl^-$	$= ZrCl_2^{2+}$	1.47	(29)
$+ 3\ Cl^-$	$= ZrCl_3^{+}$	0.80	(29)
$+ SO_4^{2-}$	$= ZrSO_4^{2+}$	3.72	(2)
$+ 2\ SO_4^{2-}$	$= Zr(SO_4)_2^{\circ}$	6.52	(2)
$+ 3\ SO_4^{2-}$	$= Zr(SO_4)_3^{2-}$	7.63	(2)
$3\ Zr(OH)_4(s)$	$= Zr_3(OH)_4^{8+} + 8\ OH^-$	-120.3	(5+2)
$4\ Zr(OH)_4(s)$	$= Zr_4(OH)_8^{8+} + 8\ OH^-$	-128.2	(5+2)

Molybdenum

$MoO_3(s) + H_2O$ Molybdite	$== MoO_4^{2-} + 2\ H^+$	-12.1 (3), -12.1 (7), -10.7 (11), -12.1 (19),
$H_2MoO_4(s)$	$== MoO_4^{2-} + 2\ H^+$	-13.4 (19),
$MoS_3(s) + 4\ H_2O$	$== MoO_4^{2-} + 3\ HS^- + 5\ H^+$	-68.1 (3), -64.5 (4), -66.3 (11), -68.9 (11), -78.7 (11), -68.2 (12), -70.4 (12),
$MoO_4^{2-} + H^+$	$== HMoO_4^-$	3.70 (12)
$+ 2\ H^+$	$== H_2MoO_4^\circ$	9.17 (29)
$+ 3\ H^+$	$== MoO_2(OH)^+ + H_2O$	7.89 (2)
$+ 4\ H^+$	$== MoO_2^{2+} + 2\ H_2O$	8.65 (19)
$+ 2\ HS^- + 2\ H^+$	$== MoO_2S_2^{2-} + 2\ H_2O$	4.60 (12)
$+ 3\ HS^- + 3\ H^+$	$== MoOS_3^{2-} + 3\ H_2O$	7.90 (12)
$+ 4\ HS^- + 4\ H^+$	$== MoS_4^{2-} + 4\ H_2O$	13.3 (12)

Silver

$Ag_2O(s) + H_2O$	$== 2\ Ag^+ + 2\ OH^-$	-15.4 (2), -15.4 (3), -15.4 (7), -15.4 (11), -15.4 (19),
$AgOH(s)$	$== Ag^+ + OH^-$	-7.71 (5), -7.56 (9), -7.71 (9), -7.73 (9), -7.84 (9), -7.95 (9), -7.71 (19),
$AgCl(s)$ Chlorargyrite	$== Ag^+ + Cl^-$	-9.75 (2), -9.75 (3), -9.75 (11), -9.73 (16), -9.76 (21), -9.75 (19),
$Ag_2CO_3(s)$	$== 2\ Ag^+ + CO_3^{2-}$	-11.1 (2), -11.0 (3), -11.1 (5), -11.1 (9), -11.4 (9), -11.2 (11), -11.1 (19),
$Ag_2S(s) + H^+$ Acanthite	$== 2\ Ag^+ + HS^-$	-36.2 (2), -36.2 (3), -36.2 (6), -36.1 (10), -36.1 (19),
$Ag_2SO_4(s)$	$== 2\ Ag^+ + SO_4^{2-}$	-4.94 (2), -4.84 (3), -4.83 (5), -4.80 (9), -4.84 (9), -4.86 (9), -4.92 (9), -4.47 (11),
$Ag_3PO_4(s)$	$== 3\ Ag^+ + PO_4^{3-}$	-15.6 (1), -17.6 (5), -15.8 (9), -16.0 (19),

$Ag^+ + OH^-$	$= Ag(OH)^\circ$	2.00	(2)
$+ 2\ OH^-$	$= Ag(OH)_2^-$	3.99	(2)
$+ 3\ OH^-$	$= Ag(OH)_3^{2-}$	-6.19	
$+ OH^-$	$= AgO^- + H^+$	-10.0	(4)
$+ F^-$	$= AgF^\circ$	0.37	(2)
$+ Cl^-$	$= AgCl^\circ$	3.31	(10)
$+ 2\ Cl^-$	$= AgCl_2^-$	5.25	(10)
$+ 3\ Cl^-$	$= AgCl_3^{2-}$	5.44	(8)
$+ 4\ Cl^-$	$= AgCl_4^{3-}$	4.19	(8)
$+ Br^-$	$= AgBr^\circ$	4.24	(1)
$+ 2\ Br^-$	$= AgBr_2^-$	7.28	(1)
$+ 3\ Br^-$	$= AgBr_3^{2-}$	8.71	(1)
$+ 4\ Br^-$	$= AgBr_4^{3-}$	9.00	(5)
$+ CO_3^{2-}$	$= AgCO_3^-$	3.40	(29)
$+ HS^-$	$= AgHS^\circ$	14.1	(2)
$+ 2\ HS^-$	$= Ag(HS)_2^-$	18.5	(2)
$+ S^{2-}$	$= AgS^-$	23.9	
$+ S_2O_3^{2-}$	$= AgS_2O_3^-$	8.60	(2)
$+ 2\ S_2O_3^{2-}$	$= Ag(S_2O_3)_2^{3-}$	13.4	(2)
$+ 3\ S_2O_3^{2-}$	$= Ag(S_2O_3)_3^{5-}$	14.2	(5)
$+ SO_3^{2-}$	$= AgSO_3^-$	5.37	(1)
$+ 2\ SO_3^{2-}$	$= Ag(SO_3)_2^{3-}$	8.52	(4)
$+ 3\ SO_3^{2-}$	$= Ag(SO_3)_3^{5-}$	9.00	(5)
$+ SO_4^{2-}$	$= AgSO_4^-$	1.30	(10)
$+ 2\ SO_4^{2-}$	$= Ag(SO_4)_2^{3-}$	0.57	(29)

$Ag^+ + 3\ SO_4^{2-}$	$== Ag(SO_4)_3^{5-}$	-1.51 (29)
$+\ NO_3^-$	$== AgNO_3^\circ$	0.20 (9)
$3\ AgOH(s) + H_2O$	$== Ag_3(OH)_4^- + H^+$	-18.3 (19)
$Ag_2S(s) + 2\ HS^-$	$== Ag_2S(HS)_2^{2-}$	-3.12 (5)
$Ag_2S(s) + HS^- + H^+ + 2\ S_4^{2-}$	$== 2\ Ag(HS)S_4^{2-}$	4.47 (17)
$Ag_2S(s) + 4\ S_4^{2-}$	$== 2\ Ag(S_4)_2^{3-} + S^{2-}$	-7.67 (17)
$Ag_2S(s) + 2\ S_4^{2-} + 2\ S_5^{2-}$	$== 2\ AgS_4S_5^{3-} + S^{2-}$	-8.76 (17)
$2\ Ag(OH)(s) + SO_3^{2-}$	$== Ag_2SO_3^\circ + 2\ OH^-$	-6.87 (1)
$2\ Ag(OH)(s) + SO_4^{2-}$	$== Ag_2SO_4^\circ + 2\ OH^-$	-14.0 (1)

Cadmium

$CdO(s) + H_2O$ Monteponite	$== Cd^{2+} + 2\ OH^-$	-12.9 (1), -12.8 (2), -12.9 (3), -12.2 (4), -12.9 (6), -13.6 (9), -12.9 (19),
$Cd(OH)_2(s)$	$== Cd^{2+} + 2\ OH^-$	-14.3 (1), -14.4 (2), -13.7 (4), -14.4 (5), -14.1 (9), -14.2 (9), -14.4 (9), -13.8 (36),
$CdF_2(s)$	$== Cd^{2+} + 2\ F^-$	-2.32 (2),
$CdCO_3(s)$ Otavite	$== Cd^{2+} + CO_3^{2-}$	-11.2 (1), -12.0 (2), -11.3 (4), -13.7 (5), -11.3 (9), -12.0 (9), -13.7 (36), -12.0 (19),
$CdS(s) + H^+$ Hawleyite	$== Cd^{2+} + HS^-$	-15.9 (1), -14.3 (2), -15.9 (3), -13.2 (4), -14.1 (6),
$CdSO_4(s)$	$== Cd^{2+} + SO_4^{2-}$	-0.10 (1), -0.13 (2), -0.07 (3), -0.05 (4), -0.04 (19),
$CdSO_4.H_2O(s)$	$== Cd^{2+} + SO_4^{2-} + H_2O$	-1.68 (2), -1.59 (19),
$CdSO_4.8/3H_2O(s)$	$== Cd^{2+} + SO_4^{2-} + 8/3\ H_2O$	-1.89 (2),

$Cd_3(SO_4)(OH)_4(s)$	$== 3\ Cd^{2+} + SO_4^{2-} + 4\ OH^-$	-33.3 (1), -33.3 (19),
$Cd_3(SO_4)_2(OH)_2(s)$	$== 3\ Cd^{2+} + 2\ SO_4^{2-} + 2\ OH^-$	-21.3 (1), -21.3 (19),
$Cd_3(PO_4)_2(s)$	$== 3\ Cd^{2+} + 2\ PO_4^{3-}$	-31.9 (1), -38.1 (19),
$CdSiO_3(s) + H_2O + 2\ H^+$	$== Cd^{2+} + H_4SiO_4^\circ$	9.05 (1), 7.93 (2), 7.63 (19),

$Cd^{2+} + OH^-$	$== Cd(OH)^+$	3.92 (7)
$+ 2\ OH^-$	$== Cd(OH)_2^\circ$	7.65 (7)
$+ 3\ OH^-$	$== Cd(OH)_3^-$	8.70 (29)
$+ 4\ OH^-$	$== Cd(OH)_4^{2-}$	8.65 (7)
$+ 5\ OH^-$	$== Cd(OH)_5^{3-}$	7.76
$+ 6\ OH^-$	$== Cd(OH)_6^{4-}$	6.88
$+ 2\ OH^-$	$== HCdO_2^- + H^+$	-5.01 (1)
$+ 2\ OH^-$	$== CdO_2^{2-} + 2\ H^+$	-18.9 (1)
$+ F^-$	$== CdF^+$	1.08 (29)
$+ 2\ F^-$	$== CdF_2^\circ$	1.41 (29)
$+ Cl^-$	$== CdCl^+$	2.00 (37)
$+ 2\ Cl^-$	$== CdCl_2^\circ$	2.70 (37)
$+ 3\ Cl^-$	$== CdCl_3^-$	2.11 (2)
$+ 4\ Cl^-$	$== CdCl_4^{2-}$	2.50 (19)
$+ OH^- + Cl^-$	$== CdCl(OH)^\circ$	6.59 (1)
$+ Br^-$	$== CdBr^+$	2.20 (3)
$+ 2\ Br^-$	$== CdBr_2^\circ$	3.00 (5)
$+ 3\ Br^-$	$== CdBr_3^-$	3.00 (5)
$+ 4\ Br^-$	$== CdBr_4^{2-}$	2.90 (5)
$+ CO_3^{2-}$	$== CdCO_3^\circ$	4.10 (19)
$+ 3\ CO_3^{2-}$	$== Cd(CO_3)_3^{4-}$	6.22 (2)
$+ HCO_3^-$	$== CdHCO_3^+$	2.10 (19)
$+ HS^-$	$== Cd(HS)^+$	10.2 (2)
$+ 2\ HS^-$	$== Cd(HS)_2^\circ$	16.5 (2)

$Cd^{2+} + 3\ HS^-$	$== Cd(HS)_3^-$	18.7 (2)
$+ 4\ HS^-$	$== Cd(HS)_4^{2-}$	20.9 (2)
$+ S_2O_3^{2-}$	$== CdS_2O_3^\circ$	3.95 (2)
$+ 2\ S_2O_3^{2-}$	$== Cd(S_2O_3)_2^{2-}$	6.44 (2)
$+ 3\ S_2O_3^{2-}$	$== Cd(S_2O_3)_3^{4-}$	6.00 (43)
$+ 2\ SO_3^{2-}$	$== Cd(SO_3)_2^{2-}$	5.50 (43)
$+ SO_4^{2-}$	$== CdSO_4^\circ$	2.46 (5)
$+ 2\ SO_4^{2-}$	$== Cd(SO_4)_2^{2-}$	3.54 (9)
$+ 3\ SO_4^{2-}$	$== Cd(SO_4)_3^{4-}$	3.09 (29)
$+ 4\ SO_4^{2-}$	$== Cd(SO_4)_4^{6-}$	-0.72 (29)
$+ NO_3^-$	$== CdNO_3^+$	-0.32 (2)
$+ 2\ NO_3^-$	$== Cd(NO_3)_2^\circ$	-0.00 (1)
$+ P_2O_7^{4-}$	$== CdP_2O_7^{2-}$	8.70 (5)
$2\ Cd(OH)_2(s)$	$== Cd_2(OH)^{3+} + 3\ OH^-$	-21.1 (5+2)
$4\ Cd(OH)_2(s)$	$== Cd_4(OH)_4^{4+} + 4\ OH^-$	-29.3 (5+2)

