# *Aquatic Chemistry*

## An Introduction Emphasizing Chemical Equilibria in Natural Waters

**WERNER STUMM**

*Professor, Swiss Federal Institute of Technology, Zurich*

**JAMES J. MORGAN**

*Professor of Environmental Engineering Science*
*California Institute of Technology*

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# *Appendix: Thermodynamic Properties; Table of $G_f^\circ$, $H_f^\circ$, and $\bar{S}^\circ$ Values for Common Chemical Species in Aquatic Systems*[a]

Valid at 25°C, 1 atm Pressure and Standard States[b]

| Species | Formation from the Elements | | Entropy | Reference[c] |
|---|---|---|---|---|
| | $G_f^0$ (kJ mol$^{-1}$) | $H_f^0$ (kJ mol$^{-1}$) | $\bar{S}^0$ J mol$^{-1}$ K$^{-1}$ | |
| **Ag (Silver)** | | | | |
| Ag (metal) | 0 | 0 | 42.6 | NBS |
| $Ag^+$(aq) | 77.12 | 105.6 | 73.4 | NBS |
| AgBr | −96.9 | −100.6 | 107 | NBS |
| AgCl | −109.8 | −127.1 | 96 | NBS |
| AgI | −66.2 | −61.84 | 115 | NBS |
| $Ag_2S(\alpha)$ | −40.7 | −29.4 | 14 | NBS |
| AgOH(aq) | −92 | — | — | NBS |
| $Ag(OH)_2^-$(aq) | −260.2 | — | — | NBS |
| AgCl(aq) | −72.8 | −72.8 | 154 | NBS |
| $AgCl_2^-$(aq) | −215.5 | −245.2 | 231 | NBS |
| **Al (Aluminum)** | | | | |
| Al | 0 | 0 | 28.3 | R |
| $Al^{3+}$(aq) | −489.4 | −531.0 | −308 | R |
| $AlOH^{2+}$(aq) | −698 | — | — | S |
| $Al(OH)_2^+$(aq) | −911 | — | — | S |
| $Al(OH)_3$(aq) | −1115 | — | — | S |
| $Al(OH)_4^-$(aq) | −1325 | — | — | S |
| $Al(OH)_3$ (amorph) | −1139 | — | — | R |
| $Al_2O_3$ (corundum) | −1582 | −1676 | 50.9 | R |
| AlOOH (boehmite) | −922 | −1000 | 17.8 | R |
| $Al(OH)_3$ (gibbsite) | −1155 | −1293 | 68.4 | R |
| $Al_2Si_2(OH)_4$ (kaolinite) | −3799 | −4120 | 203 | R |
| $KAl_3Si_3O_{10}(OH)_2$ (muscovite) | −1341 | — | — | G |

