

**Table L.1** Selected Thermodynamic Values\*

| Species                            | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|------------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Aluminum</i>                    |                                           |                                     |                                           |
| Al(s)                              | 0                                         | 28.3                                | 0                                         |
| AlCl <sub>3</sub> (s)              | −705.63                                   | 109.29                              | −630.0                                    |
| Al <sub>2</sub> O <sub>3</sub> (s) | −1675.7                                   | 50.92                               | −1582.3                                   |
| <i>Barium</i>                      |                                           |                                     |                                           |
| BaCl <sub>2</sub> (s)              | −858.6                                    | 123.68                              | −810.4                                    |
| BaCO <sub>3</sub> (s)              | −1213                                     | 112.1                               | −1134.41                                  |
| BaO(s)                             | −548.1                                    | 72.05                               | −520.38                                   |
| BaSO <sub>4</sub> (s)              | −1473.2                                   | 132.2                               | −1362.2                                   |
| <i>Beryllium</i>                   |                                           |                                     |                                           |
| Be(s)                              | 0                                         | 9.5                                 | 0                                         |
| Be(OH) <sub>2</sub> (s)            | −902.5                                    | 51.9                                | −815.0                                    |
| <i>Boron</i>                       |                                           |                                     |                                           |
| BCl <sub>3</sub> (g)               | −402.96                                   | 290.17                              | −387.95                                   |
| <i>Bromine</i>                     |                                           |                                     |                                           |
| Br(g)                              | 111.884                                   | 175.022                             | 82.396                                    |
| Br <sub>2</sub> (ℓ)                | 0                                         | 152.2                               | 0                                         |
| Br <sub>2</sub> (g)                | 30.91                                     | 245.47                              | 3.12                                      |
| BrF <sub>3</sub> (g)               | −255.60                                   | 292.53                              | −229.43                                   |
| HBr(g)                             | −36.29                                    | 198.70                              | −53.45                                    |

\*Most thermodynamic data are taken from the NIST Chemistry WebBook at <http://webbook.nist.gov>.

(continued)

**Table L.1** Selected Thermodynamic Values (*continued*)

| Species                                      | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|----------------------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Calcium</i>                               |                                           |                                     |                                           |
| Ca(s)                                        | 0                                         | 41.59                               | 0                                         |
| Ca(g)                                        | 178.2                                     | 158.884                             | 144.3                                     |
| Ca <sup>2+</sup> (g)                         | 1925.90                                   | —                                   | —                                         |
| CaC <sub>2</sub> (s)                         | −59.8                                     | 70.                                 | −64.93                                    |
| CaCO <sub>3</sub> (s, calcite)               | −1207.6                                   | 91.7                                | −1129.16                                  |
| CaCl <sub>2</sub> (s)                        | −795.8                                    | 104.6                               | −748.1                                    |
| CaF <sub>2</sub> (s)                         | −1219.6                                   | 68.87                               | −1167.3                                   |
| CaH <sub>2</sub> (s)                         | −186.2                                    | 42                                  | −147.2                                    |
| CaO(s)                                       | −635.09                                   | 38.2                                | −603.42                                   |
| CaS(s)                                       | −482.4                                    | 56.5                                | −477.4                                    |
| Ca(OH) <sub>2</sub> (s)                      | −986.09                                   | 83.39                               | −898.43                                   |
| Ca(OH) <sub>2</sub> (aq)                     | −1002.82                                  | —                                   | −868.07                                   |
| CaSO <sub>4</sub> (s)                        | −1434.52                                  | 106.5                               | −1322.02                                  |
| <i>Carbon</i>                                |                                           |                                     |                                           |
| C(s, graphite)                               | 0                                         | 5.6                                 | 0                                         |
| C(s, diamond)                                | 1.8                                       | 2.377                               | 2.900                                     |
| C(g)                                         | 716.67                                    | 158.1                               | 671.2                                     |
| CCl <sub>4</sub> (ℓ)                         | −128.4                                    | 214.39                              | −57.63                                    |
| CCl <sub>4</sub> (g)                         | −95.98                                    | 309.65                              | −53.61                                    |
| CHCl <sub>3</sub> (ℓ)                        | −134.47                                   | 201.7                               | −73.66                                    |
| CHCl <sub>3</sub> (g)                        | −103.18                                   | 295.61                              | −70.4                                     |
| CH <sub>4</sub> (g, methane)                 | −74.87                                    | 186.26                              | −50.8                                     |
| C <sub>2</sub> H <sub>2</sub> (g, ethyne)    | 226.73                                    | 200.94                              | 209.20                                    |
| C <sub>2</sub> H <sub>4</sub> (g, ethene)    | 52.47                                     | 219.36                              | 68.35                                     |
| C <sub>2</sub> H <sub>6</sub> (g, ethane)    | −83.85                                    | 229.2                               | −31.89                                    |
| C <sub>3</sub> H <sub>8</sub> (g, propane)   | −104.7                                    | 270.3                               | −24.4                                     |
| C <sub>6</sub> H <sub>6</sub> (ℓ, benzene)   | 48.95                                     | 173.26                              | 124.21                                    |
| CH <sub>3</sub> OH(ℓ, methanol)              | −238.4                                    | 127.19                              | −166.14                                   |
| CH <sub>3</sub> OH(g, methanol)              | −201.0                                    | 239.7                               | −162.5                                    |
| C <sub>2</sub> H <sub>5</sub> OH(ℓ, ethanol) | −277.0                                    | 160.7                               | −174.7                                    |
| C <sub>2</sub> H <sub>5</sub> OH(g, ethanol) | −235.3                                    | 282.70                              | −168.49                                   |
| CO(g)                                        | −110.525                                  | 197.674                             | −137.168                                  |
| CO <sub>2</sub> (g)                          | −393.509                                  | 213.74                              | −394.359                                  |