Indium

$In_2O_3(s) + 3\ H_2O$	$== 2\ In^{3+} + 6\ OH^-$	-70.5 (2), -71.8 (5), -70.6 (7), -71.8 (9),
$In(OH)_3(s)$ Djalindite	$== In^{3+} + 3\ OH^-$	-36.9 (2), -36.9 (5), -36.9 (7), -33.9 (9), -36.9 (9),
$In_2S_3(s) + 3\ H^+$	$== 2\ In^{3+} + 3\ HS^-$	-44.3 (1), -44.3 (2),

$In_2(SO_4)_3(s)$	== $2\ In^{3+} + 3\ SO_4^{2-}$	-1.68 (1),
$InPO_4(s)$	== $In^{3+} + PO_4^{3-}$	-21.6 (5),
$In^{3+} + OH^-$	== $In(OH)^{2+}$	10.4 (2)
$+ 2\ OH^-$	== $In(OH)_2^+$	20.2 (2)
$+ 3\ OH^-$	== $In(OH)_3^\circ$	29.0 (2)
$+ 4\ OH^-$	== $In(OH)_4^-$	33.9 (2)
$+ F^-$	== InF^{2+}	4.60 (2)
$+ 2\ F^-$	== InF_2^+	8.10 (5)
$+ 3\ F^-$	== InF_3°	10.3 (5)
$+ 4\ F^-$	== InF_4^-	11.5 (5)
$+ Cl^-$	== $InCl^{2+}$	3.26 (29)
$+ 2\ Cl^-$	== $InCl_2^+$	6.38 (29)
$+ 3\ Cl^-$	== $InCl_3^\circ$	5.83 (29)
$+ OH^- + Cl^-$	== $InCl(OH)^+$	13.4 (7)
$+ CO_3^{2-}$	== $InCO_3^+$	7.60 (29)
$+ SO_4^{2-}$	== $InSO_4^+$	3.04 (2)
$+ 2\ SO_4^{2-}$	== $In(SO_4)_2^-$	5.00 (2)
$+ 3\ SO_4^{2-}$	== $In(SO_4)_3^{3-}$	5.52 (29)
$2\ In(OH)_3(s)$	== $In_2(OH)_2^{4+} + 4\ OH^-$	-33.7 (9+2)
$3\ In(OH)_3(s)$	== $In_3(OH)_4^{5+} + 5\ OH^-$	-60.5 (7+2)

Tin II

$SnO(s) + H_2O$	$== Sn^{2+} + 2\ OH^-$	-26.7 (1), -26.7 (2), -26.8 (3), -26.9 (4), -26.2 (5), -26.2 (9), -26.9 (11),
$Sn(OH)_2(s)$	$== Sn^{2+} + 2\ OH^-$	-26.2 (1), -26.5 (2), -27.6 (3), -26.5 (4), -28.1 (9), -25.3 (11),
$SnS(s) + H^+$	$== Sn^{2+} + HS^-$	-14.6 (1), -14.6 (2), -14.7 (3), -12.0 (4), -15.2 (11), -15.5 (11), -14.4 (11),

$Sn^{2+} + OH^-$	$= Sn(OH)^+$	9.90	(51)
$+ 2\ OH^-$	$= Sn(OH)_2^\circ$	20.1	(51)
$+ 3\ OH^-$	$= Sn(OH)_3^-$	24.5	(51)
$+ 2\ OH^-$	$= HSnO_2^- + H^+$	12.1	(4)
$+ 3\ OH^- + H_2O$	$= HSn(OH)_4^-$	19.1	(11)
$+ F^-$	$= SnF^+$	4.84	(2)
$+ Cl^-$	$= SnCl^+$	0.73	(51)
$+ 2\ Cl^-$	$= SnCl_2^\circ$	1.08	(51)
$+ 3\ Cl^-$	$= SnCl_3^-$	2.06	(2)
$+ 4\ Cl^-$	$= SnCl_4^{2-}$	1.50	(5)
$+ OH^- + Cl^-$	$= SnCl(OH)^\circ$	11.1	(51)
$+ Br^-$	$= SnBr^+$	0.60	(51)
$+ 2\ Br^-$	$= SnBr_2^\circ$	1.13	(51)
$+ 3\ Br^-$	$= SnBr_3^-$	1.36	(1)
$+ SO_4^{2-}$	$= SnSO_4^\circ$	1.29	(51)
$+ 2\ SO_4^{2-}$	$= Sn(SO_4)_2^{2-}$	1.65	(51)
$2\ Sn(OH)_{2(s)}$	$= Sn_2O_3^{2-} + H_2O + H^+$	-27.4	(4)
$2\ Sn(OH)_{2(s)}$	$= Sn_2(OH)_2^{2+} + 2\ OH^-$	-29.3	(7+2)
$3\ Sn(OH)_{2(s)}$	$= Sn_3(OH)_4^{2+} + 2\ OH^-$	-29.7	(7+2)

Tin IV

$SnO_2(s) + 2\ H_2O$ Cassiterite	$== Sn^{4+} + 4\ OH^-$	-64.4 (1), -63.7 (4), -61.0 (7), -64.2 (11),
$Sn(OH)_4(s)$	$== Sn^{4+} + 4\ OH^-$	-57.0 (4),
$SnS_2(s) + 2\ H^+$ Berndtite	$== Sn^{4+} + 2\ HS^-$	-46.7 (11),
$Sn(SO_4)_2(s)$	$== Sn^{4+} + 2\ SO_4^{2-}$	-5.30 (4)
$Sn^{4+} + OH^-$	$== Sn(OH)^{3+}$	15.5 (29)
$+ 2\ OH^-$	$== Sn(OH)_2^{2+}$	29.3 (29)
$+ 3\ OH^-$	$== Sn(OH)_3^+$	43.7 (29)
$+ 4\ OH^-$	$== Sn(OH)_4^\circ$	55.1 (7)
$+ 6\ OH^-$	$== Sn(OH)_6^{2-}$	62.7 (4)
$+ 3\ OH^-$	$== SnO_3^{2-} + 3\ H^+$	18.5 (4)
$+ 2\ OH^-$	$== SnO(OH)^+ + H^+$	28.4 (1)
$+ 6\ F^-$	$== SnF_6^{2-}$	17.7 (4)
$+ 2\ OH + F$	$== SnO(OH)F^\circ + H^+$	34.6 (1)
$+ 4\ Cl$	$== SnCl_4^\circ$	0.01 (1)
$+ SO_4^{2-}$	$== SnSO_4^{2-}$	-3.13 (1)
$+ 2\ SO_4^{2-}$	$== Sn(SO_4)_2^\circ$	-0.84 (1)
$SnS_2(s) + S^{2-}$	$== SnS_3^{2-}$	5.04 (9)

Antimony III

$Sb_2O_3(s) + 3\ H_2O$ Valentinite	$== 2\ Sb(OH)_3^\circ$	-9.35 (2), -8.48 (7), -7.92 (9), -9.40 (9), -8.55 (11),
$Sb(OH)_3(s)$	$== Sb(OH)_3^\circ$	-4.40 (2), 1.08 (11),
$Sb_2S_3(s) + 6\ H_2O$ Stibnite	$== 2\ Sb(OH)_3^\circ + 3\ HS^- + 3\ H^+$	-60.2 (1), -56.2 (2), -60.2 (11), -61.3 (11), -54.4 (30),
$Sb(OH)_3^\circ$	$== Sb(OH)_2^+ + OH^-$	-12.8 (2)
$+ OH^-$	$== Sb(OH)_4^-$	2.20 (2)
	$== HSbO^\circ_2 + H_2O$	-0.01 (1)
	$== SbO_2^- + H_2O + H^+$	-11.8 (1)
	$== SbO^+ + H_2O + OH^-$	-12.8 (1)
$+ F^-$	$== Sb(OH)_2F^\circ + OH^-$	-7.29 (1)
$+ F^-$	$== SbOF^\circ + H_2O + OH^-$	-7.30 (1)
$+ 4\ Cl^-$	$== SbCl_4^- + 3\ OH^-$	-39.3 (2)
$+ 2\ S^{2-}$	$== SbS_2^- + 3\ OH^-$	9.30 (4)
$+ 3\ S^{2-}$	$== SbS_3^{3-} + 3\ OH^-$	9.74 (4)
$Sb_2S_3(s) + HS^-$	$== HSb_2S_4^-$	-2.33 (8)
$Sb_2S_3(s) + S^{2-}$	$== Sb_2S_4^{2-}$	2.05 (1)

Antimony V

$Sb_2O_5(s) + 5\ H_2O \quad == 2\ Sb(OH)_5^\circ$ -7.40 (7),

$Sb(OH)_5^\circ + OH^- \quad == Sb(OH)_6^-$ 11.5 (7+2)

$\quad == SbO_3^- + 2\ H_2O + H^+$ 0.37 (4+7+2)

$+ H^+ \quad == SbO_2^+ + 3\ H_2O$ -0.15 (4+7+2)

$6\ Sb_2O_5(s) + 34\ H_2O == Sb_{12}(OH)_{64}^{4-} + 4\ H^+$ -24.1 (7+2)

$6\ Sb_2O_5(s) + 35\ H_2O == Sb_{12}(OH)_{65}^{5-} + 5\ H^+$ -27.7 (7+2)

$6\ Sb_2O_5(s) + 36\ H_2O == Sb_{12}(OH)_{66}^{6-} + 6\ H^+$ -32.5 (7+2)

$6\ Sb_2O_5(s) + 37\ H_2O == Sb_{12}(OH)_{67}^{7-} + 7\ H^+$ -38.3 (7+2)

Cesium

$CsCl(s) \quad == Cs^+ + Cl^-$ 1.47 (2),

$Cs_2SO_4(s) \quad == 2\ Cs^+ + SO_4^{2-}$ 0.62 (2),

$Cs^+ + F^- \quad == CsF^\circ$ -0.37 (3)

$\quad + Cl^- \quad == CsCl^\circ$ -0.39 (5)

$\quad + Br^- \quad == CsBr^\circ$ 0.03

$\quad + NO_3^- \quad == CsNO_3^\circ$ 0.01 (5)

Barium

$Ba(OH)_2(s)$	$= Ba^{2+} + 2\ OH^-$	3.29 (4),
$BaF_2(s)$	$= Ba^{2+} + 2\ F^-$	-6.01 (2), -6.82 (3), -4.65 (4), -5.76 (5), -5.98 (9)
$BaCO_3(s)$ Witherite	$= Ba^{2+} + CO_3^{2-}$	-8.58 (1), -8.33 (2), -8.58 (3), -8.74 (4), -8.30 (5), -8.29 (9), -8.30 (9), -8.31 (9),
$BaSO_4(s)$ Barite	$= Ba^{2+} + SO_4^{2-}$	-9.98 (1), -9.74 (2), -9.89 (3), -8.84 (4), -9.96 (5), -10.3 (6), -9.87 (9), -9.70 (10),
$Ba_3(PO_4)_2(s)$	$= 3\ Ba^{2+} + 2\ PO_4^{3-}$	-38.3 (1),
$BaSiO_3(s) + H_2O + 2\ H^+$	$= Ba^{2+} + H_4SiO_4^\circ$	17.5 (1), 16.6 (2), 28.5 (4);
$Ba_2SiO_4(s) + 4\ H^+$	$= 2\ Ba^{2+} + H_4SiO_4^\circ$	71.6 (4),
$Ba_2(Si_4O_{10})(s) + 6\ H_2O + 4\ H^+$ Sanbornite	$= 2\ Ba^{2+} + 4\ H_4SiO_4^\circ$	20.9 (2),

$Ba^{2+} + OH^- == Ba(OH)^+$		0.64 (37)
$+ 2\ F^- == BaF_2^\circ$		0.32 (29)
$+ Cl^- == BaCl^+$		-0.13 (5)
$+ CO_3^{2-} == BaCO_3^\circ$		2.78 (5)
$+ S_2O_3^{2-} == BaS_2O_3^\circ$		2.27 (5)
$+ SO_4^{2-} == BaSO_4^\circ$		2.36 (2)
$+ 2\ SO_4^{2-} == Ba(SO_4)_2^{2-}$		3.20 (29)
$+ NO_3^- == BaNO_3^+$		0.90 (5)
$+ 2\ NO_3^- == Ba(NO_3)_2^\circ$		1.00 (5)