| | | | | |
|---|---|---|---|---|
| $Mg_5Al_2Si_3O_{10}(OH)_8$ (chlorite) | −1962 | — | — | R |
| $CaAl_2Si_2O_8$ (anorthite) | −4017.3 | −4243.0 | 199 | R |
| $NaAlSiO_3O_8$ (albite) | −3711.7 | −3935.1 | — | R |
| **As (Arsenic)** | | | | |
| As (α metal) | 0 | 0 | 35.1 | NBS |
| $H_3AsO_4$(aq) | −766.0 | −898.7 | 206 | NBS |
| $H_2AsO_4^-$(aq) | −748.5 | −904.5 | 117 | NBS |
| $HAsO_4^{2-}$(aq) | −707.1 | −898.7 | 3.8 | NBS |
| $AsO_4^{3-}$(aq) | −636.0 | −870.3 | −145 | NBS |
| $H_2AsO_3^-$(aq) | −587.4 | | | NBS |
| **Ba (Barium)** | | | | |
| $Ba^{2+}$(aq) | −560.7 | −537.6 | 9.6 | R |
| $BaSO_4$ (barite) | −1362 | −1473 | 132 | R |
| $BaCO_3$ (witherite) | −1132 | −1211 | 112 | R |
| **Be (Beryllium)** | | | | |
| $Be^{2+}$(aq) | −380 | −382 | −130 | NBS |
| $Be(OH)_2$(α) | −815.0 | −902 | 51.9 | NBS |
| $Be_3(OH)_3^{3+}$ | −1802 | — | — | NBS |
| **B (Boron)** | | | | |
| $H_3BO_3$(aq) | −968.7 | −1072 | 162 | NBS |
| $B(OH)_4^-$(aq) | −1153.3 | −1344 | 102 | NBS |
| **Br (Bromide)** | | | | |
| $Br_2$(l) | 0 | 0 | 152 | NBS |
| $Br_2$(aq) | 3.93 | −2.59 | 130.5 | NBS |
| $Br^-$(aq) | −104.0 | −121.5 | 82.4 | NBS |
| HBrO(aq) | −82.2 | −113.0 | 147 | NBS |
| $BrO^-$(aq) | −33.5 | −94.1 | 42 | NBS |
| **C (Carbon)** | | | | |
| C (graphite) | 0 | 0 | 152 | NBS |
| C( diamond) | 3.93 | −2.59 | 130.5 | NBS |
| $CO_2$(g) | −394.37 | −393.5 | 213.6 | NBS |
| $H_2CO_3^*$(aq) | −623.2 | −699.7 | 187.0 | R |
| $H_2CO_3$(aq) ("true") | ~ − 607.1 | — | — | S |
| $HCO_3^-$(aq) | −586.8 | −692.0 | 91.2 | S |
| $CO_3^{2-}$(aq) | −527.9 | −677.1 | −56.9 | NBS |
| $CH_4$(g) | −50.75 | −74.80 | 186 | NBS |
| $CH_4$(aq) | −34.39 | −89.04 | 83.7 | NBS |
| $CH_3OH$(aq) | −175.4 | −245.9 | 133 | NBS |
| HCOOH(aq) | −372.3 | −425.4 | 163 | NBS |
| $HCOO^-$(aq) | −351.0 | −425.6 | 92 | NBS |
| HCN(aq) | 119.7 | 107.1 | 124.6 | NBS |
| $CN^-$(aq) | 172.4 | 150.6 | 94.1 | NBS |

