

# Appendix 1

## PROPERTY TABLES AND CHARTS (SI UNITS)

|                    |                                                         |                    |                                                                                                        |
|--------------------|---------------------------------------------------------|--------------------|--------------------------------------------------------------------------------------------------------|
| <b>Table A-1</b>   | Molar mass, gas constant, and critical-point properties | <b>Table A-20</b>  | Ideal-gas properties of carbon dioxide, $\text{CO}_2$                                                  |
| <b>Table A-2</b>   | Ideal-gas specific heats of various common gases        | <b>Table A-21</b>  | Ideal-gas properties of carbon monoxide, $\text{CO}$                                                   |
| <b>Table A-3</b>   | Properties of common liquids, solids, and foods         | <b>Table A-22</b>  | Ideal-gas properties of hydrogen, $\text{H}_2$                                                         |
| <b>Table A-4</b>   | Saturated water—Temperature table                       | <b>Table A-23</b>  | Ideal-gas properties of water vapor, $\text{H}_2\text{O}$                                              |
| <b>Table A-5</b>   | Saturated water—Pressure table                          | <b>Table A-24</b>  | Ideal-gas properties of monatomic oxygen, $\text{O}$                                                   |
| <b>Table A-6</b>   | Superheated water                                       | <b>Table A-25</b>  | Ideal-gas properties of hydroxyl, $\text{OH}$                                                          |
| <b>Table A-7</b>   | Compressed liquid water                                 | <b>Table A-26</b>  | Enthalpy of formation, Gibbs function of formation, and absolute entropy at $25^\circ\text{C}$ , 1 atm |
| <b>Table A-8</b>   | Saturated ice–water vapor                               | <b>Table A-27</b>  | Properties of some common fuels and hydrocarbons                                                       |
| <b>Figure A-9</b>  | $T$ - $s$ diagram for water                             | <b>Table A-28</b>  | Natural logarithms of the equilibrium constant $K_p$                                                   |
| <b>Figure A-10</b> | Mollier diagram for water                               | <b>Figure A-29</b> | Generalized enthalpy departure chart                                                                   |
| <b>Table A-11</b>  | Saturated refrigerant-134a—Temperature table            | <b>Figure A-30</b> | Generalized entropy departure chart                                                                    |
| <b>Table A-12</b>  | Saturated refrigerant-134a—Pressure table               | <b>Figure A-31</b> | Psychrometric chart at 1 atm total pressure                                                            |
| <b>Table A-13</b>  | Superheated refrigerant-134a                            | <b>Table A-32</b>  | One-dimensional isentropic compressible-flow functions for an ideal gas with $k = 1.4$                 |
| <b>Figure A-14</b> | $P$ - $h$ diagram for refrigerant-134a                  | <b>Table A-33</b>  | One-dimensional normal-shock functions for an ideal gas with $k = 1.4$                                 |
| <b>Figure A-15</b> | Nelson–Obert generalized compressibility chart          | <b>Table A-34</b>  | Rayleigh flow functions for an ideal gas with $k = 1.4$                                                |
| <b>Table A-16</b>  | Properties of the atmosphere at high altitude           |                    |                                                                                                        |
| <b>Table A-17</b>  | Ideal-gas properties of air                             |                    |                                                                                                        |
| <b>Table A-18</b>  | Ideal-gas properties of nitrogen, $\text{N}_2$          |                    |                                                                                                        |
| <b>Table A-19</b>  | Ideal-gas properties of oxygen, $\text{O}_2$            |                    |                                                                                                        |

TABLE A – 1

Molar mass, gas constant, and critical-point properties

| Substance                      | Formula                           | Molar mass,<br>$M$ kg/kmol | Gas<br>constant,<br>$R$ kJ/kg · K* | Critical-point properties |                  |                                 |
|--------------------------------|-----------------------------------|----------------------------|------------------------------------|---------------------------|------------------|---------------------------------|
|                                |                                   |                            |                                    | Temperature,<br>K         | Pressure,<br>MPa | Volume,<br>m <sup>3</sup> /kmol |
| Air                            | —                                 | 28.97                      | 0.2870                             | 132.5                     | 3.77             | 0.0883                          |
| Ammonia                        | NH <sub>3</sub>                   | 17.03                      | 0.4882                             | 405.5                     | 11.28            | 0.0724                          |
| Argon                          | Ar                                | 39.948                     | 0.2081                             | 151                       | 4.86             | 0.0749                          |
| Benzene                        | C <sub>6</sub> H <sub>6</sub>     | 78.115                     | 0.1064                             | 562                       | 4.92             | 0.2603                          |
| Bromine                        | Br <sub>2</sub>                   | 159.808                    | 0.0520                             | 584                       | 10.34            | 0.1355                          |
| <i>n</i> -Butane               | C <sub>4</sub> H <sub>10</sub>    | 58.124                     | 0.1430                             | 425.2                     | 3.80             | 0.2547                          |
| Carbon dioxide                 | CO <sub>2</sub>                   | 44.01                      | 0.1889                             | 304.2                     | 7.39             | 0.0943                          |
| Carbon monoxide                | CO                                | 28.011                     | 0.2968                             | 133                       | 3.50             | 0.0930                          |
| Carbon tetrachloride           | CCl <sub>4</sub>                  | 153.82                     | 0.05405                            | 556.4                     | 4.56             | 0.2759                          |
| Chlorine                       | Cl <sub>2</sub>                   | 70.906                     | 0.1173                             | 417                       | 7.71             | 0.1242                          |
| Chloroform                     | CHCl <sub>3</sub>                 | 119.38                     | 0.06964                            | 536.6                     | 5.47             | 0.2403                          |
| Dichlorodifluoromethane (R-12) | CCl <sub>2</sub> F <sub>2</sub>   | 120.91                     | 0.06876                            | 384.7                     | 4.01             | 0.2179                          |
| Dichlorofluoromethane (R-21)   | CHCl <sub>2</sub> F               | 102.92                     | 0.08078                            | 451.7                     | 5.17             | 0.1973                          |
| Ethane                         | C <sub>2</sub> H <sub>6</sub>     | 30.070                     | 0.2765                             | 305.5                     | 4.48             | 0.1480                          |
| Ethyl alcohol                  | C <sub>2</sub> H <sub>5</sub> OH  | 46.07                      | 0.1805                             | 516                       | 6.38             | 0.1673                          |
| Ethylene                       | C <sub>2</sub> H <sub>4</sub>     | 28.054                     | 0.2964                             | 282.4                     | 5.12             | 0.1242                          |
| Helium                         | He                                | 4.003                      | 2.0769                             | 5.3                       | 0.23             | 0.0578                          |
| <i>n</i> -Hexane               | C <sub>6</sub> H <sub>14</sub>    | 86.179                     | 0.09647                            | 507.9                     | 3.03             | 0.3677                          |
| Hydrogen (normal)              | H <sub>2</sub>                    | 2.016                      | 4.1240                             | 33.3                      | 1.30             | 0.0649                          |
| Krypton                        | Kr                                | 83.80                      | 0.09921                            | 209.4                     | 5.50             | 0.0924                          |
| Methane                        | CH <sub>4</sub>                   | 16.043                     | 0.5182                             | 191.1                     | 4.64             | 0.0993                          |
| Methyl alcohol                 | CH <sub>3</sub> OH                | 32.042                     | 0.2595                             | 513.2                     | 7.95             | 0.1180                          |
| Methyl chloride                | CH <sub>3</sub> Cl                | 50.488                     | 0.1647                             | 416.3                     | 6.68             | 0.1430                          |
| Neon                           | Ne                                | 20.183                     | 0.4119                             | 44.5                      | 2.73             | 0.0417                          |
| Nitrogen                       | N <sub>2</sub>                    | 28.013                     | 0.2968                             | 126.2                     | 3.39             | 0.0899                          |
| Nitrous oxide                  | N <sub>2</sub> O                  | 44.013                     | 0.1889                             | 309.7                     | 7.27             | 0.0961                          |
| Oxygen                         | O <sub>2</sub>                    | 31.999                     | 0.2598                             | 154.8                     | 5.08             | 0.0780                          |
| Propane                        | C <sub>3</sub> H <sub>8</sub>     | 44.097                     | 0.1885                             | 370                       | 4.26             | 0.1998                          |
| Propylene                      | C <sub>3</sub> H <sub>6</sub>     | 42.081                     | 0.1976                             | 365                       | 4.62             | 0.1810                          |
| Sulfur dioxide                 | SO <sub>2</sub>                   | 64.063                     | 0.1298                             | 430.7                     | 7.88             | 0.1217                          |
| Tetrafluoroethane (R-134a)     | CF <sub>3</sub> CH <sub>2</sub> F | 102.03                     | 0.08149                            | 374.2                     | 4.059            | 0.1993                          |
| Trichlorofluoromethane (R-11)  | CCl <sub>3</sub> F                | 137.37                     | 0.06052                            | 471.2                     | 4.38             | 0.2478                          |
| Water                          | H <sub>2</sub> O                  | 18.015                     | 0.4615                             | 647.1                     | 22.06            | 0.0560                          |
| Xenon                          | Xe                                | 131.30                     | 0.06332                            | 289.8                     | 5.88             | 0.1186                          |

\*The unit kJ/kg · K is equivalent to kPa · m<sup>3</sup>/kg · K. The gas constant is calculated from  $R = R_u/M$ , where  $R_u = 8.31447$  kJ/kmol · K and  $M$  is the molar mass.

Source: K. A. Kobe and R. E. Lynn, Jr., *Chemical Review* 52 (1953), pp. 117–236; and ASHRAE, *Handbook of Fundamentals* (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1993), pp. 16.4 and 36.1.

TABLE A-2

Ideal-gas specific heats of various common gases

(a) At 300 K

| Gas             | Formula                        | Gas constant, $R$<br>kJ/kg · K | $c_p$<br>kJ/kg · K | $c_v$<br>kJ/kg · K | $k$   |
|-----------------|--------------------------------|--------------------------------|--------------------|--------------------|-------|
| Air             | —                              | 0.2870                         | 1.005              | 0.718              | 1.400 |
| Argon           | Ar                             | 0.2081                         | 0.5203             | 0.3122             | 1.667 |
| Butane          | C <sub>4</sub> H <sub>10</sub> | 0.1433                         | 1.7164             | 1.5734             | 1.091 |
| Carbon dioxide  | CO <sub>2</sub>                | 0.1889                         | 0.846              | 0.657              | 1.289 |
| Carbon monoxide | CO                             | 0.2968                         | 1.040              | 0.744              | 1.400 |
| Ethane          | C <sub>2</sub> H <sub>6</sub>  | 0.2765                         | 1.7662             | 1.4897             | 1.186 |
| Ethylene        | C <sub>2</sub> H <sub>4</sub>  | 0.2964                         | 1.5482             | 1.2518             | 1.237 |
| Helium          | He                             | 2.0769                         | 5.1926             | 3.1156             | 1.667 |
| Hydrogen        | H <sub>2</sub>                 | 4.1240                         | 14.307             | 10.183             | 1.405 |
| Methane         | CH <sub>4</sub>                | 0.5182                         | 2.2537             | 1.7354             | 1.299 |
| Neon            | Ne                             | 0.4119                         | 1.0299             | 0.6179             | 1.667 |
| Nitrogen        | N <sub>2</sub>                 | 0.2968                         | 1.039              | 0.743              | 1.400 |
| Octane          | C <sub>8</sub> H <sub>18</sub> | 0.0729                         | 1.7113             | 1.6385             | 1.044 |
| Oxygen          | O <sub>2</sub>                 | 0.2598                         | 0.918              | 0.658              | 1.395 |
| Propane         | C <sub>3</sub> H <sub>8</sub>  | 0.1885                         | 1.6794             | 1.4909             | 1.126 |
| Steam           | H <sub>2</sub> O               | 0.4615                         | 1.8723             | 1.4108             | 1.327 |

Note: The unit kJ/kg · K is equivalent to kJ/kg · °C.

Source: *Chemical and Process Thermodynamics 3/E* by Kyle, B. G., © 2000. Adapted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

TABLE A-2

Ideal-gas specific heats of various common gases (*Continued*)

(b) At various temperatures

| Temperature,<br>K | $c_p$<br>kJ/kg · K             | $c_v$<br>kJ/kg · K | $k$   | $c_p$<br>kJ/kg · K                    | $c_v$<br>kJ/kg · K | $k$   | $c_p$<br>kJ/kg · K           | $c_v$<br>kJ/kg · K | $k$   |
|-------------------|--------------------------------|--------------------|-------|---------------------------------------|--------------------|-------|------------------------------|--------------------|-------|
|                   | <i>Air</i>                     |                    |       | <i>Carbon dioxide, CO<sub>2</sub></i> |                    |       | <i>Carbon monoxide, CO</i>   |                    |       |
| 250               | 1.003                          | 0.716              | 1.401 | 0.791                                 | 0.602              | 1.314 | 1.039                        | 0.743              | 1.400 |
| 300               | 1.005                          | 0.718              | 1.400 | 0.846                                 | 0.657              | 1.288 | 1.040                        | 0.744              | 1.399 |
| 350               | 1.008                          | 0.721              | 1.398 | 0.895                                 | 0.706              | 1.268 | 1.043                        | 0.746              | 1.398 |
| 400               | 1.013                          | 0.726              | 1.395 | 0.939                                 | 0.750              | 1.252 | 1.047                        | 0.751              | 1.395 |
| 450               | 1.020                          | 0.733              | 1.391 | 0.978                                 | 0.790              | 1.239 | 1.054                        | 0.757              | 1.392 |
| 500               | 1.029                          | 0.742              | 1.387 | 1.014                                 | 0.825              | 1.229 | 1.063                        | 0.767              | 1.387 |
| 550               | 1.040                          | 0.753              | 1.381 | 1.046                                 | 0.857              | 1.220 | 1.075                        | 0.778              | 1.382 |
| 600               | 1.051                          | 0.764              | 1.376 | 1.075                                 | 0.886              | 1.213 | 1.087                        | 0.790              | 1.376 |
| 650               | 1.063                          | 0.776              | 1.370 | 1.102                                 | 0.913              | 1.207 | 1.100                        | 0.803              | 1.370 |
| 700               | 1.075                          | 0.788              | 1.364 | 1.126                                 | 0.937              | 1.202 | 1.113                        | 0.816              | 1.364 |
| 750               | 1.087                          | 0.800              | 1.359 | 1.148                                 | 0.959              | 1.197 | 1.126                        | 0.829              | 1.358 |
| 800               | 1.099                          | 0.812              | 1.354 | 1.169                                 | 0.980              | 1.193 | 1.139                        | 0.842              | 1.353 |
| 900               | 1.121                          | 0.834              | 1.344 | 1.204                                 | 1.015              | 1.186 | 1.163                        | 0.866              | 1.343 |
| 1000              | 1.142                          | 0.855              | 1.336 | 1.234                                 | 1.045              | 1.181 | 1.185                        | 0.888              | 1.335 |
|                   | <i>Hydrogen, H<sub>2</sub></i> |                    |       | <i>Nitrogen, N<sub>2</sub></i>        |                    |       | <i>Oxygen, O<sub>2</sub></i> |                    |       |
| 250               | 14.051                         | 9.927              | 1.416 | 1.039                                 | 0.742              | 1.400 | 0.913                        | 0.653              | 1.398 |
| 300               | 14.307                         | 10.183             | 1.405 | 1.039                                 | 0.743              | 1.400 | 0.918                        | 0.658              | 1.395 |
| 350               | 14.427                         | 10.302             | 1.400 | 1.041                                 | 0.744              | 1.399 | 0.928                        | 0.668              | 1.389 |
| 400               | 14.476                         | 10.352             | 1.398 | 1.044                                 | 0.747              | 1.397 | 0.941                        | 0.681              | 1.382 |
| 450               | 14.501                         | 10.377             | 1.398 | 1.049                                 | 0.752              | 1.395 | 0.956                        | 0.696              | 1.373 |
| 500               | 14.513                         | 10.389             | 1.397 | 1.056                                 | 0.759              | 1.391 | 0.972                        | 0.712              | 1.365 |
| 550               | 14.530                         | 10.405             | 1.396 | 1.065                                 | 0.768              | 1.387 | 0.988                        | 0.728              | 1.358 |
| 600               | 14.546                         | 10.422             | 1.396 | 1.075                                 | 0.778              | 1.382 | 1.003                        | 0.743              | 1.350 |
| 650               | 14.571                         | 10.447             | 1.395 | 1.086                                 | 0.789              | 1.376 | 1.017                        | 0.758              | 1.343 |
| 700               | 14.604                         | 10.480             | 1.394 | 1.098                                 | 0.801              | 1.371 | 1.031                        | 0.771              | 1.337 |
| 750               | 14.645                         | 10.521             | 1.392 | 1.110                                 | 0.813              | 1.365 | 1.043                        | 0.783              | 1.332 |
| 800               | 14.695                         | 10.570             | 1.390 | 1.121                                 | 0.825              | 1.360 | 1.054                        | 0.794              | 1.327 |
| 900               | 14.822                         | 10.698             | 1.385 | 1.145                                 | 0.849              | 1.349 | 1.074                        | 0.814              | 1.319 |
| 1000              | 14.983                         | 10.859             | 1.380 | 1.167                                 | 0.870              | 1.341 | 1.090                        | 0.830              | 1.313 |

Source: Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), p. 783, Table A-4M. Originally published in *Tables of Thermal Properties of Gases*, NBS Circular 564, 1955.

TABLE A-2

Ideal-gas specific heats of various common gases (*Concluded*)

(c) As a function of temperature

$$\bar{c}_p = a + bT + cT^2 + dT^3$$

(T in K,  $c_p$  in kJ/kmol · K)

| Substance         | Formula                         | a      | b                         | c                        | d                        | Temperature range, K | % error |      |
|-------------------|---------------------------------|--------|---------------------------|--------------------------|--------------------------|----------------------|---------|------|
|                   |                                 |        |                           |                          |                          |                      | Max.    | Avg. |
| Nitrogen          | N <sub>2</sub>                  | 28.90  | $-0.1571 \times 10^{-2}$  | $0.8081 \times 10^{-5}$  | $-2.873 \times 10^{-9}$  | 273–1800             | 0.59    | 0.34 |
| Oxygen            | O <sub>2</sub>                  | 25.48  | $1.520 \times 10^{-2}$    | $-0.7155 \times 10^{-5}$ | $1.312 \times 10^{-9}$   | 273–1800             | 1.19    | 0.28 |
| Air               | —                               | 28.11  | $0.1967 \times 10^{-2}$   | $0.4802 \times 10^{-5}$  | $-1.966 \times 10^{-9}$  | 273–1800             | 0.72    | 0.33 |
| Hydrogen          | H <sub>2</sub>                  | 29.11  | $-0.1916 \times 10^{-2}$  | $0.4003 \times 10^{-5}$  | $-0.8704 \times 10^{-9}$ | 273–1800             | 1.01    | 0.26 |
| Carbon monoxide   | CO                              | 28.16  | $0.1675 \times 10^{-2}$   | $0.5372 \times 10^{-5}$  | $-2.222 \times 10^{-9}$  | 273–1800             | 0.89    | 0.37 |
| Carbon dioxide    | CO <sub>2</sub>                 | 22.26  | $5.981 \times 10^{-2}$    | $-3.501 \times 10^{-5}$  | $7.469 \times 10^{-9}$   | 273–1800             | 0.67    | 0.22 |
| Water vapor       | H <sub>2</sub> O                | 32.24  | $0.1923 \times 10^{-2}$   | $1.055 \times 10^{-5}$   | $-3.595 \times 10^{-9}$  | 273–1800             | 0.53    | 0.24 |
| Nitric oxide      | NO                              | 29.34  | $-0.09395 \times 10^{-2}$ | $0.9747 \times 10^{-5}$  | $-4.187 \times 10^{-9}$  | 273–1500             | 0.97    | 0.36 |
| Nitrous oxide     | N <sub>2</sub> O                | 24.11  | $5.8632 \times 10^{-2}$   | $-3.562 \times 10^{-5}$  | $10.58 \times 10^{-9}$   | 273–1500             | 0.59    | 0.26 |
| Nitrogen dioxide  | NO <sub>2</sub>                 | 22.9   | $5.715 \times 10^{-2}$    | $-3.52 \times 10^{-5}$   | $7.87 \times 10^{-9}$    | 273–1500             | 0.46    | 0.18 |
| Ammonia           | NH <sub>3</sub>                 | 27.568 | $2.5630 \times 10^{-2}$   | $0.99072 \times 10^{-5}$ | $-6.6909 \times 10^{-9}$ | 273–1500             | 0.91    | 0.36 |
| Sulfur            | S <sub>2</sub>                  | 27.21  | $2.218 \times 10^{-2}$    | $-1.628 \times 10^{-5}$  | $3.986 \times 10^{-9}$   | 273–1800             | 0.99    | 0.38 |
| Sulfur dioxide    | SO <sub>2</sub>                 | 25.78  | $5.795 \times 10^{-2}$    | $-3.812 \times 10^{-5}$  | $8.612 \times 10^{-9}$   | 273–1800             | 0.45    | 0.24 |
| Sulfur trioxide   | SO <sub>3</sub>                 | 16.40  | $14.58 \times 10^{-2}$    | $-11.20 \times 10^{-5}$  | $32.42 \times 10^{-9}$   | 273–1300             | 0.29    | 0.13 |
| Acetylene         | C <sub>2</sub> H <sub>2</sub>   | 21.8   | $9.2143 \times 10^{-2}$   | $-6.527 \times 10^{-5}$  | $18.21 \times 10^{-9}$   | 273–1500             | 1.46    | 0.59 |
| Benzene           | C <sub>6</sub> H <sub>6</sub>   | -36.22 | $48.475 \times 10^{-2}$   | $-31.57 \times 10^{-5}$  | $77.62 \times 10^{-9}$   | 273–1500             | 0.34    | 0.20 |
| Methanol          | CH <sub>4</sub> O               | 19.0   | $9.152 \times 10^{-2}$    | $-1.22 \times 10^{-5}$   | $-8.039 \times 10^{-9}$  | 273–1000             | 0.18    | 0.08 |
| Ethanol           | C <sub>2</sub> H <sub>6</sub> O | 19.9   | $20.96 \times 10^{-2}$    | $-10.38 \times 10^{-5}$  | $20.05 \times 10^{-9}$   | 273–1500             | 0.40    | 0.22 |
| Hydrogen chloride | HCl                             | 30.33  | $-0.7620 \times 10^{-2}$  | $1.327 \times 10^{-5}$   | $-4.338 \times 10^{-9}$  | 273–1500             | 0.22    | 0.08 |
| Methane           | CH <sub>4</sub>                 | 19.89  | $5.024 \times 10^{-2}$    | $1.269 \times 10^{-5}$   | $-11.01 \times 10^{-9}$  | 273–1500             | 1.33    | 0.57 |
| Ethane            | C <sub>2</sub> H <sub>6</sub>   | 6.900  | $17.27 \times 10^{-2}$    | $-6.406 \times 10^{-5}$  | $7.285 \times 10^{-9}$   | 273–1500             | 0.83    | 0.28 |
| Propane           | C <sub>3</sub> H <sub>8</sub>   | -4.04  | $30.48 \times 10^{-2}$    | $-15.72 \times 10^{-5}$  | $31.74 \times 10^{-9}$   | 273–1500             | 0.40    | 0.12 |
| n-Butane          | C <sub>4</sub> H <sub>10</sub>  | 3.96   | $37.15 \times 10^{-2}$    | $-18.34 \times 10^{-5}$  | $35.00 \times 10^{-9}$   | 273–1500             | 0.54    | 0.24 |
| i-Butane          | C <sub>4</sub> H <sub>10</sub>  | -7.913 | $41.60 \times 10^{-2}$    | $-23.01 \times 10^{-5}$  | $49.91 \times 10^{-9}$   | 273–1500             | 0.25    | 0.13 |
| n-Pentane         | C <sub>5</sub> H <sub>12</sub>  | 6.774  | $45.43 \times 10^{-2}$    | $-22.46 \times 10^{-5}$  | $42.29 \times 10^{-9}$   | 273–1500             | 0.56    | 0.21 |
| n-Hexane          | C <sub>6</sub> H <sub>14</sub>  | 6.938  | $55.22 \times 10^{-2}$    | $-28.65 \times 10^{-5}$  | $57.69 \times 10^{-9}$   | 273–1500             | 0.72    | 0.20 |
| Ethylene          | C <sub>2</sub> H <sub>4</sub>   | 3.95   | $15.64 \times 10^{-2}$    | $-8.344 \times 10^{-5}$  | $17.67 \times 10^{-9}$   | 273–1500             | 0.54    | 0.13 |
| Propylene         | C <sub>3</sub> H <sub>6</sub>   | 3.15   | $23.83 \times 10^{-2}$    | $-12.18 \times 10^{-5}$  | $24.62 \times 10^{-9}$   | 273–1500             | 0.73    | 0.17 |

Source: B. G. Kyle, *Chemical and Process Thermodynamics* (Englewood Cliffs, NJ: Prentice-Hall, 1984). Used with permission.

TABLE A-3

Properties of common liquids, solids, and foods

(a) Liquids

| Substance                           | Boiling data at 1 atm    |                                              | Freezing data      |                                        | Liquid properties |                                    |                                 |
|-------------------------------------|--------------------------|----------------------------------------------|--------------------|----------------------------------------|-------------------|------------------------------------|---------------------------------|
|                                     | Normal boiling point, °C | Latent heat of vaporization $h_{fg}$ , kJ/kg | Freezing point, °C | Latent heat of fusion $h_{if}$ , kJ/kg | Temperature, °C   | Density $\rho$ , kg/m <sup>3</sup> | Specific heat $c_p$ , kJ/kg · K |
| Ammonia                             | -33.3                    | 1357                                         | -77.7              | 322.4                                  | -33.3             | 682                                | 4.43                            |
|                                     |                          |                                              |                    |                                        | -20               | 665                                | 4.52                            |
|                                     |                          |                                              |                    |                                        | 0                 | 639                                | 4.60                            |
|                                     |                          |                                              |                    |                                        | 25                | 602                                | 4.80                            |
|                                     |                          |                                              |                    |                                        |                   |                                    |                                 |
| Argon                               | -185.9                   | 161.6                                        | -189.3             | 28                                     | -185.6            | 1394                               | 1.14                            |
| Benzene                             | 80.2                     | 394                                          | 5.5                | 126                                    | 20                | 879                                | 1.72                            |
| Brine (20% sodium chloride by mass) | 103.9                    | —                                            | -17.4              | —                                      | 20                | 1150                               | 3.11                            |
| <i>n</i> -Butane                    | -0.5                     | 385.2                                        | -138.5             | 80.3                                   | -0.5              | 601                                | 2.31                            |
| Carbon dioxide                      | -78.4*                   | 230.5 (at 0°C)                               | -56.6              |                                        | 0                 | 298                                | 0.59                            |
| Ethanol                             | 78.2                     | 838.3                                        | -114.2             | 109                                    | 25                | 783                                | 2.46                            |
| Ethyl alcohol                       | 78.6                     | 855                                          | -156               | 108                                    | 20                | 789                                | 2.84                            |
| Ethylene glycol                     | 198.1                    | 800.1                                        | -10.8              | 181.1                                  | 20                | 1109                               | 2.84                            |
| Glycerine                           | 179.9                    | 974                                          | 18.9               | 200.6                                  | 20                | 1261                               | 2.32                            |
| Helium                              | -268.9                   | 22.8                                         | —                  | —                                      | -268.9            | 146.2                              | 22.8                            |
| Hydrogen                            | -252.8                   | 445.7                                        | -259.2             | 59.5                                   | -252.8            | 70.7                               | 10.0                            |
| Isobutane                           | -11.7                    | 367.1                                        | -160               | 105.7                                  | -11.7             | 593.8                              | 2.28                            |
| Kerosene                            | 204–293                  | 251                                          | -24.9              | —                                      | 20                | 820                                | 2.00                            |
| Mercury                             | 356.7                    | 294.7                                        | -38.9              | 11.4                                   | 25                | 13,560                             | 0.139                           |
| Methane                             | -161.5                   | 510.4                                        | -182.2             | 58.4                                   | -161.5            | 423                                | 3.49                            |
|                                     |                          |                                              |                    |                                        | -100              | 301                                | 5.79                            |
| Methanol                            | 64.5                     | 1100                                         | -97.7              | 99.2                                   | 25                | 787                                | 2.55                            |
| Nitrogen                            | -195.8                   | 198.6                                        | -210               | 25.3                                   | -195.8            | 809                                | 2.06                            |
|                                     |                          |                                              |                    |                                        | -160              | 596                                | 2.97                            |
|                                     |                          |                                              |                    |                                        | 20                | 703                                | 2.10                            |
| Octane                              | 124.8                    | 306.3                                        | -57.5              | 180.7                                  | 25                | 910                                | 1.80                            |
| Oil (light)                         |                          |                                              |                    |                                        |                   | 1141                               | 1.71                            |
| Oxygen                              | -183                     | 212.7                                        | -218.8             | 13.7                                   | -183              | 640                                | 2.0                             |
| Petroleum                           | —                        | 230–384                                      |                    |                                        | 20                | 581                                | 2.25                            |
| Propane                             | -42.1                    | 427.8                                        | -187.7             | 80.0                                   | -42.1             | 529                                | 2.53                            |
|                                     |                          |                                              |                    |                                        | 0                 | 449                                | 3.13                            |
|                                     |                          |                                              |                    |                                        | 50                | 1443                               | 1.23                            |
|                                     |                          |                                              |                    |                                        | -26.1             | 1374                               | 1.27                            |
|                                     |                          |                                              |                    |                                        | 0                 | 1295                               | 1.34                            |
| Refrigerant-134a                    | -26.1                    | 217.0                                        | -96.6              | —                                      | 25                | 1207                               | 1.43                            |
|                                     |                          |                                              |                    |                                        | 0                 | 1000                               | 4.22                            |
|                                     |                          |                                              |                    |                                        | 25                | 997                                | 4.18                            |
|                                     |                          |                                              |                    |                                        | 50                | 988                                | 4.18                            |
|                                     |                          |                                              |                    |                                        | 75                | 975                                | 4.19                            |
| Water                               | 100                      | 2257                                         | 0.0                | 333.7                                  | 100               | 958                                | 4.22                            |

\* Sublimation temperature. (At pressures below the triple-point pressure of 518 kPa, carbon dioxide exists as a solid or gas. Also, the freezing-point temperature of carbon dioxide is the triple-point temperature of -56.5°C.)

TABLE A-3

Properties of common liquids, solids, and foods (*Concluded*)

(b) Solids (values are for room temperature unless indicated otherwise)

| Substance                         | Density,<br>$\rho$ kg/m <sup>3</sup> | Specific heat,<br>$c_p$ kJ/kg · K | Substance                      | Density,<br>$\rho$ kg/m <sup>3</sup> | Specific heat,<br>$c_p$ kJ/kg · K |
|-----------------------------------|--------------------------------------|-----------------------------------|--------------------------------|--------------------------------------|-----------------------------------|
| Metals                            |                                      |                                   | Nonmetals                      |                                      |                                   |
| Aluminum                          |                                      |                                   | Asphalt                        | 2110                                 | 0.920                             |
| 200 K                             |                                      | 0.797                             | Brick, common                  | 1922                                 | 0.79                              |
| 250 K                             |                                      | 0.859                             | Brick, fireclay (500°C)        | 2300                                 | 0.960                             |
| 300 K                             | 2,700                                | 0.902                             | Concrete                       | 2300                                 | 0.653                             |
| 350 K                             |                                      | 0.929                             | Clay                           | 1000                                 | 0.920                             |
| 400 K                             |                                      | 0.949                             | Diamond                        | 2420                                 | 0.616                             |
| 450 K                             |                                      | 0.973                             | Glass, window                  | 2700                                 | 0.800                             |
| 500 K                             |                                      | 0.997                             | Glass, pyrex                   | 2230                                 | 0.840                             |
| Bronze (76% Cu, 2% Zn,<br>2% Al)  | 8,280                                | 0.400                             | Graphite                       | 2500                                 | 0.711                             |
| Brass, yellow (65% Cu,<br>35% Zn) | 8,310                                | 0.400                             | Granite                        | 2700                                 | 1.017                             |
| Copper                            |                                      |                                   | Gypsum or plaster board        | 800                                  | 1.09                              |
| −173°C                            |                                      | 0.254                             | Ice                            |                                      |                                   |
| −100°C                            |                                      | 0.342                             | 200 K                          |                                      | 1.56                              |
| −50°C                             |                                      | 0.367                             | 220 K                          |                                      | 1.71                              |
| 0°C                               |                                      | 0.381                             | 240 K                          |                                      | 1.86                              |
| 27°C                              | 8,900                                | 0.386                             | 260 K                          |                                      | 2.01                              |
| 100°C                             |                                      | 0.393                             | 273 K                          | 921                                  | 2.11                              |
| 200°C                             |                                      | 0.403                             | Limestone                      | 1650                                 | 0.909                             |
| Iron                              | 7,840                                | 0.45                              | Marble                         | 2600                                 | 0.880                             |
| Lead                              | 11,310                               | 0.128                             | Plywood (Douglas Fir)          | 545                                  | 1.21                              |
| Magnesium                         | 1,730                                | 1.000                             | Rubber (soft)                  | 1100                                 | 1.840                             |
| Nickel                            | 8,890                                | 0.440                             | Rubber (hard)                  | 1150                                 | 2.009                             |
| Silver                            | 10,470                               | 0.235                             | Sand                           | 1520                                 | 0.800                             |
| Steel, mild                       | 7,830                                | 0.500                             | Stone                          | 1500                                 | 0.800                             |
| Tungsten                          | 19,400                               | 0.130                             | Woods, hard (maple, oak, etc.) | 721                                  | 1.26                              |
|                                   |                                      |                                   | Woods, soft (fir, pine, etc.)  | 513                                  | 1.38                              |

(c) Foods

| Food          | Water<br>content,<br>% (mass) | Freezing<br>point, °C | Specific heat,<br>kJ/kg · K |                   | Latent<br>heat of<br>fusion,<br>kJ/kg | Food           | Water<br>content,<br>% (mass) | Freezing<br>point, °C | Specific heat,<br>kJ/kg · K |                   | Latent<br>heat of<br>fusion,<br>kJ/kg |
|---------------|-------------------------------|-----------------------|-----------------------------|-------------------|---------------------------------------|----------------|-------------------------------|-----------------------|-----------------------------|-------------------|---------------------------------------|
|               |                               |                       | Above<br>freezing           | Below<br>freezing |                                       |                |                               |                       | Above<br>freezing           | Below<br>freezing |                                       |
| Apples        | 84                            | −1.1                  | 3.65                        | 1.90              | 281                                   | Lettuce        | 95                            | −0.2                  | 4.02                        | 2.04              | 317                                   |
| Bananas       | 75                            | −0.8                  | 3.35                        | 1.78              | 251                                   | Milk, whole    | 88                            | −0.6                  | 3.79                        | 1.95              | 294                                   |
| Beef round    | 67                            | —                     | 3.08                        | 1.68              | 224                                   | Oranges        | 87                            | −0.8                  | 3.75                        | 1.94              | 291                                   |
| Broccoli      | 90                            | −0.6                  | 3.86                        | 1.97              | 301                                   | Potatoes       | 78                            | −0.6                  | 3.45                        | 1.82              | 261                                   |
| Butter        | 16                            | —                     | —                           | 1.04              | 53                                    | Salmon fish    | 64                            | −2.2                  | 2.98                        | 1.65              | 214                                   |
| Cheese, swiss | 39                            | −10.0                 | 2.15                        | 1.33              | 130                                   | Shrimp         | 83                            | −2.2                  | 3.62                        | 1.89              | 277                                   |
| Cherries      | 80                            | −1.8                  | 3.52                        | 1.85              | 267                                   | Spinach        | 93                            | −0.3                  | 3.96                        | 2.01              | 311                                   |
| Chicken       | 74                            | −2.8                  | 3.32                        | 1.77              | 247                                   | Strawberries   | 90                            | −0.8                  | 3.86                        | 1.97              | 301                                   |
| Corn, sweet   | 74                            | −0.6                  | 3.32                        | 1.77              | 247                                   | Tomatoes, ripe | 94                            | −0.5                  | 3.99                        | 2.02              | 314                                   |
| Eggs, whole   | 74                            | −0.6                  | 3.32                        | 1.77              | 247                                   | Turkey         | 64                            | —                     | 2.98                        | 1.65              | 214                                   |
| Ice cream     | 63                            | −5.6                  | 2.95                        | 1.63              | 210                                   | Watermelon     | 93                            | −0.4                  | 3.96                        | 2.01              | 311                                   |

Source: Values are obtained from various handbooks and other sources or are calculated. Water content and freezing-point data of foods are from ASHRAE, *Handbook of Fundamentals*, SI version (Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1993), Chapter 30, Table 1. Freezing point is the temperature at which freezing starts for fruits and vegetables, and the average freezing temperature for other foods.

TABLE A-4

Saturated water—Temperature table

| Temp.,<br>$T$ °C | Sat.<br>press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>kJ/kg |                    |                         | Enthalpy,<br>kJ/kg       |                    |                         | Entropy,<br>kJ/kg · K    |                    |                         |
|------------------|-----------------------------------------|--------------------------------------------|-------------------------|---------------------------|--------------------|-------------------------|--------------------------|--------------------|-------------------------|--------------------------|--------------------|-------------------------|
|                  |                                         | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$  | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$ | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$ | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 0.01             | 0.6117                                  | 0.001000                                   | 206.00                  | 0.000                     | 2374.9             | 2374.9                  | 0.001                    | 2500.9             | 2500.9                  | 0.0000                   | 9.1556             | 9.1556                  |
| 5                | 0.8725                                  | 0.001000                                   | 147.03                  | 21.019                    | 2360.8             | 2381.8                  | 21.020                   | 2489.1             | 2510.1                  | 0.0763                   | 8.9487             | 9.0249                  |
| 10               | 1.2281                                  | 0.001000                                   | 106.32                  | 42.020                    | 2346.6             | 2388.7                  | 42.022                   | 2477.2             | 2519.2                  | 0.1511                   | 8.7488             | 8.8999                  |
| 15               | 1.7057                                  | 0.001001                                   | 77.885                  | 62.980                    | 2332.5             | 2395.5                  | 62.982                   | 2465.4             | 2528.3                  | 0.2245                   | 8.5559             | 8.7803                  |
| 20               | 2.3392                                  | 0.001002                                   | 57.762                  | 83.913                    | 2318.4             | 2402.3                  | 83.915                   | 2453.5             | 2537.4                  | 0.2965                   | 8.3696             | 8.6661                  |
| 25               | 3.1698                                  | 0.001003                                   | 43.340                  | 104.83                    | 2304.3             | 2409.1                  | 104.83                   | 2441.7             | 2546.5                  | 0.3672                   | 8.1895             | 8.5567                  |
| 30               | 4.2469                                  | 0.001004                                   | 32.879                  | 125.73                    | 2290.2             | 2415.9                  | 125.74                   | 2429.8             | 2555.6                  | 0.4368                   | 8.0152             | 8.4520                  |
| 35               | 5.6291                                  | 0.001006                                   | 25.205                  | 146.63                    | 2276.0             | 2422.7                  | 146.64                   | 2417.9             | 2564.6                  | 0.5051                   | 7.8466             | 8.3517                  |
| 40               | 7.3851                                  | 0.001008                                   | 19.515                  | 167.53                    | 2261.9             | 2429.4                  | 167.53                   | 2406.0             | 2573.5                  | 0.5724                   | 7.6832             | 8.2556                  |
| 45               | 9.5953                                  | 0.001010                                   | 15.251                  | 188.43                    | 2247.7             | 2436.1                  | 188.44                   | 2394.0             | 2582.4                  | 0.6386                   | 7.5247             | 8.1633                  |
| 50               | 12.352                                  | 0.001012                                   | 12.026                  | 209.33                    | 2233.4             | 2442.7                  | 209.34                   | 2382.0             | 2591.3                  | 0.7038                   | 7.3710             | 8.0748                  |
| 55               | 15.763                                  | 0.001015                                   | 9.5639                  | 230.24                    | 2219.1             | 2449.3                  | 230.26                   | 2369.8             | 2600.1                  | 0.7680                   | 7.2218             | 7.9898                  |
| 60               | 19.947                                  | 0.001017                                   | 7.6670                  | 251.16                    | 2204.7             | 2455.9                  | 251.18                   | 2357.7             | 2608.8                  | 0.8313                   | 7.0769             | 7.9082                  |
| 65               | 25.043                                  | 0.001020                                   | 6.1935                  | 272.09                    | 2190.3             | 2462.4                  | 272.12                   | 2345.4             | 2617.5                  | 0.8937                   | 6.9360             | 7.8296                  |
| 70               | 31.202                                  | 0.001023                                   | 5.0396                  | 293.04                    | 2175.8             | 2468.9                  | 293.07                   | 2333.0             | 2626.1                  | 0.9551                   | 6.7989             | 7.7540                  |
| 75               | 38.597                                  | 0.001026                                   | 4.1291                  | 313.99                    | 2161.3             | 2475.3                  | 314.03                   | 2320.6             | 2634.6                  | 1.0158                   | 6.6655             | 7.6812                  |
| 80               | 47.416                                  | 0.001029                                   | 3.4053                  | 334.97                    | 2146.6             | 2481.6                  | 335.02                   | 2308.0             | 2643.0                  | 1.0756                   | 6.5355             | 7.6111                  |
| 85               | 57.868                                  | 0.001032                                   | 2.8261                  | 355.96                    | 2131.9             | 2487.8                  | 356.02                   | 2295.3             | 2651.4                  | 1.1346                   | 6.4089             | 7.5435                  |
| 90               | 70.183                                  | 0.001036                                   | 2.3593                  | 376.97                    | 2117.0             | 2494.0                  | 377.04                   | 2282.5             | 2659.6                  | 1.1929                   | 6.2853             | 7.4782                  |
| 95               | 84.609                                  | 0.001040                                   | 1.9808                  | 398.00                    | 2102.0             | 2500.1                  | 398.09                   | 2269.6             | 2667.6                  | 1.2504                   | 6.1647             | 7.4151                  |
| 100              | 101.42                                  | 0.001043                                   | 1.6720                  | 419.06                    | 2087.0             | 2506.0                  | 419.17                   | 2256.4             | 2675.6                  | 1.3072                   | 6.0470             | 7.3542                  |
| 105              | 120.90                                  | 0.001047                                   | 1.4186                  | 440.15                    | 2071.8             | 2511.9                  | 440.28                   | 2243.1             | 2683.4                  | 1.3634                   | 5.9319             | 7.2952                  |
| 110              | 143.38                                  | 0.001052                                   | 1.2094                  | 461.27                    | 2056.4             | 2517.7                  | 461.42                   | 2229.7             | 2691.1                  | 1.4188                   | 5.8193             | 7.2382                  |
| 115              | 169.18                                  | 0.001056                                   | 1.0360                  | 482.42                    | 2040.9             | 2523.3                  | 482.59                   | 2216.0             | 2698.6                  | 1.4737                   | 5.7092             | 7.1829                  |
| 120              | 198.67                                  | 0.001060                                   | 0.89133                 | 503.60                    | 2025.3             | 2528.9                  | 503.81                   | 2202.1             | 2706.0                  | 1.5279                   | 5.6013             | 7.1292                  |
| 125              | 232.23                                  | 0.001065                                   | 0.77012                 | 524.83                    | 2009.5             | 2534.3                  | 525.07                   | 2188.1             | 2713.1                  | 1.5816                   | 5.4956             | 7.0771                  |
| 130              | 270.28                                  | 0.001070                                   | 0.66808                 | 546.10                    | 1993.4             | 2539.5                  | 546.38                   | 2173.7             | 2720.1                  | 1.6346                   | 5.3919             | 7.0265                  |
| 135              | 313.22                                  | 0.001075                                   | 0.58179                 | 567.41                    | 1977.3             | 2544.7                  | 567.75                   | 2159.1             | 2726.9                  | 1.6872                   | 5.2901             | 6.9773                  |
| 140              | 361.53                                  | 0.001080                                   | 0.50850                 | 588.77                    | 1960.9             | 2549.6                  | 589.16                   | 2144.3             | 2733.5                  | 1.7392                   | 5.1901             | 6.9294                  |
| 145              | 415.68                                  | 0.001085                                   | 0.44600                 | 610.19                    | 1944.2             | 2554.4                  | 610.64                   | 2129.2             | 2739.8                  | 1.7908                   | 5.0919             | 6.8827                  |
| 150              | 476.16                                  | 0.001091                                   | 0.39248                 | 631.66                    | 1927.4             | 2559.1                  | 632.18                   | 2113.8             | 2745.9                  | 1.8418                   | 4.9953             | 6.8371                  |
| 155              | 543.49                                  | 0.001096                                   | 0.34648                 | 653.19                    | 1910.3             | 2563.5                  | 653.79                   | 2098.0             | 2751.8                  | 1.8924                   | 4.9002             | 6.7927                  |
| 160              | 618.23                                  | 0.001102                                   | 0.30680                 | 674.79                    | 1893.0             | 2567.8                  | 675.47                   | 2082.0             | 2757.5                  | 1.9426                   | 4.8066             | 6.7492                  |
| 165              | 700.93                                  | 0.001108                                   | 0.27244                 | 696.46                    | 1875.4             | 2571.9                  | 697.24                   | 2065.6             | 2762.8                  | 1.9923                   | 4.7143             | 6.7067                  |
| 170              | 792.18                                  | 0.001114                                   | 0.24260                 | 718.20                    | 1857.5             | 2575.7                  | 719.08                   | 2048.8             | 2767.9                  | 2.0417                   | 4.6233             | 6.6650                  |
| 175              | 892.60                                  | 0.001121                                   | 0.21659                 | 740.02                    | 1839.4             | 2579.4                  | 741.02                   | 2031.7             | 2772.7                  | 2.0906                   | 4.5335             | 6.6242                  |
| 180              | 1002.8                                  | 0.001127                                   | 0.19384                 | 761.92                    | 1820.9             | 2582.8                  | 763.05                   | 2014.2             | 2777.2                  | 2.1392                   | 4.4448             | 6.5841                  |
| 185              | 1123.5                                  | 0.001134                                   | 0.17390                 | 783.91                    | 1802.1             | 2586.0                  | 785.19                   | 1996.2             | 2781.4                  | 2.1875                   | 4.3572             | 6.5447                  |
| 190              | 1255.2                                  | 0.001141                                   | 0.15636                 | 806.00                    | 1783.0             | 2589.0                  | 807.43                   | 1977.9             | 2785.3                  | 2.2355                   | 4.2705             | 6.5059                  |
| 195              | 1398.8                                  | 0.001149                                   | 0.14089                 | 828.18                    | 1763.6             | 2591.7                  | 829.78                   | 1959.0             | 2788.8                  | 2.2831                   | 4.1847             | 6.4678                  |
| 200              | 1554.9                                  | 0.001157                                   | 0.12721                 | 850.46                    | 1743.7             | 2594.2                  | 852.26                   | 1939.8             | 2792.0                  | 2.3305                   | 4.0997             | 6.4302                  |



TABLE A-4

Saturated water—Temperature table (Continued)

| Temp.,<br>$T$ °C | Sat.<br>press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|------------------|-----------------------------------------|--------------------------------------------|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|-------------------------------------------|--------------------|-------------------------|
|                  |                                         | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$           | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$    | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                  | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 205              | 1724.3                                  | 0.001164                                   | 0.11508                 | 872.86                             | 1723.5             | 2596.4                  | 874.87                      | 1920.0             | 2794.8                  | 2.3776                                    | 4.0154             | 6.3930                  |
| 210              | 1907.7                                  | 0.001173                                   | 0.10429                 | 895.38                             | 1702.9             | 2598.3                  | 897.61                      | 1899.7             | 2797.3                  | 2.4245                                    | 3.9318             | 6.3563                  |
| 215              | 2105.9                                  | 0.001181                                   | 0.094680                | 918.02                             | 1681.9             | 2599.9                  | 920.50                      | 1878.8             | 2799.3                  | 2.4712                                    | 3.8489             | 6.3200                  |
| 220              | 2319.6                                  | 0.001190                                   | 0.086094                | 940.79                             | 1660.5             | 2601.3                  | 943.55                      | 1857.4             | 2801.0                  | 2.5176                                    | 3.7664             | 6.2840                  |
| 225              | 2549.7                                  | 0.001199                                   | 0.078405                | 963.70                             | 1638.6             | 2602.3                  | 966.76                      | 1835.4             | 2802.2                  | 2.5639                                    | 3.6844             | 6.2483                  |
| 230              | 2797.1                                  | 0.001209                                   | 0.071505                | 986.76                             | 1616.1             | 2602.9                  | 990.14                      | 1812.8             | 2802.9                  | 2.6100                                    | 3.6028             | 6.2128                  |
| 235              | 3062.6                                  | 0.001219                                   | 0.065300                | 1010.0                             | 1593.2             | 2603.2                  | 1013.7                      | 1789.5             | 2803.2                  | 2.6560                                    | 3.5216             | 6.1775                  |
| 240              | 3347.0                                  | 0.001229                                   | 0.059707                | 1033.4                             | 1569.8             | 2603.1                  | 1037.5                      | 1765.5             | 2803.0                  | 2.7018                                    | 3.4405             | 6.1424                  |
| 245              | 3651.2                                  | 0.001240                                   | 0.054656                | 1056.9                             | 1545.7             | 2602.7                  | 1061.5                      | 1740.8             | 2802.2                  | 2.7476                                    | 3.3596             | 6.1072                  |
| 250              | 3976.2                                  | 0.001252                                   | 0.050085                | 1080.7                             | 1521.1             | 2601.8                  | 1085.7                      | 1715.3             | 2801.0                  | 2.7933                                    | 3.2788             | 6.0721                  |
| 255              | 4322.9                                  | 0.001263                                   | 0.045941                | 1104.7                             | 1495.8             | 2600.5                  | 1110.1                      | 1689.0             | 2799.1                  | 2.8390                                    | 3.1979             | 6.0369                  |
| 260              | 4692.3                                  | 0.001276                                   | 0.042175                | 1128.8                             | 1469.9             | 2598.7                  | 1134.8                      | 1661.8             | 2796.6                  | 2.8847                                    | 3.1169             | 6.0017                  |
| 265              | 5085.3                                  | 0.001289                                   | 0.038748                | 1153.3                             | 1443.2             | 2596.5                  | 1159.8                      | 1633.7             | 2793.5                  | 2.9304                                    | 3.0358             | 5.9662                  |
| 270              | 5503.0                                  | 0.001303                                   | 0.035622                | 1177.9                             | 1415.7             | 2593.7                  | 1185.1                      | 1604.6             | 2789.7                  | 2.9762                                    | 2.9542             | 5.9305                  |
| 275              | 5946.4                                  | 0.001317                                   | 0.032767                | 1202.9                             | 1387.4             | 2590.3                  | 1210.7                      | 1574.5             | 2785.2                  | 3.0221                                    | 2.8723             | 5.8944                  |
| 280              | 6416.6                                  | 0.001333                                   | 0.030153                | 1228.2                             | 1358.2             | 2586.4                  | 1236.7                      | 1543.2             | 2779.9                  | 3.0681                                    | 2.7898             | 5.8579                  |
| 285              | 6914.6                                  | 0.001349                                   | 0.027756                | 1253.7                             | 1328.1             | 2581.8                  | 1263.1                      | 1510.7             | 2773.7                  | 3.1144                                    | 2.7066             | 5.8210                  |
| 290              | 7441.8                                  | 0.001366                                   | 0.025554                | 1279.7                             | 1296.9             | 2576.5                  | 1289.8                      | 1476.9             | 2766.7                  | 3.1608                                    | 2.6225             | 5.7834                  |
| 295              | 7999.0                                  | 0.001384                                   | 0.023528                | 1306.0                             | 1264.5             | 2570.5                  | 1317.1                      | 1441.6             | 2758.7                  | 3.2076                                    | 2.5374             | 5.7450                  |
| 300              | 8587.9                                  | 0.001404                                   | 0.021659                | 1332.7                             | 1230.9             | 2563.6                  | 1344.8                      | 1404.8             | 2749.6                  | 3.2548                                    | 2.4511             | 5.7059                  |
| 305              | 9209.4                                  | 0.001425                                   | 0.019932                | 1360.0                             | 1195.9             | 2555.8                  | 1373.1                      | 1366.3             | 2739.4                  | 3.3024                                    | 2.3633             | 5.6657                  |
| 310              | 9865.0                                  | 0.001447                                   | 0.018333                | 1387.7                             | 1159.3             | 2547.1                  | 1402.0                      | 1325.9             | 2727.9                  | 3.3506                                    | 2.2737             | 5.6243                  |
| 315              | 10,556                                  | 0.001472                                   | 0.016849                | 1416.1                             | 1121.1             | 2537.2                  | 1431.6                      | 1283.4             | 2715.0                  | 3.3994                                    | 2.1821             | 5.5816                  |
| 320              | 11,284                                  | 0.001499                                   | 0.015470                | 1445.1                             | 1080.9             | 2526.0                  | 1462.0                      | 1238.5             | 2700.6                  | 3.4491                                    | 2.0881             | 5.5372                  |
| 325              | 12,051                                  | 0.001528                                   | 0.014183                | 1475.0                             | 1038.5             | 2513.4                  | 1493.4                      | 1191.0             | 2684.3                  | 3.4998                                    | 1.9911             | 5.4908                  |
| 330              | 12,858                                  | 0.001560                                   | 0.012979                | 1505.7                             | 993.5              | 2499.2                  | 1525.8                      | 1140.3             | 2666.0                  | 3.5516                                    | 1.8906             | 5.4422                  |
| 335              | 13,707                                  | 0.001597                                   | 0.011848                | 1537.5                             | 945.5              | 2483.0                  | 1559.4                      | 1086.0             | 2645.4                  | 3.6050                                    | 1.7857             | 5.3907                  |
| 340              | 14,601                                  | 0.001638                                   | 0.010783                | 1570.7                             | 893.8              | 2464.5                  | 1594.6                      | 1027.4             | 2622.0                  | 3.6602                                    | 1.6756             | 5.3358                  |
| 345              | 15,541                                  | 0.001685                                   | 0.009772                | 1605.5                             | 837.7              | 2443.2                  | 1631.7                      | 963.4              | 2595.1                  | 3.7179                                    | 1.5585             | 5.2765                  |
| 350              | 16,529                                  | 0.001741                                   | 0.008806                | 1642.4                             | 775.9              | 2418.3                  | 1671.2                      | 892.7              | 2563.9                  | 3.7788                                    | 1.4326             | 5.2114                  |
| 355              | 17,570                                  | 0.001808                                   | 0.007872                | 1682.2                             | 706.4              | 2388.6                  | 1714.0                      | 812.9              | 2526.9                  | 3.8442                                    | 1.2942             | 5.1384                  |
| 360              | 18,666                                  | 0.001895                                   | 0.006950                | 1726.2                             | 625.7              | 2351.9                  | 1761.5                      | 720.1              | 2481.6                  | 3.9165                                    | 1.1373             | 5.0537                  |
| 365              | 19,822                                  | 0.002015                                   | 0.006009                | 1777.2                             | 526.4              | 2303.6                  | 1817.2                      | 605.5              | 2422.7                  | 4.0004                                    | 0.9489             | 4.9493                  |
| 370              | 21,044                                  | 0.002217                                   | 0.004953                | 1844.5                             | 385.6              | 2230.1                  | 1891.2                      | 443.1              | 2334.3                  | 4.1119                                    | 0.6890             | 4.8009                  |
| 373.95           | 22,064                                  | 0.003106                                   | 0.003106                | 2015.7                             | 0                  | 2015.7                  | 2084.3                      | 0                  | 2084.3                  | 4.4070                                    | 0                  | 4.4070                  |

Source: Tables A-4 through A-8 are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the highly accurate Steam\_IAPWS, which incorporates the 1995 Formulation for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, issued by The International Association for the Properties of Water and Steam (IAPWS). This formulation replaces the 1984 formulation of Haar, Gallagher, and Kell (NBS/NRC Steam Tables, Hemisphere Publishing Co., 1984), which is also available in EES as the routine STEAM. The new formulation is based on the correlations of Saul and Wagner (J. Phys. Chem. Ref. Data, 16, 893, 1987) with modifications to adjust to the International Temperature Scale of 1990. The modifications are described by Wagner and Pruss (J. Phys. Chem. Ref. Data, 22, 783, 1993). The properties of ice are based on Hyland and Wexler, "Formulations for the Thermodynamic Properties of the Saturated Phases of  $\text{H}_2\text{O}$  from 173.15 K to 473.15 K," *ASHRAE Trans.*, Part 2A, Paper 2793, 1983.

TABLE A-5

Saturated water—Pressure table

| Press.,<br>$P$ kPa | Sat.<br>temp.,<br>$T_{\text{sat}}$ °C | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|--------------------|---------------------------------------|--------------------------------------------|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|-------------------------------------------|--------------------|-------------------------|
|                    |                                       | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$           | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$    | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                  | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 1.0                | 6.97                                  | 0.001000                                   | 129.19                  | 29.302                             | 2355.2             | 2384.5                  | 29.303                      | 2484.4             | 2513.7                  | 0.1059                                    | 8.8690             | 8.9749                  |
| 1.5                | 13.02                                 | 0.001001                                   | 87.964                  | 54.686                             | 2338.1             | 2392.8                  | 54.688                      | 2470.1             | 2524.7                  | 0.1956                                    | 8.6314             | 8.8270                  |
| 2.0                | 17.50                                 | 0.001001                                   | 66.990                  | 73.431                             | 2325.5             | 2398.9                  | 73.433                      | 2459.5             | 2532.9                  | 0.2606                                    | 8.4621             | 8.7227                  |
| 2.5                | 21.08                                 | 0.001002                                   | 54.242                  | 88.422                             | 2315.4             | 2403.8                  | 88.424                      | 2451.0             | 2539.4                  | 0.3118                                    | 8.3302             | 8.6421                  |
| 3.0                | 24.08                                 | 0.001003                                   | 45.654                  | 100.98                             | 2306.9             | 2407.9                  | 100.98                      | 2443.9             | 2544.8                  | 0.3543                                    | 8.2222             | 8.5765                  |
| 4.0                | 28.96                                 | 0.001004                                   | 34.791                  | 121.39                             | 2293.1             | 2414.5                  | 121.39                      | 2432.3             | 2553.7                  | 0.4224                                    | 8.0510             | 8.4734                  |
| 5.0                | 32.87                                 | 0.001005                                   | 28.185                  | 137.75                             | 2282.1             | 2419.8                  | 137.75                      | 2423.0             | 2560.7                  | 0.4762                                    | 7.9176             | 8.3938                  |
| 7.5                | 40.29                                 | 0.001008                                   | 19.233                  | 168.74                             | 2261.1             | 2429.8                  | 168.75                      | 2405.3             | 2574.0                  | 0.5763                                    | 7.6738             | 8.2501                  |
| 10                 | 45.81                                 | 0.001010                                   | 14.670                  | 191.79                             | 2245.4             | 2437.2                  | 191.81                      | 2392.1             | 2583.9                  | 0.6492                                    | 7.4996             | 8.1488                  |
| 15                 | 53.97                                 | 0.001014                                   | 10.020                  | 225.93                             | 2222.1             | 2448.0                  | 225.94                      | 2372.3             | 2598.3                  | 0.7549                                    | 7.2522             | 8.0071                  |
| 20                 | 60.06                                 | 0.001017                                   | 7.6481                  | 251.40                             | 2204.6             | 2456.0                  | 251.42                      | 2357.5             | 2608.9                  | 0.8320                                    | 7.0752             | 7.9073                  |
| 25                 | 64.96                                 | 0.001020                                   | 6.2034                  | 271.93                             | 2190.4             | 2462.4                  | 271.96                      | 2345.5             | 2617.5                  | 0.8932                                    | 6.9370             | 7.8302                  |
| 30                 | 69.09                                 | 0.001022                                   | 5.2287                  | 289.24                             | 2178.5             | 2467.7                  | 289.27                      | 2335.3             | 2624.6                  | 0.9441                                    | 6.8234             | 7.7675                  |
| 40                 | 75.86                                 | 0.001026                                   | 3.9933                  | 317.58                             | 2158.8             | 2476.3                  | 317.62                      | 2318.4             | 2636.1                  | 1.0261                                    | 6.6430             | 7.6691                  |
| 50                 | 81.32                                 | 0.001030                                   | 3.2403                  | 340.49                             | 2142.7             | 2483.2                  | 340.54                      | 2304.7             | 2645.2                  | 1.0912                                    | 6.5019             | 7.5931                  |
| 75                 | 91.76                                 | 0.001037                                   | 2.2172                  | 384.36                             | 2111.8             | 2496.1                  | 384.44                      | 2278.0             | 2662.4                  | 1.2132                                    | 6.2426             | 7.4558                  |
| 100                | 99.61                                 | 0.001043                                   | 1.6941                  | 417.40                             | 2088.2             | 2505.6                  | 417.51                      | 2257.5             | 2675.0                  | 1.3028                                    | 6.0562             | 7.3589                  |
| 101.325            | 99.97                                 | 0.001043                                   | 1.6734                  | 418.95                             | 2087.0             | 2506.0                  | 419.06                      | 2256.5             | 2675.6                  | 1.3069                                    | 6.0476             | 7.3545                  |
| 125                | 105.97                                | 0.001048                                   | 1.3750                  | 444.23                             | 2068.8             | 2513.0                  | 444.36                      | 2240.6             | 2684.9                  | 1.3741                                    | 5.9100             | 7.2841                  |
| 150                | 111.35                                | 0.001053                                   | 1.1594                  | 466.97                             | 2052.3             | 2519.2                  | 467.13                      | 2226.0             | 2693.1                  | 1.4337                                    | 5.7894             | 7.2231                  |
| 175                | 116.04                                | 0.001057                                   | 1.0037                  | 486.82                             | 2037.7             | 2524.5                  | 487.01                      | 2213.1             | 2700.2                  | 1.4850                                    | 5.6865             | 7.1716                  |
| 200                | 120.21                                | 0.001061                                   | 0.88578                 | 504.50                             | 2024.6             | 2529.1                  | 504.71                      | 2201.6             | 2706.3                  | 1.5302                                    | 5.5968             | 7.1270                  |
| 225                | 123.97                                | 0.001064                                   | 0.79329                 | 520.47                             | 2012.7             | 2533.2                  | 520.71                      | 2191.0             | 2711.7                  | 1.5706                                    | 5.5171             | 7.0877                  |
| 250                | 127.41                                | 0.001067                                   | 0.71873                 | 535.08                             | 2001.8             | 2536.8                  | 535.35                      | 2181.2             | 2716.5                  | 1.6072                                    | 5.4453             | 7.0525                  |
| 275                | 130.58                                | 0.001070                                   | 0.65732                 | 548.57                             | 1991.6             | 2540.1                  | 548.86                      | 2172.0             | 2720.9                  | 1.6408                                    | 5.3800             | 7.0207                  |
| 300                | 133.52                                | 0.001073                                   | 0.60582                 | 561.11                             | 1982.1             | 2543.2                  | 561.43                      | 2163.5             | 2724.9                  | 1.6717                                    | 5.3200             | 6.9917                  |
| 325                | 136.27                                | 0.001076                                   | 0.56199                 | 572.84                             | 1973.1             | 2545.9                  | 573.19                      | 2155.4             | 2728.6                  | 1.7005                                    | 5.2645             | 6.9650                  |
| 350                | 138.86                                | 0.001079                                   | 0.52422                 | 583.89                             | 1964.6             | 2548.5                  | 584.26                      | 2147.7             | 2732.0                  | 1.7274                                    | 5.2128             | 6.9402                  |
| 375                | 141.30                                | 0.001081                                   | 0.49133                 | 594.32                             | 1956.6             | 2550.9                  | 594.73                      | 2140.4             | 2735.1                  | 1.7526                                    | 5.1645             | 6.9171                  |
| 400                | 143.61                                | 0.001084                                   | 0.46242                 | 604.22                             | 1948.9             | 2553.1                  | 604.66                      | 2133.4             | 2738.1                  | 1.7765                                    | 5.1191             | 6.8955                  |
| 450                | 147.90                                | 0.001088                                   | 0.41392                 | 622.65                             | 1934.5             | 2557.1                  | 623.14                      | 2120.3             | 2743.4                  | 1.8205                                    | 5.0356             | 6.8561                  |
| 500                | 151.83                                | 0.001093                                   | 0.37483                 | 639.54                             | 1921.2             | 2560.7                  | 640.09                      | 2108.0             | 2748.1                  | 1.8604                                    | 4.9603             | 6.8207                  |
| 550                | 155.46                                | 0.001097                                   | 0.34261                 | 655.16                             | 1908.8             | 2563.9                  | 655.77                      | 2096.6             | 2752.4                  | 1.8970                                    | 4.8916             | 6.7886                  |
| 600                | 158.83                                | 0.001101                                   | 0.31560                 | 669.72                             | 1897.1             | 2566.8                  | 670.38                      | 2085.8             | 2756.2                  | 1.9308                                    | 4.8285             | 6.7593                  |
| 650                | 161.98                                | 0.001104                                   | 0.29260                 | 683.37                             | 1886.1             | 2569.4                  | 684.08                      | 2075.5             | 2759.6                  | 1.9623                                    | 4.7699             | 6.7322                  |
| 700                | 164.95                                | 0.001108                                   | 0.27278                 | 696.23                             | 1875.6             | 2571.8                  | 697.00                      | 2065.8             | 2762.8                  | 1.9918                                    | 4.7153             | 6.7071                  |
| 750                | 167.75                                | 0.001111                                   | 0.25552                 | 708.40                             | 1865.6             | 2574.0                  | 709.24                      | 2056.4             | 2765.7                  | 2.0195                                    | 4.6642             | 6.6837                  |

TABLE A-5

Saturated water—Pressure table (Continued)

| Press.,<br>$P$ kPa | Sat.<br>temp.,<br>$T_{\text{sat}}$ °C | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|--------------------|---------------------------------------|--------------------------------------------|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|-------------------------------------------|--------------------|-------------------------|
|                    |                                       | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$           | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$    | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                  | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 800                | 170.41                                | 0.001115                                   | 0.24035                 | 719.97                             | 1856.1             | 2576.0                  | 720.87                      | 2047.5             | 2768.3                  | 2.0457                                    | 4.6160             | 6.6616                  |
| 850                | 172.94                                | 0.001118                                   | 0.22690                 | 731.00                             | 1846.9             | 2577.9                  | 731.95                      | 2038.8             | 2770.8                  | 2.0705                                    | 4.5705             | 6.6409                  |
| 900                | 175.35                                | 0.001121                                   | 0.21489                 | 741.55                             | 1838.1             | 2579.6                  | 742.56                      | 2030.5             | 2773.0                  | 2.0941                                    | 4.5273             | 6.6213                  |
| 950                | 177.66                                | 0.001124                                   | 0.20411                 | 751.67                             | 1829.6             | 2581.3                  | 752.74                      | 2022.4             | 2775.2                  | 2.1166                                    | 4.4862             | 6.6027                  |
| 1000               | 179.88                                | 0.001127                                   | 0.19436                 | 761.39                             | 1821.4             | 2582.8                  | 762.51                      | 2014.6             | 2777.1                  | 2.1381                                    | 4.4470             | 6.5850                  |
| 1100               | 184.06                                | 0.001133                                   | 0.17745                 | 779.78                             | 1805.7             | 2585.5                  | 781.03                      | 1999.6             | 2780.7                  | 2.1785                                    | 4.3735             | 6.5520                  |
| 1200               | 187.96                                | 0.001138                                   | 0.16326                 | 796.96                             | 1790.9             | 2587.8                  | 798.33                      | 1985.4             | 2783.8                  | 2.2159                                    | 4.3058             | 6.5217                  |
| 1300               | 191.60                                | 0.001144                                   | 0.15119                 | 813.10                             | 1776.8             | 2589.9                  | 814.59                      | 1971.9             | 2786.5                  | 2.2508                                    | 4.2428             | 6.4936                  |
| 1400               | 195.04                                | 0.001149                                   | 0.14078                 | 828.35                             | 1763.4             | 2591.8                  | 829.96                      | 1958.9             | 2788.9                  | 2.2835                                    | 4.1840             | 6.4675                  |
| 1500               | 198.29                                | 0.001154                                   | 0.13171                 | 842.82                             | 1750.6             | 2593.4                  | 844.55                      | 1946.4             | 2791.0                  | 2.3143                                    | 4.1287             | 6.4430                  |
| 1750               | 205.72                                | 0.001166                                   | 0.11344                 | 876.12                             | 1720.6             | 2596.7                  | 878.16                      | 1917.1             | 2795.2                  | 2.3844                                    | 4.0033             | 6.3877                  |
| 2000               | 212.38                                | 0.001177                                   | 0.099587                | 906.12                             | 1693.0             | 2599.1                  | 908.47                      | 1889.8             | 2798.3                  | 2.4467                                    | 3.8923             | 6.3390                  |
| 2250               | 218.41                                | 0.001187                                   | 0.088717                | 933.54                             | 1667.3             | 2600.9                  | 936.21                      | 1864.3             | 2800.5                  | 2.5029                                    | 3.7926             | 6.2954                  |
| 2500               | 223.95                                | 0.001197                                   | 0.079952                | 958.87                             | 1643.2             | 2602.1                  | 961.87                      | 1840.1             | 2801.9                  | 2.5542                                    | 3.7016             | 6.2558                  |
| 3000               | 233.85                                | 0.001217                                   | 0.066667                | 1004.6                             | 1598.5             | 2603.2                  | 1008.3                      | 1794.9             | 2803.2                  | 2.6454                                    | 3.5402             | 6.1856                  |
| 3500               | 242.56                                | 0.001235                                   | 0.057061                | 1045.4                             | 1557.6             | 2603.0                  | 1049.7                      | 1753.0             | 2802.7                  | 2.7253                                    | 3.3991             | 6.1244                  |
| 4000               | 250.35                                | 0.001252                                   | 0.049779                | 1082.4                             | 1519.3             | 2601.7                  | 1087.4                      | 1713.5             | 2800.8                  | 2.7966                                    | 3.2731             | 6.0696                  |
| 5000               | 263.94                                | 0.001286                                   | 0.039448                | 1148.1                             | 1448.9             | 2597.0                  | 1154.5                      | 1639.7             | 2794.2                  | 2.9207                                    | 3.0530             | 5.9737                  |
| 6000               | 275.59                                | 0.001319                                   | 0.032449                | 1205.8                             | 1384.1             | 2589.9                  | 1213.8                      | 1570.9             | 2784.6                  | 3.0275                                    | 2.8627             | 5.8902                  |
| 7000               | 285.83                                | 0.001352                                   | 0.027378                | 1258.0                             | 1323.0             | 2581.0                  | 1267.5                      | 1505.2             | 2772.6                  | 3.1220                                    | 2.6927             | 5.8148                  |
| 8000               | 295.01                                | 0.001384                                   | 0.023525                | 1306.0                             | 1264.5             | 2570.5                  | 1317.1                      | 1441.6             | 2758.7                  | 3.2077                                    | 2.5373             | 5.7450                  |
| 9000               | 303.35                                | 0.001418                                   | 0.020489                | 1350.9                             | 1207.6             | 2558.5                  | 1363.7                      | 1379.3             | 2742.9                  | 3.2866                                    | 2.3925             | 5.6791                  |
| 10,000             | 311.00                                | 0.001452                                   | 0.018028                | 1393.3                             | 1151.8             | 2545.2                  | 1407.8                      | 1317.6             | 2725.5                  | 3.3603                                    | 2.2556             | 5.6159                  |
| 11,000             | 318.08                                | 0.001488                                   | 0.015988                | 1433.9                             | 1096.6             | 2530.4                  | 1450.2                      | 1256.1             | 2706.3                  | 3.4299                                    | 2.1245             | 5.5544                  |
| 12,000             | 324.68                                | 0.001526                                   | 0.014264                | 1473.0                             | 1041.3             | 2514.3                  | 1491.3                      | 1194.1             | 2685.4                  | 3.4964                                    | 1.9975             | 5.4939                  |
| 13,000             | 330.85                                | 0.001566                                   | 0.012781                | 1511.0                             | 985.5              | 2496.6                  | 1531.4                      | 1131.3             | 2662.7                  | 3.5606                                    | 1.8730             | 5.4336                  |
| 14,000             | 336.67                                | 0.001610                                   | 0.011487                | 1548.4                             | 928.7              | 2477.1                  | 1571.0                      | 1067.0             | 2637.9                  | 3.6232                                    | 1.7497             | 5.3728                  |
| 15,000             | 342.16                                | 0.001657                                   | 0.010341                | 1585.5                             | 870.3              | 2455.7                  | 1610.3                      | 1000.5             | 2610.8                  | 3.6848                                    | 1.6261             | 5.3108                  |
| 16,000             | 347.36                                | 0.001710                                   | 0.009312                | 1622.6                             | 809.4              | 2432.0                  | 1649.9                      | 931.1              | 2581.0                  | 3.7461                                    | 1.5005             | 5.2466                  |
| 17,000             | 352.29                                | 0.001770                                   | 0.008374                | 1660.2                             | 745.1              | 2405.4                  | 1690.3                      | 857.4              | 2547.7                  | 3.8082                                    | 1.3709             | 5.1791                  |
| 18,000             | 356.99                                | 0.001840                                   | 0.007504                | 1699.1                             | 675.9              | 2375.0                  | 1732.2                      | 777.8              | 2510.0                  | 3.8720                                    | 1.2343             | 5.1064                  |
| 19,000             | 361.47                                | 0.001926                                   | 0.006677                | 1740.3                             | 598.9              | 2339.2                  | 1776.8                      | 689.2              | 2466.0                  | 3.9396                                    | 1.0860             | 5.0256                  |
| 20,000             | 365.75                                | 0.002038                                   | 0.005862                | 1785.8                             | 509.0              | 2294.8                  | 1826.6                      | 585.5              | 2412.1                  | 4.0146                                    | 0.9164             | 4.9310                  |
| 21,000             | 369.83                                | 0.002207                                   | 0.004994                | 1841.6                             | 391.9              | 2233.5                  | 1888.0                      | 450.4              | 2338.4                  | 4.1071                                    | 0.7005             | 4.8076                  |
| 22,000             | 373.71                                | 0.002703                                   | 0.003644                | 1951.7                             | 140.8              | 2092.4                  | 2011.1                      | 161.5              | 2172.6                  | 4.2942                                    | 0.2496             | 4.5439                  |
| 22,064             | 373.95                                | 0.003106                                   | 0.003106                | 2015.7                             | 0                  | 2015.7                  | 2084.3                      | 0                  | 2084.3                  | 4.4070                                    | 0                  | 4.4070                  |