Lanthanum

$La_2O_3(s) + 3\ H_2O$	$== 2\ La^{3+} + 6\ OH^-$	-18.6 (1), -18.7 (3),
$La(OH)_3(s)$	$== La^{3+} + 3\ OH^-$	-22.5 (2), -20.7 (5), -21.7 (7), -21.5 (9), -21.7 (9), -22.6 (9), -19.0 (11), -26.0 (11),
$LaF_3(s)$	$== La^{3+} + 3\ F^-$	-17.9 (2),
$La_2(CO_3)_3(s)$	$== 2\ La^{3+} + 3\ CO_3^{2-}$	-33.4 (1), -33.4 (5),
$LaPO_4(s)$	$== La^{3+} + PO_4^{3-}$	-23.2 (2), -22.4 (4), -22.4 (9),

$La^{3+} + OH^-$	$== La(OH)^{2+}$	5.50 (5)
$+ 2\ OH^-$	$== La(OH)_2^+$	10.6 (29)
$+ 3\ OH^-$	$== La(OH)_3^\circ$	14.5 (29)
$+ 4\ OH^-$	$== La(OH)_4^-$	17.2 (29)
$+ F^-$	$== LaF^{2+}$	3.78 (2)
$+ Cl^-$	$== LaCl^{2+}$	0.80 (29)
$+ 2\ Cl^-$	$== LaCl_2^+$	-0.29 (29)
$+ 3\ Cl^-$	$== LaCl_3^\circ$	-0.01 (1)
$+ CO_3^{2-}$	$== LaCO_3^+$	6.16 (29)
$+ S_2O_3^{2-}$	$== LaS_2O_3^+$	1.17 (1)
$+ SO_4^{2-}$	$== LaSO_4^+$	3.50 (2)
$+ 2\ SO_4^{2-}$	$== La(SO_4)_2^-$	5.67 (1)
$+ P_2O_7^{4-}$	$== LaP_2O_7^-$	16.7 (5)
$+ 2\ P_2O_7^{4-}$	$== La(P_2O_7)_2^{5-}$	18.6 (5)
$2\ La(OH)_3(s)$	$== La_2(OH)^{5+} + 5\ OH^-$	-49.6 (5+2)
$5\ La(OH)_3(s)$	$== La_5(OH)_9^{6+} + 6\ OH^-$	-57.4 (5+2)

Cerium III

$Ce_2O_3(s) + 3\ H_2O$	$== 2\ Ce^{3+} + 6\ OH^-$	-22.8 (1), -23.0 (6), -26.0 (11),
$Ce(OH)_3(s)$	$== Ce^{3+} + 3\ OH^-$	-21.2 (2), -20.8 (4), -21.2 (5), -21.2 (9),

$CeF_3(s)$ Fluocerite	$= Ce^{3+} + 3\ F^-$	-15.6 (2),
$CePO_4(s)$ Monazite	$= Ce^{3+} + PO_4^{3-}$	-21.3 (2), -21.3 (9),
$Ce^{3+} + OH^-$	$= Ce(OH)^{2+}$	5.70 (29)
$+ 2\ OH^-$	$= Ce(OH)_2^+$	10.9 (29)
$+ 3\ OH^-$	$= Ce(OH)_3^\circ$	15.2 (29)
$+ 4\ OH^-$	$= Ce(OH)_4^-$	18.4 (29)
$+ F^-$	$= CeF^{2+}$	3.70 (2)
$+ Cl^-$	$= CeCl^{2+}$	0.79 (1)
$+ 2\ Cl^-$	$= CeCl_2^+$	1.19 (29)
$+ 3\ Cl^-$	$= CeCl_3^\circ$	-0.01 (1)
$+ Br^-$	$= CeBr^{2+}$	0.62 (1)
$+ CO_3^{2-}$	$= CeCO_3^+$	6.78 (29)
$+ SO_3^{2-}$	$= CeSO_3^+$	8.04 (5)
$+ SO_4^{2-}$	$= CeSO_4^+$	3.59 (2)
$+ 2\ SO_4^{2-}$	$= Ce(SO_4)_2^-$	5.45 (1)
$+ NO_3^-$	$= CeNO_3^{2+}$	1.09 (1)
$+ PO_4^{3-}$	$= CePO_4^\circ$	18.5 (5)
$+ H_2PO_4^-$	$= CeH_2PO_4^{2+}$	2.33 (5)
$+ P_2O_7^{4-}$	$= CeP_2O_7^-$	17.2 (5)
$3\ Ce(OH)_3(s)$	$= Ce_3(OH)_5^{4+} + 4\ OH^-$	-25.8 (7+4)

Cerium IV

$CeO_2(s) + 2\ H_2O$ Cerianite	$== Ce^{4+} + 4\ OH^-$	-64.1 (1), -64.3 (6), -71.1 (11),
$CeF_4(s)$	$== Ce^{4+} + 4\ F^-$	-30.3 (11),
$CeS_2(s) + 2\ H^+$	$== Ce^{4+} + 2\ HS^-$	-34.1 (4), -33.9 (11),
$Ce(SO_4)_2(s)$	$== Ce^{4+} + 2\ SO_4^{2-}$	-29.7 (11),
$Ce_3(PO_4)_4(s)$	$== 3\ Ce^{4+} + 4\ PO_4^{3-}$	-90.1 (9),
$Ce^{4+} + OH^-$	$== Ce(OH)^{3+}$	21.5 (4)
$+ 2\ OH^-$	$== Ce(OH)_2^{2+}$	35.2 (4)

Neodymium

$Nd_2O_3(s) + 3\ H_2O$	$== 2\ Nd^{3+} + 6\ OH^-$	-25.5 (1), -33.3 (11),
$Nd(OH)_3(s)$	$== Nd^{3+} + 3\ OH^-$	-23.1 (2), -23.1 (5), -23.1 (9), -23.3 (9), -23.9 (9),
$Nd_2(CO_3)_3(s)$	$== 2\ Nd^{3+} + 3\ CO_3^{2-}$	-33.0 (1), -33.0 (5),
$Nd_2(SO_4)_3(s)$	$== 2\ Nd^{3+} + 3\ SO_4^{2-}$	-8.86 (1),
$Nd^{3+} + OH^-$	$== Nd(OH)^{2+}$	5.50 (2)
$+ 2\ OH^-$	$== Nd(OH)_2^+$	11.1 (7)
$+ 3\ OH^-$	$== Nd(OH)_3$	15.5 (7)
$+ 4\ OH^-$	$== Nd(OH)_4^-$	18.9 (7)
$+ F^-$	$== NdF^{2+}$	3.99 (29)
$+ Cl^-$	$== NdCl^{2+}$	0.80 (29)
$+ 2\ Cl^-$	$== NdCl_2^+$	-0.29 (29)
$+ 3\ Cl^-$	$== NdCl_3$	0.06 (1)
$+ CO_3^{2-}$	$== NdCO_3^+$	6.72 (29)
$+ SO_4^{2-}$	$== NdSO_4^+$	3.47 (1)
$+ 2\ SO_4^{2-}$	$== Nd(SO_4)_2^-$	5.17 (1)
$2\ Nd(OH)_3(s)$	$== Nd_2(OH)_2^{4+} + 4\ OH^-$	-32.1 (5+2)

Samarium

$Sm_2O_3(s) + 3\ H_2O$	$== 2\ Sm^{3+} + 6\ OH^-$	-29.7 (1), -29.6 (11),
$Sm(OH)_3(s)$	$== Sm^{3+} + 3\ OH^-$	-27.8 (1), -25.4 (5), -23.9 (9), -25.9 (9), -27.4 (11),
$Sm_2(CO_3)_3(s)$	$== 2\ Sm^{3+} + 3\ CO_3^{2-}$	-32.5 (1), -32.5 (5),
$Sm^{3+} + OH^-$	$== Sm(OH)^{2+}$	6.10 (7)
$+ 2\ OH^-$	$== Sm(OH)_2^+$	11.4 (29)
$+ 3\ OH^-$	$== Sm(OH)_3^o$	16.2 (29)
$+ 4\ OH^-$	$== Sm(OH)_4^-$	20.3 (29)
$+ F^-$	$== SmF^{2+}$	4.02 (29)
$+ Cl^-$	$== SmCl^{2+}$	0.80 (29)
$+ 2\ Cl^-$	$== SmCl_2^+$	-0.29 (29)
$+ 3\ Cl^-$	$== SmCl_3^o$	-0.01 (1)
$+ CO_3^{2-}$	$== SmCO_3^+$	6.86 (29)
$+ SO_4^{2-}$	$== SmSO_4^+$	3.47 (1)
$+ 2\ SO_4^{2-}$	$== Sm(SO_4)_2^-$	5.83 (1)

Europium

$Eu_2O_3(s) + 3\ H_2O$	$== 2\ Eu^{3+} + 6\ OH^-$	-30.9 (1), -29.7 (11),
$Eu(OH)_3(s)$	$== Eu^{3+} + 3\ OH^-$	-26.0 (1), -26.5 (2), -25.6 (5), -26.5 (9), -27.7 (11),
$Eu^{3+} + OH^-$	$== Eu(OH)^{2+}$	6.20 (7)
$+ 2\ OH^-$	$== Eu(OH)_2^+$	11.4 (29)
$+ 3\ OH^-$	$== Eu(OH)_3^\circ$	16.4 (29)
$+ 4\ OH^-$	$== Eu(OH)_4^-$	20.7 (29)
$+ F^-$	$== EuF^{2+}$	4.09 (29)
$+ Cl^-$	$== EuCl^{2+}$	0.90 (1)
$+ 2\ Cl^-$	$== EuCl_2^+$	0.19 (1)
$+ 3\ Cl^-$	$== EuCl_3^\circ$	-0.01 (1)
$+ CO_3^{2-}$	$== EuCO_3^+$	6.83 (29)
$+ SO_4^{2-}$	$== EuSO_4^+$	3.31 (2)
$+ 2\ SO_4^{2-}$	$== Eu(SO_4)_2^-$	5.32 (1)
$+ NO_3^-$	$== EuNO_3^{2+}$	1.23 (5)

Ytterbium

$Yb_2O_3(s) + 3\ H_2O$	$== 2\ Yb^{3+} + 6\ OH^-$	-36.2 (1), -30.9 (11),
$Yb(OH)_3(s)$	$== Yb^{3+} + 3\ OH^-$	-32.0 (2), -25.0 (5), -25.1 (9), -26.6 (9), -25.1 (11),
$Yb_2(CO_3)_3(s)$	$== 2\ Yb^{3+} + 3\ CO_3^{2-}$	-31.1 (5),
$Yb^{3+} + OH^-$	$== Yb(OH)^{2+}$	6.30 (7)
$+ 2\ OH^-$	$== Yb(OH)_2^+$	12.2 (7)
$+ 3\ OH^-$	$== Yb(OH)_3^\circ$	17.9 (7)
$+ 4\ OH^-$	$== Yb(OH)_4^-$	23.3 (7)
$+ F^-$	$== YbF^{2+}$	4.44 (1)
$+ Cl^-$	$== YbCl^{2+}$	0.70 (29)
$+ 2\ Cl^-$	$== YbCl_2^+$	-0.29 (29)
$+ 3\ Cl^-$	$== YbCl_3^\circ$	-0.01 (1)
$+ CO_3^{2-}$	$== YbCO_3^+$	7.60 (29)
$+ SO_4^{2-}$	$== YbSO_4^+$	3.32 (1)
$+ 2\ SO_4^{2-}$	$== Yb(SO_4)_2^-$	5.05 (1)
$+ P_2O_7^{4-}$	$== YbP_2O_7^-$	17.5 (5)
$+ 2\ P_2O_7^{4-}$	$== Yb(P_2O_7)_2^{5-}$	19.4 (5)

Lutetium

$Lu_2O_3(s) + 3\ H_2O$	$== 2\ Lu^{3+} + 6\ OH^-$	-52.8 (1), -44.2 (11),
$Lu(OH)_3(s)$	$== Lu^{3+} + 3\ OH^-$	-29.7 (1), -26.1 (5), -27.0 (9), -24.4 (11),
$Lu^{3+} + OH^-$	$== Lu(OH)^{2+}$	6.40 (7)
$+ 2\ OH^-$	$== Lu(OH)_2^+$	12.3 (29)
$+ 3\ OH^-$	$== Lu(OH)_3^\circ$	18.3 (29)
$+ 4\ OH^-$	$== Lu(OH)_4^-$	24.2 (29)
$+ F^-$	$== LuF^{2+}$	4.37 (1)
$+ Cl^-$	$== LuCl^{2+}$	0.50 (29)
$+ 2\ Cl^-$	$== LuCl_2^+$	-0.29 (29)
$+ 3\ Cl^-$	$== LuCl_3^\circ$	-0.09 (1)
$+ CO_3^{2-}$	$== LuCO_3^+$	7.57 (29)
$+ SO_4^{2-}$	$== LuSO_4^+$	3.69 (1)
$+ 2\ SO_4^{2-}$	$== Lu(SO_4)_2^-$	5.17 (1)