*(continued)*

**Table L.1** Selected Thermodynamic Values (*continued*)

| Species                           | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|-----------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Carbon (continued)</i>         |                                           |                                     |                                           |
| $\text{CS}_2(\ell)$               | 89.41                                     | 151                                 | 65.2                                      |
| $\text{CS}_2(\text{g})$           | 116.7                                     | 237.8                               | 66.61                                     |
| $\text{COCl}_2(\text{g})$         | −218.8                                    | 283.53                              | −204.6                                    |
| <i>Cesium</i>                     |                                           |                                     |                                           |
| $\text{Cs}(\text{s})$             | 0                                         | 85.23                               | 0                                         |
| $\text{Cs}^+(\text{g})$           | 457.964                                   | —                                   | —                                         |
| $\text{CsCl}(\text{s})$           | −443.04                                   | 101.17                              | −414.53                                   |
| <i>Chlorine</i>                   |                                           |                                     |                                           |
| $\text{Cl}(\text{g})$             | 121.3                                     | 165.19                              | 105.3                                     |
| $\text{Cl}^-(\text{g})$           | −233.13                                   | —                                   | —                                         |
| $\text{Cl}_2(\text{g})$           | 0                                         | 223.08                              | 0                                         |
| $\text{HCl}(\text{g})$            | −92.31                                    | 186.2                               | −95.09                                    |
| $\text{HCl}(\text{aq})$           | −167.159                                  | 56.5                                | −131.26                                   |
| <i>Chromium</i>                   |                                           |                                     |                                           |
| $\text{Cr}(\text{s})$             | 0                                         | 23.62                               | 0                                         |
| $\text{Cr}_2\text{O}_3(\text{s})$ | −1134.7                                   | 80.65                               | −1052.95                                  |
| $\text{CrCl}_3(\text{s})$         | −556.5                                    | 123.0                               | −486.1                                    |
| <i>Copper</i>                     |                                           |                                     |                                           |
| $\text{Cu}(\text{s})$             | 0                                         | 33.17                               | 0                                         |
| $\text{CuO}(\text{s})$            | −156.06                                   | 42.59                               | −128.3                                    |
| $\text{CuCl}_2(\text{s})$         | −220.1                                    | 108.07                              | −175.7                                    |
| $\text{CuSO}_4(\text{s})$         | −769.98                                   | 109.05                              | −660.75                                   |
| <i>Fluorine</i>                   |                                           |                                     |                                           |
| $\text{F}_2(\text{g})$            | 0                                         | 202.8                               | 0                                         |
| $\text{F}(\text{g})$              | 78.99                                     | 158.754                             | 61.91                                     |
| $\text{F}^-(\text{g})$            | −255.39                                   | —                                   | —                                         |
| $\text{F}^-(\text{aq})$           | −332.63                                   | —                                   | −278.79                                   |
| $\text{HF}(\text{g})$             | −273.3                                    | 173.779                             | −273.2                                    |
| $\text{HF}(\text{aq})$            | −332.63                                   | 88.7                                | −278.79                                   |
| <i>Hydrogen</i>                   |                                           |                                     |                                           |
| $\text{H}_2(\text{g})$            | 0                                         | 130.7                               | 0                                         |
| $\text{H}(\text{g})$              | 217.965                                   | 114.713                             | 203.247                                   |
| $\text{H}^+(\text{g})$            | 1536.202                                  | —                                   | —                                         |
| $\text{H}_2\text{O}(\ell)$        | −285.83                                   | 69.95                               | −237.15                                   |
| $\text{H}_2\text{O}(\text{g})$    | −241.83                                   | 188.84                              | −228.59                                   |
| $\text{H}_2\text{O}_2(\ell)$      | −187.78                                   | 109.6                               | −120.35                                   |