| | | | | |
|---|---|---|---|---|
| $CH_3COOH(aq)$ | −396.6 | −485.8 | 179 | NBS |
| $CH_3COO^-(aq)$ | −369.4 | −486.0 | 86.6 | NBS |
| $C_2H_5OH(aq)$ | −181.8 | −288.3 | 149 | NBS |
| $NH_2CH_2COOH(aq)$ | −370.8 | −514.0 | 158 | NBS |
| $NH_2CH_2COO^-(aq)$ | −315.0 | −469.8 | 119 | NBS |
| **Ca (Calcium)** | | | | |
| $Ca^{2+}(aq)$ | −553.54 | −542.83 | −53 | R |
| $CaOH^+(aq)$ | −718.4 | — | — | NBS |
| $Ca(OH)_2(aq)$ | −868.1 | −1003 | −74.5 | NBS |
| $Ca(OH)_2$ (portlandite) | −898.4 | −986.0 | 83 | R |
| $CaCO_3$ (calcite) | −1128.8 | −1207.4 | 91.7 | R |
| $CaCO_3$ (aragonite) | −1127.8 | −1207.4 | 88.0 | R |
| $CaMg(CO_3)_2$ (dolomite) | −2161.7 | −2324.5 | 155.2 | R |
| $CaSiO_3$ (wollastonite) | −1549.9 | −1635.2 | 82.0 | R |
| $CaSO_4$ (anhydrite) | −1321.7 | −1434.1 | 106.7 | R |
| $CaSO_4 \cdot 2H_2O$ (gypsum) | −1797.2 | −2022.6 | 194.1 | R |
| $Ca_5(PO_4)_3OH$ (hydroxyapatite) | −6338.4 | −6721.6 | 390.4 | R |
| **Cd (Cadmium)** | | | | |
| Cd ($\gamma$ metal) | | | | |
| $Cd^{2+}(aq)$ | −77.58 | −75.90 | −73.2 | R |
| $CdOH^+(aq)$ | −284.5 | | | R |
| $Cd(OH)_3^-(aq)$ | −600.8 | | | R |
| $Cd(OH)_4^{2-}(aq)$ | −758.5 | | | R |
| $Cd(OH)_2(aq)$ | −392.2 | | | R |
| CdO (s) | −228.4 | −258.1 | 54.8 | |
| $Cd(OH)_2$ (precip.) | −473.6 | −560.6 | 96.2 | R |
| $CdCl^+(aq)$ | −224.4 | −240.6 | 43.5 | R |
| $CdCl_2(aq)$ | −340.1 | −410.2 | 39.8 | R |
| $CdCl_3^-(aq)$ | −487.0 | −561.0 | 203 | R |
| $CdCO_3$ (s) | −669.4 | −750.6 | 92.5 | R |
| **Cl (Chlorine)** | | | | |
| $Cl^-(aq)$ | −131.3 | −167.2 | 56.5 | NBS |
| $Cl_2(g)$ | 0 | 0 | 223.0 | NBS |
| $Cl_2(aq)$ | 6.90 | −23.4 | 121 | NBS |
| $HClO(aq)$ | −79.9 | −120.9 | 142 | NBS |
| $ClO^-(aq)$ | −36.8 | −107.1 | 42 | NBS |
| $ClO_2(aq)$ | 117.6 | 74.9 | 173 | NBS |
| $ClO_2^-(aq)$ | 17.1 | −66.5 | 101 | NBS |
| $ClO_3^-(aq)$ | −3.35 | −99.2 | 162 | NBS |
| $ClO_4(aq)$ | −8.62 | −129.3 | 182 | NBS |
| **Co (Cobalt)** | | | | |
| Co (metal) | 0 | 0 | 30.04 | R |
| $Co^{2+}(aq)$ | −54.4 | −58.2 | −113 | R |
| $Co^{3+}$ | −134 | −92 | −305 | R |