Hafnium

$HfO_2(s) + 2\ H_2O$	$== Hf^{4+} + 4\ OH^-$	-63.8 (2), -54.8 (5),
$Hf^{4+} + OH^-$	$== Hf(OH)^{3+}$	13.7 (7)
$+ 2\ OH^-$	$== Hf(OH)_2^{2+}$	25.6 (7)
$+ 3\ OH^-$	$== Hf(OH)_3^+$	36.0 (7)
$+ 4\ OH^-$	$== Hf(OH)_4^\circ$	45.3 (7)
$+ 5\ OH^-$	$== Hf(OH)_5^-$	52.8 (7)
$+ F^-$	$== HfF^{3+}$	10.2 (29)
$+ 2\ F^-$	$== HfF_2^{2+}$	17.1 (29)
$+ 3\ F^-$	$== HfF_3^+$	25.1 (29)
$+ 4\ F^-$	$== HfF_4^\circ$	31.2 (29)
$+ 5\ F^-$	$== HfF_5^-$	36.4 (29)
$+ 6\ F^-$	$== HfF_6^{2-}$	39.5 (29)
$+ Cl^-$	$== HfCl^{3+}$	1.65 (29)
$+ 2\ Cl^-$	$== HfCl_2^{2+}$	1.55 (29)
$+ 3\ Cl^-$	$== HfCl_3^+$	0.88 (29)
$+ SO_4^{2-}$	$== HfSO_4^{2+}$	7.16 (29)
$+ 2\ SO_4^{2-}$	$== Hf(SO_4)_2^\circ$	11.6 (29)

Gold I

$AuCl(s)$	$== Au^+ + Cl^-$	-11.7 (2)
$Au^+ + OH^-$	$== Au(OH)°$	14.6 (47)
$+ 2\ OH^-$	$== Au(OH)_2^-$	24.6 (47)
$+ Cl^-$	$== AuCl°$	7.42 (47)
$+ 2\ Cl^-$	$== AuCl_2^-$	9.00 (10)
$+ OH^- + Cl^-$	$== Au(OH)Cl^-$	19.2 (47)
$+ 2\ Br^-$	$== AuBr_2^-$	15.0 (1+2)
$+ HS^-$	$== Au(HS)°$	22.6 (47)
$+ 2\ HS^-$	$== Au(HS)_2^-$	29.7 (47)
$+ S^{2-}$	$== AuS^-$	39.0
$+ S_2O_3^{2-}$	$== AuS_2O_3^-$	14.6 (47)
$+ 2\ S_2O_3^{2-}$	$== Au(S_2O_3)_2^{3-}$	28.8 (47)
$+ SO_3^{2-}$	$== AuSO_3^-$	15.0 (47)
$+ 2\ SO_3^{2-}$	$== Au(SO_3)_2^{3-}$	29.4 (47)
$2\ AuCl(s) + 3\ HS^-$	$== Au_2(HS)_2S^{2-} + 2\ Cl^- + H^+$	26.3 (47)

Gold III

$Au_2O_3(s) + 3\ H_2O$	$== 2\ Au^{3+} + 6\ OH^-$	-124.8 (11),
$Au(OH)_3(s)$	$== Au^{3+} + 3\ OH^-$	-54.4 (2), -51.6 (5), -45.3 (9),

$AuCl_3(s)$	$= Au^{3+} + 3\ Cl^-$	-15.5 (?), -15.5 (11),
$Au^{3+} + OH^-$	$= Au(OH)^{2+}$	16.0 (47)
$+ 2\ OH^-$	$= Au(OH)_2^+$	32.0 (47)
$+ 3\ OH^-$	$= Au(OH)_3^\circ$	48.9 (47)
$+ 4\ OH^-$	$= Au(OH)_4^-$	51.1 (47)
$+ 5\ OH^-$	$= Au(OH)_5^{2-}$	51.8 (47)
$+ 6\ OH^-$	$= Au(OH)_6^{3-}$	47.0 (29)
$+ 3\ OH^-$	$= H_2AuO_3^- + H^+$	26.8 (4)
$+ 3\ OH^-$	$= HAuO_3^{2-} + 2\ H^+$	13.5 (4)
$+ 3\ OH^-$	$= AuO_3^{3-} + 3\ H^+$	-2.48 (4)
$+ Cl^-$	$= AuCl^{2+}$	11.0 (47)
$+ 2\ Cl^-$	$= AuCl_2^+$	17.6 (47)
$+ 3\ Cl^-$	$= AuCl_3^\circ$	21.5 (47)
$+ 4\ Cl^-$	$= AuCl_4^-$	26.0 (10)
$+ 3\ OH^- + Cl^-$	$= Au(OH)_3Cl^-$	45.8 (47)
$+ 2\ OH^- + 2\ Cl^-$	$= Au(OH)_2Cl_2^-$	39.8 (47)
$+ OH^- + 3\ Cl^-$	$= Au(OH)Cl_3^-$	33.0 (47)
$+ 4\ Cl^- + H^+$	$= HAuCl_4^\circ$	48.2
$+ 4\ Br^-$	$= AuBr_4^-$	32.4
$+ H^+ + 2\ SO_4^{2-}$	$= HAu(SO_4)^\circ_2$	1.42 (47)

Mercury

$HgO(s) + H_2O$ Montroydite	$= Hg^{2+} + 2\ OH^-$	-25.5 (1), -25.5 (2), -25.5 (3), -25.4 (5), -25.5 (6), -25.7 (36) -25.5 (19),
$Hg(OH)_2(s)$	$= Hg^{2+} + 2\ OH^-$	-25.4 (2), -25.4 (9), -25.5 (9), -25.4 (19),
$HgS(s) + H^+$ metacinnabar (black)	$= Hg^{2+} + HS^-$	-39.3 (1), -39.3 (2), -39.2 (4), -38.5 (6), -38.5 (10), -38.7 (19),
$HgS(s) + H^+$ cinnabar (red)	$= Hg^{2+} + HS^-$	-39.8 (1), -39.8 (2), -39.8 (3), -39.6 (4), -39.8 (6), -39.8 (10), -39.1 (19),
$HgSO_4(s)$	$= Hg^{2+} + SO_4^{2-}$	-2.23 (4), -3.34 (19),

$Hg^{2+} + OH^-$	$= Hg(OH)^+$	10.4 (2)
$+ 2\ OH^-$	$= Hg(OH)_2^\circ$	21.9 (2)
$+ 3\ OH^-$	$= Hg(OH)_3^-$	35.0 (2)
$+ 2\ OH^-$	$= HHgO_2^- + H^+$	7.05 (1)
$+ F^-$	$= HgF^+$	1.58 (1)
$+ Cl^-$	$= HgCl^+$	6.25 (10)
$+ 2\ Cl^-$	$= HgCl_2^\circ$	13.25 (10)
$+ 3\ Cl^-$	$= HgCl_3^-$	15.35 (10)
$+ 4\ Cl^-$	$= HgCl_4^{2-}$	15.1 (1)

+ OH + Cl	== $Hg(OH)Cl^{\circ}$	18.1	(7)
+ Br^-	== $HgBr^+$	9.05	(1)
+ 2 Br^-	== $HgBr_2^{\circ}$	17.4	(1)
+ 3 Br^-	== $HgBr_3^-$	19.6	(1)
+ 4 Br^-	== $HgBr_4^{2-}$	21.0	(1)
+ CO_3^{2-}	== $HgCO_3^{\circ}$	10.9	(29)
+ 2 HS^-	== $Hg(HS)_2^{\circ}$	35.6	(2)
+ $S_2O_3^{2-}$	== $HgS_2O_3^{\circ}$	29.2	(2)
+ 2 $S_2O_3^{2-}$	== $Hg(S_2O_3)_2^{2-}$	30.8	(2)
+ 3 $S_2O_3^{2-}$	== $Hg(S_2O_3)_3^{4-}$	30.6	(5)
+ 2 SO_3^{2-}	== $Hg(SO_3)_2^{2-}$	24.1	(5)
+ 3 SO_3^{2-}	== $Hg(SO_3)_3^{4-}$	26.0	(5)
+ SO_4^{2-}	== $HgSO_4^{\circ}$	1.41	(1)
+ 2 SO_4^{2-}	== $Hg(SO_4)_2^{2-}$	3.86	(29)
Hg^{2+} + NO_3^-	== $HgNO_3^+$	0.33	(19)
+ 2 NO_3^-	== $Hg(NO_3)_2^{\circ}$	-1.36	(19)
2 $Hg(OH)_2(s)$	== $Hg_2(OH)^{3+}$ + 3 OH^-	-40.2	(5+2)
3 $Hg(OH)_2(s)$	== $Hg_3(OH)_3^{3+}$ + 3 OH^-	-40.8	(5+2)
$HgS(s)$ + 2 H_2S°	== $HgS(H_2S)_2^{\circ}$	-4.31	(8)
$HgS(s)$ + HS^-	== $HgS(HS)^-$	-5.28	(36)
$HgS(s)$ + 2 HS^-	== $HgS(HS)_2^{2-}$	-3.60	(8)
$HgS(s)$ + HS^- + H_2S°	== $Hg(HS)_3^-$	-3.59	(8)
$HgS(s)$ + HS^- + OH^-	== HgS_2^{2-} + H_2O	0.31	(8)

Thallium I

$Tl_2O(s) + H_2O$	$== 2\ Tl^+ + 2\ OH^-$	-0.89 (1),
$Tl(OH)(s)$	$== Tl^+ + OH^-$	-1.07 (1), -1.07 (2),
$TlCl(s)$	$== Tl^+ + Cl^-$	-3.73 (1), -3.72 (2), -3.74 (5), -3.66 (9), -3.72 (9), -3.75 (9), -3.82 (9)
$Tl_2CO_3(s)$	$== 2\ Tl^+ + CO_3^{2-}$	-3.85 (1),
$Tl_2S(s) + H^+$	$== 2\ Tl^+ + HS^-$	-7.18 (1),
$Tl_2SO_4(s)$	$== 2\ Tl^+ + SO_4^{2-}$	-3.83 (1), -3.82 (2),
$Tl^+ + OH^-$	$== Tl(OH)^\circ$	0.79 (7)
$+ F^-$	$== TlF^\circ$	0.10 (5)
$+ Cl^-$	$== TlCl^\circ$	0.51 (9)
$+ 2\ Cl^-$	$== TlCl_2^-$	0.16 (1)
$+ 3\ Cl^-$	$== TlCl_3^{2-}$	-0.90
$+ HS^-$	$== Tl(HS)^\circ$	2.27 (5)
$+ S_2O_3^{2-}$	$== TlS_2O_3^-$	1.91 (9)
$+ SO_4^{2-}$	$== TlSO_4^-$	1.37 (5)
$+ NO_3^-$	$== TlNO_3^\circ$	0.33 (5)

Thallium III

$Tl_2O_3(s) + 3\ H_2O$ Avicennite	$= 2\ Tl^{3+} + 6\ OH^-$	-89.1 (1), -90.8 (2), -90.4 (5),
$Tl(OH)_3(s)$	$= Tl^{3+} + 3\ OH^-$	-43.8 (1), -43.7 (2), -43.6 (9), -45.2 (9),
$Tl_2S_3(s) + 3\ H^+$	$= 2\ Tl^{3+} + 3\ HS^-$	-98.0 (2),
$Tl^{3+} + OH^-$	$= Tl(OH)^{2+}$	13.4 (7)
$+ 2\ OH^-$	$= Tl(OH)_2^+$	26.4 (7)
$+ 3\ OH^-$	$= Tl(OH)_3^\circ$	38.7 (7)
$+ 4\ OH^-$	$= Tl(OH)_4^-$	41.0 (7)
$+ Cl^-$	$= TlCl^{2+}$	7.72 (9)
$+ 2\ Cl^-$	$= TlCl_2^+$	13.5 (9)
$+ 3\ Cl$	$= TlCl_3^\circ$	16.5 (5)
$+ 4\ Cl^-$	$= TlCl_4^-$	18.3 (9)
$+ OH^- + Cl^-$	$= Tl(OH)Cl^+$	19.9 (7)
$+ SO_4^{2-}$	$= TlSO_4^+$	4.38 (29)

