APPENDIX 2

# Thermodynamic Data at 1 atm and 25°C*



| Inorganic Substances | | | |
|---|---|---|---|
| Substance | $\Delta H_f^o$ (kJ/mol) | $\Delta G_f^o$ (kJ/mol) | $S^\circ$ (J/K · mol) |
| $Ag(s)$ | 0 | 0 | 42.7 |
| $Ag^+(aq)$ | 105.9 | 77.1 | 73.9 |
| $AgCl(s)$ | −127.0 | −109.7 | 96.1 |
| $AgBr(s)$ | −99.5 | −95.9 | 107.1 |
| $AgI(s)$ | −62.4 | −66.3 | 114.2 |
| $AgNO_3(s)$ | −123.1 | −32.2 | 140.9 |
| $Al(s)$ | 0 | 0 | 28.3 |
| $Al^{3+}(aq)$ | −524.7 | −481.2 | −313.38 |
| $AlCl_3(s)$ | −705.6 | −630.0 | 109.3 |
| $Al_2O_3(s)$ | −1669.8 | −1576.4 | 50.99 |
| $As(s)$ | 0 | 0 | 35.15 |
| $AsO_4^{3-}(aq)$ | −870.3 | −635.97 | −144.77 |
| $AsH_3(g)$ | 171.5 | | |
| $H_3AsO_4(s)$ | −900.4 | | |
| $Au(s)$ | 0 | 0 | 47.7 |
| $Au_2O_3(s)$ | 80.8 | 163.2 | 125.5 |

| | | | |
|---|---|---|---|
| AuCl(*s*) | −35.2 | | |
| $AuCl_3$ (*s*) | −118.4 | | |
| B(*s*) | 0 | 0 | 6.5 |
| $B_2O_3$ (*s*) | −1263.6 | −1184.1 | 54.0 |
| $H_3BO_3$ (*s*) | −1087.9 | −963.16 | 89.58 |
| $H_3BO_3$ (*aq*) | −1067.8 | −963.3 | 159.8 |
| Ba(*s*) | 0 | 0 | 66.9 |
| $Ba^{2+}$ (*aq*) | −538.4 | −560.66 | 12.55 |
| BaO(*s*) | −558.2 | −528.4 | 70.3 |
| $BaCl_2$ (*s*) | −860.1 | −810.66 | 125.5 |
| $BaSO_4$ (*s*) | −1464.4 | −1353.1 | 132.2 |
| $BaCO_3$ (*s*) | −1218.8 | −1138.9 | 112.1 |
| Be(*s*) | 0 | 0 | 9.5 |
| BeO(*s*) | −610.9 | −581.58 | 14.1 |
| $Br_2$ (*l*) | 0 | 0 | 152.3 |
| $Br_2$ (*g*) | 30.91 | 3.11 | 245.3 |
| $Br^-$ (*aq*) | −120.9 | −102.8 | 80.7 |
| HBr(*g*) | −36.2 | −53.2 | 198.48 |
| C(graphite) | 0 | 0 | 5.69 |
| C(diamond) | 1.90 | 2.87 | 2.4 |
| CO(*g*) | −110.5 | −137.3 | 197.9 |
| $CO_2$ (*g*) | −393.5 | −394.4 | 213.6 |
| $CO_2$ (*aq*) | −412.9 | −386.2 | 121.3 |
| $CO_3^{2-}$ (*aq*) | −676.3 | −528.1 | −53.1 |
| $HCO_3^-$ (*aq*) | −691.1 | −587.1 | 94.98 |
| $H_2CO_3$ (*aq*) | −699.7 | −623.2 | 187.4 |
| $CS_2$ (*g*) | 115.3 | 65.1 | 237.8 |
| $CS_2$ (*l*) | 87.3 | 63.6 | 151.0 |