TABLE A-6

Superheated water

| $T$<br>°C                         | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|-----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 0.01 \text{ MPa (45.81°C)*}$ |                           |              |              |                  | $P = 0.05 \text{ MPa (81.32°C)}$  |              |              |                  | $P = 0.10 \text{ MPa (99.61°C)}$  |              |              |                  |
| Sat. <sup>†</sup>                 | 14.670                    | 2437.2       | 2583.9       | 8.1488           | 3.2403                            | 2483.2       | 2645.2       | 7.5931           | 1.6941                            | 2505.6       | 2675.0       | 7.3589           |
| 50                                | 14.867                    | 2443.3       | 2592.0       | 8.1741           |                                   |              |              |                  |                                   |              |              |                  |
| 100                               | 17.196                    | 2515.5       | 2687.5       | 8.4489           | 3.4187                            | 2511.5       | 2682.4       | 7.6953           | 1.6959                            | 2506.2       | 2675.8       | 7.3611           |
| 150                               | 19.513                    | 2587.9       | 2783.0       | 8.6893           | 3.8897                            | 2585.7       | 2780.2       | 7.9413           | 1.9367                            | 2582.9       | 2776.6       | 7.6148           |
| 200                               | 21.826                    | 2661.4       | 2879.6       | 8.9049           | 4.3562                            | 2660.0       | 2877.8       | 8.1592           | 2.1724                            | 2658.2       | 2875.5       | 7.8356           |
| 250                               | 24.136                    | 2736.1       | 2977.5       | 9.1015           | 4.8206                            | 2735.1       | 2976.2       | 8.3568           | 2.4062                            | 2733.9       | 2974.5       | 8.0346           |
| 300                               | 26.446                    | 2812.3       | 3076.7       | 9.2827           | 5.2841                            | 2811.6       | 3075.8       | 8.5387           | 2.6389                            | 2810.7       | 3074.5       | 8.2172           |
| 400                               | 31.063                    | 2969.3       | 3280.0       | 9.6094           | 6.2094                            | 2968.9       | 3279.3       | 8.8659           | 3.1027                            | 2968.3       | 3278.6       | 8.5452           |
| 500                               | 35.680                    | 3132.9       | 3489.7       | 9.8998           | 7.1338                            | 3132.6       | 3489.3       | 9.1566           | 3.5655                            | 3132.2       | 3488.7       | 8.8362           |
| 600                               | 40.296                    | 3303.3       | 3706.3       | 10.1631          | 8.0577                            | 3303.1       | 3706.0       | 9.4201           | 4.0279                            | 3302.8       | 3705.6       | 9.0999           |
| 700                               | 44.911                    | 3480.8       | 3929.9       | 10.4056          | 8.9813                            | 3480.6       | 3929.7       | 9.6626           | 4.4900                            | 3480.4       | 3929.4       | 9.3424           |
| 800                               | 49.527                    | 3665.4       | 4160.6       | 10.6312          | 9.9047                            | 3665.2       | 4160.4       | 9.8883           | 4.9519                            | 3665.0       | 4160.2       | 9.5682           |
| 900                               | 54.143                    | 3856.9       | 4398.3       | 10.8429          | 10.8280                           | 3856.8       | 4398.2       | 10.1000          | 5.4137                            | 3856.7       | 4398.0       | 9.7800           |
| 1000                              | 58.758                    | 4055.3       | 4642.8       | 11.0429          | 11.7513                           | 4055.2       | 4642.7       | 10.3000          | 5.8755                            | 4055.0       | 4642.6       | 9.9800           |
| 1100                              | 63.373                    | 4260.0       | 4893.8       | 11.2326          | 12.6745                           | 4259.9       | 4893.7       | 10.4897          | 6.3372                            | 4259.8       | 4893.6       | 10.1698          |
| 1200                              | 67.989                    | 4470.9       | 5150.8       | 11.4132          | 13.5977                           | 4470.8       | 5150.7       | 10.6704          | 6.7988                            | 4470.7       | 5150.6       | 10.3504          |
| 1300                              | 72.604                    | 4687.4       | 5413.4       | 11.5857          | 14.5209                           | 4687.3       | 5413.3       | 10.8429          | 7.2605                            | 4687.2       | 5413.3       | 10.5229          |
| $P = 0.20 \text{ MPa (120.21°C)}$ |                           |              |              |                  | $P = 0.30 \text{ MPa (133.52°C)}$ |              |              |                  | $P = 0.40 \text{ MPa (143.61°C)}$ |              |              |                  |
| Sat.                              | 0.88578                   | 2529.1       | 2706.3       | 7.1270           | 0.60582                           | 2543.2       | 2724.9       | 6.9917           | 0.46242                           | 2553.1       | 2738.1       | 6.8955           |
| 150                               | 0.95986                   | 2577.1       | 2769.1       | 7.2810           | 0.63402                           | 2571.0       | 2761.2       | 7.0792           | 0.47088                           | 2564.4       | 2752.8       | 6.9306           |
| 200                               | 1.08049                   | 2654.6       | 2870.7       | 7.5081           | 0.71643                           | 2651.0       | 2865.9       | 7.3132           | 0.53434                           | 2647.2       | 2860.9       | 7.1723           |
| 250                               | 1.19890                   | 2731.4       | 2971.2       | 7.7100           | 0.79645                           | 2728.9       | 2967.9       | 7.5180           | 0.59520                           | 2726.4       | 2964.5       | 7.3804           |
| 300                               | 1.31623                   | 2808.8       | 3072.1       | 7.8941           | 0.87535                           | 2807.0       | 3069.6       | 7.7037           | 0.65489                           | 2805.1       | 3067.1       | 7.5677           |
| 400                               | 1.54934                   | 2967.2       | 3277.0       | 8.2236           | 1.03155                           | 2966.0       | 3275.5       | 8.0347           | 0.77265                           | 2964.9       | 3273.9       | 7.9003           |
| 500                               | 1.78142                   | 3131.4       | 3487.7       | 8.5153           | 1.18672                           | 3130.6       | 3486.6       | 8.3271           | 0.88936                           | 3129.8       | 3485.5       | 8.1933           |
| 600                               | 2.01302                   | 3302.2       | 3704.8       | 8.7793           | 1.34139                           | 3301.6       | 3704.0       | 8.5915           | 1.00558                           | 3301.0       | 3703.3       | 8.4580           |
| 700                               | 2.24434                   | 3479.9       | 3928.8       | 9.0221           | 1.49580                           | 3479.5       | 3928.2       | 8.8345           | 1.12152                           | 3479.0       | 3927.6       | 8.7012           |
| 800                               | 2.47550                   | 3664.7       | 4159.8       | 9.2479           | 1.65004                           | 3664.3       | 4159.3       | 9.0605           | 1.23730                           | 3663.9       | 4158.9       | 8.9274           |
| 900                               | 2.70656                   | 3856.3       | 4397.7       | 9.4598           | 1.80417                           | 3856.0       | 4397.3       | 9.2725           | 1.35298                           | 3855.7       | 4396.9       | 9.1394           |
| 1000                              | 2.93755                   | 4054.8       | 4642.3       | 9.6599           | 1.95824                           | 4054.5       | 4642.0       | 9.4726           | 1.46859                           | 4054.3       | 4641.7       | 9.3396           |
| 1100                              | 3.16848                   | 4259.6       | 4893.3       | 9.8497           | 2.11226                           | 4259.4       | 4893.1       | 9.6624           | 1.58414                           | 4259.2       | 4892.9       | 9.5295           |
| 1200                              | 3.39938                   | 4470.5       | 5150.4       | 10.0304          | 2.26624                           | 4470.3       | 5150.2       | 9.8431           | 1.69966                           | 4470.2       | 5150.0       | 9.7102           |
| 1300                              | 3.63026                   | 4687.1       | 5413.1       | 10.2029          | 2.42019                           | 4686.9       | 5413.0       | 10.0157          | 1.81516                           | 4686.7       | 5412.8       | 9.8828           |
| $P = 0.50 \text{ MPa (151.83°C)}$ |                           |              |              |                  | $P = 0.60 \text{ MPa (158.83°C)}$ |              |              |                  | $P = 0.80 \text{ MPa (170.41°C)}$ |              |              |                  |
| Sat.                              | 0.37483                   | 2560.7       | 2748.1       | 6.8207           | 0.31560                           | 2566.8       | 2756.2       | 6.7593           | 0.24035                           | 2576.0       | 2768.3       | 6.6616           |
| 200                               | 0.42503                   | 2643.3       | 2855.8       | 7.0610           | 0.35212                           | 2639.4       | 2850.6       | 6.9683           | 0.26088                           | 2631.1       | 2839.8       | 6.8177           |
| 250                               | 0.47443                   | 2723.8       | 2961.0       | 7.2725           | 0.39390                           | 2721.2       | 2957.6       | 7.1833           | 0.29321                           | 2715.9       | 2950.4       | 7.0402           |
| 300                               | 0.52261                   | 2803.3       | 3064.6       | 7.4614           | 0.43442                           | 2801.4       | 3062.0       | 7.3740           | 0.32416                           | 2797.5       | 3056.9       | 7.2345           |
| 350                               | 0.57015                   | 2883.0       | 3168.1       | 7.6346           | 0.47428                           | 2881.6       | 3166.1       | 7.5481           | 0.35442                           | 2878.6       | 3162.2       | 7.4107           |
| 400                               | 0.61731                   | 2963.7       | 3272.4       | 7.7956           | 0.51374                           | 2962.5       | 3270.8       | 7.7097           | 0.38429                           | 2960.2       | 3267.7       | 7.5735           |
| 500                               | 0.71095                   | 3129.0       | 3484.5       | 8.0893           | 0.59200                           | 3128.2       | 3483.4       | 8.0041           | 0.44332                           | 3126.6       | 3481.3       | 7.8692           |
| 600                               | 0.80409                   | 3300.4       | 3702.5       | 8.3544           | 0.66976                           | 3299.8       | 3701.7       | 8.2695           | 0.50186                           | 3298.7       | 3700.1       | 8.1354           |
| 700                               | 0.89696                   | 3478.6       | 3927.0       | 8.5978           | 0.74725                           | 3478.1       | 3926.4       | 8.5132           | 0.56011                           | 3477.2       | 3925.3       | 8.3794           |
| 800                               | 0.98966                   | 3663.6       | 4158.4       | 8.8240           | 0.82457                           | 3663.2       | 4157.9       | 8.7395           | 0.61820                           | 3662.5       | 4157.0       | 8.6061           |
| 900                               | 1.08227                   | 3855.4       | 4396.6       | 9.0362           | 0.90179                           | 3855.1       | 4396.2       | 8.9518           | 0.67619                           | 3854.5       | 4395.5       | 8.8185           |
| 1000                              | 1.17480                   | 4054.0       | 4641.4       | 9.2364           | 0.97893                           | 4053.8       | 4641.1       | 9.1521           | 0.73411                           | 4053.3       | 4640.5       | 9.0189           |
| 1100                              | 1.26728                   | 4259.0       | 4892.6       | 9.4263           | 1.05603                           | 4258.8       | 4892.4       | 9.3420           | 0.79197                           | 4258.3       | 4891.9       | 9.2090           |
| 1200                              | 1.35972                   | 4470.0       | 5149.8       | 9.6071           | 1.13309                           | 4469.8       | 5149.6       | 9.5229           | 0.84980                           | 4469.4       | 5149.3       | 9.3898           |
| 1300                              | 1.45214                   | 4686.6       | 5412.6       | 9.7797           | 1.21012                           | 4686.4       | 5412.5       | 9.6955           | 0.90761                           | 4686.1       | 5412.2       | 9.5625           |

\*The temperature in parentheses is the saturation temperature at the specified pressure.

<sup>†</sup> Properties of saturated vapor at the specified pressure.

TABLE A-6

Superheated water (*Continued*)

| $T$<br>°C                         | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg                      | $h$<br>kJ/kg | $s$<br>kJ/kg · K |  |  |
|-----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|---------------------------|-----------------------------------|--------------|------------------|--|--|
| $P = 1.00 \text{ MPa (179.88°C)}$ |                           |              |              |                  | $P = 1.20 \text{ MPa (187.96°C)}$ |              |              |                  |                           | $P = 1.40 \text{ MPa (195.04°C)}$ |              |                  |  |  |
| Sat.                              | 0.19437                   | 2582.8       | 2777.1       | 6.5850           | 0.16326                           | 2587.8       | 2783.8       | 6.5217           | 0.14078                   | 2591.8                            | 2788.9       | 6.4675           |  |  |
| 200                               | 0.20602                   | 2622.3       | 2828.3       | 6.6956           | 0.16934                           | 2612.9       | 2816.1       | 6.5909           | 0.14303                   | 2602.7                            | 2803.0       | 6.4975           |  |  |
| 250                               | 0.23275                   | 2710.4       | 2943.1       | 6.9265           | 0.19241                           | 2704.7       | 2935.6       | 6.8313           | 0.16356                   | 2698.9                            | 2927.9       | 6.7488           |  |  |
| 300                               | 0.25799                   | 2793.7       | 3051.6       | 7.1246           | 0.21386                           | 2789.7       | 3046.3       | 7.0335           | 0.18233                   | 2785.7                            | 3040.9       | 6.9553           |  |  |
| 350                               | 0.28250                   | 2875.7       | 3158.2       | 7.3029           | 0.23455                           | 2872.7       | 3154.2       | 7.2139           | 0.20029                   | 2869.7                            | 3150.1       | 7.1379           |  |  |
| 400                               | 0.30661                   | 2957.9       | 3264.5       | 7.4670           | 0.25482                           | 2955.5       | 3261.3       | 7.3793           | 0.21782                   | 2953.1                            | 3258.1       | 7.3046           |  |  |
| 500                               | 0.35411                   | 3125.0       | 3479.1       | 7.7642           | 0.29464                           | 3123.4       | 3477.0       | 7.6779           | 0.25216                   | 3121.8                            | 3474.8       | 7.6047           |  |  |
| 600                               | 0.40111                   | 3297.5       | 3698.6       | 8.0311           | 0.33395                           | 3296.3       | 3697.0       | 7.9456           | 0.28597                   | 3295.1                            | 3695.5       | 7.8730           |  |  |
| 700                               | 0.44783                   | 3476.3       | 3924.1       | 8.2755           | 0.37297                           | 3475.3       | 3922.9       | 8.1904           | 0.31951                   | 3474.4                            | 3921.7       | 8.1183           |  |  |
| 800                               | 0.49438                   | 3661.7       | 4156.1       | 8.5024           | 0.41184                           | 3661.0       | 4155.2       | 8.4176           | 0.35288                   | 3660.3                            | 4154.3       | 8.3458           |  |  |
| 900                               | 0.54083                   | 3853.9       | 4394.8       | 8.7150           | 0.45059                           | 3853.3       | 4394.0       | 8.6303           | 0.38614                   | 3852.7                            | 4393.3       | 8.5587           |  |  |
| 1000                              | 0.58721                   | 4052.7       | 4640.0       | 8.9155           | 0.48928                           | 4052.2       | 4639.4       | 8.8310           | 0.41933                   | 4051.7                            | 4638.8       | 8.7595           |  |  |
| 1100                              | 0.63354                   | 4257.9       | 4891.4       | 9.1057           | 0.52792                           | 4257.5       | 4891.0       | 9.0212           | 0.45247                   | 4257.0                            | 4890.5       | 8.9497           |  |  |
| 1200                              | 0.67983                   | 4469.0       | 5148.9       | 9.2866           | 0.56652                           | 4468.7       | 5148.5       | 9.2022           | 0.48558                   | 4468.3                            | 5148.1       | 9.1308           |  |  |
| 1300                              | 0.72610                   | 4685.8       | 5411.9       | 9.4593           | 0.60509                           | 4685.5       | 5411.6       | 9.3750           | 0.51866                   | 4685.1                            | 5411.3       | 9.3036           |  |  |
| $P = 1.60 \text{ MPa (201.37°C)}$ |                           |              |              |                  | $P = 1.80 \text{ MPa (207.11°C)}$ |              |              |                  |                           | $P = 2.00 \text{ MPa (212.38°C)}$ |              |                  |  |  |
| Sat.                              | 0.12374                   | 2594.8       | 2792.8       | 6.4200           | 0.11037                           | 2597.3       | 2795.9       | 6.3775           | 0.09959                   | 2599.1                            | 2798.3       | 6.3390           |  |  |
| 225                               | 0.13293                   | 2645.1       | 2857.8       | 6.5537           | 0.11678                           | 2637.0       | 2847.2       | 6.4825           | 0.10381                   | 2628.5                            | 2836.1       | 6.4160           |  |  |
| 250                               | 0.14190                   | 2692.9       | 2919.9       | 6.6753           | 0.12502                           | 2686.7       | 2911.7       | 6.6088           | 0.11150                   | 2680.3                            | 2903.3       | 6.5475           |  |  |
| 300                               | 0.15866                   | 2781.6       | 3035.4       | 6.8864           | 0.14025                           | 2777.4       | 3029.9       | 6.8246           | 0.12551                   | 2773.2                            | 3024.2       | 6.7684           |  |  |
| 350                               | 0.17459                   | 2866.6       | 3146.0       | 7.0713           | 0.15460                           | 2863.6       | 3141.9       | 7.0120           | 0.13860                   | 2860.5                            | 3137.7       | 6.9583           |  |  |
| 400                               | 0.19007                   | 2950.8       | 3254.9       | 7.2394           | 0.16849                           | 2948.3       | 3251.6       | 7.1814           | 0.15122                   | 2945.9                            | 3248.4       | 7.1292           |  |  |
| 500                               | 0.22029                   | 3120.1       | 3472.6       | 7.5410           | 0.19551                           | 3118.5       | 3470.4       | 7.4845           | 0.17568                   | 3116.9                            | 3468.3       | 7.4337           |  |  |
| 600                               | 0.24999                   | 3293.9       | 3693.9       | 7.8101           | 0.22200                           | 3292.7       | 3692.3       | 7.7543           | 0.19962                   | 3291.5                            | 3690.7       | 7.7043           |  |  |
| 700                               | 0.27941                   | 3473.5       | 3920.5       | 8.0558           | 0.24822                           | 3472.6       | 3919.4       | 8.0005           | 0.22326                   | 3471.7                            | 3918.2       | 7.9509           |  |  |
| 800                               | 0.30865                   | 3659.5       | 4153.4       | 8.2834           | 0.27426                           | 3658.8       | 4152.4       | 8.2284           | 0.24674                   | 3658.0                            | 4151.5       | 8.1791           |  |  |
| 900                               | 0.33780                   | 3852.1       | 4392.6       | 8.4965           | 0.30020                           | 3851.5       | 4391.9       | 8.4417           | 0.27012                   | 3850.9                            | 4391.1       | 8.3925           |  |  |
| 1000                              | 0.36687                   | 4051.2       | 4638.2       | 8.6974           | 0.32606                           | 4050.7       | 4637.6       | 8.6427           | 0.29342                   | 4050.2                            | 4637.1       | 8.5936           |  |  |
| 1100                              | 0.39589                   | 4256.6       | 4890.0       | 8.8878           | 0.35188                           | 4256.2       | 4889.6       | 8.8331           | 0.31667                   | 4255.7                            | 4889.1       | 8.7842           |  |  |
| 1200                              | 0.42488                   | 4467.9       | 5147.7       | 9.0689           | 0.37766                           | 4467.6       | 5147.3       | 9.0143           | 0.33989                   | 4467.2                            | 5147.0       | 8.9654           |  |  |
| 1300                              | 0.45383                   | 4684.8       | 5410.9       | 9.2418           | 0.40341                           | 4684.5       | 5410.6       | 9.1872           | 0.36308                   | 4684.2                            | 5410.3       | 9.1384           |  |  |
| $P = 2.50 \text{ MPa (223.95°C)}$ |                           |              |              |                  | $P = 3.00 \text{ MPa (233.85°C)}$ |              |              |                  |                           | $P = 3.50 \text{ MPa (242.56°C)}$ |              |                  |  |  |
| Sat.                              | 0.07995                   | 2602.1       | 2801.9       | 6.2558           | 0.06667                           | 2603.2       | 2803.2       | 6.1856           | 0.05706                   | 2603.0                            | 2802.7       | 6.1244           |  |  |
| 225                               | 0.08026                   | 2604.8       | 2805.5       | 6.2629           |                                   |              |              |                  |                           |                                   |              |                  |  |  |
| 250                               | 0.08705                   | 2663.3       | 2880.9       | 6.4107           | 0.07063                           | 2644.7       | 2856.5       | 6.2893           | 0.05876                   | 2624.0                            | 2829.7       | 6.1764           |  |  |
| 300                               | 0.09894                   | 2762.2       | 3009.6       | 6.6459           | 0.08118                           | 2750.8       | 2994.3       | 6.5412           | 0.06845                   | 2738.8                            | 2978.4       | 6.4484           |  |  |
| 350                               | 0.10979                   | 2852.5       | 3127.0       | 6.8424           | 0.09056                           | 2844.4       | 3116.1       | 6.7450           | 0.07680                   | 2836.0                            | 3104.9       | 6.6601           |  |  |
| 400                               | 0.12012                   | 2939.8       | 3240.1       | 7.0170           | 0.09938                           | 2933.6       | 3231.7       | 6.9235           | 0.08456                   | 2927.2                            | 3223.2       | 6.8428           |  |  |
| 450                               | 0.13015                   | 3026.2       | 3351.6       | 7.1768           | 0.10789                           | 3021.2       | 3344.9       | 7.0856           | 0.09198                   | 3016.1                            | 3338.1       | 7.0074           |  |  |
| 500                               | 0.13999                   | 3112.8       | 3462.8       | 7.3254           | 0.11620                           | 3108.6       | 3457.2       | 7.2359           | 0.09919                   | 3104.5                            | 3451.7       | 7.1593           |  |  |
| 600                               | 0.15931                   | 3288.5       | 3686.8       | 7.5979           | 0.13245                           | 3285.5       | 3682.8       | 7.5103           | 0.11325                   | 3282.5                            | 3678.9       | 7.4357           |  |  |
| 700                               | 0.17835                   | 3469.3       | 3915.2       | 7.8455           | 0.14841                           | 3467.0       | 3912.2       | 7.7590           | 0.12702                   | 3464.7                            | 3909.3       | 7.6855           |  |  |
| 800                               | 0.19722                   | 3656.2       | 4149.2       | 8.0744           | 0.16420                           | 3654.3       | 4146.9       | 7.9885           | 0.14061                   | 3652.5                            | 4144.6       | 7.9156           |  |  |
| 900                               | 0.21597                   | 3849.4       | 4389.3       | 8.2882           | 0.17988                           | 3847.9       | 4387.5       | 8.2028           | 0.15410                   | 3846.4                            | 4385.7       | 8.1304           |  |  |
| 1000                              | 0.23466                   | 4049.0       | 4635.6       | 8.4897           | 0.19549                           | 4047.7       | 4634.2       | 8.4045           | 0.16751                   | 4046.4                            | 4632.7       | 8.3324           |  |  |
| 1100                              | 0.25330                   | 4254.7       | 4887.9       | 8.6804           | 0.21105                           | 4253.6       | 4886.7       | 8.5955           | 0.18087                   | 4252.5                            | 4885.6       | 8.5236           |  |  |
| 1200                              | 0.27190                   | 4466.3       | 5146.0       | 8.8618           | 0.22658                           | 4465.3       | 5145.1       | 8.7771           | 0.19420                   | 4464.4                            | 5144.1       | 8.7053           |  |  |
| 1300                              | 0.29048                   | 4683.4       | 5409.5       | 9.0349           | 0.24207                           | 4682.6       | 5408.8       | 8.9502           | 0.20750                   | 4681.8                            | 5408.0       | 8.8786           |  |  |

TABLE A-6

Superheated water (*Continued*)

| $T$<br>°C                        | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 4.0 \text{ MPa (250.35°C)}$ |                           |              |              |                  | $P = 4.5 \text{ MPa (257.44°C)}$  |              |              |                  | $P = 5.0 \text{ MPa (263.94°C)}$  |              |              |                  |
| Sat.                             | 0.04978                   | 2601.7       | 2800.8       | 6.0696           | 0.04406                           | 2599.7       | 2798.0       | 6.0198           | 0.03945                           | 2597.0       | 2794.2       | 5.9737           |
| 275                              | 0.05461                   | 2668.9       | 2887.3       | 6.2312           | 0.04733                           | 2651.4       | 2864.4       | 6.1429           | 0.04144                           | 2632.3       | 2839.5       | 6.0571           |
| 300                              | 0.05887                   | 2726.2       | 2961.7       | 6.3639           | 0.05138                           | 2713.0       | 2944.2       | 6.2854           | 0.04535                           | 2699.0       | 2925.7       | 6.2111           |
| 350                              | 0.06647                   | 2827.4       | 3093.3       | 6.5843           | 0.05842                           | 2818.6       | 3081.5       | 6.5153           | 0.05197                           | 2809.5       | 3069.3       | 6.4516           |
| 400                              | 0.07343                   | 2920.8       | 3214.5       | 6.7714           | 0.06477                           | 2914.2       | 3205.7       | 6.7071           | 0.05784                           | 2907.5       | 3196.7       | 6.6483           |
| 450                              | 0.08004                   | 3011.0       | 3331.2       | 6.9386           | 0.07076                           | 3005.8       | 3324.2       | 6.8770           | 0.06332                           | 3000.6       | 3317.2       | 6.8210           |
| 500                              | 0.08644                   | 3100.3       | 3446.0       | 7.0922           | 0.07652                           | 3096.0       | 3440.4       | 7.0323           | 0.06858                           | 3091.8       | 3434.7       | 6.9781           |
| 600                              | 0.09886                   | 3279.4       | 3674.9       | 7.3706           | 0.08766                           | 3276.4       | 3670.9       | 7.3127           | 0.07870                           | 3273.3       | 3666.9       | 7.2605           |
| 700                              | 0.11098                   | 3462.4       | 3906.3       | 7.6214           | 0.09850                           | 3460.0       | 3903.3       | 7.5647           | 0.08852                           | 3457.7       | 3900.3       | 7.5136           |
| 800                              | 0.12292                   | 3650.6       | 4142.3       | 7.8523           | 0.10916                           | 3648.8       | 4140.0       | 7.7962           | 0.09816                           | 3646.9       | 4137.7       | 7.7458           |
| 900                              | 0.13476                   | 3844.8       | 4383.9       | 8.0675           | 0.11972                           | 3843.3       | 4382.1       | 8.0118           | 0.10769                           | 3841.8       | 4380.2       | 7.9619           |
| 1000                             | 0.14653                   | 4045.1       | 4631.2       | 8.2698           | 0.13020                           | 4043.9       | 4629.8       | 8.2144           | 0.11715                           | 4042.6       | 4628.3       | 8.1648           |
| 1100                             | 0.15824                   | 4251.4       | 4884.4       | 8.4612           | 0.14064                           | 4250.4       | 4883.2       | 8.4060           | 0.12655                           | 4249.3       | 4882.1       | 8.3566           |
| 1200                             | 0.16992                   | 4463.5       | 5143.2       | 8.6430           | 0.15103                           | 4462.6       | 5142.2       | 8.5880           | 0.13592                           | 4461.6       | 5141.3       | 8.5388           |
| 1300                             | 0.18157                   | 4680.9       | 5407.2       | 8.8164           | 0.16140                           | 4680.1       | 5406.5       | 8.7616           | 0.14527                           | 4679.3       | 5405.7       | 8.7124           |
| $P = 6.0 \text{ MPa (275.59°C)}$ |                           |              |              |                  | $P = 7.0 \text{ MPa (285.83°C)}$  |              |              |                  | $P = 8.0 \text{ MPa (295.01°C)}$  |              |              |                  |
| Sat.                             | 0.03245                   | 2589.9       | 2784.6       | 5.8902           | 0.027378                          | 2581.0       | 2772.6       | 5.8148           | 0.023525                          | 2570.5       | 2758.7       | 5.7450           |
| 300                              | 0.03619                   | 2668.4       | 2885.6       | 6.0703           | 0.029492                          | 2633.5       | 2839.9       | 5.9337           | 0.024279                          | 2592.3       | 2786.5       | 5.7937           |
| 350                              | 0.04225                   | 2790.4       | 3043.9       | 6.3357           | 0.035262                          | 2770.1       | 3016.9       | 6.2305           | 0.029975                          | 2748.3       | 2988.1       | 6.1321           |
| 400                              | 0.04742                   | 2893.7       | 3178.3       | 6.5432           | 0.039958                          | 2879.5       | 3159.2       | 6.4502           | 0.034344                          | 2864.6       | 3139.4       | 6.3658           |
| 450                              | 0.05217                   | 2989.9       | 3302.9       | 6.7219           | 0.044187                          | 2979.0       | 3288.3       | 6.6353           | 0.038194                          | 2967.8       | 3273.3       | 6.5579           |
| 500                              | 0.05667                   | 3083.1       | 3423.1       | 6.8826           | 0.048157                          | 3074.3       | 3411.4       | 6.8000           | 0.041767                          | 3065.4       | 3399.5       | 6.7266           |
| 550                              | 0.06102                   | 3175.2       | 3541.3       | 7.0308           | 0.051966                          | 3167.9       | 3531.6       | 6.9507           | 0.045172                          | 3160.5       | 3521.8       | 6.8800           |
| 600                              | 0.06527                   | 3267.2       | 3658.8       | 7.1693           | 0.055665                          | 3261.0       | 3650.6       | 7.0910           | 0.048463                          | 3254.7       | 3642.4       | 7.0221           |
| 700                              | 0.07355                   | 3453.0       | 3894.3       | 7.4247           | 0.062850                          | 3448.3       | 3888.3       | 7.3487           | 0.054829                          | 3443.6       | 3882.2       | 7.2822           |
| 800                              | 0.08165                   | 3643.2       | 4133.1       | 7.6582           | 0.069856                          | 3639.5       | 4128.5       | 7.5836           | 0.061011                          | 3635.7       | 4123.8       | 7.5185           |
| 900                              | 0.08964                   | 3838.8       | 4376.6       | 7.8751           | 0.076750                          | 3835.7       | 4373.0       | 7.8014           | 0.067082                          | 3832.7       | 4369.3       | 7.7372           |
| 1000                             | 0.09756                   | 4040.1       | 4625.4       | 8.0786           | 0.083571                          | 4037.5       | 4622.5       | 8.0055           | 0.073079                          | 4035.0       | 4619.6       | 7.9419           |
| 1100                             | 0.10543                   | 4247.1       | 4879.7       | 8.2709           | 0.090341                          | 4245.0       | 4877.4       | 8.1982           | 0.079025                          | 4242.8       | 4875.0       | 8.1350           |
| 1200                             | 0.11326                   | 4459.8       | 5139.4       | 8.4534           | 0.097075                          | 4457.9       | 5137.4       | 8.3810           | 0.084934                          | 4456.1       | 5135.5       | 8.3181           |
| 1300                             | 0.12107                   | 4677.7       | 5404.1       | 8.6273           | 0.103781                          | 4676.1       | 5402.6       | 8.5551           | 0.090817                          | 4674.5       | 5401.0       | 8.4925           |
| $P = 9.0 \text{ MPa (303.35°C)}$ |                           |              |              |                  | $P = 10.0 \text{ MPa (311.00°C)}$ |              |              |                  | $P = 12.5 \text{ MPa (327.81°C)}$ |              |              |                  |
| Sat.                             | 0.020489                  | 2558.5       | 2742.9       | 5.6791           | 0.018028                          | 2545.2       | 2725.5       | 5.6159           | 0.013496                          | 2505.6       | 2674.3       | 5.4638           |
| 325                              | 0.023284                  | 2647.6       | 2857.1       | 5.8738           | 0.019877                          | 2611.6       | 2810.3       | 5.7596           |                                   |              |              |                  |
| 350                              | 0.025816                  | 2725.0       | 2957.3       | 6.0380           | 0.022440                          | 2699.6       | 2924.0       | 5.9460           | 0.016138                          | 2624.9       | 2826.6       | 5.7130           |
| 400                              | 0.029960                  | 2849.2       | 3118.8       | 6.2876           | 0.026436                          | 2833.1       | 3097.5       | 6.2141           | 0.020030                          | 2789.6       | 3040.0       | 6.0433           |
| 450                              | 0.033524                  | 2956.3       | 3258.0       | 6.4872           | 0.029782                          | 2944.5       | 3242.4       | 6.4219           | 0.023019                          | 2913.7       | 3201.5       | 6.2749           |
| 500                              | 0.036793                  | 3056.3       | 3387.4       | 6.6603           | 0.032811                          | 3047.0       | 3375.1       | 6.5995           | 0.025630                          | 3023.2       | 3343.6       | 6.4651           |
| 550                              | 0.039885                  | 3153.0       | 3512.0       | 6.8164           | 0.035655                          | 3145.4       | 3502.0       | 6.7585           | 0.028033                          | 3126.1       | 3476.5       | 6.6317           |
| 600                              | 0.042861                  | 3248.4       | 3634.1       | 6.9605           | 0.038378                          | 3242.0       | 3625.8       | 6.9045           | 0.030306                          | 3225.8       | 3604.6       | 6.7828           |
| 650                              | 0.045755                  | 3343.4       | 3755.2       | 7.0954           | 0.041018                          | 3338.0       | 3748.1       | 7.0408           | 0.032491                          | 3324.1       | 3730.2       | 6.9227           |
| 700                              | 0.048589                  | 3438.8       | 3876.1       | 7.2229           | 0.043597                          | 3434.0       | 3870.0       | 7.1693           | 0.034612                          | 3422.0       | 3854.6       | 7.0540           |
| 800                              | 0.054132                  | 3632.0       | 4119.2       | 7.4606           | 0.048629                          | 3628.2       | 4114.5       | 7.4085           | 0.038724                          | 3618.8       | 4102.8       | 7.2967           |
| 900                              | 0.059562                  | 3829.6       | 4365.7       | 7.6802           | 0.053547                          | 3826.5       | 4362.0       | 7.6290           | 0.042720                          | 3818.9       | 4352.9       | 7.5195           |
| 1000                             | 0.064919                  | 4032.4       | 4616.7       | 7.8855           | 0.058391                          | 4029.9       | 4613.8       | 7.8349           | 0.046641                          | 4023.5       | 4606.5       | 7.7269           |
| 1100                             | 0.070224                  | 4240.7       | 4872.7       | 8.0791           | 0.063183                          | 4238.5       | 4870.3       | 8.0289           | 0.050510                          | 4233.1       | 4864.5       | 7.9220           |
| 1200                             | 0.075492                  | 4454.2       | 5133.6       | 8.2625           | 0.067938                          | 4452.4       | 5131.7       | 8.2126           | 0.054342                          | 4447.7       | 5127.0       | 8.1065           |
| 1300                             | 0.080733                  | 4672.9       | 5399.5       | 8.4371           | 0.072667                          | 4671.3       | 5398.0       | 8.3874           | 0.058147                          | 4667.3       | 5394.1       | 8.2819           |

TABLE A-6

Superheated water (Concluded)

| $T$<br>°C                         | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg         | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|-----------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|-----------------------------------|--------------|--------------|------------------|
| $P = 15.0 \text{ MPa (342.16°C)}$ |                           |              |              |                  | $P = 17.5 \text{ MPa (354.67°C)}$ |              |              |                  | $P = 20.0 \text{ MPa (365.75°C)}$ |              |              |                  |
| Sat.                              | 0.010341                  | 2455.7       | 2610.8       | 5.3108           | 0.007932                          | 2390.7       | 2529.5       | 5.1435           | 0.005862                          | 2294.8       | 2412.1       | 4.9310           |
| 350                               | 0.011481                  | 2520.9       | 2693.1       | 5.4438           |                                   |              |              |                  |                                   |              |              |                  |
| 400                               | 0.015671                  | 2740.6       | 2975.7       | 5.8819           | 0.012463                          | 2684.3       | 2902.4       | 5.7211           | 0.009950                          | 2617.9       | 2816.9       | 5.5526           |
| 450                               | 0.018477                  | 2880.8       | 3157.9       | 6.1434           | 0.015204                          | 2845.4       | 3111.4       | 6.0212           | 0.012721                          | 2807.3       | 3061.7       | 5.9043           |
| 500                               | 0.020828                  | 2998.4       | 3310.8       | 6.3480           | 0.017385                          | 2972.4       | 3276.7       | 6.2424           | 0.014793                          | 2945.3       | 3241.2       | 6.1446           |
| 550                               | 0.022945                  | 3106.2       | 3450.4       | 6.5230           | 0.019305                          | 3085.8       | 3423.6       | 6.4266           | 0.016571                          | 3064.7       | 3396.2       | 6.3390           |
| 600                               | 0.024921                  | 3209.3       | 3583.1       | 6.6796           | 0.021073                          | 3192.5       | 3561.3       | 6.5890           | 0.018185                          | 3175.3       | 3539.0       | 6.5075           |
| 650                               | 0.026804                  | 3310.1       | 3712.1       | 6.8233           | 0.022742                          | 3295.8       | 3693.8       | 6.7366           | 0.019695                          | 3281.4       | 3675.3       | 6.6593           |
| 700                               | 0.028621                  | 3409.8       | 3839.1       | 6.9573           | 0.024342                          | 3397.5       | 3823.5       | 6.8735           | 0.021134                          | 3385.1       | 3807.8       | 6.7991           |
| 800                               | 0.032121                  | 3609.3       | 4091.1       | 7.2037           | 0.027405                          | 3599.7       | 4079.3       | 7.1237           | 0.023870                          | 3590.1       | 4067.5       | 7.0531           |
| 900                               | 0.035503                  | 3811.2       | 4343.7       | 7.4288           | 0.030348                          | 3803.5       | 4334.6       | 7.3511           | 0.026484                          | 3795.7       | 4325.4       | 7.2829           |
| 1000                              | 0.038808                  | 4017.1       | 4599.2       | 7.6378           | 0.033215                          | 4010.7       | 4592.0       | 7.5616           | 0.029020                          | 4004.3       | 4584.7       | 7.4950           |
| 1100                              | 0.042062                  | 4227.7       | 4858.6       | 7.8339           | 0.036029                          | 4222.3       | 4852.8       | 7.7588           | 0.031504                          | 4216.9       | 4847.0       | 7.6933           |
| 1200                              | 0.045279                  | 4443.1       | 5122.3       | 8.0192           | 0.038806                          | 4438.5       | 5117.6       | 7.9449           | 0.033952                          | 4433.8       | 5112.9       | 7.8802           |
| 1300                              | 0.048469                  | 4663.3       | 5390.3       | 8.1952           | 0.041556                          | 4659.2       | 5386.5       | 8.1215           | 0.036371                          | 4655.2       | 5382.7       | 8.0574           |
| $P = 25.0 \text{ MPa}$            |                           |              |              |                  | $P = 30.0 \text{ MPa}$            |              |              |                  | $P = 35.0 \text{ MPa}$            |              |              |                  |
| 375                               | 0.001978                  | 1799.9       | 1849.4       | 4.0345           | 0.001792                          | 1738.1       | 1791.9       | 3.9313           | 0.001701                          | 1702.8       | 1762.4       | 3.8724           |
| 400                               | 0.006005                  | 2428.5       | 2578.7       | 5.1400           | 0.002798                          | 2068.9       | 2152.8       | 4.4758           | 0.002105                          | 1914.9       | 1988.6       | 4.2144           |
| 425                               | 0.007886                  | 2607.8       | 2805.0       | 5.4708           | 0.005299                          | 2452.9       | 2611.8       | 5.1473           | 0.003434                          | 2253.3       | 2373.5       | 4.7751           |
| 450                               | 0.009176                  | 2721.2       | 2950.6       | 5.6759           | 0.006737                          | 2618.9       | 2821.0       | 5.4422           | 0.004957                          | 2497.5       | 2671.0       | 5.1946           |
| 500                               | 0.011143                  | 2887.3       | 3165.9       | 5.9643           | 0.008691                          | 2824.0       | 3084.8       | 5.7956           | 0.006933                          | 2755.3       | 2997.9       | 5.6331           |
| 550                               | 0.012736                  | 3020.8       | 3339.2       | 6.1816           | 0.010175                          | 2974.5       | 3279.7       | 6.0403           | 0.008348                          | 2925.8       | 3218.0       | 5.9093           |
| 600                               | 0.014140                  | 3140.0       | 3493.5       | 6.3637           | 0.011445                          | 3103.4       | 3446.8       | 6.2373           | 0.009523                          | 3065.6       | 3399.0       | 6.1229           |
| 650                               | 0.015430                  | 3251.9       | 3637.7       | 6.5243           | 0.012590                          | 3221.7       | 3599.4       | 6.4074           | 0.010565                          | 3190.9       | 3560.7       | 6.3030           |
| 700                               | 0.016643                  | 3359.9       | 3776.0       | 6.6702           | 0.013654                          | 3334.3       | 3743.9       | 6.5599           | 0.011523                          | 3308.3       | 3711.6       | 6.4623           |
| 800                               | 0.018922                  | 3570.7       | 4043.8       | 6.9322           | 0.015628                          | 3551.2       | 4020.0       | 6.8301           | 0.013278                          | 3531.6       | 3996.3       | 6.7409           |
| 900                               | 0.021075                  | 3780.2       | 4307.1       | 7.1668           | 0.017473                          | 3764.6       | 4288.8       | 7.0695           | 0.014904                          | 3749.0       | 4270.6       | 6.9853           |
| 1000                              | 0.023150                  | 3991.5       | 4570.2       | 7.3821           | 0.019240                          | 3978.6       | 4555.8       | 7.2880           | 0.016450                          | 3965.8       | 4541.5       | 7.2069           |
| 1100                              | 0.025172                  | 4206.1       | 4835.4       | 7.5825           | 0.020954                          | 4195.2       | 4823.9       | 7.4906           | 0.017942                          | 4184.4       | 4812.4       | 7.4118           |
| 1200                              | 0.027157                  | 4424.6       | 5103.5       | 7.7710           | 0.022630                          | 4415.3       | 5094.2       | 7.6807           | 0.019398                          | 4406.1       | 5085.0       | 7.6034           |
| 1300                              | 0.029115                  | 4647.2       | 5375.1       | 7.9494           | 0.024279                          | 4639.2       | 5367.6       | 7.8602           | 0.020827                          | 4631.2       | 5360.2       | 7.7841           |
| $P = 40.0 \text{ MPa}$            |                           |              |              |                  | $P = 50.0 \text{ MPa}$            |              |              |                  | $P = 60.0 \text{ MPa}$            |              |              |                  |
| 375                               | 0.001641                  | 1677.0       | 1742.6       | 3.8290           | 0.001560                          | 1638.6       | 1716.6       | 3.7642           | 0.001503                          | 1609.7       | 1699.9       | 3.7149           |
| 400                               | 0.001911                  | 1855.0       | 1931.4       | 4.1145           | 0.001731                          | 1787.8       | 1874.4       | 4.0029           | 0.001633                          | 1745.2       | 1843.2       | 3.9317           |
| 425                               | 0.002538                  | 2097.5       | 2199.0       | 4.5044           | 0.002009                          | 1960.3       | 2060.7       | 4.2746           | 0.001816                          | 1892.9       | 2001.8       | 4.1630           |
| 450                               | 0.003692                  | 2364.2       | 2511.8       | 4.9449           | 0.002487                          | 2160.3       | 2284.7       | 4.5896           | 0.002086                          | 2055.1       | 2180.2       | 4.4140           |
| 500                               | 0.005623                  | 2681.6       | 2906.5       | 5.4744           | 0.003890                          | 2528.1       | 2722.6       | 5.1762           | 0.002952                          | 2393.2       | 2570.3       | 4.9356           |
| 550                               | 0.006985                  | 2875.1       | 3154.4       | 5.7857           | 0.005118                          | 2769.5       | 3025.4       | 5.5563           | 0.003955                          | 2664.6       | 2901.9       | 5.3517           |
| 600                               | 0.008089                  | 3026.8       | 3350.4       | 6.0170           | 0.006108                          | 2947.1       | 3252.6       | 5.8245           | 0.004833                          | 2866.8       | 3156.8       | 5.6527           |
| 650                               | 0.009053                  | 3159.5       | 3521.6       | 6.2078           | 0.006957                          | 3095.6       | 3443.5       | 6.0373           | 0.005591                          | 3031.3       | 3366.8       | 5.8867           |
| 700                               | 0.009930                  | 3282.0       | 3679.2       | 6.3740           | 0.007717                          | 3228.7       | 3614.6       | 6.2179           | 0.006265                          | 3175.4       | 3551.3       | 6.0814           |
| 800                               | 0.011521                  | 3511.8       | 3972.6       | 6.6613           | 0.009073                          | 3472.2       | 3925.8       | 6.5225           | 0.007456                          | 3432.6       | 3880.0       | 6.4033           |
| 900                               | 0.012980                  | 3733.3       | 4252.5       | 6.9107           | 0.010296                          | 3702.0       | 4216.8       | 6.7819           | 0.008519                          | 3670.9       | 4182.1       | 6.6725           |
| 1000                              | 0.014360                  | 3952.9       | 4527.3       | 7.1355           | 0.011441                          | 3927.4       | 4499.4       | 7.0131           | 0.009504                          | 3902.0       | 4472.2       | 6.9099           |
| 1100                              | 0.015686                  | 4173.7       | 4801.1       | 7.3425           | 0.012534                          | 4152.2       | 4778.9       | 7.2244           | 0.010439                          | 4130.9       | 4757.3       | 7.1255           |
| 1200                              | 0.016976                  | 4396.9       | 5075.9       | 7.5357           | 0.013590                          | 4378.6       | 5058.1       | 7.4207           | 0.011339                          | 4360.5       | 5040.8       | 7.3248           |
| 1300                              | 0.018239                  | 4623.3       | 5352.8       | 7.7175           | 0.014620                          | 4607.5       | 5338.5       | 7.6048           | 0.012213                          | 4591.8       | 5324.5       | 7.5111           |



TABLE A-7

Compressed liquid water

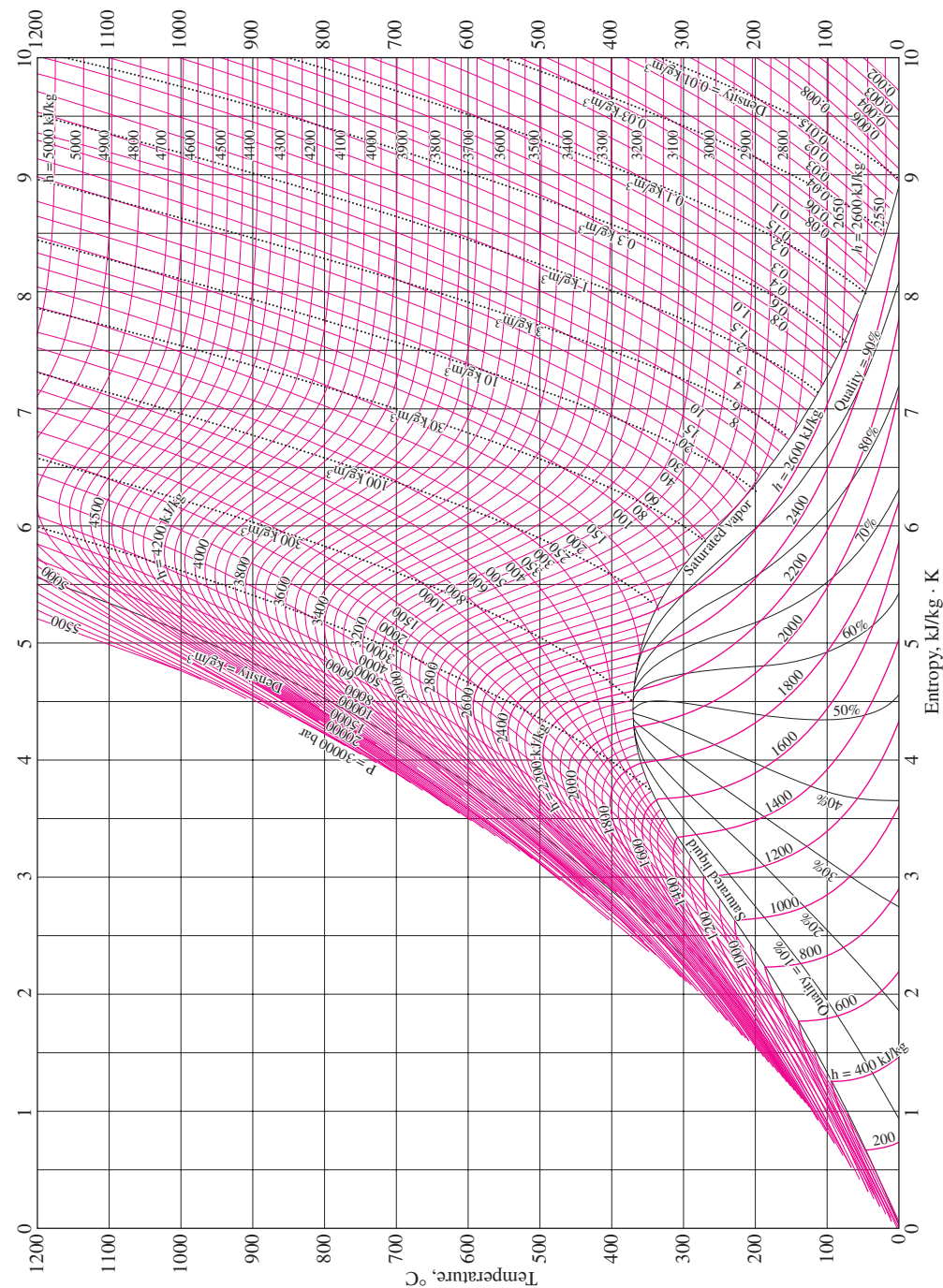
| $T$<br>°C                       | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|---------------------------------|---------------------------|--------------|--------------|------------------|---------------------------------|--------------|--------------|------------------|---------------------------------|--------------|--------------|------------------|
| $P = 5 \text{ MPa (263.94°C)}$  |                           |              |              |                  | $P = 10 \text{ MPa (311.00°C)}$ |              |              |                  | $P = 15 \text{ MPa (342.16°C)}$ |              |              |                  |
| Sat.                            | 0.0012862                 | 1148.1       | 1154.5       | 2.9207           | 0.0014522                       | 1393.3       | 1407.9       | 3.3603           | 0.0016572                       | 1585.5       | 1610.3       | 3.6848           |
| 0                               | 0.0009977                 | 0.04         | 5.03         | 0.0001           | 0.0009952                       | 0.12         | 10.07        | 0.0003           | 0.0009928                       | 0.18         | 15.07        | 0.0004           |
| 20                              | 0.0009996                 | 83.61        | 88.61        | 0.2954           | 0.0009973                       | 83.31        | 93.28        | 0.2943           | 0.0009951                       | 83.01        | 97.93        | 0.2932           |
| 40                              | 0.0010057                 | 166.92       | 171.95       | 0.5705           | 0.0010035                       | 166.33       | 176.37       | 0.5685           | 0.0010013                       | 165.75       | 180.77       | 0.5666           |
| 60                              | 0.0010149                 | 250.29       | 255.36       | 0.8287           | 0.0010127                       | 249.43       | 259.55       | 0.8260           | 0.0010105                       | 248.58       | 263.74       | 0.8234           |
| 80                              | 0.0010267                 | 333.82       | 338.96       | 1.0723           | 0.0010244                       | 332.69       | 342.94       | 1.0691           | 0.0010221                       | 331.59       | 346.92       | 1.0659           |
| 100                             | 0.0010410                 | 417.65       | 422.85       | 1.3034           | 0.0010385                       | 416.23       | 426.62       | 1.2996           | 0.0010361                       | 414.85       | 430.39       | 1.2958           |
| 120                             | 0.0010576                 | 501.91       | 507.19       | 1.5236           | 0.0010549                       | 500.18       | 510.73       | 1.5191           | 0.0010522                       | 498.50       | 514.28       | 1.5148           |
| 140                             | 0.0010769                 | 586.80       | 592.18       | 1.7344           | 0.0010738                       | 584.72       | 595.45       | 1.7293           | 0.0010708                       | 582.69       | 598.75       | 1.7243           |
| 160                             | 0.0010988                 | 672.55       | 678.04       | 1.9374           | 0.0010954                       | 670.06       | 681.01       | 1.9316           | 0.0010920                       | 667.63       | 684.01       | 1.9259           |
| 180                             | 0.0011240                 | 759.47       | 765.09       | 2.1338           | 0.0011200                       | 756.48       | 767.68       | 2.1271           | 0.0011160                       | 753.58       | 770.32       | 2.1206           |
| 200                             | 0.0011531                 | 847.92       | 853.68       | 2.3251           | 0.0011482                       | 844.32       | 855.80       | 2.3174           | 0.0011435                       | 840.84       | 858.00       | 2.3100           |
| 220                             | 0.0011868                 | 938.39       | 944.32       | 2.5127           | 0.0011809                       | 934.01       | 945.82       | 2.5037           | 0.0011752                       | 929.81       | 947.43       | 2.4951           |
| 240                             | 0.0012268                 | 1031.6       | 1037.7       | 2.6983           | 0.0012192                       | 1026.2       | 1038.3       | 2.6876           | 0.0012121                       | 1021.0       | 1039.2       | 2.6774           |
| 260                             | 0.0012755                 | 1128.5       | 1134.9       | 2.8841           | 0.0012653                       | 1121.6       | 1134.3       | 2.8710           | 0.0012560                       | 1115.1       | 1134.0       | 2.8586           |
| 280                             |                           |              |              |                  | 0.0013226                       | 1221.8       | 1235.0       | 3.0565           | 0.0013096                       | 1213.4       | 1233.0       | 3.0410           |
| 300                             |                           |              |              |                  | 0.0013980                       | 1329.4       | 1343.3       | 3.2488           | 0.0013783                       | 1317.6       | 1338.3       | 3.2279           |
| 320                             |                           |              |              |                  |                                 |              |              |                  | 0.0014733                       | 1431.9       | 1454.0       | 3.4263           |
| 340                             |                           |              |              |                  |                                 |              |              |                  | 0.0016311                       | 1567.9       | 1592.4       | 3.6555           |
| $P = 20 \text{ MPa (365.75°C)}$ |                           |              |              |                  | $P = 30 \text{ MPa}$            |              |              |                  | $P = 50 \text{ MPa}$            |              |              |                  |
| Sat.                            | 0.0020378                 | 1785.8       | 1826.6       | 4.0146           | 0.0009857                       | 0.29         | 29.86        | 0.0003           | 0.0009767                       | 0.29         | 49.13        | -0.0010          |
| 0                               | 0.0009904                 | 0.23         | 20.03        | 0.0005           | 0.0009886                       | 82.11        | 111.77       | 0.2897           | 0.0009805                       | 80.93        | 129.95       | 0.2845           |
| 20                              | 0.0009929                 | 82.71        | 102.57       | 0.2921           | 0.0009886                       | 82.11        | 111.77       | 0.2897           | 0.0009805                       | 80.93        | 129.95       | 0.2845           |
| 40                              | 0.0009992                 | 165.17       | 185.16       | 0.5646           | 0.0009951                       | 164.05       | 193.90       | 0.5607           | 0.0009872                       | 161.90       | 211.25       | 0.5528           |
| 60                              | 0.0010084                 | 247.75       | 267.92       | 0.8208           | 0.0010042                       | 246.14       | 276.26       | 0.8156           | 0.0009962                       | 243.08       | 292.88       | 0.8055           |
| 80                              | 0.0010199                 | 330.50       | 350.90       | 1.0627           | 0.0010155                       | 328.40       | 358.86       | 1.0564           | 0.0010072                       | 324.42       | 374.78       | 1.0442           |
| 100                             | 0.0010337                 | 413.50       | 434.17       | 1.2920           | 0.0010290                       | 410.87       | 441.74       | 1.2847           | 0.0010201                       | 405.94       | 456.94       | 1.2705           |
| 120                             | 0.0010496                 | 496.85       | 517.84       | 1.5105           | 0.0010445                       | 493.66       | 525.00       | 1.5020           | 0.0010349                       | 487.69       | 539.43       | 1.4859           |
| 140                             | 0.0010679                 | 580.71       | 602.07       | 1.7194           | 0.0010623                       | 576.90       | 608.76       | 1.7098           | 0.0010517                       | 569.77       | 622.36       | 1.6916           |
| 160                             | 0.0010886                 | 665.28       | 687.05       | 1.9203           | 0.0010823                       | 660.74       | 693.21       | 1.9094           | 0.0010704                       | 652.33       | 705.85       | 1.8889           |
| 180                             | 0.0011122                 | 750.78       | 773.02       | 2.1143           | 0.0011049                       | 745.40       | 778.55       | 2.1020           | 0.0010914                       | 735.49       | 790.06       | 2.0790           |
| 200                             | 0.0011390                 | 837.49       | 860.27       | 2.3027           | 0.0011304                       | 831.11       | 865.02       | 2.2888           | 0.0011149                       | 819.45       | 875.19       | 2.2628           |
| 220                             | 0.0011697                 | 925.77       | 949.16       | 2.4867           | 0.0011595                       | 918.15       | 952.93       | 2.4707           | 0.0011412                       | 904.39       | 961.45       | 2.4414           |
| 240                             | 0.0012053                 | 1016.1       | 1040.2       | 2.6676           | 0.0011927                       | 1006.9       | 1042.7       | 2.6491           | 0.0011708                       | 990.55       | 1049.1       | 2.6156           |
| 260                             | 0.0012472                 | 1109.0       | 1134.0       | 2.8469           | 0.0012314                       | 1097.8       | 1134.7       | 2.8250           | 0.0012044                       | 1078.2       | 1138.4       | 2.7864           |
| 280                             | 0.0012978                 | 1205.6       | 1231.5       | 3.0265           | 0.0012770                       | 1191.5       | 1229.8       | 3.0001           | 0.0012430                       | 1167.7       | 1229.9       | 2.9547           |
| 300                             | 0.0013611                 | 1307.2       | 1334.4       | 3.2091           | 0.0013322                       | 1288.9       | 1328.9       | 3.1761           | 0.0012879                       | 1259.6       | 1324.0       | 3.1218           |
| 320                             | 0.0014450                 | 1416.6       | 1445.5       | 3.3996           | 0.0014014                       | 1391.7       | 1433.7       | 3.3558           | 0.0013409                       | 1354.3       | 1421.4       | 3.2888           |
| 340                             | 0.0015693                 | 1540.2       | 1571.6       | 3.6086           | 0.0014932                       | 1502.4       | 1547.1       | 3.5438           | 0.0014049                       | 1452.9       | 1523.1       | 3.4575           |
| 360                             | 0.0018248                 | 1703.6       | 1740.1       | 3.8787           | 0.0016276                       | 1626.8       | 1675.6       | 3.7499           | 0.0014848                       | 1556.5       | 1630.7       | 3.6301           |
| 380                             |                           |              |              |                  | 0.0018729                       | 1782.0       | 1838.2       | 4.0026           | 0.0015884                       | 1667.1       | 1746.5       | 3.8102           |



TABLE A-8

Saturated ice–water vapor

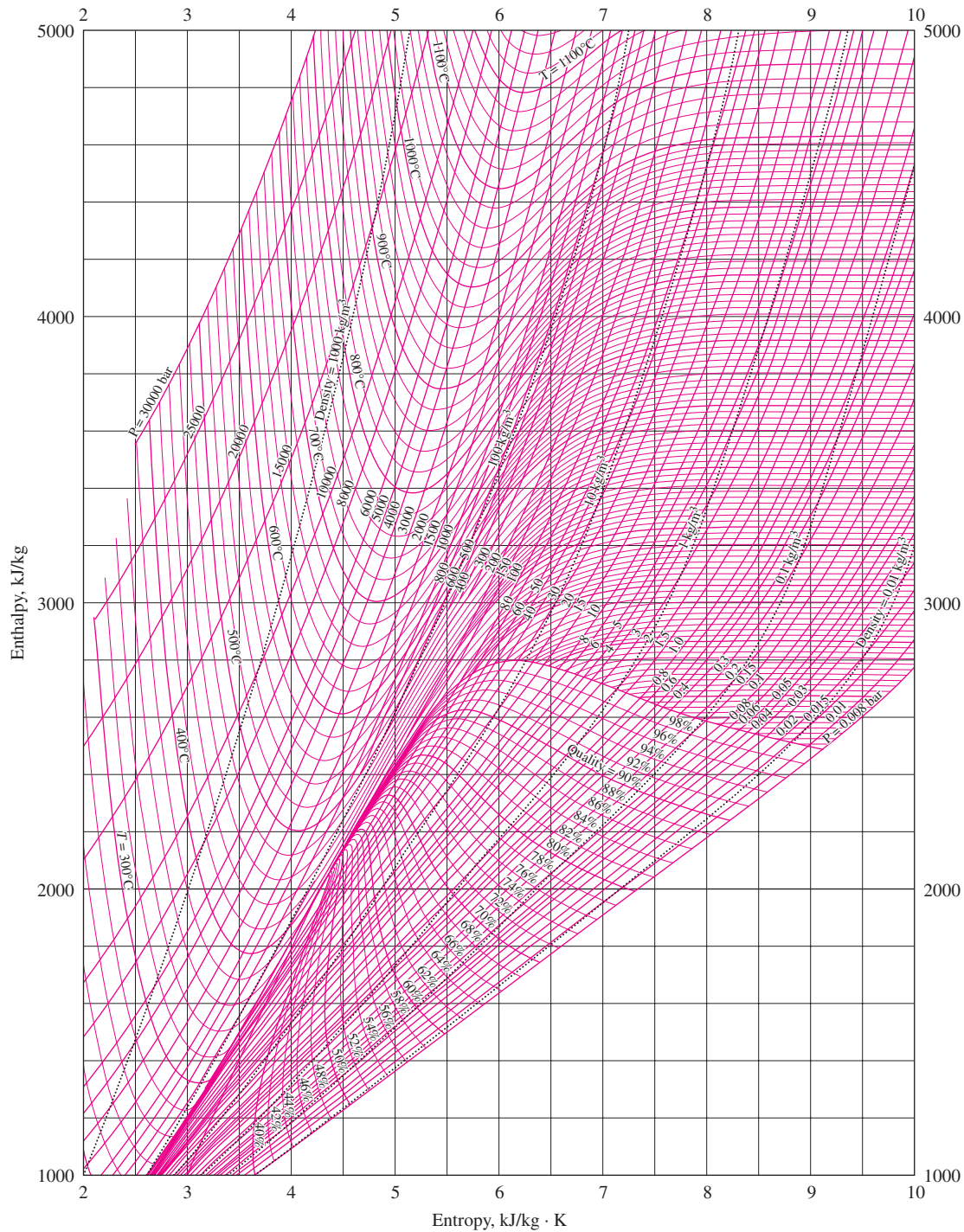
| Temp.,<br>$T$ °C | Sat.<br>press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|------------------|-----------------------------------------|--------------------------------------------|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|-------------------------------------------|--------------------|-------------------------|
|                  |                                         | Sat.<br>ice,<br>$v_i$                      | Sat.<br>vapor,<br>$v_g$ | Sat.<br>ice,<br>$u_i$              | Subl.,<br>$u_{ig}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>ice,<br>$h_i$       | Subl.,<br>$h_{ig}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>ice,<br>$s_i$                     | Subl.,<br>$s_{ig}$ | Sat.<br>vapor,<br>$s_g$ |
| 0.01             | 0.61169                                 | 0.001091                                   | 205.99                  | -333.40                            | 2707.9             | 2374.5                  | -333.40                     | 2833.9             | 2500.5                  | -1.2202                                   | 10.374             | 9.154                   |
| 0                | 0.61115                                 | 0.001091                                   | 206.17                  | -333.43                            | 2707.9             | 2374.5                  | -333.43                     | 2833.9             | 2500.5                  | -1.2204                                   | 10.375             | 9.154                   |
| -2               | 0.51772                                 | 0.001091                                   | 241.62                  | -337.63                            | 2709.4             | 2371.8                  | -337.63                     | 2834.5             | 2496.8                  | -1.2358                                   | 10.453             | 9.218                   |
| -4               | 0.43748                                 | 0.001090                                   | 283.84                  | -341.80                            | 2710.8             | 2369.0                  | -341.80                     | 2835.0             | 2493.2                  | -1.2513                                   | 10.533             | 9.282                   |
| -6               | 0.36873                                 | 0.001090                                   | 334.27                  | -345.94                            | 2712.2             | 2366.2                  | -345.93                     | 2835.4             | 2489.5                  | -1.2667                                   | 10.613             | 9.347                   |
| -8               | 0.30998                                 | 0.001090                                   | 394.66                  | -350.04                            | 2713.5             | 2363.5                  | -350.04                     | 2835.8             | 2485.8                  | -1.2821                                   | 10.695             | 9.413                   |
| -10              | 0.25990                                 | 0.001089                                   | 467.17                  | -354.12                            | 2714.8             | 2360.7                  | -354.12                     | 2836.2             | 2482.1                  | -1.2976                                   | 10.778             | 9.480                   |
| -12              | 0.21732                                 | 0.001089                                   | 554.47                  | -358.17                            | 2716.1             | 2357.9                  | -358.17                     | 2836.6             | 2478.4                  | -1.3130                                   | 10.862             | 9.549                   |
| -14              | 0.18121                                 | 0.001088                                   | 659.88                  | -362.18                            | 2717.3             | 2355.2                  | -362.18                     | 2836.9             | 2474.7                  | -1.3284                                   | 10.947             | 9.618                   |
| -16              | 0.15068                                 | 0.001088                                   | 787.51                  | -366.17                            | 2718.6             | 2352.4                  | -366.17                     | 2837.2             | 2471.0                  | -1.3439                                   | 11.033             | 9.689                   |
| -18              | 0.12492                                 | 0.001088                                   | 942.51                  | -370.13                            | 2719.7             | 2349.6                  | -370.13                     | 2837.5             | 2467.3                  | -1.3593                                   | 11.121             | 9.761                   |
| -20              | 0.10326                                 | 0.001087                                   | 1131.3                  | -374.06                            | 2720.9             | 2346.8                  | -374.06                     | 2837.7             | 2463.6                  | -1.3748                                   | 11.209             | 9.835                   |
| -22              | 0.08510                                 | 0.001087                                   | 1362.0                  | -377.95                            | 2722.0             | 2344.1                  | -377.95                     | 2837.9             | 2459.9                  | -1.3903                                   | 11.300             | 9.909                   |
| -24              | 0.06991                                 | 0.001087                                   | 1644.7                  | -381.82                            | 2723.1             | 2341.3                  | -381.82                     | 2838.1             | 2456.2                  | -1.4057                                   | 11.391             | 9.985                   |
| -26              | 0.05725                                 | 0.001087                                   | 1992.2                  | -385.66                            | 2724.2             | 2338.5                  | -385.66                     | 2838.2             | 2452.5                  | -1.4212                                   | 11.484             | 10.063                  |
| -28              | 0.04673                                 | 0.001086                                   | 2421.0                  | -389.47                            | 2725.2             | 2335.7                  | -389.47                     | 2838.3             | 2448.8                  | -1.4367                                   | 11.578             | 10.141                  |
| -30              | 0.03802                                 | 0.001086                                   | 2951.7                  | -393.25                            | 2726.2             | 2332.9                  | -393.25                     | 2838.4             | 2445.1                  | -1.4521                                   | 11.673             | 10.221                  |
| -32              | 0.03082                                 | 0.001086                                   | 3610.9                  | -397.00                            | 2727.2             | 2330.2                  | -397.00                     | 2838.4             | 2441.4                  | -1.4676                                   | 11.770             | 10.303                  |
| -34              | 0.02490                                 | 0.001085                                   | 4432.4                  | -400.72                            | 2728.1             | 2327.4                  | -400.72                     | 2838.5             | 2437.7                  | -1.4831                                   | 11.869             | 10.386                  |
| -36              | 0.02004                                 | 0.001085                                   | 5460.1                  | -404.40                            | 2729.0             | 2324.6                  | -404.40                     | 2838.4             | 2434.0                  | -1.4986                                   | 11.969             | 10.470                  |
| -38              | 0.01608                                 | 0.001085                                   | 6750.5                  | -408.07                            | 2729.9             | 2321.8                  | -408.07                     | 2838.4             | 2430.3                  | -1.5141                                   | 12.071             | 10.557                  |
| -40              | 0.01285                                 | 0.001084                                   | 8376.7                  | -411.70                            | 2730.7             | 2319.0                  | -411.70                     | 2838.3             | 2426.6                  | -1.5296                                   | 12.174             | 10.644                  |



**FIGURE A-9**

T-s diagram for water.

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**FIGURE A-10**

Mollier diagram for water.