Lead

$PbO(s) + H_2O$ Litharge	$== Pb^{2+} + 2\ OH^-$	-15.2 (2), -15.3 (3), -14.4 (4), -15.2 (5), -14.9 (9), -15.2 (9), -15.1 (19),
$Pb(OH)_2(s)$	$== Pb^{2+} + 2\ OH^-$	-19.8 (1), -19.8 (2), -18.7 (9), -20.0 (9), -14.9 (36), -19.8 (19),
$PbF_2(s)$	$== Pb^{2+} + 2\ F^-$	-6.23 (3), -7.42 (4), -7.44 (5), -7.57 (9),
$Pb(OH)Cl(s)$ Laurionite	$== Pb^{2+} + OH^- + Cl^-$	-29.3 (2),
$PbCO_3(s)$ Cerussite	$== Pb^{2+} + CO_3^{2-}$	-12.8 (1), -13.4 (2), -12.8 (3), -13.0 (4), -13.1 (5), -13.1 (9), -13.5 (10), -13.0 (36),
$Pb_3(CO_3)_2(OH)_2(s)$ Hydrocerussite	$== 3\ Pb^{2+} + 2\ CO_3^{2-} + 2\ OH^-$	-45.1 (4), -18.8 (36), -46.7 (19),
$Pb_2(CO_3)Cl_2(s)$ Phosgenite	$== 2\ Pb^{2+} + CO_3^{2-} + 2\ Cl^-$	-19.8 (2), -19.9 (19),
$PbS(s) + H^+$ Galena	$== Pb^{2+} + HS^-$	-15.1 (1), -15.1 (2), -15.2 (3), -14.2 (4), -14.7 (6), -14.7 (10), -14.5 (43), -14.6 (19),

$PbSO_4(s)$ Anglesite	$== Pb^{2+} + SO_4^{2-}$	-7.74 (1), -7.76 (2), -7.70 (3), -7.87 (4), -7.79 (5), -7.97 (6), -7.75 (10), -7.89 (36), -7.79 (19),
$Pb_2O(SO_4)(s) + H_2O$ Larnakite	$== 2\ Pb^{2+} + SO_4^{2-} + 2\ OH^-$	-28.4 (2), -32.5 (19),
$Pb_3(PO_4)_2(s)$	$== 3\ Pb^{2+} + 2\ PO_4^{3-}$	-54.1 (4), -43.5 (5), -42.1 (9), -44.6 (19),
$PbAl_3(PO_4)(SO_4)(OH)_6(s)$ Hinsdalite	$== Pb^{2+} + 3\ Al^{3+} + PO_4^{3-} + SO_4^{2-} + 6\ OH^-$	-86.5 (2),
$PbSiO_3(s) + H_2O + 2\ H^+$ Alamosite	$== Pb^{2+} + H_4SiO_4^\circ$	7.32 (1), 6.12 (2), 7.64 (4), 5.94 (19),
$Pb_2SiO_4(s) + 4\ H^+$	$== 2\ Pb^{2+} + H_4SiO_4^\circ$	19.8 (1), 18.6 (2), 19.2 (4), 18.5 (19),

$Pb^{2+} + OH^-$	$= Pb(OH)^+$	6.29 (7)
$+ 2\ OH^-$	$= Pb(OH)_2^\circ$	10.8 (2)
$+ 3\ OH^-$	$= Pb(OH)_3^-$	13.9 (2)
$+ 4\ OH^-$	$= Pb(OH)_4^{2-}$	16.5 (19)
$+ 2\ OH^-$	$= HPbO_2^- + H^+$	-0.09 (1)
$+ F^-$	$= PbF^+$	1.49 (2)
$+ 2\ F^-$	$= PbF_2^\circ$	2.70 (2)
$+ 3\ F^-$	$= PbF_3^-$	4.07 (2)
$+ 4\ F^-$	$= PbF_4^{2-}$	3.20
$+ Cl^-$	$= PbCl^+$	1.60 (10)
$+ 2\ Cl^-$	$= PbCl_2^\circ$	1.78 (10)
$+ 3\ Cl^-$	$= PbCl_3^-$	1.68 (10)
$+ 4\ Cl^-$	$= PbCl_4^{2-}$	1.38 (10)
$+ Br^-$	$= PbBr^+$	1.11 (5)
$+ 2\ Br^-$	$= PbBr_2^\circ$	1.44 (5)
$+ 3\ Br^-$	$= PbBr_3^-$	1.19 (5)
$+ 4\ Br^-$	$= PbBr_4^{2-}$	2.30 (5)
$+ CO_3^{2-}$	$= PbCO_3^\circ$	7.00 (29)
$+ 2\ CO_3^{2-}$	$= Pb(CO_3)_2^{2-}$	8.23 (2)
$+ HCO_3^-$	$= PbHCO_3^+$	2.90 (43)
$+ 2\ HCO_3^-$	$= Pb(HCO_3)_2^\circ$	4.77
$+ 3\ HCO_3^-$	$= Pb(HCO_3)_3^-$	5.19
$+ 2\ HS^-$	$= Pb(HS)_2^\circ$	15.3 (2)
$+ 3\ HS^-$	$= Pb(HS)_3^-$	16.6 (2)
$+ 2\ HS^-$	$= PbS(HS)^- + H^+$	7.81 (43)

$Pb^{2+} + S_2O_3^{2-}$	$== PbS_2O_3^\circ$	4.00 (43)
$+ 2\ S_2O_3^{2-}$	$== Pb(S_2O_3)_2^{2-}$	6.50 (43)
$+ 3\ S_2O_3^{2-}$	$== Pb(S_2O_3)_3^{4-}$	6.40 (43)
$+ 4\ S_2O_3^{2-}$	$== Pb(S_2O_3)_4^{6-}$	4.00 (43)
$+ SO_4^{2-}$	$== PbSO_4^\circ$	2.63 (2)
$+ 2\ SO_4^{2-}$	$== Pb(SO_4)_2^{2-}$	4.51 (29)
$+ NO_3^-$	$== PbNO_3^+$	1.07 (1)
$+ 2\ NO_3^-$	$== Pb(NO_3)_2^\circ$	1.40 (5)
$+ HPO_4^{2-}$	$== PbHPO_4^\circ$	3.10 (5)
$+ H_2PO_4^-$	$== PbH_2PO_4^+$	1.50 (5)
$+ P_2O_7^{4-}$	$== PbP_2O_7^{2-}$	10.4 (1)
$2\ Pb(OH)_2(s)$	$== Pb_2(OH)^{3+} + 3\ OH^-$	-32.1 (5+2)
$2\ Pb(OH)_2(s)$	$== Pb_2(OH)_2^{2+} + 2\ OH^-$	-18.1 (26)
$3\ Pb(OH)_2(s)$	$== Pb_3(OH)_4^{2+} + 2\ OH^-$	-26.9 (1)
$4\ Pb(OH)_2(s)$	$== Pb_4(OH)_4^{4+} + 4\ OH^-$	-42.7 (1)
$6\ Pb(OH)_2(s)$	$== Pb_6(OH)_8^{4+} + 4\ OH^-$	-49.8 (1)
$PbS(s) + 2\ H_2S^\circ$	$== PbS(H_2S)_2^\circ$	-2.10 (8)

Bismuth

$Bi_2O_3(s) + 3\ H_2O$ Bismite	$== 2\ Bi^{3+} + 6\ OH^-$	-74.8 (1), -78.0 (2), -68.1 (4), -74.8 (6), -74.8 (11),
$BiO(OH)(s) + H_2O$	$== Bi^{3+} + 3\ OH^-$	-37.9 (1), -37.9 (11),
$Bi(OH)_3(s)$	$== Bi^{3+} + 3\ OH^-$	-35.5 (2), -28.6 (4), -31.5 (9), -33.4 (11),
$BiCl_3(s)$	$== Bi^{3+} + 3\ Cl^-$	-1.93 (2), -0.72 (11),
$Bi(OH)_2Cl(s)$	$== Bi^{3+} + 2\ OH^- + Cl^-$	-30.7 (11),
$BiOCl(s) + H_2O$ Bismoclite	$== Bi^{3+} + 2\ OH^- + Cl^-$	-30.8 (4), -34.4 (11),
$Bi_2S_3(s) + 3\ H^+$ Bismuthinite	$== 2\ Bi^{3+} + 3\ HS^-$	-60.0 (1), -65.3 (2), -57.2 (4), -60.0 (11), -60.0 (6),
$Bi_2(SO_4)_3(s)$	$== 2\ Bi^{3+} + 3\ SO_4^{2-}$	-90.3 (11),
$BiPO_4(s)$	$== Bi^{3+} + PO_4^{3-}$	-23.0 (2),

$Bi^{3+} + OH^-$	$== Bi(OH)^{2+}$	12.9	(7)
$+ 2\ OH^-$	$== Bi(OH)_2^+$	25.5	(52)
$+ 3\ OH^-$	$== Bi(OH)_3^\circ$	33.1	(7)
$+ 4\ OH^-$	$== Bi(OH)_4^-$	34.2	(7)
$+ OH^-$	$== BiO^+ + H^+$	12.6	(1)
$+ 3\ OH^- + H_2O$	$== HBi(OH)_4^\circ$	33.3	(11)
$+ 3\ OH^- + 3\ H_2O$	$== H_3Bi(OH)_6^\circ$	33.3	(11)
$+ F^-$	$== BiF^{2+}$	2.28	(29)
$+ Cl^-$	$== BiCl^{2+}$	2.85	(29)
$+ 2\ Cl^-$	$== BiCl_2^+$	5.05	(29)
$+ 3\ Cl^-$	$== BiCl_3^\circ$	6.76	(29)
$+ 4\ Cl^-$	$== BiCl_4^-$	7.38	(29)
$+ 5\ Cl^-$	$== BiCl_5^{2-}$	7.49	(29)
$+ 6\ Cl^-$	$== BiCl_6^{3-}$	6.51	(29)
$+ Cl^- + 2\ OH^-$	$== Bi(OH)_2Cl^\circ$	25.0	(52)
$+ 2\ Cl^- + OH^-$	$== Bi(OH)Cl_2^\circ$	16.0	(52)
$+ SO_4^{2-}$	$== BiSO_4^+$	4.09	(29)
$+ 2\ SO_4^{2-}$	$== Bi(SO_4)_2^-$	7.11	(29)
$+ 3\ SO_4^{2-}$	$== Bi(SO_4)_3^{3-}$	6.33	(29)
$+ 4\ SO_4^{2-}$	$== Bi(SO_4)_4^{5-}$	6.52	(29)
$+ 5\ SO_4^{2-}$	$== Bi(SO_4)_5^{7-}$	1.90	(29)
$+ NO_3^-$	$== BiNO_3^+$	1.70	(5)
$+ 2\ NO_3^-$	$== Bi(NO_3)_2^\circ$	2.50	(5)

$6\ Bi(OH)_3(s)$	$== Bi_6(OH)_{12}^{6+} + 6\ OH^-$	-25.3
$6\ Bi(OH)_3(s)$	$== Bi_6O_6(OH)_3^{3+} + 6\ H_2O + 3\ OH^-$	7.70
$9\ Bi(OH)_3(s)$	$== Bi_9(OH)_{20}^{7+} + 7\ OH^-$	-13.4
$9\ Bi(OH)_3(s)$	$== Bi_9(OH)_{21}^{6+} + 6\ OH^-$	-12.9 (11)
$9\ Bi(OH)_3(s)$	$== Bi_9(OH)_{22}^{5+} + 5\ OH^-$	-1.52 (11)
$6\ Bi(OH)_3(s)$	$== Bi_6O_6^{6+} + 6\ H_2O + 6\ OH^-$	-33.0 (11)

Thorium

$ThO_2(s) + 2\ H_2O$ Thorianite	$== Th^{4+} + 4\ OH^-$	-50.9 (2), -49.3 (3), -48.5 (4), -49.7 (5), -49.1 (11), -54.2 (22),
$Th(OH)_4(s)$	$== Th^{4+} + 4\ OH^-$	-43.1 (2), -39.2 (4), -44.7 (5), -39.2 (11), -46.6 (22),
$ThF_4(s)$	$== Th^{4+} + 4\ F^-$	-27.7 (2), -13.3 (11), -30.2 (22),
$Th(SO_4)_2(s)$	$== Th^{4+} + 2\ SO_4^{2-}$	-14.6 (3), -13.9 (11),