| | | | |
|---|---|---|---|
| $HCN(aq)$ | 105.4 | 112.1 | 128.9 |
| $CN^-\ (aq)$ | 151.0 | 165.69 | 117.99 |
| $(NH_2)_2CO\ (s)$ | −333.19 | −197.15 | 104.6 |
| $(NH_2)_2CO\ (aq)$ | −319.2 | −203.84 | 173.85 |
| $Ca(s)$ | 0 | 0 | 41.6 |
| $Ca^{2+}\ (aq)$ | −542.96 | −553.0 | −55.2 |
| $CaO(s)$ | −635.6 | −604.2 | 39.8 |
| $Ca(OH)_2\ (s)$ | −986.6 | −896.8 | 83.4 |
| $CaF_2\ (s)$ | −1214.6 | −1161.9 | 68.87 |
| $CaCl_2\ (s)$ | −794.96 | −750.19 | 113.8 |
| $CaSO_4\ (s)$ | −1432.69 | −1320.3 | 106.69 |
| $CaCO_3\ (s)$ | −1206.9 | −1128.8 | 92.9 |
| $Cd(s)$ | 0 | 0 | 51.46 |
| $Cd^{2+}\ (aq)$ | −72.38 | −77.7 | −61.09 |
| $CdO(s)$ | −254.6 | −225.06 | 54.8 |
| $CdCl_2\ (s)$ | −389.1 | −342.59 | 118.4 |
| $CdSO_4\ (s)$ | −926.17 | −820.2 | 137.2 |
| $Cl_2\ (g)$ | 0 | 0 | 223.0 |
| $Cl^-\ (aq)$ | −167.2 | −131.2 | 56.5 |
| $HCl(g)$ | −92.3 | −95.27 | 187.0 |
| $Co(s)$ | 0 | 0 | 28.45 |
| $Co^{2+}\ (aq)$ | −67.36 | −51.46 | 155.2 |
| $CoO(s)$ | −239.3 | −213.38 | 43.9 |
| $Cr(s)$ | 0 | 0 | 23.77 |
| $Cr^{2+}\ (aq)$ | −138.9 | | |
| $Cr_2O_3\ (s)$ | −1128.4 | −1046.8 | 81.17 |
| $CrO_4^{2-}\ (aq)$ | −863.16 | −706.26 | 38.49 |

| | | | |
|---|---|---|---|
| $Cr_2O_3$ (*s*) | −1128.4 | −1046.8 | 81.17 |
| $CrO_4^{2-}$ (*aq*) | −863.16 | −706.26 | 38.49 |
| $Cr_2O_7^{2-}$ (*aq*) | −1460.6 | −1257.29 | 213.8 |
| Cs(*s*) | 0 | 0 | 82.8 |
| $Cs^+$ (*aq*) | −247.69 | −282.0 | 133.05 |
| Cu(*s*) | 0 | 0 | 33.3 |
| $Cu^+$ (*aq*) | 51.88 | 50.2 | −26.4 |
| $Cu^{2+}$ (*aq*) | 64.39 | 64.98 | −99.6 |
| CuO(*s*) | −155.2 | −127.2 | 43.5 |
| $Cu_2O$ (*s*) | −166.69 | −146.36 | 100.8 |
| CuCl(*s*) | −134.7 | −118.8 | 91.6 |
| $CuCl_2$ (*s*) | −205.85 | ? | ? |
| CuS(*s*) | −48.5 | −49.0 | 66.5 |
| $CuSO_4$ (*s*) | −769.86 | −661.9 | 113.39 |
| $F_2$ (*g*) | 0 | 0 | 203.34 |
| $F^-$ (*aq*) | −329.1 | −276.48 | −9.6 |
| HF(*g*) | −271.6 | −270.7 | 173.5 |
| Fe(*s*) | 0 | 0 | 27.2 |
| $Fe^{2+}$ (*aq*) | −87.86 | −84.9 | −113.39 |
| $Fe^{3+}$ (*aq*) | −47.7 | −10.5 | −293.3 |
| $FeCl_3$ (*s*) | −400 | −334 | 142.3 |
| FeO(*s*) | −272.0 | −255.2 | 60.8 |
| $Fe_2O_3$ (*s*) | −822.2 | −741.0 | 90.0 |
| $Fe(OH)_2$ (*s*) | −568.19 | −483.55 | 79.5 |
| $Fe(OH)_3$ (*s*) | −824.25 | ? | ? |
| H(*g*) | 218.2 | 203.2 | 114.6 |
| $H_2$ (*g*) | 0 | 0 | 131.0 |

