

# Appendix B

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## Physical Property Tables

**TABLE**

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**Table B.1** Selected Physical Property Data<sup>a</sup>

Compound	Formula	Mol. Wt.	SG (20°/4°)	$T_m$ (°C) <sup>b</sup>	$\Delta\hat{H}_m(T_m)$ <sup>c,j</sup> kJ/mol	$T_b$ (°C) <sup>d</sup>	$\Delta\hat{H}_v(T_b)$ <sup>e,j</sup> kJ/mol	$T_c$ (K) <sup>f</sup>	$P_c$ (atm) <sup>g</sup>	$(\Delta\hat{H}_f^\circ)^{h,j}$ kJ/mol	$(\Delta\hat{H}_c^\circ)^{i,j}$ kJ/mol
Acetaldehyde	CH <sub>3</sub> CHO	44.05	0.783 <sup>18°</sup>	-123.7	—	20.2	25.1	461.0	—	-166.2(g)	-1192.4(g)
Acetic acid	CH <sub>3</sub> COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	-486.18(l)	-871.69(l)
Acetone	C <sub>3</sub> H <sub>6</sub> O	58.08	0.791	-95.0	5.69	56.0	30.2	508.0	47.0	-248.2(l)	-1785.7(l)
Acetylene	C <sub>2</sub> H <sub>2</sub>	26.04	—	—	—	-81.5	17.6	309.5	61.6	+226.75(g)	-1299.6(g)
Ammonia	NH <sub>3</sub>	17.03	—	-77.8	5.653	-33.43	23.351	405.5	111.3	-67.20(l)	-46.19(g)
Ammonium hydroxide	NH <sub>4</sub> OH	35.03	—	—	—	—	—	—	—	-366.48(aq)	—
Ammonium nitrate	NH <sub>4</sub> NO <sub>3</sub>	80.05	1.725 <sup>25°</sup>	169.6	5.4	Decomposes at 210°C				-365.14(c)	—
Ammonium sulfate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	132.14	1.769	513	—	Decomposes at 513°C after melting				-1179.3(c)	-1173.1(aq)
Aniline	C <sub>6</sub> H <sub>7</sub> N	93.12	1.022	-6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C <sub>6</sub> H <sub>5</sub> CHO	106.12	1.046	-26.0	—	179.0	38.40	—	—	-88.83(l)	-3520.0(l)
Benzene	C <sub>6</sub> H <sub>6</sub>	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l)	-3267.6(l)
Benzoic acid	C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	122.12	1.266 <sup>15°</sup>	122.2	—	249.8	—	—	—	—	-3226.7(g)
Benzyl alcohol	C <sub>7</sub> H <sub>8</sub> O	108.13	1.045	-15.4	—	205.2	—	—	—	—	-3741.8(l)
Bromine	Br <sub>2</sub>	159.83	3.119	-7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C <sub>4</sub> H <sub>6</sub>	54.09	—	-136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C <sub>4</sub> H <sub>6</sub>	54.09	—	-109.1	—	-4.6	—	425	42.7	—	—
<i>n</i> -Butane	C <sub>4</sub> H <sub>10</sub>	58.12	—	-138.3	4.661	-0.6	22.305	425.17	37.47	-147.0(l)	-2855.6(l)
Isobutane	C <sub>4</sub> H <sub>10</sub>	58.12	—	-159.6	4.540	-11.73	21.292	408.1	36.0	-158.4(l)	-2849.0(l)
1-Butene	C <sub>4</sub> H <sub>8</sub>	56.10	—	-185.3	3.8480	-6.25	21.916	419.6	39.7	+1.17(g)	-2718.6(g)
Calcium carbide	CaC <sub>2</sub>	64.10	2.22 <sup>18°</sup>	2300	—	—	—	—	—	-62.76(c)	—
Calcium carbonate	CaCO <sub>3</sub>	100.09	2.93	Decomposes at 825°C				—			
Calcium chloride	CaCl <sub>2</sub>	110.99	2.152 <sup>15°</sup>	782	28.37	>1600	—	—	—	-794.96(c)	—

Specific Gravity  

$$SG = \frac{P_{\text{spars}} @ 20^\circ C}{P_{H_2O} @ 4^\circ C}$$

Calories  
 Heat of vaporizn.  
 ↓

Formation  
 ↓

Combustion  
 not conducted  
 ↓

Calcium hydroxide	$\text{Ca}(\text{OH})_2$	74.10	2.24			( $-\text{H}_2\text{O}$ at 580°C)			-986.59(c)	—
Calcium oxide	$\text{CaO}$	56.08	3.32	2570	50	2850	—	—	-635.6(c)	—
Calcium phosphate	$\text{Ca}_3(\text{PO}_4)_2$	310.19	3.14	1670	—	—	—	—	-4138(c)	—
Calcium silicate	$\text{CaSiO}_3$	116.17	2.915	1530	48.62	—	—	—	-1584(c)	—
Calcium sulfate	$\text{CaSO}_4$	136.15	2.96	—	—	—	—	—	-1432.7(c) -1450.4(aq)	—
Calcium sulfate (gypsum)	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	172.18	2.32		( $-1.5 \text{ H}_2\text{O}$ at 128°C)	—	—	—	-2021(c)	—
Carbon (graphite)	C	12.010	2.26	3600	46.0	4200	—	—	0(c)	-393.51(c)
Carbon dioxide	$\text{CO}_2$	44.01	—	—56.6 at 5.2 atm	8.33	(Sublimes at -78°C)	304.2	72.9	-412.9(l) -393.5(g)	—
Carbon disulfide	$\text{CS}_2$	76.14	1.261 <sup>22°/20°</sup>	-112.1	4.39	46.25	26.8	552.0	78.0	+87.9(l) +115.3(g)
Carbon monoxide	CO	28.01	—	-205.1	0.837	-191.5	6.042	133.0	34.5	-110.52(g)
Carbon tetrachloride	$\text{CCl}_4$	153.84	1.595	-22.9	2.51	76.7	30.0	556.4	45.0	-139.5(l) -106.7(g)
Chlorine	$\text{Cl}_2$	70.91	—	-101.00	6.406	-34.06	20.4	417.0	76.1	0(g)
Chlorobenzene	$\text{C}_6\text{H}_5\text{Cl}$	112.56	1.107	-45	—	132.10	36.5	632.4	44.6	—
Chloroethane	$\text{C}_2\text{H}_5\text{Cl}$	See ethyl chloride								

<sup>a</sup>Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, ©1974, Tables D.1 and F.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

<sup>b</sup>Melting point at 1 atm.

<sup>c</sup>Heat of fusion at  $T_m$  and 1 atm.

<sup>d</sup>Boiling point at 1 atm.

<sup>e</sup>Heat of vaporization at  $T_b$  and 1 atm.

<sup>f</sup>Critical temperature.

<sup>g</sup>Critical pressure.

<sup>h</sup>Heat of formation at 25°C and 1 atm.