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TABLE A-11

Saturated refrigerant-134a—Temperature table

| Temp.,<br>$T$ °C | Sat. press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                      | Internal energy,<br>$\text{kJ/kg}$ |                    |                      | Enthalpy,<br>$\text{kJ/kg}$ |                    |                      | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                      |
|------------------|--------------------------------------|--------------------------------------------|----------------------|------------------------------------|--------------------|----------------------|-----------------------------|--------------------|----------------------|-------------------------------------------|--------------------|----------------------|
|                  |                                      | Sat. liquid,<br>$v_f$                      | Sat. vapor,<br>$v_g$ | Sat. liquid,<br>$u_f$              | Evap.,<br>$u_{fg}$ | Sat. vapor,<br>$u_g$ | Sat. liquid,<br>$h_f$       | Evap.,<br>$h_{fg}$ | Sat. vapor,<br>$h_g$ | Sat. liquid,<br>$s_f$                     | Evap.,<br>$s_{fg}$ | Sat. vapor,<br>$s_g$ |
| -40              | 51.25                                | 0.0007054                                  | 0.36081              | -0.036                             | 207.40             | 207.37               | 0.000                       | 225.86             | 225.86               | 0.00000                                   | 0.96866            | 0.96866              |
| -38              | 56.86                                | 0.0007083                                  | 0.32732              | 2.475                              | 206.04             | 208.51               | 2.515                       | 224.61             | 227.12               | 0.01072                                   | 0.95511            | 0.96584              |
| -36              | 62.95                                | 0.0007112                                  | 0.29751              | 4.992                              | 204.67             | 209.66               | 5.037                       | 223.35             | 228.39               | 0.02138                                   | 0.94176            | 0.96315              |
| -34              | 69.56                                | 0.0007142                                  | 0.27090              | 7.517                              | 203.29             | 210.81               | 7.566                       | 222.09             | 229.65               | 0.03199                                   | 0.92859            | 0.96058              |
| -32              | 76.71                                | 0.0007172                                  | 0.24711              | 10.05                              | 201.91             | 211.96               | 10.10                       | 220.81             | 230.91               | 0.04253                                   | 0.91560            | 0.95813              |
| -30              | 84.43                                | 0.0007203                                  | 0.22580              | 12.59                              | 200.52             | 213.11               | 12.65                       | 219.52             | 232.17               | 0.05301                                   | 0.90278            | 0.95579              |
| -28              | 92.76                                | 0.0007234                                  | 0.20666              | 15.13                              | 199.12             | 214.25               | 15.20                       | 218.22             | 233.43               | 0.06344                                   | 0.89012            | 0.95356              |
| -26              | 101.73                               | 0.0007265                                  | 0.18946              | 17.69                              | 197.72             | 215.40               | 17.76                       | 216.92             | 234.68               | 0.07382                                   | 0.87762            | 0.95144              |
| -24              | 111.37                               | 0.0007297                                  | 0.17395              | 20.25                              | 196.30             | 216.55               | 20.33                       | 215.59             | 235.92               | 0.08414                                   | 0.86527            | 0.94941              |
| -22              | 121.72                               | 0.0007329                                  | 0.15995              | 22.82                              | 194.88             | 217.70               | 22.91                       | 214.26             | 237.17               | 0.09441                                   | 0.85307            | 0.94748              |
| -20              | 132.82                               | 0.0007362                                  | 0.14729              | 25.39                              | 193.45             | 218.84               | 25.49                       | 212.91             | 238.41               | 0.10463                                   | 0.84101            | 0.94564              |
| -18              | 144.69                               | 0.0007396                                  | 0.13583              | 27.98                              | 192.01             | 219.98               | 28.09                       | 211.55             | 239.64               | 0.11481                                   | 0.82908            | 0.94389              |
| -16              | 157.38                               | 0.0007430                                  | 0.12542              | 30.57                              | 190.56             | 221.13               | 30.69                       | 210.18             | 240.87               | 0.12493                                   | 0.81729            | 0.94222              |
| -14              | 170.93                               | 0.0007464                                  | 0.11597              | 33.17                              | 189.09             | 222.27               | 33.30                       | 208.79             | 242.09               | 0.13501                                   | 0.80561            | 0.94063              |
| -12              | 185.37                               | 0.0007499                                  | 0.10736              | 35.78                              | 187.62             | 223.40               | 35.92                       | 207.38             | 243.30               | 0.14504                                   | 0.79406            | 0.93911              |
| -10              | 200.74                               | 0.0007535                                  | 0.099516             | 38.40                              | 186.14             | 224.54               | 38.55                       | 205.96             | 244.51               | 0.15504                                   | 0.78263            | 0.93766              |
| -8               | 217.08                               | 0.0007571                                  | 0.092352             | 41.03                              | 184.64             | 225.67               | 41.19                       | 204.52             | 245.72               | 0.16498                                   | 0.77130            | 0.93629              |
| -6               | 234.44                               | 0.0007608                                  | 0.085802             | 43.66                              | 183.13             | 226.80               | 43.84                       | 203.07             | 246.91               | 0.17489                                   | 0.76008            | 0.93497              |
| -4               | 252.85                               | 0.0007646                                  | 0.079804             | 46.31                              | 181.61             | 227.92               | 46.50                       | 201.60             | 248.10               | 0.18476                                   | 0.74896            | 0.93372              |
| -2               | 272.36                               | 0.0007684                                  | 0.074304             | 48.96                              | 180.08             | 229.04               | 49.17                       | 200.11             | 249.28               | 0.19459                                   | 0.73794            | 0.93253              |
| 0                | 293.01                               | 0.0007723                                  | 0.069255             | 51.63                              | 178.53             | 230.16               | 51.86                       | 198.60             | 250.45               | 0.20439                                   | 0.72701            | 0.93139              |
| 2                | 314.84                               | 0.0007763                                  | 0.064612             | 54.30                              | 176.97             | 231.27               | 54.55                       | 197.07             | 251.61               | 0.21415                                   | 0.71616            | 0.93031              |
| 4                | 337.90                               | 0.0007804                                  | 0.060338             | 56.99                              | 175.39             | 232.38               | 57.25                       | 195.51             | 252.77               | 0.22387                                   | 0.70540            | 0.92927              |
| 6                | 362.23                               | 0.0007845                                  | 0.056398             | 59.68                              | 173.80             | 233.48               | 59.97                       | 193.94             | 253.91               | 0.23356                                   | 0.69471            | 0.92828              |
| 8                | 387.88                               | 0.0007887                                  | 0.052762             | 62.39                              | 172.19             | 234.58               | 62.69                       | 192.35             | 255.04               | 0.24323                                   | 0.68410            | 0.92733              |
| 10               | 414.89                               | 0.0007930                                  | 0.049403             | 65.10                              | 170.56             | 235.67               | 65.43                       | 190.73             | 256.16               | 0.25286                                   | 0.67356            | 0.92641              |
| 12               | 443.31                               | 0.0007975                                  | 0.046295             | 67.83                              | 168.92             | 236.75               | 68.18                       | 189.09             | 257.27               | 0.26246                                   | 0.66308            | 0.92554              |
| 14               | 473.19                               | 0.0008020                                  | 0.043417             | 70.57                              | 167.26             | 237.83               | 70.95                       | 187.42             | 258.37               | 0.27204                                   | 0.65266            | 0.92470              |
| 16               | 504.58                               | 0.0008066                                  | 0.040748             | 73.32                              | 165.58             | 238.90               | 73.73                       | 185.73             | 259.46               | 0.28159                                   | 0.64230            | 0.92389              |
| 18               | 537.52                               | 0.0008113                                  | 0.038271             | 76.08                              | 163.88             | 239.96               | 76.52                       | 184.01             | 260.53               | 0.29112                                   | 0.63198            | 0.92310              |

TABLE A-11

Saturated refrigerant-134a—Temperature table (Continued)

| Temp.,<br>$T$ °C | Sat. press.,<br>$P_{\text{sat}}$ kPa | Specific volume,<br>$\text{m}^3/\text{kg}$ |                      | Internal energy,<br>$\text{kJ/kg}$ |                    |                      | Enthalpy,<br>$\text{kJ/kg}$ |                    |                      | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                      |
|------------------|--------------------------------------|--------------------------------------------|----------------------|------------------------------------|--------------------|----------------------|-----------------------------|--------------------|----------------------|-------------------------------------------|--------------------|----------------------|
|                  |                                      | Sat. liquid,<br>$v_f$                      | Sat. vapor,<br>$v_g$ | Sat. liquid,<br>$u_f$              | Evap.,<br>$u_{fg}$ | Sat. vapor,<br>$u_g$ | Sat. liquid,<br>$h_f$       | Evap.,<br>$h_{fg}$ | Sat. vapor,<br>$h_g$ | Sat. liquid,<br>$s_f$                     | Evap.,<br>$s_{fg}$ | Sat. vapor,<br>$s_g$ |
| 20               | 572.07                               | 0.0008161                                  | 0.035969             | 78.86                              | 162.16             | 241.02               | 79.32                       | 182.27             | 261.59               | 0.30063                                   | 0.62172            | 0.92234              |
| 22               | 608.27                               | 0.0008210                                  | 0.033828             | 81.64                              | 160.42             | 242.06               | 82.14                       | 180.49             | 262.64               | 0.31011                                   | 0.61149            | 0.92160              |
| 24               | 646.18                               | 0.0008261                                  | 0.031834             | 84.44                              | 158.65             | 243.10               | 84.98                       | 178.69             | 263.67               | 0.31958                                   | 0.60130            | 0.92088              |
| 26               | 685.84                               | 0.0008313                                  | 0.029976             | 87.26                              | 156.87             | 244.12               | 87.83                       | 176.85             | 264.68               | 0.32903                                   | 0.59115            | 0.92018              |
| 28               | 727.31                               | 0.0008366                                  | 0.028242             | 90.09                              | 155.05             | 245.14               | 90.69                       | 174.99             | 265.68               | 0.33846                                   | 0.58102            | 0.91948              |
| 30               | 770.64                               | 0.0008421                                  | 0.026622             | 92.93                              | 153.22             | 246.14               | 93.58                       | 173.08             | 266.66               | 0.34789                                   | 0.57091            | 0.91879              |
| 32               | 815.89                               | 0.0008478                                  | 0.025108             | 95.79                              | 151.35             | 247.14               | 96.48                       | 171.14             | 267.62               | 0.35730                                   | 0.56082            | 0.91811              |
| 34               | 863.11                               | 0.0008536                                  | 0.023691             | 98.66                              | 149.46             | 248.12               | 99.40                       | 169.17             | 268.57               | 0.36670                                   | 0.55074            | 0.91743              |
| 36               | 912.35                               | 0.0008595                                  | 0.022364             | 101.55                             | 147.54             | 249.08               | 102.33                      | 167.16             | 269.49               | 0.37609                                   | 0.54066            | 0.91675              |
| 38               | 963.68                               | 0.0008657                                  | 0.021119             | 104.45                             | 145.58             | 250.04               | 105.29                      | 165.10             | 270.39               | 0.38548                                   | 0.53058            | 0.91606              |
| 40               | 1017.1                               | 0.0008720                                  | 0.019952             | 107.38                             | 143.60             | 250.97               | 108.26                      | 163.00             | 271.27               | 0.39486                                   | 0.52049            | 0.91536              |
| 42               | 1072.8                               | 0.0008786                                  | 0.018855             | 110.32                             | 141.58             | 251.89               | 111.26                      | 160.86             | 272.12               | 0.40425                                   | 0.51039            | 0.91464              |
| 44               | 1130.7                               | 0.0008854                                  | 0.017824             | 113.28                             | 139.52             | 252.80               | 114.28                      | 158.67             | 272.95               | 0.41363                                   | 0.50027            | 0.91391              |
| 46               | 1191.0                               | 0.0008924                                  | 0.016853             | 116.26                             | 137.42             | 253.68               | 117.32                      | 156.43             | 273.75               | 0.42302                                   | 0.49012            | 0.91315              |
| 48               | 1253.6                               | 0.0008996                                  | 0.015939             | 119.26                             | 135.29             | 254.55               | 120.39                      | 154.14             | 274.53               | 0.43242                                   | 0.47993            | 0.91236              |
| 52               | 1386.2                               | 0.0009150                                  | 0.014265             | 125.33                             | 130.88             | 256.21               | 126.59                      | 149.39             | 275.98               | 0.45126                                   | 0.45941            | 0.91067              |
| 56               | 1529.1                               | 0.0009317                                  | 0.012771             | 131.49                             | 126.28             | 257.77               | 132.91                      | 144.38             | 277.30               | 0.47018                                   | 0.43863            | 0.90880              |
| 60               | 1682.8                               | 0.0009498                                  | 0.011434             | 137.76                             | 121.46             | 259.22               | 139.36                      | 139.10             | 278.46               | 0.48920                                   | 0.41749            | 0.90669              |
| 65               | 1891.0                               | 0.0009750                                  | 0.009950             | 145.77                             | 115.05             | 260.82               | 147.62                      | 132.02             | 279.64               | 0.51320                                   | 0.39039            | 0.90359              |
| 70               | 2118.2                               | 0.0010037                                  | 0.008642             | 154.01                             | 108.14             | 262.15               | 156.13                      | 124.32             | 280.46               | 0.53755                                   | 0.36227            | 0.89982              |
| 75               | 2365.8                               | 0.0010372                                  | 0.007480             | 162.53                             | 100.60             | 263.13               | 164.98                      | 115.85             | 280.82               | 0.56241                                   | 0.33272            | 0.89512              |
| 80               | 2635.3                               | 0.0010772                                  | 0.006436             | 171.40                             | 92.23              | 263.63               | 174.24                      | 106.35             | 280.59               | 0.58800                                   | 0.30111            | 0.88912              |
| 85               | 2928.2                               | 0.0011270                                  | 0.005486             | 180.77                             | 82.67              | 263.44               | 184.07                      | 95.44              | 279.51               | 0.61473                                   | 0.26644            | 0.88117              |
| 90               | 3246.9                               | 0.0011932                                  | 0.004599             | 190.89                             | 71.29              | 262.18               | 194.76                      | 82.35              | 277.11               | 0.64336                                   | 0.22674            | 0.87010              |
| 95               | 3594.1                               | 0.0012933                                  | 0.003726             | 202.40                             | 56.47              | 258.87               | 207.05                      | 65.21              | 272.26               | 0.67578                                   | 0.17711            | 0.85289              |
| 100              | 3975.1                               | 0.0015269                                  | 0.002630             | 218.72                             | 29.19              | 247.91               | 224.79                      | 33.58              | 258.37               | 0.72217                                   | 0.08999            | 0.81215              |

Source: Tables A-11 through A-13 are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the R134a, which is based on the fundamental equation of state developed by R. Tillner-Roth and H.D. Baehr, "An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for temperatures from 170 K to 455 K and Pressures up to 70 MPa," *J. Phys. Chem. Ref. Data*, Vol. 23, No. 5, 1994. The enthalpy and entropy values of saturated liquid are set to zero at  $-40^\circ\text{C}$  (and  $-40^\circ\text{F}$ ).

TABLE A-12

Saturated refrigerant-134a—Pressure table

| Press.,<br>$P$ kPa | Sat.<br>temp.,<br>$T_{\text{sat}}$ °C | Specific volume,<br>$\text{m}^3/\text{kg}$ |                         | Internal energy,<br>$\text{kJ/kg}$ |                    |                         | Enthalpy,<br>$\text{kJ/kg}$ |                    |                         | Entropy,<br>$\text{kJ/kg} \cdot \text{K}$ |                    |                         |
|--------------------|---------------------------------------|--------------------------------------------|-------------------------|------------------------------------|--------------------|-------------------------|-----------------------------|--------------------|-------------------------|-------------------------------------------|--------------------|-------------------------|
|                    |                                       | Sat.<br>liquid,<br>$v_f$                   | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$           | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$    | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                  | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 60                 | -36.95                                | 0.0007098                                  | 0.31121                 | 3.798                              | 205.32             | 209.12                  | 3.841                       | 223.95             | 227.79                  | 0.01634                                   | 0.94807            | 0.96441                 |
| 70                 | -33.87                                | 0.0007144                                  | 0.26929                 | 7.680                              | 203.20             | 210.88                  | 7.730                       | 222.00             | 229.73                  | 0.03267                                   | 0.92775            | 0.96042                 |
| 80                 | -31.13                                | 0.0007185                                  | 0.23753                 | 11.15                              | 201.30             | 212.46                  | 11.21                       | 220.25             | 231.46                  | 0.04711                                   | 0.90999            | 0.95710                 |
| 90                 | -28.65                                | 0.0007223                                  | 0.21263                 | 14.31                              | 199.57             | 213.88                  | 14.37                       | 218.65             | 233.02                  | 0.06008                                   | 0.89419            | 0.95427                 |
| 100                | -26.37                                | 0.0007259                                  | 0.19254                 | 17.21                              | 197.98             | 215.19                  | 17.28                       | 217.16             | 234.44                  | 0.07188                                   | 0.87995            | 0.95183                 |
| 120                | -22.32                                | 0.0007324                                  | 0.16212                 | 22.40                              | 195.11             | 217.51                  | 22.49                       | 214.48             | 236.97                  | 0.09275                                   | 0.85503            | 0.94779                 |
| 140                | -18.77                                | 0.0007383                                  | 0.14014                 | 26.98                              | 192.57             | 219.54                  | 27.08                       | 212.08             | 239.16                  | 0.11087                                   | 0.83368            | 0.94456                 |
| 160                | -15.60                                | 0.0007437                                  | 0.12348                 | 31.09                              | 190.27             | 221.35                  | 31.21                       | 209.90             | 241.11                  | 0.12693                                   | 0.81496            | 0.94190                 |
| 180                | -12.73                                | 0.0007487                                  | 0.11041                 | 34.83                              | 188.16             | 222.99                  | 34.97                       | 207.90             | 242.86                  | 0.14139                                   | 0.79826            | 0.93965                 |
| 200                | -10.09                                | 0.0007533                                  | 0.099867                | 38.28                              | 186.21             | 224.48                  | 38.43                       | 206.03             | 244.46                  | 0.15457                                   | 0.78316            | 0.93773                 |
| 240                | -5.38                                 | 0.0007620                                  | 0.083897                | 44.48                              | 182.67             | 227.14                  | 44.66                       | 202.62             | 247.28                  | 0.17794                                   | 0.75664            | 0.93458                 |
| 280                | -1.25                                 | 0.0007699                                  | 0.072352                | 49.97                              | 179.50             | 229.46                  | 50.18                       | 199.54             | 249.72                  | 0.19829                                   | 0.73381            | 0.93210                 |
| 320                | 2.46                                  | 0.0007772                                  | 0.063604                | 54.92                              | 176.61             | 231.52                  | 55.16                       | 196.71             | 251.88                  | 0.21637                                   | 0.71369            | 0.93006                 |
| 360                | 5.82                                  | 0.0007841                                  | 0.056738                | 59.44                              | 173.94             | 233.38                  | 59.72                       | 194.08             | 253.81                  | 0.23270                                   | 0.69566            | 0.92836                 |
| 400                | 8.91                                  | 0.0007907                                  | 0.051201                | 63.62                              | 171.45             | 235.07                  | 63.94                       | 191.62             | 255.55                  | 0.24761                                   | 0.67929            | 0.92691                 |
| 450                | 12.46                                 | 0.0007985                                  | 0.045619                | 68.45                              | 168.54             | 237.00                  | 68.81                       | 188.71             | 257.53                  | 0.26465                                   | 0.66069            | 0.92535                 |
| 500                | 15.71                                 | 0.0008059                                  | 0.041118                | 72.93                              | 165.82             | 238.75                  | 73.33                       | 185.98             | 259.30                  | 0.28023                                   | 0.64377            | 0.92400                 |
| 550                | 18.73                                 | 0.0008130                                  | 0.037408                | 77.10                              | 163.25             | 240.35                  | 77.54                       | 183.38             | 260.92                  | 0.29461                                   | 0.62821            | 0.92282                 |
| 600                | 21.55                                 | 0.0008199                                  | 0.034295                | 81.02                              | 160.81             | 241.83                  | 81.51                       | 180.90             | 262.40                  | 0.30799                                   | 0.61378            | 0.92177                 |
| 650                | 24.20                                 | 0.0008266                                  | 0.031646                | 84.72                              | 158.48             | 243.20                  | 85.26                       | 178.51             | 263.77                  | 0.32051                                   | 0.60030            | 0.92081                 |
| 700                | 26.69                                 | 0.0008331                                  | 0.029361                | 88.24                              | 156.24             | 244.48                  | 88.82                       | 176.21             | 265.03                  | 0.33230                                   | 0.58763            | 0.91994                 |
| 750                | 29.06                                 | 0.0008395                                  | 0.027371                | 91.59                              | 154.08             | 245.67                  | 92.22                       | 173.98             | 266.20                  | 0.34345                                   | 0.57567            | 0.91912                 |
| 800                | 31.31                                 | 0.0008458                                  | 0.025621                | 94.79                              | 152.00             | 246.79                  | 95.47                       | 171.82             | 267.29                  | 0.35404                                   | 0.56431            | 0.91835                 |
| 850                | 33.45                                 | 0.0008520                                  | 0.024069                | 97.87                              | 149.98             | 247.85                  | 98.60                       | 169.71             | 268.31                  | 0.36413                                   | 0.55349            | 0.91762                 |
| 900                | 35.51                                 | 0.0008580                                  | 0.022683                | 100.83                             | 148.01             | 248.85                  | 101.61                      | 167.66             | 269.26                  | 0.37377                                   | 0.54315            | 0.91692                 |
| 950                | 37.48                                 | 0.0008641                                  | 0.021438                | 103.69                             | 146.10             | 249.79                  | 104.51                      | 165.64             | 270.15                  | 0.38301                                   | 0.53323            | 0.91624                 |
| 1000               | 39.37                                 | 0.0008700                                  | 0.020313                | 106.45                             | 144.23             | 250.68                  | 107.32                      | 163.67             | 270.99                  | 0.39189                                   | 0.52368            | 0.91558                 |
| 1200               | 46.29                                 | 0.0008934                                  | 0.016715                | 116.70                             | 137.11             | 253.81                  | 117.77                      | 156.10             | 273.87                  | 0.42441                                   | 0.48863            | 0.91303                 |
| 1400               | 52.40                                 | 0.0009166                                  | 0.014107                | 125.94                             | 130.43             | 256.37                  | 127.22                      | 148.90             | 276.12                  | 0.45315                                   | 0.45734            | 0.91050                 |
| 1600               | 57.88                                 | 0.0009400                                  | 0.012123                | 134.43                             | 124.04             | 258.47                  | 135.93                      | 141.93             | 277.86                  | 0.47911                                   | 0.42873            | 0.90784                 |
| 1800               | 62.87                                 | 0.0009639                                  | 0.010559                | 142.33                             | 117.83             | 260.17                  | 144.07                      | 135.11             | 279.17                  | 0.50294                                   | 0.40204            | 0.90498                 |
| 2000               | 67.45                                 | 0.0009886                                  | 0.009288                | 149.78                             | 111.73             | 261.51                  | 151.76                      | 128.33             | 280.09                  | 0.52509                                   | 0.37675            | 0.90184                 |
| 2500               | 77.54                                 | 0.0010566                                  | 0.006936                | 166.99                             | 96.47              | 263.45                  | 169.63                      | 111.16             | 280.79                  | 0.57531                                   | 0.31695            | 0.89226                 |
| 3000               | 86.16                                 | 0.0011406                                  | 0.005275                | 183.04                             | 80.22              | 263.26                  | 186.46                      | 92.63              | 279.09                  | 0.62118                                   | 0.25776            | 0.87894                 |



TABLE A-13

Superheated refrigerant-134a

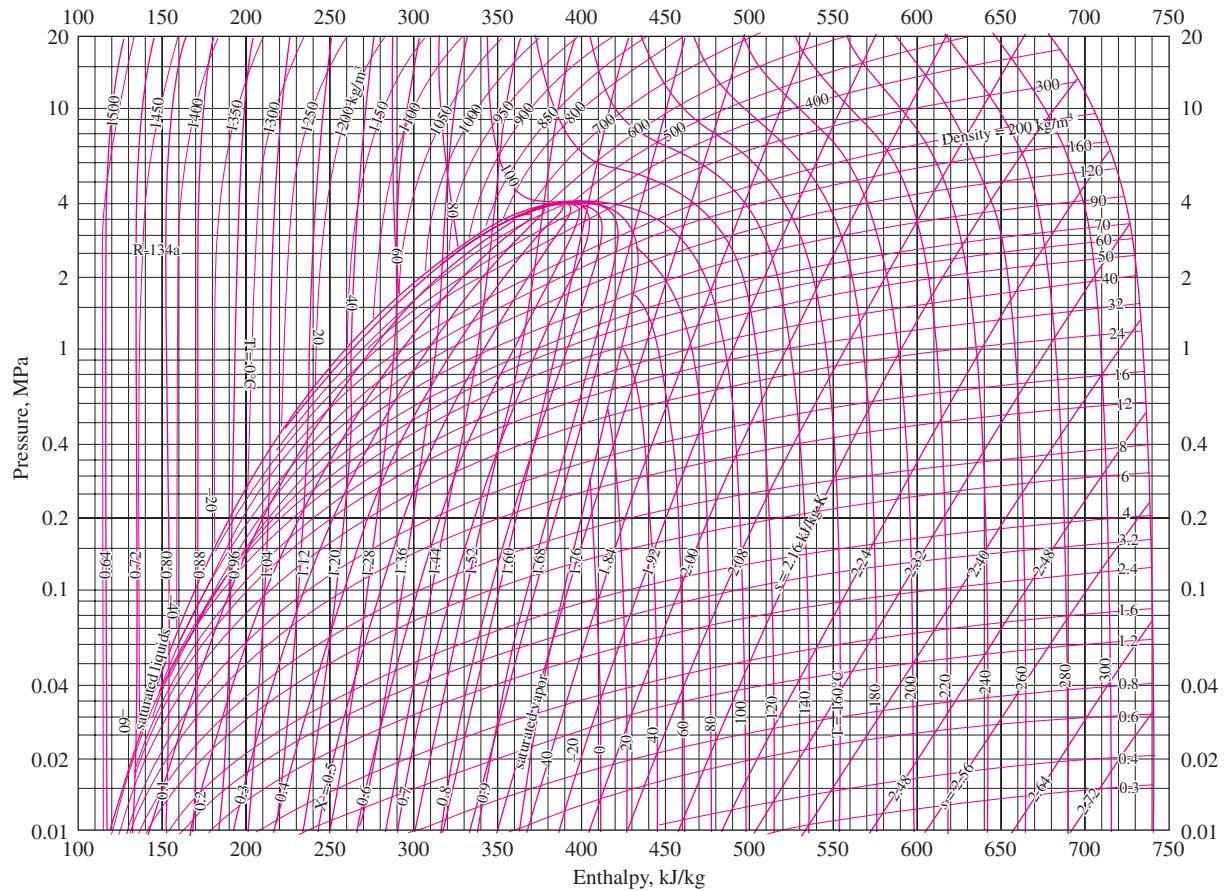
| $T$<br>°C                                                       | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg                                       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg                                       | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|-----------------------------------------------------------------|---------------------------|--------------|--------------|------------------|-----------------------------------------------------------------|--------------|--------------|------------------|-----------------------------------------------------------------|--------------|--------------|------------------|
| $P = 0.06 \text{ MPa } (T_{\text{sat}} = -36.95^\circ\text{C})$ |                           |              |              |                  | $P = 0.10 \text{ MPa } (T_{\text{sat}} = -26.37^\circ\text{C})$ |              |              |                  | $P = 0.14 \text{ MPa } (T_{\text{sat}} = -18.77^\circ\text{C})$ |              |              |                  |
| Sat.                                                            | 0.31121                   | 209.12       | 227.79       | 0.9644           | 0.19254                                                         | 215.19       | 234.44       | 0.9518           | 0.14014                                                         | 219.54       | 239.16       | 0.9446           |
| -20                                                             | 0.33608                   | 220.60       | 240.76       | 1.0174           | 0.19841                                                         | 219.66       | 239.50       | 0.9721           |                                                                 |              |              |                  |
| -10                                                             | 0.35048                   | 227.55       | 248.58       | 1.0477           | 0.20743                                                         | 226.75       | 247.49       | 1.0030           | 0.14605                                                         | 225.91       | 246.36       | 0.9724           |
| 0                                                               | 0.36476                   | 234.66       | 256.54       | 1.0774           | 0.21630                                                         | 233.95       | 255.58       | 1.0332           | 0.15263                                                         | 233.23       | 254.60       | 1.0031           |
| 10                                                              | 0.37893                   | 241.92       | 264.66       | 1.1066           | 0.22506                                                         | 241.30       | 263.81       | 1.0628           | 0.15908                                                         | 240.66       | 262.93       | 1.0331           |
| 20                                                              | 0.39302                   | 249.35       | 272.94       | 1.1353           | 0.23373                                                         | 248.79       | 272.17       | 1.0918           | 0.16544                                                         | 248.22       | 271.38       | 1.0624           |
| 30                                                              | 0.40705                   | 256.95       | 281.37       | 1.1636           | 0.24233                                                         | 256.44       | 280.68       | 1.1203           | 0.17172                                                         | 255.93       | 279.97       | 1.0912           |
| 40                                                              | 0.42102                   | 264.71       | 289.97       | 1.1915           | 0.25088                                                         | 264.25       | 289.34       | 1.1484           | 0.17794                                                         | 263.79       | 288.70       | 1.1195           |
| 50                                                              | 0.43495                   | 272.64       | 298.74       | 1.2191           | 0.25937                                                         | 272.22       | 298.16       | 1.1762           | 0.18412                                                         | 271.79       | 297.57       | 1.1474           |
| 60                                                              | 0.44883                   | 280.73       | 307.66       | 1.2463           | 0.26783                                                         | 280.35       | 307.13       | 1.2035           | 0.19025                                                         | 279.96       | 306.59       | 1.1749           |
| 70                                                              | 0.46269                   | 288.99       | 316.75       | 1.2732           | 0.27626                                                         | 288.64       | 316.26       | 1.2305           | 0.19635                                                         | 288.28       | 315.77       | 1.2020           |
| 80                                                              | 0.47651                   | 297.41       | 326.00       | 1.2997           | 0.28465                                                         | 297.08       | 325.55       | 1.2572           | 0.20242                                                         | 296.75       | 325.09       | 1.2288           |
| 90                                                              | 0.49032                   | 306.00       | 335.42       | 1.3260           | 0.29303                                                         | 305.69       | 334.99       | 1.2836           | 0.20847                                                         | 305.38       | 334.57       | 1.2553           |
| 100                                                             | 0.50410                   | 314.74       | 344.99       | 1.3520           | 0.30138                                                         | 314.46       | 344.60       | 1.3096           | 0.21449                                                         | 314.17       | 344.20       | 1.2814           |
| $P = 0.18 \text{ MPa } (T_{\text{sat}} = -12.73^\circ\text{C})$ |                           |              |              |                  | $P = 0.20 \text{ MPa } (T_{\text{sat}} = -10.09^\circ\text{C})$ |              |              |                  | $P = 0.24 \text{ MPa } (T_{\text{sat}} = -5.38^\circ\text{C})$  |              |              |                  |
| Sat.                                                            | 0.11041                   | 222.99       | 242.86       | 0.9397           | 0.09987                                                         | 224.48       | 244.46       | 0.9377           | 0.08390                                                         | 227.14       | 247.28       | 0.9346           |
| -10                                                             | 0.11189                   | 225.02       | 245.16       | 0.9484           | 0.09991                                                         | 224.55       | 244.54       | 0.9380           |                                                                 |              |              |                  |
| 0                                                               | 0.11722                   | 232.48       | 253.58       | 0.9798           | 0.10481                                                         | 232.09       | 253.05       | 0.9698           | 0.08617                                                         | 231.29       | 251.97       | 0.9519           |
| 10                                                              | 0.12240                   | 240.00       | 262.04       | 1.0102           | 0.10955                                                         | 239.67       | 261.58       | 1.0004           | 0.09026                                                         | 238.98       | 260.65       | 0.9831           |
| 20                                                              | 0.12748                   | 247.64       | 270.59       | 1.0399           | 0.11418                                                         | 247.35       | 270.18       | 1.0303           | 0.09423                                                         | 246.74       | 269.36       | 1.0134           |
| 30                                                              | 0.13248                   | 255.41       | 279.25       | 1.0690           | 0.11874                                                         | 255.14       | 278.89       | 1.0595           | 0.09812                                                         | 254.61       | 278.16       | 1.0429           |
| 40                                                              | 0.13741                   | 263.31       | 288.05       | 1.0975           | 0.12322                                                         | 263.08       | 287.72       | 1.0882           | 0.10193                                                         | 262.59       | 287.06       | 1.0718           |
| 50                                                              | 0.14230                   | 271.36       | 296.98       | 1.1256           | 0.12766                                                         | 271.15       | 296.68       | 1.1163           | 0.10570                                                         | 270.71       | 296.08       | 1.1001           |
| 60                                                              | 0.14715                   | 279.56       | 306.05       | 1.1532           | 0.13206                                                         | 279.37       | 305.78       | 1.1441           | 0.10942                                                         | 278.97       | 305.23       | 1.1280           |
| 70                                                              | 0.15196                   | 287.91       | 315.27       | 1.1805           | 0.13641                                                         | 287.73       | 315.01       | 1.1714           | 0.11310                                                         | 287.36       | 314.51       | 1.1554           |
| 80                                                              | 0.15673                   | 296.42       | 324.63       | 1.2074           | 0.14074                                                         | 296.25       | 324.40       | 1.1983           | 0.11675                                                         | 295.91       | 323.93       | 1.1825           |
| 90                                                              | 0.16149                   | 305.07       | 334.14       | 1.2339           | 0.14504                                                         | 304.92       | 333.93       | 1.2249           | 0.12038                                                         | 304.60       | 333.49       | 1.2092           |
| 100                                                             | 0.16622                   | 313.88       | 343.80       | 1.2602           | 0.14933                                                         | 313.74       | 343.60       | 1.2512           | 0.12398                                                         | 313.44       | 343.20       | 1.2356           |
| $P = 0.28 \text{ MPa } (T_{\text{sat}} = -1.25^\circ\text{C})$  |                           |              |              |                  | $P = 0.32 \text{ MPa } (T_{\text{sat}} = 2.46^\circ\text{C})$   |              |              |                  | $P = 0.40 \text{ MPa } (T_{\text{sat}} = 8.91^\circ\text{C})$   |              |              |                  |
| Sat.                                                            | 0.07235                   | 229.46       | 249.72       | 0.9321           | 0.06360                                                         | 231.52       | 251.88       | 0.9301           | 0.051201                                                        | 235.07       | 255.55       | 0.9269           |
| 0                                                               | 0.07282                   | 230.44       | 250.83       | 0.9362           |                                                                 |              |              |                  |                                                                 |              |              |                  |
| 10                                                              | 0.07646                   | 238.27       | 259.68       | 0.9680           | 0.06609                                                         | 237.54       | 258.69       | 0.9544           | 0.051506                                                        | 235.97       | 256.58       | 0.9305           |
| 20                                                              | 0.07997                   | 246.13       | 268.52       | 0.9987           | 0.06925                                                         | 245.50       | 267.66       | 0.9856           | 0.054213                                                        | 244.18       | 265.86       | 0.9628           |
| 30                                                              | 0.08338                   | 254.06       | 277.41       | 1.0285           | 0.07231                                                         | 253.50       | 276.65       | 1.0157           | 0.056796                                                        | 252.36       | 275.07       | 0.9937           |
| 40                                                              | 0.08672                   | 262.10       | 286.38       | 1.0576           | 0.07530                                                         | 261.60       | 285.70       | 1.0451           | 0.059292                                                        | 260.58       | 284.30       | 1.0236           |
| 50                                                              | 0.09000                   | 270.27       | 295.47       | 1.0862           | 0.07823                                                         | 269.82       | 294.85       | 1.0739           | 0.061724                                                        | 268.90       | 293.59       | 1.0528           |
| 60                                                              | 0.09324                   | 278.56       | 304.67       | 1.1142           | 0.08111                                                         | 278.15       | 304.11       | 1.1021           | 0.064104                                                        | 277.32       | 302.96       | 1.0814           |
| 70                                                              | 0.09644                   | 286.99       | 314.00       | 1.1418           | 0.08395                                                         | 286.62       | 313.48       | 1.1298           | 0.066443                                                        | 285.86       | 312.44       | 1.1094           |
| 80                                                              | 0.09961                   | 295.57       | 323.46       | 1.1690           | 0.08675                                                         | 295.22       | 322.98       | 1.1571           | 0.068747                                                        | 294.53       | 322.02       | 1.1369           |
| 90                                                              | 0.10275                   | 304.29       | 333.06       | 1.1958           | 0.08953                                                         | 303.97       | 332.62       | 1.1840           | 0.071023                                                        | 303.32       | 331.73       | 1.1640           |
| 100                                                             | 0.10587                   | 313.15       | 342.80       | 1.2222           | 0.09229                                                         | 312.86       | 342.39       | 1.2105           | 0.073274                                                        | 312.26       | 341.57       | 1.1907           |
| 110                                                             | 0.10897                   | 322.16       | 352.68       | 1.2483           | 0.09503                                                         | 321.89       | 352.30       | 1.2367           | 0.075504                                                        | 321.33       | 351.53       | 1.2171           |
| 120                                                             | 0.11205                   | 331.32       | 362.70       | 1.2742           | 0.09775                                                         | 331.07       | 362.35       | 1.2626           | 0.077717                                                        | 330.55       | 361.63       | 1.2431           |
| 130                                                             | 0.11512                   | 340.63       | 372.87       | 1.2997           | 0.10045                                                         | 340.39       | 372.54       | 1.2882           | 0.079913                                                        | 339.90       | 371.87       | 1.2688           |
| 140                                                             | 0.11818                   | 350.09       | 383.18       | 1.3250           | 0.10314                                                         | 349.86       | 382.87       | 1.3135           | 0.082096                                                        | 349.41       | 382.24       | 1.2942           |



TABLE A-13

Superheated refrigerant-134a (Continued)

| $T$<br>°C                                                      | $v$<br>m <sup>3</sup> /kg | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg                                      | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K | $v$<br>m <sup>3</sup> /kg                                      | $u$<br>kJ/kg | $h$<br>kJ/kg | $s$<br>kJ/kg · K |
|----------------------------------------------------------------|---------------------------|--------------|--------------|------------------|----------------------------------------------------------------|--------------|--------------|------------------|----------------------------------------------------------------|--------------|--------------|------------------|
| $P = 0.50 \text{ MPa } (T_{\text{sat}} = 15.71^\circ\text{C})$ |                           |              |              |                  | $P = 0.60 \text{ MPa } (T_{\text{sat}} = 21.55^\circ\text{C})$ |              |              |                  | $P = 0.70 \text{ MPa } (T_{\text{sat}} = 26.69^\circ\text{C})$ |              |              |                  |
| Sat.                                                           | 0.041118                  | 238.75       | 259.30       | 0.9240           | 0.034295                                                       | 241.83       | 262.40       | 0.9218           | 0.029361                                                       | 244.48       | 265.03       | 0.9199           |
| 20                                                             | 0.042115                  | 242.40       | 263.46       | 0.9383           |                                                                |              |              |                  |                                                                |              |              |                  |
| 30                                                             | 0.044338                  | 250.84       | 273.01       | 0.9703           | 0.035984                                                       | 249.22       | 270.81       | 0.9499           | 0.029966                                                       | 247.48       | 268.45       | 0.9313           |
| 40                                                             | 0.046456                  | 259.26       | 282.48       | 1.0011           | 0.037865                                                       | 257.86       | 280.58       | 0.9816           | 0.031696                                                       | 256.39       | 278.57       | 0.9641           |
| 50                                                             | 0.048499                  | 267.72       | 291.96       | 1.0309           | 0.039659                                                       | 266.48       | 290.28       | 1.0121           | 0.033322                                                       | 265.20       | 288.53       | 0.9954           |
| 60                                                             | 0.050485                  | 276.25       | 301.50       | 1.0599           | 0.041389                                                       | 275.15       | 299.98       | 1.0417           | 0.034875                                                       | 274.01       | 298.42       | 1.0256           |
| 70                                                             | 0.052427                  | 284.89       | 311.10       | 1.0883           | 0.043069                                                       | 283.89       | 309.73       | 1.0705           | 0.036373                                                       | 282.87       | 308.33       | 1.0549           |
| 80                                                             | 0.054331                  | 293.64       | 320.80       | 1.1162           | 0.044710                                                       | 292.73       | 319.55       | 1.0987           | 0.037829                                                       | 291.80       | 318.28       | 1.0835           |
| 90                                                             | 0.056205                  | 302.51       | 330.61       | 1.1436           | 0.046318                                                       | 301.67       | 329.46       | 1.1264           | 0.039250                                                       | 300.82       | 328.29       | 1.1114           |
| 100                                                            | 0.058053                  | 311.50       | 340.53       | 1.1705           | 0.047900                                                       | 310.73       | 339.47       | 1.1536           | 0.040642                                                       | 309.95       | 338.40       | 1.1389           |
| 110                                                            | 0.059880                  | 320.63       | 350.57       | 1.1971           | 0.049458                                                       | 319.91       | 349.59       | 1.1803           | 0.042010                                                       | 319.19       | 348.60       | 1.1658           |
| 120                                                            | 0.061687                  | 329.89       | 360.73       | 1.2233           | 0.050997                                                       | 329.23       | 359.82       | 1.2067           | 0.043358                                                       | 328.55       | 358.90       | 1.1924           |
| 130                                                            | 0.063479                  | 339.29       | 371.03       | 1.2491           | 0.052519                                                       | 338.67       | 370.18       | 1.2327           | 0.044688                                                       | 338.04       | 369.32       | 1.2186           |
| 140                                                            | 0.065256                  | 348.83       | 381.46       | 1.2747           | 0.054027                                                       | 348.25       | 380.66       | 1.2584           | 0.046004                                                       | 347.66       | 379.86       | 1.2444           |
| 150                                                            | 0.067021                  | 358.51       | 392.02       | 1.2999           | 0.055522                                                       | 357.96       | 391.27       | 1.2838           | 0.047306                                                       | 357.41       | 390.52       | 1.2699           |
| 160                                                            | 0.068775                  | 368.33       | 402.72       | 1.3249           | 0.057006                                                       | 367.81       | 402.01       | 1.3088           | 0.048597                                                       | 367.29       | 401.31       | 1.2951           |
| $P = 0.80 \text{ MPa } (T_{\text{sat}} = 31.31^\circ\text{C})$ |                           |              |              |                  | $P = 0.90 \text{ MPa } (T_{\text{sat}} = 35.51^\circ\text{C})$ |              |              |                  | $P = 1.00 \text{ MPa } (T_{\text{sat}} = 39.37^\circ\text{C})$ |              |              |                  |
| Sat.                                                           | 0.025621                  | 246.79       | 267.29       | 0.9183           | 0.022683                                                       | 248.85       | 269.26       | 0.9169           | 0.020313                                                       | 250.68       | 270.99       | 0.9156           |
| 40                                                             | 0.027035                  | 254.82       | 276.45       | 0.9480           | 0.023375                                                       | 253.13       | 274.17       | 0.9327           | 0.020406                                                       | 251.30       | 271.71       | 0.9179           |
| 50                                                             | 0.028547                  | 263.86       | 286.69       | 0.9802           | 0.024809                                                       | 262.44       | 284.77       | 0.9660           | 0.021796                                                       | 260.94       | 282.74       | 0.9525           |
| 60                                                             | 0.029973                  | 272.83       | 296.81       | 1.0110           | 0.026146                                                       | 271.60       | 295.13       | 0.9976           | 0.023068                                                       | 270.32       | 293.38       | 0.9850           |
| 70                                                             | 0.031340                  | 281.81       | 306.88       | 1.0408           | 0.027413                                                       | 280.72       | 305.39       | 1.0280           | 0.024261                                                       | 279.59       | 303.85       | 1.0160           |
| 80                                                             | 0.032659                  | 290.84       | 316.97       | 1.0698           | 0.028630                                                       | 289.86       | 315.63       | 1.0574           | 0.025398                                                       | 288.86       | 314.25       | 1.0458           |
| 90                                                             | 0.033941                  | 299.95       | 327.10       | 1.0981           | 0.029806                                                       | 299.06       | 325.89       | 1.0860           | 0.026492                                                       | 298.15       | 324.64       | 1.0748           |
| 100                                                            | 0.035193                  | 309.15       | 337.30       | 1.1258           | 0.030951                                                       | 308.34       | 336.19       | 1.1140           | 0.027552                                                       | 307.51       | 335.06       | 1.1031           |
| 110                                                            | 0.036420                  | 318.45       | 347.59       | 1.1530           | 0.032068                                                       | 317.70       | 346.56       | 1.1414           | 0.028584                                                       | 316.94       | 345.53       | 1.1308           |
| 120                                                            | 0.037625                  | 327.87       | 357.97       | 1.1798           | 0.033164                                                       | 327.18       | 357.02       | 1.1684           | 0.029592                                                       | 326.47       | 356.06       | 1.1580           |
| 130                                                            | 0.038813                  | 337.40       | 368.45       | 1.2061           | 0.034241                                                       | 336.76       | 367.58       | 1.1949           | 0.030581                                                       | 336.11       | 366.69       | 1.1846           |
| 140                                                            | 0.039985                  | 347.06       | 379.05       | 1.2321           | 0.035302                                                       | 346.46       | 378.23       | 1.2210           | 0.031554                                                       | 345.85       | 377.40       | 1.2109           |
| 150                                                            | 0.041143                  | 356.85       | 389.76       | 1.2577           | 0.036349                                                       | 356.28       | 389.00       | 1.2467           | 0.032512                                                       | 355.71       | 388.22       | 1.2368           |
| 160                                                            | 0.042290                  | 366.76       | 400.59       | 1.2830           | 0.037384                                                       | 366.23       | 399.88       | 1.2721           | 0.033457                                                       | 365.70       | 399.15       | 1.2623           |
| 170                                                            | 0.043427                  | 376.81       | 411.55       | 1.3080           | 0.038408                                                       | 376.31       | 410.88       | 1.2972           | 0.034392                                                       | 375.81       | 410.20       | 1.2875           |
| 180                                                            | 0.044554                  | 386.99       | 422.64       | 1.3327           | 0.039423                                                       | 386.52       | 422.00       | 1.3221           | 0.035317                                                       | 386.04       | 421.36       | 1.3124           |
| $P = 1.20 \text{ MPa } (T_{\text{sat}} = 46.29^\circ\text{C})$ |                           |              |              |                  | $P = 1.40 \text{ MPa } (T_{\text{sat}} = 52.40^\circ\text{C})$ |              |              |                  | $P = 1.60 \text{ MPa } (T_{\text{sat}} = 57.88^\circ\text{C})$ |              |              |                  |
| Sat.                                                           | 0.016715                  | 253.81       | 273.87       | 0.9130           | 0.014107                                                       | 256.37       | 276.12       | 0.9105           | 0.012123                                                       | 258.47       | 277.86       | 0.9078           |
| 50                                                             | 0.017201                  | 257.63       | 278.27       | 0.9267           |                                                                |              |              |                  |                                                                |              |              |                  |
| 60                                                             | 0.018404                  | 267.56       | 289.64       | 0.9614           | 0.015005                                                       | 264.46       | 285.47       | 0.9389           | 0.012372                                                       | 260.89       | 280.69       | 0.9163           |
| 70                                                             | 0.019502                  | 277.21       | 300.61       | 0.9938           | 0.016060                                                       | 274.62       | 297.10       | 0.9733           | 0.013430                                                       | 271.76       | 293.25       | 0.9535           |
| 80                                                             | 0.020529                  | 286.75       | 311.39       | 1.0248           | 0.017023                                                       | 284.51       | 308.34       | 1.0056           | 0.014362                                                       | 282.09       | 305.07       | 0.9875           |
| 90                                                             | 0.021506                  | 296.26       | 322.07       | 1.0546           | 0.017923                                                       | 294.28       | 319.37       | 1.0364           | 0.015215                                                       | 292.17       | 316.52       | 1.0194           |
| 100                                                            | 0.022442                  | 305.80       | 332.73       | 1.0836           | 0.018778                                                       | 304.01       | 330.30       | 1.0661           | 0.016014                                                       | 302.14       | 327.76       | 1.0500           |
| 110                                                            | 0.023348                  | 315.38       | 343.40       | 1.1118           | 0.019597                                                       | 313.76       | 341.19       | 1.0949           | 0.016773                                                       | 312.07       | 338.91       | 1.0795           |
| 120                                                            | 0.024228                  | 325.03       | 354.11       | 1.1394           | 0.020388                                                       | 323.55       | 352.09       | 1.1230           | 0.017500                                                       | 322.02       | 350.02       | 1.1081           |
| 130                                                            | 0.025086                  | 334.77       | 364.88       | 1.1664           | 0.021155                                                       | 333.41       | 363.02       | 1.1504           | 0.018201                                                       | 332.00       | 361.12       | 1.1360           |
| 140                                                            | 0.025927                  | 344.61       | 375.72       | 1.1930           | 0.021904                                                       | 343.34       | 374.01       | 1.1773           | 0.018882                                                       | 342.05       | 372.26       | 1.1632           |
| 150                                                            | 0.026753                  | 354.56       | 386.66       | 1.2192           | 0.022636                                                       | 353.37       | 385.07       | 1.2038           | 0.019545                                                       | 352.17       | 383.44       | 1.1900           |
| 160                                                            | 0.027566                  | 364.61       | 397.69       | 1.2449           | 0.023355                                                       | 363.51       | 396.20       | 1.2298           | 0.020194                                                       | 362.38       | 394.69       | 1.2163           |
| 170                                                            | 0.028367                  | 374.78       | 408.82       | 1.2703           | 0.024061                                                       | 373.75       | 407.43       | 1.2554           | 0.020830                                                       | 372.69       | 406.02       | 1.2421           |
| 180                                                            | 0.029158                  | 385.08       | 420.07       | 1.2954           | 0.024757                                                       | 384.10       | 418.76       | 1.2807           | 0.021456                                                       | 383.11       | 417.44       | 1.2676           |



**FIGURE A-14**

*P-h* diagram for refrigerant-134a.

*Note:* The reference point used for the chart is different than that used in the R-134a tables. Therefore, problems should be solved using all property data either from the tables or from the chart, but not from both.

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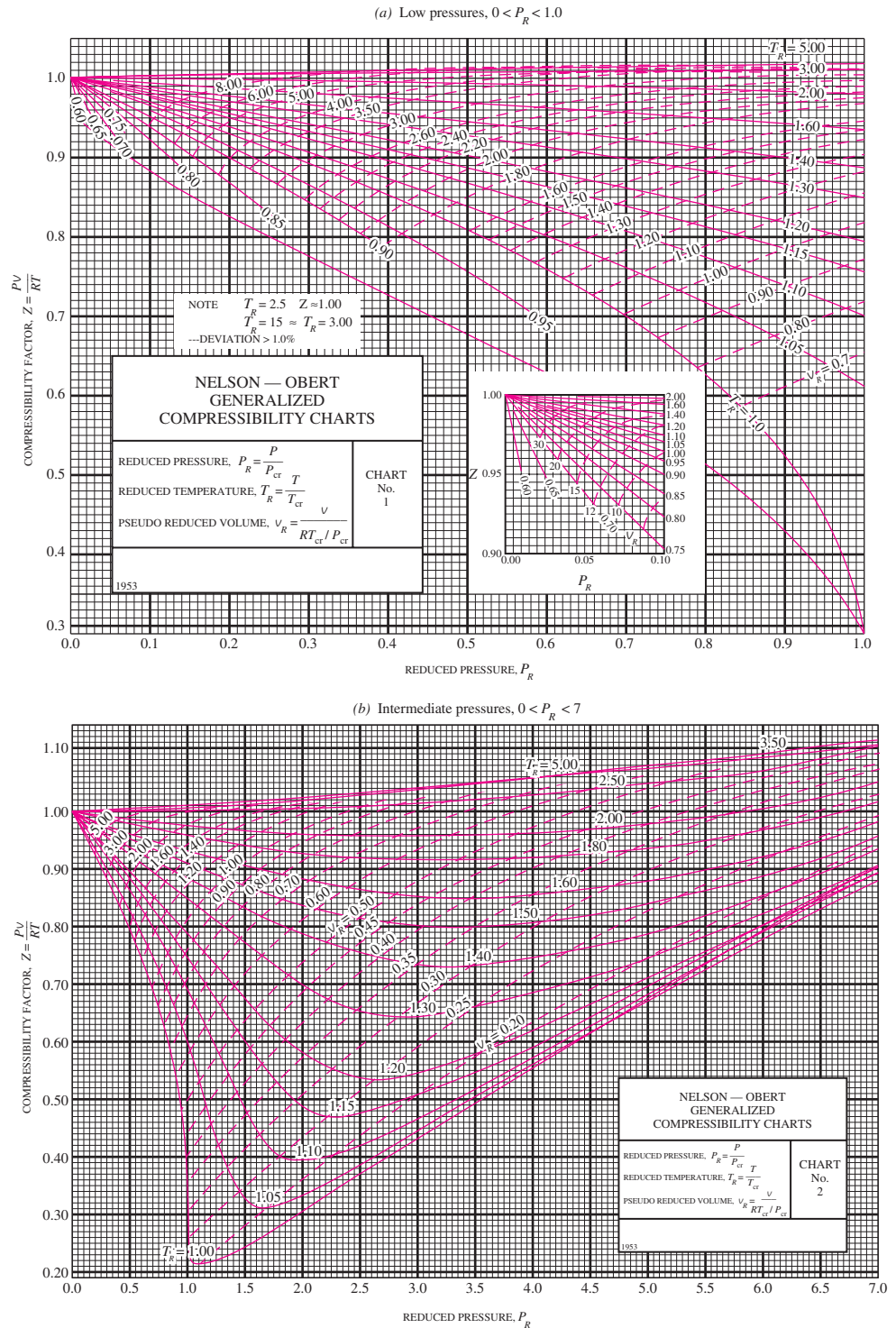


FIGURE A-15

Nelson–Obert generalized compressibility chart.

Used with permission of Dr. Edward E. Obert, University of Wisconsin.

TABLE A-16

Properties of the atmosphere at high altitude

| Altitude,<br>m | Temperature,<br>°C | Pressure,<br>kPa | Gravity<br>$g$ , m/s <sup>2</sup> | Speed of<br>Sound,<br>m/s | Density,<br>kg/m <sup>3</sup> | Viscosity<br>$\mu$ , kg/m · s | Thermal<br>Conductivity,<br>W/m · K |
|----------------|--------------------|------------------|-----------------------------------|---------------------------|-------------------------------|-------------------------------|-------------------------------------|
| 0              | 15.00              | 101.33           | 9.807                             | 340.3                     | 1.225                         | $1.789 \times 10^{-5}$        | 0.0253                              |
| 200            | 13.70              | 98.95            | 9.806                             | 339.5                     | 1.202                         | $1.783 \times 10^{-5}$        | 0.0252                              |
| 400            | 12.40              | 96.61            | 9.805                             | 338.8                     | 1.179                         | $1.777 \times 10^{-5}$        | 0.0252                              |
| 600            | 11.10              | 94.32            | 9.805                             | 338.0                     | 1.156                         | $1.771 \times 10^{-5}$        | 0.0251                              |
| 800            | 9.80               | 92.08            | 9.804                             | 337.2                     | 1.134                         | $1.764 \times 10^{-5}$        | 0.0250                              |
| 1000           | 8.50               | 89.88            | 9.804                             | 336.4                     | 1.112                         | $1.758 \times 10^{-5}$        | 0.0249                              |
| 1200           | 7.20               | 87.72            | 9.803                             | 335.7                     | 1.090                         | $1.752 \times 10^{-5}$        | 0.0248                              |
| 1400           | 5.90               | 85.60            | 9.802                             | 334.9                     | 1.069                         | $1.745 \times 10^{-5}$        | 0.0247                              |
| 1600           | 4.60               | 83.53            | 9.802                             | 334.1                     | 1.048                         | $1.739 \times 10^{-5}$        | 0.0245                              |
| 1800           | 3.30               | 81.49            | 9.801                             | 333.3                     | 1.027                         | $1.732 \times 10^{-5}$        | 0.0244                              |
| 2000           | 2.00               | 79.50            | 9.800                             | 332.5                     | 1.007                         | $1.726 \times 10^{-5}$        | 0.0243                              |
| 2200           | 0.70               | 77.55            | 9.800                             | 331.7                     | 0.987                         | $1.720 \times 10^{-5}$        | 0.0242                              |
| 2400           | -0.59              | 75.63            | 9.799                             | 331.0                     | 0.967                         | $1.713 \times 10^{-5}$        | 0.0241                              |
| 2600           | -1.89              | 73.76            | 9.799                             | 330.2                     | 0.947                         | $1.707 \times 10^{-5}$        | 0.0240                              |
| 2800           | -3.19              | 71.92            | 9.798                             | 329.4                     | 0.928                         | $1.700 \times 10^{-5}$        | 0.0239                              |
| 3000           | -4.49              | 70.12            | 9.797                             | 328.6                     | 0.909                         | $1.694 \times 10^{-5}$        | 0.0238                              |
| 3200           | -5.79              | 68.36            | 9.797                             | 327.8                     | 0.891                         | $1.687 \times 10^{-5}$        | 0.0237                              |
| 3400           | -7.09              | 66.63            | 9.796                             | 327.0                     | 0.872                         | $1.681 \times 10^{-5}$        | 0.0236                              |
| 3600           | -8.39              | 64.94            | 9.796                             | 326.2                     | 0.854                         | $1.674 \times 10^{-5}$        | 0.0235                              |
| 3800           | -9.69              | 63.28            | 9.795                             | 325.4                     | 0.837                         | $1.668 \times 10^{-5}$        | 0.0234                              |
| 4000           | -10.98             | 61.66            | 9.794                             | 324.6                     | 0.819                         | $1.661 \times 10^{-5}$        | 0.0233                              |
| 4200           | -12.3              | 60.07            | 9.794                             | 323.8                     | 0.802                         | $1.655 \times 10^{-5}$        | 0.0232                              |
| 4400           | -13.6              | 58.52            | 9.793                             | 323.0                     | 0.785                         | $1.648 \times 10^{-5}$        | 0.0231                              |
| 4600           | -14.9              | 57.00            | 9.793                             | 322.2                     | 0.769                         | $1.642 \times 10^{-5}$        | 0.0230                              |
| 4800           | -16.2              | 55.51            | 9.792                             | 321.4                     | 0.752                         | $1.635 \times 10^{-5}$        | 0.0229                              |
| 5000           | -17.5              | 54.05            | 9.791                             | 320.5                     | 0.736                         | $1.628 \times 10^{-5}$        | 0.0228                              |
| 5200           | -18.8              | 52.62            | 9.791                             | 319.7                     | 0.721                         | $1.622 \times 10^{-5}$        | 0.0227                              |
| 5400           | -20.1              | 51.23            | 9.790                             | 318.9                     | 0.705                         | $1.615 \times 10^{-5}$        | 0.0226                              |
| 5600           | -21.4              | 49.86            | 9.789                             | 318.1                     | 0.690                         | $1.608 \times 10^{-5}$        | 0.0224                              |
| 5800           | -22.7              | 48.52            | 9.785                             | 317.3                     | 0.675                         | $1.602 \times 10^{-5}$        | 0.0223                              |
| 6000           | -24.0              | 47.22            | 9.788                             | 316.5                     | 0.660                         | $1.595 \times 10^{-5}$        | 0.0222                              |
| 6200           | -25.3              | 45.94            | 9.788                             | 315.6                     | 0.646                         | $1.588 \times 10^{-5}$        | 0.0221                              |
| 6400           | -26.6              | 44.69            | 9.787                             | 314.8                     | 0.631                         | $1.582 \times 10^{-5}$        | 0.0220                              |
| 6600           | -27.9              | 43.47            | 9.786                             | 314.0                     | 0.617                         | $1.575 \times 10^{-5}$        | 0.0219                              |
| 6800           | -29.2              | 42.27            | 9.785                             | 313.1                     | 0.604                         | $1.568 \times 10^{-5}$        | 0.0218                              |
| 7000           | -30.5              | 41.11            | 9.785                             | 312.3                     | 0.590                         | $1.561 \times 10^{-5}$        | 0.0217                              |
| 8000           | -36.9              | 35.65            | 9.782                             | 308.1                     | 0.526                         | $1.527 \times 10^{-5}$        | 0.0212                              |
| 9000           | -43.4              | 30.80            | 9.779                             | 303.8                     | 0.467                         | $1.493 \times 10^{-5}$        | 0.0206                              |
| 10,000         | -49.9              | 26.50            | 9.776                             | 299.5                     | 0.414                         | $1.458 \times 10^{-5}$        | 0.0201                              |
| 12,000         | -56.5              | 19.40            | 9.770                             | 295.1                     | 0.312                         | $1.422 \times 10^{-5}$        | 0.0195                              |
| 14,000         | -56.5              | 14.17            | 9.764                             | 295.1                     | 0.228                         | $1.422 \times 10^{-5}$        | 0.0195                              |
| 16,000         | -56.5              | 10.53            | 9.758                             | 295.1                     | 0.166                         | $1.422 \times 10^{-5}$        | 0.0195                              |
| 18,000         | -56.5              | 7.57             | 9.751                             | 295.1                     | 0.122                         | $1.422 \times 10^{-5}$        | 0.0195                              |

Source: U.S. Standard Atmosphere Supplements, U.S. Government Printing Office, 1966. Based on year-round mean conditions at 45° latitude and varies with the time of the year and the weather patterns. The conditions at sea level ( $z = 0$ ) are taken to be  $P = 101.325$  kPa,  $T = 15^\circ\text{C}$ ,  $\rho = 1.2250$  kg/m<sup>3</sup>,  $g = 9.80665$  m/s<sup>2</sup>.

TABLE A-17

Ideal-gas properties of air

| $T$<br>K | $h$<br>kJ/kg | $P_r$  | $u$<br>kJ/kg | $v_r$  | $s^\circ$<br>kJ/kg · K | $T$<br>K | $h$<br>kJ/kg | $P_r$ | $u$<br>kJ/kg | $v_r$  | $s^\circ$<br>kJ/kg · K |
|----------|--------------|--------|--------------|--------|------------------------|----------|--------------|-------|--------------|--------|------------------------|
| 200      | 199.97       | 0.3363 | 142.56       | 1707.0 | 1.29559                | 580      | 586.04       | 14.38 | 419.55       | 115.7  | 2.37348                |
| 210      | 209.97       | 0.3987 | 149.69       | 1512.0 | 1.34444                | 590      | 596.52       | 15.31 | 427.15       | 110.6  | 2.39140                |
| 220      | 219.97       | 0.4690 | 156.82       | 1346.0 | 1.39105                | 600      | 607.02       | 16.28 | 434.78       | 105.8  | 2.40902                |
| 230      | 230.02       | 0.5477 | 164.00       | 1205.0 | 1.43557                | 610      | 617.53       | 17.30 | 442.42       | 101.2  | 2.42644                |
| 240      | 240.02       | 0.6355 | 171.13       | 1084.0 | 1.47824                | 620      | 628.07       | 18.36 | 450.09       | 96.92  | 2.44356                |
| 250      | 250.05       | 0.7329 | 178.28       | 979.0  | 1.51917                | 630      | 638.63       | 19.84 | 457.78       | 92.84  | 2.46048                |
| 260      | 260.09       | 0.8405 | 185.45       | 887.8  | 1.55848                | 640      | 649.22       | 20.64 | 465.50       | 88.99  | 2.47716                |
| 270      | 270.11       | 0.9590 | 192.60       | 808.0  | 1.59634                | 650      | 659.84       | 21.86 | 473.25       | 85.34  | 2.49364                |
| 280      | 280.13       | 1.0889 | 199.75       | 738.0  | 1.63279                | 660      | 670.47       | 23.13 | 481.01       | 81.89  | 2.50985                |
| 285      | 285.14       | 1.1584 | 203.33       | 706.1  | 1.65055                | 670      | 681.14       | 24.46 | 488.81       | 78.61  | 2.52589                |
| 290      | 290.16       | 1.2311 | 206.91       | 676.1  | 1.66802                | 680      | 691.82       | 25.85 | 496.62       | 75.50  | 2.54175                |
| 295      | 295.17       | 1.3068 | 210.49       | 647.9  | 1.68515                | 690      | 702.52       | 27.29 | 504.45       | 72.56  | 2.55731                |
| 298      | 298.18       | 1.3543 | 212.64       | 631.9  | 1.69528                | 700      | 713.27       | 28.80 | 512.33       | 69.76  | 2.57277                |
| 300      | 300.19       | 1.3860 | 214.07       | 621.2  | 1.70203                | 710      | 724.04       | 30.38 | 520.23       | 67.07  | 2.58810                |
| 305      | 305.22       | 1.4686 | 217.67       | 596.0  | 1.71865                | 720      | 734.82       | 32.02 | 528.14       | 64.53  | 2.60319                |
| 310      | 310.24       | 1.5546 | 221.25       | 572.3  | 1.73498                | 730      | 745.62       | 33.72 | 536.07       | 62.13  | 2.61803                |
| 315      | 315.27       | 1.6442 | 224.85       | 549.8  | 1.75106                | 740      | 756.44       | 35.50 | 544.02       | 59.82  | 2.63280                |
| 320      | 320.29       | 1.7375 | 228.42       | 528.6  | 1.76690                | 750      | 767.29       | 37.35 | 551.99       | 57.63  | 2.64737                |
| 325      | 325.31       | 1.8345 | 232.02       | 508.4  | 1.78249                | 760      | 778.18       | 39.27 | 560.01       | 55.54  | 2.66176                |
| 330      | 330.34       | 1.9352 | 235.61       | 489.4  | 1.79783                | 780      | 800.03       | 43.35 | 576.12       | 51.64  | 2.69013                |
| 340      | 340.42       | 2.149  | 242.82       | 454.1  | 1.82790                | 800      | 821.95       | 47.75 | 592.30       | 48.08  | 2.71787                |
| 350      | 350.49       | 2.379  | 250.02       | 422.2  | 1.85708                | 820      | 843.98       | 52.59 | 608.59       | 44.84  | 2.74504                |
| 360      | 360.58       | 2.626  | 257.24       | 393.4  | 1.88543                | 840      | 866.08       | 57.60 | 624.95       | 41.85  | 2.77170                |
| 370      | 370.67       | 2.892  | 264.46       | 367.2  | 1.91313                | 860      | 888.27       | 63.09 | 641.40       | 39.12  | 2.79783                |
| 380      | 380.77       | 3.176  | 271.69       | 343.4  | 1.94001                | 880      | 910.56       | 68.98 | 657.95       | 36.61  | 2.82344                |
| 390      | 390.88       | 3.481  | 278.93       | 321.5  | 1.96633                | 900      | 932.93       | 75.29 | 674.58       | 34.31  | 2.84856                |
| 400      | 400.98       | 3.806  | 286.16       | 301.6  | 1.99194                | 920      | 955.38       | 82.05 | 691.28       | 32.18  | 2.87324                |
| 410      | 411.12       | 4.153  | 293.43       | 283.3  | 2.01699                | 940      | 977.92       | 89.28 | 708.08       | 30.22  | 2.89748                |
| 420      | 421.26       | 4.522  | 300.69       | 266.6  | 2.04142                | 960      | 1000.55      | 97.00 | 725.02       | 28.40  | 2.92128                |
| 430      | 431.43       | 4.915  | 307.99       | 251.1  | 2.06533                | 980      | 1023.25      | 105.2 | 741.98       | 26.73  | 2.94468                |
| 440      | 441.61       | 5.332  | 315.30       | 236.8  | 2.08870                | 1000     | 1046.04      | 114.0 | 758.94       | 25.17  | 2.96770                |
| 450      | 451.80       | 5.775  | 322.62       | 223.6  | 2.11161                | 1020     | 1068.89      | 123.4 | 776.10       | 23.72  | 2.99034                |
| 460      | 462.02       | 6.245  | 329.97       | 211.4  | 2.13407                | 1040     | 1091.85      | 133.3 | 793.36       | 23.29  | 3.01260                |
| 470      | 472.24       | 6.742  | 337.32       | 200.1  | 2.15604                | 1060     | 1114.86      | 143.9 | 810.62       | 21.14  | 3.03449                |
| 480      | 482.49       | 7.268  | 344.70       | 189.5  | 2.17760                | 1080     | 1137.89      | 155.2 | 827.88       | 19.98  | 3.05608                |
| 490      | 492.74       | 7.824  | 352.08       | 179.7  | 2.19876                | 1100     | 1161.07      | 167.1 | 845.33       | 18.896 | 3.07732                |
| 500      | 503.02       | 8.411  | 359.49       | 170.6  | 2.21952                | 1120     | 1184.28      | 179.7 | 862.79       | 17.886 | 3.09825                |
| 510      | 513.32       | 9.031  | 366.92       | 162.1  | 2.23993                | 1140     | 1207.57      | 193.1 | 880.35       | 16.946 | 3.11883                |
| 520      | 523.63       | 9.684  | 374.36       | 154.1  | 2.25997                | 1160     | 1230.92      | 207.2 | 897.91       | 16.064 | 3.13916                |
| 530      | 533.98       | 10.37  | 381.84       | 146.7  | 2.27967                | 1180     | 1254.34      | 222.2 | 915.57       | 15.241 | 3.15916                |
| 540      | 544.35       | 11.10  | 389.34       | 139.7  | 2.29906                | 1200     | 1277.79      | 238.0 | 933.33       | 14.470 | 3.17888                |
| 550      | 555.74       | 11.86  | 396.86       | 133.1  | 2.31809                | 1220     | 1301.31      | 254.7 | 951.09       | 13.747 | 3.19834                |
| 560      | 565.17       | 12.66  | 404.42       | 127.0  | 2.33685                | 1240     | 1324.93      | 272.3 | 968.95       | 13.069 | 3.21751                |
| 570      | 575.59       | 13.50  | 411.97       | 121.2  | 2.35531                |          |              |       |              |        |                        |

TABLE A-17

Ideal-gas properties of air (*Concluded*)

| $T$<br>K | $h$<br>kJ/kg | $P_r$ | $u$<br>kJ/kg | $v_r$  | $s^\circ$<br>kJ/kg · K | $T$<br>K | $h$<br>kJ/kg | $P_r$ | $u$<br>kJ/kg | $v_r$ | $s^\circ$<br>kJ/kg · K |
|----------|--------------|-------|--------------|--------|------------------------|----------|--------------|-------|--------------|-------|------------------------|
| 1260     | 1348.55      | 290.8 | 986.90       | 12.435 | 3.23638                | 1600     | 1757.57      | 791.2 | 1298.30      | 5.804 | 3.52364                |
| 1280     | 1372.24      | 310.4 | 1004.76      | 11.835 | 3.25510                | 1620     | 1782.00      | 834.1 | 1316.96      | 5.574 | 3.53879                |
| 1300     | 1395.97      | 330.9 | 1022.82      | 11.275 | 3.27345                | 1640     | 1806.46      | 878.9 | 1335.72      | 5.355 | 3.55381                |
| 1320     | 1419.76      | 352.5 | 1040.88      | 10.747 | 3.29160                | 1660     | 1830.96      | 925.6 | 1354.48      | 5.147 | 3.56867                |
| 1340     | 1443.60      | 375.3 | 1058.94      | 10.247 | 3.30959                | 1680     | 1855.50      | 974.2 | 1373.24      | 4.949 | 3.58335                |
| 1360     | 1467.49      | 399.1 | 1077.10      | 9.780  | 3.32724                | 1700     | 1880.1       | 1025  | 1392.7       | 4.761 | 3.5979                 |
| 1380     | 1491.44      | 424.2 | 1095.26      | 9.337  | 3.34474                | 1750     | 1941.6       | 1161  | 1439.8       | 4.328 | 3.6336                 |
| 1400     | 1515.42      | 450.5 | 1113.52      | 8.919  | 3.36200                | 1800     | 2003.3       | 1310  | 1487.2       | 3.994 | 3.6684                 |
| 1420     | 1539.44      | 478.0 | 1131.77      | 8.526  | 3.37901                | 1850     | 2065.3       | 1475  | 1534.9       | 3.601 | 3.7023                 |
| 1440     | 1563.51      | 506.9 | 1150.13      | 8.153  | 3.39586                | 1900     | 2127.4       | 1655  | 1582.6       | 3.295 | 3.7354                 |
| 1460     | 1587.63      | 537.1 | 1168.49      | 7.801  | 3.41247                | 1950     | 2189.7       | 1852  | 1630.6       | 3.022 | 3.7677                 |
| 1480     | 1611.79      | 568.8 | 1186.95      | 7.468  | 3.42892                | 2000     | 2252.1       | 2068  | 1678.7       | 2.776 | 3.7994                 |
| 1500     | 1635.97      | 601.9 | 1205.41      | 7.152  | 3.44516                | 2050     | 2314.6       | 2303  | 1726.8       | 2.555 | 3.8303                 |
| 1520     | 1660.23      | 636.5 | 1223.87      | 6.854  | 3.46120                | 2100     | 2377.7       | 2559  | 1775.3       | 2.356 | 3.8605                 |
| 1540     | 1684.51      | 672.8 | 1242.43      | 6.569  | 3.47712                | 2150     | 2440.3       | 2837  | 1823.8       | 2.175 | 3.8901                 |
| 1560     | 1708.82      | 710.5 | 1260.99      | 6.301  | 3.49276                | 2200     | 2503.2       | 3138  | 1872.4       | 2.012 | 3.9191                 |
| 1580     | 1733.17      | 750.0 | 1279.65      | 6.046  | 3.50829                | 2250     | 2566.4       | 3464  | 1921.3       | 1.864 | 3.9474                 |

Note: The properties  $P_r$  (relative pressure) and  $v_r$  (relative specific volume) are dimensionless quantities used in the analysis of isentropic processes, and should not be confused with the properties pressure and specific volume.

Source: Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), pp. 785–86, table A–5. Originally published in J. H. Keenan and J. Kaye, *Gas Tables* (New York: John Wiley & Sons, 1948).



TABLE A-18

Ideal-gas properties of nitrogen,  $N_2$ 

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 600      | 17,563               | 12,574               | 212.066                        |
| 220      | 6,391                | 4,562                | 182.639                        | 610      | 17,864               | 12,792               | 212.564                        |
| 230      | 6,683                | 4,770                | 183.938                        | 620      | 18,166               | 13,011               | 213.055                        |
| 240      | 6,975                | 4,979                | 185.180                        | 630      | 18,468               | 13,230               | 213.541                        |
| 250      | 7,266                | 5,188                | 186.370                        | 640      | 18,772               | 13,450               | 214.018                        |
| 260      | 7,558                | 5,396                | 187.514                        | 650      | 19,075               | 13,671               | 214.489                        |
| 270      | 7,849                | 5,604                | 188.614                        | 660      | 19,380               | 13,892               | 214.954                        |
| 280      | 8,141                | 5,813                | 189.673                        | 670      | 19,685               | 14,114               | 215.413                        |
| 290      | 8,432                | 6,021                | 190.695                        | 680      | 19,991               | 14,337               | 215.866                        |
| 298      | 8,669                | 6,190                | 191.502                        | 690      | 20,297               | 14,560               | 216.314                        |
| 300      | 8,723                | 6,229                | 191.682                        | 700      | 20,604               | 14,784               | 216.756                        |
| 310      | 9,014                | 6,437                | 192.638                        | 710      | 20,912               | 15,008               | 217.192                        |
| 320      | 9,306                | 6,645                | 193.562                        | 720      | 21,220               | 15,234               | 217.624                        |
| 330      | 9,597                | 6,853                | 194.459                        | 730      | 21,529               | 15,460               | 218.059                        |
| 340      | 9,888                | 7,061                | 195.328                        | 740      | 21,839               | 15,686               | 218.472                        |
| 350      | 10,180               | 7,270                | 196.173                        | 750      | 22,149               | 15,913               | 218.889                        |
| 360      | 10,471               | 7,478                | 196.995                        | 760      | 22,460               | 16,141               | 219.301                        |
| 370      | 10,763               | 7,687                | 197.794                        | 770      | 22,772               | 16,370               | 219.709                        |
| 380      | 11,055               | 7,895                | 198.572                        | 780      | 23,085               | 16,599               | 220.113                        |
| 390      | 11,347               | 8,104                | 199.331                        | 790      | 23,398               | 16,830               | 220.512                        |
| 400      | 11,640               | 8,314                | 200.071                        | 800      | 23,714               | 17,061               | 220.907                        |
| 410      | 11,932               | 8,523                | 200.794                        | 810      | 24,027               | 17,292               | 221.298                        |
| 420      | 12,225               | 8,733                | 201.499                        | 820      | 24,342               | 17,524               | 221.684                        |
| 430      | 12,518               | 8,943                | 202.189                        | 830      | 24,658               | 17,757               | 222.067                        |
| 440      | 12,811               | 9,153                | 202.863                        | 840      | 24,974               | 17,990               | 222.447                        |
| 450      | 13,105               | 9,363                | 203.523                        | 850      | 25,292               | 18,224               | 222.822                        |
| 460      | 13,399               | 9,574                | 204.170                        | 860      | 25,610               | 18,459               | 223.194                        |
| 470      | 13,693               | 9,786                | 204.803                        | 870      | 25,928               | 18,695               | 223.562                        |
| 480      | 13,988               | 9,997                | 205.424                        | 880      | 26,248               | 18,931               | 223.927                        |
| 490      | 14,285               | 10,210               | 206.033                        | 890      | 26,568               | 19,168               | 224.288                        |
| 500      | 14,581               | 10,423               | 206.630                        | 900      | 26,890               | 19,407               | 224.647                        |
| 510      | 14,876               | 10,635               | 207.216                        | 910      | 27,210               | 19,644               | 225.002                        |
| 520      | 15,172               | 10,848               | 207.792                        | 920      | 27,532               | 19,883               | 225.353                        |
| 530      | 15,469               | 11,062               | 208.358                        | 930      | 27,854               | 20,122               | 225.701                        |
| 540      | 15,766               | 11,277               | 208.914                        | 940      | 28,178               | 20,362               | 226.047                        |
| 550      | 16,064               | 11,492               | 209.461                        | 950      | 28,501               | 20,603               | 226.389                        |
| 560      | 16,363               | 11,707               | 209.999                        | 960      | 28,826               | 20,844               | 226.728                        |
| 570      | 16,662               | 11,923               | 210.528                        | 970      | 29,151               | 21,086               | 227.064                        |
| 580      | 16,962               | 12,139               | 211.049                        | 980      | 29,476               | 21,328               | 227.398                        |
| 590      | 17,262               | 12,356               | 211.562                        | 990      | 29,803               | 21,571               | 227.728                        |



TABLE A-18

Ideal-gas properties of nitrogen,  $N_2$  (Concluded)

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 1000     | 30,129               | 21,815               | 228.057                        | 1760     | 56,227               | 41,594               | 247.396                        |
| 1020     | 30,784               | 22,304               | 228.706                        | 1780     | 56,938               | 42,139               | 247.798                        |
| 1040     | 31,442               | 22,795               | 229.344                        | 1800     | 57,651               | 42,685               | 248.195                        |
| 1060     | 32,101               | 23,288               | 229.973                        | 1820     | 58,363               | 43,231               | 248.589                        |
| 1080     | 32,762               | 23,782               | 230.591                        | 1840     | 59,075               | 43,777               | 248.979                        |
| 1100     | 33,426               | 24,280               | 231.199                        | 1860     | 59,790               | 44,324               | 249.365                        |
| 1120     | 34,092               | 24,780               | 231.799                        | 1880     | 60,504               | 44,873               | 249.748                        |
| 1140     | 34,760               | 25,282               | 232.391                        | 1900     | 61,220               | 45,423               | 250.128                        |
| 1160     | 35,430               | 25,786               | 232.973                        | 1920     | 61,936               | 45,973               | 250.502                        |
| 1180     | 36,104               | 26,291               | 233.549                        | 1940     | 62,654               | 46,524               | 250.874                        |
| 1200     | 36,777               | 26,799               | 234.115                        | 1960     | 63,381               | 47,075               | 251.242                        |
| 1220     | 37,452               | 27,308               | 234.673                        | 1980     | 64,090               | 47,627               | 251.607                        |
| 1240     | 38,129               | 27,819               | 235.223                        | 2000     | 64,810               | 48,181               | 251.969                        |
| 1260     | 38,807               | 28,331               | 235.766                        | 2050     | 66,612               | 49,567               | 252.858                        |
| 1280     | 39,488               | 28,845               | 236.302                        | 2100     | 68,417               | 50,957               | 253.726                        |
| 1300     | 40,170               | 29,361               | 236.831                        | 2150     | 70,226               | 52,351               | 254.578                        |
| 1320     | 40,853               | 29,378               | 237.353                        | 2200     | 72,040               | 53,749               | 255.412                        |
| 1340     | 41,539               | 30,398               | 237.867                        | 2250     | 73,856               | 55,149               | 256.227                        |
| 1360     | 42,227               | 30,919               | 238.376                        | 2300     | 75,676               | 56,553               | 257.027                        |
| 1380     | 42,915               | 31,441               | 238.878                        | 2350     | 77,496               | 57,958               | 257.810                        |
| 1400     | 43,605               | 31,964               | 239.375                        | 2400     | 79,320               | 59,366               | 258.580                        |
| 1420     | 44,295               | 32,489               | 239.865                        | 2450     | 81,149               | 60,779               | 259.332                        |
| 1440     | 44,988               | 33,014               | 240.350                        | 2500     | 82,981               | 62,195               | 260.073                        |
| 1460     | 45,682               | 33,543               | 240.827                        | 2550     | 84,814               | 63,613               | 260.799                        |
| 1480     | 46,377               | 34,071               | 241.301                        | 2600     | 86,650               | 65,033               | 261.512                        |
| 1500     | 47,073               | 34,601               | 241.768                        | 2650     | 88,488               | 66,455               | 262.213                        |
| 1520     | 47,771               | 35,133               | 242.228                        | 2700     | 90,328               | 67,880               | 262.902                        |
| 1540     | 48,470               | 35,665               | 242.685                        | 2750     | 92,171               | 69,306               | 263.577                        |
| 1560     | 49,168               | 36,197               | 243.137                        | 2800     | 94,014               | 70,734               | 264.241                        |
| 1580     | 49,869               | 36,732               | 243.585                        | 2850     | 95,859               | 72,163               | 264.895                        |
| 1600     | 50,571               | 37,268               | 244.028                        | 2900     | 97,705               | 73,593               | 265.538                        |
| 1620     | 51,275               | 37,806               | 244.464                        | 2950     | 99,556               | 75,028               | 266.170                        |
| 1640     | 51,980               | 38,344               | 244.896                        | 3000     | 101,407              | 76,464               | 266.793                        |
| 1660     | 52,686               | 38,884               | 245.324                        | 3050     | 103,260              | 77,902               | 267.404                        |
| 1680     | 53,393               | 39,424               | 245.747                        | 3100     | 105,115              | 79,341               | 268.007                        |
| 1700     | 54,099               | 39,965               | 246.166                        | 3150     | 106,972              | 80,782               | 268.601                        |
| 1720     | 54,807               | 40,507               | 246.580                        | 3200     | 108,830              | 82,224               | 269.186                        |
| 1740     | 55,516               | 41,049               | 246.990                        | 3250     | 110,690              | 83,668               | 269.763                        |

Source: Tables A-18 through A-25 are adapted from Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), pp. 787–98. Originally published in JANAF, *Thermochemical Tables*, NSRDS-NBS-37, 1971.

