

APPENDIX 3

Thermodynamic Data at 1 atm and 25°C*

| Inorganic Substances | | | |
|-------------------------------------|-----------------------------|-----------------------------|-----------------------|
| Substance | ΔH_f° (kJ/mol) | ΔG_f° (kJ/mol) | S° (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 |
| Al ₂ O 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 ₃ AsO ₄ (s) | -900.4 | | |
| Au(s) | 0 | 0 | 47.7 |
| Au ₂ O ₃ (s) | 80.8 | 163.2 | 125.5 |
| AuCl(s) | -35.2 | | |
| AuCl ₃ (s) | -118.4 | | |
| B(s) | 0 | 0 | 6.5 |
| B ₂ O ₃ (s) | -1263.6 | -1184.1 | 54.0 |
| H ₃ BO ₃ (s) | -1087.9 | -963.16 | 89.58 |
| H ₃ BO 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 ⁻ (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 |

*The thermodynamic quantities of ions are based on the reference states that $\Delta H_f^\circ[\text{H}^+(\text{aq})] = 0$, $\Delta G_f^\circ[\text{H}^+(\text{aq})] = 0$, and $S^\circ[\text{H}^+(\text{aq})] = 0$ (see p. 807).

(Continued)

| Substance | ΔH_f° (kJ/mol) | ΔG_f° (kJ/mol) | S° (J/K · mol) |
|---|-----------------------------|-----------------------------|-----------------------|
| HCO ₃ ⁻ (aq) | -691.1 | -587.1 | 94.98 |
| H ₂ CO 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) ₂ CO(s) | -333.19 | -197.15 | 104.6 |
| (NH ₂) ₂ CO(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 ₂ O ₃ (s) | -1128.4 | -1046.8 | 81.17 |
| CrO ₄ ²⁻ (aq) | -863.16 | -706.26 | 38.49 |
| Cr ₂ O 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 ₂ O(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 |

(Continued)

| Substance | ΔH_f° (kJ/mol) | ΔG_f° (kJ/mol) | S° (J/K · mol) |
|-------------------------------------|-----------------------------|-----------------------------|-----------------------|
| Fe ³⁺ (aq) | -47.7 | -10.5 | -293.3 |
| FeO(s) | -272.0 | -255.2 | 60.8 |
| Fe ₂ O 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 ⁺ (aq) | 0 | 0 | 0 |
| OH ⁻ (aq) | -229.94 | -157.30 | -10.5 |
| H ₂ O(g) | -241.8 | -228.6 | 188.7 |
| H ₂ O(l) | -285.8 | -237.2 | 69.9 |
| H ₂ O 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 ₂ Cl ₂ (s) | -264.9 | -210.66 | 196.2 |
| HgS(s) | -58.16 | -48.8 | 77.8 |
| HgSO ₄ (s) | -704.17 | | |
| Hg ₂ SO ₄ (s) | -741.99 | -623.92 | 200.75 |
| I ₂ (s) | 0 | 0 | 116.7 |
| 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 ₂ O(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 | ? | ? |

(Continued)

| Substance | ΔH_f° (kJ/mol) | ΔG_f° (kJ/mol) | S° (J/K · mol) |
|--|-----------------------------|-----------------------------|-----------------------|
| NH ₃ (g) | -46.3 | -16.6 | 193.0 |
| NH ₄ ⁺ (aq) | -132.80 | -79.5 | 112.8 |
| NH ₄ Cl(s) | -315.39 | -203.89 | 94.56 |
| NH ₃ (aq) | -80.3 | -26.5 | 111.3 |
| N ₂ H ₄ (l) | 50.4 | | |
| NO(g) | 90.4 | 86.7 | 210.6 |
| NO ₂ (g) | 33.85 | 51.8 | 240.46 |
| N ₂ O ₄ (g) | 9.66 | 98.29 | 304.3 |
| N ₂ O(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 ₂ O(s) | -415.9 | -376.56 | 72.8 |
| NaCl(s) | -411.0 | -384.0 | 72.38 |
| NaI(s) | -288.0 | | |
| Na ₂ SO ₄ (s) | -1384.49 | -1266.8 | 149.49 |
| NaNO ₃ (s) | -466.68 | -365.89 | 116.3 |
| Na ₂ CO 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 ₄ O ₁₀ (s) | -3012.48 | | |
| PH ₃ (g) | 9.25 | 18.2 | 210.0 |
| HPO ₄ ²⁻ (aq) | -1298.7 | -1094.1 | -35.98 |
| H ₂ PO 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 |

(Continued)

| Substance | ΔH_f° (kJ/mol) | ΔG_f° (kJ/mol) | S° (J/K · mol) |
|------------------------------------|-----------------------------|-----------------------------|-----------------------|
| 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 ₂ S(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 ₂ SO 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 |

Organic Substances

| Substance | Formula | ΔH_f° (kJ/mol) | ΔG_f° (kJ/mol) | S° (J/K · mol) |
|-----------------|---|-----------------------------|-----------------------------|-----------------------|
| Acetic acid(l) | CH ₃ COOH | -484.2 | -389.45 | 159.8 |
| Acetaldehyde(g) | CH ₃ CHO | -166.35 | -139.08 | 264.2 |
| Acetone(l) | CH ₃ COCH ₃ | -246.8 | -153.55 | 198.7 |
| Acetylene(g) | C ₂ H ₂ | 226.6 | 209.2 | 200.8 |
| Benzene(l) | C ₆ H ₆ | 49.04 | 124.5 | 172.8 |
| Butane(g) | C ₄ H ₁₀ | -124.7 | -15.7 | 310.0 |
| Ethanol(l) | C ₂ H ₅ OH | -276.98 | -174.18 | 161.0 |
| Ethane(g) | C ₂ H ₆ | -84.7 | -32.89 | 229.5 |
| Ethylene(g) | C ₂ H ₄ | 52.3 | 68.1 | 219.5 |
| Formic acid(l) | HCOOH | -409.2 | -346.0 | 129.0 |
| Glucose(s) | C ₆ H ₁₂ O ₆ | -1274.5 | -910.56 | 212.1 |
| Methane(g) | CH ₄ | -74.85 | -50.8 | 186.2 |
| Methanol(l) | CH ₃ OH | -238.7 | -166.3 | 126.8 |
| Propane(g) | C ₃ H ₈ | -103.9 | -23.5 | 269.9 |
| Sucrose(s) | C ₁₂ H ₂₂ O ₁₁ | -2221.7 | -1544.3 | 360.2 |