<sup>i</sup>Heat of combustion at 25°C and 1 atm. Standard states of products are  $\text{CO}_2(\text{g})$ ,  $\text{H}_2\text{O}(\text{l})$ ,  $\text{SO}_2(\text{g})$ ,  $\text{HCl}(\text{aq})$ , and  $\text{N}_2(\text{g})$ . To calculate  $\Delta\hat{H}_c^\circ$  with  $\text{H}_2\text{O}(\text{g})$  as a product, add 44.01 $n_w$  to the tabulated value, where  $n_w$  = moles  $\text{H}_2\text{O}$  formed/mole fuel burned.

<sup>j</sup>To convert  $\Delta\hat{H}$  to kcal/mol, divide given value by 4.184; to convert to Btu/lb-mole, multiply by 430.28.

(continued)

**Table B.1** (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	$T_m$ (°C) <sup>b</sup>	$\Delta\hat{H}_m(T_m)$ <sup>c,j</sup> kJ/mol	$T_b$ (°C) <sup>d</sup>	$\Delta\hat{H}_v(T_b)$ <sup>e,j</sup> kJ/mol	$T_c$ (K) <sup>f</sup>	$P_c$ (atm) <sup>g</sup>	$(\Delta\hat{H}_f^\circ)$ <sup>h,j</sup> kJ/mol	$(\Delta\hat{H}_c^\circ)$ <sup>i,j</sup> kJ/mol
Chloroform	CHCl <sub>3</sub>	119.39	1.489	-63.7	—	61.0	—	536.0	54.0	-131.8(l) 0(c)	-373(l)
Copper	Cu	63.54	8.92	1083	13.01	2595	304.6	—	—	-769.9(c)	—
Cupric sulfate	CuSO <sub>4</sub>	159.61	3.606 <sup>15°</sup>			Decomposes > 600°C				-843.1(aq)	—
Cyclohexane	C <sub>6</sub> H <sub>12</sub>	84.16	0.779	6.7	2.677	80.7	30.1	553.7	40.4	-156.2(l) -123.1(g)	-3919.9(l) -3953.0(g)
Cyclopentane	C <sub>5</sub> H <sub>10</sub>	70.13	0.745	-93.4	0.609	49.3	27.30	511.8	44.55	-105.9(l) -77.2(g)	-3290.9(l) -3319.5(g)
<i>n</i> -Decane	C <sub>10</sub> H <sub>22</sub>	142.28	0.730	-29.9	—	173.8	—	619.0	20.8	-249.7(l)	-6778.3(l) -6829.7(g)
Diethyl ether	(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> O	74.12	0.708 <sup>25°</sup>	-116.3	7.30	34.6	26.05	467	35.6	-272.8(l)	-2726.7(l)
Ethane	C <sub>2</sub> H <sub>6</sub>	30.07	—	-183.3	2.859	-88.6	14.72	305.4	48.2	-84.67(g)	-1559.9(g)
Ethyl acetate	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	88.10	0.901	-83.8	—	77.0	—	523.1	37.8	-463.2(l) -426.8(g)	-2246.4(l)
Ethyl alcohol (Ethanol)	C <sub>2</sub> H <sub>5</sub> OH	46.07	0.789	-114.6	5.021	78.5	38.58	516.3	63.0	-277.63(l) -235.31(g)	-1366.91(l) -1409.25(g)
Ethyl benzene	C <sub>8</sub> H <sub>10</sub>	106.16	0.867	-94.67	9.163	136.2	35.98	619.7	37.0	-12.46(l) +29.79(g)	-4564.9(l) -4607.1(g)
Ethyl bromide	C <sub>2</sub> H <sub>5</sub> Br	108.98	1.460	-119.1	—	38.2	—	504	61.5	-54.4(g)	—
Ethyl chloride	C <sub>2</sub> H <sub>5</sub> Cl	64.52	0.903 <sup>15°</sup>	-138.3	4.452	13.1	24.7	460.4	52.0	-105.0(g)	—
3-Ethyl hexane	C <sub>8</sub> H <sub>18</sub>	114.22	0.717	—	—	118.5	34.27	567.0	26.4	-250.5(l) -210.9(g)	-5407.1(l) -5509.8(g)
Ethylene	C <sub>2</sub> H <sub>4</sub>	28.05	—	-169.2	3.350	-103.7	13.54	283.1	50.5	+52.28(g)	-1410.99(g)
Ethylene glycol	C <sub>2</sub> H <sub>6</sub> O <sub>2</sub>	62.07	1.113 <sup>19°</sup>	-13	11.23	197.2	56.9	—	—	-451.5(l) -387.1(g)	-1179.5(l) —
Ferric oxide	Fe <sub>2</sub> O <sub>3</sub>	159.70	5.12			Decomposes at 1560°C				-822.2(c)	—
Ferrous oxide	FeO	71.85	5.7	—	—	—	—	—	—	-266.5(c)	—
Ferrous sulfide	FeS	87.92	4.84	1193	—	—	—	—	—	-95.1(c)	—
Formaldehyde	H <sub>2</sub> CO	30.03	0.815 <sup>-20°</sup>	-92	—	-19.3	24.48	—	—	-115.90(g)	-563.46(g)
Formic acid	CH <sub>2</sub> O <sub>2</sub>	46.03	1.220	8.30	12.68	100.5	22.25	—	—	-409.2(l) -362.6(g)	-262.8(l) —
Glycerol	C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>	92.09	1.260 <sup>50°</sup>	18.20	18.30	290.0	—	—	—	-665.9(l)	-1661.1(l)
Helium	He	4.00	—	-269.7	0.02	-268.9	0.084	5.26	2.26	0(g)	—