| | | | | |
|---|---|---|---|---|
| $HCoO_2^-$(aq) | −407.5 | — | — | NBS |
| $Co(OH)_2$(aq) | −369 | −518 | 134 | NBS |
| $Co(OH)_2$ (blue precip.) | −450 | | | NBS |
| CoO | −214.2 | −237.9 | 53.0 | R |
| $Co_3O_4$ (cobalt spinel) | −725.5 | −891.2 | 102.5 | R |
| **Cr (Chromium)** | | | | |
| Cr (metal) | 0 | 0 | 23.8 | NBS |
| $Cr^{2+}$(aq) | — | −143.5 | — | NBS |
| $Cr^{3+}$(aq) | −215.5 | −256.0 | 308 | NBS |
| $Cr_2O_3$ (eskolaite) | −1053 | −1135 | 81 | R |
| $HCrO_4^-$(aq) | −764.8 | −878.2 | 184 | R |
| $CrO_4^{2-}$(aq) | −727.9 | −881.1 | 50 | R |
| $Cr_2O_7^{2-}$(aq) | −1301 | −1490 | 262 | R |
| **Cu (Copper)** | | | | |
| Cu(metal) | 0 | 0 | 33.1 | NBS |
| $Cu^+$(aq) | 50.0 | 71.7 | 40.6 | NBS |
| $Cu^{2+}$(aq) | 65.5 | 64.8 | −99.6 | NBS |
| $Cu(OH)_2$(aq) | −249.1 | −395.2 | −121 | NBS |
| $HCuO_2^-$(aq) | −258 | — | — | |
| CuS (covellite) | −53.6 | −53.1 | 66.5 | NBS |
| $Cu_2S$ (α) | −86.2 | −79.5 | 121 | NBS |
| CuO (tenorite) | −129.7 | −157.3 | 43 | NBS |
| $CuCO_3 \cdot Cu(OH)_2$ (malachite) | −893.7 | −1051.4 | 186 | NBS |
| $2CuCO_3 \cdot Cu(OH)_2$ (azurite) | | −1632 | | NBS |
| **F (Fluorine)** | | | | |
| $F_2$(g) | 0 | 0 | 202 | NBS |
| $F^-$(aq) | −278.8 | −332.6 | −13.8 | NBS |
| HF(aq) | −296.8 | 320.0 | 88.7 | NBS |
| $HF_2^-$(aq) | −578.1 | −650 | 92.5 | NBS |
| **Fe (Iron)** | | | | |
| Fe (metal) | 0 | 0 | 27.3 | NBS |
| $Fe^{2+}$(aq) | −78.87 | −89.10 | −138 | NBS |
| $FeOH^+$(aq) | −277.3 | — | — | NBS |
| $Fe^{3+}$(aq) | −4.60 | −48.5 | −316 | NBS |
| $FeOH^{2+}$(aq) | −229.4 | −324.7 | −29.2 | NBS |
| $Fe(OH)_2^+$(aq) | −438 | — | — | NBS |
| $Fe(OH)_2^-$(aq) | −659 | — | — | NBS |
| $Fe_2(OH)_2^{4+}$(aq) | −467.3 | — | — | NBS |
| $FeS_2$ (pyrite) | −160.2 | −171.5 | 52.9 | R |
| $FeS_2$ (marcasite) | −158.4 | −169.4 | 53.9 | R |
| FeO(s) | −251.1 | −272.0 | 59.8 | R |
| $Fe(OH)_2$ (precip.) | −486.6 | −569 | 87.9 | NBS |

| | | | | |
|---|---|---|---|---|
| $\alpha$-$Fe_2O_3$ (hematite)[e] | −742.7 | −824.6 | 87.4 | R |
| $Fe_3O_4$ (magnetite) | −1012.6 | −1115.7 | 146 | R |
| $\alpha$-FeOOH (goethite)[e] | −488.6 | −559.3 | 60.5 | R |
| FeOOH (amorph)[e] | −462 | — | — | S |
| $Fe(OH)_3$ (amorph)[e] | −699(−712) | | | S |
| $FeCO_3$ (siderite) | −666.7 | −737.0 | 105 | R |
| $Fe_2SiO_4$ (fayalite) | −1379.4 | −1479.3 | 148 | R |
| **H (Hydrogen)** | | | | |
| $H_2$(g) | 0 | 0 | 130.6 | NBS |
| $H_2$(aq) | 17.57 | −4.18 | 57.7 | NBS |
| $H^+$(aq) | 0 | 0 | 0 | NBS |
| $H_2O$(l) | −237.18 | −285.83 | 69.91 | NBS |
| $H_2O_2$(aq) | −134.1 | −191.1 | 144 | NBS |
| $HO_2^-$(aq) | −67.4 | −160.3 | 23.8 | NBS |
| $H_2O$(g) | −228.57 | −241.8 | 188.72 | R |
| **Hg (Mercury)** | | | | |
| Hg(l) | 0 | 0 | 76.0 | NBS |
| $Hg_2^{2+}$(aq) | 153.6 | 172.4 | 84.5 | NBS |
| $Hg^{2+}$(aq) | 164.4 | 171.0 | −32.2 | NBS |
| $Hg_2Cl_2$ (calomel) | −210.8 | 265.2 | 192.4 | NBS |
| HgO (red) | −58.5 | −90.8 | 70.3 | NBS |
| HgS (metacinnabar) | −43.3 | −46.7 | 96.2 | NBS |
| $HgI_2$ (red) | −101.7 | −105.4 | 180 | NBS |
| $HgCl^+$(aq) | −5.44 | −18.8 | 75.3 | NBS |
| $HgCl_2$(aq) | −173.2 | −216.3 | 155 | NBS |
| $HgCl_3^-$(aq) | −309.2 | −388.7 | 209 | NBS |
| $HgCl_4^{2-}$(aq) | −446.8 | −554.0 | 293 | NBS |
| $HgOH^+$(aq) | −52.3 | −84.5 | 71 | NBS |
| $Hg(OH)_2$(aq) | −274.9 | −355.2 | 142 | NBS |
| $HgO_2^-$(aq) | −190.3 | — | — | NBS |
| **I (Iodine)** | | | | |
| $I_2$ (crystal) | 0 | 0 | 116 | NBS |
| $I_2$(aq) | 16.4 | 22.6 | 137 | NBS |
| $I^-$(aq) | −51.59 | −55.19 | 111 | NBS |
| $I_3^-$(aq) | −51.5 | −51.5 | 239 | NBS |
| HIO(aq) | −99.2 | −138 | 95.4 | NBS |
| $IO^-$(aq) | −38.5 | −107.5 | −5.4 | NBS |
| $HIO_3$(aq) | −132.6 | −211.3 | 167 | NBS |
| $IO_3^-$ | −128.0 | −221.3 | 118 | NBS |
| **Mg (Magnesium)** | | | | |
| Mg (metal) | 0 | 0 | 32.7 | R |
| $Mg^{2+}$(aq) | −454.8 | −466.8 | −138 | R |
| $MgOH^+$(aq) | −626.8 | — | — | S |
| $Mg(OH)_2$(aq) | −769.4 | −926.8 | −149 | NBS |
| $Mg(OH)_2$ (brucite) | −833.5 | −924.5 | 63.2 | R |