TABLE A-19

Ideal-gas properties of oxygen,  $O_2$ 

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 600      | 17,929               | 12,940               | 226.346                        |
| 220      | 6,404                | 4,575                | 196.171                        | 610      | 18,250               | 13,178               | 226.877                        |
| 230      | 6,694                | 4,782                | 197.461                        | 620      | 18,572               | 13,417               | 227.400                        |
| 240      | 6,984                | 4,989                | 198.696                        | 630      | 18,895               | 13,657               | 227.918                        |
| 250      | 7,275                | 5,197                | 199.885                        | 640      | 19,219               | 13,898               | 228.429                        |
| 260      | 7,566                | 5,405                | 201.027                        | 650      | 19,544               | 14,140               | 228.932                        |
| 270      | 7,858                | 5,613                | 202.128                        | 660      | 19,870               | 14,383               | 229.430                        |
| 280      | 8,150                | 5,822                | 203.191                        | 670      | 20,197               | 14,626               | 229.920                        |
| 290      | 8,443                | 6,032                | 204.218                        | 680      | 20,524               | 14,871               | 230.405                        |
| 298      | 8,682                | 6,203                | 205.033                        | 690      | 20,854               | 15,116               | 230.885                        |
| 300      | 8,736                | 6,242                | 205.213                        | 700      | 21,184               | 15,364               | 231.358                        |
| 310      | 9,030                | 6,453                | 206.177                        | 710      | 21,514               | 15,611               | 231.827                        |
| 320      | 9,325                | 6,664                | 207.112                        | 720      | 21,845               | 15,859               | 232.291                        |
| 330      | 9,620                | 6,877                | 208.020                        | 730      | 22,177               | 16,107               | 232.748                        |
| 340      | 9,916                | 7,090                | 208.904                        | 740      | 22,510               | 16,357               | 233.201                        |
| 350      | 10,213               | 7,303                | 209.765                        | 750      | 22,844               | 16,607               | 233.649                        |
| 360      | 10,511               | 7,518                | 210.604                        | 760      | 23,178               | 16,859               | 234.091                        |
| 370      | 10,809               | 7,733                | 211.423                        | 770      | 23,513               | 17,111               | 234.528                        |
| 380      | 11,109               | 7,949                | 212.222                        | 780      | 23,850               | 17,364               | 234.960                        |
| 390      | 11,409               | 8,166                | 213.002                        | 790      | 24,186               | 17,618               | 235.387                        |
| 400      | 11,711               | 8,384                | 213.765                        | 800      | 24,523               | 17,872               | 235.810                        |
| 410      | 12,012               | 8,603                | 214.510                        | 810      | 24,861               | 18,126               | 236.230                        |
| 420      | 12,314               | 8,822                | 215.241                        | 820      | 25,199               | 18,382               | 236.644                        |
| 430      | 12,618               | 9,043                | 215.955                        | 830      | 25,537               | 18,637               | 237.055                        |
| 440      | 12,923               | 9,264                | 216.656                        | 840      | 25,877               | 18,893               | 237.462                        |
| 450      | 13,228               | 9,487                | 217.342                        | 850      | 26,218               | 19,150               | 237.864                        |
| 460      | 13,525               | 9,710                | 218.016                        | 860      | 26,559               | 19,408               | 238.264                        |
| 470      | 13,842               | 9,935                | 218.676                        | 870      | 26,899               | 19,666               | 238.660                        |
| 480      | 14,151               | 10,160               | 219.326                        | 880      | 27,242               | 19,925               | 239.051                        |
| 490      | 14,460               | 10,386               | 219.963                        | 890      | 27,584               | 20,185               | 239.439                        |
| 500      | 14,770               | 10,614               | 220.589                        | 900      | 27,928               | 20,445               | 239.823                        |
| 510      | 15,082               | 10,842               | 221.206                        | 910      | 28,272               | 20,706               | 240.203                        |
| 520      | 15,395               | 11,071               | 221.812                        | 920      | 28,616               | 20,967               | 240.580                        |
| 530      | 15,708               | 11,301               | 222.409                        | 930      | 28,960               | 21,228               | 240.953                        |
| 540      | 16,022               | 11,533               | 222.997                        | 940      | 29,306               | 21,491               | 241.323                        |
| 550      | 16,338               | 11,765               | 223.576                        | 950      | 29,652               | 21,754               | 241.689                        |
| 560      | 16,654               | 11,998               | 224.146                        | 960      | 29,999               | 22,017               | 242.052                        |
| 570      | 16,971               | 12,232               | 224.708                        | 970      | 30,345               | 22,280               | 242.411                        |
| 580      | 17,290               | 12,467               | 225.262                        | 980      | 30,692               | 22,544               | 242.768                        |
| 590      | 17,609               | 12,703               | 225.808                        | 990      | 31,041               | 22,809               | 242.120                        |

TABLE A-19

Ideal-gas properties of oxygen,  $O_2$  (Concluded)

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 1000     | 31,389               | 23,075               | 243.471                        | 1760     | 58,880               | 44,247               | 263.861                        |
| 1020     | 32,088               | 23,607               | 244.164                        | 1780     | 59,624               | 44,825               | 264.283                        |
| 1040     | 32,789               | 24,142               | 244.844                        | 1800     | 60,371               | 45,405               | 264.701                        |
| 1060     | 33,490               | 24,677               | 245.513                        | 1820     | 61,118               | 45,986               | 265.113                        |
| 1080     | 34,194               | 25,214               | 246.171                        | 1840     | 61,866               | 46,568               | 265.521                        |
| 1100     | 34,899               | 25,753               | 246.818                        | 1860     | 62,616               | 47,151               | 265.925                        |
| 1120     | 35,606               | 26,294               | 247.454                        | 1880     | 63,365               | 47,734               | 266.326                        |
| 1140     | 36,314               | 26,836               | 248.081                        | 1900     | 64,116               | 48,319               | 266.722                        |
| 1160     | 37,023               | 27,379               | 248.698                        | 1920     | 64,868               | 48,904               | 267.115                        |
| 1180     | 37,734               | 27,923               | 249.307                        | 1940     | 65,620               | 49,490               | 267.505                        |
| 1200     | 38,447               | 28,469               | 249.906                        | 1960     | 66,374               | 50,078               | 267.891                        |
| 1220     | 39,162               | 29,018               | 250.497                        | 1980     | 67,127               | 50,665               | 268.275                        |
| 1240     | 39,877               | 29,568               | 251.079                        | 2000     | 67,881               | 51,253               | 268.655                        |
| 1260     | 40,594               | 30,118               | 251.653                        | 2050     | 69,772               | 52,727               | 269.588                        |
| 1280     | 41,312               | 30,670               | 252.219                        | 2100     | 71,668               | 54,208               | 270.504                        |
| 1300     | 42,033               | 31,224               | 252.776                        | 2150     | 73,573               | 55,697               | 271.399                        |
| 1320     | 42,753               | 31,778               | 253.325                        | 2200     | 75,484               | 57,192               | 272.278                        |
| 1340     | 43,475               | 32,334               | 253.868                        | 2250     | 77,397               | 58,690               | 273.136                        |
| 1360     | 44,198               | 32,891               | 254.404                        | 2300     | 79,316               | 60,193               | 273.891                        |
| 1380     | 44,923               | 33,449               | 254.932                        | 2350     | 81,243               | 61,704               | 274.809                        |
| 1400     | 45,648               | 34,008               | 255.454                        | 2400     | 83,174               | 63,219               | 275.625                        |
| 1420     | 46,374               | 34,567               | 255.968                        | 2450     | 85,112               | 64,742               | 276.424                        |
| 1440     | 47,102               | 35,129               | 256.475                        | 2500     | 87,057               | 66,271               | 277.207                        |
| 1460     | 47,831               | 35,692               | 256.978                        | 2550     | 89,004               | 67,802               | 277.979                        |
| 1480     | 48,561               | 36,256               | 257.474                        | 2600     | 90,956               | 69,339               | 278.738                        |
| 1500     | 49,292               | 36,821               | 257.965                        | 2650     | 92,916               | 70,883               | 279.485                        |
| 1520     | 50,024               | 37,387               | 258.450                        | 2700     | 94,881               | 72,433               | 280.219                        |
| 1540     | 50,756               | 37,952               | 258.928                        | 2750     | 96,852               | 73,987               | 280.942                        |
| 1560     | 51,490               | 38,520               | 259.402                        | 2800     | 98,826               | 75,546               | 281.654                        |
| 1580     | 52,224               | 39,088               | 259.870                        | 2850     | 100,808              | 77,112               | 282.357                        |
| 1600     | 52,961               | 39,658               | 260.333                        | 2900     | 102,793              | 78,682               | 283.048                        |
| 1620     | 53,696               | 40,227               | 260.791                        | 2950     | 104,785              | 80,258               | 283.728                        |
| 1640     | 54,434               | 40,799               | 261.242                        | 3000     | 106,780              | 81,837               | 284.399                        |
| 1660     | 55,172               | 41,370               | 261.690                        | 3050     | 108,778              | 83,419               | 285.060                        |
| 1680     | 55,912               | 41,944               | 262.132                        | 3100     | 110,784              | 85,009               | 285.713                        |
| 1700     | 56,652               | 42,517               | 262.571                        | 3150     | 112,795              | 86,601               | 286.355                        |
| 1720     | 57,394               | 43,093               | 263.005                        | 3200     | 114,809              | 88,203               | 286.989                        |
| 1740     | 58,136               | 43,669               | 263.435                        | 3250     | 116,827              | 89,804               | 287.614                        |

TABLE A-20

Ideal-gas properties of carbon dioxide, CO<sub>2</sub>

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 600      | 22,280               | 17,291               | 243.199                        |
| 220      | 6,601                | 4,772                | 202.966                        | 610      | 22,754               | 17,683               | 243.983                        |
| 230      | 6,938                | 5,026                | 204.464                        | 620      | 23,231               | 18,076               | 244.758                        |
| 240      | 7,280                | 5,285                | 205.920                        | 630      | 23,709               | 18,471               | 245.524                        |
| 250      | 7,627                | 5,548                | 207.337                        | 640      | 24,190               | 18,869               | 246.282                        |
| 260      | 7,979                | 5,817                | 208.717                        | 650      | 24,674               | 19,270               | 247.032                        |
| 270      | 8,335                | 6,091                | 210.062                        | 660      | 25,160               | 19,672               | 247.773                        |
| 280      | 8,697                | 6,369                | 211.376                        | 670      | 25,648               | 20,078               | 248.507                        |
| 290      | 9,063                | 6,651                | 212.660                        | 680      | 26,138               | 20,484               | 249.233                        |
| 298      | 9,364                | 6,885                | 213.685                        | 690      | 26,631               | 20,894               | 249.952                        |
| 300      | 9,431                | 6,939                | 213.915                        | 700      | 27,125               | 21,305               | 250.663                        |
| 310      | 9,807                | 7,230                | 215.146                        | 710      | 27,622               | 21,719               | 251.368                        |
| 320      | 10,186               | 7,526                | 216.351                        | 720      | 28,121               | 22,134               | 252.065                        |
| 330      | 10,570               | 7,826                | 217.534                        | 730      | 28,622               | 22,522               | 252.755                        |
| 340      | 10,959               | 8,131                | 218.694                        | 740      | 29,124               | 22,972               | 253.439                        |
| 350      | 11,351               | 8,439                | 219.831                        | 750      | 29,629               | 23,393               | 254.117                        |
| 360      | 11,748               | 8,752                | 220.948                        | 760      | 30,135               | 23,817               | 254.787                        |
| 370      | 12,148               | 9,068                | 222.044                        | 770      | 30,644               | 24,242               | 255.452                        |
| 380      | 12,552               | 9,392                | 223.122                        | 780      | 31,154               | 24,669               | 256.110                        |
| 390      | 12,960               | 9,718                | 224.182                        | 790      | 31,665               | 25,097               | 256.762                        |
| 400      | 13,372               | 10,046               | 225.225                        | 800      | 32,179               | 25,527               | 257.408                        |
| 410      | 13,787               | 10,378               | 226.250                        | 810      | 32,694               | 25,959               | 258.048                        |
| 420      | 14,206               | 10,714               | 227.258                        | 820      | 33,212               | 26,394               | 258.682                        |
| 430      | 14,628               | 11,053               | 228.252                        | 830      | 33,730               | 26,829               | 259.311                        |
| 440      | 15,054               | 11,393               | 229.230                        | 840      | 34,251               | 27,267               | 259.934                        |
| 450      | 15,483               | 11,742               | 230.194                        | 850      | 34,773               | 27,706               | 260.551                        |
| 460      | 15,916               | 12,091               | 231.144                        | 860      | 35,296               | 28,125               | 261.164                        |
| 470      | 16,351               | 12,444               | 232.080                        | 870      | 35,821               | 28,588               | 261.770                        |
| 480      | 16,791               | 12,800               | 233.004                        | 880      | 36,347               | 29,031               | 262.371                        |
| 490      | 17,232               | 13,158               | 233.916                        | 890      | 36,876               | 29,476               | 262.968                        |
| 500      | 17,678               | 13,521               | 234.814                        | 900      | 37,405               | 29,922               | 263.559                        |
| 510      | 18,126               | 13,885               | 235.700                        | 910      | 37,935               | 30,369               | 264.146                        |
| 520      | 18,576               | 14,253               | 236.575                        | 920      | 38,467               | 30,818               | 264.728                        |
| 530      | 19,029               | 14,622               | 237.439                        | 930      | 39,000               | 31,268               | 265.304                        |
| 540      | 19,485               | 14,996               | 238.292                        | 940      | 39,535               | 31,719               | 265.877                        |
| 550      | 19,945               | 15,372               | 239.135                        | 950      | 40,070               | 32,171               | 266.444                        |
| 560      | 20,407               | 15,751               | 239.962                        | 960      | 40,607               | 32,625               | 267.007                        |
| 570      | 20,870               | 16,131               | 240.789                        | 970      | 41,145               | 33,081               | 267.566                        |
| 580      | 21,337               | 16,515               | 241.602                        | 980      | 41,685               | 33,537               | 268.119                        |
| 590      | 21,807               | 16,902               | 242.405                        | 990      | 42,226               | 33,995               | 268.670                        |

TABLE A-20

Ideal-gas properties of carbon dioxide, CO<sub>2</sub> (Concluded)

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 1000     | 42,769               | 34,455               | 269.215                        | 1760     | 86,420               | 71,787               | 301.543                        |
| 1020     | 43,859               | 35,378               | 270.293                        | 1780     | 87,612               | 72,812               | 302.217                        |
| 1040     | 44,953               | 36,306               | 271.354                        | 1800     | 88,806               | 73,840               | 302.884                        |
| 1060     | 46,051               | 37,238               | 272.400                        | 1820     | 90,000               | 74,868               | 303.544                        |
| 1080     | 47,153               | 38,174               | 273.430                        | 1840     | 91,196               | 75,897               | 304.198                        |
| 1100     | 48,258               | 39,112               | 274.445                        | 1860     | 92,394               | 76,929               | 304.845                        |
| 1120     | 49,369               | 40,057               | 275.444                        | 1880     | 93,593               | 77,962               | 305.487                        |
| 1140     | 50,484               | 41,006               | 276.430                        | 1900     | 94,793               | 78,996               | 306.122                        |
| 1160     | 51,602               | 41,957               | 277.403                        | 1920     | 95,995               | 80,031               | 306.751                        |
| 1180     | 52,724               | 42,913               | 278.361                        | 1940     | 97,197               | 81,067               | 307.374                        |
| 1200     | 53,848               | 43,871               | 297.307                        | 1960     | 98,401               | 82,105               | 307.992                        |
| 1220     | 54,977               | 44,834               | 280.238                        | 1980     | 99,606               | 83,144               | 308.604                        |
| 1240     | 56,108               | 45,799               | 281.158                        | 2000     | 100,804              | 84,185               | 309.210                        |
| 1260     | 57,244               | 46,768               | 282.066                        | 2050     | 103,835              | 86,791               | 310.701                        |
| 1280     | 58,381               | 47,739               | 282.962                        | 2100     | 106,864              | 89,404               | 312.160                        |
| 1300     | 59,522               | 48,713               | 283.847                        | 2150     | 109,898              | 92,023               | 313.589                        |
| 1320     | 60,666               | 49,691               | 284.722                        | 2200     | 112,939              | 94,648               | 314.988                        |
| 1340     | 61,813               | 50,672               | 285.586                        | 2250     | 115,984              | 97,277               | 316.356                        |
| 1360     | 62,963               | 51,656               | 286.439                        | 2300     | 119,035              | 99,912               | 317.695                        |
| 1380     | 64,116               | 52,643               | 287.283                        | 2350     | 122,091              | 102,552              | 319.011                        |
| 1400     | 65,271               | 53,631               | 288.106                        | 2400     | 125,152              | 105,197              | 320.302                        |
| 1420     | 66,427               | 54,621               | 288.934                        | 2450     | 128,219              | 107,849              | 321.566                        |
| 1440     | 67,586               | 55,614               | 289.743                        | 2500     | 131,290              | 110,504              | 322.808                        |
| 1460     | 68,748               | 56,609               | 290.542                        | 2550     | 134,368              | 113,166              | 324.026                        |
| 1480     | 66,911               | 57,606               | 291.333                        | 2600     | 137,449              | 115,832              | 325.222                        |
| 1500     | 71,078               | 58,606               | 292.114                        | 2650     | 140,533              | 118,500              | 326.396                        |
| 1520     | 72,246               | 59,609               | 292.888                        | 2700     | 143,620              | 121,172              | 327.549                        |
| 1540     | 73,417               | 60,613               | 292.654                        | 2750     | 146,713              | 123,849              | 328.684                        |
| 1560     | 74,590               | 61,620               | 294.411                        | 2800     | 149,808              | 126,528              | 329.800                        |
| 1580     | 76,767               | 62,630               | 295.161                        | 2850     | 152,908              | 129,212              | 330.896                        |
| 1600     | 76,944               | 63,741               | 295.901                        | 2900     | 156,009              | 131,898              | 331.975                        |
| 1620     | 78,123               | 64,653               | 296.632                        | 2950     | 159,117              | 134,589              | 333.037                        |
| 1640     | 79,303               | 65,668               | 297.356                        | 3000     | 162,226              | 137,283              | 334.084                        |
| 1660     | 80,486               | 66,592               | 298.072                        | 3050     | 165,341              | 139,982              | 335.114                        |
| 1680     | 81,670               | 67,702               | 298.781                        | 3100     | 168,456              | 142,681              | 336.126                        |
| 1700     | 82,856               | 68,721               | 299.482                        | 3150     | 171,576              | 145,385              | 337.124                        |
| 1720     | 84,043               | 69,742               | 300.177                        | 3200     | 174,695              | 148,089              | 338.109                        |
| 1740     | 85,231               | 70,764               | 300.863                        | 3250     | 177,822              | 150,801              | 339.069                        |

TABLE A – 21

Ideal-gas properties of carbon monoxide, CO

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 600      | 17,611               | 12,622               | 218.204                        |
| 220      | 6,391                | 4,562                | 188.683                        | 610      | 17,915               | 12,843               | 218.708                        |
| 230      | 6,683                | 4,771                | 189.980                        | 620      | 18,221               | 13,066               | 219.205                        |
| 240      | 6,975                | 4,979                | 191.221                        | 630      | 18,527               | 13,289               | 219.695                        |
| 250      | 7,266                | 5,188                | 192.411                        | 640      | 18,833               | 13,512               | 220.179                        |
| 260      | 7,558                | 5,396                | 193.554                        | 650      | 19,141               | 13,736               | 220.656                        |
| 270      | 7,849                | 5,604                | 194.654                        | 660      | 19,449               | 13,962               | 221.127                        |
| 280      | 8,140                | 5,812                | 195.713                        | 670      | 19,758               | 14,187               | 221.592                        |
| 290      | 8,432                | 6,020                | 196.735                        | 680      | 20,068               | 14,414               | 222.052                        |
| 298      | 8,669                | 6,190                | 197.543                        | 690      | 20,378               | 14,641               | 222.505                        |
| 300      | 8,723                | 6,229                | 197.723                        | 700      | 20,690               | 14,870               | 222.953                        |
| 310      | 9,014                | 6,437                | 198.678                        | 710      | 21,002               | 15,099               | 223.396                        |
| 320      | 9,306                | 6,645                | 199.603                        | 720      | 21,315               | 15,328               | 223.833                        |
| 330      | 9,597                | 6,854                | 200.500                        | 730      | 21,628               | 15,558               | 224.265                        |
| 340      | 9,889                | 7,062                | 201.371                        | 740      | 21,943               | 15,789               | 224.692                        |
| 350      | 10,181               | 7,271                | 202.217                        | 750      | 22,258               | 16,022               | 225.115                        |
| 360      | 10,473               | 7,480                | 203.040                        | 760      | 22,573               | 16,255               | 225.533                        |
| 370      | 10,765               | 7,689                | 203.842                        | 770      | 22,890               | 16,488               | 225.947                        |
| 380      | 11,058               | 7,899                | 204.622                        | 780      | 23,208               | 16,723               | 226.357                        |
| 390      | 11,351               | 8,108                | 205.383                        | 790      | 23,526               | 16,957               | 226.762                        |
| 400      | 11,644               | 8,319                | 206.125                        | 800      | 23,844               | 17,193               | 227.162                        |
| 410      | 11,938               | 8,529                | 206.850                        | 810      | 24,164               | 17,429               | 227.559                        |
| 420      | 12,232               | 8,740                | 207.549                        | 820      | 24,483               | 17,665               | 227.952                        |
| 430      | 12,526               | 8,951                | 208.252                        | 830      | 24,803               | 17,902               | 228.339                        |
| 440      | 12,821               | 9,163                | 208.929                        | 840      | 25,124               | 18,140               | 228.724                        |
| 450      | 13,116               | 9,375                | 209.593                        | 850      | 25,446               | 18,379               | 229.106                        |
| 460      | 13,412               | 9,587                | 210.243                        | 860      | 25,768               | 18,617               | 229.482                        |
| 470      | 13,708               | 9,800                | 210.880                        | 870      | 26,091               | 18,858               | 229.856                        |
| 480      | 14,005               | 10,014               | 211.504                        | 880      | 26,415               | 19,099               | 230.227                        |
| 490      | 14,302               | 10,228               | 212.117                        | 890      | 26,740               | 19,341               | 230.593                        |
| 500      | 14,600               | 10,443               | 212.719                        | 900      | 27,066               | 19,583               | 230.957                        |
| 510      | 14,898               | 10,658               | 213.310                        | 910      | 27,392               | 19,826               | 231.317                        |
| 520      | 15,197               | 10,874               | 213.890                        | 920      | 27,719               | 20,070               | 231.674                        |
| 530      | 15,497               | 11,090               | 214.460                        | 930      | 28,046               | 20,314               | 232.028                        |
| 540      | 15,797               | 11,307               | 215.020                        | 940      | 28,375               | 20,559               | 232.379                        |
| 550      | 16,097               | 11,524               | 215.572                        | 950      | 28,703               | 20,805               | 232.727                        |
| 560      | 16,399               | 11,743               | 216.115                        | 960      | 29,033               | 21,051               | 233.072                        |
| 570      | 16,701               | 11,961               | 216.649                        | 970      | 29,362               | 21,298               | 233.413                        |
| 580      | 17,003               | 12,181               | 217.175                        | 980      | 29,693               | 21,545               | 233.752                        |
| 590      | 17,307               | 12,401               | 217.693                        | 990      | 30,024               | 21,793               | 234.088                        |

TABLE A-21

Ideal-gas properties of carbon monoxide, CO (*Concluded*)

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 1000     | 30,355               | 22,041               | 234.421                        | 1760     | 56,756               | 42,123               | 253.991                        |
| 1020     | 31,020               | 22,540               | 235.079                        | 1780     | 57,473               | 42,673               | 254.398                        |
| 1040     | 31,688               | 23,041               | 235.728                        | 1800     | 58,191               | 43,225               | 254.797                        |
| 1060     | 32,357               | 23,544               | 236.364                        | 1820     | 58,910               | 43,778               | 255.194                        |
| 1080     | 33,029               | 24,049               | 236.992                        | 1840     | 59,629               | 44,331               | 255.587                        |
| 1100     | 33,702               | 24,557               | 237.609                        | 1860     | 60,351               | 44,886               | 255.976                        |
| 1120     | 34,377               | 25,065               | 238.217                        | 1880     | 61,072               | 45,441               | 256.361                        |
| 1140     | 35,054               | 25,575               | 238.817                        | 1900     | 61,794               | 45,997               | 256.743                        |
| 1160     | 35,733               | 26,088               | 239.407                        | 1920     | 62,516               | 46,552               | 257.122                        |
| 1180     | 36,406               | 26,602               | 239.989                        | 1940     | 63,238               | 47,108               | 257.497                        |
| 1200     | 37,095               | 27,118               | 240.663                        | 1960     | 63,961               | 47,665               | 257.868                        |
| 1220     | 37,780               | 27,637               | 241.128                        | 1980     | 64,684               | 48,221               | 258.236                        |
| 1240     | 38,466               | 28,156               | 241.686                        | 2000     | 65,408               | 48,780               | 258.600                        |
| 1260     | 39,154               | 28,678               | 242.236                        | 2050     | 67,224               | 50,179               | 259.494                        |
| 1280     | 39,844               | 29,201               | 242.780                        | 2100     | 69,044               | 51,584               | 260.370                        |
| 1300     | 40,534               | 29,725               | 243.316                        | 2150     | 70,864               | 52,988               | 261.226                        |
| 1320     | 41,226               | 30,251               | 243.844                        | 2200     | 72,688               | 54,396               | 262.065                        |
| 1340     | 41,919               | 30,778               | 244.366                        | 2250     | 74,516               | 55,809               | 262.887                        |
| 1360     | 42,613               | 31,306               | 244.880                        | 2300     | 76,345               | 57,222               | 263.692                        |
| 1380     | 43,309               | 31,836               | 245.388                        | 2350     | 78,178               | 58,640               | 264.480                        |
| 1400     | 44,007               | 32,367               | 245.889                        | 2400     | 80,015               | 60,060               | 265.253                        |
| 1420     | 44,707               | 32,900               | 246.385                        | 2450     | 81,852               | 61,482               | 266.012                        |
| 1440     | 45,408               | 33,434               | 246.876                        | 2500     | 83,692               | 62,906               | 266.755                        |
| 1460     | 46,110               | 33,971               | 247.360                        | 2550     | 85,537               | 64,335               | 267.485                        |
| 1480     | 46,813               | 34,508               | 247.839                        | 2600     | 87,383               | 65,766               | 268.202                        |
| 1500     | 47,517               | 35,046               | 248.312                        | 2650     | 89,230               | 67,197               | 268.905                        |
| 1520     | 48,222               | 35,584               | 248.778                        | 2700     | 91,077               | 68,628               | 269.596                        |
| 1540     | 48,928               | 36,124               | 249.240                        | 2750     | 92,930               | 70,066               | 270.285                        |
| 1560     | 49,635               | 36,665               | 249.695                        | 2800     | 94,784               | 71,504               | 270.943                        |
| 1580     | 50,344               | 37,207               | 250.147                        | 2850     | 96,639               | 72,945               | 271.602                        |
| 1600     | 51,053               | 37,750               | 250.592                        | 2900     | 98,495               | 74,383               | 272.249                        |
| 1620     | 51,763               | 38,293               | 251.033                        | 2950     | 100,352              | 75,825               | 272.884                        |
| 1640     | 52,472               | 38,837               | 251.470                        | 3000     | 102,210              | 77,267               | 273.508                        |
| 1660     | 53,184               | 39,382               | 251.901                        | 3050     | 104,073              | 78,715               | 274.123                        |
| 1680     | 53,895               | 39,927               | 252.329                        | 3100     | 105,939              | 80,164               | 274.730                        |
| 1700     | 54,609               | 40,474               | 252.751                        | 3150     | 107,802              | 81,612               | 275.326                        |
| 1720     | 55,323               | 41,023               | 253.169                        | 3200     | 109,667              | 83,061               | 275.914                        |
| 1740     | 56,039               | 41,572               | 253.582                        | 3250     | 111,534              | 84,513               | 276.494                        |



TABLE A-22

Ideal-gas properties of hydrogen,  $H_2$ 

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 1440     | 42,808               | 30,835               | 177.410                        |
| 260      | 7,370                | 5,209                | 126.636                        | 1480     | 44,091               | 31,786               | 178.291                        |
| 270      | 7,657                | 5,412                | 127.719                        | 1520     | 45,384               | 32,746               | 179.153                        |
| 280      | 7,945                | 5,617                | 128.765                        | 1560     | 46,683               | 33,713               | 179.995                        |
| 290      | 8,233                | 5,822                | 129.775                        | 1600     | 47,990               | 34,687               | 180.820                        |
| 298      | 8,468                | 5,989                | 130.574                        | 1640     | 49,303               | 35,668               | 181.632                        |
| 300      | 8,522                | 6,027                | 130.754                        | 1680     | 50,622               | 36,654               | 182.428                        |
| 320      | 9,100                | 6,440                | 132.621                        | 1720     | 51,947               | 37,646               | 183.208                        |
| 340      | 9,680                | 6,853                | 134.378                        | 1760     | 53,279               | 38,645               | 183.973                        |
| 360      | 10,262               | 7,268                | 136.039                        | 1800     | 54,618               | 39,652               | 184.724                        |
| 380      | 10,843               | 7,684                | 137.612                        | 1840     | 55,962               | 40,663               | 185.463                        |
| 400      | 11,426               | 8,100                | 139.106                        | 1880     | 57,311               | 41,680               | 186.190                        |
| 420      | 12,010               | 8,518                | 140.529                        | 1920     | 58,668               | 42,705               | 186.904                        |
| 440      | 12,594               | 8,936                | 141.888                        | 1960     | 60,031               | 43,735               | 187.607                        |
| 460      | 13,179               | 9,355                | 143.187                        | 2000     | 61,400               | 44,771               | 188.297                        |
| 480      | 13,764               | 9,773                | 144.432                        | 2050     | 63,119               | 46,074               | 189.148                        |
| 500      | 14,350               | 10,193               | 145.628                        | 2100     | 64,847               | 47,386               | 189.979                        |
| 520      | 14,935               | 10,611               | 146.775                        | 2150     | 66,584               | 48,708               | 190.796                        |
| 560      | 16,107               | 11,451               | 148.945                        | 2200     | 68,328               | 50,037               | 191.598                        |
| 600      | 17,280               | 12,291               | 150.968                        | 2250     | 70,080               | 51,373               | 192.385                        |
| 640      | 18,453               | 13,133               | 152.863                        | 2300     | 71,839               | 52,716               | 193.159                        |
| 680      | 19,630               | 13,976               | 154.645                        | 2350     | 73,608               | 54,069               | 193.921                        |
| 720      | 20,807               | 14,821               | 156.328                        | 2400     | 75,383               | 55,429               | 194.669                        |
| 760      | 21,988               | 15,669               | 157.923                        | 2450     | 77,168               | 56,798               | 195.403                        |
| 800      | 23,171               | 16,520               | 159.440                        | 2500     | 78,960               | 58,175               | 196.125                        |
| 840      | 24,359               | 17,375               | 160.891                        | 2550     | 80,755               | 59,554               | 196.837                        |
| 880      | 25,551               | 18,235               | 162.277                        | 2600     | 82,558               | 60,941               | 197.539                        |
| 920      | 26,747               | 19,098               | 163.607                        | 2650     | 84,368               | 62,335               | 198.229                        |
| 960      | 27,948               | 19,966               | 164.884                        | 2700     | 86,186               | 63,737               | 198.907                        |
| 1000     | 29,154               | 20,839               | 166.114                        | 2750     | 88,008               | 65,144               | 199.575                        |
| 1040     | 30,364               | 21,717               | 167.300                        | 2800     | 89,838               | 66,558               | 200.234                        |
| 1080     | 31,580               | 22,601               | 168.449                        | 2850     | 91,671               | 67,976               | 200.885                        |
| 1120     | 32,802               | 23,490               | 169.560                        | 2900     | 93,512               | 69,401               | 201.527                        |
| 1160     | 34,028               | 24,384               | 170.636                        | 2950     | 95,358               | 70,831               | 202.157                        |
| 1200     | 35,262               | 25,284               | 171.682                        | 3000     | 97,211               | 72,268               | 202.778                        |
| 1240     | 36,502               | 26,192               | 172.698                        | 3050     | 99,065               | 73,707               | 203.391                        |
| 1280     | 37,749               | 27,106               | 173.687                        | 3100     | 100,926              | 75,152               | 203.995                        |
| 1320     | 39,002               | 28,027               | 174.652                        | 3150     | 102,793              | 76,604               | 204.592                        |
| 1360     | 40,263               | 28,955               | 175.593                        | 3200     | 104,667              | 78,061               | 205.181                        |
| 1400     | 41,530               | 29,889               | 176.510                        | 3250     | 106,545              | 79,523               | 205.765                        |

TABLE A-23

Ideal-gas properties of water vapor,  $H_2O$ 

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 600      | 20,402               | 15,413               | 212.920                        |
| 220      | 7,295                | 5,466                | 178.576                        | 610      | 20,765               | 15,693               | 213.529                        |
| 230      | 7,628                | 5,715                | 180.054                        | 620      | 21,130               | 15,975               | 214.122                        |
| 240      | 7,961                | 5,965                | 181.471                        | 630      | 21,495               | 16,257               | 214.707                        |
| 250      | 8,294                | 6,215                | 182.831                        | 640      | 21,862               | 16,541               | 215.285                        |
| 260      | 8,627                | 6,466                | 184.139                        | 650      | 22,230               | 16,826               | 215.856                        |
| 270      | 8,961                | 6,716                | 185.399                        | 660      | 22,600               | 17,112               | 216.419                        |
| 280      | 9,296                | 6,968                | 186.616                        | 670      | 22,970               | 17,399               | 216.976                        |
| 290      | 9,631                | 7,219                | 187.791                        | 680      | 23,342               | 17,688               | 217.527                        |
| 298      | 9,904                | 7,425                | 188.720                        | 690      | 23,714               | 17,978               | 218.071                        |
| 300      | 9,966                | 7,472                | 188.928                        | 700      | 24,088               | 18,268               | 218.610                        |
| 310      | 10,302               | 7,725                | 190.030                        | 710      | 24,464               | 18,561               | 219.142                        |
| 320      | 10,639               | 7,978                | 191.098                        | 720      | 24,840               | 18,854               | 219.668                        |
| 330      | 10,976               | 8,232                | 192.136                        | 730      | 25,218               | 19,148               | 220.189                        |
| 340      | 11,314               | 8,487                | 193.144                        | 740      | 25,597               | 19,444               | 220.707                        |
| 350      | 11,652               | 8,742                | 194.125                        | 750      | 25,977               | 19,741               | 221.215                        |
| 360      | 11,992               | 8,998                | 195.081                        | 760      | 26,358               | 20,039               | 221.720                        |
| 370      | 12,331               | 9,255                | 196.012                        | 770      | 26,741               | 20,339               | 222.221                        |
| 380      | 12,672               | 9,513                | 196.920                        | 780      | 27,125               | 20,639               | 222.717                        |
| 390      | 13,014               | 9,771                | 197.807                        | 790      | 27,510               | 20,941               | 223.207                        |
| 400      | 13,356               | 10,030               | 198.673                        | 800      | 27,896               | 21,245               | 223.693                        |
| 410      | 13,699               | 10,290               | 199.521                        | 810      | 28,284               | 21,549               | 224.174                        |
| 420      | 14,043               | 10,551               | 200.350                        | 820      | 28,672               | 21,855               | 224.651                        |
| 430      | 14,388               | 10,813               | 201.160                        | 830      | 29,062               | 22,162               | 225.123                        |
| 440      | 14,734               | 11,075               | 201.955                        | 840      | 29,454               | 22,470               | 225.592                        |
| 450      | 15,080               | 11,339               | 202.734                        | 850      | 29,846               | 22,779               | 226.057                        |
| 460      | 15,428               | 11,603               | 203.497                        | 860      | 30,240               | 23,090               | 226.517                        |
| 470      | 15,777               | 11,869               | 204.247                        | 870      | 30,635               | 23,402               | 226.973                        |
| 480      | 16,126               | 12,135               | 204.982                        | 880      | 31,032               | 23,715               | 227.426                        |
| 490      | 16,477               | 12,403               | 205.705                        | 890      | 31,429               | 24,029               | 227.875                        |
| 500      | 16,828               | 12,671               | 206.413                        | 900      | 31,828               | 24,345               | 228.321                        |
| 510      | 17,181               | 12,940               | 207.112                        | 910      | 32,228               | 24,662               | 228.763                        |
| 520      | 17,534               | 13,211               | 207.799                        | 920      | 32,629               | 24,980               | 229.202                        |
| 530      | 17,889               | 13,482               | 208.475                        | 930      | 33,032               | 25,300               | 229.637                        |
| 540      | 18,245               | 13,755               | 209.139                        | 940      | 33,436               | 25,621               | 230.070                        |
| 550      | 18,601               | 14,028               | 209.795                        | 950      | 33,841               | 25,943               | 230.499                        |
| 560      | 18,959               | 14,303               | 210.440                        | 960      | 34,247               | 26,265               | 230.924                        |
| 570      | 19,318               | 14,579               | 211.075                        | 970      | 34,653               | 26,588               | 231.347                        |
| 580      | 19,678               | 14,856               | 211.702                        | 980      | 35,061               | 26,913               | 231.767                        |
| 590      | 20,039               | 15,134               | 212.320                        | 990      | 35,472               | 27,240               | 232.184                        |

TABLE A-23

Ideal-gas properties of water vapor,  $H_2O$  (Concluded)

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 1000     | 35,882               | 27,568               | 232.597                        | 1760     | 70,535               | 55,902               | 258.151                        |
| 1020     | 36,709               | 28,228               | 233.415                        | 1780     | 71,523               | 56,723               | 258.708                        |
| 1040     | 37,542               | 28,895               | 234.223                        | 1800     | 72,513               | 57,547               | 259.262                        |
| 1060     | 38,380               | 29,567               | 235.020                        | 1820     | 73,507               | 58,375               | 259.811                        |
| 1080     | 39,223               | 30,243               | 235.806                        | 1840     | 74,506               | 59,207               | 260.357                        |
| 1100     | 40,071               | 30,925               | 236.584                        | 1860     | 75,506               | 60,042               | 260.898                        |
| 1120     | 40,923               | 31,611               | 237.352                        | 1880     | 76,511               | 60,880               | 261.436                        |
| 1140     | 41,780               | 32,301               | 238.110                        | 1900     | 77,517               | 61,720               | 261.969                        |
| 1160     | 42,642               | 32,997               | 238.859                        | 1920     | 78,527               | 62,564               | 262.497                        |
| 1180     | 43,509               | 33,698               | 239.600                        | 1940     | 79,540               | 63,411               | 263.022                        |
| 1200     | 44,380               | 34,403               | 240.333                        | 1960     | 80,555               | 64,259               | 263.542                        |
| 1220     | 45,256               | 35,112               | 241.057                        | 1980     | 81,573               | 65,111               | 264.059                        |
| 1240     | 46,137               | 35,827               | 241.773                        | 2000     | 82,593               | 65,965               | 264.571                        |
| 1260     | 47,022               | 36,546               | 242.482                        | 2050     | 85,156               | 68,111               | 265.838                        |
| 1280     | 47,912               | 37,270               | 243.183                        | 2100     | 87,735               | 70,275               | 267.081                        |
| 1300     | 48,807               | 38,000               | 243.877                        | 2150     | 90,330               | 72,454               | 268.301                        |
| 1320     | 49,707               | 38,732               | 244.564                        | 2200     | 92,940               | 74,649               | 269.500                        |
| 1340     | 50,612               | 39,470               | 245.243                        | 2250     | 95,562               | 76,855               | 270.679                        |
| 1360     | 51,521               | 40,213               | 245.915                        | 2300     | 98,199               | 79,076               | 271.839                        |
| 1380     | 52,434               | 40,960               | 246.582                        | 2350     | 100,846              | 81,308               | 272.978                        |
| 1400     | 53,351               | 41,711               | 247.241                        | 2400     | 103,508              | 83,553               | 274.098                        |
| 1420     | 54,273               | 42,466               | 247.895                        | 2450     | 106,183              | 85,811               | 275.201                        |
| 1440     | 55,198               | 43,226               | 248.543                        | 2500     | 108,868              | 88,082               | 276.286                        |
| 1460     | 56,128               | 43,989               | 249.185                        | 2550     | 111,565              | 90,364               | 277.354                        |
| 1480     | 57,062               | 44,756               | 249.820                        | 2600     | 114,273              | 92,656               | 278.407                        |
| 1500     | 57,999               | 45,528               | 250.450                        | 2650     | 116,991              | 94,958               | 279.441                        |
| 1520     | 58,942               | 46,304               | 251.074                        | 2700     | 119,717              | 97,269               | 280.462                        |
| 1540     | 59,888               | 47,084               | 251.693                        | 2750     | 122,453              | 99,588               | 281.464                        |
| 1560     | 60,838               | 47,868               | 252.305                        | 2800     | 125,198              | 101,917              | 282.453                        |
| 1580     | 61,792               | 48,655               | 252.912                        | 2850     | 127,952              | 104,256              | 283.429                        |
| 1600     | 62,748               | 49,445               | 253.513                        | 2900     | 130,717              | 106,605              | 284.390                        |
| 1620     | 63,709               | 50,240               | 254.111                        | 2950     | 133,486              | 108,959              | 285.338                        |
| 1640     | 64,675               | 51,039               | 254.703                        | 3000     | 136,264              | 111,321              | 286.273                        |
| 1660     | 65,643               | 51,841               | 255.290                        | 3050     | 139,051              | 113,692              | 287.194                        |
| 1680     | 66,614               | 52,646               | 255.873                        | 3100     | 141,846              | 116,072              | 288.102                        |
| 1700     | 67,589               | 53,455               | 256.450                        | 3150     | 144,648              | 118,458              | 288.999                        |
| 1720     | 68,567               | 54,267               | 257.022                        | 3200     | 147,457              | 120,851              | 289.884                        |
| 1740     | 69,550               | 55,083               | 257.589                        | 3250     | 150,272              | 123,250              | 290.756                        |

TABLE A-24

Ideal-gas properties of monatomic oxygen, O

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 2400     | 50,894               | 30,940               | 204.932                        |
| 298      | 6,852                | 4,373                | 160.944                        | 2450     | 51,936               | 31,566               | 205.362                        |
| 300      | 6,892                | 4,398                | 161.079                        | 2500     | 52,979               | 32,193               | 205.783                        |
| 500      | 11,197               | 7,040                | 172.088                        | 2550     | 54,021               | 32,820               | 206.196                        |
| 1000     | 21,713               | 13,398               | 186.678                        | 2600     | 55,064               | 33,447               | 206.601                        |
| 1500     | 32,150               | 19,679               | 195.143                        | 2650     | 56,108               | 34,075               | 206.999                        |
| 1600     | 34,234               | 20,931               | 196.488                        | 2700     | 57,152               | 34,703               | 207.389                        |
| 1700     | 36,317               | 22,183               | 197.751                        | 2750     | 58,196               | 35,332               | 207.772                        |
| 1800     | 38,400               | 23,434               | 198.941                        | 2800     | 59,241               | 35,961               | 208.148                        |
| 1900     | 40,482               | 24,685               | 200.067                        | 2850     | 60,286               | 36,590               | 208.518                        |
| 2000     | 42,564               | 25,935               | 201.135                        | 2900     | 61,332               | 37,220               | 208.882                        |
| 2050     | 43,605               | 26,560               | 201.649                        | 2950     | 62,378               | 37,851               | 209.240                        |
| 2100     | 44,646               | 27,186               | 202.151                        | 3000     | 63,425               | 38,482               | 209.592                        |
| 2150     | 45,687               | 27,811               | 202.641                        | 3100     | 65,520               | 39,746               | 210.279                        |
| 2200     | 46,728               | 28,436               | 203.119                        | 3200     | 67,619               | 41,013               | 210.945                        |
| 2250     | 47,769               | 29,062               | 203.588                        | 3300     | 69,720               | 42,283               | 211.592                        |
| 2300     | 48,811               | 29,688               | 204.045                        | 3400     | 71,824               | 43,556               | 212.220                        |
| 2350     | 49,852               | 30,314               | 204.493                        | 3500     | 73,932               | 44,832               | 212.831                        |

TABLE A-25

Ideal-gas properties of hydroxyl, OH

| $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K | $T$<br>K | $\bar{h}$<br>kJ/kmol | $\bar{u}$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|----------|----------------------|----------------------|--------------------------------|----------|----------------------|----------------------|--------------------------------|
| 0        | 0                    | 0                    | 0                              | 2400     | 77,015               | 57,061               | 248.628                        |
| 298      | 9,188                | 6,709                | 183.594                        | 2450     | 78,801               | 58,431               | 249.364                        |
| 300      | 9,244                | 6,749                | 183.779                        | 2500     | 80,592               | 59,806               | 250.088                        |
| 500      | 15,181               | 11,024               | 198.955                        | 2550     | 82,388               | 61,186               | 250.799                        |
| 1000     | 30,123               | 21,809               | 219.624                        | 2600     | 84,189               | 62,572               | 251.499                        |
| 1500     | 46,046               | 33,575               | 232.506                        | 2650     | 85,995               | 63,962               | 252.187                        |
| 1600     | 49,358               | 36,055               | 234.642                        | 2700     | 87,806               | 65,358               | 252.864                        |
| 1700     | 52,706               | 38,571               | 236.672                        | 2750     | 89,622               | 66,757               | 253.530                        |
| 1800     | 56,089               | 41,123               | 238.606                        | 2800     | 91,442               | 68,162               | 254.186                        |
| 1900     | 59,505               | 43,708               | 240.453                        | 2850     | 93,266               | 69,570               | 254.832                        |
| 2000     | 62,952               | 46,323               | 242.221                        | 2900     | 95,095               | 70,983               | 255.468                        |
| 2050     | 64,687               | 47,642               | 243.077                        | 2950     | 96,927               | 72,400               | 256.094                        |
| 2100     | 66,428               | 48,968               | 243.917                        | 3000     | 98,763               | 73,820               | 256.712                        |
| 2150     | 68,177               | 50,301               | 244.740                        | 3100     | 102,447              | 76,673               | 257.919                        |
| 2200     | 69,932               | 51,641               | 245.547                        | 3200     | 106,145              | 79,539               | 259.093                        |
| 2250     | 71,694               | 52,987               | 246.338                        | 3300     | 109,855              | 82,418               | 260.235                        |
| 2300     | 73,462               | 54,339               | 247.116                        | 3400     | 113,578              | 85,309               | 261.347                        |
| 2350     | 75,236               | 55,697               | 247.879                        | 3500     | 117,312              | 88,212               | 262.429                        |

TABLE A-26

Enthalpy of formation, Gibbs function of formation, and absolute entropy at 25°C, 1 atm

| Substance         | Formula                             | $\bar{h}_f^\circ$<br>kJ/kmol | $\bar{g}_f^\circ$<br>kJ/kmol | $\bar{s}^\circ$<br>kJ/kmol · K |
|-------------------|-------------------------------------|------------------------------|------------------------------|--------------------------------|
| Carbon            | C(s)                                | 0                            | 0                            | 5.74                           |
| Hydrogen          | H <sub>2</sub> (g)                  | 0                            | 0                            | 130.68                         |
| Nitrogen          | N <sub>2</sub> (g)                  | 0                            | 0                            | 191.61                         |
| Oxygen            | O <sub>2</sub> (g)                  | 0                            | 0                            | 205.04                         |
| Carbon monoxide   | CO(g)                               | -110,530                     | -137,150                     | 197.65                         |
| Carbon dioxide    | CO <sub>2</sub> (g)                 | -393,520                     | -394,360                     | 213.80                         |
| Water vapor       | H <sub>2</sub> O(g)                 | -241,820                     | -228,590                     | 188.83                         |
| Water             | H <sub>2</sub> O(l)                 | -285,830                     | -237,180                     | 69.92                          |
| Hydrogen peroxide | H <sub>2</sub> O <sub>2</sub> (g)   | -136,310                     | -105,600                     | 232.63                         |
| Ammonia           | NH <sub>3</sub> (g)                 | -46,190                      | -16,590                      | 192.33                         |
| Methane           | CH <sub>4</sub> (g)                 | -74,850                      | -50,790                      | 186.16                         |
| Acetylene         | C <sub>2</sub> H <sub>2</sub> (g)   | +226,730                     | +209,170                     | 200.85                         |
| Ethylene          | C <sub>2</sub> H <sub>4</sub> (g)   | +52,280                      | +68,120                      | 219.83                         |
| Ethane            | C <sub>2</sub> H <sub>6</sub> (g)   | -84,680                      | -32,890                      | 229.49                         |
| Propylene         | C <sub>3</sub> H <sub>6</sub> (g)   | +20,410                      | +62,720                      | 266.94                         |
| Propane           | C <sub>3</sub> H <sub>8</sub> (g)   | -103,850                     | -23,490                      | 269.91                         |
| n-Butane          | C <sub>4</sub> H <sub>10</sub> (g)  | -126,150                     | -15,710                      | 310.12                         |
| n-Octane          | C <sub>8</sub> H <sub>18</sub> (g)  | -208,450                     | +16,530                      | 466.73                         |
| n-Octane          | C <sub>8</sub> H <sub>18</sub> (l)  | -249,950                     | +6,610                       | 360.79                         |
| n-Dodecane        | C <sub>12</sub> H <sub>26</sub> (g) | -291,010                     | +50,150                      | 622.83                         |
| Benzene           | C <sub>6</sub> H <sub>6</sub> (g)   | +82,930                      | +129,660                     | 269.20                         |
| Methyl alcohol    | CH <sub>3</sub> OH(g)               | -200,670                     | -162,000                     | 239.70                         |
| Methyl alcohol    | CH <sub>3</sub> OH(l)               | -238,660                     | -166,360                     | 126.80                         |
| Ethyl alcohol     | C <sub>2</sub> H <sub>5</sub> OH(g) | -235,310                     | -168,570                     | 282.59                         |
| Ethyl alcohol     | C <sub>2</sub> H <sub>5</sub> OH(l) | -277,690                     | -174,890                     | 160.70                         |
| Oxygen            | O(g)                                | +249,190                     | +231,770                     | 161.06                         |
| Hydrogen          | H(g)                                | +218,000                     | +203,290                     | 114.72                         |
| Nitrogen          | N(g)                                | +472,650                     | +455,510                     | 153.30                         |
| Hydroxyl          | OH(g)                               | +39,460                      | +34,280                      | 183.70                         |

Source: From JANAF, *Thermochemical Tables* (Midland, MI: Dow Chemical Co., 1971); *Selected Values of Chemical Thermodynamic Properties*, NBS Technical Note 270-3, 1968; and *API Research Project 44* (Carnegie Press, 1953).

TABLE A-27

Properties of some common fuels and hydrocarbons

| Fuel (phase)        | Formula                                            | Molar mass, kg/kmol | Density, <sup>1</sup> kg/L | Enthalpy of vaporization, <sup>2</sup> kJ/kg | Specific heat, <sup>1</sup> $c_p$ , kJ/kg · K | Higher heating value, <sup>3</sup> kJ/kg | Lower heating value, <sup>3</sup> kJ/kg |
|---------------------|----------------------------------------------------|---------------------|----------------------------|----------------------------------------------|-----------------------------------------------|------------------------------------------|-----------------------------------------|
| Carbon (s)          | C                                                  | 12.011              | 2                          | —                                            | 0.708                                         | 32,800                                   | 32,800                                  |
| Hydrogen (g)        | H <sub>2</sub>                                     | 2.016               | —                          | —                                            | 14.4                                          | 141,800                                  | 120,000                                 |
| Carbon monoxide (g) | CO                                                 | 28.013              | —                          | —                                            | 1.05                                          | 10,100                                   | 10,100                                  |
| Methane (g)         | CH <sub>4</sub>                                    | 16.043              | —                          | 509                                          | 2.20                                          | 55,530                                   | 50,050                                  |
| Methanol (ℓ)        | CH <sub>4</sub> O                                  | 32.042              | 0.790                      | 1168                                         | 2.53                                          | 22,660                                   | 19,920                                  |
| Acetylene (g)       | C <sub>2</sub> H <sub>2</sub>                      | 26.038              | —                          | —                                            | 1.69                                          | 49,970                                   | 48,280                                  |
| Ethane (g)          | C <sub>2</sub> H <sub>6</sub>                      | 30.070              | —                          | 172                                          | 1.75                                          | 51,900                                   | 47,520                                  |
| Ethanol (ℓ)         | C <sub>2</sub> H <sub>6</sub> O                    | 46.069              | 0.790                      | 919                                          | 2.44                                          | 29,670                                   | 26,810                                  |
| Propane (ℓ)         | C <sub>3</sub> H <sub>8</sub>                      | 44.097              | 0.500                      | 335                                          | 2.77                                          | 50,330                                   | 46,340                                  |
| Butane (ℓ)          | C <sub>4</sub> H <sub>10</sub>                     | 58.123              | 0.579                      | 362                                          | 2.42                                          | 49,150                                   | 45,370                                  |
| 1-Pentene (ℓ)       | C <sub>5</sub> H <sub>10</sub>                     | 70.134              | 0.641                      | 363                                          | 2.20                                          | 47,760                                   | 44,630                                  |
| Isopentane (ℓ)      | C <sub>5</sub> H <sub>12</sub>                     | 72.150              | 0.626                      | —                                            | 2.32                                          | 48,570                                   | 44,910                                  |
| Benzene (ℓ)         | C <sub>6</sub> H <sub>6</sub>                      | 78.114              | 0.877                      | 433                                          | 1.72                                          | 41,800                                   | 40,100                                  |
| Hexene (ℓ)          | C <sub>6</sub> H <sub>12</sub>                     | 84.161              | 0.673                      | 392                                          | 1.84                                          | 47,500                                   | 44,400                                  |
| Hexane (ℓ)          | C <sub>6</sub> H <sub>14</sub>                     | 86.177              | 0.660                      | 366                                          | 2.27                                          | 48,310                                   | 44,740                                  |
| Toluene (ℓ)         | C <sub>7</sub> H <sub>8</sub>                      | 92.141              | 0.867                      | 412                                          | 1.71                                          | 42,400                                   | 40,500                                  |
| Heptane (ℓ)         | C <sub>7</sub> H <sub>16</sub>                     | 100.204             | 0.684                      | 365                                          | 2.24                                          | 48,100                                   | 44,600                                  |
| Octane (ℓ)          | C <sub>8</sub> H <sub>18</sub>                     | 114.231             | 0.703                      | 363                                          | 2.23                                          | 47,890                                   | 44,430                                  |
| Decane (ℓ)          | C <sub>10</sub> H <sub>22</sub>                    | 142.285             | 0.730                      | 361                                          | 2.21                                          | 47,640                                   | 44,240                                  |
| Gasoline (ℓ)        | C <sub>n</sub> H <sub>1.87n</sub>                  | 100–110             | 0.72–0.78                  | 350                                          | 2.4                                           | 47,300                                   | 44,000                                  |
| Light diesel (ℓ)    | C <sub>n</sub> H <sub>1.8n</sub>                   | 170                 | 0.78–0.84                  | 270                                          | 2.2                                           | 46,100                                   | 43,200                                  |
| Heavy diesel (ℓ)    | C <sub>n</sub> H <sub>1.7n</sub>                   | 200                 | 0.82–0.88                  | 230                                          | 1.9                                           | 45,500                                   | 42,800                                  |
| Natural gas (g)     | C <sub>n</sub> H <sub>3.8n</sub> N <sub>0.1n</sub> | 18                  | —                          | —                                            | 2                                             | 50,000                                   | 45,000                                  |

<sup>1</sup>At 1 atm and 20°C.<sup>2</sup>At 25°C for liquid fuels, and 1 atm and normal boiling temperature for gaseous fuels.<sup>3</sup>At 25°C. Multiply by molar mass to obtain heating values in kJ/kmol.

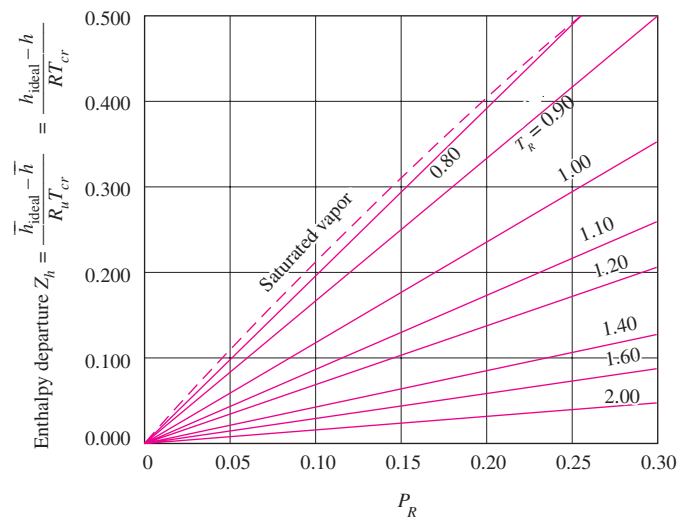
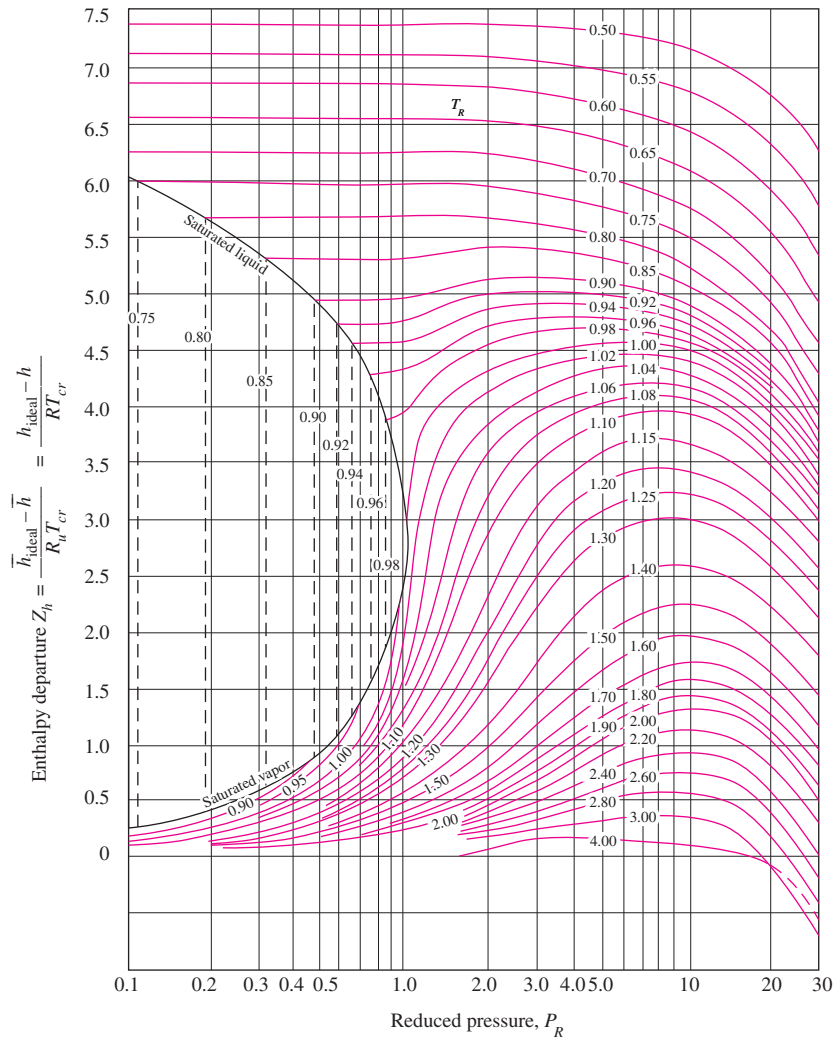
TABLE A-28

Natural logarithms of the equilibrium constant  $K_p$ The equilibrium constant  $K_p$  for the reaction  $\nu_A A + \nu_B B \rightleftharpoons \nu_C C + \nu_D D$  is defined as  $K_p \equiv \frac{P_C^{\nu_C} P_D^{\nu_D}}{P_A^{\nu_A} P_B^{\nu_B}}$ 

| Temp.,<br>K | $\text{H}_2 \rightleftharpoons 2\text{H}$ | $\text{O}_2 \rightleftharpoons 2\text{O}$ | $\text{N}_2 \rightleftharpoons 2\text{N}$ | $\text{H}_2\text{O} \rightleftharpoons \text{H}_2 + \frac{1}{2}\text{O}_2$ | $\text{H}_2\text{O} \rightleftharpoons \frac{1}{2}\text{H}_2 + \text{OH}$ | $\text{CO}_2 \rightleftharpoons \text{CO} + \frac{1}{2}\text{O}_2$ | $\frac{1}{2}\text{N}_2 + \frac{1}{2}\text{O}_2 \rightleftharpoons \text{NO}$ |
|-------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------------------|
| 298         | -164.005                                  | -186.975                                  | -367.480                                  | -92.208                                                                    | -106.208                                                                  | -103.762                                                           | -35.052                                                                      |
| 500         | -92.827                                   | -105.630                                  | -213.372                                  | -52.691                                                                    | -60.281                                                                   | -57.616                                                            | -20.295                                                                      |
| 1000        | -39.803                                   | -45.150                                   | -99.127                                   | -23.163                                                                    | -26.034                                                                   | -23.529                                                            | -9.388                                                                       |
| 1200        | -30.874                                   | -35.005                                   | -80.011                                   | -18.182                                                                    | -20.283                                                                   | -17.871                                                            | -7.569                                                                       |
| 1400        | -24.463                                   | -27.742                                   | -66.329                                   | -14.609                                                                    | -16.099                                                                   | -13.842                                                            | -6.270                                                                       |
| 1600        | -19.637                                   | -22.285                                   | -56.055                                   | -11.921                                                                    | -13.066                                                                   | -10.830                                                            | -5.294                                                                       |
| 1800        | -15.866                                   | -18.030                                   | -48.051                                   | -9.826                                                                     | -10.657                                                                   | -8.497                                                             | -4.536                                                                       |
| 2000        | -12.840                                   | -14.622                                   | -41.645                                   | -8.145                                                                     | -8.728                                                                    | -6.635                                                             | -3.931                                                                       |
| 2200        | -10.353                                   | -11.827                                   | -36.391                                   | -6.768                                                                     | -7.148                                                                    | -5.120                                                             | -3.433                                                                       |
| 2400        | -8.276                                    | -9.497                                    | -32.011                                   | -5.619                                                                     | -5.832                                                                    | -3.860                                                             | -3.019                                                                       |
| 2600        | -6.517                                    | -7.521                                    | -28.304                                   | -4.648                                                                     | -4.719                                                                    | -2.801                                                             | -2.671                                                                       |
| 2800        | -5.002                                    | -5.826                                    | -25.117                                   | -3.812                                                                     | -3.763                                                                    | -1.894                                                             | -2.372                                                                       |
| 3000        | -3.685                                    | -4.357                                    | -22.359                                   | -3.086                                                                     | -2.937                                                                    | -1.111                                                             | -2.114                                                                       |
| 3200        | -2.534                                    | -3.072                                    | -19.937                                   | -2.451                                                                     | -2.212                                                                    | -0.429                                                             | -1.888                                                                       |
| 3400        | -1.516                                    | -1.935                                    | -17.800                                   | -1.891                                                                     | -1.576                                                                    | 0.169                                                              | -1.690                                                                       |
| 3600        | -0.609                                    | -0.926                                    | -15.898                                   | -1.392                                                                     | -1.088                                                                    | 0.701                                                              | -1.513                                                                       |
| 3800        | 0.202                                     | -0.019                                    | -14.199                                   | -0.945                                                                     | -0.501                                                                    | 1.176                                                              | -1.356                                                                       |
| 4000        | 0.934                                     | 0.796                                     | -12.660                                   | -0.542                                                                     | -0.044                                                                    | 1.599                                                              | -1.216                                                                       |
| 4500        | 2.486                                     | 2.513                                     | -9.414                                    | 0.312                                                                      | 0.920                                                                     | 2.490                                                              | -0.921                                                                       |
| 5000        | 3.725                                     | 3.895                                     | -6.807                                    | 0.996                                                                      | 1.689                                                                     | 3.197                                                              | -0.686                                                                       |
| 5500        | 4.743                                     | 5.023                                     | -4.666                                    | 1.560                                                                      | 2.318                                                                     | 3.771                                                              | -0.497                                                                       |
| 6000        | 5.590                                     | 5.963                                     | -2.865                                    | 2.032                                                                      | 2.843                                                                     | 4.245                                                              | -0.341                                                                       |

Source: Gordon J. Van Wylen and Richard E. Sonntag, *Fundamentals of Classical Thermodynamics*, English/SI Version, 3rd ed. (New York: John Wiley & Sons, 1986), p. 723, table A.14. Based on thermodynamic data given in JANAF, *Thermochemical Tables* (Midland, MI: Thermal Research Laboratory, The Dow Chemical Company, 1971).



**FIGURE A-29**

Generalized enthalpy departure chart.

Source: John R. Howell and Richard O. Buckius, Fundamentals of Engineering Thermodynamics, SI Version (New York: McGraw-Hill, 1987), p. 558, fig. C.2, and p. 561, fig. C.5.

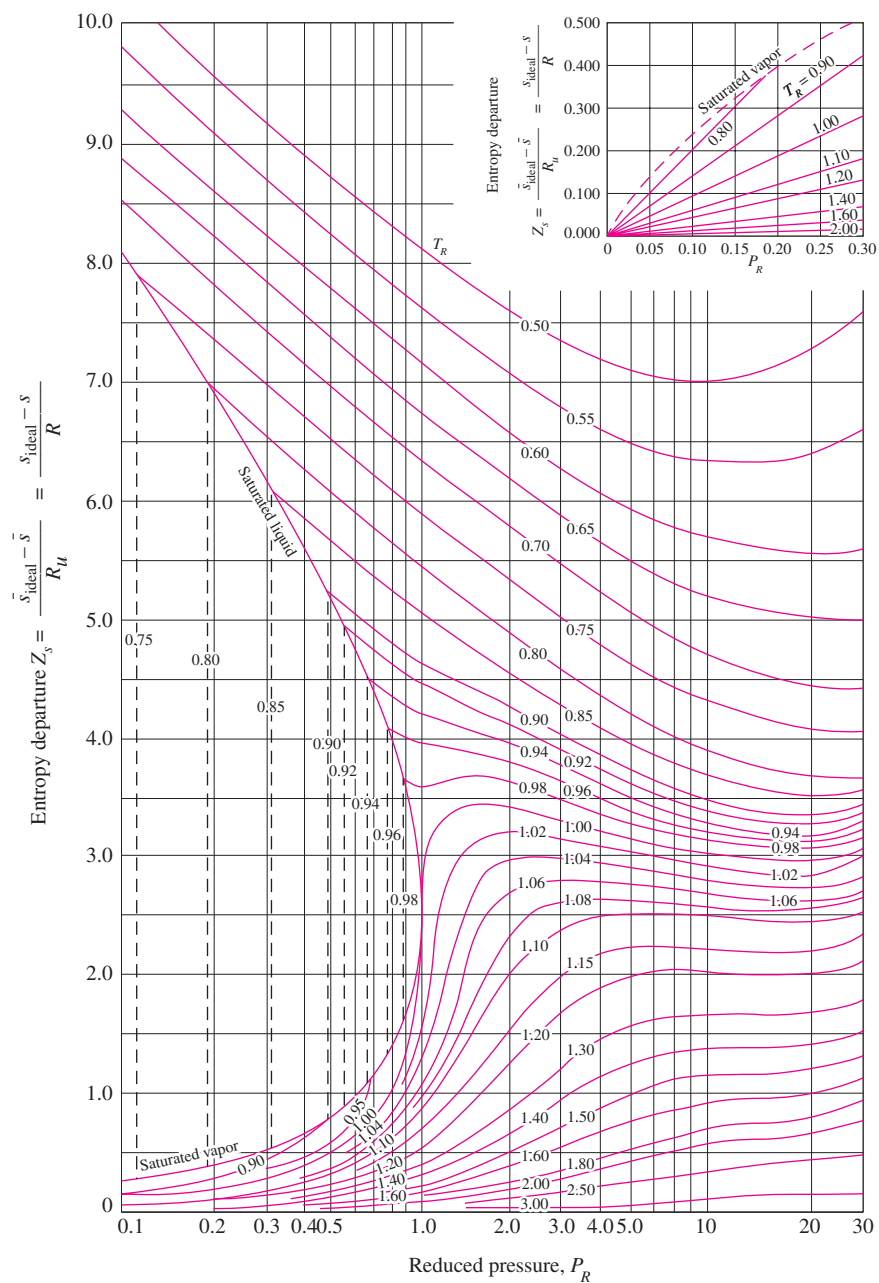


FIGURE A-30

Generalized entropy departure chart.

Source: John R. Howell and Richard O. Buckius, Fundamentals of Engineering Thermodynamics, SI Version (New York: McGraw-Hill, 1987), p. 559, fig. C.3, and p. 561, fig. C.5.



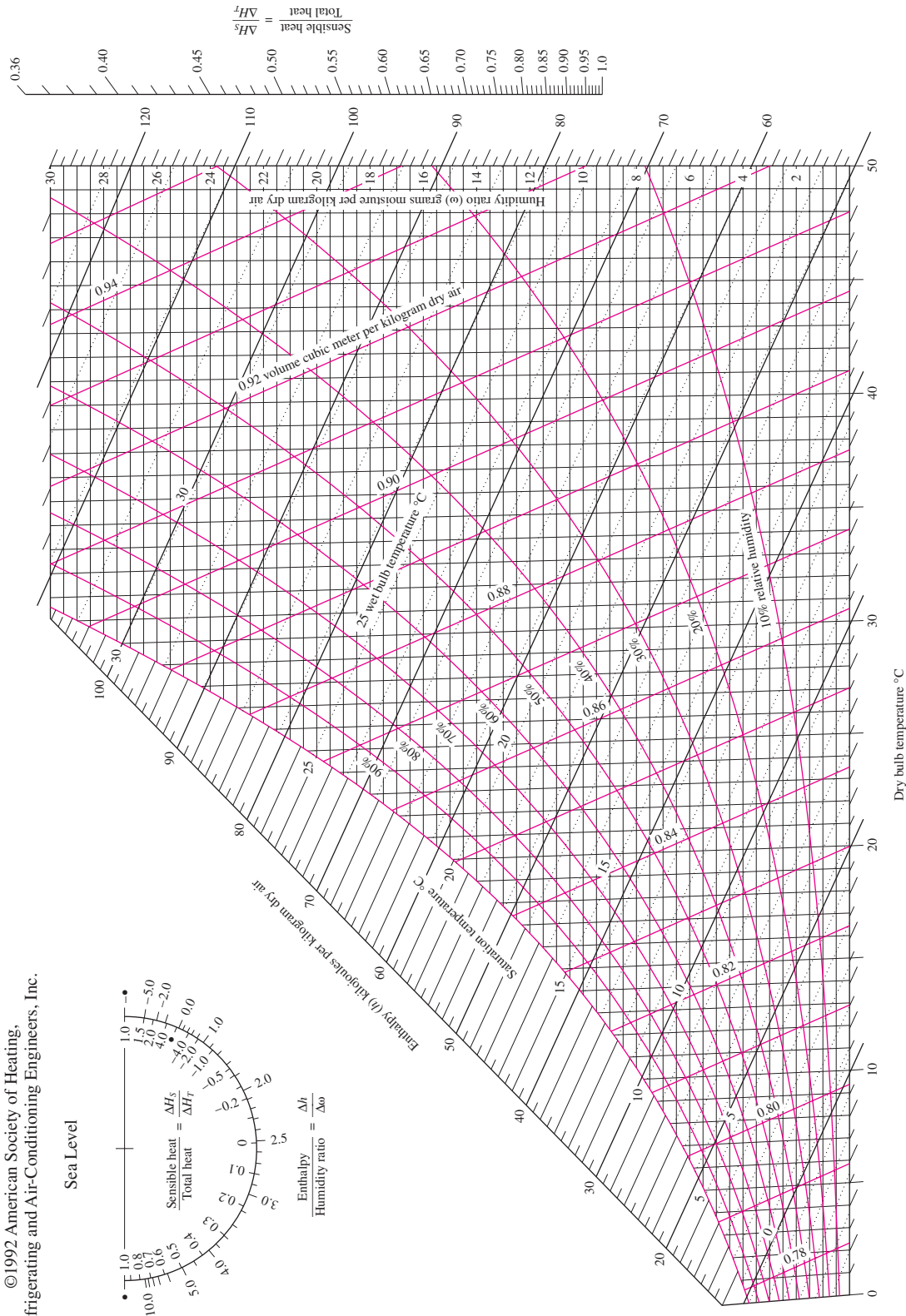
# ASHRAE Psychrometric Chart No. 1

Normal Temperature

Barometric Pressure: 101.325 kPa

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Refrigerating and Air-Conditioning Engineers, Inc.