<i>n</i> -Heptane	C <sub>7</sub> H <sub>16</sub>	100.20	0.684	-90.59	14.03	98.43	31.69	540.2	27.0	-224.4(l) -187.8(g)	-4816.9(l) -4853.5(g)
<i>n</i> -Hexane	C <sub>6</sub> H <sub>14</sub>	86.17	0.659	-95.32	13.03	68.74	28.85	507.9	29.9	-198.8(l) -167.2(g)	-4163.1(l) -4194.8(g)
Hydrogen	H <sub>2</sub>	2.016	—	-259.19	0.12	-252.76	0.904	33.3	12.8	0(g) -36.23(g)	-285.84(g)
Hydrogen bromide	HBr	80.92	—	-86	—	-67	—	—	—	—	—
Hydrogen chloride	HCl	36.47	—	-114.2	1.99	-85.0	16.1	324.6	81.5	-92.31(g)	—
Hydrogen cyanide	HCN	27.03	—	-14	—	26	—	—	—	+130.54(g)	—
Hydrogen fluoride	HF	20.0	—	-83	—	20	—	503.2	—	-268.6(g) -316.9(aq, 200)	—
Hydrogen sulfide	H <sub>2</sub> S	34.08	—	-85.5	2.38	-60.3	18.67	373.6	88.9	-19.96(g)	-562.59(g)
Iodine	I <sub>2</sub>	253.8	4.93	113.3	—	184.2	—	826.0	—	0(c)	—
Iron	Fe	55.85	7.7	1535	15.1	2800	354.0	—	—	0(c)	—
Lead	Pb	207.21	11.337 <sup>20°/20°</sup>	327.4	5.10	1750	179.9	—	—	0(c)	—
Lead oxide	PbO	223.21	9.5	886	11.7	1472	213	—	—	-219.2(c)	—
Magnesium	Mg	24.32	1.74	650	9.2	1120	131.8	—	—	0(c)	—
Magnesium chloride	MgCl <sub>2</sub>	95.23	2.325 <sup>25°</sup>	714	43.1	1418	136.8	—	—	-641.8(c)	—
Magnesium hydroxide	Mg(OH) <sub>2</sub>	58.34	2.4	Decomposes at 350°C						—	—
Magnesium oxide	MgO	40.32	3.65	2900	77.4	3600	—	—	—	-601.8(c)	—
Mercury	Hg	200.61	13.546	-38.87	—	-356.9	—	—	—	0(c)	—
Methane	CH <sub>4</sub>	16.04	—	-182.5	0.94	-161.5	8.179	190.70	45.8	-74.85(g)	-890.36(g)
Methyl acetate	C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	74.08	0.933	-98.9	—	57.1	—	506.7	46.30	-409.4(l)	-1595(l)
Methyl alcohol (Methanol)	CH <sub>3</sub> OH	32.04	0.792	-97.9	3.167	64.7	35.27	513.20	78.50	-238.6(l) -201.2(g)	726.6(l) -764.0(g)
Methyl amine	CH <sub>5</sub> N	31.06	0.699 <sup>-11°</sup>	-92.7	—	-6.9	—	429.9	73.60	-28.0(g)	-1071.5(l)
Methyl chloride	CH <sub>3</sub> Cl	50.49	—	-97.9	—	-24	—	416.1	65.80	-81.92(g)	—

(continued)

**Table B.1** (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T <sub>m</sub> (°C) <sup>b</sup>	ΔH <sub>m</sub> (T <sub>m</sub> ) <sup>c,j</sup> kJ/mol	T <sub>b</sub> (°C) <sup>d</sup>	ΔH <sub>v</sub> (T <sub>b</sub> ) <sup>e,j</sup> kJ/mol	T <sub>c</sub> (K) <sup>f</sup>	P <sub>c</sub> (atm) <sup>g</sup>	(ΔH <sub>f</sub> °) <sup>h,i</sup> kJ/mol	(ΔH <sub>c</sub> °) <sup>j</sup> kJ/mol
Methyl ethyl ketone	C <sub>4</sub> H <sub>8</sub> O	72.10	0.805	-87.1	—	78.2	32.0	—	—	—	-2436(l)
Naphthalene	C <sub>10</sub> H <sub>8</sub>	128.16	1.145	80.0	—	217.8	—	—	—	—	-5157(g)
Nickel	Ni	58.69	8.90	1452	—	2900	—	—	—	0(c)	—
Nitric acid	HNO <sub>3</sub>	63.02	1.502	-41.6	10.47	86	30.30	—	—	-173.23(l) -206.57(aq)	—
Nitrobenzene	C <sub>6</sub> H <sub>5</sub> O <sub>2</sub> N	123.11	1.203	5.5	—	210.7	—	—	—	—	-3092.8(l)
Nitrogen	N <sub>2</sub>	28.02	—	-210.0	0.720	-195.8	5.577	126.20	33.5	0(g)	—
Nitrogen dioxide	NO <sub>2</sub>	46.01	—	-9.3	7.335	21.3	14.73	431.0	100.0	+33.8(g)	—
Nitric oxide	NO	30.01	—	-163.6	2.301	-151.8	13.78	179.20	65.0	+90.37(g)	—
Nitrogen pentoxide	N <sub>2</sub> O <sub>5</sub>	108.02	1.63 <sup>18°</sup>	30	—	47	—	—	—	—	—
Nitrogen tetraoxide	N <sub>2</sub> O <sub>4</sub>	92.0	1.448	-9.5	—	21.1	—	431.0	99.0	+9.3(g)	—
Nitrous oxide	N <sub>2</sub> O	44.02	1.226 <sup>-89°</sup>	-91.1	—	-88.8	—	309.5	71.70	+81.5(g)	—
n-Nonane	C <sub>9</sub> H <sub>20</sub>	128.25	0.718	-53.8	—	150.6	—	595	23.0	-229.0(l)	-6124.5(l) -6171.0(g)
n-Octane	C <sub>8</sub> H <sub>18</sub>	114.22	0.703	-57.0	—	125.5	—	568.8	24.5	-249.9(l) -208.4(g)	-5470.7(l) -5512.2(g)
Oxalic acid	C <sub>2</sub> H <sub>2</sub> O <sub>4</sub>	90.04	1.90	—	Decomposes at 186°C			—	—	-826.8(c)	-251.9(s)
Oxygen	O <sub>2</sub>	32.00	—	-218.75	0.444	-182.97	6.82	154.4	49.7	0(g)	—
n-Pentane	C <sub>5</sub> H <sub>12</sub>	72.15	0.63 <sup>18°</sup>	-129.6	8.393	36.07	25.77	469.80	33.3	-173.0(l) -146.4(g)	-3509.5(l) -3536.1(g)
Isopentane	C <sub>5</sub> H <sub>12</sub>	72.15	0.62 <sup>19°</sup>	-160.1	—	27.7	—	461.00	32.9	-179.3(l) -152.0(g)	-3507.5(l) -3529.2(g)
1-Pentene	C <sub>5</sub> H <sub>10</sub>	70.13	0.641	-165.2	4.94	29.97	—	474	39.9	-20.9(g)	-3375.8(g)
Phenol	C <sub>6</sub> H <sub>5</sub> OH	94.11	1.071 <sup>25°</sup>	42.5	11.43	181.4	—	692.1	60.5	-158.1(l) -90.8(g)	-3063.5(s)
Phosphoric acid	H <sub>3</sub> PO <sub>4</sub>	98.00	1.834 <sup>18°</sup>	42.3	10.54	(-½H <sub>2</sub> O at 213°C)	—	—	—	-1281.1(c) -1278.6(aq, 1H <sub>2</sub> O)	—
Phosphorus (red)	P <sub>4</sub>	123.90	2.20	590 <sup>43 atm</sup>	81.17	Ignites in air, 725°C	—	—	—	-17.6(c) 0(c)	—