| | | | | |
|---|---|---|---|---|
| **Mn (Manganese)** | | | | |
| Mn (metal) | 0 | 0 | 32.0 | R |
| $Mn^{2+}$(aq) | −228.0 | −220.7 | −73.6 | R |
| $Mn(OH)_2$ (precip.) | −616 | | | S |
| $Mn_3O_4$ (hausmannite) | −1281 | | | S |
| MnOOH (manganite) | −557.7 | | | S |
| $MnO_2$ (manganate) (IV) ($MnO_{1.7}$ − $MnO_2$) | −453.1 | | | S |
| $MnO_2$ (pyrolusite) | −465.1 | −520.0 | 53 | R |
| $MnCO_3$ (rhodochrosite) | −816.0 | −889.3 | 100 | R |
| MnS (albandite) | −218.1 | −213.8 | 87 | R |
| $MnSiO_3$ (rhodonite) | −1243 | −1319 | 131 | R |
| **N (Nitrogen)** | | | | |
| $N_2$(g) | 0 | 0 | 191.5 | NBS |
| $N_2O$(g) | 104.2 | 82.0 | 220 | NBS |
| $NH_3$(g) | −16.48 | −46.1 | 192 | NBS |
| $NH_3$(aq) | −26.57 | −80.29 | 111 | NBS |
| $NH_4^+$(aq) | −79.37 | −132.5 | 113.4 | NBS |
| $HNO_2$(aq) | −42.97 | −119.2 | 153 | NBS |
| $NO_2^-$(aq) | −37.2 | −104.6 | 140 | NBS |
| $HNO_3$(aq) | −111.3 | −207.3 | 146. | NBS |
| $NO_3^-$(aq) | −111.3 | −207.3 | 146.4 | NBS |
| **Ni (Nickel)** | | | | |
| $Ni^{2+}$(aq) | −45.6 | −54.0 | −129 | R |
| NiO (bunsenite) | −211.6 | −239.7 | 38 | R |
| NiS (millerite) | −86.2 | −84.9 | 66 | R |
| **O (Oxygen)** | | | | |
| $O_2$(g) | 0 | 0 | 205 | NBS |
| $O_2$(aq) | 16.32 | −11.71 | 111 | NBS |
| $O_3$(g) | 163.2 | 142.7 | 239 | NBS |
| $OH^-$(aq) | −157.3 | −230.0 | −10.75 | NBS |
| **P (Phosphorus)** | | | | |
| P (α, white) | 0 | 0 | 41.1 | |
| $PO_4^{3-}$(aq) | −1018.8 | −1277.4 | −222 | NBS |
| $HPO_4^{2-}$(aq) | −1089.3 | −1292.1 | −33.4 | NBS |
| $H_2PO_4^-$(aq) | −1130.4 | −1296.3 | 90.4 | NBS |
| $H_3PO_4$(aq) | −1142.6 | −1288.3 | 158 | NBS |
| **Pb (Lead)** | | | | |
| Pb (metal) | 0 | 0 | 64.8 | NBS |
| $Pb^{2+}$(aq) | −24.39 | −1.67 | 10.5 | NBS |
| $PbOH^+$(aq) | −226.3 | — | — | NBS |
| $Pb(OH)_3^-$(aq) | −575.7 | | | NBS |
| $Pb(OH)_2$ (precip.) | −452.2 | | | NBS |
| PbO (yellow) | −187.9 | −217.3 | 68.7 | NBS |