$Th^{4+} + OH^-$	$= Th(OH)^{3+}$	10.8	(5)
$+ 2\ OH^-$	$= Th(OH)_2^{2+}$	21.1	(5)
$+ 3\ OH^-$	$= Th(OH)_3^{+}$	30.3	(7)
$+ 4\ OH^-$	$= Th(OH)_4^{\circ}$	40.1	(7)
$+ 5\ OH^-$	$= Th(OH)_5^{-}$	37.3	(2)
$+ 6\ OH^-$	$= Th(OH)_6^{2-}$	37.3	(2)
$+ F^-$	$= ThF^{3+}$	8.03	(22)
$+ 2\ F^-$	$= ThF_2^{2+}$	14.3	(22)
$+ 3\ F^-$	$= ThF_3^{+}$	18.9	(22)
$+ 4\ F^-$	$= ThF_4^{\circ}$	22.3	(22)
$+ Cl^-$	$= ThCl^{3+}$	1.09	(22)
$+ 2\ Cl^-$	$= ThCl_2^{2+}$	0.80	(22)
$+ 3\ Cl^-$	$= ThCl_3^{+}$	1.65	(22)
$+ 4\ Cl^-$	$= ThCl_4^{\circ}$	1.26	(22)
$+ CO_3^{2-}$	$= ThCO_3^{2+}$	11.0	(29)
$+ SO_4^{2-}$	$= ThSO_4^{2+}$	5.45	(22)
$+ 2\ SO_4^{2-}$	$= Th(SO_4)_2^{\circ}$	9.73	(22)
$+ 3\ SO_4^{2-}$	$= Th(SO_4)_3^{2-}$	10.5	(22)
$+ 4\ SO_4^{2-}$	$= Th(SO_4)_4^{4-}$	8.48	(22)
$+ NO_3^-$	$= ThNO_3^{3+}$	0.94	(22)
$+ 2\ NO_3^-$	$= Th(NO_3)_2^{2+}$	1.97	(22)
$+ HPO_4^{2-}$	$= ThHPO_4^{2+}$	10.8	(22)
$+ 2\ HPO_4^{2-}$	$= Th(HPO_4)_2^{\circ}$	22.8	(22)
$+ 3\ HPO_4^{2-}$	$= Th(HPO_4)_3^{2-}$	31.3	(22)

$Th^{4+} + H_2PO_4^-$	$== ThH_2PO_4^{3+}$	4.52 (22)
$+ 2\ H_2PO_4^-$	$== Th(H_2PO_4)_2^{2+}$	8.88 (22)
$+ H_3PO_4^\circ$	$== Th(H_3PO_4)^{4+}$	1.91 (22)
$2\ ThO_2(s) + 4\ H_2O$	$== Th_2(OH)_2^{6+} + 6\ OH^-$	-86.5 (22)
$4\ ThO_2(s) + 8\ H_2O$	$== Th_4(OH)_8^{8+} + 8\ OH^-$	-125.9 (22)
$6\ ThO_2(s) + 12\ H_2O$	$== Th_6(OH)_{15}^{9+} + 9\ OH^-$	-151.9 (22)

Uranium IV

$UO_2(s) + 2\ H_2O$ Uraninite	$== U^{4+} + 4\ OH^-$	-52.2 (3), -56.2 (5), -52.2 (6), -60.6 (14)
$U(OH)_4(s)$	$== U^{4+} + 4\ OH^-$	-52.0 (12),
$UF_4(s)$	$== U^{4+} + 4\ F^-$	-19.7 (14),
$U(HPO_4)_2 \cdot 4H_2O(s)$	$== U^{4+} + 4\ H_2O + 2\ HPO_4^{2-}$	-26.8 (12),
$CaU(PO_4)_2 \cdot 2H_2O(s)$ Ningyoite	$== U^{4+} + Ca^{2+} + 2\ H_2O + 2\ PO_4^{3-}$	-54.3 (12),
$USiO_4(s) + 4\ H^+$ Coffinite	$== U^{4+} + H_4SiO_4^\circ$	-8.82 (14)

$U^{4+} + OH^-$	$== U(OH)^{3+}$	13.4	(14)
$+ 2\ OH^-$	$== U(OH)_2^{2+}$	25.7	(14)
$+ 3\ OH^-$	$== U(OH)_3^{+}$	37.1	(14)
$+ 4\ OH^-$	$== U(OH)_4^{\circ}$	47.5	(14)
$+ 5\ OH^-$	$== U(OH)_5^-$	56.8	(14)
$+ F^-$	$== UF^{3+}$	8.93	(14)
$+ 2\ F^-$	$== UF_2^{2+}$	15.1	(14)
$+ 3\ F^-$	$== UF_3^{+}$	20.0	(14)
$+ 4\ F^-$	$== UF_4^{\circ}$	24.9	(14)
$+ 5\ F^-$	$== UF_5^-$	26.8	(14)
$+ 6\ F^-$	$== UF_6^{2-}$	29.5	(14)
$+ Cl^-$	$== UCl^{3+}$	1.34	(14)
$+ SO_4^{2-}$	$== USO_4^{2+}$	5.59	(14)
$+ 2\ SO_4^{2-}$	$== U(SO_4)_2^{\circ}$	10.0	(14)
$+ NO_3^-$	$== UNO_3^{3+}$	1.60	(5)
$+ HPO_4^{2-}$	$== UHPO_4^{2+}$	12.0	(14)
$+ 2\ HPO_4^{2-}$	$== U(HPO_4)_2^{\circ}$	22.0	(14)
$+ 3\ HPO_4^{2-}$	$== U(HPO_4)_3^{2-}$	30.6	(14)
$+ 4\ HPO_4^{2-}$	$== U(HPO_4)_4^{4-}$	38.7	(14)
$6\ UO_2(s) + 12\ H_2O$	$== U_6(OH)_{15}^{9+} + 9\ OH^-$	-170.9	(14)

Uranium VI

$UO_3(s) + H_2O$	$== UO_2^{2+} + 2\ OH^-$	-15.1 (3), -20.3 (14),
$UO_2(OH)_2(s)$ Ianthinite	$== UO_2^{2+} + 2\ OH^-$	-21.9 (2), -22.4 (5), -17.2 (9), -20.9 (9), -22.4 (14),
$UO_2(OH)_2.H_2O(s)$ Schoepite	$== UO_2^{2+} + 2\ OH^- + H_2O$	-22.0 (2), -22.6 (14),
$UO_2F_2(s)$	$== UO_2^{2+} + 2\ F^-$	-5.89 (2),
$UO_2CO_3(s)$ Rutherfordine	$== UO_2^{2+} + CO_3^{2-}$	-14.2 (2), -10.5 (4), -14.5 (14),
$(UO_2)_3(PO_4)_2(s)$	$== 3\ UO_2^{2+} + 2\ PO_4^{3-}$	-46.7 (2), -49.7 (5), -49.3 (14),
$KUO_2PO_4(s)$ K-Autunite	$== UO_2^{2+} + K^+ + PO_4^{3-}$	-22.4 (2), -24.2 (14),
$Ca(UO_2)_2(PO_4)_2(s)$ Autunite	$== 2\ UO_2^{2+} + Ca^{2+} + 2\ PO_4^{3-}$	-44.5 (14),

UO_2^{2+} + OH^-	== $UO_2(OH)^+$	8.84	(2)
+ 2 OH^-	== $UO_2(OH)_2^\circ$	15.6	(2)
+ 3 OH^-	== $UO_2(OH)_3^-$	18.4	(2)
+ 4 OH^-	== $UO_2(OH)_4^{2-}$	18.2	(2)
+ F^-	== UO_2F^+	4.93	(2)
+ 2 F^-	== $UO_2F_2^\circ$	9.29	(2)
+ 3 F^-	== $UO_2F_3^-$	11.9	(2)
+ 4 F^-	== $UO_2F_4^{2-}$	13.2	(2)
+ Cl^-	== UO_2Cl^+	0.21	(2)
+ CO_3^{2-}	== $UO_2CO_3^\circ$	10.1	(14)
+ 2 CO_3^{2-}	== $UO_2(CO_3)_2^{2-}$	18.1	(2)
+ 3 CO_3^{2-}	== $UO_2(CO_3)_3^{4-}$	22.4	(2)
+ 2 CO_3^{2-} + 2 H_2O	== $UO_2(CO_3)_2(H_2O)_2^{2-}$	14.5	(4)
+ $S_2O_3^{2-}$	== $UO_2S_2O_3^\circ$	1.85	(2)
+ SO_4^{2-}	== $UO_2SO_4^\circ$	2.72	(2)
+ 2 SO_4^{2-}	== $UO_2(SO_4)_2^{2-}$	4.20	(2)
+ 3 SO_4^{2-}	== $UO_2(SO_4)_3^{4-}$	4.70	(29)
+ HPO_4^{2-}	== $UO_2HPO_4^\circ$	8.40	(14)
+ 2 HPO_4^{2-}	== $UO_2(HPO_4)_2^{2-}$	18.6	(14)
+ $H_2PO_4^-$	== $UO_2H_2PO_4^+$	3.03	(14)
+ 2 $H_2PO_4^-$	== $UO_2(H_2PO_4)_2^\circ$	5.47	(14)
+ 3 $H_2PO_4^-$	== $UO_2(H_2PO_4)_3^-$	7.18	(14)
2 $UO_2(OH)_2$(s)	== $(UO_2)_2(OH)_2^{2+}$ + 2 OH^-	-21.6	(2)
3 $UO_2(OH)_2$(s)	== $(UO_2)_3(OH)_5^+$ + OH^-	-13.0	(14)

It should be borne in mind that the accuracy of calculations based on thermodynamic data is limited by several factors:

(1) Although for most of the reactions, reliable equilibrium concentrations may be estimated, it is not always certain that kinetically, these reactions will proceed.

(2) It is implicitly assumed that all solid phases under consideration can be treated apart, but in practice, adsorption processes, coprecipitation and the formation of solid solutions cannot always be ruled out. In order to perform exact quantitative calculations, it would be necessary to know the composition of such solids, the distribution coefficients and the activity coefficients in the solid phases.

(3) As can sometimes be seen in Table 1, the thermodynamic data are not always sufficiently accurate. This is particularly true for the solubility products, which may differ by several order of magnitude in different compilations. Another case in point, for anoxic waters, is the dissociation constant of $HS^- \rightleftharpoons H^+ + S^{2-}$, which is not well known (see Table 2). Therefore, it is important to use the same value for the second dissociation constant of H_2S as did the author who reported the K^0-value for a certain sulfide reaction; otherwise, large and unnecessary errors may be introduced.

TABLE 2. Dissociation constants for acids that are of interest in natural waters.

Equilibrium reaction under consideration	Literature values of $\log K^0$ (and references)
$H_2CO_3^* = H^+ + HCO_3^-$	-6.36 (1)(2)(9)(19)(20), -6.37 (4)(6), -6.30 (3), -6.35 (5)(9)(10)(37), -6.45 (9), -6.46 (9), -6.339 (34),
$HCO_3^- = H^+ + CO_3^{2-}$	-10.33 (1)(2)(3)(4)(5)(9)(19)(20), -10.34 (6), -10.36 (9), -10.41 (9), -10.32 (10)(37), -10.329 (34),
$H_2S^\circ = H^+ + HS^-$	-6.99 (1)(2)(9)(10)(11)(17), -7.00 (4)(9), -6.96 (3)(9), -7.02 (5)(9)(19), -7.04 (9), -6.97 (9), -6.91 (9), -7.07 (9), -6.79 (9), -7.06 (9), -7.01 (18), -6.90 (38),
$HS^- = H^+ + S^{2-}$	-12.91 (1)(2)(11), -12.90 (3)(9), -13.89 (4), -13.90 (5)(9)(10), -12.92 (6)(9), -10.8 (8), -14.92 (9), -15.00 (9), -12.89 (9), -14.00 (9), -12.20 (9), -13.48 (38),
$H_4SiO_4^\circ = H^+ + H_3SiO_4^-$	-9.80 (2)(20), -9.89 (4), -9.86 (5)(7)(29), -9.82 (14), -9.70 (19), -9.84 (24),
$H_3PO_4^\circ = H^+ + H_2PO_4^-$	-9.48 (1), -2.15 (2)(5)(14)(19), -5.35 (3), -2.13 (4), -2.10 (9), -1.74 (11), -2.16 (9), -1.98 (9), -2.12 (9), -2.11 (9), -2.20 (29), -2.15 (37),
$H_2PO_4^- = H^+ + HPO_4^{2-}$	0.125 (1), -7.20 (2)(5)(11)(14)(19), 0.07 (3), -7.18 (4), -7.23 (9), -7.15 (9), -7.13 (9), -7.06 (9), -7.22 (9), -7.21 (9), -7.17 (29),

HPO_4^{2-}	$= H^+ + PO_4^{3-}$	-12.34 (1)(2), -12.31 (3), -12.02 (4), -12.35 (5)(19)(29), -12.30 (9), -12.66 (9), -12.36 (9),
$H_4P_2O_7$	$= H^+ + H_3P_2O_7^-$	-1.54 (1)(3)(11), -0.80 (5)(19),
$H_3P_2O_7^-$	$= H^+ + H_2P_2O_7^{2-}$	-2.27 (1)(3)(9)(11), -2.20 (5), -2.28 (19),
$H_2P_2O_7^{2-}$	$= H^+ + HP_2O_7^{3-}$	-6.67 (1)(3)(11), -6.70 (5)(19), -6.57 (9), -6.63 (9),
$HP_2O_7^{3-}$	$= H^+ + P_2O_7^{4-}$	-9.31 (1)(3)(10), -9.40 (5), -9.62 (9), -9.29 (9), -9.53 (9), -9.41 (19),