Phosphorus (white)	P <sub>4</sub>	123.90	1.82	44.2	2.51	280	49.71	—	—	—
Phosphorus pentoxide	P <sub>2</sub> O <sub>5</sub>	141.95	2.387		Sublimes at 250°C			—	—	-1506.2(c)
Propane	C <sub>3</sub> H <sub>8</sub>	44.09	—	-187.69	3.52	-42.07	18.77	369.9	42.0	-119.8(l) -103.8(g)
Propylene	C <sub>3</sub> H <sub>6</sub>	42.08	—	-185.2	3.00	-47.70	18.42	365.1	45.4	+20.41(g)
<i>n</i> -Propyl alcohol	C <sub>3</sub> H <sub>7</sub> OH	60.09	0.804	-127	—	97.04	—	536.7	49.95	-300.70(l) -255.2(g)
Isopropyl alcohol	C <sub>3</sub> H <sub>7</sub> OH	60.09	0.785	-89.7	—	82.24	—	508.8	53.0	-310.9(l) -2068.6(g)
<i>n</i> -Propyl benzene	C <sub>9</sub> H <sub>12</sub>	120.19	0.862	-99.50	8.54	159.2	38.24	638.7	31.3	-38.40(l) +7.82(g)
Silicon dioxide	SiO <sub>2</sub>	60.09	2.25	1710	14.2	2230	—	—	—	-851.0(c)
Sodium bicarbonate	NaHCO <sub>3</sub>	84.01	2.20		Decomposes at 270°C			—	—	-945.6(c)
Sodium bisulfate	NaHSO <sub>4</sub>	120.07	2.742	—	—	—	—	—	—	-1126.3(c)
Sodium carbonate	Na <sub>2</sub> CO <sub>3</sub>	105.99	2.533		Decomposes at 854°C			—	—	-1130.9(c)
Sodium chloride	NaCl	58.45	2.163	808	28.5	1465	170.7	—	—	-411.0(c)
Sodium cyanide	NaCN	49.01	—	562	16.7	1497	155	—	—	-89.79(c)
Sodium hydroxide	NaOH	40.00	2.130	319	8.34	1390	—	—	—	-426.6(c) -469.4(aq)
Sodium nitrate	NaNO <sub>3</sub>	85.00	2.257	310	15.9		Decomposes at 380°C			-466.7(c)
Sodium nitrite	NaNO <sub>2</sub>	69.00	2.168°	271	—		Decomposes at 320°C			-359.4(c)
Sodium sulfate	Na <sub>2</sub> SO <sub>4</sub>	142.05	2.698	890	24.3	—	—	—	—	-1384.5(c)
Sodium sulfide	Na <sub>2</sub> S	78.05	1.856	950	6.7	—	—	—	—	-373.2(c)
Sodium sulfite	Na <sub>2</sub> SO <sub>3</sub>	126.05	2.633 <sup>15°</sup>		Decomposes			—	—	-1090.3(c)

(continued)

**Table B.1** (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	$T_m$ (°C) <sup>b</sup>	$\Delta\hat{H}_m(T_m)$ <sup>c,j</sup> kJ/mol	$T_b$ (°C) <sup>d</sup>	$\Delta\hat{H}_v(T_b)$ <sup>e,j</sup> kJ/mol	$T_c$ (K) <sup>f</sup>	$P_c$ (atm) <sup>g</sup>	$(\Delta\hat{H}_f^\circ)$ <sup>h,j</sup> kJ/mol	$(\Delta\hat{H}_c^\circ)$ <sup>i,j</sup> kJ/mol
Sodium thiosulfate	Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	158.11	1.667	—	—	—	—	—	—	-1117.1(c)	—
Sulfur (rhombic)	S <sub>8</sub>	256.53	2.07	113	10.04	444.6	83.7	—	—	0(c)	—
Sulfur (monoclinic)	S <sub>8</sub>	256.53	1.96	119	14.17	444.6	83.7	—	—	+0.30(c)	—
Sulfur dioxide	SO <sub>2</sub>	64.07	—	-75.48	7.402	-10.02	24.91	430.7	77.8	-296.90(g)	—
Sulfur trioxide	SO <sub>3</sub>	80.07	—	16.84	25.48	43.3	41.80	491.4	83.8	-395.18(g)	—
Sulfuric acid	H <sub>2</sub> SO <sub>4</sub>	98.08	1.834 <sup>18°</sup>	10.35	9.87	Decomposes at 340°C	—	—	—	-811.32(l) -907.51(aq)	—
Toluene	C <sub>7</sub> H <sub>8</sub>	92.13	0.866	-94.99	6.619	110.62	33.47	593.9	40.3	+12.00(l) +50.00(g)	-3909.9(l) -3947.9(g)
Water	H <sub>2</sub> O	18.016	1.00 <sup>4°</sup>	0.00	6.0095	100.00	40.656	647.4	218.3	-285.84(l) -241.83(g)	—
<i>m</i> -Xylene	C <sub>8</sub> H <sub>10</sub>	106.16	0.864	-47.87	11.569	139.10	36.40	619	34.6	-25.42(l) +17.24(g)	-4551.9(l) -4594.5(g)
<i>o</i> -Xylene	C <sub>8</sub> H <sub>10</sub>	106.16	0.880	-25.18	13.598	144.42	36.82	631.5	35.7	-24.44(l) +18.99(g)	-4552.9(l) -4596.3(g)
<i>p</i> -Xylene	C <sub>8</sub> H <sub>10</sub>	106.16	0.861	13.26	17.11	138.35	36.07	618	33.9	-24.43(l) 17.95(g)	-4552.91(l) -4595.2(g)
Zinc	Zn	65.38	7.140	419.5	6.674	907	114.77	—	—	0(c)	—



**Physical Property database**  
Quickly integrates  
tabulated heat  
capacities

**Table B.2** Heat Capacities<sup>a</sup>

Form 1:  $C_p[\text{kJ}/(\text{mol}\cdot\text{°C})]$  or  $[\text{kJ}/(\text{mol}\cdot\text{K})] = a + bT + cT^2 + dT^3$

Form 2:  $C_p[\text{kJ}/(\text{mol}\cdot\text{°C})]$  or  $[\text{kJ}/(\text{mol}\cdot\text{K})] = a + bT + cT^{-2}$

*Example:*  $(C_p)_{\text{acetone(g)}} = 0.07196 + (20.10 \times 10^{-5})T - (12.78 \times 10^{-8})T^2 + (34.76 \times 10^{-12})T^3$ , where  $T$  is in °C.

*Note:* The formulas for gases are strictly applicable at pressures low enough for the ideal gas equation of state to apply.