*(continued)*

**Table L.1** Selected Thermodynamic Values (*continued*)

| Species                      | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Iodine</i>                |                                           |                                     |                                           |
| $I_2(s)$                     | 0                                         | 116.135                             | 0                                         |
| $I_2(g)$                     | 62.438                                    | 260.69                              | 19.327                                    |
| $I(g)$                       | 106.838                                   | 180.791                             | 70.250                                    |
| $I^-(g)$                     | −197                                      | —                                   | —                                         |
| $ICl(g)$                     | 17.51                                     | 247.56                              | −5.73                                     |
| <i>Iron</i>                  |                                           |                                     |                                           |
| $Fe(s)$                      | 0                                         | 27.78                               | 0                                         |
| $FeO(s)$                     | −272                                      | —                                   | —                                         |
| $Fe_2O_3(s)$ ,<br>hematite)  | −825.5                                    | 87.40                               | −742.2                                    |
| $Fe_3O_4(s)$ ,<br>magnetite) | −1118.4                                   | 146.4                               | −1015.4                                   |
| $FeCl_2(s)$                  | −341.79                                   | 117.95                              | −302.30                                   |
| $FeCl_3(s)$                  | −399.49                                   | 142.3                               | −344.00                                   |
| $FeS_2(s)$ , pyrite)         | −178.2                                    | 52.93                               | −166.9                                    |
| $Fe(CO)_5(l)$                | −774.0                                    | 338.1                               | −705.3                                    |
| <i>Lead</i>                  |                                           |                                     |                                           |
| $Pb(s)$                      | 0                                         | 64.81                               | 0                                         |
| $PbCl_2(s)$                  | −359.41                                   | 136.0                               | −314.10                                   |
| $PbO(s)$ , yellow)           | −219                                      | 66.5                                | −196                                      |
| $PbO_2(s)$                   | −277.4                                    | 68.6                                | −217.39                                   |
| $PbS(s)$                     | −100.4                                    | 91.2                                | −98.7                                     |
| <i>Lithium</i>               |                                           |                                     |                                           |
| $Li(s)$                      | 0                                         | 29.12                               | 0                                         |
| $Li^+(g)$                    | 685.783                                   | —                                   | —                                         |
| $LiOH(s)$                    | −484.93                                   | 42.81                               | −438.96                                   |
| $LiOH(aq)$                   | −508.48                                   | 2.80                                | −450.58                                   |
| $LiCl(s)$                    | −408.701                                  | 59.33                               | −384.37                                   |
| <i>Magnesium</i>             |                                           |                                     |                                           |
| $Mg(s)$                      | 0                                         | 32.67                               | 0                                         |
| $MgCl_2(s)$                  | −641.62                                   | 89.62                               | −592.09                                   |
| $MgCO_3(s)$                  | −1111.69                                  | 65.84                               | −1028.2                                   |
| $MgO(s)$                     | −601.24                                   | 26.85                               | −568.93                                   |
| $Mg(OH)_2(s)$                | −924.54                                   | 63.18                               | −833.51                                   |
| $MgS(s)$                     | −346.0                                    | 50.33                               | −341.8                                    |

(continued)