| | | | | |
|---|---|---|---|---|
| $PbO_2$ | −217.4 | −277.4 | 68.6 | NBS |
| $Pb_3O_4$ | −601.2 | −718.4 | 211 | NBS |
| PbS | −98.7 | −100.4 | 91.2 | NBS |
| $PbSO_4$ | −813.2 | −920.0 | 149 | NBS |
| $PbCO_3$ (cerussite) | −625.5 | −699.1 | 131 | NBS |
| **S (Sulfur)** | | | | |
| S (rhombic) | 0 | 0 | 31.8 | NBS |
| $SO_2(g)$ | −300.2 | −296.8 | 248 | NBS |
| $SO_3(g)$ | −371.1 | −395.7 | 257 | NBS |
| $H_2S(g)$ | −33.56 | −20.63 | 205.7 | NBS |
| $H_2S(aq)$ | −27.87 | −39.75 | 121.3 | NBS |
| $S^{2-}(aq)$ | 85.8 | 33.0 | −14.6 | NBS |
| $HS^-(aq)$ | 12.05 | −17.6 | 62.8 | NBS |
| $SO_3^{2-}(aq)$ | −486.6 | −635.5 | −29 | NBS |
| $HSO_3^-(aq)$ | −527.8 | −626.2 | 140 | NBS |
| $H_2SO_3^*(aq)$ | −537.9 | −608.8 | 232 | NBS[f] |
| $SO_4^{2-}(aq)$ | −744.6 | −909.2 | 20.1 | NBS |
| $HSO_4^-(aq)$ | −756.0 | −887.3 | 132 | NBS |
| **Se (Selenium)** | | | | |
| Se (black) | 0 | 0 | 42.4 | NBS |
| $SeO_3^{2-}(aq)$ | −369.9 | −509.2 | 12.6 | NBS |
| $HSeO_3^-(aq)$ | −431.5 | −514.5 | 135 | NBS |
| $H_2SeO_3(aq)$ | −426.2 | −507.5 | 208 | NBS |
| $SeO_4^{2-}(aq)$ | −441.4 | −599.1 | 54.0 | NBS |
| $HSeO_4^-(aq)$ | −452.3 | −581.6 | 149 | NBS |
| **Si (Silicon)** | | | | |
| Si (metal) | 0 | 0 | 18.8 | NBS |
| $SiO_2$ (α, quartz) | −856.67 | −910.94 | 41.8 | NBS |
| $SiO_2$ (α, cristobalite) | −855.88 | −909.48 | 42.7 | NBS |
| $SiO_2$ (α, tridymite) | −855.29 | −909.06 | 43.5 | NBS |
| $SiO_2$ (amorph) | −850.73 | −903.49 | 46.9 | NBS |
| $H_4SiO_4(aq)$ | −1316.7 | −1468.6 | 180 | NBS |
| **Sr (Strontium)** | | | | |
| $Sr^{2+}(aq)$ | −559.4 | −545.8 | −33 | R |
| $SrOH^+(aq)$ | −721 | — | — | NBS |
| $SrCO_3$ (strontianite) | −1137.6 | −1218.7 | 97 | R |
| $SrSO_4$ (celestite) | −1341.0 | −1453.2 | 118 | R |
| **Zn (Zinc)** | | | | |
| Zn, metal | 0 | 0 | 29.3 | NBS |
| $Zn^{2+}(aq)$ | −147.0 | −153.9 | 112 | NBS |
| $ZnOH^+(aq)$ | −330.1 | | | NBS |
| $Zn(OH)_2(aq)$ | −522.3 | | | NBS |
| $Zn(OH)_3^-(aq)$ | −694.3 | | | NBS |
| $Zn(OH)_4^{2-}(aq)$ | −858.7 | | | NBS |