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of $T$ )
Acetone	CH <sub>3</sub> COCH <sub>3</sub>	58.08	l	1	°C	123.0	18.6			-30–60
			g	1	°C	71.96	20.10	-12.78	34.76	0–1200
Acetylene	C <sub>2</sub> H <sub>2</sub>	26.04	g	1	°C	42.43	6.053	-5.033	18.20	0–1200
Air		29.0	g	1	°C	28.94	0.4147	0.3191	-1.965	0–1500
			g	1	K	28.09	0.1965	0.4799	-1.965	273–1800
Ammonia	NH <sub>3</sub>	17.03	g	1	°C	35.15	2.954	0.4421	-6.686	0–1200
Ammonium sulfate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	132.15	c	1	K	215.9				275–328
Benzene	C <sub>6</sub> H <sub>6</sub>	78.11	l	1	°C	126.5	23.4			6–67
			g	1	°C	74.06	32.95	-25.20	77.57	0–1200
Isobutane	C <sub>4</sub> H <sub>10</sub>	58.12	g	1	°C	89.46	30.13	-18.91	49.87	0–1200
n-Butane	C <sub>4</sub> H <sub>10</sub>	58.12	g	1	°C	92.30	27.88	-15.47	34.98	0–1200
Isobutene	C <sub>4</sub> H <sub>8</sub>	56.10	g	1	°C	82.88	25.64	-17.27	50.50	0–1200
Calcium carbide	CaC <sub>2</sub>	64.10	c	2	K	68.62	1.19	-8.66 × 10 <sup>10</sup>	—	298–720
Calcium carbonate	CaCO <sub>3</sub>	100.09	c	2	K	82.34	4.975	-12.87 × 10 <sup>10</sup>	—	273–1033
Calcium hydroxide	Ca(OH) <sub>2</sub>	74.10	c	1	K	89.5				276–373
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52 × 10 <sup>10</sup>		273–1173
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891 × 10 <sup>10</sup>		273–1373
Carbon dioxide	CO <sub>2</sub>	44.01	g	1	°C	36.11	4.233	-2.887	7.464	0–1500
Carbon monoxide	CO	28.01	g	1	°C	28.95	0.4110	0.3548	-2.220	0–1500
Carbon tetrachloride	CCl <sub>4</sub>	153.84	l	1	K	93.39	12.98			273–343
Chlorine	Cl <sub>2</sub>	70.91	g	1	°C	33.60	1.367	-1.607	6.473	0–1200
Copper	Cu	63.54	c	1	K	22.76	0.6117			273–1357

<sup>a</sup>Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, © 1974, Table E.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

(continued)

**Table B.2** (Continued)

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of $T$ )
Cumene (Isopropyl benzene)	C <sub>9</sub> H <sub>12</sub>	120.19	g	1	°C	139.2	53.76	-39.79	120.5	0–1200
Cyclohexane	C <sub>6</sub> H <sub>12</sub>	84.16	g	1	°C	94.140	49.62	-31.90	80.63	0–1200
Cyclopentane	C <sub>5</sub> H <sub>10</sub>	70.13	g	1	°C	73.39	39.28	-25.54	68.66	0–1200
Ethane	C <sub>2</sub> H <sub>6</sub>	30.07	g	1	°C	49.37	13.92	-5.816	7.280	0–1200
Ethyl alcohol (Ethanol)	C <sub>2</sub> H <sub>5</sub> OH	46.07	l	1	°C	103.1			0	
			l	1	°C	158.8			100	
			g	1	°C	61.34	15.72	-8.749	19.83	0–1200
Ethylene	C <sub>2</sub> H <sub>4</sub>	28.05	g	1	°C	+40.75	11.47	-6.891	17.66	0–1200
Ferric oxide	Fe <sub>2</sub> O <sub>3</sub>	159.70	c	2	K	103.4	6.711	-17.72 × 10 <sup>10</sup>	—	273–1097
Formaldehyde	CH <sub>2</sub> O	30.03	g	1	°C	34.28	4.268	0.0000	-8.694	0–1200
Helium	He	4.00	g	1	°C	20.8			0–1200	
n-Hexane	C <sub>6</sub> H <sub>14</sub>	86.17	l	1	°C	216.3			20–100	
			g	1	°C	137.44	40.85	-23.92	57.66	0–1200
Hydrogen	H <sub>2</sub>	2.016	g	1	°C	28.84	0.00765	0.3288	-0.8698	0–1500
Hydrogen bromide	HBr	80.92	g	1	°C	29.10	-0.0227	0.9887	-4.858	0–1200
Hydrogen chloride	HCl	36.47	g	1	°C	29.13	-0.1341	0.9715	-4.335	0–1200
Hydrogen cyanide	HCN	27.03	g	1	°C	35.3	2.908	1.092	0–1200	
Hydrogen sulfide	H <sub>2</sub> S	34.08	g	1	°C	33.51	1.547	0.3012	-3.292	0–1500
Magnesium chloride	MgCl <sub>2</sub>	95.23	c	1	K	72.4	1.58			273–991
Magnesium oxide	MgO	40.32	c	2	K	45.44	0.5008	-8.732 × 10 <sup>10</sup>		273–2073
Methane	CH <sub>4</sub>	16.04	g	1	°C	34.31	5.469	0.3661	-11.00	0–1200
			g	1	K	19.87	5.021	1.268	-11.00	273–1500
Methyl alcohol (Methanol)	CH <sub>3</sub> OH	32.04	l	1	°C	75.86	16.83			0–65
			g	1	°C	42.93	8.301	-1.87	-8.03	0–700
Methyl cyclohexane	C <sub>7</sub> H <sub>14</sub>	98.18	g	1	°C	121.3	56.53	-37.72	100.8	0–1200
Methyl cyclopentane	C <sub>6</sub> H <sub>12</sub>	84.16	g	1	°C	98.83	45.857	-30.44	83.81	0–1200
Nitric acid	NHO <sub>3</sub>	63.02	l	1	°C	110.0				25
Nitric oxide	NO	30.01	g	1	°C	29.50	0.8188	-0.2925	0.3652	0–3500

Nitrogen	$\text{N}_2$	28.02	g	1	°C	29.00	0.2199	0.5723	-2.871	0–1500
Nitrogen dioxide	$\text{NO}_2$	46.01	g	1	°C	36.07	3.97	-2.88	7.87	0–1200
Nitrogen tetraoxide	$\text{N}_2\text{O}_4$	92.02	g	1	°C	75.7	12.5	-11.3		0–300
Nitrous oxide	$\text{N}_2\text{O}$	44.02	g	1	°C	37.66	4.151	-2.694	10.57	0–1200
Oxygen	$\text{O}_2$	32.00	g	1	°C	29.10	1.158	-0.6076	1.311	0–1500
<i>n</i> -Pentane	$\text{C}_5\text{H}_{12}$	72.15	l	1	°C	155.4	43.68			0–36
			g	1	°C	114.8	34.09	-18.99	42.26	0–1200
Propane	$\text{C}_3\text{H}_8$	44.09	g	1	°C	68.032	22.59	-13.11	31.71	0–1200
Propylene	$\text{C}_3\text{H}_6$	42.08	g	1	°C	59.580	17.71	-10.17	24.60	0–1200
Sodium carbonate	$\text{Na}_2\text{CO}_3$	105.99	c	1	K	121				288–371
Sodium carbonate decahydrate	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$	286.15	c	1	K	535.6				298
Sulfur	S	32.07	c	1	K	15.2	2.68			273–368
			(Rhombic)							
			c	1	K	18.3	1.84			368–392
			(Monoclinic)							
Sulfuric acid	$\text{H}_2\text{SO}_4$	98.08	l	1	°C	139.1	15.59			10–45
Sulfur dioxide	$\text{SO}_2$	64.07	g	1	°C	38.91	3.904	-3.104	8.606	0–1500
Sulfur trioxide	$\text{SO}_3$	80.07	g	1	°C	48.50	9.188	-8.540	32.40	0–1000
Toluene	$\text{C}_7\text{H}_8$	92.13	l	1	°C	148.8	32.4			0–110
			g	1	°C	94.18	38.00	-27.86	80.33	0–1200
Water	$\text{H}_2\text{O}$	18.016	l	1	°C	75.4				0–100
			g	1	°C	33.46	0.6880	0.7604	-3.593	0–1500