Sea Level



Prepared by Center for Applied Thermodynamic Studies, University of Idaho.

**FIGURE A-31**

Psychrometric chart at 1 atm total pressure.

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$$\text{Ma}^* = \text{Ma} \sqrt{\frac{k+1}{2+(k-1)\text{Ma}^2}}$$

$$\frac{A}{A^*} = \frac{1}{\text{Ma}} \left[ \left( \frac{2}{k+1} \right) \left( 1 + \frac{k-1}{2} \text{Ma}^2 \right) \right]^{0.5(k+1)/(k-1)}$$

$$\frac{P}{P_0} = \left( 1 + \frac{k-1}{2} \text{Ma}^2 \right)^{-k/(k-1)}$$

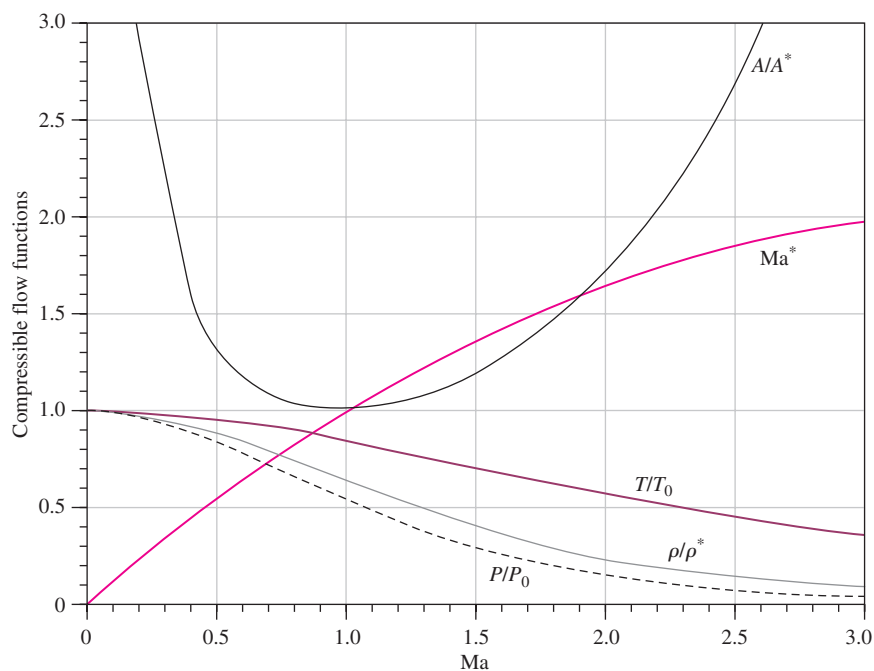
$$\frac{\rho}{\rho_0} = \left( 1 + \frac{k-1}{2} \text{Ma}^2 \right)^{-1/(k-1)}$$

$$\frac{T}{T_0} = \left( 1 + \frac{k-1}{2} \text{Ma}^2 \right)^{-1}$$

TABLE A-32

One-dimensional isentropic compressible flow functions for an ideal gas with  $k = 1.4$

| Ma  | Ma*    | A/A*   | P/P <sub>0</sub> | ρ/ρ <sub>0</sub> | T/T <sub>0</sub> |
|-----|--------|--------|------------------|------------------|------------------|
| 0   | 0      | ∞      | 1.0000           | 1.0000           | 1.0000           |
| 0.1 | 0.1094 | 5.8218 | 0.9930           | 0.9950           | 0.9980           |
| 0.2 | 0.2182 | 2.9635 | 0.9725           | 0.9803           | 0.9921           |
| 0.3 | 0.3257 | 2.0351 | 0.9395           | 0.9564           | 0.9823           |
| 0.4 | 0.4313 | 1.5901 | 0.8956           | 0.9243           | 0.9690           |
| 0.5 | 0.5345 | 1.3398 | 0.8430           | 0.8852           | 0.9524           |
| 0.6 | 0.6348 | 1.1882 | 0.7840           | 0.8405           | 0.9328           |
| 0.7 | 0.7318 | 1.0944 | 0.7209           | 0.7916           | 0.9107           |
| 0.8 | 0.8251 | 1.0382 | 0.6560           | 0.7400           | 0.8865           |
| 0.9 | 0.9146 | 1.0089 | 0.5913           | 0.6870           | 0.8606           |
| 1.0 | 1.0000 | 1.0000 | 0.5283           | 0.6339           | 0.8333           |
| 1.2 | 1.1583 | 1.0304 | 0.4124           | 0.5311           | 0.7764           |
| 1.4 | 1.2999 | 1.1149 | 0.3142           | 0.4374           | 0.7184           |
| 1.6 | 1.4254 | 1.2502 | 0.2353           | 0.3557           | 0.6614           |
| 1.8 | 1.5360 | 1.4390 | 0.1740           | 0.2868           | 0.6068           |
| 2.0 | 1.6330 | 1.6875 | 0.1278           | 0.2300           | 0.5556           |
| 2.2 | 1.7179 | 2.0050 | 0.0935           | 0.1841           | 0.5081           |
| 2.4 | 1.7922 | 2.4031 | 0.0684           | 0.1472           | 0.4647           |
| 2.6 | 1.8571 | 2.8960 | 0.0501           | 0.1179           | 0.4252           |
| 2.8 | 1.9140 | 3.5001 | 0.0368           | 0.0946           | 0.3894           |
| 3.0 | 1.9640 | 4.2346 | 0.0272           | 0.0760           | 0.3571           |
| 5.0 | 2.2361 | 25.000 | 0.0019           | 0.0113           | 0.1667           |
| ∞   | 2.2495 | ∞      | 0                | 0                | 0                |



$$T_{01} = T_{02}$$

$$Ma_2 = \sqrt{\frac{(k-1)Ma_1^2 + 2}{2kMa_1^2 - k + 1}}$$

$$\frac{P_2}{P_1} = \frac{1 + kMa_1^2}{1 + kMa_2^2} = \frac{2kMa_1^2 - k + 1}{k + 1}$$

$$\frac{\rho_2}{\rho_1} = \frac{P_2/P_1}{T_2/T_1} = \frac{(k+1)Ma_1^2}{2 + (k-1)Ma_1^2} = \frac{V_1}{V_2}$$

$$\frac{T_2}{T_1} = \frac{2 + Ma_1^2(k-1)}{2 + Ma_2^2(k-1)}$$

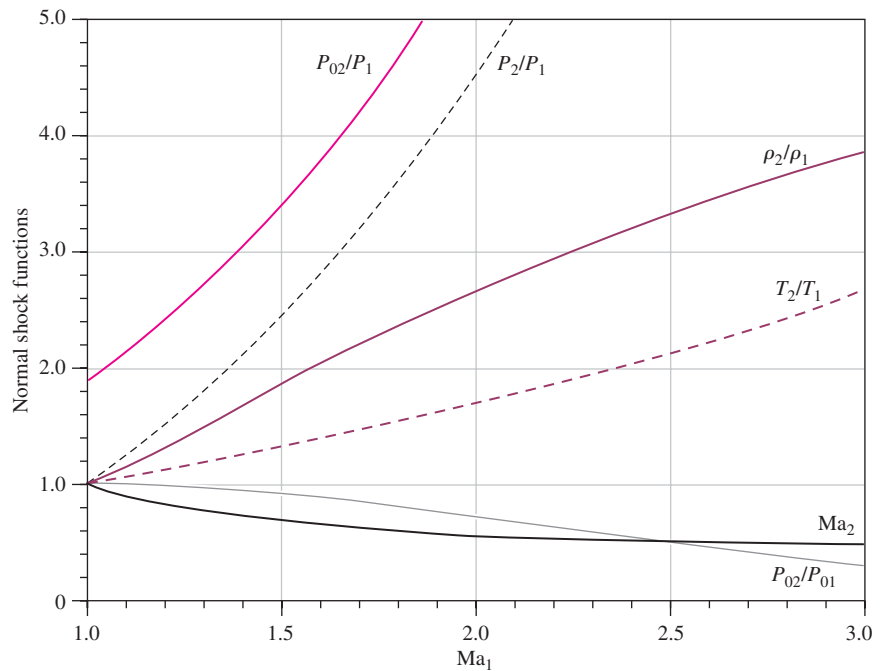
$$\frac{P_{02}}{P_{01}} = \frac{Ma_1 \left[ 1 + Ma_2^2(k-1)/2 \right]^{(k+1)/[2(k-1)]}}{Ma_2 \left[ 1 + Ma_1^2(k-1)/2 \right]}$$

$$\frac{P_{02}}{P_1} = \frac{(1 + kMa_1^2) \left[ 1 + Ma_2^2(k-1)/2 \right]^{k/(k-1)}}{1 + kMa_2^2}$$

TABLE A-33

One-dimensional normal shock functions for an ideal gas with  $k = 1.4$ 

| $Ma_1$   | $Ma_2$ | $P_2/P_1$ | $\rho_2/\rho_1$ | $T_2/T_1$ | $P_{02}/P_{01}$ | $P_{02}/P_1$ |
|----------|--------|-----------|-----------------|-----------|-----------------|--------------|
| 1.0      | 1.0000 | 1.0000    | 1.0000          | 1.0000    | 1.0000          | 1.8929       |
| 1.1      | 0.9118 | 1.2450    | 1.1691          | 1.0649    | 0.9989          | 2.1328       |
| 1.2      | 0.8422 | 1.5133    | 1.3416          | 1.1280    | 0.9928          | 2.4075       |
| 1.3      | 0.7860 | 1.8050    | 1.5157          | 1.1909    | 0.9794          | 2.7136       |
| 1.4      | 0.7397 | 2.1200    | 1.6897          | 1.2547    | 0.9582          | 3.0492       |
| 1.5      | 0.7011 | 2.4583    | 1.8621          | 1.3202    | 0.9298          | 3.4133       |
| 1.6      | 0.6684 | 2.8200    | 2.0317          | 1.3880    | 0.8952          | 3.8050       |
| 1.7      | 0.6405 | 3.2050    | 2.1977          | 1.4583    | 0.8557          | 4.2238       |
| 1.8      | 0.6165 | 3.6133    | 2.3592          | 1.5316    | 0.8127          | 4.6695       |
| 1.9      | 0.5956 | 4.0450    | 2.5157          | 1.6079    | 0.7674          | 5.1418       |
| 2.0      | 0.5774 | 4.5000    | 2.6667          | 1.6875    | 0.7209          | 5.6404       |
| 2.1      | 0.5613 | 4.9783    | 2.8119          | 1.7705    | 0.6742          | 6.1654       |
| 2.2      | 0.5471 | 5.4800    | 2.9512          | 1.8569    | 0.6281          | 6.7165       |
| 2.3      | 0.5344 | 6.0050    | 3.0845          | 1.9468    | 0.5833          | 7.2937       |
| 2.4      | 0.5231 | 6.5533    | 3.2119          | 2.0403    | 0.5401          | 7.8969       |
| 2.5      | 0.5130 | 7.1250    | 3.3333          | 2.1375    | 0.4990          | 8.5261       |
| 2.6      | 0.5039 | 7.7200    | 3.4490          | 2.2383    | 0.4601          | 9.1813       |
| 2.7      | 0.4956 | 8.3383    | 3.5590          | 2.3429    | 0.4236          | 9.8624       |
| 2.8      | 0.4882 | 8.9800    | 3.6636          | 2.4512    | 0.3895          | 10.5694      |
| 2.9      | 0.4814 | 9.6450    | 3.7629          | 2.5632    | 0.3577          | 11.3022      |
| 3.0      | 0.4752 | 10.3333   | 3.8571          | 2.6790    | 0.3283          | 12.0610      |
| 4.0      | 0.4350 | 18.5000   | 4.5714          | 4.0469    | 0.1388          | 21.0681      |
| 5.0      | 0.4152 | 29.0000   | 5.0000          | 5.8000    | 0.0617          | 32.6335      |
| $\infty$ | 0.3780 | $\infty$  | 6.0000          | $\infty$  | 0               | $\infty$     |



$$\frac{T_0}{T_0^*} = \frac{(k+1)Ma^2[2 + (k-1)Ma^2]}{(1+kMa^2)^2}$$

$$\frac{P_0}{P_0^*} = \frac{k+1}{1+kMa^2} \left( \frac{2 + (k-1)Ma^2}{k+1} \right)^{k/(k-1)}$$

$$\frac{T}{T^*} = \left( \frac{Ma(1+k)}{1+kMa^2} \right)^2$$

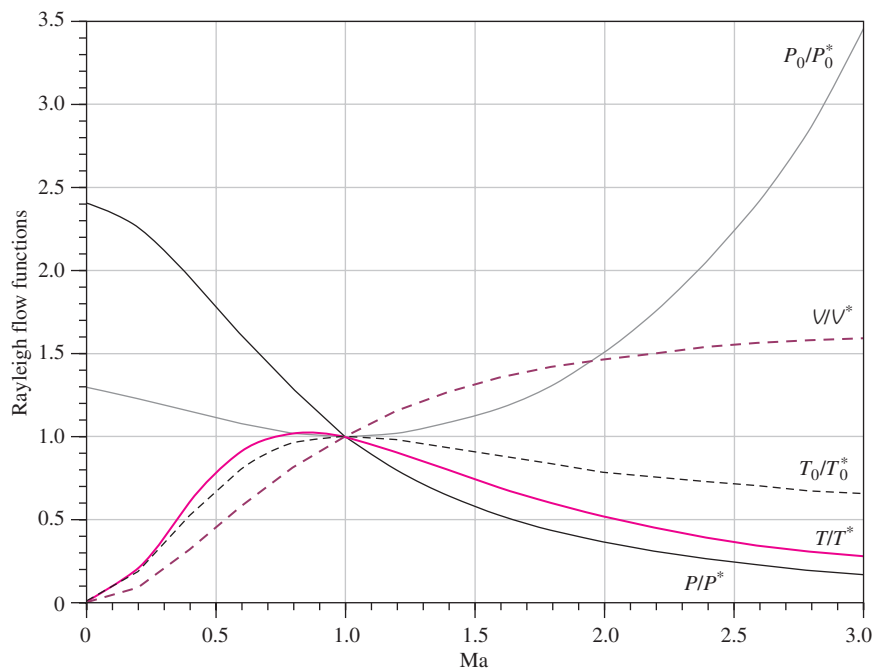
$$\frac{P}{P^*} = \frac{1+k}{1+kMa^2}$$

$$\frac{V}{V^*} = \frac{\rho^*}{\rho} = \frac{(1+k)Ma^2}{1+kMa^2}$$

TABLE A-34

Rayleigh flow functions for an ideal gas with  $k = 1.4$ 

| Ma  | $T_0/T_0^*$ | $P_0/P_0^*$ | $T/T^*$ | $P/P^*$ | $V/V^*$ |
|-----|-------------|-------------|---------|---------|---------|
| 0.0 | 0.0000      | 1.2679      | 0.0000  | 2.4000  | 0.0000  |
| 0.1 | 0.0468      | 1.2591      | 0.0560  | 2.3669  | 0.0237  |
| 0.2 | 0.1736      | 1.2346      | 0.2066  | 2.2727  | 0.0909  |
| 0.3 | 0.3469      | 1.1985      | 0.4089  | 2.1314  | 0.1918  |
| 0.4 | 0.5290      | 1.1566      | 0.6151  | 1.9608  | 0.3137  |
| 0.5 | 0.6914      | 1.1141      | 0.7901  | 1.7778  | 0.4444  |
| 0.6 | 0.8189      | 1.0753      | 0.9167  | 1.5957  | 0.5745  |
| 0.7 | 0.9085      | 1.0431      | 0.9929  | 1.4235  | 0.6975  |
| 0.8 | 0.9639      | 1.0193      | 1.0255  | 1.2658  | 0.8101  |
| 0.9 | 0.9921      | 1.0049      | 1.0245  | 1.1246  | 0.9110  |
| 1.0 | 1.0000      | 1.0000      | 1.0000  | 1.0000  | 1.0000  |
| 1.2 | 0.9787      | 1.0194      | 0.9118  | 0.7958  | 1.1459  |
| 1.4 | 0.9343      | 1.0777      | 0.8054  | 0.6410  | 1.2564  |
| 1.6 | 0.8842      | 1.1756      | 0.7017  | 0.5236  | 1.3403  |
| 1.8 | 0.8363      | 1.3159      | 0.6089  | 0.4335  | 1.4046  |
| 2.0 | 0.7934      | 1.5031      | 0.5289  | 0.3636  | 1.4545  |
| 2.2 | 0.7561      | 1.7434      | 0.4611  | 0.3086  | 1.4938  |
| 2.4 | 0.7242      | 2.0451      | 0.4038  | 0.2648  | 1.5252  |
| 2.6 | 0.6970      | 2.4177      | 0.3556  | 0.2294  | 1.5505  |
| 2.8 | 0.6738      | 2.8731      | 0.3149  | 0.2004  | 1.5711  |
| 3.0 | 0.6540      | 3.4245      | 0.2803  | 0.1765  | 1.5882  |



# Appendix 2

## PROPERTY TABLES AND CHARTS (ENGLISH UNITS)

|                     |                                                         |                     |                                                                                                  |
|---------------------|---------------------------------------------------------|---------------------|--------------------------------------------------------------------------------------------------|
| <b>Table A-1E</b>   | Molar mass, gas constant, and critical-point properties | <b>Table A-16E</b>  | Properties of the atmosphere at high altitude                                                    |
| <b>Table A-2E</b>   | Ideal-gas specific heats of various common gases        | <b>Table A-17E</b>  | Ideal-gas properties of air                                                                      |
| <b>Table A-3E</b>   | Properties of common liquids, solids, and foods         | <b>Table A-18E</b>  | Ideal-gas properties of nitrogen, $N_2$                                                          |
| <b>Table A-4E</b>   | Saturated water—Temperature table                       | <b>Table A-19E</b>  | Ideal-gas properties of oxygen, $O_2$                                                            |
| <b>Table A-5E</b>   | Saturated water—Pressure table                          | <b>Table A-20E</b>  | Ideal-gas properties of carbon dioxide, $CO_2$                                                   |
| <b>Table A-6E</b>   | Superheated water                                       | <b>Table A-21E</b>  | Ideal-gas properties of carbon monoxide, $CO$                                                    |
| <b>Table A-7E</b>   | Compressed liquid water                                 | <b>Table A-22E</b>  | Ideal-gas properties of hydrogen, $H_2$                                                          |
| <b>Table A-8E</b>   | Saturated ice–water vapor                               | <b>Table A-23E</b>  | Ideal-gas properties of water vapor, $H_2O$                                                      |
| <b>Figure A-9E</b>  | $T$ - $s$ diagram for water                             | <b>Table A-26E</b>  | Enthalpy of formation, Gibbs function of formation, and absolute entropy at $77^\circ C$ , 1 atm |
| <b>Figure A-10E</b> | Mollier diagram for water                               | <b>Table A-27E</b>  | Properties of some common fuels and hydrocarbons                                                 |
| <b>Table A-11E</b>  | Saturated refrigerant-134a—Temperature table            | <b>Figure A-31E</b> | Psychrometric chart at 1 atm total pressure                                                      |
| <b>Table A-12E</b>  | Saturated refrigerant-134a—Pressure table               |                     |                                                                                                  |
| <b>Table A-13E</b>  | Superheated refrigerant-134a                            |                     |                                                                                                  |
| <b>Figure A-14E</b> | $P$ - $h$ diagram for refrigerant-134a                  |                     |                                                                                                  |



TABLE A-1E

Molar mass, gas constant, and critical-point properties

| Substance                      | Formula                           | Molar mass, $M$<br>lbm/lbmol | Gas constant, $R$ |                                      | Critical-point properties |                   |                                   |
|--------------------------------|-----------------------------------|------------------------------|-------------------|--------------------------------------|---------------------------|-------------------|-----------------------------------|
|                                |                                   |                              | Btu/<br>lbm · R*  | psia · ft <sup>3</sup> /<br>lbm · R* | Temperature,<br>R         | Pressure,<br>psia | Volume,<br>ft <sup>3</sup> /lbmol |
| Air                            | —                                 | 28.97                        | 0.06855           | 0.3704                               | 238.5                     | 547               | 1.41                              |
| Ammonia                        | NH <sub>3</sub>                   | 17.03                        | 0.1166            | 0.6301                               | 729.8                     | 1636              | 1.16                              |
| Argon                          | Ar                                | 39.948                       | 0.04971           | 0.2686                               | 272                       | 705               | 1.20                              |
| Benzene                        | C <sub>6</sub> H <sub>6</sub>     | 78.115                       | 0.02542           | 0.1374                               | 1012                      | 714               | 4.17                              |
| Bromine                        | Br <sub>2</sub>                   | 159.808                      | 0.01243           | 0.06714                              | 1052                      | 1500              | 2.17                              |
| <i>n</i> -Butane               | C <sub>4</sub> H <sub>10</sub>    | 58.124                       | 0.03417           | 0.1846                               | 765.2                     | 551               | 4.08                              |
| Carbon dioxide                 | CO <sub>2</sub>                   | 44.01                        | 0.04513           | 0.2438                               | 547.5                     | 1071              | 1.51                              |
| Carbon monoxide                | CO                                | 28.011                       | 0.07090           | 0.3831                               | 240                       | 507               | 1.49                              |
| Carbon tetrachloride           | CCl <sub>4</sub>                  | 153.82                       | 0.01291           | 0.06976                              | 1001.5                    | 661               | 4.42                              |
| Chlorine                       | Cl <sub>2</sub>                   | 70.906                       | 0.02801           | 0.1517                               | 751                       | 1120              | 1.99                              |
| Chloroform                     | CHCl <sub>3</sub>                 | 119.38                       | 0.01664           | 0.08988                              | 965.8                     | 794               | 3.85                              |
| Dichlorodifluoromethane (R-12) | CCl <sub>2</sub> F <sub>2</sub>   | 120.91                       | 0.01643           | 0.08874                              | 692.4                     | 582               | 3.49                              |
| Dichlorofluoromethane (R-21)   | CHCl <sub>2</sub> F               | 102.92                       | 0.01930           | 0.1043                               | 813.0                     | 749               | 3.16                              |
| Ethane                         | C <sub>2</sub> H <sub>6</sub>     | 30.020                       | 0.06616           | 0.3574                               | 549.8                     | 708               | 2.37                              |
| Ethyl alcohol                  | C <sub>2</sub> H <sub>5</sub> OH  | 46.07                        | 0.04311           | 0.2329                               | 929.0                     | 926               | 2.68                              |
| Ethylene                       | C <sub>2</sub> H <sub>4</sub>     | 28.054                       | 0.07079           | 0.3825                               | 508.3                     | 742               | 1.99                              |
| Helium                         | He                                | 4.003                        | 0.4961            | 2.6809                               | 9.5                       | 33.2              | 0.926                             |
| <i>n</i> -Hexane               | C <sub>6</sub> H <sub>14</sub>    | 86.178                       | 0.02305           | 0.1245                               | 914.2                     | 439               | 5.89                              |
| Hydrogen (normal)              | H <sub>2</sub>                    | 2.016                        | 0.9851            | 5.3224                               | 59.9                      | 188.1             | 1.04                              |
| Krypton                        | Kr                                | 83.80                        | 0.02370           | 0.1280                               | 376.9                     | 798               | 1.48                              |
| Methane                        | CH <sub>4</sub>                   | 16.043                       | 0.1238            | 0.6688                               | 343.9                     | 673               | 1.59                              |
| Methyl alcohol                 | CH <sub>3</sub> OH                | 32.042                       | 0.06198           | 0.3349                               | 923.7                     | 1154              | 1.89                              |
| Methyl chloride                | CH <sub>3</sub> Cl                | 50.488                       | 0.03934           | 0.2125                               | 749.3                     | 968               | 2.29                              |
| Neon                           | Ne                                | 20.183                       | 0.09840           | 0.5316                               | 80.1                      | 395               | 0.668                             |
| Nitrogen                       | N <sub>2</sub>                    | 28.013                       | 0.07090           | 0.3830                               | 227.1                     | 492               | 1.44                              |
| Nitrous oxide                  | N <sub>2</sub> O                  | 44.013                       | 0.04512           | 0.2438                               | 557.4                     | 1054              | 1.54                              |
| Oxygen                         | O <sub>2</sub>                    | 31.999                       | 0.06206           | 0.3353                               | 278.6                     | 736               | 1.25                              |
| Propane                        | C <sub>3</sub> H <sub>8</sub>     | 44.097                       | 0.04504           | 0.2433                               | 665.9                     | 617               | 3.20                              |
| Propylene                      | C <sub>3</sub> H <sub>6</sub>     | 42.081                       | 0.04719           | 0.2550                               | 656.9                     | 670               | 2.90                              |
| Sulfur dioxide                 | SO <sub>2</sub>                   | 64.063                       | 0.03100           | 1.1675                               | 775.2                     | 1143              | 1.95                              |
| Tetrafluoroethane (R-134a)     | CF <sub>3</sub> CH <sub>2</sub> F | 102.03                       | 0.01946           | 0.1052                               | 673.6                     | 588.7             | 3.19                              |
| Trichlorofluoromethane (R-11)  | CCl <sub>3</sub> F                | 137.37                       | 0.01446           | 0.07811                              | 848.1                     | 635               | 3.97                              |
| Water                          | H <sub>2</sub> O                  | 18.015                       | 0.1102            | 0.5956                               | 1164.8                    | 3200              | 0.90                              |
| Xenon                          | Xe                                | 131.30                       | 0.01513           | 0.08172                              | 521.55                    | 852               | 1.90                              |

\*Calculated from  $R = R_u/M$ , where  $R_u = 1.98588$  Btu/lbmol · R = 10.7316 psia · ft<sup>3</sup>/lbmol · R and  $M$  is the molar mass.Source: K. A. Kobe and R. E. Lynn, Jr., *Chemical Review* 52 (1953), pp. 117–236, and ASHRAE, *Handbook of Fundamentals* (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1993), pp. 16.4 and 36.1.

TABLE A-2E

Ideal-gas specific heats of various common gases  
(a) At 80°F

| Gas             | Formula                        | Gas constant, $R$<br>Btu/lbm · R | $c_p$<br>Btu/lbm · R | $c_v$<br>Btu/lbm · R | $k$   |
|-----------------|--------------------------------|----------------------------------|----------------------|----------------------|-------|
| Air             | —                              | 0.06855                          | 0.240                | 0.171                | 1.400 |
| Argon           | Ar                             | 0.04971                          | 0.1253               | 0.0756               | 1.667 |
| Butane          | C <sub>4</sub> H <sub>10</sub> | 0.03424                          | 0.415                | 0.381                | 1.09  |
| Carbon dioxide  | CO <sub>2</sub>                | 0.04513                          | 0.203                | 0.158                | 1.285 |
| Carbon monoxide | CO                             | 0.07090                          | 0.249                | 0.178                | 1.399 |
| Ethane          | C <sub>2</sub> H <sub>6</sub>  | 0.06616                          | 0.427                | 0.361                | 1.183 |
| Ethylene        | C <sub>2</sub> H <sub>4</sub>  | 0.07079                          | 0.411                | 0.340                | 1.208 |
| Helium          | He                             | 0.4961                           | 1.25                 | 0.753                | 1.667 |
| Hydrogen        | H <sub>2</sub>                 | 0.9851                           | 3.43                 | 2.44                 | 1.404 |
| Methane         | CH <sub>4</sub>                | 0.1238                           | 0.532                | 0.403                | 1.32  |
| Neon            | Ne                             | 0.09840                          | 0.246                | 0.1477               | 1.667 |
| Nitrogen        | N <sub>2</sub>                 | 0.07090                          | 0.248                | 0.177                | 1.400 |
| Octane          | C <sub>8</sub> H <sub>18</sub> | 0.01742                          | 0.409                | 0.392                | 1.044 |
| Oxygen          | O <sub>2</sub>                 | 0.06206                          | 0.219                | 0.157                | 1.395 |
| Propane         | C <sub>3</sub> H <sub>8</sub>  | 0.04504                          | 0.407                | 0.362                | 1.124 |
| Steam           | H <sub>2</sub> O               | 0.1102                           | 0.445                | 0.335                | 1.329 |

Source: Gordon J. Van Wylen and Richard E. Sonntag, *Fundamentals of Classical Thermodynamics*, English/SI Version, 3rd ed. (New York: John Wiley & Sons, 1986), p. 687, Table A-8E.

TABLE A-2E

Ideal-gas specific heats of various common gases (*Continued*)

(b) At various temperatures

| Temp.,<br>°F                   | $c_p$<br>Btu/lbm · R | $c_v$<br>Btu/lbm · R | $k$   | $c_p$<br>Btu/lbm · R                  | $c_v$<br>Btu/lbm · R | $k$   | $c_p$<br>Btu/lbm · R         | $c_v$<br>Btu/lbm · R | $k$   |
|--------------------------------|----------------------|----------------------|-------|---------------------------------------|----------------------|-------|------------------------------|----------------------|-------|
| <i>Air</i>                     |                      |                      |       | <i>Carbon dioxide, CO<sub>2</sub></i> |                      |       | <i>Carbon monoxide, CO</i>   |                      |       |
| 40                             | 0.240                | 0.171                | 1.401 | 0.195                                 | 0.150                | 1.300 | 0.248                        | 0.177                | 1.400 |
| 100                            | 0.240                | 0.172                | 1.400 | 0.205                                 | 0.160                | 1.283 | 0.249                        | 0.178                | 1.399 |
| 200                            | 0.241                | 0.173                | 1.397 | 0.217                                 | 0.172                | 1.262 | 0.249                        | 0.179                | 1.397 |
| 300                            | 0.243                | 0.174                | 1.394 | 0.229                                 | 0.184                | 1.246 | 0.251                        | 0.180                | 1.394 |
| 400                            | 0.245                | 0.176                | 1.389 | 0.239                                 | 0.193                | 1.233 | 0.253                        | 0.182                | 1.389 |
| 500                            | 0.248                | 0.179                | 1.383 | 0.247                                 | 0.202                | 1.223 | 0.256                        | 0.185                | 1.384 |
| 600                            | 0.250                | 0.182                | 1.377 | 0.255                                 | 0.210                | 1.215 | 0.259                        | 0.188                | 1.377 |
| 700                            | 0.254                | 0.185                | 1.371 | 0.262                                 | 0.217                | 1.208 | 0.262                        | 0.191                | 1.371 |
| 800                            | 0.257                | 0.188                | 1.365 | 0.269                                 | 0.224                | 1.202 | 0.266                        | 0.195                | 1.364 |
| 900                            | 0.259                | 0.191                | 1.358 | 0.275                                 | 0.230                | 1.197 | 0.269                        | 0.198                | 1.357 |
| 1000                           | 0.263                | 0.195                | 1.353 | 0.280                                 | 0.235                | 1.192 | 0.273                        | 0.202                | 1.351 |
| 1500                           | 0.276                | 0.208                | 1.330 | 0.298                                 | 0.253                | 1.178 | 0.287                        | 0.216                | 1.328 |
| 2000                           | 0.286                | 0.217                | 1.312 | 0.312                                 | 0.267                | 1.169 | 0.297                        | 0.226                | 1.314 |
| <i>Hydrogen, H<sub>2</sub></i> |                      |                      |       | <i>Nitrogen, N<sub>2</sub></i>        |                      |       | <i>Oxygen, O<sub>2</sub></i> |                      |       |
| 40                             | 3.397                | 2.412                | 1.409 | 0.248                                 | 0.177                | 1.400 | 0.219                        | 0.156                | 1.397 |
| 100                            | 3.426                | 2.441                | 1.404 | 0.248                                 | 0.178                | 1.399 | 0.220                        | 0.158                | 1.394 |
| 200                            | 3.451                | 2.466                | 1.399 | 0.249                                 | 0.178                | 1.398 | 0.223                        | 0.161                | 1.387 |
| 300                            | 3.461                | 2.476                | 1.398 | 0.250                                 | 0.179                | 1.396 | 0.226                        | 0.164                | 1.378 |
| 400                            | 3.466                | 2.480                | 1.397 | 0.251                                 | 0.180                | 1.393 | 0.230                        | 0.168                | 1.368 |
| 500                            | 3.469                | 2.484                | 1.397 | 0.254                                 | 0.183                | 1.388 | 0.235                        | 0.173                | 1.360 |
| 600                            | 3.473                | 2.488                | 1.396 | 0.256                                 | 0.185                | 1.383 | 0.239                        | 0.177                | 1.352 |
| 700                            | 3.477                | 2.492                | 1.395 | 0.260                                 | 0.189                | 1.377 | 0.242                        | 0.181                | 1.344 |
| 800                            | 3.494                | 2.509                | 1.393 | 0.262                                 | 0.191                | 1.371 | 0.246                        | 0.184                | 1.337 |
| 900                            | 3.502                | 2.519                | 1.392 | 0.265                                 | 0.194                | 1.364 | 0.249                        | 0.187                | 1.331 |
| 1000                           | 3.513                | 2.528                | 1.390 | 0.269                                 | 0.198                | 1.359 | 0.252                        | 0.190                | 1.326 |
| 1500                           | 3.618                | 2.633                | 1.374 | 0.283                                 | 0.212                | 1.334 | 0.263                        | 0.201                | 1.309 |
| 2000                           | 3.758                | 2.773                | 1.355 | 0.293                                 | 0.222                | 1.319 | 0.270                        | 0.208                | 1.298 |

Note: The unit Btu/lbm · R is equivalent to Btu/lbm · °F.

Source: Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), p. 830, Table A-4. Originally published in *Tables of Properties of Gases*, NBS Circular 564, 1955.

TABLE A-2E

Ideal-gas specific heats of various common gases (*Concluded*)

(c) As a function of temperature

$$\bar{c}_p = a + bT + cT^2 + dT^3$$

( $T$  in R,  $c_p$  in Btu/lbmol · R)

| Substance         | Formula                         | $a$    | $b$                       | $c$                       | $d$                       | Temperature range, R | % error |      |
|-------------------|---------------------------------|--------|---------------------------|---------------------------|---------------------------|----------------------|---------|------|
|                   |                                 |        |                           |                           |                           |                      | Max.    | Avg. |
| Nitrogen          | N <sub>2</sub>                  | 6.903  | $-0.02085 \times 10^{-2}$ | $0.05957 \times 10^{-5}$  | $-0.1176 \times 10^{-9}$  | 491-3240             | 0.59    | 0.34 |
| Oxygen            | O <sub>2</sub>                  | 6.085  | $0.2017 \times 10^{-2}$   | $-0.05275 \times 10^{-5}$ | $0.05372 \times 10^{-9}$  | 491-3240             | 1.19    | 0.28 |
| Air               | —                               | 6.713  | $0.02609 \times 10^{-2}$  | $0.03540 \times 10^{-5}$  | $-0.08052 \times 10^{-9}$ | 491-3240             | 0.72    | 0.33 |
| Hydrogen          | H <sub>2</sub>                  | 6.952  | $-0.02542 \times 10^{-2}$ | $0.02952 \times 10^{-5}$  | $-0.03565 \times 10^{-9}$ | 491-3240             | 1.02    | 0.26 |
| Carbon monoxide   | CO                              | 6.726  | $0.02222 \times 10^{-2}$  | $0.03960 \times 10^{-5}$  | $-0.09100 \times 10^{-9}$ | 491-3240             | 0.89    | 0.37 |
| Carbon dioxide    | CO <sub>2</sub>                 | 5.316  | $0.79361 \times 10^{-2}$  | $-0.2581 \times 10^{-5}$  | $0.3059 \times 10^{-9}$   | 491-3240             | 0.67    | 0.22 |
| Water vapor       | H <sub>2</sub> O                | 7.700  | $0.02552 \times 10^{-2}$  | $0.07781 \times 10^{-5}$  | $-0.1472 \times 10^{-9}$  | 491-3240             | 0.53    | 0.24 |
| Nitric oxide      | NO                              | 7.008  | $-0.01247 \times 10^{-2}$ | $0.07185 \times 10^{-5}$  | $-0.1715 \times 10^{-9}$  | 491-2700             | 0.97    | 0.36 |
| Nitrous oxide     | N <sub>2</sub> O                | 5.758  | $0.7780 \times 10^{-2}$   | $-0.2596 \times 10^{-5}$  | $0.4331 \times 10^{-9}$   | 491-2700             | 0.59    | 0.26 |
| Nitrogen dioxide  | NO <sub>2</sub>                 | 5.48   | $0.7583 \times 10^{-2}$   | $-0.260 \times 10^{-5}$   | $0.322 \times 10^{-9}$    | 491-2700             | 0.46    | 0.18 |
| Ammonia           | NH <sub>3</sub>                 | 6.5846 | $0.34028 \times 10^{-2}$  | $0.073034 \times 10^{-5}$ | $-0.27402 \times 10^{-9}$ | 491-2700             | 0.91    | 0.36 |
| Sulfur            | S <sub>2</sub>                  | 6.499  | $0.2943 \times 10^{-2}$   | $-0.1200 \times 10^{-5}$  | $0.1632 \times 10^{-9}$   | 491-3240             | 0.99    | 0.38 |
| Sulfur dioxide    | SO <sub>2</sub>                 | 6.157  | $0.7689 \times 10^{-2}$   | $-0.2810 \times 10^{-5}$  | $0.3527 \times 10^{-9}$   | 491-3240             | 0.45    | 0.24 |
| Sulfur trioxide   | SO <sub>3</sub>                 | 3.918  | $1.935 \times 10^{-2}$    | $-0.8256 \times 10^{-5}$  | $1.328 \times 10^{-9}$    | 491-2340             | 0.29    | 0.13 |
| Acetylene         | C <sub>2</sub> H <sub>2</sub>   | 5.21   | $1.2227 \times 10^{-2}$   | $-0.4812 \times 10^{-5}$  | $0.7457 \times 10^{-9}$   | 491-2700             | 1.46    | 0.59 |
| Benzene           | C <sub>6</sub> H <sub>6</sub>   | -8.650 | $6.4322 \times 10^{-2}$   | $-2.327 \times 10^{-5}$   | $3.179 \times 10^{-9}$    | 491-2700             | 0.34    | 0.20 |
| Methanol          | CH <sub>4</sub> O               | 4.55   | $1.214 \times 10^{-2}$    | $-0.0898 \times 10^{-5}$  | $-0.329 \times 10^{-9}$   | 491-1800             | 0.18    | 0.08 |
| Ethanol           | C <sub>2</sub> H <sub>6</sub> O | 4.75   | $2.781 \times 10^{-2}$    | $-0.7651 \times 10^{-5}$  | $0.821 \times 10^{-9}$    | 491-2700             | 0.40    | 0.22 |
| Hydrogen chloride | HCl                             | 7.244  | $-0.1011 \times 10^{-2}$  | $0.09783 \times 10^{-5}$  | $-0.1776 \times 10^{-9}$  | 491-2740             | 0.22    | 0.08 |
| Methane           | CH <sub>4</sub>                 | 4.750  | $0.6666 \times 10^{-2}$   | $0.09352 \times 10^{-5}$  | $-0.4510 \times 10^{-9}$  | 491-2740             | 1.33    | 0.57 |
| Ethane            | C <sub>2</sub> H <sub>6</sub>   | 1.648  | $2.291 \times 10^{-2}$    | $-0.4722 \times 10^{-5}$  | $0.2984 \times 10^{-9}$   | 491-2740             | 0.83    | 0.28 |
| Propane           | C <sub>3</sub> H <sub>8</sub>   | -0.966 | $4.044 \times 10^{-2}$    | $-1.159 \times 10^{-5}$   | $1.300 \times 10^{-9}$    | 491-2740             | 0.40    | 0.12 |
| <i>n</i> -Butane  | C <sub>4</sub> H <sub>10</sub>  | 0.945  | $4.929 \times 10^{-2}$    | $-1.352 \times 10^{-5}$   | $1.433 \times 10^{-9}$    | 491-2740             | 0.54    | 0.24 |
| <i>i</i> -Butane  | C <sub>4</sub> H <sub>10</sub>  | -1.890 | $5.520 \times 10^{-2}$    | $-1.696 \times 10^{-5}$   | $2.044 \times 10^{-9}$    | 491-2740             | 0.25    | 0.13 |
| <i>n</i> -Pentane | C <sub>5</sub> H <sub>12</sub>  | 1.618  | $6.028 \times 10^{-2}$    | $-1.656 \times 10^{-5}$   | $1.732 \times 10^{-9}$    | 491-2740             | 0.56    | 0.21 |
| <i>n</i> -Hexane  | C <sub>6</sub> H <sub>14</sub>  | 1.657  | $7.328 \times 10^{-2}$    | $-2.112 \times 10^{-5}$   | $2.363 \times 10^{-9}$    | 491-2740             | 0.72    | 0.20 |
| Ethylene          | C <sub>2</sub> H <sub>4</sub>   | 0.944  | $2.075 \times 10^{-2}$    | $-0.6151 \times 10^{-5}$  | $0.7326 \times 10^{-9}$   | 491-2740             | 0.54    | 0.13 |
| Propylene         | C <sub>3</sub> H <sub>6</sub>   | 0.753  | $3.162 \times 10^{-2}$    | $-0.8981 \times 10^{-5}$  | $1.008 \times 10^{-9}$    | 491-2740             | 0.73    | 0.17 |

Source: Chemical and Process Thermodynamics 3/E by Kyle, B. G., © 2000. Adapted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

TABLE A-3E

Properties of common liquids, solids, and foods

(a) Liquids

| Substance                           | Boiling data at 1 atm    |                                               | Freezing data      |                                         | Liquid properties      |                                     |                                  |
|-------------------------------------|--------------------------|-----------------------------------------------|--------------------|-----------------------------------------|------------------------|-------------------------------------|----------------------------------|
|                                     | Normal boiling point, °F | Latent heat of vaporization, $h_{fg}$ Btu/lbm | Freezing point, °F | Latent heat of fusion, $h_{if}$ Btu/lbm | Temperature, °F        | Density, $\rho$ lbm/ft <sup>3</sup> | Specific heat, $c_p$ Btu/lbm · R |
| Ammonia                             | -27.9                    | 24.54                                         | -107.9             | 138.6                                   | -27.9<br>0<br>40<br>80 | 42.6<br>41.3<br>39.5<br>37.5        | 1.06<br>1.083<br>1.103<br>1.135  |
| Argon                               | -302.6                   | 69.5                                          | -308.7             | 12.0                                    | -302.6                 | 87.0                                | 0.272                            |
| Benzene                             | 176.4                    | 169.4                                         | 41.9               | 54.2                                    | 68                     | 54.9                                | 0.411                            |
| Brine (20% sodium chloride by mass) | 219.0                    | —                                             | 0.7                | —                                       | 68                     | 71.8                                | 0.743                            |
| <i>n</i> -Butane                    | 31.1                     | 165.6                                         | -217.3             | 34.5                                    | 31.1                   | 37.5                                | 0.552                            |
| Carbon dioxide                      | -109.2*                  | 99.6 (at 32°F)                                | -69.8              | —                                       | 32                     | 57.8                                | 0.583                            |
| Ethanol                             | 172.8                    | 360.5                                         | -173.6             | 46.9                                    | 77                     | 48.9                                | 0.588                            |
| Ethyl alcohol                       | 173.5                    | 368                                           | -248.8             | 46.4                                    | 68                     | 49.3                                | 0.678                            |
| Ethylene glycol                     | 388.6                    | 344.0                                         | 12.6               | 77.9                                    | 68                     | 69.2                                | 0.678                            |
| Glycerine                           | 355.8                    | 419                                           | 66.0               | 86.3                                    | 68                     | 78.7                                | 0.554                            |
| Helium                              | -452.1                   | 9.80                                          | —                  | —                                       | -452.1                 | 9.13                                | 5.45                             |
| Hydrogen                            | -423.0                   | 191.7                                         | -434.5             | 25.6                                    | -423.0                 | 4.41                                | 2.39                             |
| Isobutane                           | 10.9                     | 157.8                                         | -255.5             | 45.5                                    | 10.9                   | 37.1                                | 0.545                            |
| Kerosene                            | 399–559                  | 108                                           | -12.8              | —                                       | 68                     | 51.2                                | 0.478                            |
| Mercury                             | 674.1                    | 126.7                                         | -38.0              | 4.90                                    | 77                     | 847                                 | 0.033                            |
| Methane                             | -258.7                   | 219.6                                         | 296.0              | 25.1                                    | -258.7<br>-160         | 26.4<br>20.0                        | 0.834<br>1.074                   |
| Methanol                            | 148.1                    | 473                                           | -143.9             | 42.7                                    | 77                     | 49.1                                | 0.609                            |
| Nitrogen                            | -320.4                   | 85.4                                          | -346.0             | 10.9                                    | -320.4<br>-260         | 50.5<br>38.2                        | 0.492<br>0.643                   |
| Octane                              | 256.6                    | 131.7                                         | -71.5              | 77.9                                    | 68                     | 43.9                                | 0.502                            |
| Oil (light)                         | —                        | —                                             | —                  | —                                       | 77                     | 56.8                                | 0.430                            |
| Oxygen                              | -297.3                   | 91.5                                          | -361.8             | 5.9                                     | -297.3                 | 71.2                                | 0.408                            |
| Petroleum                           | —                        | 99–165                                        | —                  | —                                       | 68                     | 40.0                                | 0.478                            |
| Propane                             | -43.7                    | 184.0                                         | -305.8             | 34.4                                    | -43.7<br>32<br>100     | 36.3<br>33.0<br>29.4                | 0.538<br>0.604<br>0.673          |
| Refrigerant-134a                    | -15.0                    | 93.3                                          | -141.9             | —                                       | -40<br>-15<br>32<br>90 | 88.5<br>86.0<br>80.9<br>73.6        | 0.283<br>0.294<br>0.318<br>0.348 |
| Water                               | 212                      | 970.1                                         | 32                 | 143.5                                   | 32<br>90<br>150<br>212 | 62.4<br>62.1<br>61.2<br>59.8        | 1.01<br>1.00<br>1.00<br>1.01     |

\*Sublimation temperature. (At pressures below the triple-point pressure of 75.1 psia, carbon dioxide exists as a solid or gas. Also, the freezing-point temperature of carbon dioxide is the triple-point temperature of -69.8°F.)

TABLE A-3E

Properties of common liquids, solids, and foods (*Continued*)  
 (b) Solids (values are for room temperature unless indicated otherwise)

| Substance                         | Density,<br>$\rho$ lbm/ft <sup>3</sup> | Specific<br>heat, $c_p$<br>Btu/lbm · R | Substance                      | Density,<br>$\rho$ lbm/ft <sup>3</sup> | Specific<br>heat, $c_p$<br>Btu/lbm · R |
|-----------------------------------|----------------------------------------|----------------------------------------|--------------------------------|----------------------------------------|----------------------------------------|
| <b>Metals</b>                     |                                        |                                        | <b>Nonmetals</b>               |                                        |                                        |
| Aluminum                          |                                        |                                        | Asphalt                        | 132                                    | 0.220                                  |
| −100°F                            |                                        | 0.192                                  | Brick, common                  | 120                                    | 0.189                                  |
| 32°F                              |                                        | 0.212                                  | Brick, fireclay (500°C)        | 144                                    | 0.229                                  |
| 100°F                             | 170                                    | 0.218                                  | Concrete                       | 144                                    | 0.156                                  |
| 200°F                             |                                        | 0.224                                  | Clay                           | 62.4                                   | 0.220                                  |
| 300°F                             |                                        | 0.229                                  | Diamond                        | 151                                    | 0.147                                  |
| 400°F                             |                                        | 0.235                                  | Glass, window                  | 169                                    | 0.191                                  |
| 500°F                             |                                        | 0.240                                  | Glass, pyrex                   | 139                                    | 0.200                                  |
| Bronze (76% Cu, 2% Zn,<br>2% Al)  | 517                                    | 0.0955                                 | Graphite                       | 156                                    | 0.170                                  |
| Brass, yellow (65% Cu,<br>35% Zn) | 519                                    | 0.0955                                 | Granite                        | 169                                    | 0.243                                  |
| Copper                            |                                        |                                        | Gypsum or plaster board        | 50                                     | 0.260                                  |
| −60°F                             |                                        | 0.0862                                 | Ice                            |                                        |                                        |
| 0°F                               |                                        | 0.0893                                 | −50°F                          |                                        | 0.424                                  |
| 100°F                             | 555                                    | 0.0925                                 | 0°F                            |                                        | 0.471                                  |
| 200°F                             |                                        | 0.0938                                 | 20°F                           |                                        | 0.491                                  |
| 390°F                             |                                        | 0.0963                                 | 32°F                           | 57.5                                   | 0.502                                  |
| Iron                              | 490                                    | 0.107                                  | Limestone                      | 103                                    | 0.217                                  |
| Lead                              | 705                                    | 0.030                                  | Marble                         | 162                                    | 0.210                                  |
| Magnesium                         | 108                                    | 0.239                                  | Plywood (Douglas fir)          | 34.0                                   |                                        |
| Nickel                            | 555                                    | 0.105                                  | Rubber (soft)                  | 68.7                                   |                                        |
| Silver                            | 655                                    | 0.056                                  | Rubber (hard)                  | 71.8                                   |                                        |
| Steel, mild                       | 489                                    | 0.119                                  | Sand                           | 94.9                                   |                                        |
| Tungsten                          | 1211                                   | 0.031                                  | Stone                          | 93.6                                   |                                        |
|                                   |                                        |                                        | Woods, hard (maple, oak, etc.) | 45.0                                   |                                        |
|                                   |                                        |                                        | Woods, soft (fir, pine, etc.)  | 32.0                                   |                                        |

(c) Foods

| Food          | Water<br>content,<br>% (mass) | Freezing<br>point,<br>°F | Specific heat,<br>Btu/lbm · R |                   | Latent<br>heat of<br>fusion,<br>Btu/lbm | Food           | Water<br>content,<br>% (mass) | Freezing<br>point,<br>°F | Specific heat,<br>Btu/lbm · R |                   | Latent<br>heat of<br>fusion,<br>Btu/lbm |
|---------------|-------------------------------|--------------------------|-------------------------------|-------------------|-----------------------------------------|----------------|-------------------------------|--------------------------|-------------------------------|-------------------|-----------------------------------------|
|               |                               |                          | Above<br>freezing             | Below<br>freezing |                                         |                |                               |                          | Above<br>freezing             | Below<br>freezing |                                         |
| Apples        | 84                            | 30                       | 0.873                         | 0.453             | 121                                     | Lettuce        | 95                            | 32                       | 0.961                         | 0.487             | 136                                     |
| Bananas       | 75                            | 31                       | 0.801                         | 0.426             | 108                                     | Milk, whole    | 88                            | 31                       | 0.905                         | 0.465             | 126                                     |
| Beef round    | 67                            | —                        | 0.737                         | 0.402             | 96                                      | Oranges        | 87                            | 31                       | 0.897                         | 0.462             | 125                                     |
| Broccoli      | 90                            | 31                       | 0.921                         | 0.471             | 129                                     | Potatoes       | 78                            | 31                       | 0.825                         | 0.435             | 112                                     |
| Butter        | 16                            | —                        | —                             | 0.249             | 23                                      | Salmon fish    | 64                            | 28                       | 0.713                         | 0.393             | 92                                      |
| Cheese, Swiss | 39                            | 14                       | 0.513                         | 0.318             | 56                                      | Shrimp         | 83                            | 28                       | 0.865                         | 0.450             | 119                                     |
| Cherries      | 80                            | 29                       | 0.841                         | 0.441             | 115                                     | Spinach        | 93                            | 31                       | 0.945                         | 0.481             | 134                                     |
| Chicken       | 74                            | 27                       | 0.793                         | 0.423             | 106                                     | Strawberries   | 90                            | 31                       | 0.921                         | 0.471             | 129                                     |
| Corn, sweet   | 74                            | 31                       | 0.793                         | 0.423             | 106                                     | Tomatoes, ripe | 94                            | 31                       | 0.953                         | 0.484             | 135                                     |
| Eggs, whole   | 74                            | 31                       | 0.793                         | 0.423             | 106                                     | Turkey         | 64                            | —                        | 0.713                         | 0.393             | 92                                      |
| Ice cream     | 63                            | 22                       | 0.705                         | 0.390             | 90                                      | Watermelon     | 93                            | 31                       | 0.945                         | 0.481             | 134                                     |

Source: Values are obtained from various handbooks and other sources or are calculated. Water content and freezing-point data of foods are from ASHRAE, *Handbook of Fundamentals*, I-P version (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1993), Chap. 30, Table 1. Freezing point is the temperature at which freezing starts for fruits and vegetables, and the average freezing temperature for other foods.

TABLE A-4E

Saturated water—Temperature table

| Temp.,<br>$T$ °F | Sat.<br>press.,<br>$P_{\text{sat}}$ psia | Specific volume,<br>ft <sup>3</sup> /lbm |                         | Internal energy,<br>Btu/lbm |                    |                         | Enthalpy,<br>Btu/lbm     |                    |                         | Entropy,<br>Btu/lbm · R  |                    |                         |
|------------------|------------------------------------------|------------------------------------------|-------------------------|-----------------------------|--------------------|-------------------------|--------------------------|--------------------|-------------------------|--------------------------|--------------------|-------------------------|
|                  |                                          | Sat.<br>liquid,<br>$v_f$                 | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$    | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$ | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$ | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 32.018           | 0.08871                                  | 0.01602                                  | 3299.9                  | 0.000                       | 1021.0             | 1021.0                  | 0.000                    | 1075.2             | 1075.2                  | 0.00000                  | 2.18672            | 2.1867                  |
| 35               | 0.09998                                  | 0.01602                                  | 2945.7                  | 3.004                       | 1019.0             | 1022.0                  | 3.004                    | 1073.5             | 1076.5                  | 0.00609                  | 2.17011            | 2.1762                  |
| 40               | 0.12173                                  | 0.01602                                  | 2443.6                  | 8.032                       | 1015.6             | 1023.7                  | 8.032                    | 1070.7             | 1078.7                  | 0.01620                  | 2.14271            | 2.1589                  |
| 45               | 0.14756                                  | 0.01602                                  | 2035.8                  | 13.05                       | 1012.2             | 1025.3                  | 13.05                    | 1067.8             | 1080.9                  | 0.02620                  | 2.11587            | 2.1421                  |
| 50               | 0.17812                                  | 0.01602                                  | 1703.1                  | 18.07                       | 1008.9             | 1026.9                  | 18.07                    | 1065.0             | 1083.1                  | 0.03609                  | 2.08956            | 2.1256                  |
| 55               | 0.21413                                  | 0.01603                                  | 1430.4                  | 23.07                       | 1005.5             | 1028.6                  | 23.07                    | 1062.2             | 1085.3                  | 0.04586                  | 2.06377            | 2.1096                  |
| 60               | 0.25638                                  | 0.01604                                  | 1206.1                  | 28.08                       | 1002.1             | 1030.2                  | 28.08                    | 1059.4             | 1087.4                  | 0.05554                  | 2.03847            | 2.0940                  |
| 65               | 0.30578                                  | 0.01604                                  | 1020.8                  | 33.08                       | 998.76             | 1031.8                  | 33.08                    | 1056.5             | 1089.6                  | 0.06511                  | 2.01366            | 2.0788                  |
| 70               | 0.36334                                  | 0.01605                                  | 867.18                  | 38.08                       | 995.39             | 1033.5                  | 38.08                    | 1053.7             | 1091.8                  | 0.07459                  | 1.98931            | 2.0639                  |
| 75               | 0.43016                                  | 0.01606                                  | 739.27                  | 43.07                       | 992.02             | 1035.1                  | 43.07                    | 1050.9             | 1093.9                  | 0.08398                  | 1.96541            | 2.0494                  |
| 80               | 0.50745                                  | 0.01607                                  | 632.41                  | 48.06                       | 988.65             | 1036.7                  | 48.07                    | 1048.0             | 1096.1                  | 0.09328                  | 1.94196            | 2.0352                  |
| 85               | 0.59659                                  | 0.01609                                  | 542.80                  | 53.06                       | 985.28             | 1038.3                  | 53.06                    | 1045.2             | 1098.3                  | 0.10248                  | 1.91892            | 2.0214                  |
| 90               | 0.69904                                  | 0.01610                                  | 467.40                  | 58.05                       | 981.90             | 1040.0                  | 58.05                    | 1042.4             | 1100.4                  | 0.11161                  | 1.89630            | 2.0079                  |
| 95               | 0.81643                                  | 0.01612                                  | 403.74                  | 63.04                       | 978.52             | 1041.6                  | 63.04                    | 1039.5             | 1102.6                  | 0.12065                  | 1.87408            | 1.9947                  |
| 100              | 0.95052                                  | 0.01613                                  | 349.83                  | 68.03                       | 975.14             | 1043.2                  | 68.03                    | 1036.7             | 1104.7                  | 0.12961                  | 1.85225            | 1.9819                  |
| 110              | 1.2767                                   | 0.01617                                  | 264.96                  | 78.01                       | 968.36             | 1046.4                  | 78.02                    | 1031.0             | 1109.0                  | 0.14728                  | 1.80970            | 1.9570                  |
| 120              | 1.6951                                   | 0.01620                                  | 202.94                  | 88.00                       | 961.56             | 1049.6                  | 88.00                    | 1025.2             | 1113.2                  | 0.16466                  | 1.76856            | 1.9332                  |
| 130              | 2.2260                                   | 0.01625                                  | 157.09                  | 97.99                       | 954.73             | 1052.7                  | 97.99                    | 1019.4             | 1117.4                  | 0.18174                  | 1.72877            | 1.9105                  |
| 140              | 2.8931                                   | 0.01629                                  | 122.81                  | 107.98                      | 947.87             | 1055.9                  | 107.99                   | 1013.6             | 1121.6                  | 0.19855                  | 1.69024            | 1.8888                  |
| 150              | 3.7234                                   | 0.01634                                  | 96.929                  | 117.98                      | 940.98             | 1059.0                  | 117.99                   | 1007.8             | 1125.7                  | 0.21508                  | 1.65291            | 1.8680                  |
| 160              | 4.7474                                   | 0.01639                                  | 77.185                  | 127.98                      | 934.05             | 1062.0                  | 128.00                   | 1001.8             | 1129.8                  | 0.23136                  | 1.61670            | 1.8481                  |
| 170              | 5.9999                                   | 0.01645                                  | 61.982                  | 138.00                      | 927.08             | 1065.1                  | 138.02                   | 995.88             | 1133.9                  | 0.24739                  | 1.58155            | 1.8289                  |
| 180              | 7.5197                                   | 0.01651                                  | 50.172                  | 148.02                      | 920.06             | 1068.1                  | 148.04                   | 989.85             | 1137.9                  | 0.26318                  | 1.54741            | 1.8106                  |
| 190              | 9.3497                                   | 0.01657                                  | 40.920                  | 158.05                      | 912.99             | 1071.0                  | 158.08                   | 983.76             | 1141.8                  | 0.27874                  | 1.51421            | 1.7930                  |
| 200              | 11.538                                   | 0.01663                                  | 33.613                  | 168.10                      | 905.87             | 1074.0                  | 168.13                   | 977.60             | 1145.7                  | 0.29409                  | 1.48191            | 1.7760                  |
| 210              | 14.136                                   | 0.01670                                  | 27.798                  | 178.15                      | 898.68             | 1076.8                  | 178.20                   | 971.35             | 1149.5                  | 0.30922                  | 1.45046            | 1.7597                  |
| 212              | 14.709                                   | 0.01671                                  | 26.782                  | 180.16                      | 897.24             | 1077.4                  | 180.21                   | 970.09             | 1150.3                  | 0.31222                  | 1.44427            | 1.7565                  |
| 220              | 17.201                                   | 0.01677                                  | 23.136                  | 188.22                      | 891.43             | 1079.6                  | 188.28                   | 965.02             | 1153.3                  | 0.32414                  | 1.41980            | 1.7439                  |
| 230              | 20.795                                   | 0.01684                                  | 19.374                  | 198.31                      | 884.10             | 1082.4                  | 198.37                   | 958.59             | 1157.0                  | 0.33887                  | 1.38989            | 1.7288                  |
| 240              | 24.985                                   | 0.01692                                  | 16.316                  | 208.41                      | 876.70             | 1085.1                  | 208.49                   | 952.06             | 1160.5                  | 0.35342                  | 1.36069            | 1.7141                  |
| 250              | 29.844                                   | 0.01700                                  | 13.816                  | 218.54                      | 869.21             | 1087.7                  | 218.63                   | 945.41             | 1164.0                  | 0.36779                  | 1.33216            | 1.6999                  |
| 260              | 35.447                                   | 0.01708                                  | 11.760                  | 228.68                      | 861.62             | 1090.3                  | 228.79                   | 938.65             | 1167.4                  | 0.38198                  | 1.30425            | 1.6862                  |
| 270              | 41.877                                   | 0.01717                                  | 10.059                  | 238.85                      | 853.94             | 1092.8                  | 238.98                   | 931.76             | 1170.7                  | 0.39601                  | 1.27694            | 1.6730                  |
| 280              | 49.222                                   | 0.01726                                  | 8.6439                  | 249.04                      | 846.16             | 1095.2                  | 249.20                   | 924.74             | 1173.9                  | 0.40989                  | 1.25018            | 1.6601                  |
| 290              | 57.573                                   | 0.01735                                  | 7.4607                  | 259.26                      | 838.27             | 1097.5                  | 259.45                   | 917.57             | 1177.0                  | 0.42361                  | 1.22393            | 1.6475                  |
| 300              | 67.028                                   | 0.01745                                  | 6.4663                  | 269.51                      | 830.25             | 1099.8                  | 269.73                   | 910.24             | 1180.0                  | 0.43720                  | 1.19818            | 1.6354                  |
| 310              | 77.691                                   | 0.01755                                  | 5.6266                  | 279.79                      | 822.11             | 1101.9                  | 280.05                   | 902.75             | 1182.8                  | 0.45065                  | 1.17289            | 1.6235                  |
| 320              | 89.667                                   | 0.01765                                  | 4.9144                  | 290.11                      | 813.84             | 1104.0                  | 290.40                   | 895.09             | 1185.5                  | 0.46396                  | 1.14802            | 1.6120                  |
| 330              | 103.07                                   | 0.01776                                  | 4.3076                  | 300.46                      | 805.43             | 1105.9                  | 300.80                   | 887.25             | 1188.1                  | 0.47716                  | 1.12355            | 1.6007                  |
| 340              | 118.02                                   | 0.01787                                  | 3.7885                  | 310.85                      | 796.87             | 1107.7                  | 311.24                   | 879.22             | 1190.5                  | 0.49024                  | 1.09945            | 1.5897                  |
| 350              | 134.63                                   | 0.01799                                  | 3.3425                  | 321.29                      | 788.16             | 1109.4                  | 321.73                   | 870.98             | 1192.7                  | 0.50321                  | 1.07570            | 1.5789                  |
| 360              | 153.03                                   | 0.01811                                  | 2.9580                  | 331.76                      | 779.28             | 1111.0                  | 332.28                   | 862.53             | 1194.8                  | 0.51607                  | 1.05227            | 1.5683                  |
| 370              | 173.36                                   | 0.01823                                  | 2.6252                  | 342.29                      | 770.23             | 1112.5                  | 342.88                   | 853.86             | 1196.7                  | 0.52884                  | 1.02914            | 1.5580                  |
| 380              | 195.74                                   | 0.01836                                  | 2.3361                  | 352.87                      | 761.00             | 1113.9                  | 353.53                   | 844.96             | 1198.5                  | 0.54152                  | 1.00628            | 1.5478                  |
| 390              | 220.33                                   | 0.01850                                  | 2.0842                  | 363.50                      | 751.58             | 1115.1                  | 364.25                   | 835.81             | 1200.1                  | 0.55411                  | 0.98366            | 1.5378                  |



TABLE A-4E

Saturated water—Temperature table (Concluded)

| Temp.,<br>$T$ °F | Sat.<br>press.,<br>$P_{\text{sat}}$ psia | Specific volume,<br>$\text{ft}^3/\text{lbm}$ |                         | Internal energy,<br>$\text{Btu}/\text{lbm}$ |                    |                         | Enthalpy,<br>$\text{Btu}/\text{lbm}$ |                    |                         | Entropy,<br>$\text{Btu}/\text{lbm} \cdot \text{R}$ |                    |                         |
|------------------|------------------------------------------|----------------------------------------------|-------------------------|---------------------------------------------|--------------------|-------------------------|--------------------------------------|--------------------|-------------------------|----------------------------------------------------|--------------------|-------------------------|
|                  |                                          | Sat.<br>liquid,<br>$v_f$                     | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$                    | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>liquid,<br>$h_f$             | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                           | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| 400              | 247.26                                   | 0.01864                                      | 1.8639                  | 374.19                                      | 741.97             | 1116.2                  | 375.04                               | 826.39             | 1201.4                  | 0.56663                                            | 0.96127            | 1.5279                  |
| 410              | 276.69                                   | 0.01878                                      | 1.6706                  | 384.94                                      | 732.14             | 1117.1                  | 385.90                               | 816.71             | 1202.6                  | 0.57907                                            | 0.93908            | 1.5182                  |
| 420              | 308.76                                   | 0.01894                                      | 1.5006                  | 395.76                                      | 722.08             | 1117.8                  | 396.84                               | 806.74             | 1203.6                  | 0.59145                                            | 0.91707            | 1.5085                  |
| 430              | 343.64                                   | 0.01910                                      | 1.3505                  | 406.65                                      | 711.80             | 1118.4                  | 407.86                               | 796.46             | 1204.3                  | 0.60377                                            | 0.89522            | 1.4990                  |
| 440              | 381.49                                   | 0.01926                                      | 1.2178                  | 417.61                                      | 701.26             | 1118.9                  | 418.97                               | 785.87             | 1204.8                  | 0.61603                                            | 0.87349            | 1.4895                  |
| 450              | 422.47                                   | 0.01944                                      | 1.0999                  | 428.66                                      | 690.47             | 1119.1                  | 430.18                               | 774.94             | 1205.1                  | 0.62826                                            | 0.85187            | 1.4801                  |
| 460              | 466.75                                   | 0.01962                                      | 0.99510                 | 439.79                                      | 679.39             | 1119.2                  | 441.48                               | 763.65             | 1205.1                  | 0.64044                                            | 0.83033            | 1.4708                  |
| 470              | 514.52                                   | 0.01981                                      | 0.90158                 | 451.01                                      | 668.02             | 1119.0                  | 452.90                               | 751.98             | 1204.9                  | 0.65260                                            | 0.80885            | 1.4615                  |
| 480              | 565.96                                   | 0.02001                                      | 0.81794                 | 462.34                                      | 656.34             | 1118.7                  | 464.43                               | 739.91             | 1204.3                  | 0.66474                                            | 0.78739            | 1.4521                  |
| 490              | 621.24                                   | 0.02022                                      | 0.74296                 | 473.77                                      | 644.32             | 1118.1                  | 476.09                               | 727.40             | 1203.5                  | 0.67686                                            | 0.76594            | 1.4428                  |
| 500              | 680.56                                   | 0.02044                                      | 0.67558                 | 485.32                                      | 631.94             | 1117.3                  | 487.89                               | 714.44             | 1202.3                  | 0.68899                                            | 0.74445            | 1.4334                  |
| 510              | 744.11                                   | 0.02067                                      | 0.61489                 | 496.99                                      | 619.17             | 1116.2                  | 499.84                               | 700.99             | 1200.8                  | 0.70112                                            | 0.72290            | 1.4240                  |
| 520              | 812.11                                   | 0.02092                                      | 0.56009                 | 508.80                                      | 605.99             | 1114.8                  | 511.94                               | 687.01             | 1199.0                  | 0.71327                                            | 0.70126            | 1.4145                  |
| 530              | 884.74                                   | 0.02118                                      | 0.51051                 | 520.76                                      | 592.35             | 1113.1                  | 524.23                               | 672.47             | 1196.7                  | 0.72546                                            | 0.67947            | 1.4049                  |
| 540              | 962.24                                   | 0.02146                                      | 0.46553                 | 532.88                                      | 578.23             | 1111.1                  | 536.70                               | 657.31             | 1194.0                  | 0.73770                                            | 0.65751            | 1.3952                  |
| 550              | 1044.8                                   | 0.02176                                      | 0.42465                 | 545.18                                      | 563.58             | 1108.8                  | 549.39                               | 641.47             | 1190.9                  | 0.75000                                            | 0.63532            | 1.3853                  |
| 560              | 1132.7                                   | 0.02207                                      | 0.38740                 | 557.68                                      | 548.33             | 1106.0                  | 562.31                               | 624.91             | 1187.2                  | 0.76238                                            | 0.61284            | 1.3752                  |
| 570              | 1226.2                                   | 0.02242                                      | 0.35339                 | 570.40                                      | 532.45             | 1102.8                  | 575.49                               | 607.55             | 1183.0                  | 0.77486                                            | 0.59003            | 1.3649                  |
| 580              | 1325.5                                   | 0.02279                                      | 0.32225                 | 583.37                                      | 515.84             | 1099.2                  | 588.95                               | 589.29             | 1178.2                  | 0.78748                                            | 0.56679            | 1.3543                  |
| 590              | 1430.8                                   | 0.02319                                      | 0.29367                 | 596.61                                      | 498.43             | 1095.0                  | 602.75                               | 570.04             | 1172.8                  | 0.80026                                            | 0.54306            | 1.3433                  |
| 600              | 1542.5                                   | 0.02362                                      | 0.26737                 | 610.18                                      | 480.10             | 1090.3                  | 616.92                               | 549.67             | 1166.6                  | 0.81323                                            | 0.51871            | 1.3319                  |
| 610              | 1660.9                                   | 0.02411                                      | 0.24309                 | 624.11                                      | 460.73             | 1084.8                  | 631.52                               | 528.03             | 1159.5                  | 0.82645                                            | 0.49363            | 1.3201                  |
| 620              | 1786.2                                   | 0.02464                                      | 0.22061                 | 638.47                                      | 440.14             | 1078.6                  | 646.62                               | 504.92             | 1151.5                  | 0.83998                                            | 0.46765            | 1.3076                  |
| 630              | 1918.9                                   | 0.02524                                      | 0.19972                 | 653.35                                      | 418.12             | 1071.5                  | 662.32                               | 480.07             | 1142.4                  | 0.85389                                            | 0.44056            | 1.2944                  |
| 640              | 2059.3                                   | 0.02593                                      | 0.18019                 | 668.86                                      | 394.36             | 1063.2                  | 678.74                               | 453.14             | 1131.9                  | 0.86828                                            | 0.41206            | 1.2803                  |
| 650              | 2207.8                                   | 0.02673                                      | 0.16184                 | 685.16                                      | 368.44             | 1053.6                  | 696.08                               | 423.65             | 1119.7                  | 0.88332                                            | 0.38177            | 1.2651                  |
| 660              | 2364.9                                   | 0.02767                                      | 0.14444                 | 702.48                                      | 339.74             | 1042.2                  | 714.59                               | 390.84             | 1105.4                  | 0.89922                                            | 0.34906            | 1.2483                  |
| 670              | 2531.2                                   | 0.02884                                      | 0.12774                 | 721.23                                      | 307.22             | 1028.5                  | 734.74                               | 353.54             | 1088.3                  | 0.91636                                            | 0.31296            | 1.2293                  |
| 680              | 2707.3                                   | 0.03035                                      | 0.11134                 | 742.11                                      | 269.00             | 1011.1                  | 757.32                               | 309.57             | 1066.9                  | 0.93541                                            | 0.27163            | 1.2070                  |
| 690              | 2894.1                                   | 0.03255                                      | 0.09451                 | 766.81                                      | 220.77             | 987.6                   | 784.24                               | 253.96             | 1038.2                  | 0.95797                                            | 0.22089            | 1.1789                  |
| 700              | 3093.0                                   | 0.03670                                      | 0.07482                 | 801.75                                      | 146.50             | 948.3                   | 822.76                               | 168.32             | 991.1                   | 0.99023                                            | 0.14514            | 1.1354                  |
| 705.10           | 3200.1                                   | 0.04975                                      | 0.04975                 | 866.61                                      | 0                  | 866.6                   | 896.07                               | 0                  | 896.1                   | 1.05257                                            | 0                  | 1.0526                  |

Source: Tables A-4E through A-8E are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the highly accurate Steam\_IAPWS, which incorporates the 1995 Formulation for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, issued by The International Association for the Properties of Water and Steam (IAPWS). This formulation replaces the 1984 formulation of Haar, Gallagher, and Kell (NBS/NRC Steam Tables, Hemisphere Publishing Co., 1984), which is also available in EES as the routine STEAM. The new formulation is based on the correlations of Saul and Wagner (J. Phys. Chem. Ref. Data, 16, 893, 1987) with modifications to adjust to the International Temperature Scale of 1990. The modifications are described by Wagner and Pruss (J. Phys. Chem. Ref. Data, 22, 783, 1993). The properties of ice are based on Hyland and Wexler, "Formulations for the Thermodynamic Properties of the Saturated Phases of  $\text{H}_2\text{O}$  from 173.15 K to 473.15 K," *ASHRAE Trans.*, Part 2A, Paper 2793, 1983.