CALCULATION OF CHEMICAL SPECIATION

Equilibrium concentrations of the various chemical species of an element can be calculated on the basis of their equilibrium constants. Let us consider the reactions in solution for a cation M in the presence of k ligands L. Omitting charges, one can write:

$$M + L_1 \rightleftharpoons ML_1 \qquad \text{with} \quad K_{(1)_1} = \frac{[ML_1]}{[M]\,[L_1]}$$

$$M + 2L_1 \rightleftharpoons M(L_1)_2 \qquad K_{(1)_2} = \frac{[M(L_1)_2]}{[M]\,[L_1]^2}$$

$$\vdots \qquad\qquad\qquad\qquad \vdots$$

$$M + nL_1 \rightleftharpoons M(L_1)_n \qquad K_{(1)_n} = \frac{[M(L_1)_n]}{[M]\,[L_1]^n}$$

$$\vdots \qquad\qquad \vdots$$

$$M + NL_k \rightleftharpoons M(L_k)_n \qquad K_{(k)_n} = \frac{[M(L_k)_n]}{[M]\,[L_k]^n}$$

For the total concentration of the element M in solution, the mass balance is given by:

$$[M]_{tot} = [M] + [ML_1] + [M(L_1)_2] + \ldots + [M(L_1)_n] + \ldots$$

$$\ldots + [M(L_k)_n] = [M]\left\{1 + \sum_{n=1}^{n}\sum_{i=1}^{k} K_{(i)_n}[L_i]^n\right\}$$

where

$[M]$: the uncomplexed and/or hydrated M ion concentration

$[M(L_i)_n]$: concentration of the nth order complex between M and the ith ligand L

$[L_i]$: the fraction of total L_i ($[L_i]_{tot}$) present in the form L_i

k : total number of ligand types included in the model

$K_{(i)_n}$: the overall stability constant for the complex $M(L_i)_n$

The side reaction coefficients α_M and α_{L_i} constitute quantitative representations of all the competing side reactions which tend to reduce the extent to which the main coordination reaction proceeds:

$$\alpha_M = \frac{[M]}{[M]_{tot}} = \left\{1 + \sum_{n=1}^{n}\sum_{i=1}^{k} K_{(i)_n}[L_i]^n\right\}^{-1}$$

similarly:

$$\alpha_{L_x} = \frac{[L_x]}{[L_x]_{tot}} \qquad \text{with} \quad 1 \leqslant x \leqslant k$$

and with $[L_x]_{tot}$ the ligand in all dissolved forms, except in the complexes with M.

Important complexing agents L_i in natural waters are humic and fulvic matter, for which data are not well known and not very useful anyway, in view of the complexity and variability of these materials. Other major complexing agents are anions of inorganic acids (H_2CO_3,

H_2S, H_4SiO_4, phosphoric acids). In order to aid in the calculations of the chemical speciation, the dissociation constants for these acids are given in the auxiliary Table 2.

CALCULATION OF SOLUBILITY AND SATURATION INDEX

For the solubility equilibrium one can write:

$$ML_x(s) \rightleftharpoons M + L_x \qquad \text{with} \quad 1 \leqslant x \leqslant k,$$

and the solubility product is given by:

$$K_{s_0} = [M]\,[L_x]$$

In order to make solubility predictions, all side reactions, those of dissolved cationic elements with inorganic and organic ligands, of anionic elements with cations and both cationic and anionic elements in various redox states, have to be considered. The involvment of so many species may lead to rather complicated calculations requiring the use of suitable computer programs e.g. WATEQ (54), MINEQL (55), WATSPEC (56) and SIAS (57).

In order to simplify the calculations, the concept of "conditional constants", that is, equilibrium constants that hold only under given experimental conditions (e.g. at a given pH and temperature), has been introduced by Schwarzenbach (64). The resulting expression for the conditional solubility product P_s, for instance, simply quantifies the modification of the main reaction by the side reactions:

$$P_s = \frac{K_{s_0}}{\alpha_M \cdot \alpha_{L_x}}$$

The saturation index, Ω, of M with respect to a slightly soluble compound ($ML_x(s)$) is defined as the ratio of the measured concentration, $[M]_{exp}$, to the calculated maximum concentration of M which can be in equilibrium with that slightly soluble compound, $[M]_{calc}$, irrespective of the chemical form of M but at a specified pH, temperature and in a given environment:

$$[M]_{calc} = [M]_{tot} = \frac{P_s}{[L_x]_{tot}}$$

and

$$\Omega_M = \frac{[M]_{exp}}{[M]_{calc}}$$

INFLUENCE OF THE IONIC STRENGTH

Equilibrium constants are defined in agreement with the units in which reactants and products are expressed. If equilibrium constants are defined as concentration constants, however, they have the disadvantage to change with changing ionic strength and therefore may only be used in systems of the same ionic strength in which they were determined. If they are expressed as activities, the equilibrium constants are activity constants. These are true constants that hold for solutions of any ionic strength. These constants have the disadvantage that many reactants and products consist of ionic or molecular species whose activities are difficult or impossible to measure. The data in Table 1 are for an assumed zero ionic strength.

Ionic Strength

Ionic strength (μ) is defined as:

$$\mu = \tfrac{1}{2} \sum_i C_i Z_i^2$$

where C_i is the concentration in $mol \cdot L^{-1}$ of an ion i, Z_i is the valency of that ion. (A convenient and direct way of estimating the ionic strength of a solution is to measure its electrical conductivity. Griffin and Jurinak /58/ defined the following empirical relationship:

$$\mu = 0.013\ EC$$

where EC is the electrical conductivity expressed in $mS \cdot cm^{-2}$).

Activity Coefficients

Only in infinitely dilute solutions are activities and concentrations equal. The ratio of the activity of an ion i, a_i, to its concentration, c_i, is defined as the activity coefficient, γ_i:

$$\gamma_i = \frac{a_i}{c_i}$$

These activity coefficients can be estimated using different equations. Up to an ionic strength of about 0.001M, the simple Debye-Hückel relation gives a good approximation of the actual activity coefficients:

$$\log\gamma_i = -A Z_i^2 \mu^{1/2}$$

where A is the molal Debye-Hückel parameter which is a function of the density, the dielectric constant and the temperature of the water.

By extending the Debye-Hückel equation to account for the effective size of the hydrated ions, a more precise relation is obtained which holds up to ionic strengths of about 0.2M:

$$\log\gamma_i = -A Z_i^2 \frac{\mu^{1/2}}{1 + B d_i \mu^{1/2}}$$

where A and B are the molal Debye-Hückel parameters and d_i is the effective distance of closest approach in cm. Values for A and B are again dependent upon the density, the dielectric constant and the temperature of the water. Values for the molal Debye-Hückel parameters A and B for temperatures from 25 to 300°C can be found in Table 3 /59/. Values of d_i for selected ions, were calculated by Kielland /60/ and can be found in Table 4. They do not change appreciably with temperature. If d_i is unknown for a certain species, Guntelberg suggested to use a value of $3 \cdot 10^{-8}$ cm. The extended Debye-Hückel equation gives values for γ_i that are often too small for many electrolytes. Therefore Davies /61/ proposed the following equation:

$$\log\gamma_i = -A Z_i^2 \frac{\mu^{1/2}}{1 + \mu^{1/2}} - 0.3\mu$$

This relation is often used in preference to the extended Debye-Hückel equation because it is more amenable for computer use. Table 5 gives single ion activity coefficients for 25°C, calculated from the extended Debye-Hückel relation /19/.

INFLUENCE ON THE TEMPERATURE

The data, given in Table 1, are only valid for a temperature of 25°C and at atmospheric pressure. The pressure dependence of hydrothermal equilibria is negligible below 300°C /10/ and, therefore, will not be considered in the present work. The influence of a different temperature can be taken into account as follows.

The basic thermodynamic equation describing the temperature dependence of an equilibrium constant (at constant pressure) is given by:

$$\log K_T = \log K_{T_0} - \frac{\Delta H^0_{T_0}}{2.303\,R}\left[\frac{1}{T} - \frac{1}{T_0}\right] -$$

$$- \frac{1}{2.303\,R\,T}\int_{T_0}^{T} \Delta C_p^0(T)\,dT + \frac{1}{2.303\,R}\int_{T_0}^{T} \frac{\Delta C_p^0(T)}{T}\,dT \quad (1)$$

with:

$\Delta H^0_{T_0}$ = standard enthalpy of a chemical reaction for the reference temperature (T_0 = 298.15 K)

$\Delta C_p^0(T)$ = heat capacity of the reaction for a temperature T.

To solve this equation, one needs values for $\Delta C_p^0(T)$, which in many cases are not available. The relation between the heat capacity and temperature is usually described by the Maier-Kelley /63/ empirical power function (2):

$$C^0_{p,i}(T) = a_i + b_i T + c_i T^{-2} + \ldots$$

where a_i, b_i and c_i are constants, characteristic for the substance i being considered. Values for a, b and c are mentioned by Naumov *et al.* /2/.

The change in heat capacity as the result of a chemical reaction is then given by:

$$\Delta C_p^0(T) = \Sigma C^0_{p,\text{products}} - \Sigma C^0_{p,\text{reactants}}$$

or

$$\Delta C_p^0(T) = \Delta a + \Delta b T + \Delta c T^{-2} + \ldots$$

For the conversion of enthalpy and entropy from one temperature to another, one can write:

TABLE 3. Molal values of the Debye-Hückel electrostatic parameters A and B. The values of the dielectric constant ϵ /65/ and density ρ /66/ of water employed in the calculations.

Temperature	A	B 10^{-3}	ϵ_{H_2O}	ρ_{H_2O}
25	0.5095	0.3284	78.420	0.9968
30	0.5144	0.3292	76.618	0.9956
40	0.5244	0.3310	73.125	0.9919
50	0.5354	0.3329	69.800	0.9882
60	0.5471	0.3347	66.629	0.9833
70	0.5596	0.3366	63.604	0.9779
80	0.5729	0.3386	60.718	0.9720
90	0.5871	0.3406	57.965	0.9656
100	0.6019	0.3425	55.336	0.9580
110	0.6180	0.3447	52.826	0.9512
120	0.6347	0.3468	50.427	0.9428
130	0.6525	0.3490	48.134	0.9346
140	0.6715	0.3512	45.939	0.9259
150	0.6915	0.3536	43.838	0.9169
160	0.7129	0.3559	41.824	0.9076
170	0.7354	0.3583	39.891	0.8974
180	0.7595	0.3608	38.033	0.8870
190	0.7851	0.3632	36.244	0.8758
200	0.8127	0.3659	34.519	0.8645
210	0.8427	0.3686	32.852	0.8530
220	0.8746	0.3714	31.238	0.8401
230	0.9099	0.3744	29.671	0.8274
240	0.9484	0.3775	28.145	0.8140
250	0.9907	0.3807	26.655	0.7993
260	1.0385	0.3845	25.196	0.7852
270	1.0905	0.3879	23.762	0.7679
280	1.1502	0.3919	22.347	0.7506
290	1.2185	0.3962	20.947	0.7321
300	1.2979	0.4010	19.557	0.7126

TABLE 4. Values for the effective distance of closest approach, d_i, in cm, after Kielland /60/.

$10^8 d_i$	
	inorganic ions: charge 1
9.	H^+
6.	Li^+
4. - 4.5	Na^+, $CdCl^+$, ClO_2^-, IO_3^-, HCO_3^-, $H_2PO_4^-$, HSO_3^-, $H_2AsO_4^-$
3.5	OH^-, F^-, NCO^-, HS^-, ClO_3^-, ClO_4^-, BrO_3^-, IO_4^-, MnO_4^-, NCS^-
3.	K^+, Cl^-, Br^-, I^-, CN^-, NO_2^-, NO_3^-
2.5	Rb^+, Cs^+, NH_4^+, Tl^+, Ag^+
	inorganic ions: charge 2
8.	Mg^{2+}, Be^{2+}
6.	Ca^{2+}, Cu^{2+}, Zn^{2+}, Sn^{2+}, Mn^{2+}, Fe^{2+}, Ni^{2+}, Co^{2+}
5.	Sr^{2+}, Ba^{2+}, Ra^{2+}, Cd^{2+}, Hg^{2+}, S^{2-}, $S_2O_4^{2-}$, WO_4^{2-}
4.5	Pb^{2+}, CO_3^{2-}, SO_3^{2-}, MoO_4^{2-}, $Co(NH_3)Cl_5^{2-}$, $Fe(CN)_5NO^{2-}$
4.	Hg_2^{2+}, SO_4^{2-}, $S_2O_3^{2-}$, $S_2O_8^{2-}$, SeO_4^{2-}, CrO_4^{2-}, $S_2O_6^{2-}$, HPO_4^{2-}
	inorganic ions: charge 3
9.	Al^{3+}, Fe^{3+}, Cr^{3+}, Se^{3+}, Y^{3+}, La^{3+}, In^{3+}, Ce^{3+}, Pr^{3+}, Nd^{3+}, Sm^{3+}
4.	PO_4^{3-}, $Fe(CN)_6^{3-}$, $Cr(NH_3)_6^{3+}$, $Co(NH_3)_6^{3+}$, $Co(NH_3)_5.H_2O^{3+}$
	inorganic ions: charge 4
11.	Th^{4+}, Zr^{4+}, Ce^{4+}, Sn^{4+}
6.	$Co(S_2O_3)(CN)_5^{4-}$
5.	$Fe(CN)_6^{4-}$
	inorganic ions: charge 5
9.	$Co(SO_3)_2(CN)_4^{5-}$

TABLE 5. Single ion activity coefficients calculated from the extended Debye-Hückel relation, after Lindsay /19/.