**Table B.3** Vapor Pressure of Water<sup>a</sup>

$p_v$ (mm Hg) versus $T$ (°C)											
Example: The vapor pressure of liquid water at 4.3°C is 6.230 mm Hg											
	$T$ (°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Ice	-14	1.361	1.348	1.336	1.324	1.312	1.300	1.288	1.276	1.264	1.253
	-13	1.490	1.477	1.464	1.450	1.437	1.424	1.411	1.399	1.386	1.373
	-12	1.632	1.617	1.602	1.588	1.574	1.559	1.546	1.532	1.518	1.504
	-11	1.785	1.769	1.753	1.737	1.722	1.707	1.691	1.676	1.661	1.646
	-10	1.950	1.934	1.916	1.899	1.883	1.866	1.849	1.833	1.817	1.800
	-9	2.131	2.122	2.093	2.075	2.057	2.039	2.021	2.003	1.985	1.968
	-8	2.326	2.306	2.285	2.266	2.246	2.226	2.207	2.187	2.168	2.149
	-7	2.537	2.515	2.493	2.472	2.450	2.429	2.408	2.387	2.367	2.346
	-6	2.765	2.742	2.718	2.695	2.672	2.649	2.626	2.603	2.581	2.559
	-5	3.013	2.987	2.962	2.937	2.912	2.887	2.862	2.838	2.813	2.790
	-4	3.280	3.252	3.225	3.198	3.171	3.144	3.117	3.091	3.065	3.039
	-3	3.568	3.539	3.509	3.480	3.451	3.422	3.393	3.364	3.336	3.308
	-2	3.880	3.848	3.816	3.785	3.753	3.722	3.691	3.660	3.630	3.599
	-1	4.217	4.182	4.147	4.113	4.079	4.045	4.012	3.979	3.946	3.913
	-0	4.579	4.542	4.504	4.467	4.431	4.395	4.359	4.323	4.287	4.252
Liquid water	0	4.579	4.613	4.647	4.681	4.715	4.750	4.785	4.820	4.855	4.890
	1	4.926	4.962	4.998	5.034	5.070	5.107	5.144	5.181	5.219	5.256
	2	5.294	5.332	5.370	5.408	5.447	5.486	5.525	5.565	5.605	5.645
	3	5.685	5.725	5.766	5.807	5.848	5.889	5.931	5.973	6.015	6.058
	4	6.101	6.144	6.187	6.230	6.274	6.318	6.363	6.408	6.453	6.498
	5	6.543	6.589	6.635	6.681	6.728	6.775	6.822	6.869	6.917	6.965
	6	7.013	7.062	7.111	7.160	7.209	7.259	7.309	7.360	7.411	7.462
	7	7.513	7.565	7.617	7.669	7.722	7.775	7.828	7.882	7.936	7.990
	8	8.045	8.100	8.155	8.211	8.267	8.323	8.380	8.437	8.494	8.551
	9	8.609	8.668	8.727	8.786	8.845	8.905	8.965	9.025	9.086	9.147
	10	9.209	9.271	9.333	9.395	9.458	9.521	9.585	9.649	9.714	9.779
	11	9.844	9.910	9.976	10.042	10.109	10.176	10.244	10.312	10.380	10.449
	12	10.518	10.588	10.658	10.728	10.799	10.870	10.941	11.013	11.085	11.158
	13	11.231	11.305	11.379	11.453	11.528	11.604	11.680	11.756	11.833	11.910
	14	11.987	12.065	12.144	12.223	12.302	12.382	12.462	12.543	12.624	12.706
	15	12.788	12.870	12.953	13.037	13.121	13.205	13.290	13.375	13.461	13.547
	16	13.634	13.721	13.809	13.898	13.987	14.076	14.166	14.256	14.347	14.438
	17	14.530	14.622	14.715	14.809	14.903	14.997	15.092	15.188	15.284	15.380
	18	15.477	15.575	15.673	15.772	15.871	15.971	16.771	16.171	16.272	16.374
	19	16.477	16.581	16.685	16.789	16.894	16.999	17.105	17.212	17.319	17.427
	20	17.535	17.644	17.753	17.863	17.974	18.085	18.197	18.309	18.422	18.536
	21	18.650	18.765	18.880	18.996	19.113	19.231	19.349	19.468	19.587	19.707
	22	19.827	19.948	20.070	20.193	20.316	20.440	20.565	20.690	20.815	20.941
	23	21.068	21.196	21.324	21.453	21.583	21.714	21.845	21.977	22.110	22.243
	24	22.377	22.512	22.648	22.785	22.922	23.060	23.198	23.337	23.476	23.616

<sup>a</sup>From R. H. Perry and C. H. Chilton, Eds., *Chemical Engineers' Handbook*, 5th Edition, McGraw-Hill, New York, 1973, Tables 3-3 and 3-5. Reprinted by permission of McGraw-Hill Book Co.

(continued)