| | | | |
|---|---|---|---|
| $H_2$ (g) | 0 | 0 | 131.0 |
| $H^+$ (*aq*) | 0 | 0 | 0 |
| $OH^-$ (*aq*) | −229.94 | −157.30 | −10.5 |
| $H_2O$ (*l*) | −285.8 | −237.2 | 69.9 |
| $H_2O$ (*g*) | −241.8 | −228.6 | 188.7 |
| $H_2O_2$ (*l*) | −187.6 | −118.1 | ? |
| Hg(*l*) | 0 | 0 | 77.4 |
| $Hg^{2+}$ (*aq*) | | −164.38 | |
| HgO(*s*) | −90.7 | −58.5 | 72.0 |
| $HgCl_2$ (*s*) | −230.1 | | |
| $Hg_2Cl_2$ (*s*) | −264.9 | −210.66 | 196.2 |
| HgS(*s*) | −58.16 | −48.8 | 77.8 |
| $HgSO_4$ (*s*) | −704.17 | | |
| $Hg_2SO_4$ (*s*) | −741.99 | −623.92 | 200.75 |
| $I_2$ (*s*) | 0 | 0 | 116.7 |
| $I_2$ (*g*) | 62.25 | 19.37 | 260.6 |
| I(*g*) | 106.6 | 70.16 | 180.7 |
| $I^-$ (*aq*) | −55.9 | −51.67 | 109.37 |
| HI(*g*) | 25.9 | 1.30 | 206.3 |
| K(*s*) | 0 | 0 | 63.6 |
| $K^+$ (*aq*) | −251.2 | −282.28 | 102.5 |
| KOH(*s*) | −425.85 | | |
| KCl(*s*) | −435.87 | −408.3 | 82.68 |
| $KClO_3$ (*s*) | −391.20 | −289.9 | 142.97 |
| $KClO_4$ (*s*) | −433.46 | −304.18 | 151.0 |
| KBr(*s*) | −392.17 | −379.2 | 96.4 |
| KI(*s*) | −327.65 | −322.29 | 104.35 |
| $KNO_3$ (*s*) | −492.7 | −393.1 | 132.9 |
| Li(*s*) | 0 | 0 | 28.0 |

| | | | |
|---|---|---|---|
| $Li^+$ $(aq)$ | −278.46 | −293.8 | 14.2 |
| $Li_2O$ $(s)$ | −595.8 | ? | ? |
| $LiOH(s)$ | −487.2 | −443.9 | 50.2 |
| $Mg(s)$ | 0 | 0 | 32.5 |
| $Mg^{2+}$ $(aq)$ | −461.96 | −456.0 | −117.99 |
| $MgO(s)$ | −601.8 | −569.6 | 26.78 |
| $Mg(OH)_2$ $(s)$ | −924.66 | −833.75 | 63.1 |
| $MgCl_2$ $(s)$ | −641.8 | −592.3 | 89.5 |
| $MgSO_4$ $(s)$ | −1278.2 | −1173.6 | 91.6 |
| $MgCO_3$ $(s)$ | −1112.9 | −1029.3 | 65.69 |
| $Mn(s)$ | 0 | 0 | 31.76 |
| $Mn^{2+}$ $(aq)$ | −218.8 | −223.4 | −83.68 |
| $MnO_2$ $(s)$ | −520.9 | −466.1 | 53.1 |
| $N_2$ $(g)$ | 0 | 0 | 191.5 |
| $N_3^-$ $(aq)$ | 245.18 | ? | ? |
| $NH_3$ $(g)$ | −46.3 | −16.6 | 193.0 |
| $NH_4^+$ $(aq)$ | −132.80 | −79.5 | 112.8 |
| $NH_4Cl$ $(s)$ | −315.39 | −203.89 | 94.56 |
| $NH_4NO_3$ $(s)$ | −365.6 | −184.0 | 151 |
| $NH_3$ $(aq)$ | −80.3 | −26.5 | 111.3 |
| $N_2H_4$ $(l)$ | 50.4 | | |
| $NO(g)$ | 90.4 | 86.7 | 210.6 |
| $NO_2$ $(g)$ | 33.85 | 51.8 | 240.46 |
| $N_2O_4$ $(g)$ | 9.66 | 98.29 | 304.3 |
| $N_2O$ $(g)$ | 81.56 | 103.6 | 219.99 |
| $HNO_2$ $(aq)$ | −118.8 | −53.6 | |
| $HNO_3$ $(l)$ | −173.2 | −79.9 | 155.6 |
| $NO_3^-$ $(aq)$ | −206.57 | −110.5 | 146.4 |