TABLE A-5E

Saturated water—Pressure table

| Press.,<br><i>P</i> psia | Sat.<br>temp.,<br><i>T</i> <sub>sat</sub> °F | Specific volume,<br>ft <sup>3</sup> /lbm |                                         | Internal energy,<br>Btu/lbm              |                                  |                                         | Enthalpy,<br>Btu/lbm                     |                                  |                                         | Entropy,<br>Btu/lbm · R                  |                                  |                                         |
|--------------------------|----------------------------------------------|------------------------------------------|-----------------------------------------|------------------------------------------|----------------------------------|-----------------------------------------|------------------------------------------|----------------------------------|-----------------------------------------|------------------------------------------|----------------------------------|-----------------------------------------|
|                          |                                              | Sat.<br>liquid,<br><i>v</i> <sub>f</sub> | Sat.<br>vapor,<br><i>v</i> <sub>g</sub> | Sat.<br>liquid,<br><i>u</i> <sub>f</sub> | Evap.,<br><i>u</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>u</i> <sub>g</sub> | Sat.<br>liquid,<br><i>h</i> <sub>f</sub> | Evap.,<br><i>h</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>h</i> <sub>g</sub> | Sat.<br>liquid,<br><i>s</i> <sub>f</sub> | Evap.,<br><i>s</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>s</i> <sub>g</sub> |
| 1                        | 101.69                                       | 0.01614                                  | 333.49                                  | 69.72                                    | 973.99                           | 1043.7                                  | 69.72                                    | 1035.7                           | 1105.4                                  | 0.13262                                  | 1.84495                          | 1.9776                                  |
| 2                        | 126.02                                       | 0.01623                                  | 173.71                                  | 94.02                                    | 957.45                           | 1051.5                                  | 94.02                                    | 1021.7                           | 1115.8                                  | 0.17499                                  | 1.74444                          | 1.9194                                  |
| 3                        | 141.41                                       | 0.01630                                  | 118.70                                  | 109.39                                   | 946.90                           | 1056.3                                  | 109.40                                   | 1012.8                           | 1122.2                                  | 0.20090                                  | 1.68489                          | 1.8858                                  |
| 4                        | 152.91                                       | 0.01636                                  | 90.629                                  | 120.89                                   | 938.97                           | 1059.9                                  | 120.90                                   | 1006.0                           | 1126.9                                  | 0.21985                                  | 1.64225                          | 1.8621                                  |
| 5                        | 162.18                                       | 0.01641                                  | 73.525                                  | 130.17                                   | 932.53                           | 1062.7                                  | 130.18                                   | 1000.5                           | 1130.7                                  | 0.23488                                  | 1.60894                          | 1.8438                                  |
| 6                        | 170.00                                       | 0.01645                                  | 61.982                                  | 138.00                                   | 927.08                           | 1065.1                                  | 138.02                                   | 995.88                           | 1133.9                                  | 0.24739                                  | 1.58155                          | 1.8289                                  |
| 8                        | 182.81                                       | 0.01652                                  | 47.347                                  | 150.83                                   | 918.08                           | 1068.9                                  | 150.86                                   | 988.15                           | 1139.0                                  | 0.26757                                  | 1.53800                          | 1.8056                                  |
| 10                       | 193.16                                       | 0.01659                                  | 38.425                                  | 161.22                                   | 910.75                           | 1072.0                                  | 161.25                                   | 981.82                           | 1143.1                                  | 0.28362                                  | 1.50391                          | 1.7875                                  |
| 14.696                   | 211.95                                       | 0.01671                                  | 26.805                                  | 180.12                                   | 897.27                           | 1077.4                                  | 180.16                                   | 970.12                           | 1150.3                                  | 0.31215                                  | 1.44441                          | 1.7566                                  |
| 15                       | 212.99                                       | 0.01672                                  | 26.297                                  | 181.16                                   | 896.52                           | 1077.7                                  | 181.21                                   | 969.47                           | 1150.7                                  | 0.31370                                  | 1.44441                          | 1.7549                                  |
| 20                       | 227.92                                       | 0.01683                                  | 20.093                                  | 196.21                                   | 885.63                           | 1081.8                                  | 196.27                                   | 959.93                           | 1156.2                                  | 0.33582                                  | 1.39606                          | 1.7319                                  |
| 25                       | 240.03                                       | 0.01692                                  | 16.307                                  | 208.45                                   | 876.67                           | 1085.1                                  | 208.52                                   | 952.03                           | 1160.6                                  | 0.35347                                  | 1.36060                          | 1.7141                                  |
| 30                       | 250.30                                       | 0.01700                                  | 13.749                                  | 218.84                                   | 868.98                           | 1087.8                                  | 218.93                                   | 945.21                           | 1164.1                                  | 0.36821                                  | 1.33132                          | 1.6995                                  |
| 35                       | 259.25                                       | 0.01708                                  | 11.901                                  | 227.92                                   | 862.19                           | 1090.1                                  | 228.03                                   | 939.16                           | 1167.2                                  | 0.38093                                  | 1.30632                          | 1.6872                                  |
| 40                       | 267.22                                       | 0.01715                                  | 10.501                                  | 236.02                                   | 856.09                           | 1092.1                                  | 236.14                                   | 933.69                           | 1169.8                                  | 0.39213                                  | 1.28448                          | 1.6766                                  |
| 45                       | 274.41                                       | 0.01721                                  | 9.4028                                  | 243.34                                   | 850.52                           | 1093.9                                  | 243.49                                   | 928.68                           | 1172.2                                  | 0.40216                                  | 1.26506                          | 1.6672                                  |
| 50                       | 280.99                                       | 0.01727                                  | 8.5175                                  | 250.05                                   | 845.39                           | 1095.4                                  | 250.21                                   | 924.03                           | 1174.2                                  | 0.41125                                  | 1.24756                          | 1.6588                                  |
| 55                       | 287.05                                       | 0.01732                                  | 7.7882                                  | 256.25                                   | 840.61                           | 1096.9                                  | 256.42                                   | 919.70                           | 1176.1                                  | 0.41958                                  | 1.23162                          | 1.6512                                  |
| 60                       | 292.69                                       | 0.01738                                  | 7.1766                                  | 262.01                                   | 836.13                           | 1098.1                                  | 262.20                                   | 915.61                           | 1177.8                                  | 0.42728                                  | 1.21697                          | 1.6442                                  |
| 65                       | 297.95                                       | 0.01743                                  | 6.6560                                  | 267.41                                   | 831.90                           | 1099.3                                  | 267.62                                   | 911.75                           | 1179.4                                  | 0.43443                                  | 1.20341                          | 1.6378                                  |
| 70                       | 302.91                                       | 0.01748                                  | 6.2075                                  | 272.50                                   | 827.90                           | 1100.4                                  | 272.72                                   | 908.08                           | 1180.8                                  | 0.44112                                  | 1.19078                          | 1.6319                                  |
| 75                       | 307.59                                       | 0.01752                                  | 5.8167                                  | 277.31                                   | 824.09                           | 1101.4                                  | 277.55                                   | 904.58                           | 1182.1                                  | 0.44741                                  | 1.17895                          | 1.6264                                  |
| 80                       | 312.02                                       | 0.01757                                  | 5.4733                                  | 281.87                                   | 820.45                           | 1102.3                                  | 282.13                                   | 901.22                           | 1183.4                                  | 0.45335                                  | 1.16783                          | 1.6212                                  |
| 85                       | 316.24                                       | 0.01761                                  | 5.1689                                  | 286.22                                   | 816.97                           | 1103.2                                  | 286.50                                   | 898.00                           | 1184.5                                  | 0.45897                                  | 1.15732                          | 1.6163                                  |
| 90                       | 320.26                                       | 0.01765                                  | 4.8972                                  | 290.38                                   | 813.62                           | 1104.0                                  | 290.67                                   | 894.89                           | 1185.6                                  | 0.46431                                  | 1.14737                          | 1.6117                                  |
| 95                       | 324.11                                       | 0.01770                                  | 4.6532                                  | 294.36                                   | 810.40                           | 1104.8                                  | 294.67                                   | 891.89                           | 1186.6                                  | 0.46941                                  | 1.13791                          | 1.6073                                  |
| 100                      | 327.81                                       | 0.01774                                  | 4.4327                                  | 298.19                                   | 807.29                           | 1105.5                                  | 298.51                                   | 888.99                           | 1187.5                                  | 0.47427                                  | 1.12888                          | 1.6032                                  |
| 110                      | 334.77                                       | 0.01781                                  | 4.0410                                  | 305.41                                   | 801.37                           | 1106.8                                  | 305.78                                   | 883.44                           | 1189.2                                  | 0.48341                                  | 1.11201                          | 1.5954                                  |
| 120                      | 341.25                                       | 0.01789                                  | 3.7289                                  | 312.16                                   | 795.79                           | 1107.9                                  | 312.55                                   | 878.20                           | 1190.8                                  | 0.49187                                  | 1.09646                          | 1.5883                                  |
| 130                      | 347.32                                       | 0.01796                                  | 3.4557                                  | 318.48                                   | 790.51                           | 1109.0                                  | 318.92                                   | 873.21                           | 1192.1                                  | 0.49974                                  | 1.08204                          | 1.5818                                  |
| 140                      | 353.03                                       | 0.01802                                  | 3.2202                                  | 324.45                                   | 785.49                           | 1109.9                                  | 324.92                                   | 868.45                           | 1193.4                                  | 0.50711                                  | 1.06858                          | 1.5757                                  |
| 150                      | 358.42                                       | 0.01809                                  | 3.0150                                  | 330.11                                   | 780.69                           | 1110.8                                  | 330.61                                   | 863.88                           | 1194.5                                  | 0.51405                                  | 1.05595                          | 1.5700                                  |
| 160                      | 363.54                                       | 0.01815                                  | 2.8347                                  | 335.49                                   | 776.10                           | 1111.6                                  | 336.02                                   | 859.49                           | 1195.5                                  | 0.52061                                  | 1.04405                          | 1.5647                                  |
| 170                      | 368.41                                       | 0.01821                                  | 2.6749                                  | 340.62                                   | 771.68                           | 1112.3                                  | 341.19                                   | 855.25                           | 1196.4                                  | 0.52682                                  | 1.03279                          | 1.5596                                  |
| 180                      | 373.07                                       | 0.01827                                  | 2.5322                                  | 345.53                                   | 767.42                           | 1113.0                                  | 346.14                                   | 851.16                           | 1197.3                                  | 0.53274                                  | 1.02210                          | 1.5548                                  |
| 190                      | 377.52                                       | 0.01833                                  | 2.4040                                  | 350.24                                   | 763.31                           | 1113.6                                  | 350.89                                   | 847.19                           | 1198.1                                  | 0.53839                                  | 1.01191                          | 1.5503                                  |
| 200                      | 381.80                                       | 0.01839                                  | 2.2882                                  | 354.78                                   | 759.32                           | 1114.1                                  | 355.46                                   | 843.33                           | 1198.8                                  | 0.54379                                  | 1.00219                          | 1.5460                                  |
| 250                      | 400.97                                       | 0.01865                                  | 1.8440                                  | 375.23                                   | 741.02                           | 1116.3                                  | 376.09                                   | 825.47                           | 1201.6                                  | 0.56784                                  | 0.95912                          | 1.5270                                  |
| 300                      | 417.35                                       | 0.01890                                  | 1.5435                                  | 392.89                                   | 724.77                           | 1117.7                                  | 393.94                                   | 809.41                           | 1203.3                                  | 0.58818                                  | 0.92289                          | 1.5111                                  |
| 350                      | 431.74                                       | 0.01912                                  | 1.3263                                  | 408.55                                   | 709.98                           | 1118.5                                  | 409.79                                   | 794.65                           | 1204.4                                  | 0.60590                                  | 0.89143                          | 1.4973                                  |
| 400                      | 444.62                                       | 0.01934                                  | 1.1617                                  | 422.70                                   | 696.31                           | 1119.0                                  | 424.13                                   | 780.87                           | 1205.0                                  | 0.62168                                  | 0.86350                          | 1.4852                                  |
| 450                      | 456.31                                       | 0.01955                                  | 1.0324                                  | 435.67                                   | 683.52                           | 1119.2                                  | 437.30                                   | 767.86                           | 1205.2                                  | 0.63595                                  | 0.83828                          | 1.4742                                  |
| 500                      | 467.04                                       | 0.01975                                  | 0.92819                                 | 447.68                                   | 671.42                           | 1119.1                                  | 449.51                                   | 755.48                           | 1205.0                                  | 0.64900                                  | 0.81521                          | 1.4642                                  |
| 550                      | 476.97                                       | 0.01995                                  | 0.84228                                 | 458.90                                   | 659.91                           | 1118.8                                  | 460.93                                   | 743.60                           | 1204.5                                  | 0.66107                                  | 0.79388                          | 1.4550                                  |
| 600                      | 486.24                                       | 0.02014                                  | 0.77020                                 | 469.46                                   | 648.88                           | 1118.3                                  | 471.70                                   | 732.15                           | 1203.9                                  | 0.67231                                  | 0.77400                          | 1.4463                                  |

TABLE A-5E

Saturated water—Pressure table (*Concluded*)

| Press.,<br><i>P</i> psia | Sat.<br>temp.,<br><i>T</i> <sub>sat</sub> °F | Specific volume,<br>ft <sup>3</sup> /lbm |                                         | Internal energy,<br>Btu/lbm              |                                  |                                         | Enthalpy,<br>Btu/lbm                     |                                  |                                         | Entropy,<br>Btu/lbm · R                  |                                  |                                         |
|--------------------------|----------------------------------------------|------------------------------------------|-----------------------------------------|------------------------------------------|----------------------------------|-----------------------------------------|------------------------------------------|----------------------------------|-----------------------------------------|------------------------------------------|----------------------------------|-----------------------------------------|
|                          |                                              | Sat.<br>liquid,<br><i>v</i> <sub>f</sub> | Sat.<br>vapor,<br><i>v</i> <sub>g</sub> | Sat.<br>liquid,<br><i>u</i> <sub>f</sub> | Evap.,<br><i>u</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>u</i> <sub>g</sub> | Sat.<br>liquid,<br><i>h</i> <sub>f</sub> | Evap.,<br><i>h</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>h</i> <sub>g</sub> | Sat.<br>liquid,<br><i>s</i> <sub>f</sub> | Evap.,<br><i>s</i> <sub>fg</sub> | Sat.<br>vapor,<br><i>s</i> <sub>g</sub> |
| 700                      | 503.13                                       | 0.02051                                  | 0.65589                                 | 488.96                                   | 627.98                           | 1116.9                                  | 491.62                                   | 710.29                           | 1201.9                                  | 0.69279                                  | 0.73771                          | 1.4305                                  |
| 800                      | 518.27                                       | 0.02087                                  | 0.56920                                 | 506.74                                   | 608.30                           | 1115.0                                  | 509.83                                   | 689.48                           | 1199.3                                  | 0.71117                                  | 0.70502                          | 1.4162                                  |
| 900                      | 532.02                                       | 0.02124                                  | 0.50107                                 | 523.19                                   | 589.54                           | 1112.7                                  | 526.73                                   | 669.46                           | 1196.2                                  | 0.72793                                  | 0.67505                          | 1.4030                                  |
| 1000                     | 544.65                                       | 0.02159                                  | 0.44604                                 | 538.58                                   | 571.49                           | 1110.1                                  | 542.57                                   | 650.03                           | 1192.6                                  | 0.74341                                  | 0.64722                          | 1.3906                                  |
| 1200                     | 567.26                                       | 0.02232                                  | 0.36241                                 | 566.89                                   | 536.87                           | 1103.8                                  | 571.85                                   | 612.39                           | 1184.2                                  | 0.77143                                  | 0.59632                          | 1.3677                                  |
| 1400                     | 587.14                                       | 0.02307                                  | 0.30161                                 | 592.79                                   | 503.50                           | 1096.3                                  | 598.76                                   | 575.66                           | 1174.4                                  | 0.79658                                  | 0.54991                          | 1.3465                                  |
| 1600                     | 604.93                                       | 0.02386                                  | 0.25516                                 | 616.99                                   | 470.69                           | 1087.7                                  | 624.06                                   | 539.18                           | 1163.2                                  | 0.81972                                  | 0.50645                          | 1.3262                                  |
| 1800                     | 621.07                                       | 0.02470                                  | 0.21831                                 | 640.03                                   | 437.86                           | 1077.9                                  | 648.26                                   | 502.35                           | 1150.6                                  | 0.84144                                  | 0.46482                          | 1.3063                                  |
| 2000                     | 635.85                                       | 0.02563                                  | 0.18815                                 | 662.33                                   | 404.46                           | 1066.8                                  | 671.82                                   | 464.60                           | 1136.4                                  | 0.86224                                  | 0.42409                          | 1.2863                                  |
| 2500                     | 668.17                                       | 0.02860                                  | 0.13076                                 | 717.67                                   | 313.53                           | 1031.2                                  | 730.90                                   | 360.79                           | 1091.7                                  | 0.91311                                  | 0.31988                          | 1.2330                                  |
| 3000                     | 695.41                                       | 0.03433                                  | 0.08460                                 | 783.39                                   | 186.41                           | 969.8                                   | 802.45                                   | 214.32                           | 1016.8                                  | 0.97321                                  | 0.18554                          | 1.1587                                  |
| 3200.1                   | 705.10                                       | 0.04975                                  | 0.04975                                 | 866.61                                   | 0                                | 866.6                                   | 896.07                                   | 0                                | 896.1                                   | 1.05257                                  | 0                                | 1.0526                                  |

TABLE A-6E

Superheated water

| <i>T</i><br>°F                  | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R |
|---------------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|
| <i>P</i> = 1.0 psia (101.69°F)* |                                  |                     |                     |                             | <i>P</i> = 5.0 psia (162.18°F)   |                     |                     |                             | <i>P</i> = 10 psia (193.16°F)    |                     |                     |                             |
| Sat.†                           | 333.49                           | 1043.7              | 1105.4              | 1.9776                      | 73.525                           | 1062.7              | 1130.7              | 1.8438                      | 38.425                           | 1072.0              | 1143.1              | 1.7875                      |
| 200                             | 392.53                           | 1077.5              | 1150.1              | 2.0509                      | 78.153                           | 1076.2              | 1148.5              | 1.8716                      | 38.849                           | 1074.5              | 1146.4              | 1.7926                      |
| 240                             | 416.44                           | 1091.2              | 1168.3              | 2.0777                      | 83.009                           | 1090.3              | 1167.1              | 1.8989                      | 41.326                           | 1089.1              | 1165.5              | 1.8207                      |
| 280                             | 440.33                           | 1105.0              | 1186.5              | 2.1030                      | 87.838                           | 1104.3              | 1185.6              | 1.9246                      | 43.774                           | 1103.4              | 1184.4              | 1.8469                      |
| 320                             | 464.20                           | 1118.9              | 1204.8              | 2.1271                      | 92.650                           | 1118.4              | 1204.1              | 1.9490                      | 46.205                           | 1117.6              | 1203.1              | 1.8716                      |
| 360                             | 488.07                           | 1132.9              | 1223.3              | 2.1502                      | 97.452                           | 1132.5              | 1222.6              | 1.9722                      | 48.624                           | 1131.9              | 1221.8              | 1.8950                      |
| 400                             | 511.92                           | 1147.1              | 1241.8              | 2.1722                      | 102.25                           | 1146.7              | 1241.3              | 1.9944                      | 51.035                           | 1146.2              | 1240.6              | 1.9174                      |
| 440                             | 535.77                           | 1161.3              | 1260.4              | 2.1934                      | 107.03                           | 1160.9              | 1260.0              | 2.0156                      | 53.441                           | 1160.5              | 1259.4              | 1.9388                      |
| 500                             | 571.54                           | 1182.8              | 1288.6              | 2.2237                      | 114.21                           | 1182.6              | 1288.2              | 2.0461                      | 57.041                           | 1182.2              | 1287.8              | 1.9693                      |
| 600                             | 631.14                           | 1219.4              | 1336.2              | 2.2709                      | 126.15                           | 1219.2              | 1335.9              | 2.0933                      | 63.029                           | 1219.0              | 1335.6              | 2.0167                      |
| 700                             | 690.73                           | 1256.8              | 1384.6              | 2.3146                      | 138.09                           | 1256.7              | 1384.4              | 2.1371                      | 69.007                           | 1256.5              | 1384.2              | 2.0605                      |
| 800                             | 750.31                           | 1295.1              | 1433.9              | 2.3553                      | 150.02                           | 1294.9              | 1433.7              | 2.1778                      | 74.980                           | 1294.8              | 1433.5              | 2.1013                      |
| 1000                            | 869.47                           | 1374.2              | 1535.1              | 2.4299                      | 173.86                           | 1374.2              | 1535.0              | 2.2524                      | 86.913                           | 1374.1              | 1534.9              | 2.1760                      |
| 1200                            | 988.62                           | 1457.1              | 1640.0              | 2.4972                      | 197.70                           | 1457.0              | 1640.0              | 2.3198                      | 98.840                           | 1457.0              | 1639.9              | 2.2433                      |
| 1400                            | 1107.8                           | 1543.7              | 1748.7              | 2.5590                      | 221.54                           | 1543.7              | 1748.7              | 2.3816                      | 110.762                          | 1543.6              | 1748.6              | 2.3052                      |
| <i>P</i> = 15 psia (212.99°F)   |                                  |                     |                     |                             | <i>P</i> = 20 psia (227.92°F)    |                     |                     |                             | <i>P</i> = 40 psia (267.22°F)    |                     |                     |                             |
| Sat.                            | 26.297                           | 1077.7              | 1150.7              | 1.7549                      | 20.093                           | 1081.8              | 1156.2              | 1.7319                      | 10.501                           | 1092.1              | 1169.8              | 1.6766                      |
| 240                             | 27.429                           | 1087.8              | 1163.9              | 1.7742                      | 20.478                           | 1086.5              | 1162.3              | 1.7406                      |                                  |                     |                     |                             |
| 280                             | 29.085                           | 1102.4              | 1183.2              | 1.8010                      | 21.739                           | 1101.4              | 1181.9              | 1.7679                      | 10.713                           | 1097.3              | 1176.6              | 1.6858                      |
| 320                             | 30.722                           | 1116.9              | 1202.2              | 1.8260                      | 22.980                           | 1116.1              | 1201.2              | 1.7933                      | 11.363                           | 1112.9              | 1197.1              | 1.7128                      |
| 360                             | 32.348                           | 1131.3              | 1221.1              | 1.8496                      | 24.209                           | 1130.7              | 1220.2              | 1.8171                      | 11.999                           | 1128.1              | 1216.9              | 1.7376                      |
| 400                             | 33.965                           | 1145.7              | 1239.9              | 1.8721                      | 25.429                           | 1145.1              | 1239.3              | 1.8398                      | 12.625                           | 1143.1              | 1236.5              | 1.7610                      |
| 440                             | 35.576                           | 1160.1              | 1258.8              | 1.8936                      | 26.644                           | 1159.7              | 1258.3              | 1.8614                      | 13.244                           | 1157.9              | 1256.0              | 1.7831                      |
| 500                             | 37.986                           | 1181.9              | 1287.3              | 1.9243                      | 28.458                           | 1181.6              | 1286.9              | 1.8922                      | 14.165                           | 1180.2              | 1285.0              | 1.8143                      |
| 600                             | 41.988                           | 1218.7              | 1335.3              | 1.9718                      | 31.467                           | 1218.5              | 1334.9              | 1.9398                      | 15.686                           | 1217.5              | 1333.6              | 1.8625                      |
| 700                             | 45.981                           | 1256.3              | 1383.9              | 2.0156                      | 34.467                           | 1256.1              | 1383.7              | 1.9837                      | 17.197                           | 1255.3              | 1382.6              | 1.9067                      |
| 800                             | 49.967                           | 1294.6              | 1433.3              | 2.0565                      | 37.461                           | 1294.5              | 1433.1              | 2.0247                      | 18.702                           | 1293.9              | 1432.3              | 1.9478                      |
| 1000                            | 57.930                           | 1374.0              | 1534.8              | 2.1312                      | 43.438                           | 1373.8              | 1534.6              | 2.0994                      | 21.700                           | 1373.4              | 1534.1              | 2.0227                      |
| 1200                            | 65.885                           | 1456.9              | 1639.8              | 2.1986                      | 49.407                           | 1456.8              | 1639.7              | 2.1668                      | 24.691                           | 1456.5              | 1639.3              | 2.0902                      |
| 1400                            | 73.836                           | 1543.6              | 1748.5              | 2.2604                      | 55.373                           | 1543.5              | 1748.4              | 2.2287                      | 27.678                           | 1543.3              | 1748.1              | 2.1522                      |
| 1600                            | 81.784                           | 1634.0              | 1861.0              | 2.3178                      | 61.335                           | 1633.9              | 1860.9              | 2.2861                      | 30.662                           | 1633.7              | 1860.7              | 2.2096                      |
| <i>P</i> = 60 psia (292.69°F)   |                                  |                     |                     |                             | <i>P</i> = 80 psia (312.02°F)    |                     |                     |                             | <i>P</i> = 100 psia (327.81°F)   |                     |                     |                             |
| Sat.                            | 7.1766                           | 1098.1              | 1177.8              | 1.6442                      | 5.4733                           | 1102.3              | 1183.4              | 1.6212                      | 4.4327                           | 1105.5              | 1187.5              | 1.6032                      |
| 320                             | 7.4863                           | 1109.6              | 1192.7              | 1.6636                      | 5.5440                           | 1105.9              | 1187.9              | 1.6271                      |                                  |                     |                     |                             |
| 360                             | 7.9259                           | 1125.5              | 1213.5              | 1.6897                      | 5.8876                           | 1122.7              | 1209.9              | 1.6545                      | 4.6628                           | 1119.8              | 1206.1              | 1.6263                      |
| 400                             | 8.3548                           | 1140.9              | 1233.7              | 1.7138                      | 6.2187                           | 1138.7              | 1230.8              | 1.6794                      | 4.9359                           | 1136.4              | 1227.8              | 1.6521                      |
| 440                             | 8.7766                           | 1156.1              | 1253.6              | 1.7364                      | 6.5420                           | 1154.3              | 1251.2              | 1.7026                      | 5.2006                           | 1152.4              | 1248.7              | 1.6759                      |
| 500                             | 9.4005                           | 1178.8              | 1283.1              | 1.7682                      | 7.0177                           | 1177.3              | 1281.2              | 1.7350                      | 5.5876                           | 1175.9              | 1279.3              | 1.7088                      |
| 600                             | 10.4256                          | 1216.5              | 1332.2              | 1.8168                      | 7.7951                           | 1215.4              | 1330.8              | 1.7841                      | 6.2167                           | 1214.4              | 1329.4              | 1.7586                      |
| 700                             | 11.4401                          | 1254.5              | 1381.6              | 1.8613                      | 8.5616                           | 1253.8              | 1380.5              | 1.8289                      | 6.8344                           | 1253.0              | 1379.5              | 1.8037                      |
| 800                             | 12.4484                          | 1293.3              | 1431.5              | 1.9026                      | 9.3218                           | 1292.6              | 1430.6              | 1.8704                      | 7.4457                           | 1292.0              | 1429.8              | 1.8453                      |
| 1000                            | 14.4543                          | 1373.0              | 1533.5              | 1.9777                      | 10.8313                          | 1372.6              | 1532.9              | 1.9457                      | 8.6575                           | 1372.2              | 1532.4              | 1.9208                      |
| 1200                            | 16.4525                          | 1456.2              | 1638.9              | 2.0454                      | 12.3331                          | 1455.9              | 1638.5              | 2.0135                      | 9.8615                           | 1455.6              | 1638.1              | 1.9887                      |
| 1400                            | 18.4464                          | 1543.0              | 1747.8              | 2.1073                      | 13.8306                          | 1542.8              | 1747.5              | 2.0755                      | 11.0612                          | 1542.6              | 1747.2              | 2.0508                      |
| 1600                            | 20.438                           | 1633.5              | 1860.5              | 2.1648                      | 15.3257                          | 1633.3              | 1860.2              | 2.1330                      | 12.2584                          | 1633.2              | 1860.0              | 2.1083                      |
| 1800                            | 22.428                           | 1727.6              | 1976.6              | 2.2187                      | 16.8192                          | 1727.5              | 1976.5              | 2.1869                      | 13.4541                          | 1727.3              | 1976.3              | 2.1622                      |
| 2000                            | 24.417                           | 1825.2              | 2096.3              | 2.2694                      | 18.3117                          | 1825.0              | 2096.1              | 2.2376                      | 14.6487                          | 1824.9              | 2096.0              | 2.2130                      |

\*The temperature in parentheses is the saturation temperature at the specified pressure.

† Properties of saturated vapor at the specified pressure.

TABLE A-6E

Superheated water (Continued)

| <i>T</i><br>°F                 | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R |
|--------------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|
| <i>P</i> = 120 psia (341.25°F) |                                  |                     |                     |                             | <i>P</i> = 140 psia (353.03°F)   |                     |                     |                             | <i>P</i> = 160 psia (363.54°F)   |                     |                     |                             |
| Sat.                           | 3.7289                           | 1107.9              | 1190.8              | 1.5883                      | 3.2202                           | 1109.9              | 1193.4              | 1.5757                      | 2.8347                           | 1111.6              | 1195.5              | 1.5647                      |
| 360                            | 3.8446                           | 1116.7              | 1202.1              | 1.6023                      | 3.2584                           | 1113.4              | 1197.8              | 1.5811                      |                                  |                     |                     |                             |
| 400                            | 4.0799                           | 1134.0              | 1224.6              | 1.6292                      | 3.4676                           | 1131.5              | 1221.4              | 1.6092                      | 3.0076                           | 1129.0              | 1218.0              | 1.5914                      |
| 450                            | 4.3613                           | 1154.5              | 1251.4              | 1.6594                      | 3.7147                           | 1152.6              | 1248.9              | 1.6403                      | 3.2293                           | 1150.7              | 1246.3              | 1.6234                      |
| 500                            | 4.6340                           | 1174.4              | 1277.3              | 1.6872                      | 3.9525                           | 1172.9              | 1275.3              | 1.6686                      | 3.4412                           | 1171.4              | 1273.2              | 1.6522                      |
| 550                            | 4.9010                           | 1193.9              | 1302.8              | 1.7131                      | 4.1845                           | 1192.7              | 1301.1              | 1.6948                      | 3.6469                           | 1191.4              | 1299.4              | 1.6788                      |
| 600                            | 5.1642                           | 1213.4              | 1328.0              | 1.7375                      | 4.4124                           | 1212.3              | 1326.6              | 1.7195                      | 3.8484                           | 1211.3              | 1325.2              | 1.7037                      |
| 700                            | 5.6829                           | 1252.2              | 1378.4              | 1.7829                      | 4.8604                           | 1251.4              | 1377.3              | 1.7652                      | 4.2434                           | 1250.6              | 1376.3              | 1.7498                      |
| 800                            | 6.1950                           | 1291.4              | 1429.0              | 1.8247                      | 5.3017                           | 1290.8              | 1428.1              | 1.8072                      | 4.6316                           | 1290.2              | 1427.3              | 1.7920                      |
| 1000                           | 7.2083                           | 1371.7              | 1531.8              | 1.9005                      | 6.1732                           | 1371.3              | 1531.3              | 1.8832                      | 5.3968                           | 1370.9              | 1530.7              | 1.8682                      |
| 1200                           | 8.2137                           | 1455.3              | 1637.7              | 1.9684                      | 7.0367                           | 1455.0              | 1637.3              | 1.9512                      | 6.1540                           | 1454.7              | 1636.9              | 1.9363                      |
| 1400                           | 9.2149                           | 1542.3              | 1746.9              | 2.0305                      | 7.8961                           | 1542.1              | 1746.6              | 2.0134                      | 6.9070                           | 1541.8              | 1746.3              | 1.9986                      |
| 1600                           | 10.2135                          | 1633.0              | 1859.8              | 2.0881                      | 8.7529                           | 1632.8              | 1859.5              | 2.0711                      | 7.6574                           | 1632.6              | 1859.3              | 2.0563                      |
| 1800                           | 11.2106                          | 1727.2              | 1976.1              | 2.1420                      | 9.6082                           | 1727.0              | 1975.9              | 2.1250                      | 8.4063                           | 1726.9              | 1975.7              | 2.1102                      |
| 2000                           | 12.2067                          | 1824.8              | 2095.8              | 2.1928                      | 10.4624                          | 1824.6              | 2095.7              | 2.1758                      | 9.1542                           | 1824.5              | 2095.5              | 2.1610                      |
| <i>P</i> = 180 psia (373.07°F) |                                  |                     |                     |                             | <i>P</i> = 200 psia (381.80°F)   |                     |                     |                             | <i>P</i> = 225 psia (391.80°F)   |                     |                     |                             |
| Sat.                           | 2.5322                           | 1113.0              | 1197.3              | 1.5548                      | 2.2882                           | 1114.1              | 1198.8              | 1.5460                      | 2.0423                           | 1115.3              | 1200.3              | 1.5360                      |
| 400                            | 2.6490                           | 1126.3              | 1214.5              | 1.5752                      | 2.3615                           | 1123.5              | 1210.9              | 1.5602                      | 2.0728                           | 1119.7              | 1206.0              | 1.5427                      |
| 450                            | 2.8514                           | 1148.7              | 1243.7              | 1.6082                      | 2.5488                           | 1146.7              | 1241.0              | 1.5943                      | 2.2457                           | 1144.1              | 1237.6              | 1.5783                      |
| 500                            | 3.0433                           | 1169.8              | 1271.2              | 1.6376                      | 2.7247                           | 1168.2              | 1269.0              | 1.6243                      | 2.4059                           | 1166.2              | 1266.3              | 1.6091                      |
| 550                            | 3.2286                           | 1190.2              | 1297.7              | 1.6646                      | 2.8939                           | 1188.9              | 1296.0              | 1.6516                      | 2.5590                           | 1187.2              | 1293.8              | 1.6370                      |
| 600                            | 3.4097                           | 1210.2              | 1323.8              | 1.6897                      | 3.0586                           | 1209.1              | 1322.3              | 1.6771                      | 2.7075                           | 1207.7              | 1320.5              | 1.6628                      |
| 700                            | 3.7635                           | 1249.8              | 1375.2              | 1.7361                      | 3.3796                           | 1249.0              | 1374.1              | 1.7238                      | 2.9956                           | 1248.0              | 1372.7              | 1.7099                      |
| 800                            | 4.1104                           | 1289.5              | 1426.5              | 1.7785                      | 3.6934                           | 1288.9              | 1425.6              | 1.7664                      | 3.2765                           | 1288.1              | 1424.5              | 1.7528                      |
| 900                            | 4.4531                           | 1329.7              | 1478.0              | 1.8179                      | 4.0031                           | 1329.2              | 1477.3              | 1.8059                      | 3.5530                           | 1328.5              | 1476.5              | 1.7925                      |
| 1000                           | 4.7929                           | 1370.5              | 1530.1              | 1.8549                      | 4.3099                           | 1370.1              | 1529.6              | 1.8430                      | 3.8268                           | 1369.5              | 1528.9              | 1.8296                      |
| 1200                           | 5.4674                           | 1454.3              | 1636.5              | 1.9231                      | 4.9182                           | 1454.0              | 1636.1              | 1.9113                      | 4.3689                           | 1453.6              | 1635.6              | 1.8981                      |
| 1400                           | 6.1377                           | 1541.6              | 1746.0              | 1.9855                      | 5.5222                           | 1541.4              | 1745.7              | 1.9737                      | 4.9068                           | 1541.1              | 1745.4              | 1.9606                      |
| 1600                           | 6.8054                           | 1632.4              | 1859.1              | 2.0432                      | 6.1238                           | 1632.2              | 1858.8              | 2.0315                      | 5.4422                           | 1632.0              | 1858.6              | 2.0184                      |
| 1800                           | 7.4716                           | 1726.7              | 1975.6              | 2.0971                      | 6.7238                           | 1726.5              | 1975.4              | 2.0855                      | 5.9760                           | 1726.4              | 1975.2              | 2.0724                      |
| 2000                           | 8.1367                           | 1824.4              | 2095.4              | 2.1479                      | 7.3227                           | 1824.3              | 2095.3              | 2.1363                      | 6.5087                           | 1824.1              | 2095.1              | 2.1232                      |
| <i>P</i> = 250 psia (400.97°F) |                                  |                     |                     |                             | <i>P</i> = 275 psia (409.45°F)   |                     |                     |                             | <i>P</i> = 300 psia (417.35°F)   |                     |                     |                             |
| Sat.                           | 1.8440                           | 1116.3              | 1201.6              | 1.5270                      | 1.6806                           | 1117.0              | 1202.6              | 1.5187                      | 1.5435                           | 1117.7              | 1203.3              | 1.5111                      |
| 450                            | 2.0027                           | 1141.3              | 1234.0              | 1.5636                      | 1.8034                           | 1138.5              | 1230.3              | 1.5499                      | 1.6369                           | 1135.6              | 1226.4              | 1.5369                      |
| 500                            | 2.1506                           | 1164.1              | 1263.6              | 1.5953                      | 1.9415                           | 1162.0              | 1260.8              | 1.5825                      | 1.7670                           | 1159.8              | 1257.9              | 1.5706                      |
| 550                            | 2.2910                           | 1185.6              | 1291.5              | 1.6237                      | 2.0715                           | 1183.9              | 1289.3              | 1.6115                      | 1.8885                           | 1182.1              | 1287.0              | 1.6001                      |
| 600                            | 2.4264                           | 1206.3              | 1318.6              | 1.6499                      | 2.1964                           | 1204.9              | 1316.7              | 1.6380                      | 2.0046                           | 1203.5              | 1314.8              | 1.6270                      |
| 650                            | 2.5586                           | 1226.8              | 1345.1              | 1.6743                      | 2.3179                           | 1225.6              | 1343.5              | 1.6627                      | 2.1172                           | 1224.4              | 1341.9              | 1.6520                      |
| 700                            | 2.6883                           | 1247.0              | 1371.4              | 1.6974                      | 2.4369                           | 1246.0              | 1370.0              | 1.6860                      | 2.2273                           | 1244.9              | 1368.6              | 1.6755                      |
| 800                            | 2.9429                           | 1287.3              | 1423.5              | 1.7406                      | 2.6699                           | 1286.5              | 1422.4              | 1.7294                      | 2.4424                           | 1285.7              | 1421.3              | 1.7192                      |
| 900                            | 3.1930                           | 1327.9              | 1475.6              | 1.7804                      | 2.8984                           | 1327.3              | 1474.8              | 1.7694                      | 2.6529                           | 1326.6              | 1473.9              | 1.7593                      |
| 1000                           | 3.4403                           | 1369.0              | 1528.2              | 1.8177                      | 3.1241                           | 1368.5              | 1527.4              | 1.8068                      | 2.8605                           | 1367.9              | 1526.7              | 1.7968                      |
| 1200                           | 3.9295                           | 1453.3              | 1635.0              | 1.8863                      | 3.5700                           | 1452.9              | 1634.5              | 1.8755                      | 3.2704                           | 1452.5              | 1634.0              | 1.8657                      |
| 1400                           | 4.4144                           | 1540.8              | 1745.0              | 1.9488                      | 4.0116                           | 1540.5              | 1744.6              | 1.9381                      | 3.6759                           | 1540.2              | 1744.2              | 1.9284                      |
| 1600                           | 4.8969                           | 1631.7              | 1858.3              | 2.0066                      | 4.4507                           | 1631.5              | 1858.0              | 1.9960                      | 4.0789                           | 1631.3              | 1857.7              | 1.9863                      |
| 1800                           | 5.3777                           | 1726.2              | 1974.9              | 2.0607                      | 4.8882                           | 1726.0              | 1974.7              | 2.0501                      | 4.4803                           | 1725.8              | 1974.5              | 2.0404                      |
| 2000                           | 5.8575                           | 1823.9              | 2094.9              | 2.1116                      | 5.3247                           | 1823.8              | 2094.7              | 2.1010                      | 4.8807                           | 1823.6              | 2094.6              | 2.0913                      |

TABLE A-6E

Superheated water (Continued)

| <i>T</i><br>°F                 | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R |
|--------------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|
| <i>P</i> = 350 psia (431.74°F) |                                  |                     |                     |                             | <i>P</i> = 400 psia (444.62°F)   |                     |                     |                             | <i>P</i> = 450 psia (456.31°F)   |                     |                     |                             |
| Sat.                           | 1.3263                           | 1118.5              | 1204.4              | 1.4973                      | 1.1617                           | 1119.0              | 1205.0              | 1.4852                      | 1.0324                           | 1119.2              | 1205.2              | 1.4742                      |
| 450                            | 1.3739                           | 1129.3              | 1218.3              | 1.5128                      | 1.1747                           | 1122.5              | 1209.4              | 1.4901                      |                                  |                     |                     |                             |
| 500                            | 1.4921                           | 1155.2              | 1251.9              | 1.5487                      | 1.2851                           | 1150.4              | 1245.6              | 1.5288                      | 1.1233                           | 1145.4              | 1238.9              | 1.5103                      |
| 550                            | 1.6004                           | 1178.6              | 1282.2              | 1.5795                      | 1.3840                           | 1174.9              | 1277.3              | 1.5610                      | 1.2152                           | 1171.1              | 1272.3              | 1.5441                      |
| 600                            | 1.7030                           | 1200.6              | 1310.9              | 1.6073                      | 1.4765                           | 1197.6              | 1306.9              | 1.5897                      | 1.3001                           | 1194.6              | 1302.8              | 1.5737                      |
| 650                            | 1.8018                           | 1221.9              | 1338.6              | 1.6328                      | 1.5650                           | 1219.4              | 1335.3              | 1.6158                      | 1.3807                           | 1216.9              | 1331.9              | 1.6005                      |
| 700                            | 1.8979                           | 1242.8              | 1365.8              | 1.6567                      | 1.6507                           | 1240.7              | 1362.9              | 1.6401                      | 1.4584                           | 1238.5              | 1360.0              | 1.6253                      |
| 800                            | 2.0848                           | 1284.1              | 1419.1              | 1.7009                      | 1.8166                           | 1282.5              | 1417.0              | 1.6849                      | 1.6080                           | 1280.8              | 1414.7              | 1.6706                      |
| 900                            | 2.2671                           | 1325.3              | 1472.2              | 1.7414                      | 1.9777                           | 1324.0              | 1470.4              | 1.7257                      | 1.7526                           | 1322.7              | 1468.6              | 1.7117                      |
| 1000                           | 2.4464                           | 1366.9              | 1525.3              | 1.7791                      | 2.1358                           | 1365.8              | 1523.9              | 1.7636                      | 1.8942                           | 1364.7              | 1522.4              | 1.7499                      |
| 1200                           | 2.7996                           | 1451.7              | 1633.0              | 1.8483                      | 2.4465                           | 1450.9              | 1632.0              | 1.8331                      | 2.1718                           | 1450.1              | 1631.0              | 1.8196                      |
| 1400                           | 3.1484                           | 1539.6              | 1743.5              | 1.9111                      | 2.7527                           | 1539.0              | 1742.7              | 1.8960                      | 2.4450                           | 1538.4              | 1742.0              | 1.8827                      |
| 1600                           | 3.4947                           | 1630.8              | 1857.1              | 1.9691                      | 3.0565                           | 1630.3              | 1856.5              | 1.9541                      | 2.7157                           | 1629.8              | 1856.0              | 1.9409                      |
| 1800                           | 3.8394                           | 1725.4              | 1974.0              | 2.0233                      | 3.3586                           | 1725.0              | 1973.6              | 2.0084                      | 2.9847                           | 1724.6              | 1973.2              | 1.9952                      |
| 2000                           | 4.1830                           | 1823.3              | 2094.2              | 2.0742                      | 3.6597                           | 1823.0              | 2093.9              | 2.0594                      | 3.2527                           | 1822.6              | 2093.5              | 2.0462                      |
| <i>P</i> = 500 psia (467.04°F) |                                  |                     |                     |                             | <i>P</i> = 600 psia (486.24°F)   |                     |                     |                             | <i>P</i> = 700 psia (503.13°F)   |                     |                     |                             |
| Sat.                           | 0.92815                          | 1119.1              | 1205.0              | 1.4642                      | 0.77020                          | 1118.3              | 1203.9              | 1.4463                      | 0.65589                          | 1116.9              | 1201.9              | 1.4305                      |
| 500                            | 0.99304                          | 1140.1              | 1231.9              | 1.4928                      | 0.79526                          | 1128.2              | 1216.5              | 1.4596                      |                                  |                     |                     |                             |
| 550                            | 1.07974                          | 1167.1              | 1267.0              | 1.5284                      | 0.87542                          | 1158.7              | 1255.9              | 1.4996                      | 0.72799                          | 1149.5              | 1243.8              | 1.4730                      |
| 600                            | 1.15876                          | 1191.4              | 1298.6              | 1.5590                      | 0.94605                          | 1184.9              | 1289.9              | 1.5325                      | 0.79332                          | 1177.9              | 1280.7              | 1.5087                      |
| 650                            | 1.23312                          | 1214.3              | 1328.4              | 1.5865                      | 1.01133                          | 1209.0              | 1321.3              | 1.5614                      | 0.85242                          | 1203.4              | 1313.8              | 1.5393                      |
| 700                            | 1.30440                          | 1236.4              | 1357.0              | 1.6117                      | 1.07316                          | 1231.9              | 1351.0              | 1.5877                      | 0.90769                          | 1227.2              | 1344.8              | 1.5666                      |
| 800                            | 1.44097                          | 1279.2              | 1412.5              | 1.6576                      | 1.19038                          | 1275.8              | 1408.0              | 1.6348                      | 1.01125                          | 1272.4              | 1403.4              | 1.6150                      |
| 900                            | 1.57252                          | 1321.4              | 1466.9              | 1.6992                      | 1.30230                          | 1318.7              | 1463.3              | 1.6771                      | 1.10921                          | 1316.0              | 1459.7              | 1.6581                      |
| 1000                           | 1.70094                          | 1363.6              | 1521.0              | 1.7376                      | 1.41097                          | 1361.4              | 1518.1              | 1.7160                      | 1.20381                          | 1359.2              | 1515.2              | 1.6974                      |
| 1100                           | 1.82726                          | 1406.2              | 1575.3              | 1.7735                      | 1.51749                          | 1404.4              | 1572.9              | 1.7522                      | 1.29621                          | 1402.5              | 1570.4              | 1.7341                      |
| 1200                           | 1.95211                          | 1449.4              | 1630.0              | 1.8075                      | 1.62252                          | 1447.8              | 1627.9              | 1.7865                      | 1.38709                          | 1446.2              | 1625.9              | 1.7685                      |
| 1400                           | 2.1988                           | 1537.8              | 1741.2              | 1.8708                      | 1.82957                          | 1536.6              | 1739.7              | 1.8501                      | 1.56580                          | 1535.4              | 1738.2              | 1.8324                      |
| 1600                           | 2.4430                           | 1629.4              | 1855.4              | 1.9291                      | 2.0340                           | 1628.4              | 1854.2              | 1.9085                      | 1.74192                          | 1627.5              | 1853.1              | 1.8911                      |
| 1800                           | 2.6856                           | 1724.2              | 1972.7              | 1.9834                      | 2.2369                           | 1723.4              | 1971.8              | 1.9630                      | 1.91643                          | 1722.7              | 1970.9              | 1.9457                      |
| 2000                           | 2.9271                           | 1822.3              | 2093.1              | 2.0345                      | 2.4387                           | 1821.7              | 2092.4              | 2.0141                      | 2.08987                          | 1821.0              | 2091.7              | 1.9969                      |
| <i>P</i> = 800 psia (518.27°F) |                                  |                     |                     |                             | <i>P</i> = 1000 psia (544.65°F)  |                     |                     |                             | <i>P</i> = 1250 psia (572.45°F)  |                     |                     |                             |
| Sat.                           | 0.56920                          | 1115.0              | 1199.3              | 1.4162                      | 0.44604                          | 1110.1              | 1192.6              | 1.3906                      | 0.34549                          | 1102.0              | 1181.9              | 1.3623                      |
| 550                            | 0.61586                          | 1139.4              | 1230.5              | 1.4476                      | 0.45375                          | 1115.2              | 1199.2              | 1.3972                      |                                  |                     |                     |                             |
| 600                            | 0.67799                          | 1170.5              | 1270.9              | 1.4866                      | 0.51431                          | 1154.1              | 1249.3              | 1.4457                      | 0.37894                          | 1129.5              | 1217.2              | 1.3961                      |
| 650                            | 0.73279                          | 1197.6              | 1306.0              | 1.5191                      | 0.56411                          | 1185.1              | 1289.5              | 1.4827                      | 0.42703                          | 1167.5              | 1266.3              | 1.4414                      |
| 700                            | 0.78330                          | 1222.4              | 1338.4              | 1.5476                      | 0.60844                          | 1212.4              | 1325.0              | 1.5140                      | 0.46735                          | 1198.7              | 1306.8              | 1.4771                      |
| 750                            | 0.83102                          | 1246.0              | 1369.1              | 1.5735                      | 0.64944                          | 1237.6              | 1357.8              | 1.5418                      | 0.50344                          | 1226.4              | 1342.9              | 1.5076                      |
| 800                            | 0.87678                          | 1268.9              | 1398.7              | 1.5975                      | 0.68821                          | 1261.7              | 1389.0              | 1.5670                      | 0.53687                          | 1252.2              | 1376.4              | 1.5347                      |
| 900                            | 0.96434                          | 1313.3              | 1456.0              | 1.6413                      | 0.76136                          | 1307.7              | 1448.6              | 1.6126                      | 0.59876                          | 1300.5              | 1439.0              | 1.5826                      |
| 1000                           | 1.04841                          | 1357.0              | 1512.2              | 1.6812                      | 0.83078                          | 1352.5              | 1506.2              | 1.6535                      | 0.65656                          | 1346.7              | 1498.6              | 1.6249                      |
| 1100                           | 1.13024                          | 1400.7              | 1568.0              | 1.7181                      | 0.89783                          | 1396.9              | 1563.1              | 1.6911                      | 0.71184                          | 1392.2              | 1556.8              | 1.6635                      |
| 1200                           | 1.21051                          | 1444.6              | 1623.8              | 1.7528                      | 0.96327                          | 1441.4              | 1619.7              | 1.7263                      | 0.76545                          | 1437.4              | 1614.5              | 1.6993                      |
| 1400                           | 1.36797                          | 1534.2              | 1736.7              | 1.8170                      | 1.09101                          | 1531.8              | 1733.7              | 1.7911                      | 0.86944                          | 1528.7              | 1729.8              | 1.7649                      |
| 1600                           | 1.52283                          | 1626.5              | 1851.9              | 1.8759                      | 1.21610                          | 1624.6              | 1849.6              | 1.8504                      | 0.97072                          | 1622.2              | 1846.7              | 1.8246                      |
| 1800                           | 1.67606                          | 1721.9              | 1970.0              | 1.9306                      | 1.33956                          | 1720.3              | 1968.2              | 1.9053                      | 1.07036                          | 1718.4              | 1966.0              | 1.8799                      |
| 2000                           | 1.82823                          | 1820.4              | 2091.0              | 1.9819                      | 1.46194                          | 1819.1              | 2089.6              | 1.9568                      | 1.16892                          | 1817.5              | 2087.9              | 1.9315                      |

TABLE A-6E

Superheated water (Concluded)

| <i>T</i><br>°F                  | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R | <i>v</i><br>ft <sup>3</sup> /lbm | <i>u</i><br>Btu/lbm | <i>h</i><br>Btu/lbm | <i>s</i><br>Btu/<br>lbm · R |
|---------------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|----------------------------------|---------------------|---------------------|-----------------------------|
| <i>P</i> = 1500 psia (596.26°F) |                                  |                     |                     |                             | <i>P</i> = 1750 psia (617.17°F)  |                     |                     |                             | <i>P</i> = 2000 psia (635.85°F)  |                     |                     |                             |
| Sat.                            | 0.27695                          | 1092.1              | 1169.0              | 1.3362                      | 0.22681                          | 1080.5              | 1153.9              | 1.3112                      | 0.18815                          | 1066.8              | 1136.4              | 1.2863                      |
| 600                             | 0.28189                          | 1097.2              | 1175.4              | 1.3423                      |                                  |                     |                     |                             |                                  |                     |                     |                             |
| 650                             | 0.33310                          | 1147.2              | 1239.7              | 1.4016                      | 0.26292                          | 1122.8              | 1207.9              | 1.3607                      | 0.20586                          | 1091.4              | 1167.6              | 1.3146                      |
| 700                             | 0.37198                          | 1183.6              | 1286.9              | 1.4433                      | 0.30252                          | 1166.8              | 1264.7              | 1.4108                      | 0.24894                          | 1147.6              | 1239.8              | 1.3783                      |
| 750                             | 0.40535                          | 1214.4              | 1326.9              | 1.4771                      | 0.33455                          | 1201.5              | 1309.8              | 1.4489                      | 0.28074                          | 1187.4              | 1291.3              | 1.4218                      |
| 800                             | 0.43550                          | 1242.2              | 1363.1              | 1.5064                      | 0.36266                          | 1231.7              | 1349.1              | 1.4807                      | 0.30763                          | 1220.5              | 1334.3              | 1.4567                      |
| 850                             | 0.46356                          | 1268.2              | 1396.9              | 1.5328                      | 0.38835                          | 1259.3              | 1385.1              | 1.5088                      | 0.33169                          | 1250.0              | 1372.8              | 1.4867                      |
| 900                             | 0.49015                          | 1293.1              | 1429.2              | 1.5569                      | 0.41238                          | 1285.4              | 1419.0              | 1.5341                      | 0.35390                          | 1277.5              | 1408.5              | 1.5134                      |
| 1000                            | 0.54031                          | 1340.9              | 1490.8              | 1.6007                      | 0.45719                          | 1334.9              | 1482.9              | 1.5796                      | 0.39479                          | 1328.7              | 1474.9              | 1.5606                      |
| 1100                            | 0.58781                          | 1387.3              | 1550.5              | 1.6402                      | 0.49917                          | 1382.4              | 1544.1              | 1.6201                      | 0.43266                          | 1377.5              | 1537.6              | 1.6021                      |
| 1200                            | 0.63355                          | 1433.3              | 1609.2              | 1.6767                      | 0.53932                          | 1429.2              | 1603.9              | 1.6572                      | 0.46864                          | 1425.1              | 1598.5              | 1.6400                      |
| 1400                            | 0.72172                          | 1525.7              | 1726.0              | 1.7432                      | 0.61621                          | 1522.6              | 1722.1              | 1.7245                      | 0.53708                          | 1519.5              | 1718.3              | 1.7081                      |
| 1600                            | 0.80714                          | 1619.8              | 1843.8              | 1.8033                      | 0.69031                          | 1617.4              | 1840.9              | 1.7852                      | 0.60269                          | 1615.0              | 1838.0              | 1.7693                      |
| 1800                            | 0.89090                          | 1716.4              | 1963.7              | 1.8589                      | 0.76273                          | 1714.5              | 1961.5              | 1.8410                      | 0.66660                          | 1712.5              | 1959.2              | 1.8255                      |
| 2000                            | 0.97358                          | 1815.9              | 2086.1              | 1.9108                      | 0.83406                          | 1814.2              | 2084.3              | 1.8931                      | 0.72942                          | 1812.6              | 2082.6              | 1.8778                      |
| <i>P</i> = 2500 psia (668.17°F) |                                  |                     |                     |                             | <i>P</i> = 3000 psia (695.41°F)  |                     |                     |                             | <i>P</i> = 3500 psia             |                     |                     |                             |
| Sat.                            | 0.13076                          | 1031.2              | 1091.7              | 1.2330                      | 0.08460                          | 969.8               | 1016.8              | 1.1587                      |                                  |                     |                     |                             |
| 650                             |                                  |                     |                     |                             |                                  |                     |                     |                             | 0.02492                          | 663.7               | 679.9               | 0.8632                      |
| 700                             | 0.16849                          | 1098.4              | 1176.3              | 1.3072                      | 0.09838                          | 1005.3              | 1059.9              | 1.1960                      | 0.03065                          | 760.0               | 779.9               | 0.9511                      |
| 750                             | 0.20327                          | 1154.9              | 1249.0              | 1.3686                      | 0.14840                          | 1114.1              | 1196.5              | 1.3118                      | 0.10460                          | 1057.6              | 1125.4              | 1.2434                      |
| 800                             | 0.22949                          | 1195.9              | 1302.0              | 1.4116                      | 0.17601                          | 1167.5              | 1265.3              | 1.3676                      | 0.13639                          | 1134.3              | 1222.6              | 1.3224                      |
| 850                             | 0.25174                          | 1230.1              | 1346.6              | 1.4463                      | 0.19771                          | 1208.2              | 1317.9              | 1.4086                      | 0.15847                          | 1183.8              | 1286.5              | 1.3721                      |
| 900                             | 0.27165                          | 1260.7              | 1386.4              | 1.4761                      | 0.21640                          | 1242.8              | 1362.9              | 1.4423                      | 0.17659                          | 1223.4              | 1337.8              | 1.4106                      |
| 950                             | 0.29001                          | 1289.1              | 1423.3              | 1.5028                      | 0.23321                          | 1273.9              | 1403.3              | 1.4716                      | 0.19245                          | 1257.8              | 1382.4              | 1.4428                      |
| 1000                            | 0.30726                          | 1316.1              | 1458.2              | 1.5271                      | 0.24876                          | 1302.8              | 1440.9              | 1.4978                      | 0.20687                          | 1289.0              | 1423.0              | 1.4711                      |
| 1100                            | 0.33949                          | 1367.3              | 1524.4              | 1.5710                      | 0.27732                          | 1356.8              | 1510.8              | 1.5441                      | 0.23289                          | 1346.1              | 1496.9              | 1.5201                      |
| 1200                            | 0.36966                          | 1416.6              | 1587.6              | 1.6103                      | 0.30367                          | 1408.0              | 1576.6              | 1.5850                      | 0.25654                          | 1399.3              | 1565.4              | 1.5627                      |
| 1400                            | 0.42631                          | 1513.3              | 1710.5              | 1.6802                      | 0.35249                          | 1507.0              | 1702.7              | 1.6567                      | 0.29978                          | 1500.7              | 1694.8              | 1.6364                      |
| 1600                            | 0.48004                          | 1610.1              | 1832.2              | 1.7424                      | 0.39830                          | 1605.3              | 1826.4              | 1.7199                      | 0.33994                          | 1600.4              | 1820.5              | 1.7006                      |
| 1800                            | 0.53205                          | 1708.6              | 1954.8              | 1.7991                      | 0.44237                          | 1704.7              | 1950.3              | 1.7773                      | 0.37833                          | 1700.8              | 1945.8              | 1.7586                      |
| 2000                            | 0.58295                          | 1809.4              | 2079.1              | 1.8518                      | 0.48532                          | 1806.1              | 2075.6              | 1.8304                      | 0.41561                          | 1802.9              | 2072.1              | 1.8121                      |
| <i>P</i> = 4000 psia            |                                  |                     |                     |                             | <i>P</i> = 5000 psia             |                     |                     |                             | <i>P</i> = 6000 psia             |                     |                     |                             |
| 650                             | 0.02448                          | 657.9               | 676.1               | 0.8577                      | 0.02379                          | 648.3               | 670.3               | 0.8485                      | 0.02325                          | 640.3               | 666.1               | 0.8408                      |
| 700                             | 0.02871                          | 742.3               | 763.6               | 0.9347                      | 0.02678                          | 721.8               | 746.6               | 0.9156                      | 0.02564                          | 708.1               | 736.5               | 0.9028                      |
| 750                             | 0.06370                          | 962.1               | 1009.2              | 1.1410                      | 0.03373                          | 821.8               | 853.0               | 1.0054                      | 0.02981                          | 788.7               | 821.8               | 0.9747                      |
| 800                             | 0.10520                          | 1094.2              | 1172.1              | 1.2734                      | 0.05937                          | 986.9               | 1041.8              | 1.1581                      | 0.03949                          | 897.1               | 941.0               | 1.0711                      |
| 850                             | 0.12848                          | 1156.7              | 1251.8              | 1.3355                      | 0.08551                          | 1092.4              | 1171.5              | 1.2593                      | 0.05815                          | 1018.6              | 1083.1              | 1.1819                      |
| 900                             | 0.14647                          | 1202.5              | 1310.9              | 1.3799                      | 0.10390                          | 1155.9              | 1252.1              | 1.3198                      | 0.07584                          | 1103.5              | 1187.7              | 1.2603                      |
| 950                             | 0.16176                          | 1240.7              | 1360.5              | 1.4157                      | 0.11863                          | 1203.9              | 1313.6              | 1.3643                      | 0.09010                          | 1163.7              | 1263.7              | 1.3153                      |
| 1000                            | 0.17538                          | 1274.6              | 1404.4              | 1.4463                      | 0.13128                          | 1244.0              | 1365.5              | 1.4004                      | 0.10208                          | 1211.4              | 1324.7              | 1.3578                      |
| 1100                            | 0.19957                          | 1335.1              | 1482.8              | 1.4983                      | 0.15298                          | 1312.2              | 1453.8              | 1.4590                      | 0.12211                          | 1288.4              | 1424.0              | 1.4237                      |
| 1200                            | 0.22121                          | 1390.3              | 1554.1              | 1.5426                      | 0.17185                          | 1372.1              | 1531.1              | 1.5070                      | 0.13911                          | 1353.4              | 1507.8              | 1.4758                      |
| 1300                            | 0.24128                          | 1443.0              | 1621.6              | 1.5821                      | 0.18902                          | 1427.8              | 1602.7              | 1.5490                      | 0.15434                          | 1412.5              | 1583.8              | 1.5203                      |
| 1400                            | 0.26028                          | 1494.3              | 1687.0              | 1.6182                      | 0.20508                          | 1481.4              | 1671.1              | 1.5868                      | 0.16841                          | 1468.4              | 1655.4              | 1.5598                      |
| 1600                            | 0.29620                          | 1595.5              | 1814.7              | 1.6835                      | 0.23505                          | 1585.6              | 1803.1              | 1.6542                      | 0.19438                          | 1575.7              | 1791.5              | 1.6294                      |
| 1800                            | 0.33033                          | 1696.8              | 1941.4              | 1.7422                      | 0.26320                          | 1689.0              | 1932.5              | 1.7142                      | 0.21853                          | 1681.1              | 1923.7              | 1.6907                      |
| 2000                            | 0.36335                          | 1799.7              | 2068.6              | 1.7961                      | 0.29023                          | 1793.2              | 2061.7              | 1.7689                      | 0.24155                          | 1786.7              | 2054.9              | 1.7463                      |

TABLE A-7E

Compressed liquid water

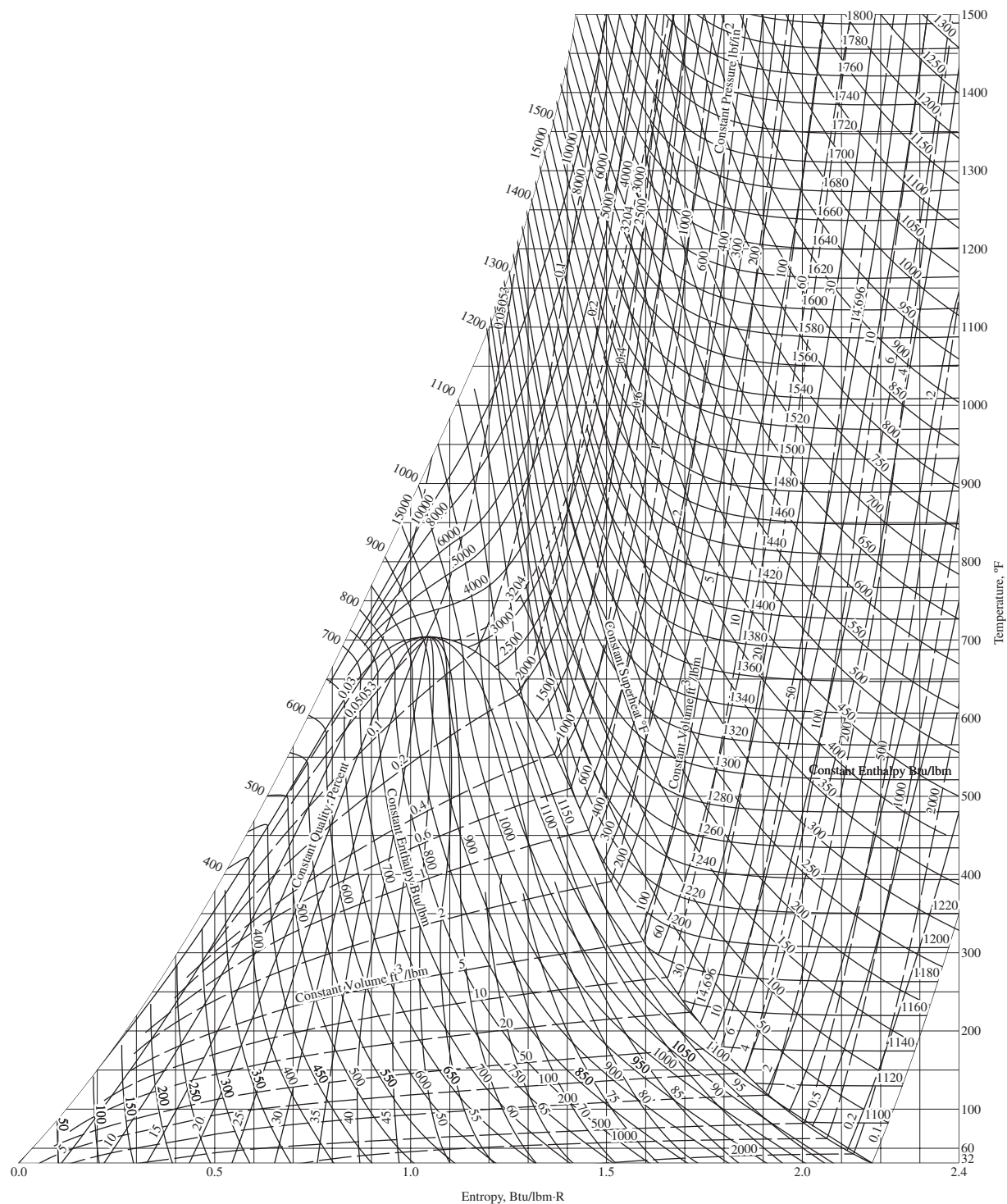
| $T$<br>°F                          | $v$<br>ft <sup>3</sup> /lbm | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/lbm · R | $v$<br>ft <sup>3</sup> /lbm        | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/lbm · R | $v$<br>ft <sup>3</sup> /lbm        | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/lbm · R |
|------------------------------------|-----------------------------|----------------|----------------|--------------------|------------------------------------|----------------|----------------|--------------------|------------------------------------|----------------|----------------|--------------------|
| $P = 500 \text{ psia (467.04°F)}$  |                             |                |                |                    | $P = 1000 \text{ psia (544.65°F)}$ |                |                |                    | $P = 1500 \text{ psia (596.26°F)}$ |                |                |                    |
| Sat.                               | 0.019750                    | 447.68         | 449.51         | 0.64900            | 0.021595                           | 538.58         | 542.57         | 0.74341            | 0.023456                           | 605.07         | 611.58         | 0.80836            |
| 32                                 | 0.015994                    | 0.01           | 1.49           | 0.00001            | 0.015966                           | 0.03           | 2.99           | 0.00005            | 0.015939                           | 0.05           | 4.48           | 0.00008            |
| 50                                 | 0.015998                    | 18.03          | 19.51          | 0.03601            | 0.015972                           | 17.99          | 20.95          | 0.03593            | 0.015946                           | 17.95          | 22.38          | 0.03584            |
| 100                                | 0.016107                    | 67.86          | 69.35          | 0.12930            | 0.016083                           | 67.69          | 70.67          | 0.12899            | 0.016059                           | 67.53          | 71.98          | 0.12869            |
| 150                                | 0.016317                    | 117.70         | 119.21         | 0.21462            | 0.016292                           | 117.42         | 120.43         | 0.21416            | 0.016267                           | 117.14         | 121.66         | 0.21369            |
| 200                                | 0.016607                    | 167.70         | 169.24         | 0.29349            | 0.016580                           | 167.31         | 170.38         | 0.29289            | 0.016553                           | 166.92         | 171.52         | 0.29229            |
| 250                                | 0.016972                    | 218.04         | 219.61         | 0.36708            | 0.016941                           | 217.51         | 220.65         | 0.36634            | 0.016911                           | 217.00         | 221.69         | 0.36560            |
| 300                                | 0.017417                    | 268.92         | 270.53         | 0.43641            | 0.017380                           | 268.24         | 271.46         | 0.43551            | 0.017345                           | 267.57         | 272.39         | 0.43463            |
| 350                                | 0.017954                    | 320.64         | 322.30         | 0.50240            | 0.017910                           | 319.77         | 323.08         | 0.50132            | 0.017866                           | 318.91         | 323.87         | 0.50025            |
| 400                                | 0.018609                    | 373.61         | 375.33         | 0.56595            | 0.018552                           | 372.48         | 375.91         | 0.56463            | 0.018496                           | 371.37         | 376.51         | 0.56333            |
| 450                                | 0.019425                    | 428.44         | 430.24         | 0.62802            | 0.019347                           | 426.93         | 430.51         | 0.62635            | 0.019271                           | 425.47         | 430.82         | 0.62472            |
| 500                                |                             |                |                |                    | 0.020368                           | 484.03         | 487.80         | 0.68764            | 0.020258                           | 482.01         | 487.63         | 0.68550            |
| 550                                |                             |                |                |                    |                                    |                |                |                    | 0.021595                           | 542.50         | 548.50         | 0.74731            |
| $P = 2000 \text{ psia (635.85°F)}$ |                             |                |                |                    | $P = 3000 \text{ psia (695.41°F)}$ |                |                |                    | $P = 5000 \text{ psia}$            |                |                |                    |
| Sat.                               | 0.025634                    | 662.33         | 671.82         | 0.86224            | 0.034335                           | 783.39         | 802.45         | 0.97321            |                                    |                |                |                    |
| 32                                 | 0.015912                    | 0.07           | 5.96           | 0.00010            | 0.015859                           | 0.10           | 8.90           | 0.00011            | 0.015756                           | 0.13           | 14.71          | 0.00002            |
| 50                                 | 0.015921                    | 17.91          | 23.80          | 0.03574            | 0.015870                           | 17.83          | 26.64          | 0.03554            | 0.015773                           | 17.65          | 32.25          | 0.03505            |
| 100                                | 0.016035                    | 67.36          | 73.30          | 0.12838            | 0.015988                           | 67.04          | 75.91          | 0.12776            | 0.015897                           | 66.41          | 81.12          | 0.12652            |
| 200                                | 0.016527                    | 166.54         | 172.66         | 0.29170            | 0.016475                           | 165.79         | 174.94         | 0.29053            | 0.016375                           | 164.36         | 179.51         | 0.28824            |
| 300                                | 0.017310                    | 266.92         | 273.33         | 0.43376            | 0.017242                           | 265.65         | 275.22         | 0.43204            | 0.017112                           | 263.24         | 279.07         | 0.42874            |
| 400                                | 0.018442                    | 370.30         | 377.12         | 0.56205            | 0.018338                           | 368.22         | 378.41         | 0.55959            | 0.018145                           | 364.35         | 381.14         | 0.55492            |
| 450                                | 0.019199                    | 424.06         | 431.16         | 0.62314            | 0.019062                           | 421.36         | 431.94         | 0.62010            | 0.018812                           | 416.40         | 433.80         | 0.61445            |
| 500                                | 0.020154                    | 480.08         | 487.54         | 0.68346            | 0.019960                           | 476.45         | 487.53         | 0.67958            | 0.019620                           | 469.94         | 488.10         | 0.67254            |
| 560                                | 0.021739                    | 552.21         | 560.26         | 0.75692            | 0.021405                           | 546.59         | 558.47         | 0.75126            | 0.020862                           | 537.08         | 556.38         | 0.74154            |
| 600                                | 0.023317                    | 605.77         | 614.40         | 0.80898            | 0.022759                           | 597.42         | 610.06         | 0.80086            | 0.021943                           | 584.42         | 604.72         | 0.78803            |
| 640                                |                             |                |                |                    | 0.024765                           | 654.52         | 668.27         | 0.85476            | 0.023358                           | 634.95         | 656.56         | 0.83603            |
| 680                                |                             |                |                |                    | 0.028821                           | 728.63         | 744.64         | 0.92288            | 0.025366                           | 690.67         | 714.14         | 0.88745            |
| 700                                |                             |                |                |                    |                                    |                |                |                    | 0.026777                           | 721.78         | 746.56         | 0.91564            |



TABLE A-8E

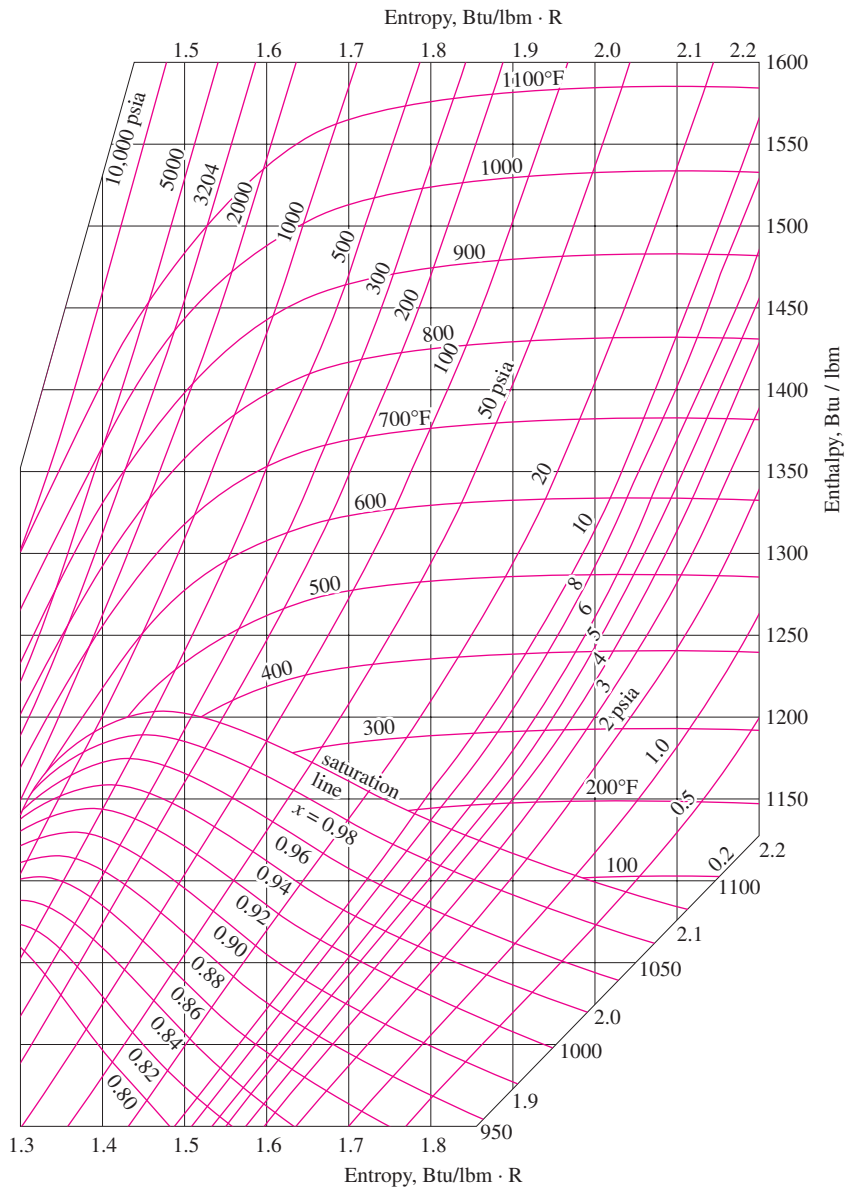
Saturated ice—water vapor

| Temp.,<br>$T$ °F | Sat.<br>press.,<br>$P_{\text{sat}}$<br>psia | Specific volume,<br>ft <sup>3</sup> /lbm |                         | Internal energy,<br>Btu/lbm |                    |                         | Enthalpy,<br>Btu/lbm  |                    |                         | Entropy,<br>Btu/lbm · R |                    |                         |
|------------------|---------------------------------------------|------------------------------------------|-------------------------|-----------------------------|--------------------|-------------------------|-----------------------|--------------------|-------------------------|-------------------------|--------------------|-------------------------|
|                  |                                             | Sat.<br>ice,<br>$v_i$                    | Sat.<br>vapor,<br>$v_g$ | Sat.<br>ice,<br>$u_i$       | Subl.,<br>$u_{ig}$ | Sat.<br>vapor,<br>$u_g$ | Sat.<br>ice,<br>$h_i$ | Subl.,<br>$h_{ig}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>ice,<br>$s_i$   | Subl.,<br>$s_{ig}$ | Sat.<br>vapor,<br>$s_g$ |
| 32.018           | 0.08871                                     | 0.01747                                  | 3299.6                  | -143.34                     | 1164.2             | 1020.9                  | -143.34               | 1218.3             | 1075.0                  | -0.29146                | 2.4779             | 2.1864                  |
| 32               | 0.08864                                     | 0.01747                                  | 3302.6                  | -143.35                     | 1164.2             | 1020.9                  | -143.35               | 1218.4             | 1075.0                  | -0.29148                | 2.4779             | 2.1865                  |
| 30               | 0.08086                                     | 0.01747                                  | 3605.8                  | -144.35                     | 1164.6             | 1020.2                  | -144.35               | 1218.5             | 1074.2                  | -0.29353                | 2.4883             | 2.1948                  |
| 25               | 0.06405                                     | 0.01746                                  | 4505.8                  | -146.85                     | 1165.4             | 1018.6                  | -146.85               | 1218.8             | 1072.0                  | -0.29865                | 2.5146             | 2.2160                  |
| 20               | 0.05049                                     | 0.01746                                  | 5657.6                  | -149.32                     | 1166.2             | 1016.9                  | -149.32               | 1219.1             | 1069.8                  | -0.30377                | 2.5414             | 2.2376                  |
| 15               | 0.03960                                     | 0.01745                                  | 7138.9                  | -151.76                     | 1167.0             | 1015.2                  | -151.76               | 1219.3             | 1067.6                  | -0.30889                | 2.5687             | 2.2598                  |
| 10               | 0.03089                                     | 0.01744                                  | 9054.0                  | -154.18                     | 1167.8             | 1013.6                  | -154.18               | 1219.5             | 1065.4                  | -0.31401                | 2.5965             | 2.2825                  |
| 5                | 0.02397                                     | 0.01743                                  | 11,543                  | -156.57                     | 1168.5             | 1011.9                  | -156.57               | 1219.7             | 1063.1                  | -0.31913                | 2.6248             | 2.3057                  |
| 0                | 0.01850                                     | 0.01743                                  | 14,797                  | -158.94                     | 1169.2             | 1010.3                  | -158.94               | 1219.9             | 1060.9                  | -0.32426                | 2.6537             | 2.3295                  |
| -5               | 0.01420                                     | 0.01742                                  | 19,075                  | -161.28                     | 1169.9             | 1008.6                  | -161.28               | 1220.0             | 1058.7                  | -0.32938                | 2.6832             | 2.3538                  |
| -10              | 0.01083                                     | 0.01741                                  | 24,731                  | -163.60                     | 1170.6             | 1007.0                  | -163.60               | 1220.1             | 1056.5                  | -0.33451                | 2.7133             | 2.3788                  |
| -15              | 0.00821                                     | 0.01740                                  | 32,257                  | -165.90                     | 1171.2             | 1005.3                  | -165.90               | 1220.2             | 1054.3                  | -0.33964                | 2.7440             | 2.4044                  |
| -20              | 0.00619                                     | 0.01740                                  | 42,335                  | -168.16                     | 1171.8             | 1003.6                  | -168.16               | 1220.3             | 1052.1                  | -0.34478                | 2.7754             | 2.4306                  |
| -25              | 0.00463                                     | 0.01739                                  | 55,917                  | -170.41                     | 1172.4             | 1002.0                  | -170.41               | 1220.3             | 1049.9                  | -0.34991                | 2.8074             | 2.4575                  |
| -30              | 0.00344                                     | 0.01738                                  | 74,345                  | -172.63                     | 1173.0             | 1000.3                  | -172.63               | 1220.3             | 1047.7                  | -0.35505                | 2.8401             | 2.4850                  |
| -35              | 0.00254                                     | 0.01738                                  | 99,526                  | -174.83                     | 1173.5             | 998.7                   | -174.83               | 1220.3             | 1045.5                  | -0.36019                | 2.8735             | 2.5133                  |
| -40              | 0.00186                                     | 0.01737                                  | 134,182                 | -177.00                     | 1174.0             | 997.0                   | -177.00               | 1220.3             | 1043.3                  | -0.36534                | 2.9076             | 2.5423                  |

**FIGURE A-9E**

*T-s* diagram for water.