**Table B.3** (Continued)

<i>T</i> (°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
25	23.756	23.897	24.039	24.182	24.326	24.471	24.617	24.764	24.912	25.060
26	25.209	25.359	25.509	25.660	25.812	25.964	26.117	26.271	26.426	26.582
27	26.739	26.897	27.055	27.214	27.374	27.535	27.696	27.858	28.021	28.185
28	28.349	28.514	28.680	28.847	29.015	29.184	29.354	29.525	29.697	29.870
29	30.043	30.217	30.392	30.568	30.745	30.923	31.102	31.281	31.461	31.642
30	31.824	32.007	32.191	32.376	32.561	32.747	32.934	33.122	33.312	33.503
31	33.695	33.888	34.082	34.276	34.471	34.667	34.864	35.062	35.261	35.462
32	35.663	35.865	36.068	36.272	36.477	36.683	36.891	37.099	37.308	37.518
33	37.729	37.942	38.155	38.369	38.584	38.801	38.018	39.237	39.457	39.677
34	39.898	40.121	40.344	40.569	40.796	41.023	41.251	41.480	41.710	41.942
35	42.175	42.409	42.644	42.880	43.117	43.355	43.595	43.836	44.078	44.320
36	44.563	44.808	45.054	45.301	45.549	45.799	46.050	46.302	46.556	46.811
37	47.067	47.324	47.582	47.841	48.102	48.364	48.627	48.891	49.157	49.424
38	49.692	49.961	50.231	50.502	50.774	51.048	51.323	51.600	51.879	52.160
39	52.442	52.725	53.009	53.294	53.580	53.867	54.156	54.446	54.737	55.030
40	55.324	55.61	55.91	56.21	56.51	56.81	57.11	57.41	57.72	58.03
41	58.34	58.65	58.96	59.27	59.58	59.90	60.22	60.54	60.86	61.18
42	61.50	61.82	62.14	62.47	62.80	63.13	63.46	63.79	64.12	64.46
43	64.80	65.14	65.48	65.82	66.16	66.51	66.86	67.21	67.56	67.91
44	68.26	68.61	68.97	69.33	69.69	70.05	70.41	70.77	71.14	71.51
45	71.88	72.25	72.62	72.99	73.36	73.74	74.12	74.50	74.88	75.26
46	75.65	76.04	76.43	76.82	77.21	77.60	78.00	78.40	78.80	79.20
47	79.60	80.00	80.41	80.82	81.23	81.64	82.05	82.46	82.87	83.29
48	83.71	84.13	84.56	84.99	85.42	85.85	86.28	86.71	87.14	87.58
49	88.02	88.46	88.90	89.34	89.79	90.24	90.69	91.14	91.59	92.05
<i>T</i> (°C)	0	1	2	3	4	5	6	7	8	9
50	92.51	97.20	102.09	107.20	112.51	118.04	123.80	129.82	136.08	142.60
60	149.38	156.43	163.77	171.38	179.31	187.54	196.09	204.96	214.17	223.73
70	233.7	243.9	254.6	265.7	277.2	289.1	301.4	314.1	327.3	341.0
80	355.1	369.7	384.9	400.6	416.8	433.6	450.9	468.7	487.1	506.1
<i>T</i> (°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
90	525.76	527.76	529.77	531.78	533.80	535.82	537.86	539.90	541.95	544.00
91	546.05	548.11	550.18	552.26	554.35	556.44	558.53	560.64	562.75	564.87
92	566.99	569.12	571.26	573.40	575.55	577.71	579.87	582.04	584.22	586.41
93	588.60	590.80	593.00	595.21	597.43	599.66	601.89	604.13	606.38	608.64
94	610.90	613.17	615.44	617.72	620.01	622.31	624.61	626.92	629.24	631.57
95	633.90	636.24	638.59	640.94	643.30	645.67	648.05	650.43	652.82	655.22
96	657.62	660.03	662.45	664.88	667.31	669.75	672.20	674.66	677.12	679.69
97	682.07	684.55	687.04	689.54	692.05	694.57	697.10	699.63	702.17	704.71
98	707.27	709.83	712.40	714.98	717.56	720.15	722.75	725.36	727.98	730.61
99	733.24	735.88	738.53	741.18	743.85	746.52	749.20	751.89	754.58	757.29
100	760.00	762.72	765.45	768.19	770.93	773.68	776.44	779.22	782.00	784.78
101	787.57	790.37	793.18	796.00	798.82	801.66	804.50	807.35	810.21	813.08

**Table B.4** Antoine Equation Constants<sup>a</sup>

$$\log_{10} p^* = A - \frac{B}{T + C} \quad p^* \text{ in mm Hg, } T \text{ in } ^\circ\text{C}$$

*Example:* The vapor pressure of acetaldehyde at 25°C is determined as follows:

$$\log_{10} p_{\text{C}_2\text{H}_4\text{O}}^*(25^\circ\text{C}) = 8.00552 - \frac{1600.017}{25 + 291.809} = 2.9551$$

$$\implies p_{\text{C}_2\text{H}_4\text{O}}^*(25^\circ\text{C}) = 10^{2.9551} = 902 \text{ mm Hg}$$

Compound	Formula	Range (°C)	A	B	C
Acetaldehyde	C <sub>2</sub> H <sub>4</sub> O	-0.2 to 34.4	8.00552	1600.017	291.809
Acetic acid	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	29.8 to 126.5	7.38782	1533.313	222.309
Acetic acid*	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	0 to 36	7.18807	1416.7	225
Acetic anhydride	C <sub>4</sub> H <sub>6</sub> O <sub>3</sub>	62.8 to 139.4	7.14948	1444.718	199.817
Acetone	C <sub>3</sub> H <sub>6</sub> O	-12.9 to 55.3	7.11714	1210.595	229.664
Acrylic acid	C <sub>3</sub> H <sub>4</sub> O <sub>2</sub>	20.0 to 70.0	5.65204	648.629	154.683
Ammonia*	NH <sub>3</sub>	-83 to 60	7.55466	1002.711	247.885
Aniline	C <sub>6</sub> H <sub>7</sub> N	102.6 to 185.2	7.32010	1731.515	206.049
Benzene	C <sub>6</sub> H <sub>6</sub>	14.5 to 80.9	6.89272	1203.531	219.888
n-Butane	n-C <sub>4</sub> H <sub>10</sub>	-78.0 to -0.3	6.82485	943.453	239.711
i-Butane	i-C <sub>4</sub> H <sub>10</sub>	-85.1 to -11.6	6.78866	899.617	241.942
1-Butanol	C <sub>4</sub> H <sub>10</sub> O	89.2 to 125.7	7.36366	1305.198	173.427
2-Butanol	C <sub>4</sub> H <sub>10</sub> O	72.4 to 107.1	7.20131	1157.000	168.279
1-Butene	C <sub>4</sub> H <sub>8</sub>	-77.5 to -3.7	6.53101	810.261	228.066
Butyric acid	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	20.0 to 150.0	8.71019	2433.014	255.189
Carbon disulfide	CS <sub>2</sub>	3.6 to 79.9	6.94279	1169.110	241.593
Carbon tetrachloride	CCl <sub>4</sub>	14.1 to 76.0	6.87926	1212.021	226.409
Chlorobenzene	C <sub>6</sub> H <sub>5</sub> Cl	62.0 to 131.7	6.97808	1431.053	217.550
Chlorobenzene*	C <sub>6</sub> H <sub>5</sub> Cl	0 to 42	7.10690	1500.0	224.0
Chlorobenzene*	C <sub>6</sub> H <sub>5</sub> Cl	42 to 230	6.94504	1413.12	216.0
Chloroform	CHCl <sub>3</sub>	-10.4 to 60.3	6.95465	1170.966	226.232
Chloroform*	CHCl <sub>3</sub>	-30 to 150	6.90328	1163.03	227.4
Cyclohexane	C <sub>6</sub> H <sub>12</sub>	19.9 to 81.6	6.84941	1206.001	223.148
Cyclohexanol	C <sub>6</sub> H <sub>12</sub> O	93.7 to 160.7	6.25530	912.866	109.126
n-Decane	n-C <sub>10</sub> H <sub>22</sub>	94.5 to 175.1	6.95707	1503.568	194.738
1-Decene	C <sub>10</sub> H <sub>20</sub>	86.8 to 171.6	6.95433	1497.527	197.056
1,1-Dichloroethane	C <sub>2</sub> H <sub>4</sub> Cl <sub>2</sub>	-38.8 to 17.6	6.97702	1174.022	229.060
1,2-Dichloroethane	C <sub>2</sub> H <sub>4</sub> Cl	-30.8 to 99.4	7.02530	1271.254	222.927
Dichloromethane	CH <sub>2</sub> Cl <sub>2</sub>	-40.0 to 40	7.40916	1325.938	252.616
Diethyl ether	C <sub>4</sub> H <sub>10</sub> O	-60.8 to 19.9	6.92032	1064.066	228.799
Diethyl ketone	C <sub>5</sub> H <sub>10</sub> O	56.5 to 111.3	7.02529	1310.281	214.192
Diethylene glycol	C <sub>4</sub> H <sub>10</sub> O <sub>2</sub>	130.0 to 243.0	7.63666	1939.359	162.714
Dimethyl ether	C <sub>2</sub> H <sub>6</sub> O	-78.2 to -24.9	6.97603	889.264	241.957
Dimethylamine	C <sub>2</sub> H <sub>7</sub> N	-71.8 to 6.9	7.08212	960.242	221.667
N,N-Dimethylformamide	C <sub>3</sub> H <sub>7</sub> NO	30.0 to 90.0	6.92796	1400.869	196.434
1,4-Dioxane	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	20.0 to 105.0	7.43155	1554.679	240.337
Ethanol	C <sub>2</sub> H <sub>6</sub> O	19.6 to 93.4	8.11220	1592.864	226.184
Ethanolamine	C <sub>2</sub> H <sub>7</sub> NO	65.4 to 170.9	7.45680	1577.670	173.368
Ethyl acetate	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	15.6 to 75.8	7.10179	1244.951	217.881
Ethyl acetate*	C <sub>4</sub> H <sub>8</sub> O <sub>2</sub>	-20 to 150	7.09808	1238.710	217.0
Ethyl chloride	C <sub>2</sub> H <sub>5</sub> Cl	-55.9 to 12.5	6.98647	1030.007	238.612
Ethylbenzene	C <sub>8</sub> H <sub>10</sub>	56.5 to 137.1	6.95650	1423.543	213.091