**Table L.1** Selected Thermodynamic Values (*continued*)

| Species                                   | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|-------------------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Mercury</i>                            |                                           |                                     |                                           |
| Hg( $\ell$ )                              | 0                                         | 76.02                               | 0                                         |
| HgCl <sub>2</sub> (s)                     | −224.3                                    | 146.0                               | −178.6                                    |
| HgO(s, red)                               | −90.83                                    | 70.29                               | −58.539                                   |
| HgS(s, red)                               | −58.2                                     | 82.4                                | −50.6                                     |
| <i>Nickel</i>                             |                                           |                                     |                                           |
| Ni(s)                                     | 0                                         | 29.87                               | 0                                         |
| NiO(s)                                    | −239.7                                    | 37.99                               | −211.7                                    |
| NiCl <sub>2</sub> (s)                     | −305.332                                  | 97.65                               | −259.032                                  |
| <i>Nitrogen</i>                           |                                           |                                     |                                           |
| N <sub>2</sub> (g)                        | 0                                         | 191.56                              | 0                                         |
| N(g)                                      | 472.704                                   | 153.298                             | 455.563                                   |
| NH <sub>3</sub> (g)                       | −45.90                                    | 192.77                              | −16.37                                    |
| N <sub>2</sub> H <sub>4</sub> ( $\ell$ )  | 50.63                                     | 121.52                              | 149.45                                    |
| NH <sub>4</sub> Cl(s)                     | −314.55                                   | 94.85                               | −203.08                                   |
| NH <sub>4</sub> Cl(aq)                    | −299.66                                   | 169.9                               | −210.57                                   |
| NH <sub>4</sub> NO <sub>3</sub> (s)       | −365.56                                   | 151.08                              | −183.84                                   |
| NH <sub>4</sub> NO <sub>3</sub> (aq)      | −339.87                                   | 259.8                               | −190.57                                   |
| NO(g)                                     | 90.29                                     | 210.76                              | 86.58                                     |
| NO <sub>2</sub> (g)                       | 33.1                                      | 240.04                              | 51.23                                     |
| N <sub>2</sub> O(g)                       | 82.05                                     | 219.85                              | 104.20                                    |
| N <sub>2</sub> O <sub>4</sub> (g)         | 9.08                                      | 304.38                              | 97.73                                     |
| NOCl(g)                                   | 51.71                                     | 261.8                               | 66.08                                     |
| HNO <sub>3</sub> ( $\ell$ )               | −174.10                                   | 155.60                              | −80.71                                    |
| HNO <sub>3</sub> (g)                      | −135.06                                   | 266.38                              | −74.72                                    |
| HNO <sub>3</sub> (aq)                     | −207.36                                   | 146.4                               | −111.25                                   |
| <i>Oxygen</i>                             |                                           |                                     |                                           |
| O <sub>2</sub> (g)                        | 0                                         | 205.07                              | 0                                         |
| O(g)                                      | 249.170                                   | 161.055                             | 231.731                                   |
| O <sub>3</sub> (g)                        | 142.67                                    | 238.92                              | 163.2                                     |
| <i>Phosphorus</i>                         |                                           |                                     |                                           |
| P <sub>4</sub> (s, white)                 | 0                                         | 41.1                                | 0                                         |
| P <sub>4</sub> (s, red)                   | −17.6                                     | 22.80                               | −12.1                                     |
| P(g)                                      | 314.64                                    | 163.193                             | 278.25                                    |
| PH <sub>3</sub> (g)                       | 5.47                                      | 210.24                              | 6.64                                      |
| PCl <sub>3</sub> (g)                      | −287.0                                    | 311.78                              | −267.8                                    |
| P <sub>4</sub> O <sub>10</sub> (s)        | −2984.0                                   | 228.86                              | −2697.7                                   |
| H <sub>3</sub> PO <sub>4</sub> ( $\ell$ ) | −1279.0                                   | 110.5                               | −1119.1                                   |