| | | | |
|---|---|---|---|
| $Na(s)$ | 0 | 0 | 51.05 |
| $Na^+(aq)$ | −239.66 | −261.87 | 60.25 |
| $Na_2O(s)$ | −415.9 | −376.56 | 72.8 |
| $NaCl(s)$ | −411.0 | −384.0 | 72.38 |
| $NaI(s)$ | −288.0 | | |
| $Na_2SO_4(s)$ | −1384.49 | −1266.8 | 149.49 |
| $NaNO_3(s)$ | −466.68 | −365.89 | 116.3 |
| $Na_2CO_3(s)$ | −1130.9 | −1047.67 | 135.98 |
| $NaHCO_3(s)$ | −947.68 | −851.86 | 102.09 |
| $Ni(s)$ | 0 | 0 | 30.1 |
| $Ni^{2+}(aq)$ | −64.0 | −46.4 | −159.4 |
| $NiO(s)$ | −244.35 | −216.3 | 38.58 |
| $Ni(OH)_2(s)$ | −538.06 | −453.1 | 79.5 |
| $O(g)$ | 249.4 | 230.1 | 160.95 |
| $O_2(g)$ | 0 | 0 | 205.0 |
| $O_3(aq)$ | −12.09 | 16.3 | 110.88 |
| $O_3(g)$ | 142.2 | 163.4 | 237.6 |
| P(white) | 0 | 0 | 44.0 |
| P(red) | −18.4 | 13.8 | 29.3 |
| $PO_4^{3-}(aq)$ | −1284.07 | −1025.59 | −217.57 |
| $P_4O_{10}(s)$ | −3012.48 | | |
| $PH_3(g)$ | 9.25 | 18.2 | 210.0 |
| $HPO_4^{2-}(aq)$ | −1298.7 | −1094.1 | −35.98 |
| $H_2PO_4^-(aq)$ | −1302.48 | −1135.1 | 89.1 |
| $Pb(s)$ | 0 | 0 | 64.89 |
| $Pb^{2+}(aq)$ | 1.6 | −24.3 | 21.3 |
| $PbO(s)$ | −217.86 | −188.49 | 69.45 |

| | | | |
|---|---|---|---|
| $PbO_2$ (*s*) | −276.65 | −218.99 | 76.57 |
| $PbCl_2$ (*s*) | −359.2 | −313.97 | 136.4 |
| PbS(*s*) | −94.3 | −92.68 | 91.2 |
| $PbSO_4$ (*s*) | −918.4 | −811.2 | 147.28 |
| Pt(*s*) | 0 | 0 | 41.84 |
| $PtCl_4^{2-}$ (*aq*) | −516.3 | −384.5 | 175.7 |
| Rb(*s*) | 0 | 0 | 69.45 |
| $Rb^+$ (*aq*) | −246.4 | −282.2 | 124.27 |
| S(rhombic) | 0 | 0 | 31.88 |
| S(monoclinic) | 0.30 | 0.10 | 32.55 |
| $SO_2$ (*g*) | −296.4 | −300.4 | 248.5 |
| $SO_3$ (*g*) | −395.2 | −370.4 | 256.2 |
| $SO_3^{2-}$ (*aq*) | −624.25 | −497.06 | 43.5 |
| $SO_4^{2-}$ (*aq*) | −907.5 | −741.99 | 17.15 |
| $H_2S$ (*g*) | −20.15 | −33.0 | 205.64 |
| $HSO_3^-$ (*aq*) | −627.98 | −527.3 | 132.38 |
| $HSO_4^-$ (*aq*) | −885.75 | −752.87 | 126.86 |
| $H_2SO_4$ (*l*) | −811.3 | ? | ? |
| $SF_6$ (*g*) | −1096.2 | ? | ? |
| Si(*s*) | 0 | 0 | 18.70 |
| $SiO_2$ (*s*) | −859.3 | −805.0 | 41.84 |
| Sr(*s*) | 0 | 0 | 54.39 |
| $Sr^{2+}$ (*aq*) | −545.5 | −557.3 | −39.33 |
| $SrCl_2$ (*s*) | −828.4 | −781.15 | 117.15 |
| $SrSO_4$ (*s*) | −1444.74 | −1334.28 | 121.75 |
| $SrCO_3$ (*s*) | −1218.38 | −1137.6 | 97.07 |
| Zn(*s*) | 0 | 0 | 41.6 |
| $Zn^{2+}$ (*aq*) | −152.4 | −147.2 | −106.48 |
| ZnO(*s*) | −348.0 | −318.2 | 43.9 |
| $ZnCl_2$ (*s*) | −415.89 | −369.26 | 108.37 |
| ZnS(*s*) | −202.9 | −198.3 | 57.7 |
| $ZnSO_4$ (*s*) | −978.6 | −871.6 | 124.7 |