Source: Joseph H. Keenan, Frederick G. Keyes, Philip G. Hill, and Joan G. Moore, *Steam Tables* (New York: John Wiley & Sons, 1969).

**FIGURE A-10E**

Mollier diagram for water.

Source: Joseph H. Keenan, Frederick G. Keyes, Philip G. Hill, and Joan G. Moore, *Steam Tables* (New York: John Wiley & Sons, 1969).

TABLE A-11E

Saturated refrigerant-134a—Temperature table

| Temp.,<br>$T$ °F | Sat.<br>press.,<br>$P_{\text{sat}}$ psia | Specific volume,<br>$\text{ft}^3/\text{lbm}$ |                         | Internal energy,<br>$\text{Btu}/\text{lbm}$ |                    | Enthalpy,<br>$\text{Btu}/\text{lbm}$ |                          |                    |                         | Entropy,<br>$\text{Btu}/\text{lbm} \cdot \text{R}$ |                    |                         |
|------------------|------------------------------------------|----------------------------------------------|-------------------------|---------------------------------------------|--------------------|--------------------------------------|--------------------------|--------------------|-------------------------|----------------------------------------------------|--------------------|-------------------------|
|                  |                                          | Sat.<br>liquid,<br>$v_f$                     | Sat.<br>vapor,<br>$v_g$ | Sat.<br>liquid,<br>$u_f$                    | Evap.,<br>$u_{fg}$ | Sat.<br>vapor,<br>$u_g$              | Sat.<br>liquid,<br>$h_f$ | Evap.,<br>$h_{fg}$ | Sat.<br>vapor,<br>$h_g$ | Sat.<br>liquid,<br>$s_f$                           | Evap.,<br>$s_{fg}$ | Sat.<br>vapor,<br>$s_g$ |
| -40              | 7.432                                    | 0.01130                                      | 5.7796                  | -0.016                                      | 89.167             | 89.15                                | 0.000                    | 97.100             | 97.10                   | 0.00000                                            | 0.23135            | 0.23135                 |
| -35              | 8.581                                    | 0.01136                                      | 5.0509                  | 1.484                                       | 88.352             | 89.84                                | 1.502                    | 96.354             | 97.86                   | 0.00355                                            | 0.22687            | 0.23043                 |
| -30              | 9.869                                    | 0.01143                                      | 4.4300                  | 2.990                                       | 87.532             | 90.52                                | 3.011                    | 95.601             | 98.61                   | 0.00708                                            | 0.22248            | 0.22956                 |
| -25              | 11.306                                   | 0.01150                                      | 3.8988                  | 4.502                                       | 86.706             | 91.21                                | 4.526                    | 94.839             | 99.36                   | 0.01058                                            | 0.21817            | 0.22875                 |
| -20              | 12.906                                   | 0.01156                                      | 3.4426                  | 6.019                                       | 85.874             | 91.89                                | 6.047                    | 94.068             | 100.12                  | 0.01405                                            | 0.21394            | 0.22798                 |
| -15              | 14.680                                   | 0.01163                                      | 3.0494                  | 7.543                                       | 85.036             | 92.58                                | 7.574                    | 93.288             | 100.86                  | 0.01749                                            | 0.20978            | 0.22727                 |
| -10              | 16.642                                   | 0.01171                                      | 2.7091                  | 9.073                                       | 84.191             | 93.26                                | 9.109                    | 92.498             | 101.61                  | 0.02092                                            | 0.20569            | 0.22660                 |
| -5               | 18.806                                   | 0.01178                                      | 2.4137                  | 10.609                                      | 83.339             | 93.95                                | 10.650                   | 91.698             | 102.35                  | 0.02431                                            | 0.20166            | 0.22598                 |
| 0                | 21.185                                   | 0.01185                                      | 2.1564                  | 12.152                                      | 82.479             | 94.63                                | 12.199                   | 90.886             | 103.08                  | 0.02769                                            | 0.19770            | 0.22539                 |
| 5                | 23.793                                   | 0.01193                                      | 1.9316                  | 13.702                                      | 81.610             | 95.31                                | 13.755                   | 90.062             | 103.82                  | 0.03104                                            | 0.19380            | 0.22485                 |
| 10               | 26.646                                   | 0.01201                                      | 1.7345                  | 15.259                                      | 80.733             | 95.99                                | 15.318                   | 89.226             | 104.54                  | 0.03438                                            | 0.18996            | 0.22434                 |
| 15               | 29.759                                   | 0.01209                                      | 1.5612                  | 16.823                                      | 79.846             | 96.67                                | 16.889                   | 88.377             | 105.27                  | 0.03769                                            | 0.18617            | 0.22386                 |
| 20               | 33.147                                   | 0.01217                                      | 1.4084                  | 18.394                                      | 78.950             | 97.34                                | 18.469                   | 87.514             | 105.98                  | 0.04098                                            | 0.18243            | 0.22341                 |
| 25               | 36.826                                   | 0.01225                                      | 1.2732                  | 19.973                                      | 78.043             | 98.02                                | 20.056                   | 86.636             | 106.69                  | 0.04426                                            | 0.17874            | 0.22300                 |
| 30               | 40.813                                   | 0.01234                                      | 1.1534                  | 21.560                                      | 77.124             | 98.68                                | 21.653                   | 85.742             | 107.40                  | 0.04752                                            | 0.17509            | 0.22260                 |
| 35               | 45.124                                   | 0.01242                                      | 1.0470                  | 23.154                                      | 76.195             | 99.35                                | 23.258                   | 84.833             | 108.09                  | 0.05076                                            | 0.17148            | 0.22224                 |
| 40               | 49.776                                   | 0.01251                                      | 0.95205                 | 24.757                                      | 75.253             | 100.01                               | 24.873                   | 83.907             | 108.78                  | 0.05398                                            | 0.16791            | 0.22189                 |
| 45               | 54.787                                   | 0.01261                                      | 0.86727                 | 26.369                                      | 74.298             | 100.67                               | 26.497                   | 82.963             | 109.46                  | 0.05720                                            | 0.16437            | 0.22157                 |
| 50               | 60.175                                   | 0.01270                                      | 0.79136                 | 27.990                                      | 73.329             | 101.32                               | 28.131                   | 82.000             | 110.13                  | 0.06039                                            | 0.16087            | 0.22127                 |
| 55               | 65.957                                   | 0.01280                                      | 0.72323                 | 29.619                                      | 72.346             | 101.97                               | 29.775                   | 81.017             | 110.79                  | 0.06358                                            | 0.15740            | 0.22098                 |
| 60               | 72.152                                   | 0.01290                                      | 0.66195                 | 31.258                                      | 71.347             | 102.61                               | 31.431                   | 80.013             | 111.44                  | 0.06675                                            | 0.15396            | 0.22070                 |
| 65               | 78.780                                   | 0.01301                                      | 0.60671                 | 32.908                                      | 70.333             | 103.24                               | 33.097                   | 78.988             | 112.09                  | 0.06991                                            | 0.15053            | 0.22044                 |
| 70               | 85.858                                   | 0.01312                                      | 0.55681                 | 34.567                                      | 69.301             | 103.87                               | 34.776                   | 77.939             | 112.71                  | 0.07306                                            | 0.14713            | 0.22019                 |
| 75               | 93.408                                   | 0.01323                                      | 0.51165                 | 36.237                                      | 68.251             | 104.49                               | 36.466                   | 76.866             | 113.33                  | 0.07620                                            | 0.14375            | 0.21995                 |
| 80               | 101.45                                   | 0.01334                                      | 0.47069                 | 37.919                                      | 67.181             | 105.10                               | 38.169                   | 75.767             | 113.94                  | 0.07934                                            | 0.14038            | 0.21972                 |
| 85               | 110.00                                   | 0.01347                                      | 0.43348                 | 39.612                                      | 66.091             | 105.70                               | 39.886                   | 74.641             | 114.53                  | 0.08246                                            | 0.13703            | 0.21949                 |
| 90               | 119.08                                   | 0.01359                                      | 0.39959                 | 41.317                                      | 64.979             | 106.30                               | 41.617                   | 73.485             | 115.10                  | 0.08559                                            | 0.13368            | 0.21926                 |
| 95               | 128.72                                   | 0.01372                                      | 0.36869                 | 43.036                                      | 63.844             | 106.88                               | 43.363                   | 72.299             | 115.66                  | 0.08870                                            | 0.13033            | 0.21904                 |
| 100              | 138.93                                   | 0.01386                                      | 0.34045                 | 44.768                                      | 62.683             | 107.45                               | 45.124                   | 71.080             | 116.20                  | 0.09182                                            | 0.12699            | 0.21881                 |
| 105              | 149.73                                   | 0.01400                                      | 0.31460                 | 46.514                                      | 61.496             | 108.01                               | 46.902                   | 69.825             | 116.73                  | 0.09493                                            | 0.12365            | 0.21858                 |
| 110              | 161.16                                   | 0.01415                                      | 0.29090                 | 48.276                                      | 60.279             | 108.56                               | 48.698                   | 68.533             | 117.23                  | 0.09804                                            | 0.12029            | 0.21834                 |
| 115              | 173.23                                   | 0.01430                                      | 0.26913                 | 50.054                                      | 59.031             | 109.08                               | 50.512                   | 67.200             | 117.71                  | 0.10116                                            | 0.11693            | 0.21809                 |
| 120              | 185.96                                   | 0.01446                                      | 0.24909                 | 51.849                                      | 57.749             | 109.60                               | 52.346                   | 65.823             | 118.17                  | 0.10428                                            | 0.11354            | 0.21782                 |
| 130              | 213.53                                   | 0.01482                                      | 0.21356                 | 55.495                                      | 55.071             | 110.57                               | 56.080                   | 62.924             | 119.00                  | 0.11054                                            | 0.10670            | 0.21724                 |
| 140              | 244.06                                   | 0.01521                                      | 0.18315                 | 59.226                                      | 52.216             | 111.44                               | 59.913                   | 59.801             | 119.71                  | 0.11684                                            | 0.09971            | 0.21655                 |
| 150              | 277.79                                   | 0.01567                                      | 0.15692                 | 63.059                                      | 49.144             | 112.20                               | 63.864                   | 56.405             | 120.27                  | 0.12321                                            | 0.09251            | 0.21572                 |
| 160              | 314.94                                   | 0.01619                                      | 0.13410                 | 67.014                                      | 45.799             | 112.81                               | 67.958                   | 52.671             | 120.63                  | 0.12970                                            | 0.08499            | 0.21469                 |
| 170              | 355.80                                   | 0.01681                                      | 0.11405                 | 71.126                                      | 42.097             | 113.22                               | 72.233                   | 48.499             | 120.73                  | 0.13634                                            | 0.07701            | 0.21335                 |
| 180              | 400.66                                   | 0.01759                                      | 0.09618                 | 75.448                                      | 37.899             | 113.35                               | 76.752                   | 43.726             | 120.48                  | 0.14323                                            | 0.06835            | 0.21158                 |
| 190              | 449.90                                   | 0.01860                                      | 0.07990                 | 80.082                                      | 32.950             | 113.03                               | 81.631                   | 38.053             | 119.68                  | 0.15055                                            | 0.05857            | 0.20911                 |
| 200              | 504.00                                   | 0.02009                                      | 0.06441                 | 85.267                                      | 26.651             | 111.92                               | 87.140                   | 30.785             | 117.93                  | 0.15867                                            | 0.04666            | 0.20533                 |
| 210              | 563.76                                   | 0.02309                                      | 0.04722                 | 91.986                                      | 16.498             | 108.48                               | 94.395                   | 19.015             | 113.41                  | 0.16922                                            | 0.02839            | 0.19761                 |

Source: Tables A-11E through A-13E are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the R134a, which is based on the fundamental equation of state developed by R. Tillner-Roth and H.D. Baehr, "An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for Temperatures from 170 K to 455 K and Pressures up to 70 MPa," *J. Phys. Chem. Ref. Data*, Vol. 23, No. 5, 1994. The enthalpy and entropy values of saturated liquid are set to zero at  $-40^\circ\text{C}$  (and  $-40^\circ\text{F}$ ).

TABLE A-12E

Saturated refrigerant-134a—Pressure table

| Press.,<br><i>P</i> psia | Sat.<br>temp.,<br><i>T</i> °F | Specific volume,<br>ft <sup>3</sup> /lbm |                                        | Internal energy,<br>Btu/lbm             |                                 |                                        | Enthalpy,<br>Btu/lbm                    |                                 |                                        | Entropy,<br>Btu/lbm · R                 |                                 |                                        |
|--------------------------|-------------------------------|------------------------------------------|----------------------------------------|-----------------------------------------|---------------------------------|----------------------------------------|-----------------------------------------|---------------------------------|----------------------------------------|-----------------------------------------|---------------------------------|----------------------------------------|
|                          |                               | Sat.<br>liquid,<br><i>v<sub>f</sub></i>  | Sat.<br>vapor,<br><i>v<sub>g</sub></i> | Sat.<br>liquid,<br><i>u<sub>f</sub></i> | Evap.,<br><i>u<sub>fg</sub></i> | Sat.<br>vapor,<br><i>u<sub>g</sub></i> | Sat.<br>liquid,<br><i>h<sub>f</sub></i> | Evap.,<br><i>h<sub>fg</sub></i> | Sat.<br>vapor,<br><i>h<sub>g</sub></i> | Sat.<br>liquid,<br><i>s<sub>f</sub></i> | Evap.,<br><i>s<sub>fg</sub></i> | Sat.<br>vapor,<br><i>s<sub>g</sub></i> |
| 5                        | −53.09                        | 0.01113                                  | 8.3785                                 | −3.918                                  | 91.280                          | 87.36                                  | −3.907                                  | 99.022                          | 95.11                                  | −0.00945                                | 0.24353                         | 0.23408                                |
| 10                       | −29.52                        | 0.01144                                  | 4.3753                                 | 3.135                                   | 87.453                          | 90.59                                  | 3.156                                   | 95.528                          | 98.68                                  | 0.00742                                 | 0.22206                         | 0.22948                                |
| 15                       | −14.15                        | 0.01165                                  | 2.9880                                 | 7.803                                   | 84.893                          | 92.70                                  | 7.835                                   | 93.155                          | 100.99                                 | 0.01808                                 | 0.20908                         | 0.22715                                |
| 20                       | −2.43                         | 0.01182                                  | 2.2772                                 | 11.401                                  | 82.898                          | 94.30                                  | 11.445                                  | 91.282                          | 102.73                                 | 0.02605                                 | 0.19962                         | 0.22567                                |
| 25                       | 7.17                          | 0.01196                                  | 1.8429                                 | 14.377                                  | 81.231                          | 95.61                                  | 14.432                                  | 89.701                          | 104.13                                 | 0.03249                                 | 0.19213                         | 0.22462                                |
| 30                       | 15.37                         | 0.01209                                  | 1.5492                                 | 16.939                                  | 79.780                          | 96.72                                  | 17.006                                  | 88.313                          | 105.32                                 | 0.03793                                 | 0.18589                         | 0.22383                                |
| 35                       | 22.57                         | 0.01221                                  | 1.3369                                 | 19.205                                  | 78.485                          | 97.69                                  | 19.284                                  | 87.064                          | 106.35                                 | 0.04267                                 | 0.18053                         | 0.22319                                |
| 40                       | 29.01                         | 0.01232                                  | 1.1760                                 | 21.246                                  | 77.307                          | 98.55                                  | 21.337                                  | 85.920                          | 107.26                                 | 0.04688                                 | 0.17580                         | 0.22268                                |
| 45                       | 34.86                         | 0.01242                                  | 1.0497                                 | 23.110                                  | 76.221                          | 99.33                                  | 23.214                                  | 84.858                          | 108.07                                 | 0.05067                                 | 0.17158                         | 0.22225                                |
| 50                       | 40.23                         | 0.01252                                  | 0.94791                                | 24.832                                  | 75.209                          | 100.04                                 | 24.948                                  | 83.863                          | 108.81                                 | 0.05413                                 | 0.16774                         | 0.22188                                |
| 55                       | 45.20                         | 0.01261                                  | 0.86400                                | 26.435                                  | 74.258                          | 100.69                                 | 26.564                                  | 82.924                          | 109.49                                 | 0.05733                                 | 0.16423                         | 0.22156                                |
| 60                       | 49.84                         | 0.01270                                  | 0.79361                                | 27.939                                  | 73.360                          | 101.30                                 | 28.080                                  | 82.030                          | 110.11                                 | 0.06029                                 | 0.16098                         | 0.22127                                |
| 65                       | 54.20                         | 0.01279                                  | 0.73370                                | 29.357                                  | 72.505                          | 101.86                                 | 29.510                                  | 81.176                          | 110.69                                 | 0.06307                                 | 0.15796                         | 0.22102                                |
| 70                       | 58.30                         | 0.01287                                  | 0.68205                                | 30.700                                  | 71.688                          | 102.39                                 | 30.867                                  | 80.357                          | 111.22                                 | 0.06567                                 | 0.15512                         | 0.22080                                |
| 75                       | 62.19                         | 0.01295                                  | 0.63706                                | 31.979                                  | 70.905                          | 102.88                                 | 32.159                                  | 79.567                          | 111.73                                 | 0.06813                                 | 0.15245                         | 0.22059                                |
| 80                       | 65.89                         | 0.01303                                  | 0.59750                                | 33.201                                  | 70.151                          | 103.35                                 | 33.394                                  | 78.804                          | 112.20                                 | 0.07047                                 | 0.14993                         | 0.22040                                |
| 85                       | 69.41                         | 0.01310                                  | 0.56244                                | 34.371                                  | 69.424                          | 103.79                                 | 34.577                                  | 78.064                          | 112.64                                 | 0.07269                                 | 0.14753                         | 0.22022                                |
| 90                       | 72.78                         | 0.01318                                  | 0.53113                                | 35.495                                  | 68.719                          | 104.21                                 | 35.715                                  | 77.345                          | 113.06                                 | 0.07481                                 | 0.14525                         | 0.22006                                |
| 95                       | 76.02                         | 0.01325                                  | 0.50301                                | 36.578                                  | 68.035                          | 104.61                                 | 36.811                                  | 76.645                          | 113.46                                 | 0.07684                                 | 0.14307                         | 0.21991                                |
| 100                      | 79.12                         | 0.01332                                  | 0.47760                                | 37.623                                  | 67.371                          | 104.99                                 | 37.869                                  | 75.962                          | 113.83                                 | 0.07879                                 | 0.14097                         | 0.21976                                |
| 110                      | 85.00                         | 0.01347                                  | 0.43347                                | 39.612                                  | 66.091                          | 105.70                                 | 39.886                                  | 74.641                          | 114.53                                 | 0.08246                                 | 0.13703                         | 0.21949                                |
| 120                      | 90.49                         | 0.01360                                  | 0.39644                                | 41.485                                  | 64.869                          | 106.35                                 | 41.787                                  | 73.371                          | 115.16                                 | 0.08589                                 | 0.13335                         | 0.21924                                |
| 130                      | 95.64                         | 0.01374                                  | 0.36491                                | 43.258                                  | 63.696                          | 106.95                                 | 43.589                                  | 72.144                          | 115.73                                 | 0.08911                                 | 0.12990                         | 0.21901                                |
| 140                      | 100.51                        | 0.01387                                  | 0.33771                                | 44.945                                  | 62.564                          | 107.51                                 | 45.304                                  | 70.954                          | 116.26                                 | 0.09214                                 | 0.12665                         | 0.21879                                |
| 150                      | 105.12                        | 0.01400                                  | 0.31401                                | 46.556                                  | 61.467                          | 108.02                                 | 46.945                                  | 69.795                          | 116.74                                 | 0.09501                                 | 0.12357                         | 0.21857                                |
| 160                      | 109.50                        | 0.01413                                  | 0.29316                                | 48.101                                  | 60.401                          | 108.50                                 | 48.519                                  | 68.662                          | 117.18                                 | 0.09774                                 | 0.12062                         | 0.21836                                |
| 170                      | 113.69                        | 0.01426                                  | 0.27466                                | 49.586                                  | 59.362                          | 108.95                                 | 50.035                                  | 67.553                          | 117.59                                 | 0.10034                                 | 0.11781                         | 0.21815                                |
| 180                      | 117.69                        | 0.01439                                  | 0.25813                                | 51.018                                  | 58.345                          | 109.36                                 | 51.497                                  | 66.464                          | 117.96                                 | 0.10284                                 | 0.11511                         | 0.21795                                |
| 190                      | 121.53                        | 0.01452                                  | 0.24327                                | 52.402                                  | 57.349                          | 109.75                                 | 52.912                                  | 65.392                          | 118.30                                 | 0.10524                                 | 0.11250                         | 0.21774                                |
| 200                      | 125.22                        | 0.01464                                  | 0.22983                                | 53.743                                  | 56.371                          | 110.11                                 | 54.285                                  | 64.335                          | 118.62                                 | 0.10754                                 | 0.10998                         | 0.21753                                |
| 220                      | 132.21                        | 0.01490                                  | 0.20645                                | 56.310                                  | 54.458                          | 110.77                                 | 56.917                                  | 62.256                          | 119.17                                 | 0.11192                                 | 0.10517                         | 0.21710                                |
| 240                      | 138.73                        | 0.01516                                  | 0.18677                                | 58.746                                  | 52.591                          | 111.34                                 | 59.419                                  | 60.213                          | 119.63                                 | 0.11603                                 | 0.10061                         | 0.21665                                |
| 260                      | 144.85                        | 0.01543                                  | 0.16996                                | 61.071                                  | 50.757                          | 111.83                                 | 61.813                                  | 58.192                          | 120.00                                 | 0.11992                                 | 0.09625                         | 0.21617                                |
| 280                      | 150.62                        | 0.01570                                  | 0.15541                                | 63.301                                  | 48.945                          | 112.25                                 | 64.115                                  | 56.184                          | 120.30                                 | 0.12362                                 | 0.09205                         | 0.21567                                |
| 300                      | 156.09                        | 0.01598                                  | 0.14266                                | 65.452                                  | 47.143                          | 112.60                                 | 66.339                                  | 54.176                          | 120.52                                 | 0.12715                                 | 0.08797                         | 0.21512                                |
| 350                      | 168.64                        | 0.01672                                  | 0.11664                                | 70.554                                  | 42.627                          | 113.18                                 | 71.638                                  | 49.099                          | 120.74                                 | 0.13542                                 | 0.07814                         | 0.21356                                |
| 400                      | 179.86                        | 0.01757                                  | 0.09642                                | 75.385                                  | 37.963                          | 113.35                                 | 76.686                                  | 43.798                          | 120.48                                 | 0.14314                                 | 0.06848                         | 0.21161                                |
| 450                      | 190.02                        | 0.01860                                  | 0.07987                                | 80.092                                  | 32.939                          | 113.03                                 | 81.641                                  | 38.041                          | 119.68                                 | 0.15056                                 | 0.05854                         | 0.20911                                |
| 500                      | 199.29                        | 0.01995                                  | 0.06551                                | 84.871                                  | 27.168                          | 112.04                                 | 86.718                                  | 31.382                          | 118.10                                 | 0.15805                                 | 0.04762                         | 0.20566                                |

TABLE A-13E

Superheated refrigerant-134a

| $T$<br>°F                                                 | $v$<br>ft <sup>3</sup> /lbm | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/<br>lbm · R | $v$<br>ft <sup>3</sup> /lbm                               | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/<br>lbm · R | $v$<br>ft <sup>3</sup> /lbm                              | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/<br>lbm · R |
|-----------------------------------------------------------|-----------------------------|----------------|----------------|------------------------|-----------------------------------------------------------|----------------|----------------|------------------------|----------------------------------------------------------|----------------|----------------|------------------------|
| $P = 10$ psia ( $T_{\text{sat}} = -29.52^\circ\text{F}$ ) |                             |                |                |                        | $P = 15$ psia ( $T_{\text{sat}} = -14.15^\circ\text{F}$ ) |                |                |                        | $P = 20$ psia ( $T_{\text{sat}} = -2.43^\circ\text{F}$ ) |                |                |                        |
| Sat.                                                      | 4.3753                      | 90.59          | 98.68          | 0.22948                | 2.9880                                                    | 92.70          | 100.99         | 0.22715                | 2.2772                                                   | 94.30          | 102.73         | 0.22567                |
| -20                                                       | 4.4856                      | 92.13          | 100.43         | 0.23350                |                                                           |                |                |                        |                                                          |                |                |                        |
| 0                                                         | 4.7135                      | 95.41          | 104.14         | 0.24174                | 3.1001                                                    | 95.08          | 103.68         | 0.23310                | 2.2922                                                   | 94.72          | 103.20         | 0.22671                |
| 20                                                        | 4.9380                      | 98.77          | 107.91         | 0.24976                | 3.2551                                                    | 98.48          | 107.52         | 0.24127                | 2.4130                                                   | 98.19          | 107.12         | 0.23504                |
| 40                                                        | 5.1600                      | 102.20         | 111.75         | 0.25761                | 3.4074                                                    | 101.95         | 111.41         | 0.24922                | 2.5306                                                   | 101.70         | 111.07         | 0.24311                |
| 60                                                        | 5.3802                      | 105.72         | 115.67         | 0.26531                | 3.5577                                                    | 105.50         | 115.38         | 0.25700                | 2.6461                                                   | 105.28         | 115.07         | 0.25097                |
| 80                                                        | 5.5989                      | 109.32         | 119.68         | 0.27288                | 3.7064                                                    | 109.13         | 119.42         | 0.26463                | 2.7600                                                   | 108.93         | 119.15         | 0.25866                |
| 100                                                       | 5.8165                      | 113.01         | 123.78         | 0.28033                | 3.8540                                                    | 112.84         | 123.54         | 0.27212                | 2.8726                                                   | 112.66         | 123.29         | 0.26621                |
| 120                                                       | 6.0331                      | 116.79         | 127.96         | 0.28767                | 4.0006                                                    | 116.63         | 127.74         | 0.27950                | 2.9842                                                   | 116.47         | 127.52         | 0.27363                |
| 140                                                       | 6.2490                      | 120.66         | 132.22         | 0.29490                | 4.1464                                                    | 120.51         | 132.02         | 0.28677                | 3.0950                                                   | 120.37         | 131.82         | 0.28093                |
| 160                                                       | 6.4642                      | 124.61         | 136.57         | 0.30203                | 4.2915                                                    | 124.48         | 136.39         | 0.29393                | 3.2051                                                   | 124.35         | 136.21         | 0.28812                |
| 180                                                       | 6.6789                      | 128.65         | 141.01         | 0.30908                | 4.4361                                                    | 128.53         | 140.84         | 0.30100                | 3.3146                                                   | 128.41         | 140.67         | 0.29521                |
| 200                                                       | 6.8930                      | 132.77         | 145.53         | 0.31604                | 4.5802                                                    | 132.66         | 145.37         | 0.30798                | 3.4237                                                   | 132.55         | 145.22         | 0.30221                |
| 220                                                       | 7.1068                      | 136.98         | 150.13         | 0.32292                | 4.7239                                                    | 136.88         | 149.99         | 0.31487                | 3.5324                                                   | 136.78         | 149.85         | 0.30912                |
| $P = 30$ psia ( $T_{\text{sat}} = 15.37^\circ\text{F}$ )  |                             |                |                |                        | $P = 40$ psia ( $T_{\text{sat}} = 29.01^\circ\text{F}$ )  |                |                |                        | $P = 50$ psia ( $T_{\text{sat}} = 40.23^\circ\text{F}$ ) |                |                |                        |
| Sat.                                                      | 1.5492                      | 96.72          | 105.32         | 0.22383                | 1.1760                                                    | 98.55          | 107.26         | 0.22268                | 0.9479                                                   | 100.04         | 108.81         | 0.22188                |
| 20                                                        | 1.5691                      | 97.56          | 106.27         | 0.22581                |                                                           |                |                |                        |                                                          |                |                |                        |
| 40                                                        | 1.6528                      | 101.17         | 110.35         | 0.23414                | 1.2126                                                    | 100.61         | 109.58         | 0.22738                |                                                          |                |                |                        |
| 60                                                        | 1.7338                      | 104.82         | 114.45         | 0.24219                | 1.2768                                                    | 104.34         | 113.79         | 0.23565                | 1.0019                                                   | 103.84         | 113.11         | 0.23031                |
| 80                                                        | 1.8130                      | 108.53         | 118.59         | 0.25002                | 1.3389                                                    | 108.11         | 118.02         | 0.24363                | 1.0540                                                   | 107.68         | 117.43         | 0.23847                |
| 100                                                       | 1.8908                      | 112.30         | 122.80         | 0.25767                | 1.3995                                                    | 111.93         | 122.29         | 0.25140                | 1.1043                                                   | 111.55         | 121.77         | 0.24637                |
| 120                                                       | 1.9675                      | 116.15         | 127.07         | 0.26517                | 1.4588                                                    | 115.82         | 126.62         | 0.25900                | 1.1534                                                   | 115.48         | 126.16         | 0.25406                |
| 140                                                       | 2.0434                      | 120.08         | 131.42         | 0.27254                | 1.5173                                                    | 119.78         | 131.01         | 0.26644                | 1.2015                                                   | 119.47         | 130.59         | 0.26159                |
| 160                                                       | 2.1185                      | 124.08         | 135.84         | 0.27979                | 1.5750                                                    | 123.81         | 135.47         | 0.27375                | 1.2488                                                   | 123.53         | 135.09         | 0.26896                |
| 180                                                       | 2.1931                      | 128.16         | 140.34         | 0.28693                | 1.6321                                                    | 127.91         | 140.00         | 0.28095                | 1.2955                                                   | 127.66         | 139.65         | 0.27621                |
| 200                                                       | 2.2671                      | 132.32         | 144.91         | 0.29398                | 1.6887                                                    | 132.10         | 144.60         | 0.28803                | 1.3416                                                   | 131.87         | 144.28         | 0.28333                |
| 220                                                       | 2.3408                      | 136.57         | 149.56         | 0.30092                | 1.7449                                                    | 136.36         | 149.27         | 0.29501                | 1.3873                                                   | 136.15         | 148.98         | 0.29036                |
| 240                                                       | 2.4141                      | 140.89         | 154.29         | 0.30778                | 1.8007                                                    | 140.70         | 154.03         | 0.30190                | 1.4326                                                   | 140.50         | 153.76         | 0.29728                |
| 260                                                       | 2.4871                      | 145.30         | 159.10         | 0.31456                | 1.8562                                                    | 145.12         | 158.86         | 0.30871                | 1.4776                                                   | 144.93         | 158.60         | 0.30411                |
| 280                                                       | 2.5598                      | 149.78         | 163.99         | 0.32126                | 1.9114                                                    | 149.61         | 163.76         | 0.31543                | 1.5223                                                   | 149.44         | 163.53         | 0.31086                |
| $P = 60$ psia ( $T_{\text{sat}} = 49.84^\circ\text{F}$ )  |                             |                |                |                        | $P = 70$ psia ( $T_{\text{sat}} = 58.30^\circ\text{F}$ )  |                |                |                        | $P = 80$ psia ( $T_{\text{sat}} = 65.89^\circ\text{F}$ ) |                |                |                        |
| Sat.                                                      | 0.7936                      | 101.30         | 110.11         | 0.22127                | 0.6821                                                    | 102.39         | 111.22         | 0.22080                | 0.59750                                                  | 103.35         | 112.20         | 0.22040                |
| 60                                                        | 0.8179                      | 103.31         | 112.39         | 0.22570                | 0.6857                                                    | 102.73         | 111.62         | 0.22155                |                                                          |                |                |                        |
| 80                                                        | 0.8636                      | 107.23         | 116.82         | 0.23407                | 0.7271                                                    | 106.76         | 116.18         | 0.23016                | 0.62430                                                  | 106.26         | 115.51         | 0.22661                |
| 100                                                       | 0.9072                      | 111.16         | 121.24         | 0.24211                | 0.7662                                                    | 110.76         | 120.68         | 0.23836                | 0.66009                                                  | 110.34         | 120.11         | 0.23499                |
| 120                                                       | 0.9495                      | 115.14         | 125.68         | 0.24991                | 0.8037                                                    | 114.78         | 125.19         | 0.24628                | 0.69415                                                  | 114.42         | 124.69         | 0.24304                |
| 140                                                       | 0.9908                      | 119.16         | 130.16         | 0.25751                | 0.8401                                                    | 118.85         | 129.73         | 0.25398                | 0.72698                                                  | 118.52         | 129.29         | 0.25083                |
| 160                                                       | 1.0312                      | 123.25         | 134.70         | 0.26496                | 0.8756                                                    | 122.97         | 134.31         | 0.26149                | 0.75888                                                  | 122.68         | 133.91         | 0.25841                |
| 180                                                       | 1.0709                      | 127.41         | 139.30         | 0.27226                | 0.9105                                                    | 127.15         | 138.94         | 0.26885                | 0.79003                                                  | 126.89         | 138.58         | 0.26583                |
| 200                                                       | 1.1101                      | 131.63         | 143.96         | 0.27943                | 0.9447                                                    | 131.40         | 143.63         | 0.27607                | 0.82059                                                  | 131.16         | 143.31         | 0.27310                |
| 220                                                       | 1.1489                      | 135.93         | 148.69         | 0.28649                | 0.9785                                                    | 135.71         | 148.39         | 0.28317                | 0.85065                                                  | 135.49         | 148.09         | 0.28024                |
| 240                                                       | 1.1872                      | 140.30         | 153.48         | 0.29344                | 1.0118                                                    | 140.10         | 153.21         | 0.29015                | 0.88030                                                  | 139.90         | 152.93         | 0.28726                |
| 260                                                       | 1.2252                      | 144.75         | 158.35         | 0.30030                | 1.0449                                                    | 144.56         | 158.10         | 0.29704                | 0.90961                                                  | 144.37         | 157.84         | 0.29418                |
| 280                                                       | 1.2629                      | 149.27         | 163.29         | 0.30707                | 1.0776                                                    | 149.10         | 163.06         | 0.30384                | 0.93861                                                  | 148.92         | 162.82         | 0.30100                |
| 300                                                       | 1.3004                      | 153.87         | 168.31         | 0.31376                | 1.1101                                                    | 153.71         | 168.09         | 0.31055                | 0.96737                                                  | 153.54         | 167.86         | 0.30773                |
| 320                                                       | 1.3377                      | 158.54         | 173.39         | 0.32037                | 1.1424                                                    | 158.39         | 173.19         | 0.31718                | 0.99590                                                  | 158.24         | 172.98         | 0.31438                |

TABLE A-13E

Superheated refrigerant-134a (Concluded)

| $T$<br>°F                                                       | $v$<br>ft <sup>3</sup> /lbm | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/<br>lbm · R | $v$<br>ft <sup>3</sup> /lbm                                     | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/<br>lbm · R | $v$<br>ft <sup>3</sup> /lbm                                     | $u$<br>Btu/lbm | $h$<br>Btu/lbm | $s$<br>Btu/<br>lbm · R |
|-----------------------------------------------------------------|-----------------------------|----------------|----------------|------------------------|-----------------------------------------------------------------|----------------|----------------|------------------------|-----------------------------------------------------------------|----------------|----------------|------------------------|
| $P = 90 \text{ psia } (T_{\text{sat}} = 72.78^\circ\text{F})$   |                             |                |                |                        | $P = 100 \text{ psia } (T_{\text{sat}} = 79.12^\circ\text{F})$  |                |                |                        | $P = 120 \text{ psia } (T_{\text{sat}} = 90.49^\circ\text{F})$  |                |                |                        |
| Sat.                                                            | 0.53113                     | 104.21         | 113.06         | 0.22006                | 0.47760                                                         | 104.99         | 113.83         | 0.21976                | 0.39644                                                         | 106.35         | 115.16         | 0.21924                |
| 80                                                              | 0.54388                     | 105.74         | 114.80         | 0.22330                | 0.47906                                                         | 105.18         | 114.05         | 0.22016                |                                                                 |                |                |                        |
| 100                                                             | 0.57729                     | 109.91         | 119.52         | 0.23189                | 0.51076                                                         | 109.45         | 118.90         | 0.22900                | 0.41013                                                         | 108.48         | 117.59         | 0.22362                |
| 120                                                             | 0.60874                     | 114.04         | 124.18         | 0.24008                | 0.54022                                                         | 113.66         | 123.65         | 0.23733                | 0.43692                                                         | 112.84         | 122.54         | 0.23232                |
| 140                                                             | 0.63885                     | 118.19         | 128.83         | 0.24797                | 0.56821                                                         | 117.86         | 128.37         | 0.24534                | 0.46190                                                         | 117.15         | 127.41         | 0.24058                |
| 160                                                             | 0.66796                     | 122.38         | 133.51         | 0.25563                | 0.59513                                                         | 122.08         | 133.09         | 0.25309                | 0.48563                                                         | 121.46         | 132.25         | 0.24851                |
| 180                                                             | 0.69629                     | 126.62         | 138.22         | 0.26311                | 0.62122                                                         | 126.35         | 137.85         | 0.26063                | 0.50844                                                         | 125.79         | 137.09         | 0.25619                |
| 200                                                             | 0.72399                     | 130.92         | 142.97         | 0.27043                | 0.64667                                                         | 130.67         | 142.64         | 0.26801                | 0.53054                                                         | 130.17         | 141.95         | 0.26368                |
| 220                                                             | 0.75119                     | 135.27         | 147.78         | 0.27762                | 0.67158                                                         | 135.05         | 147.47         | 0.27523                | 0.55206                                                         | 134.59         | 146.85         | 0.27100                |
| 240                                                             | 0.77796                     | 139.69         | 152.65         | 0.28468                | 0.69605                                                         | 139.49         | 152.37         | 0.28233                | 0.57312                                                         | 139.07         | 151.80         | 0.27817                |
| 260                                                             | 0.80437                     | 144.19         | 157.58         | 0.29162                | 0.72016                                                         | 143.99         | 157.32         | 0.28931                | 0.59379                                                         | 143.61         | 156.79         | 0.28521                |
| 280                                                             | 0.83048                     | 148.75         | 162.58         | 0.29847                | 0.74396                                                         | 148.57         | 162.34         | 0.29618                | 0.61413                                                         | 148.21         | 161.85         | 0.29214                |
| 300                                                             | 0.85633                     | 153.38         | 167.64         | 0.30522                | 0.76749                                                         | 153.21         | 167.42         | 0.30296                | 0.63420                                                         | 152.88         | 166.96         | 0.29896                |
| 320                                                             | 0.88195                     | 158.08         | 172.77         | 0.31189                | 0.79079                                                         | 157.93         | 172.56         | 0.30964                | 0.65402                                                         | 157.62         | 172.14         | 0.30569                |
| $P = 140 \text{ psia } (T_{\text{sat}} = 100.50^\circ\text{F})$ |                             |                |                |                        | $P = 160 \text{ psia } (T_{\text{sat}} = 109.50^\circ\text{F})$ |                |                |                        | $P = 180 \text{ psia } (T_{\text{sat}} = 117.69^\circ\text{F})$ |                |                |                        |
| Sat.                                                            | 0.33771                     | 107.51         | 116.26         | 0.21879                | 0.29316                                                         | 108.50         | 117.18         | 0.21836                | 0.25813                                                         | 109.36         | 117.96         | 0.21795                |
| 120                                                             | 0.36243                     | 111.96         | 121.35         | 0.22773                | 0.30578                                                         | 111.01         | 120.06         | 0.22337                | 0.26083                                                         | 109.94         | 118.63         | 0.21910                |
| 140                                                             | 0.38551                     | 116.41         | 126.40         | 0.23628                | 0.32774                                                         | 115.62         | 125.32         | 0.23230                | 0.28231                                                         | 114.77         | 124.17         | 0.22850                |
| 160                                                             | 0.40711                     | 120.81         | 131.36         | 0.24443                | 0.34790                                                         | 120.13         | 130.43         | 0.24069                | 0.30154                                                         | 119.42         | 129.46         | 0.23718                |
| 180                                                             | 0.42766                     | 125.22         | 136.30         | 0.25227                | 0.36686                                                         | 124.62         | 135.49         | 0.24871                | 0.31936                                                         | 124.00         | 134.64         | 0.24540                |
| 200                                                             | 0.44743                     | 129.65         | 141.24         | 0.25988                | 0.38494                                                         | 129.12         | 140.52         | 0.25645                | 0.33619                                                         | 128.57         | 139.77         | 0.25330                |
| 220                                                             | 0.46657                     | 134.12         | 146.21         | 0.26730                | 0.40234                                                         | 133.64         | 145.55         | 0.26397                | 0.35228                                                         | 133.15         | 144.88         | 0.26094                |
| 240                                                             | 0.48522                     | 138.64         | 151.21         | 0.27455                | 0.41921                                                         | 138.20         | 150.62         | 0.27131                | 0.36779                                                         | 137.76         | 150.01         | 0.26837                |
| 260                                                             | 0.50345                     | 143.21         | 156.26         | 0.28166                | 0.43564                                                         | 142.81         | 155.71         | 0.27849                | 0.38284                                                         | 142.40         | 155.16         | 0.27562                |
| 280                                                             | 0.52134                     | 147.85         | 161.35         | 0.28864                | 0.45171                                                         | 147.48         | 160.85         | 0.28554                | 0.39751                                                         | 147.10         | 160.34         | 0.28273                |
| 300                                                             | 0.53895                     | 152.54         | 166.50         | 0.29551                | 0.46748                                                         | 152.20         | 166.04         | 0.29246                | 0.41186                                                         | 151.85         | 165.57         | 0.28970                |
| 320                                                             | 0.55630                     | 157.30         | 171.71         | 0.30228                | 0.48299                                                         | 156.98         | 171.28         | 0.29927                | 0.42594                                                         | 156.66         | 170.85         | 0.29656                |
| 340                                                             | 0.57345                     | 162.13         | 176.98         | 0.30896                | 0.49828                                                         | 161.83         | 176.58         | 0.30598                | 0.43980                                                         | 161.53         | 176.18         | 0.30331                |
| 360                                                             | 0.59041                     | 167.02         | 182.32         | 0.31555                | 0.51338                                                         | 166.74         | 181.94         | 0.31260                | 0.45347                                                         | 166.46         | 181.56         | 0.30996                |
| $P = 200 \text{ psia } (T_{\text{sat}} = 125.22^\circ\text{F})$ |                             |                |                |                        | $P = 300 \text{ psia } (T_{\text{sat}} = 156.09^\circ\text{F})$ |                |                |                        | $P = 400 \text{ psia } (T_{\text{sat}} = 179.86^\circ\text{F})$ |                |                |                        |
| Sat.                                                            | 0.22983                     | 110.11         | 118.62         | 0.21753                | 0.14266                                                         | 112.60         | 120.52         | 0.21512                | 0.09642                                                         | 113.35         | 120.48         | 0.21161                |
| 140                                                             | 0.24541                     | 113.85         | 122.93         | 0.22481                |                                                                 |                |                |                        |                                                                 |                |                |                        |
| 160                                                             | 0.26412                     | 118.66         | 128.44         | 0.23384                | 0.14656                                                         | 113.82         | 121.95         | 0.21745                |                                                                 |                |                |                        |
| 180                                                             | 0.28115                     | 123.35         | 133.76         | 0.24229                | 0.16355                                                         | 119.52         | 128.60         | 0.22802                | 0.09658                                                         | 113.41         | 120.56         | 0.21173                |
| 200                                                             | 0.29704                     | 128.00         | 138.99         | 0.25035                | 0.17776                                                         | 124.78         | 134.65         | 0.23733                | 0.11440                                                         | 120.52         | 128.99         | 0.22471                |
| 220                                                             | 0.31212                     | 132.64         | 144.19         | 0.25812                | 0.19044                                                         | 129.85         | 140.42         | 0.24594                | 0.12746                                                         | 126.44         | 135.88         | 0.23500                |
| 240                                                             | 0.32658                     | 137.30         | 149.38         | 0.26565                | 0.20211                                                         | 134.83         | 146.05         | 0.25410                | 0.13853                                                         | 131.95         | 142.20         | 0.24418                |
| 260                                                             | 0.34054                     | 141.99         | 154.59         | 0.27298                | 0.21306                                                         | 139.77         | 151.59         | 0.26192                | 0.14844                                                         | 137.26         | 148.25         | 0.25270                |
| 280                                                             | 0.35410                     | 146.72         | 159.82         | 0.28015                | 0.22347                                                         | 144.70         | 157.11         | 0.26947                | 0.15756                                                         | 142.48         | 154.14         | 0.26077                |
| 300                                                             | 0.36733                     | 151.50         | 165.09         | 0.28718                | 0.23346                                                         | 149.65         | 162.61         | 0.27681                | 0.16611                                                         | 147.65         | 159.94         | 0.26851                |
| 320                                                             | 0.38029                     | 156.33         | 170.40         | 0.29408                | 0.24310                                                         | 154.63         | 168.12         | 0.28398                | 0.17423                                                         | 152.80         | 165.70         | 0.27599                |
| 340                                                             | 0.39300                     | 161.22         | 175.77         | 0.30087                | 0.25246                                                         | 159.64         | 173.66         | 0.29098                | 0.18201                                                         | 157.97         | 171.44         | 0.28326                |
| 360                                                             | 0.40552                     | 166.17         | 181.18         | 0.30756                | 0.26159                                                         | 164.70         | 179.22         | 0.29786                | 0.18951                                                         | 163.15         | 177.18         | 0.29035                |



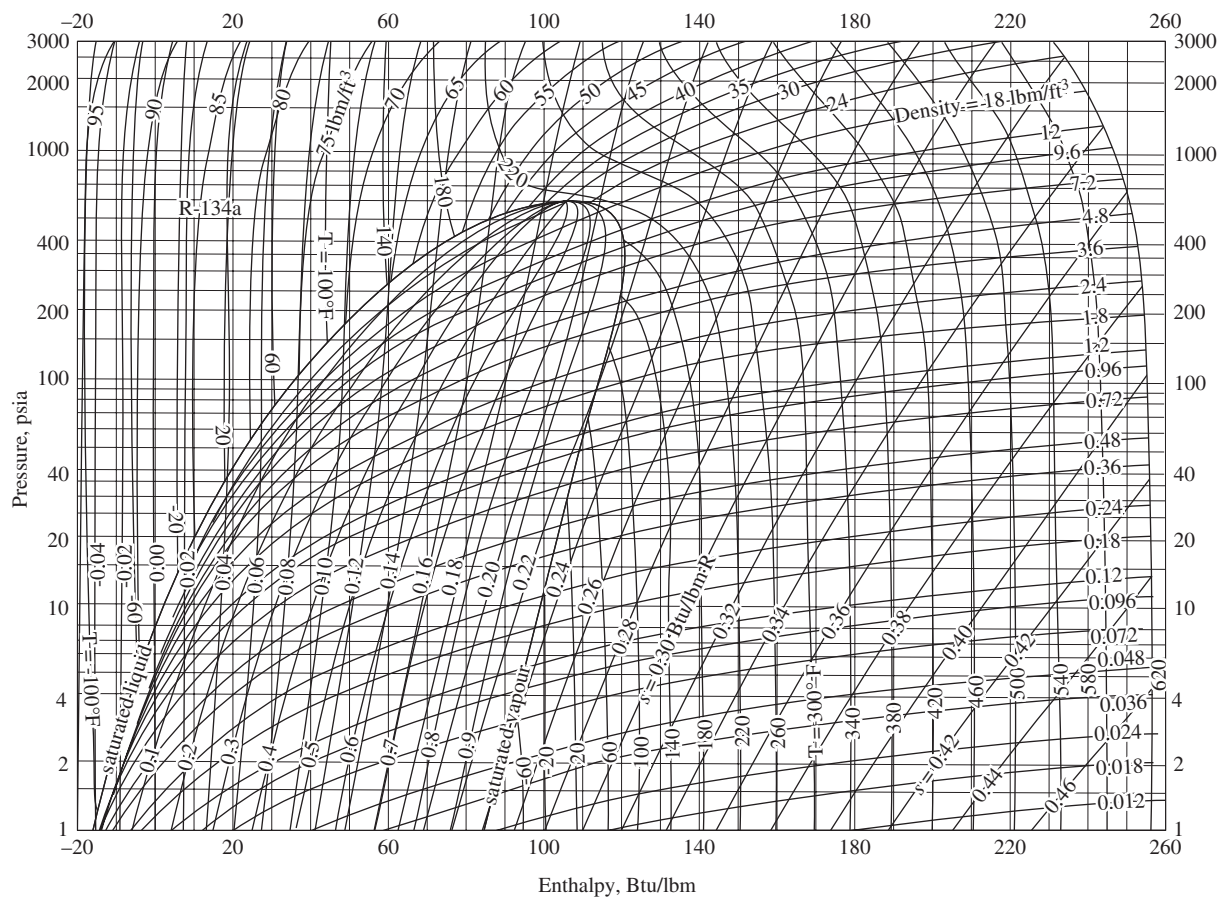


FIGURE A-14E

*P-h* diagram for refrigerant-134a.

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TABLE A-16E

Properties of the atmosphere at high altitude

| Altitude,<br>ft | Temperature,<br>°F | Pressure,<br>psia | Gravity,<br>$g$ , ft/s <sup>2</sup> | Speed of<br>sound,<br>ft/s | Density,<br>lbm/ft <sup>3</sup> | Viscosity<br>$\mu$ , lbm/ft · s | Thermal<br>conductivity,<br>Btu/h · ft · R |
|-----------------|--------------------|-------------------|-------------------------------------|----------------------------|---------------------------------|---------------------------------|--------------------------------------------|
| 0               | 59.00              | 14.7              | 32.174                              | 1116                       | 0.07647                         | $1.202 \times 10^{-5}$          | 0.0146                                     |
| 500             | 57.22              | 14.4              | 32.173                              | 1115                       | 0.07536                         | $1.199 \times 10^{-5}$          | 0.0146                                     |
| 1000            | 55.43              | 14.2              | 32.171                              | 1113                       | 0.07426                         | $1.196 \times 10^{-5}$          | 0.0146                                     |
| 1500            | 53.65              | 13.9              | 32.169                              | 1111                       | 0.07317                         | $1.193 \times 10^{-5}$          | 0.0145                                     |
| 2000            | 51.87              | 13.7              | 32.168                              | 1109                       | 0.07210                         | $1.190 \times 10^{-5}$          | 0.0145                                     |
| 2500            | 50.09              | 13.4              | 32.166                              | 1107                       | 0.07104                         | $1.186 \times 10^{-5}$          | 0.0144                                     |
| 3000            | 48.30              | 13.2              | 32.165                              | 1105                       | 0.06998                         | $1.183 \times 10^{-5}$          | 0.0144                                     |
| 3500            | 46.52              | 12.9              | 32.163                              | 1103                       | 0.06985                         | $1.180 \times 10^{-5}$          | 0.0143                                     |
| 4000            | 44.74              | 12.7              | 32.162                              | 1101                       | 0.06792                         | $1.177 \times 10^{-5}$          | 0.0143                                     |
| 4500            | 42.96              | 12.5              | 32.160                              | 1099                       | 0.06690                         | $1.173 \times 10^{-5}$          | 0.0142                                     |
| 5000            | 41.17              | 12.2              | 32.159                              | 1097                       | 0.06590                         | $1.170 \times 10^{-5}$          | 0.0142                                     |
| 5500            | 39.39              | 12.0              | 32.157                              | 1095                       | 0.06491                         | $1.167 \times 10^{-5}$          | 0.0141                                     |
| 6000            | 37.61              | 11.8              | 32.156                              | 1093                       | 0.06393                         | $1.164 \times 10^{-5}$          | 0.0141                                     |
| 6500            | 35.83              | 11.6              | 32.154                              | 1091                       | 0.06296                         | $1.160 \times 10^{-5}$          | 0.0141                                     |
| 7000            | 34.05              | 11.3              | 32.152                              | 1089                       | 0.06200                         | $1.157 \times 10^{-5}$          | 0.0140                                     |
| 7500            | 32.26              | 11.1              | 32.151                              | 1087                       | 0.06105                         | $1.154 \times 10^{-5}$          | 0.0140                                     |
| 8000            | 30.48              | 10.9              | 32.149                              | 1085                       | 0.06012                         | $1.150 \times 10^{-5}$          | 0.0139                                     |
| 8500            | 28.70              | 10.7              | 32.148                              | 1083                       | 0.05919                         | $1.147 \times 10^{-5}$          | 0.0139                                     |
| 9000            | 26.92              | 10.5              | 32.146                              | 1081                       | 0.05828                         | $1.144 \times 10^{-5}$          | 0.0138                                     |
| 9500            | 25.14              | 10.3              | 32.145                              | 1079                       | 0.05738                         | $1.140 \times 10^{-5}$          | 0.0138                                     |
| 10,000          | 23.36              | 10.1              | 32.145                              | 1077                       | 0.05648                         | $1.137 \times 10^{-5}$          | 0.0137                                     |
| 11,000          | 19.79              | 9.72              | 32.140                              | 1073                       | 0.05473                         | $1.130 \times 10^{-5}$          | 0.0136                                     |
| 12,000          | 16.23              | 9.34              | 32.137                              | 1069                       | 0.05302                         | $1.124 \times 10^{-5}$          | 0.0136                                     |
| 13,000          | 12.67              | 8.99              | 32.134                              | 1065                       | 0.05135                         | $1.117 \times 10^{-5}$          | 0.0135                                     |
| 14,000          | 9.12               | 8.63              | 32.131                              | 1061                       | 0.04973                         | $1.110 \times 10^{-5}$          | 0.0134                                     |
| 15,000          | 5.55               | 8.29              | 32.128                              | 1057                       | 0.04814                         | $1.104 \times 10^{-5}$          | 0.0133                                     |
| 16,000          | +1.99              | 7.97              | 32.125                              | 1053                       | 0.04659                         | $1.097 \times 10^{-5}$          | 0.0132                                     |
| 17,000          | -1.58              | 7.65              | 32.122                              | 1049                       | 0.04508                         | $1.090 \times 10^{-5}$          | 0.0132                                     |
| 18,000          | -5.14              | 7.34              | 32.119                              | 1045                       | 0.04361                         | $1.083 \times 10^{-5}$          | 0.0130                                     |
| 19,000          | -8.70              | 7.05              | 32.115                              | 1041                       | 0.04217                         | $1.076 \times 10^{-5}$          | 0.0129                                     |
| 20,000          | -12.2              | 6.76              | 32.112                              | 1037                       | 0.04077                         | $1.070 \times 10^{-5}$          | 0.0128                                     |
| 22,000          | -19.4              | 6.21              | 32.106                              | 1029                       | 0.03808                         | $1.056 \times 10^{-5}$          | 0.0126                                     |
| 24,000          | -26.5              | 5.70              | 32.100                              | 1020                       | 0.03553                         | $1.042 \times 10^{-5}$          | 0.0124                                     |
| 26,000          | -33.6              | 5.22              | 32.094                              | 1012                       | 0.03311                         | $1.028 \times 10^{-5}$          | 0.0122                                     |
| 28,000          | -40.7              | 4.78              | 32.088                              | 1003                       | 0.03082                         | $1.014 \times 10^{-5}$          | 0.0121                                     |
| 30,000          | -47.8              | 4.37              | 32.082                              | 995                        | 0.02866                         | $1.000 \times 10^{-5}$          | 0.0119                                     |
| 32,000          | -54.9              | 3.99              | 32.08                               | 987                        | 0.02661                         | $0.986 \times 10^{-5}$          | 0.0117                                     |
| 34,000          | -62.0              | 3.63              | 32.07                               | 978                        | 0.02468                         | $0.971 \times 10^{-5}$          | 0.0115                                     |
| 36,000          | -69.2              | 3.30              | 32.06                               | 969                        | 0.02285                         | $0.956 \times 10^{-5}$          | 0.0113                                     |
| 38,000          | -69.7              | 3.05              | 32.06                               | 968                        | 0.02079                         | $0.955 \times 10^{-5}$          | 0.0113                                     |
| 40,000          | -69.7              | 2.73              | 32.05                               | 968                        | 0.01890                         | $0.955 \times 10^{-5}$          | 0.0113                                     |
| 45,000          | -69.7              | 2.148             | 32.04                               | 968                        | 0.01487                         | $0.955 \times 10^{-5}$          | 0.0113                                     |
| 50,000          | -69.7              | 1.691             | 32.02                               | 968                        | 0.01171                         | $0.955 \times 10^{-5}$          | 0.0113                                     |
| 55,000          | -69.7              | 1.332             | 32.00                               | 968                        | 0.00922                         | $0.955 \times 10^{-5}$          | 0.0113                                     |
| 60,000          | -69.7              | 1.048             | 31.99                               | 968                        | 0.00726                         | $0.955 \times 10^{-5}$          | 0.0113                                     |

Source: U.S. Standard Atmosphere Supplements, U.S. Government Printing Office, 1966. Based on year-round mean conditions at 45° latitude and varies with the time of the year and the weather patterns. The conditions at sea level ( $z = 0$ ) are taken to be  $P = 14.696$  psia,  $T = 59^\circ\text{F}$ ,  $\rho = 0.076474$  lbm/ft<sup>3</sup>,  $g = 32.1741$  ft/s<sup>2</sup>.

TABLE A-17E

Ideal-gas properties of air

| $T$<br>R | $h$<br>Btu/lbm | $P_r$  | $u$<br>Btu/lbm | $v_r$  | $s^\circ$<br>Btu/lbm · R | $T$<br>R | $h$<br>Btu/lbm | $P_r$  | $u$<br>Btu/lbm | $v_r$  | $s^\circ$<br>Btu/lbm · R |
|----------|----------------|--------|----------------|--------|--------------------------|----------|----------------|--------|----------------|--------|--------------------------|
| 360      | 85.97          | 0.3363 | 61.29          | 396.6  | 0.50369                  | 1600     | 395.74         | 71.13  | 286.06         | 8.263  | 0.87130                  |
| 380      | 90.75          | 0.4061 | 64.70          | 346.6  | 0.51663                  | 1650     | 409.13         | 80.89  | 296.03         | 7.556  | 0.87954                  |
| 400      | 95.53          | 0.4858 | 68.11          | 305.0  | 0.52890                  | 1700     | 422.59         | 90.95  | 306.06         | 6.924  | 0.88758                  |
| 420      | 100.32         | 0.5760 | 71.52          | 270.1  | 0.54058                  | 1750     | 436.12         | 101.98 | 316.16         | 6.357  | 0.89542                  |
| 440      | 105.11         | 0.6776 | 74.93          | 240.6  | 0.55172                  | 1800     | 449.71         | 114.0  | 326.32         | 5.847  | 0.90308                  |
| 460      | 109.90         | 0.7913 | 78.36          | 215.33 | 0.56235                  | 1850     | 463.37         | 127.2  | 336.55         | 5.388  | 0.91056                  |
| 480      | 114.69         | 0.9182 | 81.77          | 193.65 | 0.57255                  | 1900     | 477.09         | 141.5  | 346.85         | 4.974  | 0.91788                  |
| 500      | 119.48         | 1.0590 | 85.20          | 174.90 | 0.58233                  | 1950     | 490.88         | 157.1  | 357.20         | 4.598  | 0.92504                  |
| 520      | 124.27         | 1.2147 | 88.62          | 158.58 | 0.59173                  | 2000     | 504.71         | 174.0  | 367.61         | 4.258  | 0.93205                  |
| 537      | 128.10         | 1.3593 | 91.53          | 146.34 | 0.59945                  | 2050     | 518.71         | 192.3  | 378.08         | 3.949  | 0.93891                  |
| 540      | 129.06         | 1.3860 | 92.04          | 144.32 | 0.60078                  | 2100     | 532.55         | 212.1  | 388.60         | 3.667  | 0.94564                  |
| 560      | 133.86         | 1.5742 | 95.47          | 131.78 | 0.60950                  | 2150     | 546.54         | 223.5  | 399.17         | 3.410  | 0.95222                  |
| 580      | 138.66         | 1.7800 | 98.90          | 120.70 | 0.61793                  | 2200     | 560.59         | 256.6  | 409.78         | 3.176  | 0.95919                  |
| 600      | 143.47         | 2.005  | 102.34         | 110.88 | 0.62607                  | 2250     | 574.69         | 281.4  | 420.46         | 2.961  | 0.96501                  |
| 620      | 148.28         | 2.249  | 105.78         | 102.12 | 0.63395                  | 2300     | 588.82         | 308.1  | 431.16         | 2.765  | 0.97123                  |
| 640      | 153.09         | 2.514  | 109.21         | 94.30  | 0.64159                  | 2350     | 603.00         | 336.8  | 441.91         | 2.585  | 0.97732                  |
| 660      | 157.92         | 2.801  | 112.67         | 87.27  | 0.64902                  | 2400     | 617.22         | 367.6  | 452.70         | 2.419  | 0.98331                  |
| 680      | 162.73         | 3.111  | 116.12         | 80.96  | 0.65621                  | 2450     | 631.48         | 400.5  | 463.54         | 2.266  | 0.98919                  |
| 700      | 167.56         | 3.446  | 119.58         | 75.25  | 0.66321                  | 2500     | 645.78         | 435.7  | 474.40         | 2.125  | 0.99497                  |
| 720      | 172.39         | 3.806  | 123.04         | 70.07  | 0.67002                  | 2550     | 660.12         | 473.3  | 485.31         | 1.996  | 1.00064                  |
| 740      | 177.23         | 4.193  | 126.51         | 65.38  | 0.67665                  | 2600     | 674.49         | 513.5  | 496.26         | 1.876  | 1.00623                  |
| 760      | 182.08         | 4.607  | 129.99         | 61.10  | 0.68312                  | 2650     | 688.90         | 556.3  | 507.25         | 1.765  | 1.01172                  |
| 780      | 186.94         | 5.051  | 133.47         | 57.20  | 0.68942                  | 2700     | 703.35         | 601.9  | 518.26         | 1.662  | 1.01712                  |
| 800      | 191.81         | 5.526  | 136.97         | 53.63  | 0.69558                  | 2750     | 717.83         | 650.4  | 529.31         | 1.566  | 1.02244                  |
| 820      | 196.69         | 6.033  | 140.47         | 50.35  | 0.70160                  | 2800     | 732.33         | 702.0  | 540.40         | 1.478  | 1.02767                  |
| 840      | 201.56         | 6.573  | 143.98         | 47.34  | 0.70747                  | 2850     | 746.88         | 756.7  | 551.52         | 1.395  | 1.03282                  |
| 860      | 206.46         | 7.149  | 147.50         | 44.57  | 0.71323                  | 2900     | 761.45         | 814.8  | 562.66         | 1.318  | 1.03788                  |
| 880      | 211.35         | 7.761  | 151.02         | 42.01  | 0.71886                  | 2950     | 776.05         | 876.4  | 573.84         | 1.247  | 1.04288                  |
| 900      | 216.26         | 8.411  | 154.57         | 39.64  | 0.72438                  | 3000     | 790.68         | 941.4  | 585.04         | 1.180  | 1.04779                  |
| 920      | 221.18         | 9.102  | 158.12         | 37.44  | 0.72979                  | 3050     | 805.34         | 1011   | 596.28         | 1.118  | 1.05264                  |
| 940      | 226.11         | 9.834  | 161.68         | 35.41  | 0.73509                  | 3100     | 820.03         | 1083   | 607.53         | 1.060  | 1.05741                  |
| 960      | 231.06         | 10.61  | 165.26         | 33.52  | 0.74030                  | 3150     | 834.75         | 1161   | 618.82         | 1.006  | 1.06212                  |
| 980      | 236.02         | 11.43  | 168.83         | 31.76  | 0.74540                  | 3200     | 849.48         | 1242   | 630.12         | 0.955  | 1.06676                  |
| 1000     | 240.98         | 12.30  | 172.43         | 30.12  | 0.75042                  | 3250     | 864.24         | 1328   | 641.46         | 0.907  | 1.07134                  |
| 1040     | 250.95         | 14.18  | 179.66         | 27.17  | 0.76019                  | 3300     | 879.02         | 1418   | 652.81         | 0.8621 | 1.07585                  |
| 1080     | 260.97         | 16.28  | 186.93         | 24.58  | 0.76964                  | 3350     | 893.83         | 1513   | 664.20         | 0.8202 | 1.08031                  |
| 1120     | 271.03         | 18.60  | 194.25         | 22.30  | 0.77880                  | 3400     | 908.66         | 1613   | 675.60         | 0.7807 | 1.08470                  |
| 1160     | 281.14         | 21.18  | 201.63         | 20.29  | 0.78767                  | 3450     | 923.52         | 1719   | 687.04         | 0.7436 | 1.08904                  |
| 1200     | 291.30         | 24.01  | 209.05         | 18.51  | 0.79628                  | 3500     | 938.40         | 1829   | 698.48         | 0.7087 | 1.09332                  |
| 1240     | 301.52         | 27.13  | 216.53         | 16.93  | 0.80466                  | 3550     | 953.30         | 1946   | 709.95         | 0.6759 | 1.09755                  |
| 1280     | 311.79         | 30.55  | 224.05         | 15.52  | 0.81280                  | 3600     | 968.21         | 2068   | 721.44         | 0.6449 | 1.10172                  |
| 1320     | 322.11         | 34.31  | 231.63         | 14.25  | 0.82075                  | 3650     | 983.15         | 2196   | 732.95         | 0.6157 | 1.10584                  |
| 1360     | 332.48         | 38.41  | 239.25         | 13.12  | 0.82848                  | 3700     | 998.11         | 2330   | 744.48         | 0.5882 | 1.10991                  |
| 1400     | 342.90         | 42.88  | 246.93         | 12.10  | 0.83604                  | 3750     | 1013.1         | 2471   | 756.04         | 0.5621 | 1.11393                  |
| 1440     | 353.37         | 47.75  | 254.66         | 11.17  | 0.84341                  | 3800     | 1028.1         | 2618   | 767.60         | 0.5376 | 1.11791                  |
| 1480     | 363.89         | 53.04  | 262.44         | 10.34  | 0.85062                  | 3850     | 1043.1         | 2773   | 779.19         | 0.5143 | 1.12183                  |
| 1520     | 374.47         | 58.78  | 270.26         | 9.578  | 0.85767                  | 3900     | 1058.1         | 2934   | 790.80         | 0.4923 | 1.12571                  |
| 1560     | 385.08         | 65.00  | 278.13         | 8.890  | 0.86456                  | 3950     | 1073.2         | 3103   | 802.43         | 0.4715 | 1.12955                  |

TABLE A-17E

Ideal-gas properties of air (*Concluded*)

| $T$<br>R | $h$<br>Btu/lbm | $P_r$ | $u$<br>Btu/lbm | $v_r$  | $s^\circ$<br>Btu/lbm · R | $T$<br>R | $h$<br>Btu/lbm | $P_r$  | $u$<br>Btu/lbm | $v_r$  | $s^\circ$<br>Btu/lbm · R |
|----------|----------------|-------|----------------|--------|--------------------------|----------|----------------|--------|----------------|--------|--------------------------|
| 4000     | 1088.3         | 3280  | 814.06         | 0.4518 | 1.13334                  | 4600     | 1270.4         | 6089   | 955.04         | 0.2799 | 1.17575                  |
| 4050     | 1103.4         | 3464  | 825.72         | 0.4331 | 1.13709                  | 4700     | 1300.9         | 6701   | 978.73         | 0.2598 | 1.18232                  |
| 4100     | 1118.5         | 3656  | 837.40         | 0.4154 | 1.14079                  | 4800     | 1331.5         | 7362   | 1002.5         | 0.2415 | 1.18876                  |
| 4150     | 1133.6         | 3858  | 849.09         | 0.3985 | 1.14446                  | 4900     | 1362.2         | 8073   | 1026.3         | 0.2248 | 1.19508                  |
| 4200     | 1148.7         | 4067  | 860.81         | 0.3826 | 1.14809                  | 5000     | 1392.9         | 8837   | 1050.1         | 0.2096 | 1.20129                  |
| 4300     | 1179.0         | 4513  | 884.28         | 0.3529 | 1.15522                  | 5100     | 1423.6         | 9658   | 1074.0         | 0.1956 | 1.20738                  |
| 4400     | 1209.4         | 4997  | 907.81         | 0.3262 | 1.16221                  | 5200     | 1454.4         | 10,539 | 1098.0         | 0.1828 | 1.21336                  |
| 4500     | 1239.9         | 5521  | 931.39         | 0.3019 | 1.16905                  | 5300     | 1485.3         | 11,481 | 1122.0         | 0.1710 | 1.21923                  |

*Note:* The properties  $P_r$  (relative pressure) and  $v_r$  (relative specific volume) are dimensionless quantities used in the analysis of isentropic processes, and should not be confused with the properties pressure and specific volume.