*(continued)*

**Table L.1** Selected Thermodynamic Values (*continued*)

| Species                             | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|-------------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Potassium</i>                    |                                           |                                     |                                           |
| K(s)                                | 0                                         | 64.63                               | 0                                         |
| KCl(s)                              | −436.68                                   | 82.56                               | −408.77                                   |
| KClO <sub>3</sub> (s)               | −397.73                                   | 143.1                               | −296.25                                   |
| KI(s)                               | −327.90                                   | 106.32                              | −324.892                                  |
| KOH(s)                              | −424.72                                   | 78.9                                | −378.92                                   |
| KOH(aq)                             | −482.37                                   | 91.6                                | −440.50                                   |
| <i>Silicon</i>                      |                                           |                                     |                                           |
| Si(s)                               | 0                                         | 18.82                               | 0                                         |
| SiBr <sub>4</sub> (ℓ)               | −457.3                                    | 277.8                               | −443.9                                    |
| SiC(s)                              | −65.3                                     | 16.61                               | −62.8                                     |
| SiCl <sub>4</sub> (g)               | −662.75                                   | 330.86                              | −622.76                                   |
| SiH <sub>4</sub> (g)                | 34.31                                     | 204.65                              | 56.84                                     |
| SiF <sub>4</sub> (g)                | −1614.94                                  | 282.49                              | −1572.65                                  |
| SiO <sub>2</sub> (s, quartz)        | −910.86                                   | 41.46                               | −856.97                                   |
| <i>Silver</i>                       |                                           |                                     |                                           |
| Ag(s)                               | 0                                         | 42.55                               | 0                                         |
| Ag <sub>2</sub> O(s)                | −31.1                                     | 121.3                               | −11.32                                    |
| AgCl(s)                             | −127.01                                   | 96.25                               | −109.76                                   |
| AgNO <sub>3</sub> (s)               | −124.39                                   | 140.92                              | −33.41                                    |
| <i>Sodium</i>                       |                                           |                                     |                                           |
| Na(s)                               | 0                                         | 51.21                               | 0                                         |
| Na(g)                               | 107.3                                     | 153.765                             | 76.83                                     |
| Na <sup>+</sup> (g)                 | 609.358                                   | —                                   | —                                         |
| NaBr(s)                             | −361.02                                   | 86.82                               | −348.983                                  |
| NaCl(s)                             | −411.12                                   | 72.11                               | −384.04                                   |
| NaCl(g)                             | −181.42                                   | 229.79                              | −201.33                                   |
| NaCl(aq)                            | −407.27                                   | 115.5                               | −393.133                                  |
| NaOH(s)                             | −425.93                                   | 64.46                               | −379.75                                   |
| NaOH(aq)                            | −469.15                                   | 48.1                                | −418.09                                   |
| Na <sub>2</sub> CO <sub>3</sub> (s) | −1130.77                                  | 134.79                              | −1048.08                                  |

*(continued)*

**Table L.1** Selected Thermodynamic Values (*continued*)

| Species                             | $\Delta_f H^\circ$ (298.15 K)<br>(kJ/mol) | $S^\circ$ (298.15 K)<br>(J/K · mol) | $\Delta_f G^\circ$ (298.15 K)<br>(kJ/mol) |
|-------------------------------------|-------------------------------------------|-------------------------------------|-------------------------------------------|
| <i>Sulfur</i>                       |                                           |                                     |                                           |
| S(s, rhombic)                       | 0                                         | 32.1                                | 0                                         |
| S(g)                                | 278.98                                    | 167.83                              | 236.51                                    |
| S <sub>2</sub> Cl <sub>2</sub> (g)  | −18.4                                     | 331.5                               | −31.8                                     |
| SF <sub>6</sub> (g)                 | −1209                                     | 291.82                              | −1105.3                                   |
| H <sub>2</sub> S(g)                 | −20.63                                    | 205.79                              | −33.56                                    |
| SO <sub>2</sub> (g)                 | −296.84                                   | 248.21                              | −300.13                                   |
| SO <sub>3</sub> (g)                 | −395.77                                   | 256.77                              | −371.04                                   |
| SOCl <sub>2</sub> (g)               | −212.5                                    | 309.77                              | −198.3                                    |
| H <sub>2</sub> SO <sub>4</sub> (ℓ)  | −814                                      | 156.9                               | −689.96                                   |
| H <sub>2</sub> SO <sub>4</sub> (aq) | −909.27                                   | 20.1                                | −744.53                                   |
| <i>Tin</i>                          |                                           |                                     |                                           |
| Sn(s, white)                        | 0                                         | 51.08                               | 0                                         |
| Sn(s, gray)                         | −2.09                                     | 44.14                               | 0.13                                      |
| SnCl <sub>4</sub> (ℓ)               | −511.3                                    | 258.6                               | −440.15                                   |
| SnCl <sub>4</sub> (g)               | −471.5                                    | 365.8                               | −432.31                                   |
| SnO <sub>2</sub> (s)                | −577.63                                   | 49.04                               | −515.88                                   |
| <i>Titanium</i>                     |                                           |                                     |                                           |
| Ti(s)                               | 0                                         | 30.72                               | 0                                         |
| TiCl <sub>4</sub> (ℓ)               | −804.2                                    | 252.34                              | −737.2                                    |
| TiCl <sub>4</sub> (g)               | −763.16                                   | 354.84                              | −726.7                                    |
| TiO <sub>2</sub> (s)                | −939.7                                    | 49.92                               | −884.5                                    |
| <i>Zinc</i>                         |                                           |                                     |                                           |
| Zn(s)                               | 0                                         | 41.63                               | 0                                         |
| ZnCl <sub>2</sub> (s)               | −415.05                                   | 111.46                              | −369.398                                  |
| ZnO(s)                              | −348.28                                   | 43.64                               | −318.30                                   |
| ZnS(s, sphalerite)                  | −205.98                                   | 57.7                                | −201.29                                   |