| | | | | |
|---|---|---|---|---|
| $Zn(OH)_2$ (solid $\beta$) | −553.2 | −641.9 | 81.2 | R |
| $ZnCl^+$(aq) | −275.3 | | | NBS |
| $ZnCl_2$(aq) | −403.8 | | | NBS |
| $ZnCl_3^-$(aq) | −540.6 | | | NBS |
| $ZnCl_4^{2-}$(aq) | −666.1 | | | S |
| $ZnCO_3$ (smithsonite) | −731.6 | −812.8 | 82.4 | NBS |

[a] The quality of the data is highly variable; the authors do not claim to have critically selected the "best" data. For information on precision of the data and for a more complete compendium which includes less common substances, the reader is referred to the references. For research work, the original literature should be consulted.

[b] Thermodynamic properties taken from Robie, Hemingway, and Fisher are based on a reference state of the elements in their standard states at 1 bar ($10^5$ P = 0.987 atm). This change in reference pressure has a negligible effect upon the tabulated values for the condensed phases. [For gas phases only data from NBS (reference state = 1 atm) are given].

[c] NBS: D. D. Wagman et al., Selected Values of Chemical Thermodynamic Properties, U.S. National Bureau of Standards, Technical Notes 270–3 (1968), 270–4 (1969), 270–5 (1971). R: R. A. Robie, B. S. Hemingway, and J. R. Fisher, *Thermodynamic Properties of Minerals and Related Substances at 298.15 K and 1 Bar ($10^5$ Pascals) Pressure and at Higher Temperatures*, Geological Survey Bulletin No. 1452, Washington D.C., 1978. S: Other sources (e.g., computed from data in *Stability Constants*).

[d] $[H_2CO_3^*] = CO_2(aq)$ + "true" $[H_2CO_3]$.

[e] The thermodynamic stability of oxides, hydroxides, or oxyhydroxides of Fe(III) depends on mode of preparation, age, and molar surface. Reported solubility products ($K_{s0}$ = $\{Fe^{3+}\}\{OH^-\}^3$) range from $10^{-37.3}$ to $10^{-43.7}$. Correspondingly FeOOH may have $G_f^0$ values between −452 J $mol^{-1}$ (freshly precipitated amorphous FeOOH) and −489 J $mol^{-1}$ (aged goethite). If the precipitate is written as $Fe(OH)_3$, its $G_f^\circ$ values vary from −692 to −729 J $mol^{-1}$. (See also Figure 5.23*b*).

[f] $[H_2SO_3^*] = [SO_2(aq)]$ + "true" $[H_2SO_3]$.