	Ionic strength (μ)							
d_i	0.001	0.0025	0.005	0.010	0.025	0.030	0.050	0.100
	Ionic charge 1							
9.	0.967	0.950	0.934	0.914	0.881	0.874	0.854	0.826
8.	0.966	0.950	0.933	0.911	0.877	0.870	0.848	0.817
7.	0.966	0.949	0.931	0.909	0.873	0.865	0.841	0.807
6.	0.966	0.948	0.930	0.907	0.868	0.860	0.834	0.796
5.	0.965	0.947	0.928	0.904	0.863	0.854	0.826	0.783
4.	0.965	0.946	0.927	0.902	0.858	0.848	0.817	0.770
3.	0.965	0.946	0.925	0.899	0.852	0.841	0.807	0.754
	Ionic charge 2							
8.	0.872	0.813	0.756	0.690	0.592	0.572	0.517	0.445
7.	0.871	0.810	0.752	0.683	0.581	0.559	0.500	0.424
6.	0.870	0.808	0.748	0.676	0.568	0.546	0.483	0.401
5.	0.869	0.805	0.743	0.668	0.555	0.531	0.464	0.377
4.	0.867	0.803	0.738	0.661	0.541	0.516	0.445	0.351
	Ionic charge 3							
9.	0.737	0.632	0.540	0.443	0.321	0.299	0.242	0.178
6.	0.731	0.619	0.520	0.414	0.280	0.256	0.194	0.128
5.	0.728	0.614	0.513	0.404	0.266	0.241	0.178	0.111
4.	0.726	0.610	0.505	0.394	0.251	0.226	0.161	0.095
	Ionic charge 4							
11.	0.587	0.452	0.348	0.252	0.151	0.135	0.098	0.063
6.	0.572	0.426	0.312	0.209	0.104	0.089	0.054	0.026
5.	0.569	0.420	0.305	0.200	0.095	0.080	0.047	0.020

$$\Delta H_T^0 = \Delta aT + 0.5\Delta bT^2 - \Delta cT^{-1} + x$$

$$\Delta S_T^0 = \Delta a \ln T + \Delta bT - 0.5\Delta cT^{-2} + y$$

where x and y are integration constants that can be calculated knowing ΔH^0 and ΔS^0 for any single temperature (for instance 298.15 K). Hence:

$$\Delta G_T^0 = \Delta H_T^0 - T\Delta S_T^0$$

$$= x + (\Delta a - y)T - \Delta aT \ln T - 0.5\Delta bT^2 - 0.5\Delta cT^{-1}$$

and

$$\log K_T = \frac{-\Delta G_T^0}{2.303\,RT} \tag{2}$$

In the absence of individual heat capacity data or heat capacity power functions, one often uses the integrated form of the Van't Hoff equation:

$$\log K_T = \log K_{T_0} - \frac{\Delta H_{T_0}^0}{2.303\,R}\left[\frac{1}{T} - \frac{1}{T_0}\right] \tag{3}$$

which assumes ΔH^0 to be independent of temperature (equivalent to state $\Delta C_p^0(T)$ is zero in equation (1)).

The assumption that $\Delta C_p^0(T)$ is constant, is usually far superior to assuming that it is zero. Equation (1) then becomes:

$$\log K_T = \log K_{T_0} - \frac{\Delta H_{T_0}^0}{2.303\,R}\left[\frac{1}{T} - \frac{1}{T_0}\right] +$$

$$+ \frac{\Delta C_p^0}{R}\left\{\frac{1}{2.303}\left[\frac{T_0}{T} - 1\right] + \log\frac{T}{T_0}\right\} \tag{4}$$

Equilibrium constants for a number of solids and aqueous species are known experimentally over a limited temperature range. Assuming that ΔH_T^0 is a linear function of temperature, one can solve equation (4) for ΔC_p^0 over that temperature interval, and then re-enter this value (constant ΔC_p^0) to calculate logK at higher temperatures.

Errors introduced by the assumption that ΔC_p^0 is zero (equation (3)), depend on the relative sizes of the enthalpy and heat capacity

terms. If $\Delta C_p^\circ(T)$ is insignificantly small as compared to $\Delta H_{T_0}^\circ$, a fair agreement is expected between estimated and true values of $\log K_T$ at elevated temperatures. When the standard enthalpy is smaller than about 8 kJ (e.g. some aqueous complexes such as sulfates), the $\Delta C_p^\circ(T)$ is zero assumption commonly introduces serious errors which increase with increasing temperature.

The assumption that $\Delta C_p^\circ(T)$ is a constant may also lead to errors. Indeed, tabulated dissociation or equilibrium constants in the literature may differ seriously, resulting in divergent ΔC_p° values and consequently erratic $\log K_T$ values. Ambiguities and uncertainties, resulting from the assumptions $\Delta C_p^\circ(T)$ is zero or constant (especially when dealing with high temperatures ($> 200°C$)), can be avoided by adapting one of the following approaches:

(1) Prediction of dissociation constants when no heat capacity data of any kind (products, reactants) are available; despite this handicap, dissociation constants often can be closely approximated up to $\cong 200°C$ by evaluating /37/:

$$\log K_T = \frac{\Delta S_{T_0}^\circ}{2.303\,R\,T}\left\{T_0 - \frac{\theta}{\omega}\left[1 - \exp(\exp(b + aT) - c + \right.\right.$$

$$\left.\left. + (T - T_0)/\theta)\right]\right\} - \frac{\Delta H_{T_0}^\circ}{2.303\,R\,T} \qquad (5)$$

where θ, ω, a, b and c are temperature independent constants characteristic of the solvent; for aqueous solutions, they have values 219.0, 1.00322, 0.01875, −12.741 and 7.84×10^{-4} respectively. Equation (5) can be rewritten as:

$$\log K_T = \frac{0.05223}{T}\left(X\,\Delta S_{T_0}^\circ - \Delta H_{T_0}^\circ\right)$$

with X: variable dependent upon temperature: 298.15 (298.15 K), 388.05 (373.15 K) and 451.14 (413.15 K) and with $\Delta H_{T_0}^\circ$ and $\Delta S_{T_0}^\circ$ and R expressed in $kJ \cdot mol^{-1}$, $J \cdot mol^{-1} \cdot K^{-1}$ and $J \cdot mol^{-1} \cdot K^{-1}$ respectively.

(2) Calculation from average heat capacities.

(3) Calculation from a combination of actual and average heat capacities. The alternative $\log K_T$ computations for higher temperatures are described by Helgeson /10, 37/.

We prefer to use equations (2) and (3) for calculating $\log K_T$ values. In Fig. 1, we plotted for several sulfide compounds and for some sulfur complexes, the available solubility products K_{s_0}: $\log K_{413.15}$ data versus $\log K_{298.15}$. Data were taken from Naumov *et al.* /2/ and Helgeson /10/. The slope of the curve (obtained by best fit through all the points) can be calculated as follows. For an MS or M_2S_3 compound (M = metal ion), one can write for $\log K_{413.15}$ according to equation (3):

$$\log \frac{K_{298.15}}{K_{413.15}} = \frac{\Delta H^0_{298.15}}{2.303\,R} \left[\frac{1}{413.15} - \frac{1}{298.15} \right]$$

The slope between NiS and ZnS, for instance, will be given by $\Delta y/\Delta x$ with:

$$\Delta x = \log K^1_{298.15} - \log K^2_{298.15}$$

where 1 and 2 refer to NiS and ZnS respectively; and with:

$$\Delta y = \log K^1_{298.15} - \frac{\Delta H^{0\,1}_{298.15}}{2.303\,R} \left[\frac{1}{413.15} - \frac{1}{298.15} \right] -$$

$$- \log K^2_{298.15} + \frac{\Delta H^{0\,2}_{298.15}}{2.303\,R} \left[\frac{1}{413.15} - \frac{1}{298.15} \right] =$$

$$= \log K^1_{298.15} - \log K^2_{298.15} +$$

$$+ \left[\frac{1}{2.303\,R} \left(\frac{1}{413.15} - \frac{1}{298.15} \right) (\Delta H^{0\,2}_{298.15} - \Delta H^{0\,1}_{298.15}) \right]$$

Hence:

$$\frac{\Delta y}{\Delta x} = 1 - 2.040 \times 10^{-4} \left[\frac{\Delta H^{0\,2}_{298.15} - \Delta H^{0\,1}_{298.15}}{\log K^1_{298.15} - \log K^2_{298.15}} \right] \qquad (6)$$

For the couple NiS-ZnS, with $\Delta H^0_{298.15}$ (NiS) = 61.13 kJ · mol^{-1} and with $\log K_{298.15}$ (NiS) = –21.0 and $\Delta H^0_{298.15}$ (ZnS) = 87.80 kJ · mol^{-1} and $\log K_{298.15}$ (ZnS) = –24.9 for the following reactions:

$$NiS(s) \rightleftharpoons Ni^{2+} + S^{2-}$$

$$ZnS(s) \rightleftharpoons Zn^{2+} + S^{2-}$$

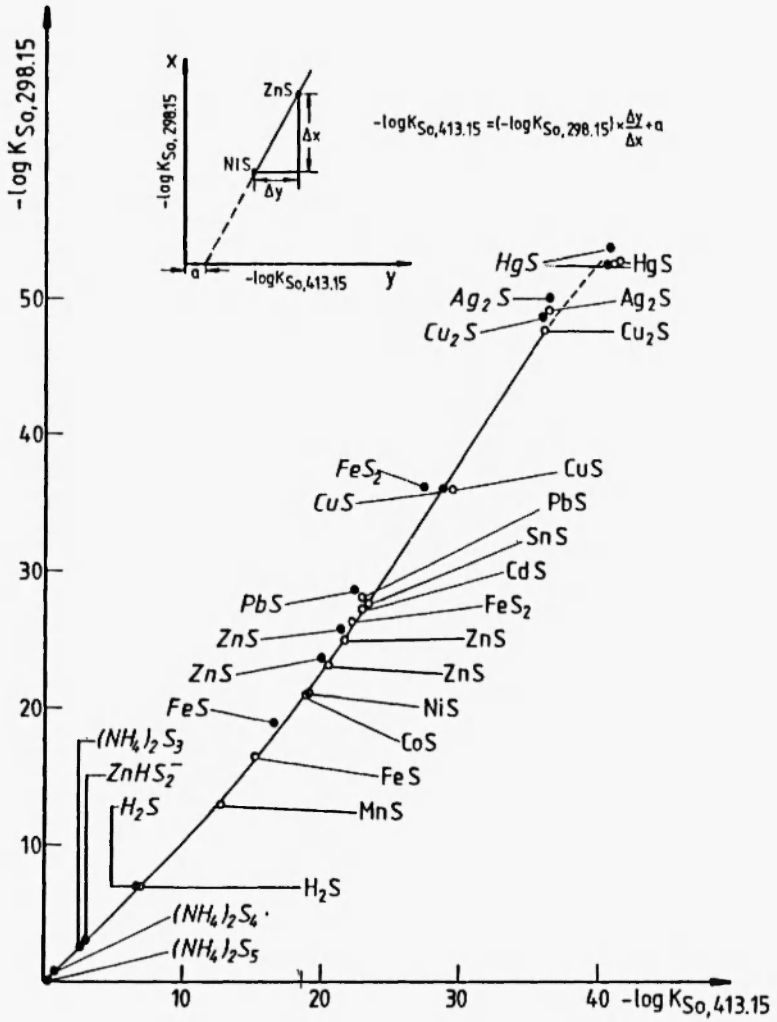

Fig. 1. Relation between log K_{S_0} at 298.15 and 413.15 K for some sulfide compounds. ○ data from Naumov et al. /2/. ● data from Helgeson /10/.

we obtain a slope of 0.666. It appears that a fair agreement (except for FeS and CoS) is found between slope values calculated by means of equation (6) and equation (2). For oxides, hydroxides, fluorides, . . . similar figures can be drawn.

Data for $\Delta H^0_{298.15}$ can be found in the NBS technical notes /1/, Naumov *et al.* /2/, Robie *et al.* /6/, Sillen and Martell /9/, Helgeson /10/, and Karapet'yants and Karapet'yants /11/.

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