*Source:* Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), pp. 832–33, Table A–5. Originally published in J. H. Keenan and J. Kaye, *Gas Tables* (New York: John Wiley & Sons, 1948).

TABLE A-18E

Ideal-gas properties of nitrogen,  $N_2$ 

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 300      | 2,082.0                | 1,486.2                | 41.695                           | 1080     | 7,551.0                | 5,406.2                | 50.651                           |
| 320      | 2,221.0                | 1,585.5                | 42.143                           | 1100     | 7,695.0                | 5,510.5                | 50.783                           |
| 340      | 2,360.0                | 1,684.4                | 42.564                           | 1120     | 7,839.3                | 5,615.2                | 50.912                           |
| 360      | 2,498.9                | 1,784.0                | 42.962                           | 1140     | 7,984.0                | 5,720.1                | 51.040                           |
| 380      | 2,638.0                | 1,883.4                | 43.337                           | 1160     | 8,129.0                | 5,825.4                | 51.167                           |
| 400      | 2,777.0                | 1,982.6                | 43.694                           | 1180     | 8,274.4                | 5,931.0                | 51.291                           |
| 420      | 2,916.1                | 2,082.0                | 44.034                           | 1200     | 8,420.0                | 6,037.0                | 51.143                           |
| 440      | 3,055.1                | 2,181.3                | 44.357                           | 1220     | 8,566.1                | 6,143.4                | 51.534                           |
| 460      | 3,194.1                | 2,280.6                | 44.665                           | 1240     | 8,712.6                | 6,250.1                | 51.653                           |
| 480      | 3,333.1                | 2,379.9                | 44.962                           | 1260     | 8,859.3                | 6,357.2                | 51.771                           |
| 500      | 3,472.2                | 2,479.3                | 45.246                           | 1280     | 9,006.4                | 6,464.5                | 51.887                           |
| 520      | 3,611.3                | 2,578.6                | 45.519                           | 1300     | 9,153.9                | 6,572.3                | 51.001                           |
| 537      | 3,729.5                | 2,663.1                | 45.743                           | 1320     | 9,301.8                | 6,680.4                | 52.114                           |
| 540      | 3,750.3                | 2,678.0                | 45.781                           | 1340     | 9,450.0                | 6,788.9                | 52.225                           |
| 560      | 3,889.5                | 2,777.4                | 46.034                           | 1360     | 9,598.6                | 6,897.8                | 52.335                           |
| 580      | 4,028.7                | 2,876.9                | 46.278                           | 1380     | 9,747.5                | 7,007.0                | 52.444                           |
| 600      | 4,167.9                | 2,976.4                | 46.514                           | 1400     | 9,896.9                | 7,116.7                | 52.551                           |
| 620      | 4,307.1                | 3,075.9                | 46.742                           | 1420     | 10,046.6               | 7,226.7                | 52.658                           |
| 640      | 4,446.4                | 3,175.5                | 46.964                           | 1440     | 10,196.6               | 7,337.0                | 52.763                           |
| 660      | 4,585.8                | 3,275.2                | 47.178                           | 1460     | 10,347.0               | 7,447.6                | 52.867                           |
| 680      | 4,725.3                | 3,374.9                | 47.386                           | 1480     | 10,497.8               | 7,558.7                | 52.969                           |
| 700      | 4,864.9                | 3,474.8                | 47.588                           | 1500     | 10,648.0               | 7,670.1                | 53.071                           |
| 720      | 5,004.5                | 3,574.7                | 47.785                           | 1520     | 10,800.4               | 7,781.9                | 53.171                           |
| 740      | 5,144.3                | 3,674.7                | 47.977                           | 1540     | 10,952.2               | 7,893.9                | 53.271                           |
| 760      | 5,284.1                | 3,774.9                | 48.164                           | 1560     | 11,104.3               | 8,006.4                | 53.369                           |
| 780      | 5,424.2                | 3,875.2                | 48.345                           | 1580     | 11,256.9               | 8,119.2                | 53.465                           |
| 800      | 5,564.4                | 3,975.7                | 48.522                           | 1600     | 11,409.7               | 8,232.3                | 53.561                           |
| 820      | 5,704.7                | 4,076.3                | 48.696                           | 1620     | 11,562.8               | 8,345.7                | 53.656                           |
| 840      | 5,845.3                | 4,177.1                | 48.865                           | 1640     | 11,716.4               | 8,459.6                | 53.751                           |
| 860      | 5,985.9                | 4,278.1                | 49.031                           | 1660     | 11,870.2               | 8,573.6                | 53.844                           |
| 880      | 6,126.9                | 4,379.4                | 49.193                           | 1680     | 12,024.3               | 8,688.1                | 53.936                           |
| 900      | 6,268.1                | 4,480.8                | 49.352                           | 1700     | 12,178.9               | 8,802.9                | 54.028                           |
| 920      | 6,409.6                | 4,582.6                | 49.507                           | 1720     | 12,333.7               | 8,918.0                | 54.118                           |
| 940      | 6,551.2                | 4,684.5                | 49.659                           | 1740     | 12,488.8               | 9,033.4                | 54.208                           |
| 960      | 6,693.1                | 4,786.7                | 49.808                           | 1760     | 12,644.3               | 9,149.2                | 54.297                           |
| 980      | 6,835.4                | 4,889.3                | 49.955                           | 1780     | 12,800.2               | 9,265.3                | 54.385                           |
| 1000     | 6,977.9                | 4,992.0                | 50.099                           | 1800     | 12,956.3               | 9,381.7                | 54.472                           |
| 1020     | 7,120.7                | 5,095.1                | 50.241                           | 1820     | 13,112.7               | 9,498.4                | 54.559                           |
| 1040     | 7,263.8                | 5,198.5                | 50.380                           | 1840     | 13,269.5               | 9,615.5                | 54.645                           |
| 1060     | 7,407.2                | 5,302.2                | 50.516                           | 1860     | 13,426.5               | 9,732.8                | 54.729                           |

TABLE A-18E

Ideal-gas properties of nitrogen,  $N_2$  (Concluded)

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 1900     | 13,742                 | 9,968                  | 54.896                           | 3500     | 27,016                 | 20,065                 | 59.944                           |
| 1940     | 14,058                 | 10,205                 | 55.061                           | 3540     | 27,359                 | 20,329                 | 60.041                           |
| 1980     | 14,375                 | 10,443                 | 55.223                           | 3580     | 27,703                 | 20,593                 | 60.138                           |
| 2020     | 14,694                 | 10,682                 | 55.383                           | 3620     | 28,046                 | 20,858                 | 60.234                           |
| 2060     | 15,013                 | 10,923                 | 55.540                           | 3660     | 28,391                 | 21,122                 | 60.328                           |
| 2100     | 15,334                 | 11,164                 | 55.694                           | 3700     | 28,735                 | 21,387                 | 60.422                           |
| 2140     | 15,656                 | 11,406                 | 55.846                           | 3740     | 29,080                 | 21,653                 | 60.515                           |
| 2180     | 15,978                 | 11,649                 | 55.995                           | 3780     | 29,425                 | 21,919                 | 60.607                           |
| 2220     | 16,302                 | 11,893                 | 56.141                           | 3820     | 29,771                 | 22,185                 | 60.698                           |
| 2260     | 16,626                 | 12,138                 | 56.286                           | 3860     | 30,117                 | 22,451                 | 60.788                           |
| 2300     | 16,951                 | 12,384                 | 56.429                           | 3900     | 30,463                 | 22,718                 | 60.877                           |
| 2340     | 17,277                 | 12,630                 | 56.570                           | 3940     | 30,809                 | 22,985                 | 60.966                           |
| 2380     | 17,604                 | 12,878                 | 56.708                           | 3980     | 31,156                 | 23,252                 | 61.053                           |
| 2420     | 17,932                 | 13,126                 | 56.845                           | 4020     | 31,503                 | 23,520                 | 61.139                           |
| 2460     | 18,260                 | 13,375                 | 56.980                           | 4060     | 31,850                 | 23,788                 | 61.225                           |
| 2500     | 18,590                 | 13,625                 | 57.112                           | 4100     | 32,198                 | 24,056                 | 61.310                           |
| 2540     | 18,919                 | 13,875                 | 57.243                           | 4140     | 32,546                 | 24,324                 | 61.395                           |
| 2580     | 19,250                 | 14,127                 | 57.372                           | 4180     | 32,894                 | 24,593                 | 61.479                           |
| 2620     | 19,582                 | 14,379                 | 57.499                           | 4220     | 33,242                 | 24,862                 | 61.562                           |
| 2660     | 19,914                 | 14,631                 | 57.625                           | 4260     | 33,591                 | 25,131                 | 61.644                           |
| 2700     | 20,246                 | 14,885                 | 57.750                           | 4300     | 33,940                 | 25,401                 | 61.726                           |
| 2740     | 20,580                 | 15,139                 | 57.872                           | 4340     | 34,289                 | 25,670                 | 61.806                           |
| 2780     | 20,914                 | 15,393                 | 57.993                           | 4380     | 34,638                 | 25,940                 | 61.887                           |
| 2820     | 21,248                 | 15,648                 | 58.113                           | 4420     | 34,988                 | 26,210                 | 61.966                           |
| 2860     | 21,584                 | 15,905                 | 58.231                           | 4460     | 35,338                 | 26,481                 | 62.045                           |
| 2900     | 21,920                 | 16,161                 | 58.348                           | 4500     | 35,688                 | 26,751                 | 62.123                           |
| 2940     | 22,256                 | 16,417                 | 58.463                           | 4540     | 36,038                 | 27,022                 | 62.201                           |
| 2980     | 22,593                 | 16,675                 | 58.576                           | 4580     | 36,389                 | 27,293                 | 62.278                           |
| 3020     | 22,930                 | 16,933                 | 58.688                           | 4620     | 36,739                 | 27,565                 | 62.354                           |
| 3060     | 23,268                 | 17,192                 | 58.800                           | 4660     | 37,090                 | 27,836                 | 62.429                           |
| 3100     | 23,607                 | 17,451                 | 58.910                           | 4700     | 37,441                 | 28,108                 | 62.504                           |
| 3140     | 23,946                 | 17,710                 | 59.019                           | 4740     | 37,792                 | 28,379                 | 62.578                           |
| 3180     | 24,285                 | 17,970                 | 59.126                           | 4780     | 38,144                 | 28,651                 | 62.652                           |
| 3220     | 24,625                 | 18,231                 | 59.232                           | 4820     | 38,495                 | 28,924                 | 62.725                           |
| 3260     | 24,965                 | 18,491                 | 59.338                           | 4860     | 38,847                 | 29,196                 | 62.798                           |
| 3300     | 25,306                 | 18,753                 | 59.442                           | 4900     | 39,199                 | 29,468                 | 62.870                           |
| 3340     | 25,647                 | 19,014                 | 59.544                           | 5000     | 40,080                 | 30,151                 | 63.049                           |
| 3380     | 25,989                 | 19,277                 | 59.646                           | 5100     | 40,962                 | 30,834                 | 63.223                           |
| 3420     | 26,331                 | 19,539                 | 59.747                           | 5200     | 41,844                 | 31,518                 | 63.395                           |
| 3460     | 26,673                 | 19,802                 | 59.846                           | 5300     | 42,728                 | 32,203                 | 63.563                           |

Source: Tables A-18E through A-23E are adapted from Kenneth Wark, *Thermodynamics*, 4th ed. (New York: McGraw-Hill, 1983), pp. 834–44. Originally published in J. H. Keenan and J. Kaye, *Gas Tables* (New York: John Wiley & Sons, 1945).

TABLE A-19E

Ideal-gas properties of oxygen, O<sub>2</sub>

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 300      | 2,073.5                | 1,477.8                | 44.927                           | 1080     | 7,696.8                | 5,552.1                | 54.064                           |
| 320      | 2,212.6                | 1,577.1                | 45.375                           | 1100     | 7,850.4                | 5,665.9                | 54.204                           |
| 340      | 2,351.7                | 1,676.5                | 45.797                           | 1120     | 8,004.5                | 5,780.3                | 54.343                           |
| 360      | 2,490.8                | 1,775.9                | 46.195                           | 1140     | 8,159.1                | 5,895.2                | 54.480                           |
| 380      | 2,630.0                | 1,875.3                | 46.571                           | 1160     | 8,314.2                | 6,010.6                | 54.614                           |
| 400      | 2,769.1                | 1,974.8                | 46.927                           | 1180     | 8,469.8                | 6,126.5                | 54.748                           |
| 420      | 2,908.3                | 2,074.3                | 47.267                           | 1200     | 8,625.8                | 6,242.8                | 54.879                           |
| 440      | 3,047.5                | 2,173.8                | 47.591                           | 1220     | 8,782.4                | 6,359.6                | 55.008                           |
| 460      | 3,186.9                | 2,273.4                | 47.900                           | 1240     | 8,939.4                | 6,476.9                | 55.136                           |
| 480      | 3,326.5                | 2,373.3                | 48.198                           | 1260     | 9,096.7                | 6,594.5                | 55.262                           |
| 500      | 3,466.2                | 2,473.2                | 48.483                           | 1280     | 9,254.6                | 6,712.7                | 55.386                           |
| 520      | 3,606.1                | 2,573.4                | 48.757                           | 1300     | 9,412.9                | 6,831.3                | 55.508                           |
| 537      | 3,725.1                | 2,658.7                | 48.982                           | 1320     | 9,571.9                | 6,950.2                | 55.630                           |
| 540      | 3,746.2                | 2,673.8                | 49.021                           | 1340     | 9,730.7                | 7,069.6                | 55.750                           |
| 560      | 3,886.6                | 2,774.5                | 49.276                           | 1360     | 9,890.2                | 7,189.4                | 55.867                           |
| 580      | 4,027.3                | 2,875.5                | 49.522                           | 1380     | 10,050.1               | 7,309.6                | 55.984                           |
| 600      | 4,168.3                | 2,976.8                | 49.762                           | 1400     | 10,210.4               | 7,430.1                | 56.099                           |
| 620      | 4,309.7                | 3,078.4                | 49.993                           | 1420     | 10,371.0               | 7,551.1                | 56.213                           |
| 640      | 4,451.4                | 3,180.4                | 50.218                           | 1440     | 10,532.0               | 7,672.4                | 56.326                           |
| 660      | 4,593.5                | 3,282.9                | 50.437                           | 1460     | 10,693.3               | 7,793.9                | 56.437                           |
| 680      | 4,736.2                | 3,385.8                | 50.650                           | 1480     | 10,855.1               | 7,916.0                | 56.547                           |
| 700      | 4,879.3                | 3,489.2                | 50.858                           | 1500     | 11,017.1               | 8,038.3                | 56.656                           |
| 720      | 5,022.9                | 3,593.1                | 51.059                           | 1520     | 11,179.6               | 8,161.1                | 56.763                           |
| 740      | 5,167.0                | 3,697.4                | 51.257                           | 1540     | 11,342.4               | 8,284.2                | 56.869                           |
| 760      | 5,311.4                | 3,802.4                | 51.450                           | 1560     | 11,505.4               | 8,407.4                | 56.975                           |
| 780      | 5,456.4                | 3,907.5                | 51.638                           | 1580     | 11,668.8               | 8,531.1                | 57.079                           |
| 800      | 5,602.0                | 4,013.3                | 51.821                           | 1600     | 11,832.5               | 8,655.1                | 57.182                           |
| 820      | 5,748.1                | 4,119.7                | 52.002                           | 1620     | 11,996.6               | 8,779.5                | 57.284                           |
| 840      | 5,894.8                | 4,226.6                | 52.179                           | 1640     | 12,160.9               | 8,904.1                | 57.385                           |
| 860      | 6,041.9                | 4,334.1                | 52.352                           | 1660     | 12,325.5               | 9,029.0                | 57.484                           |
| 880      | 6,189.6                | 4,442.0                | 52.522                           | 1680     | 12,490.4               | 9,154.1                | 57.582                           |
| 900      | 6,337.9                | 4,550.6                | 52.688                           | 1700     | 12,655.6               | 9,279.6                | 57.680                           |
| 920      | 6,486.7                | 4,659.7                | 52.852                           | 1720     | 12,821.1               | 9,405.4                | 57.777                           |
| 940      | 6,636.1                | 4,769.4                | 53.012                           | 1740     | 12,986.9               | 9,531.5                | 57.873                           |
| 960      | 6,786.0                | 4,879.5                | 53.170                           | 1760     | 13,153.0               | 9,657.9                | 57.968                           |
| 980      | 6,936.4                | 4,990.3                | 53.326                           | 1780     | 13,319.2               | 9,784.4                | 58.062                           |
| 1000     | 7,087.5                | 5,101.6                | 53.477                           | 1800     | 13,485.8               | 9,911.2                | 58.155                           |
| 1020     | 7,238.9                | 5,213.3                | 53.628                           | 1820     | 13,652.5               | 10,038.2               | 58.247                           |
| 1040     | 7,391.0                | 5,325.7                | 53.775                           | 1840     | 13,819.6               | 10,165.6               | 58.339                           |
| 1060     | 7,543.6                | 5,438.6                | 53.921                           | 1860     | 13,986.8               | 10,293.1               | 58.428                           |

TABLE A-19E

Ideal-gas properties of oxygen,  $O_2$  (Concluded)

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 1900     | 14,322                 | 10,549                 | 58.607                           | 3500     | 28,273                 | 21,323                 | 63.914                           |
| 1940     | 14,658                 | 10,806                 | 58.782                           | 3540     | 28,633                 | 21,603                 | 64.016                           |
| 1980     | 14,995                 | 11,063                 | 58.954                           | 3580     | 28,994                 | 21,884                 | 64.114                           |
| 2020     | 15,333                 | 11,321                 | 59.123                           | 3620     | 29,354                 | 22,165                 | 64.217                           |
| 2060     | 15,672                 | 11,581                 | 59.289                           | 3660     | 29,716                 | 22,447                 | 64.316                           |
| 2100     | 16,011                 | 11,841                 | 59.451                           | 3700     | 30,078                 | 22,730                 | 64.415                           |
| 2140     | 16,351                 | 12,101                 | 59.612                           | 3740     | 30,440                 | 23,013                 | 64.512                           |
| 2180     | 16,692                 | 12,363                 | 59.770                           | 3780     | 30,803                 | 23,296                 | 64.609                           |
| 2220     | 17,036                 | 12,625                 | 59.926                           | 3820     | 31,166                 | 23,580                 | 64.704                           |
| 2260     | 17,376                 | 12,888                 | 60.077                           | 3860     | 31,529                 | 23,864                 | 64.800                           |
| 2300     | 17,719                 | 13,151                 | 60.228                           | 3900     | 31,894                 | 24,149                 | 64.893                           |
| 2340     | 18,062                 | 13,416                 | 60.376                           | 3940     | 32,258                 | 24,434                 | 64.986                           |
| 2380     | 18,407                 | 13,680                 | 60.522                           | 3980     | 32,623                 | 24,720                 | 65.078                           |
| 2420     | 18,572                 | 13,946                 | 60.666                           | 4020     | 32,989                 | 25,006                 | 65.169                           |
| 2460     | 19,097                 | 14,212                 | 60.808                           | 4060     | 33,355                 | 25,292                 | 65.260                           |
| 2500     | 19,443                 | 14,479                 | 60.946                           | 4100     | 33,722                 | 25,580                 | 65.350                           |
| 2540     | 19,790                 | 14,746                 | 61.084                           | 4140     | 34,089                 | 25,867                 | 64.439                           |
| 2580     | 20,138                 | 15,014                 | 61.220                           | 4180     | 34,456                 | 26,155                 | 65.527                           |
| 2620     | 20,485                 | 15,282                 | 61.354                           | 4220     | 34,824                 | 26,144                 | 65.615                           |
| 2660     | 20,834                 | 15,551                 | 61.486                           | 4260     | 35,192                 | 26,733                 | 65.702                           |
| 2700     | 21,183                 | 15,821                 | 61.616                           | 4300     | 35,561                 | 27,022                 | 65.788                           |
| 2740     | 21,533                 | 16,091                 | 61.744                           | 4340     | 35,930                 | 27,312                 | 65.873                           |
| 2780     | 21,883                 | 16,362                 | 61.871                           | 4380     | 36,300                 | 27,602                 | 65.958                           |
| 2820     | 22,232                 | 16,633                 | 61.996                           | 4420     | 36,670                 | 27,823                 | 66.042                           |
| 2860     | 22,584                 | 16,905                 | 62.120                           | 4460     | 37,041                 | 28,184                 | 66.125                           |
| 2900     | 22,936                 | 17,177                 | 62.242                           | 4500     | 37,412                 | 28,475                 | 66.208                           |
| 2940     | 23,288                 | 17,450                 | 62.363                           | 4540     | 37,783                 | 28,768                 | 66.290                           |
| 2980     | 23,641                 | 17,723                 | 62.483                           | 4580     | 38,155                 | 29,060                 | 66.372                           |
| 3020     | 23,994                 | 17,997                 | 62.599                           | 4620     | 38,528                 | 29,353                 | 66.453                           |
| 3060     | 24,348                 | 18,271                 | 62.716                           | 4660     | 38,900                 | 29,646                 | 66.533                           |
| 3100     | 24,703                 | 18,546                 | 62.831                           | 4700     | 39,274                 | 29,940                 | 66.613                           |
| 3140     | 25,057                 | 18,822                 | 62.945                           | 4740     | 39,647                 | 30,234                 | 66.691                           |
| 3180     | 25,413                 | 19,098                 | 63.057                           | 4780     | 40,021                 | 30,529                 | 66.770                           |
| 3220     | 25,769                 | 19,374                 | 63.169                           | 4820     | 40,396                 | 30,824                 | 66.848                           |
| 3260     | 26,175                 | 19,651                 | 63.279                           | 4860     | 40,771                 | 31,120                 | 66.925                           |
| 3300     | 26,412                 | 19,928                 | 63.386                           | 4900     | 41,146                 | 31,415                 | 67.003                           |
| 3340     | 26,839                 | 20,206                 | 63.494                           | 5000     | 42,086                 | 32,157                 | 67.193                           |
| 3380     | 27,197                 | 20,485                 | 63.601                           | 5100     | 43,021                 | 32,901                 | 67.380                           |
| 3420     | 27,555                 | 20,763                 | 63.706                           | 5200     | 43,974                 | 33,648                 | 67.562                           |
| 3460     | 27,914                 | 21,043                 | 63.811                           | 5300     | 44,922                 | 34,397                 | 67.743                           |



TABLE A-20E

Ideal-gas properties of carbon dioxide, CO<sub>2</sub>

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 300      | 2,108.2                | 1,512.4                | 46.353                           | 1080     | 9,575.8                | 7,431.1                | 58.072                           |
| 320      | 2,256.6                | 1,621.1                | 46.832                           | 1100     | 9,802.6                | 7,618.1                | 58.281                           |
| 340      | 2,407.3                | 1,732.1                | 47.289                           | 1120     | 10,030.6               | 7,806.4                | 58.485                           |
| 360      | 2,560.5                | 1,845.6                | 47.728                           | 1140     | 10,260.1               | 7,996.2                | 58.689                           |
| 380      | 2,716.4                | 1,961.8                | 48.148                           | 1160     | 10,490.6               | 8,187.0                | 58.889                           |
| 400      | 2,874.7                | 2,080.4                | 48.555                           | 1180     | 10,722.3               | 8,379.0                | 59.088                           |
| 420      | 3,035.7                | 2,201.7                | 48.947                           | 1200     | 10,955.3               | 8,572.3                | 59.283                           |
| 440      | 3,199.4                | 2,325.6                | 49.329                           | 1220     | 11,189.4               | 8,766.6                | 59.477                           |
| 460      | 3,365.7                | 2,452.2                | 49.698                           | 1240     | 11,424.6               | 8,962.1                | 59.668                           |
| 480      | 3,534.7                | 2,581.5                | 50.058                           | 1260     | 11,661.0               | 9,158.8                | 59.858                           |
| 500      | 3,706.2                | 2,713.3                | 50.408                           | 1280     | 11,898.4               | 9,356.5                | 60.044                           |
| 520      | 3,880.3                | 2,847.7                | 50.750                           | 1300     | 12,136.9               | 9,555.3                | 60.229                           |
| 537      | 4,027.5                | 2,963.8                | 51.032                           | 1320     | 12,376.4               | 9,755.0                | 60.412                           |
| 540      | 4,056.8                | 2,984.4                | 51.082                           | 1340     | 12,617.0               | 9,955.9                | 60.593                           |
| 560      | 4,235.8                | 3,123.7                | 51.408                           | 1360     | 12,858.5               | 10,157.7               | 60.772                           |
| 580      | 4,417.2                | 3,265.4                | 51.726                           | 1380     | 13,101.0               | 10,360.5               | 60.949                           |
| 600      | 4,600.9                | 3,409.4                | 52.038                           | 1400     | 13,344.7               | 10,564.5               | 61.124                           |
| 620      | 4,786.6                | 3,555.6                | 52.343                           | 1420     | 13,589.1               | 10,769.2               | 61.298                           |
| 640      | 4,974.9                | 3,704.0                | 52.641                           | 1440     | 13,834.5               | 10,974.8               | 61.469                           |
| 660      | 5,165.2                | 3,854.6                | 52.934                           | 1460     | 14,080.8               | 11,181.4               | 61.639                           |
| 680      | 5,357.6                | 4,007.2                | 53.225                           | 1480     | 14,328.0               | 11,388.9               | 61.800                           |
| 700      | 5,552.0                | 4,161.9                | 53.503                           | 1500     | 14,576.0               | 11,597.2               | 61.974                           |
| 720      | 5,748.4                | 4,318.6                | 53.780                           | 1520     | 14,824.9               | 11,806.4               | 62.138                           |
| 740      | 5,946.8                | 4,477.3                | 54.051                           | 1540     | 15,074.7               | 12,016.5               | 62.302                           |
| 760      | 6,147.0                | 4,637.9                | 54.319                           | 1560     | 15,325.3               | 12,227.3               | 62.464                           |
| 780      | 6,349.1                | 4,800.1                | 54.582                           | 1580     | 15,576.7               | 12,439.0               | 62.624                           |
| 800      | 6,552.9                | 4,964.2                | 54.839                           | 1600     | 15,829.0               | 12,651.6               | 62.783                           |
| 820      | 6,758.3                | 5,129.9                | 55.093                           | 1620     | 16,081.9               | 12,864.8               | 62.939                           |
| 840      | 6,965.7                | 5,297.6                | 55.343                           | 1640     | 16,335.7               | 13,078.9               | 63.095                           |
| 860      | 7,174.7                | 5,466.9                | 55.589                           | 1660     | 16,590.2               | 13,293.7               | 63.250                           |
| 880      | 7,385.3                | 5,637.7                | 55.831                           | 1680     | 16,845.5               | 13,509.2               | 63.403                           |
| 900      | 7,597.6                | 5,810.3                | 56.070                           | 1700     | 17,101.4               | 13,725.4               | 63.555                           |
| 920      | 7,811.4                | 5,984.4                | 56.305                           | 1720     | 17,358.1               | 13,942.4               | 63.704                           |
| 940      | 8,026.8                | 6,160.1                | 56.536                           | 1740     | 17,615.5               | 14,160.1               | 63.853                           |
| 960      | 8,243.8                | 6,337.4                | 56.765                           | 1760     | 17,873.5               | 14,378.4               | 64.001                           |
| 980      | 8,462.2                | 6,516.1                | 56.990                           | 1780     | 18,132.2               | 14,597.4               | 64.147                           |
| 1000     | 8,682.1                | 6,696.2                | 57.212                           | 1800     | 18,391.5               | 14,816.9               | 64.292                           |
| 1020     | 8,903.4                | 6,877.8                | 57.432                           | 1820     | 18,651.5               | 15,037.2               | 64.435                           |
| 1040     | 9,126.2                | 7,060.9                | 57.647                           | 1840     | 18,912.2               | 15,258.2               | 64.578                           |
| 1060     | 9,350.3                | 7,245.3                | 57.861                           | 1860     | 19,173.4               | 15,479.7               | 64.719                           |

TABLE A-20E

Ideal-gas properties of carbon dioxide, CO<sub>2</sub> (Concluded)

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 1900     | 19,698                 | 15,925                 | 64.999                           | 3500     | 41,965                 | 35,015                 | 73.462                           |
| 1940     | 20,224                 | 16,372                 | 65.272                           | 3540     | 42,543                 | 35,513                 | 73.627                           |
| 1980     | 20,753                 | 16,821                 | 65.543                           | 3580     | 43,121                 | 36,012                 | 73.789                           |
| 2020     | 21,284                 | 17,273                 | 65.809                           | 3620     | 43,701                 | 36,512                 | 73.951                           |
| 2060     | 21,818                 | 17,727                 | 66.069                           | 3660     | 44,280                 | 37,012                 | 74.110                           |
| 2100     | 22,353                 | 18,182                 | 66.327                           | 3700     | 44,861                 | 37,513                 | 74.267                           |
| 2140     | 22,890                 | 18,640                 | 66.581                           | 3740     | 45,442                 | 38,014                 | 74.423                           |
| 2180     | 23,429                 | 19,101                 | 66.830                           | 3780     | 46,023                 | 38,517                 | 74.578                           |
| 2220     | 23,970                 | 19,561                 | 67.076                           | 3820     | 46,605                 | 39,019                 | 74.732                           |
| 2260     | 24,512                 | 20,024                 | 67.319                           | 3860     | 47,188                 | 39,522                 | 74.884                           |
| 2300     | 25,056                 | 20,489                 | 67.557                           | 3900     | 47,771                 | 40,026                 | 75.033                           |
| 2340     | 25,602                 | 20,955                 | 67.792                           | 3940     | 48,355                 | 40,531                 | 75.182                           |
| 2380     | 26,150                 | 21,423                 | 68.025                           | 3980     | 48,939                 | 41,035                 | 75.330                           |
| 2420     | 26,699                 | 21,893                 | 68.253                           | 4020     | 49,524                 | 41,541                 | 75.477                           |
| 2460     | 27,249                 | 22,364                 | 68.479                           | 4060     | 50,109                 | 42,047                 | 75.622                           |
| 2500     | 27,801                 | 22,837                 | 68.702                           | 4100     | 50,695                 | 42,553                 | 75.765                           |
| 2540     | 28,355                 | 23,310                 | 68.921                           | 4140     | 51,282                 | 43,060                 | 75.907                           |
| 2580     | 28,910                 | 23,786                 | 69.138                           | 4180     | 51,868                 | 43,568                 | 76.048                           |
| 2620     | 29,465                 | 24,262                 | 69.352                           | 4220     | 52,456                 | 44,075                 | 76.188                           |
| 2660     | 30,023                 | 24,740                 | 69.563                           | 4260     | 53,044                 | 44,584                 | 76.327                           |
| 2700     | 30,581                 | 25,220                 | 69.771                           | 4300     | 53,632                 | 45,093                 | 76.464                           |
| 2740     | 31,141                 | 25,701                 | 69.977                           | 4340     | 54,221                 | 45,602                 | 76.601                           |
| 2780     | 31,702                 | 26,181                 | 70.181                           | 4380     | 54,810                 | 46,112                 | 76.736                           |
| 2820     | 32,264                 | 26,664                 | 70.382                           | 4420     | 55,400                 | 46,622                 | 76.870                           |
| 2860     | 32,827                 | 27,148                 | 70.580                           | 4460     | 55,990                 | 47,133                 | 77.003                           |
| 2900     | 33,392                 | 27,633                 | 70.776                           | 4500     | 56,581                 | 47,645                 | 77.135                           |
| 2940     | 33,957                 | 28,118                 | 70.970                           | 4540     | 57,172                 | 48,156                 | 77.266                           |
| 2980     | 34,523                 | 28,605                 | 71.160                           | 4580     | 57,764                 | 48,668                 | 77.395                           |
| 3020     | 35,090                 | 29,093                 | 71.350                           | 4620     | 58,356                 | 49,181                 | 77.581                           |
| 3060     | 35,659                 | 29,582                 | 71.537                           | 4660     | 58,948                 | 49,694                 | 77.652                           |
| 3100     | 36,228                 | 30,072                 | 71.722                           | 4700     | 59,541                 | 50,208                 | 77.779                           |
| 3140     | 36,798                 | 30,562                 | 71.904                           | 4740     | 60,134                 | 50,721                 | 77.905                           |
| 3180     | 37,369                 | 31,054                 | 72.085                           | 4780     | 60,728                 | 51,236                 | 78.029                           |
| 3220     | 37,941                 | 31,546                 | 72.264                           | 4820     | 61,322                 | 51,750                 | 78.153                           |
| 3260     | 38,513                 | 32,039                 | 72.441                           | 4860     | 61,916                 | 52,265                 | 78.276                           |
| 3300     | 39,087                 | 32,533                 | 72.616                           | 4900     | 62,511                 | 52,781                 | 78.398                           |
| 3340     | 39,661                 | 33,028                 | 72.788                           | 5000     | 64,000                 | 54,071                 | 78.698                           |
| 3380     | 40,236                 | 33,524                 | 72.960                           | 5100     | 65,491                 | 55,363                 | 78.994                           |
| 3420     | 40,812                 | 34,020                 | 73.129                           | 5200     | 66,984                 | 56,658                 | 79.284                           |
| 3460     | 41,388                 | 34,517                 | 73.297                           | 5300     | 68,471                 | 57,954                 | 79.569                           |

TABLE A-21E

Ideal-gas properties of carbon monoxide, CO

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 300      | 2,081.9                | 1,486.1                | 43.223                           | 1080     | 7,571.1                | 5,426.4                | 52.203                           |
| 320      | 2,220.9                | 1,585.4                | 43.672                           | 1100     | 7,716.8                | 5,532.3                | 52.337                           |
| 340      | 2,359.9                | 1,684.7                | 44.093                           | 1120     | 7,862.9                | 5,638.7                | 52.468                           |
| 360      | 2,498.8                | 1,783.9                | 44.490                           | 1140     | 8,009.2                | 5,745.4                | 52.598                           |
| 380      | 2,637.9                | 1,883.3                | 44.866                           | 1160     | 8,156.1                | 5,851.5                | 52.726                           |
| 400      | 2,776.9                | 1,982.6                | 45.223                           | 1180     | 8,303.3                | 5,960.0                | 52.852                           |
| 420      | 2,916.0                | 2,081.9                | 45.563                           | 1200     | 8,450.8                | 6,067.8                | 52.976                           |
| 440      | 3,055.0                | 2,181.2                | 45.886                           | 1220     | 8,598.8                | 6,176.0                | 53.098                           |
| 460      | 3,194.0                | 2,280.5                | 46.194                           | 1240     | 8,747.2                | 6,284.7                | 53.218                           |
| 480      | 3,333.0                | 2,379.8                | 46.491                           | 1260     | 8,896.0                | 6,393.8                | 53.337                           |
| 500      | 3,472.1                | 2,479.2                | 46.775                           | 1280     | 9,045.0                | 6,503.1                | 53.455                           |
| 520      | 3,611.2                | 2,578.6                | 47.048                           | 1300     | 9,194.6                | 6,613.0                | 53.571                           |
| 537      | 3,725.1                | 2,663.1                | 47.272                           | 1320     | 9,344.6                | 6,723.2                | 53.685                           |
| 540      | 3,750.3                | 2,677.9                | 47.310                           | 1340     | 9,494.8                | 6,833.7                | 53.799                           |
| 560      | 3,889.5                | 2,777.4                | 47.563                           | 1360     | 9,645.5                | 6,944.7                | 53.910                           |
| 580      | 4,028.7                | 2,876.9                | 47.807                           | 1380     | 9,796.6                | 7,056.1                | 54.021                           |
| 600      | 4,168.0                | 2,976.5                | 48.044                           | 1400     | 9,948.1                | 7,167.9                | 54.129                           |
| 620      | 4,307.4                | 3,076.2                | 48.272                           | 1420     | 10,100.0               | 7,280.1                | 54.237                           |
| 640      | 4,446.9                | 3,175.9                | 48.494                           | 1440     | 10,252.2               | 7,392.6                | 54.344                           |
| 660      | 4,586.6                | 3,275.8                | 48.709                           | 1460     | 10,404.8               | 7,505.4                | 54.448                           |
| 680      | 4,726.2                | 3,375.8                | 48.917                           | 1480     | 10,557.8               | 7,618.7                | 54.522                           |
| 700      | 4,886.0                | 3,475.9                | 49.120                           | 1500     | 10,711.1               | 7,732.3                | 54.665                           |
| 720      | 5,006.1                | 3,576.3                | 49.317                           | 1520     | 10,864.9               | 7,846.4                | 54.757                           |
| 740      | 5,146.4                | 3,676.9                | 49.509                           | 1540     | 11,019.0               | 7,960.8                | 54.858                           |
| 760      | 5,286.8                | 3,777.5                | 49.697                           | 1560     | 11,173.4               | 8,075.4                | 54.958                           |
| 780      | 5,427.4                | 3,878.4                | 49.880                           | 1580     | 11,328.2               | 8,190.5                | 55.056                           |
| 800      | 5,568.2                | 3,979.5                | 50.058                           | 1600     | 11,483.4               | 8,306.0                | 55.154                           |
| 820      | 5,709.4                | 4,081.0                | 50.232                           | 1620     | 11,638.9               | 8,421.8                | 55.251                           |
| 840      | 5,850.7                | 4,182.6                | 50.402                           | 1640     | 11,794.7               | 8,537.9                | 55.347                           |
| 860      | 5,992.3                | 4,284.5                | 50.569                           | 1660     | 11,950.9               | 8,654.4                | 55.411                           |
| 880      | 6,134.2                | 4,386.6                | 50.732                           | 1680     | 12,107.5               | 8,771.2                | 55.535                           |
| 900      | 6,276.4                | 4,489.1                | 50.892                           | 1700     | 12,264.3               | 8,888.3                | 55.628                           |
| 920      | 6,419.0                | 4,592.0                | 51.048                           | 1720     | 12,421.4               | 9,005.7                | 55.720                           |
| 940      | 6,561.7                | 4,695.0                | 51.202                           | 1740     | 12,579.0               | 9,123.6                | 55.811                           |
| 960      | 6,704.9                | 4,798.5                | 51.353                           | 1760     | 12,736.7               | 9,241.6                | 55.900                           |
| 980      | 6,848.4                | 4,902.3                | 51.501                           | 1780     | 12,894.9               | 9,360.0                | 55.990                           |
| 1000     | 6,992.2                | 5,006.3                | 51.646                           | 1800     | 13,053.2               | 9,478.6                | 56.078                           |
| 1020     | 7,136.4                | 5,110.8                | 51.788                           | 1820     | 13,212.0               | 9,597.7                | 56.166                           |
| 1040     | 7,281.0                | 5,215.7                | 51.929                           | 1840     | 13,371.0               | 9,717.0                | 56.253                           |
| 1060     | 7,425.9                | 5,320.9                | 52.067                           | 1860     | 13,530.2               | 9,836.5                | 56.339                           |

TABLE A-21E

Ideal-gas properties of carbon monoxide, CO (*Concluded*)

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 1900     | 13,850                 | 10,077                 | 56.509                           | 3500     | 27,262                 | 20,311                 | 61.612                           |
| 1940     | 14,170                 | 10,318                 | 56.677                           | 3540     | 27,608                 | 20,576                 | 61.710                           |
| 1980     | 14,492                 | 10,560                 | 56.841                           | 3580     | 27,954                 | 20,844                 | 61.807                           |
| 2020     | 14,815                 | 10,803                 | 57.007                           | 3620     | 28,300                 | 21,111                 | 61.903                           |
| 2060     | 15,139                 | 11,048                 | 57.161                           | 3660     | 28,647                 | 21,378                 | 61.998                           |
| 2100     | 15,463                 | 11,293                 | 57.317                           | 3700     | 28,994                 | 21,646                 | 62.093                           |
| 2140     | 15,789                 | 11,539                 | 57.470                           | 3740     | 29,341                 | 21,914                 | 62.186                           |
| 2180     | 16,116                 | 11,787                 | 57.621                           | 3780     | 29,688                 | 22,182                 | 62.279                           |
| 2220     | 16,443                 | 12,035                 | 57.770                           | 3820     | 30,036                 | 22,450                 | 62.370                           |
| 2260     | 16,722                 | 12,284                 | 57.917                           | 3860     | 30,384                 | 22,719                 | 62.461                           |
| 2300     | 17,101                 | 12,534                 | 58.062                           | 3900     | 30,733                 | 22,988                 | 62.511                           |
| 2340     | 17,431                 | 12,784                 | 58.204                           | 3940     | 31,082                 | 23,257                 | 62.640                           |
| 2380     | 17,762                 | 13,035                 | 58.344                           | 3980     | 31,431                 | 23,527                 | 62.728                           |
| 2420     | 18,093                 | 13,287                 | 58.482                           | 4020     | 31,780                 | 23,797                 | 62.816                           |
| 2460     | 18,426                 | 13,541                 | 58.619                           | 4060     | 32,129                 | 24,067                 | 62.902                           |
| 2500     | 18,759                 | 13,794                 | 58.754                           | 4100     | 32,479                 | 24,337                 | 62.988                           |
| 2540     | 19,093                 | 14,048                 | 58.885                           | 4140     | 32,829                 | 24,608                 | 63.072                           |
| 2580     | 19,427                 | 14,303                 | 59.016                           | 4180     | 33,179                 | 24,878                 | 63.156                           |
| 2620     | 19,762                 | 14,559                 | 59.145                           | 4220     | 33,530                 | 25,149                 | 63.240                           |
| 2660     | 20,098                 | 14,815                 | 59.272                           | 4260     | 33,880                 | 25,421                 | 63.323                           |
| 2700     | 20,434                 | 15,072                 | 59.398                           | 4300     | 34,231                 | 25,692                 | 63.405                           |
| 2740     | 20,771                 | 15,330                 | 59.521                           | 4340     | 34,582                 | 25,934                 | 63.486                           |
| 2780     | 21,108                 | 15,588                 | 59.644                           | 4380     | 34,934                 | 26,235                 | 63.567                           |
| 2820     | 21,446                 | 15,846                 | 59.765                           | 4420     | 35,285                 | 26,508                 | 63.647                           |
| 2860     | 21,785                 | 16,105                 | 59.884                           | 4460     | 35,637                 | 26,780                 | 63.726                           |
| 2900     | 22,124                 | 16,365                 | 60.002                           | 4500     | 35,989                 | 27,052                 | 63.805                           |
| 2940     | 22,463                 | 16,225                 | 60.118                           | 4540     | 36,341                 | 27,325                 | 63.883                           |
| 2980     | 22,803                 | 16,885                 | 60.232                           | 4580     | 36,693                 | 27,598                 | 63.960                           |
| 3020     | 23,144                 | 17,146                 | 60.346                           | 4620     | 37,046                 | 27,871                 | 64.036                           |
| 3060     | 23,485                 | 17,408                 | 60.458                           | 4660     | 37,398                 | 28,144                 | 64.113                           |
| 3100     | 23,826                 | 17,670                 | 60.569                           | 4700     | 37,751                 | 28,417                 | 64.188                           |
| 3140     | 24,168                 | 17,932                 | 60.679                           | 4740     | 38,104                 | 28,691                 | 64.263                           |
| 3180     | 24,510                 | 18,195                 | 60.787                           | 4780     | 38,457                 | 28,965                 | 64.337                           |
| 3220     | 24,853                 | 18,458                 | 60.894                           | 4820     | 38,811                 | 29,239                 | 64.411                           |
| 3260     | 25,196                 | 18,722                 | 61.000                           | 4860     | 39,164                 | 29,513                 | 64.484                           |
| 3300     | 25,539                 | 18,986                 | 61.105                           | 4900     | 39,518                 | 29,787                 | 64.556                           |
| 3340     | 25,883                 | 19,250                 | 61.209                           | 5000     | 40,403                 | 30,473                 | 64.735                           |
| 3380     | 26,227                 | 19,515                 | 61.311                           | 5100     | 41,289                 | 31,161                 | 64.910                           |
| 3420     | 26,572                 | 19,780                 | 61.412                           | 5200     | 42,176                 | 31,849                 | 65.082                           |
| 3460     | 26,917                 | 20,045                 | 61.513                           | 5300     | 43,063                 | 32,538                 | 65.252                           |

TABLE A-22E

Ideal-gas properties of hydrogen,  $H_2$ 

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 300      | 2,063.5                | 1,467.7                | 27.337                           | 1400     | 9,673.8                | 6,893.6                | 37.883                           |
| 320      | 2,189.4                | 1,553.9                | 27.742                           | 1500     | 10,381.5               | 7,402.7                | 38.372                           |
| 340      | 2,317.2                | 1,642.0                | 28.130                           | 1600     | 11,092.5               | 7,915.1                | 38.830                           |
| 360      | 2,446.8                | 1,731.9                | 28.501                           | 1700     | 11,807.4               | 8,431.4                | 39.264                           |
| 380      | 2,577.8                | 1,823.2                | 28.856                           | 1800     | 12,526.8               | 8,952.2                | 39.675                           |
| 400      | 2,710.2                | 1,915.8                | 29.195                           | 1900     | 13,250.9               | 9,477.8                | 40.067                           |
| 420      | 2,843.7                | 2,009.6                | 29.520                           | 2000     | 13,980.1               | 10,008.4               | 40.441                           |
| 440      | 2,978.1                | 2,104.3                | 29.833                           | 2100     | 14,714.5               | 10,544.2               | 40.799                           |
| 460      | 3,113.5                | 2,200.0                | 30.133                           | 2200     | 15,454.4               | 11,085.5               | 41.143                           |
| 480      | 3,249.4                | 2,296.2                | 30.424                           | 2300     | 16,199.8               | 11,632.3               | 41.475                           |
| 500      | 3,386.1                | 2,393.2                | 30.703                           | 2400     | 16,950.6               | 12,184.5               | 41.794                           |
| 520      | 3,523.2                | 2,490.6                | 30.972                           | 2500     | 17,707.3               | 12,742.6               | 42.104                           |
| 537      | 3,640.3                | 2,573.9                | 31.194                           | 2600     | 18,469.7               | 13,306.4               | 42.403                           |
| 540      | 3,660.9                | 2,588.5                | 31.232                           | 2700     | 19,237.8               | 13,876.0               | 42.692                           |
| 560      | 3,798.8                | 2,686.7                | 31.482                           | 2800     | 20,011.8               | 14,451.4               | 42.973                           |
| 580      | 3,937.1                | 2,785.3                | 31.724                           | 2900     | 20,791.5               | 15,032.5               | 43.247                           |
| 600      | 4,075.6                | 2,884.1                | 31.959                           | 3000     | 21,576.9               | 15,619.3               | 43.514                           |
| 620      | 4,214.3                | 2,983.1                | 32.187                           | 3100     | 22,367.7               | 16,211.5               | 43.773                           |
| 640      | 4,353.1                | 3,082.1                | 32.407                           | 3200     | 23,164.1               | 16,809.3               | 44.026                           |
| 660      | 4,492.1                | 3,181.4                | 32.621                           | 3300     | 23,965.5               | 17,412.1               | 44.273                           |
| 680      | 4,631.1                | 3,280.7                | 32.829                           | 3400     | 24,771.9               | 18,019.9               | 44.513                           |
| 700      | 4,770.2                | 3,380.1                | 33.031                           | 3500     | 25,582.9               | 18,632.4               | 44.748                           |
| 720      | 4,909.5                | 3,479.6                | 33.226                           | 3600     | 26,398.5               | 19,249.4               | 44.978                           |
| 740      | 5,048.8                | 3,579.2                | 33.417                           | 3700     | 27,218.5               | 19,870.8               | 45.203                           |
| 760      | 5,188.1                | 3,678.8                | 33.603                           | 3800     | 28,042.8               | 20,496.5               | 45.423                           |
| 780      | 5,327.6                | 3,778.6                | 33.784                           | 3900     | 28,871.1               | 21,126.2               | 45.638                           |
| 800      | 5,467.1                | 3,878.4                | 33.961                           | 4000     | 29,703.5               | 21,760.0               | 45.849                           |
| 820      | 5,606.7                | 3,978.3                | 34.134                           | 4100     | 30,539.8               | 22,397.7               | 46.056                           |
| 840      | 5,746.3                | 4,078.2                | 34.302                           | 4200     | 31,379.8               | 23,039.2               | 46.257                           |
| 860      | 5,885.9                | 4,178.0                | 34.466                           | 4300     | 32,223.5               | 23,684.3               | 46.456                           |
| 880      | 6,025.6                | 4,278.0                | 34.627                           | 4400     | 33,070.9               | 24,333.1               | 46.651                           |
| 900      | 6,165.3                | 4,378.0                | 34.784                           | 4500     | 33,921.6               | 24,985.2               | 46.842                           |
| 920      | 6,305.1                | 4,478.1                | 34.938                           | 4600     | 34,775.7               | 25,640.7               | 47.030                           |
| 940      | 6,444.9                | 4,578.1                | 35.087                           | 4700     | 35,633.0               | 26,299.4               | 47.215                           |
| 960      | 6,584.7                | 4,678.3                | 35.235                           | 4800     | 36,493.4               | 26,961.2               | 47.396                           |
| 980      | 6,724.6                | 4,778.4                | 35.379                           | 4900     | 35,356.9               | 27,626.1               | 47.574                           |
| 1000     | 6,864.5                | 4,878.6                | 35.520                           | 5000     | 38,223.3               | 28,294.0               | 47.749                           |
| 1100     | 7,564.6                | 5,380.1                | 36.188                           | 5100     | 39,092.8               | 28,964.9               | 47.921                           |
| 1200     | 8,265.8                | 5,882.8                | 36.798                           | 5200     | 39,965.1               | 29,638.6               | 48.090                           |
| 1300     | 8,968.7                | 6,387.1                | 37.360                           | 5300     | 40,840.2               | 30,315.1               | 48.257                           |

TABLE A-23E

Ideal-gas properties of water vapor, H<sub>2</sub>O

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 300      | 2,367.6                | 1,771.8                | 40.439                           | 1080     | 8,768.2                | 6,623.5                | 50.854                           |
| 320      | 2,526.8                | 1,891.3                | 40.952                           | 1100     | 8,942.0                | 6,757.5                | 51.013                           |
| 340      | 2,686.0                | 2,010.8                | 41.435                           | 1120     | 9,116.4                | 6,892.2                | 51.171                           |
| 360      | 2,845.1                | 2,130.2                | 41.889                           | 1140     | 9,291.4                | 7,027.5                | 51.325                           |
| 380      | 3,004.4                | 2,249.8                | 42.320                           | 1160     | 9,467.1                | 7,163.5                | 51.478                           |
| 400      | 3,163.8                | 2,369.4                | 42.728                           | 1180     | 9,643.4                | 7,300.1                | 51.360                           |
| 420      | 3,323.2                | 2,489.1                | 43.117                           | 1200     | 9,820.4                | 7,437.4                | 51.777                           |
| 440      | 3,482.7                | 2,608.9                | 43.487                           | 1220     | 9,998.0                | 7,575.2                | 51.925                           |
| 460      | 3,642.3                | 2,728.8                | 43.841                           | 1240     | 10,176.1               | 7,713.6                | 52.070                           |
| 480      | 3,802.0                | 2,848.8                | 44.182                           | 1260     | 10,354.9               | 7,852.7                | 52.212                           |
| 500      | 3,962.0                | 2,969.1                | 44.508                           | 1280     | 10,534.4               | 7,992.5                | 52.354                           |
| 520      | 4,122.0                | 3,089.4                | 44.821                           | 1300     | 10,714.5               | 8,132.9                | 52.494                           |
| 537      | 4,258.0                | 3,191.9                | 45.079                           | 1320     | 10,895.3               | 8,274.0                | 52.631                           |
| 540      | 4,282.4                | 3,210.0                | 45.124                           | 1340     | 11,076.6               | 8,415.5                | 52.768                           |
| 560      | 4,442.8                | 3,330.7                | 45.415                           | 1360     | 11,258.7               | 8,557.9                | 52.903                           |
| 580      | 4,603.7                | 3,451.9                | 45.696                           | 1380     | 11,441.4               | 8,700.9                | 53.037                           |
| 600      | 4,764.7                | 3,573.2                | 45.970                           | 1400     | 11,624.8               | 8,844.6                | 53.168                           |
| 620      | 4,926.1                | 3,694.9                | 46.235                           | 1420     | 11,808.8               | 8,988.9                | 53.299                           |
| 640      | 5,087.8                | 3,816.8                | 46.492                           | 1440     | 11,993.4               | 9,133.8                | 53.428                           |
| 660      | 5,250.0                | 3,939.3                | 46.741                           | 1460     | 12,178.8               | 9,279.4                | 53.556                           |
| 680      | 5,412.5                | 4,062.1                | 46.984                           | 1480     | 12,364.8               | 9,425.7                | 53.682                           |
| 700      | 5,575.4                | 4,185.3                | 47.219                           | 1500     | 12,551.4               | 9,572.7                | 53.808                           |
| 720      | 5,738.8                | 4,309.0                | 47.450                           | 1520     | 12,738.8               | 9,720.3                | 53.932                           |
| 740      | 5,902.6                | 4,433.1                | 47.673                           | 1540     | 12,926.8               | 9,868.6                | 54.055                           |
| 760      | 6,066.9                | 4,557.6                | 47.893                           | 1560     | 13,115.6               | 10,017.6               | 54.117                           |
| 780      | 6,231.7                | 4,682.7                | 48.106                           | 1580     | 13,305.0               | 10,167.3               | 54.298                           |
| 800      | 6,396.9                | 4,808.2                | 48.316                           | 1600     | 13,494.4               | 10,317.6               | 54.418                           |
| 820      | 6,562.6                | 4,934.2                | 48.520                           | 1620     | 13,685.7               | 10,468.6               | 54.535                           |
| 840      | 6,728.9                | 5,060.8                | 48.721                           | 1640     | 13,877.0               | 10,620.2               | 54.653                           |
| 860      | 6,895.6                | 5,187.8                | 48.916                           | 1660     | 14,069.2               | 10,772.7               | 54.770                           |
| 880      | 7,062.9                | 5,315.3                | 49.109                           | 1680     | 14,261.9               | 10,925.6               | 54.886                           |
| 900      | 7,230.9                | 5,443.6                | 49.298                           | 1700     | 14,455.4               | 11,079.4               | 54.999                           |
| 920      | 7,399.4                | 5,572.4                | 49.483                           | 1720     | 14,649.5               | 11,233.8               | 55.113                           |
| 940      | 7,568.4                | 5,701.7                | 49.665                           | 1740     | 14,844.3               | 11,388.9               | 55.226                           |
| 960      | 7,738.0                | 5,831.6                | 49.843                           | 1760     | 15,039.8               | 11,544.7               | 55.339                           |
| 980      | 7,908.2                | 5,962.0                | 50.019                           | 1780     | 15,236.1               | 11,701.2               | 55.449                           |
| 1000     | 8,078.2                | 6,093.0                | 50.191                           | 1800     | 15,433.0               | 11,858.4               | 55.559                           |
| 1020     | 8,250.4                | 6,224.8                | 50.360                           | 1820     | 15,630.6               | 12,016.3               | 55.668                           |
| 1040     | 8,422.4                | 6,357.1                | 50.528                           | 1840     | 15,828.7               | 12,174.7               | 55.777                           |
| 1060     | 8,595.0                | 6,490.0                | 50.693                           | 1860     | 16,027.6               | 12,333.9               | 55.884                           |

TABLE A-23E

Ideal-gas properties of water vapor,  $H_2O$  (Concluded)

| $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R | $T$<br>R | $\bar{h}$<br>Btu/lbmol | $\bar{u}$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|----------|------------------------|------------------------|----------------------------------|----------|------------------------|------------------------|----------------------------------|
| 1900     | 16,428                 | 12,654                 | 56.097                           | 3500     | 34,324                 | 27,373                 | 62.876                           |
| 1940     | 16,830                 | 12,977                 | 56.307                           | 3540     | 34,809                 | 27,779                 | 63.015                           |
| 1980     | 17,235                 | 13,303                 | 56.514                           | 3580     | 35,296                 | 28,187                 | 63.153                           |
| 2020     | 17,643                 | 13,632                 | 56.719                           | 3620     | 35,785                 | 28,596                 | 63.288                           |
| 2060     | 18,054                 | 13,963                 | 56.920                           | 3660     | 36,274                 | 29,006                 | 63.423                           |
| 2100     | 18,467                 | 14,297                 | 57.119                           | 3700     | 36,765                 | 29,418                 | 63.557                           |
| 2140     | 18,883                 | 14,633                 | 57.315                           | 3740     | 37,258                 | 29,831                 | 63.690                           |
| 2180     | 19,301                 | 14,972                 | 57.509                           | 3780     | 37,752                 | 30,245                 | 63.821                           |
| 2220     | 19,722                 | 15,313                 | 57.701                           | 3820     | 38,247                 | 30,661                 | 63.952                           |
| 2260     | 20,145                 | 15,657                 | 57.889                           | 3860     | 38,743                 | 31,077                 | 64.082                           |
| 2300     | 20,571                 | 16,003                 | 58.077                           | 3900     | 39,240                 | 31,495                 | 64.210                           |
| 2340     | 20,999                 | 16,352                 | 58.261                           | 3940     | 39,739                 | 31,915                 | 64.338                           |
| 2380     | 21,429                 | 16,703                 | 58.445                           | 3980     | 40,239                 | 32,335                 | 64.465                           |
| 2420     | 21,862                 | 17,057                 | 58.625                           | 4020     | 40,740                 | 32,757                 | 64.591                           |
| 2460     | 22,298                 | 17,413                 | 58.803                           | 4060     | 41,242                 | 33,179                 | 64.715                           |
| 2500     | 22,735                 | 17,771                 | 58.980                           | 4100     | 41,745                 | 33,603                 | 64.839                           |
| 2540     | 23,175                 | 18,131                 | 59.155                           | 4140     | 42,250                 | 34,028                 | 64.962                           |
| 2580     | 23,618                 | 18,494                 | 59.328                           | 4180     | 42,755                 | 34,454                 | 65.084                           |
| 2620     | 24,062                 | 18,859                 | 59.500                           | 4220     | 43,267                 | 34,881                 | 65.204                           |
| 2660     | 24,508                 | 19,226                 | 59.669                           | 4260     | 43,769                 | 35,310                 | 65.325                           |
| 2700     | 24,957                 | 19,595                 | 59.837                           | 4300     | 44,278                 | 35,739                 | 65.444                           |
| 2740     | 25,408                 | 19,967                 | 60.003                           | 4340     | 44,788                 | 36,169                 | 65.563                           |
| 2780     | 25,861                 | 20,340                 | 60.167                           | 4380     | 45,298                 | 36,600                 | 65.680                           |
| 2820     | 26,316                 | 20,715                 | 60.330                           | 4420     | 45,810                 | 37,032                 | 65.797                           |
| 2860     | 26,773                 | 21,093                 | 60.490                           | 4460     | 46,322                 | 37,465                 | 65.913                           |
| 2900     | 27,231                 | 21,472                 | 60.650                           | 4500     | 46,836                 | 37,900                 | 66.028                           |
| 2940     | 27,692                 | 21,853                 | 60.809                           | 4540     | 47,350                 | 38,334                 | 66.142                           |
| 2980     | 28,154                 | 22,237                 | 60.965                           | 4580     | 47,866                 | 38,770                 | 66.255                           |
| 3020     | 28,619                 | 22,621                 | 61.120                           | 4620     | 48,382                 | 39,207                 | 66.368                           |
| 3060     | 29,085                 | 23,085                 | 61.274                           | 4660     | 48,899                 | 39,645                 | 66.480                           |
| 3100     | 29,553                 | 23,397                 | 61.426                           | 4700     | 49,417                 | 40,083                 | 66.591                           |
| 3140     | 30,023                 | 23,787                 | 61.577                           | 4740     | 49,936                 | 40,523                 | 66.701                           |
| 3180     | 30,494                 | 24,179                 | 61.727                           | 4780     | 50,455                 | 40,963                 | 66.811                           |
| 3220     | 30,967                 | 24,572                 | 61.874                           | 4820     | 50,976                 | 41,404                 | 66.920                           |
| 3260     | 31,442                 | 24,968                 | 62.022                           | 4860     | 51,497                 | 41,856                 | 67.028                           |
| 3300     | 31,918                 | 25,365                 | 62.167                           | 4900     | 52,019                 | 42,288                 | 67.135                           |
| 3340     | 32,396                 | 25,763                 | 62.312                           | 5000     | 53,327                 | 43,398                 | 67.401                           |
| 3380     | 32,876                 | 26,164                 | 62.454                           | 5100     | 54,640                 | 44,512                 | 67.662                           |
| 3420     | 33,357                 | 26,565                 | 62.597                           | 5200     | 55,957                 | 45,631                 | 67.918                           |
| 3460     | 33,839                 | 26,968                 | 62.738                           | 5300     | 57,279                 | 46,754                 | 68.172                           |



TABLE A-26E

Enthalpy of formation, Gibbs function of formation, and absolute entropy at 77°F, 1 atm

| Substance         | Formula                             | $\bar{h}_f^\circ$<br>Btu/lbmol | $\bar{g}_f^\circ$<br>Btu/lbmol | $\bar{s}^\circ$<br>Btu/lbmol · R |
|-------------------|-------------------------------------|--------------------------------|--------------------------------|----------------------------------|
| Carbon            | C(s)                                | 0                              | 0                              | 1.36                             |
| Hydrogen          | H <sub>2</sub> (g)                  | 0                              | 0                              | 31.21                            |
| Nitrogen          | N <sub>2</sub> (g)                  | 0                              | 0                              | 45.77                            |
| Oxygen            | O <sub>2</sub> (g)                  | 0                              | 0                              | 49.00                            |
| Carbon monoxide   | CO(g)                               | -47,540                        | -59,010                        | 47.21                            |
| Carbon dioxide    | CO <sub>2</sub> (g)                 | -169,300                       | -169,680                       | 51.07                            |
| Water vapor       | H <sub>2</sub> O(g)                 | -104,040                       | -98,350                        | 45.11                            |
| Water             | H <sub>2</sub> O(l)                 | -122,970                       | -102,040                       | 16.71                            |
| Hydrogen peroxide | H <sub>2</sub> O <sub>2</sub> (g)   | -58,640                        | -45,430                        | 55.60                            |
| Ammonia           | NH <sub>3</sub> (g)                 | -19,750                        | -7,140                         | 45.97                            |
| Methane           | CH <sub>4</sub> (g)                 | -32,210                        | -21,860                        | 44.49                            |
| Acetylene         | C <sub>2</sub> H <sub>2</sub> (g)   | +97,540                        | +87,990                        | 48.00                            |
| Ethylene          | C <sub>2</sub> H <sub>4</sub> (g)   | +22,490                        | +29,306                        | 52.54                            |
| Ethane            | C <sub>2</sub> H <sub>6</sub> (g)   | -36,420                        | -14,150                        | 54.85                            |
| Propylene         | C <sub>3</sub> H <sub>6</sub> (g)   | +8,790                         | +26,980                        | 63.80                            |
| Propane           | C <sub>3</sub> H <sub>8</sub> (g)   | -44,680                        | -10,105                        | 64.51                            |
| n-Butane          | C <sub>4</sub> H <sub>10</sub> (g)  | -54,270                        | -6,760                         | 74.11                            |
| n-Octane          | C <sub>8</sub> H <sub>18</sub> (g)  | -89,680                        | +7,110                         | 111.55                           |
| n-Octane          | C <sub>8</sub> H <sub>18</sub> (l)  | -107,530                       | +2,840                         | 86.23                            |
| n-Dodecane        | C <sub>12</sub> H <sub>26</sub> (g) | -125,190                       | +21,570                        | 148.86                           |
| Benzene           | C <sub>6</sub> H <sub>6</sub> (g)   | +35,680                        | +55,780                        | 64.34                            |
| Methyl alcohol    | CH <sub>3</sub> OH(g)               | -86,540                        | -69,700                        | 57.29                            |
| Methyl alcohol    | CH <sub>3</sub> OH(l)               | -102,670                       | -71,570                        | 30.30                            |
| Ethyl alcohol     | C <sub>2</sub> H <sub>5</sub> OH(g) | -101,230                       | -72,520                        | 67.54                            |
| Ethyl alcohol     | C <sub>2</sub> H <sub>5</sub> OH(l) | -119,470                       | -75,240                        | 38.40                            |
| Oxygen            | O(g)                                | +107,210                       | +99,710                        | 38.47                            |
| Hydrogen          | H(g)                                | +93,780                        | +87,460                        | 27.39                            |
| Nitrogen          | N(g)                                | +203,340                       | +195,970                       | 36.61                            |
| Hydroxyl          | OH(g)                               | +16,790                        | +14,750                        | 43.92                            |

Source: From JANAF, *Thermochemical Tables* (Midland, MI: Dow Chemical Co., 1971), *Selected Values of Chemical Thermodynamic Properties*, NBS Technical Note 270-3, 1968; and *API Research Project 44* (Carnegie Press, 1953).

TABLE A-27E

Properties of some common fuels and hydrocarbons

| Fuel (phase)        | Formula                                            | Molar mass, lbm/lbmol | Density, <sup>1</sup> lbm/ft <sup>3</sup> | Enthalpy of vaporization, <sup>2</sup> Btu/lbm | Specific heat, <sup>1</sup> $c_p$ Btu/lbm · °F | Higher heating value, <sup>3</sup> Btu/lbm | Lower heating value, <sup>3</sup> Btu/lbm |
|---------------------|----------------------------------------------------|-----------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|--------------------------------------------|-------------------------------------------|
| Carbon (s)          | C                                                  | 12.011                | 125                                       | —                                              | 0.169                                          | 14,100                                     | 14,100                                    |
| Hydrogen (g)        | H <sub>2</sub>                                     | 2.016                 | —                                         | —                                              | 3.44                                           | 60,970                                     | 51,600                                    |
| Carbon monoxide (g) | CO                                                 | 28.013                | —                                         | —                                              | 0.251                                          | 4,340                                      | 4,340                                     |
| Methane (g)         | CH <sub>4</sub>                                    | 16.043                | —                                         | 219                                            | 0.525                                          | 23,880                                     | 21,520                                    |
| Methanol (ℓ)        | CH <sub>4</sub> O                                  | 32.042                | 49.3                                      | 502                                            | 0.604                                          | 9,740                                      | 8,570                                     |
| Acetylene (g)       | C <sub>2</sub> H <sub>2</sub>                      | 26.038                | —                                         | —                                              | 0.404                                          | 21,490                                     | 20,760                                    |
| Ethane (g)          | C <sub>2</sub> H <sub>6</sub>                      | 30.070                | —                                         | 74                                             | 0.418                                          | 22,320                                     | 20,430                                    |
| Ethanol (ℓ)         | C <sub>2</sub> H <sub>6</sub> O                    | 46.069                | 49.3                                      | 395                                            | 0.583                                          | 12,760                                     | 11,530                                    |
| Propane (ℓ)         | C <sub>3</sub> H <sub>8</sub>                      | 44.097                | 31.2                                      | 144                                            | 0.662                                          | 21,640                                     | 19,930                                    |
| Butane (ℓ)          | C <sub>4</sub> H <sub>10</sub>                     | 58.123                | 36.1                                      | 156                                            | 0.578                                          | 21,130                                     | 19,510                                    |
| 1-Pentene (ℓ)       | C <sub>5</sub> H <sub>10</sub>                     | 70.134                | 40.0                                      | 156                                            | 0.525                                          | 20,540                                     | 19,190                                    |
| Isopentane (ℓ)      | C <sub>5</sub> H <sub>12</sub>                     | 72.150                | 39.1                                      | —                                              | 0.554                                          | 20,890                                     | 19,310                                    |
| Benzene (ℓ)         | C <sub>6</sub> H <sub>6</sub>                      | 78.114                | 54.7                                      | 186                                            | 0.411                                          | 17,970                                     | 17,240                                    |
| Hexene (ℓ)          | C <sub>6</sub> H <sub>12</sub>                     | 84.161                | 42.0                                      | 169                                            | 0.439                                          | 20,430                                     | 19,090                                    |
| Hexane (ℓ)          | C <sub>6</sub> H <sub>14</sub>                     | 86.177                | 41.2                                      | 157                                            | 0.542                                          | 20,770                                     | 19,240                                    |
| Toluene (ℓ)         | C <sub>7</sub> H <sub>8</sub>                      | 92.141                | 54.1                                      | 177                                            | 0.408                                          | 18,230                                     | 17,420                                    |
| Heptane (ℓ)         | C <sub>7</sub> H <sub>16</sub>                     | 100.204               | 42.7                                      | 157                                            | 0.535                                          | 20,680                                     | 19,180                                    |
| Octane (ℓ)          | C <sub>8</sub> H <sub>18</sub>                     | 114.231               | 43.9                                      | 156                                            | 0.533                                          | 20,590                                     | 19,100                                    |
| Decane (ℓ)          | C <sub>10</sub> H <sub>22</sub>                    | 142.285               | 45.6                                      | 155                                            | 0.528                                          | 20,490                                     | 19,020                                    |
| Gasoline (ℓ)        | C <sub>n</sub> H <sub>1.87n</sub>                  | 100–110               | 45–49                                     | 151                                            | 0.57                                           | 20,300                                     | 18,900                                    |
| Light diesel (ℓ)    | C <sub>n</sub> H <sub>1.8n</sub>                   | 170                   | 49–52                                     | 116                                            | 0.53                                           | 19,800                                     | 18,600                                    |
| Heavy diesel (ℓ)    | C <sub>n</sub> H <sub>1.7n</sub>                   | 200                   | 51–55                                     | 99                                             | 0.45                                           | 19,600                                     | 18,400                                    |
| Natural gas (g)     | C <sub>n</sub> H <sub>3.8n</sub> N <sub>0.1n</sub> | 18                    | —                                         | —                                              | 0.48                                           | 21,500                                     | 19,400                                    |

<sup>1</sup>At 1 atm and 68°F.<sup>2</sup>At 77°F for liquid fuels, and 1 atm and normal boiling temperature for gaseous fuels.<sup>3</sup>At 77°F. Multiply by molar mass to obtain heating values in Btu/lbmol.



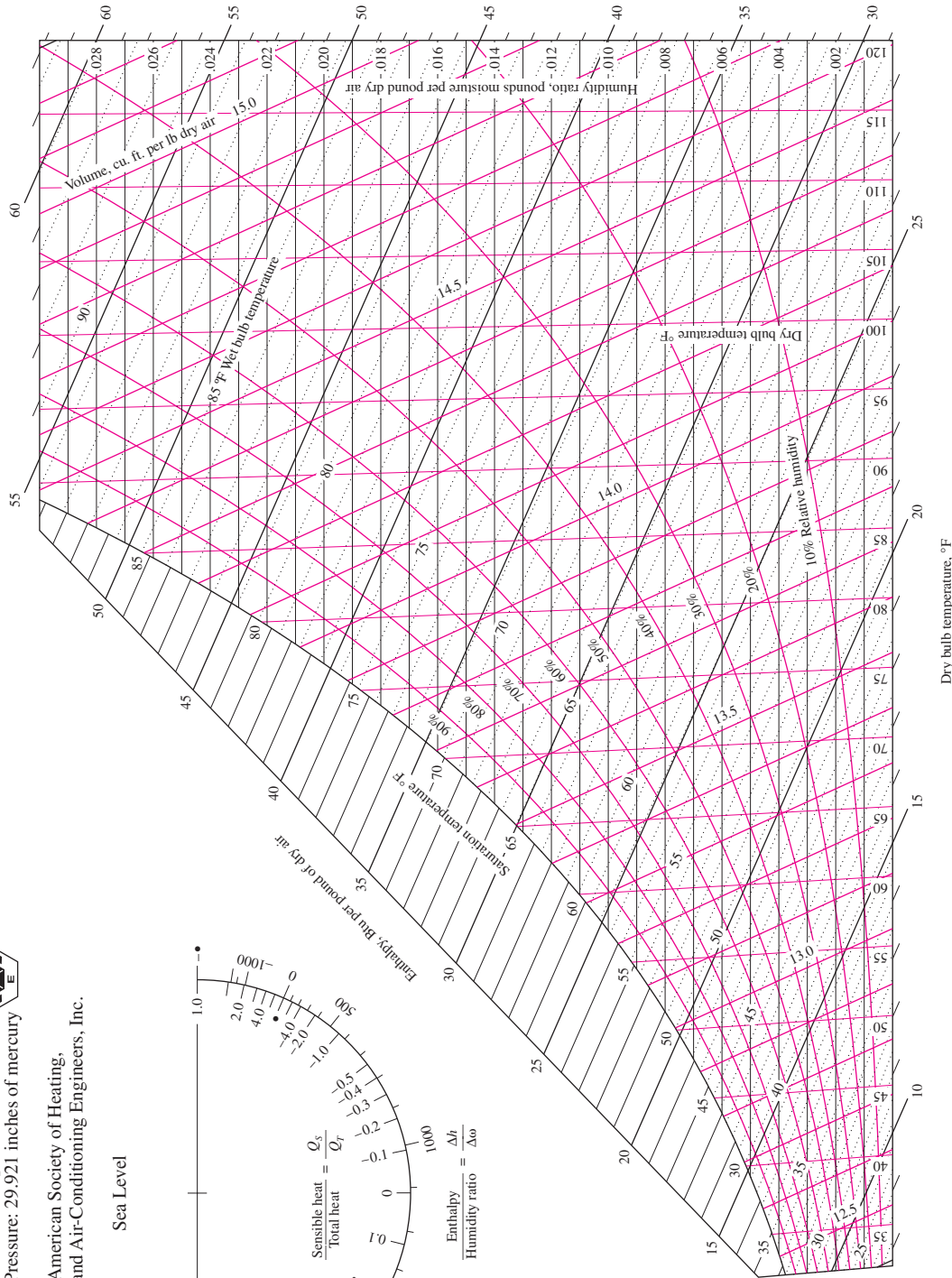
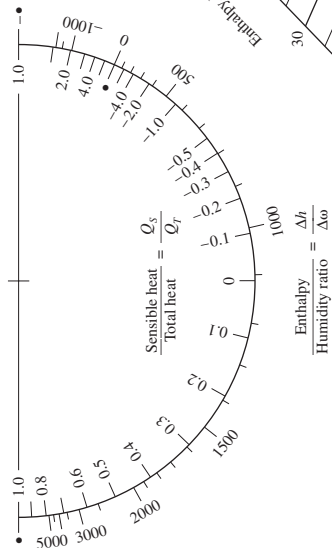
# ASHRAE Psychrometric Chart No. 1

Normal Temperature

Barometric Pressure: 29.921 inches of mercury

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Sea Level



Prepared by Center for Applied Thermodynamic Studies, University of Idaho.

**FIGURE A-31E**

Psychrometric chart at 1 atm total pressure.

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