<sup>a</sup> Adapted from T. Boublík, V. Fried, and E. Hala, *The Vapour Pressures of Pure Substances*, Elsevier, Amsterdam, 1973. If marked with an asterisk (\*), constants are from Lange's *Handbook of Chemistry*, 9th Edition, Handbook Publishers, Inc., Sandusky, OH, 1956.

(continued)

**Table B.4** (Continued)

Compound	Formula	Range (°C)	A	B	C
Ethylene glycol	C <sub>2</sub> H <sub>6</sub> O <sub>2</sub>	50.0 to 200.0	8.09083	2088.936	203.454
Ethylene oxide	C <sub>2</sub> H <sub>4</sub> O	0.3 to 31.8	8.69016	2005.779	334.765
1,2-Ethylenediamine	C <sub>2</sub> H <sub>8</sub> N <sub>2</sub>	26.5 to 117.4	7.16871	1336.235	194.366
Formaldehyde	HCHO	-109.4 to -22.3	7.19578	970.595	244.124
Formic acid	CH <sub>2</sub> O <sub>2</sub>	37.4 to 100.7	7.58178	1699.173	260.714
Glycerol	C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>	183.3 to 260.4	6.16501	1036.056	28.097
<i>n</i> -Heptane	<i>n</i> -C <sub>7</sub> H <sub>16</sub>	25.9 to 99.3	6.90253	1267.828	216.823
<i>i</i> -Heptane	<i>i</i> -C <sub>7</sub> H <sub>16</sub>	18.5 to 90.9	6.87689	1238.122	219.783
1-Heptene	C <sub>7</sub> H <sub>14</sub>	21.6 to 94.5	6.91381	1265.120	220.051
<i>n</i> -Hexane	<i>n</i> -C <sub>6</sub> H <sub>14</sub>	13.0 to 69.5	6.88555	1175.817	224.867
<i>i</i> -Hexane	<i>i</i> -C <sub>6</sub> H <sub>14</sub>	12.8 to 61.1	6.86839	1151.401	228.477
1-Hexene	C <sub>6</sub> H <sub>12</sub>	15.9 to 64.3	6.86880	1154.646	226.046
Hydrogen Cyanide	HCN	-16.4 to 46.2	7.52823	1329.49	260.418
Methanol	CH <sub>3</sub> OH	14.9 to 83.7	8.08097	1582.271	239.726
Methanol*	CH <sub>3</sub> OH	-20 to 140	7.87863	1473.11	230.0
Methyl acetate	C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	1.8 to 55.8	7.06524	1157.630	219.726
Methyl bromide	CH <sub>3</sub> Br	-70.0 to 3.6	7.09084	1046.066	244.914
Methyl chloride	CH <sub>3</sub> Cl	-75.0 to 5.0	7.09349	948.582	249.336
Methyl ethyl ketone	C <sub>4</sub> H <sub>8</sub> O	42.8 to 88.4	7.06356	1261.339	221.969
Methyl isobutyl ketone	C <sub>6</sub> H <sub>12</sub> O	21.7 to 116.2	6.67272	1168.408	191.944
Methyl methacrylate	C <sub>5</sub> H <sub>8</sub> O <sub>2</sub>	39.2 to 89.2	8.40919	2050.467	274.369
Methylamine	CH <sub>5</sub> N	-83.1 to -6.2	7.33690	1011.532	233.286
Methylcyclohexane	C <sub>7</sub> H <sub>14</sub>	25.6 to 101.8	6.82827	1273.673	221.723
Naphthalene	C <sub>10</sub> H <sub>8</sub>	80.3 to 179.5	7.03358	1756.328	204.842
Nitrobenzene	C <sub>6</sub> H <sub>5</sub> NO <sub>2</sub>	134.1 to 210.6	7.11562	1746.586	201.783
Nitromethane	CH <sub>3</sub> NO <sub>2</sub>	55.7 to 136.4	7.28166	1446.937	227.600
<i>n</i> -Nonane	<i>n</i> -C <sub>9</sub> H <sub>20</sub>	70.3 to 151.8	6.93764	1430.459	201.808
1-Nonene	C <sub>9</sub> H <sub>18</sub>	66.6 to 147.9	6.95777	1437.862	205.814
<i>n</i> -Octane	<i>n</i> -C <sub>8</sub> H <sub>18</sub>	52.9 to 126.6	6.91874	1351.756	209.100
<i>i</i> -Octane	<i>i</i> -C <sub>8</sub> H <sub>18</sub>	41.7 to 118.5	6.88814	1319.529	211.625
1-Octene	C <sub>8</sub> H <sub>16</sub>	44.9 to 122.2	6.93637	1355.779	213.022
<i>n</i> -Pentane	<i>n</i> -C <sub>5</sub> H <sub>12</sub>	13.3 to 36.8	6.84471	1060.793	231.541
<i>i</i> -Pentane	<i>i</i> -C <sub>5</sub> H <sub>12</sub>	16.3 to 28.6	6.73457	992.019	229.564
1-Pentanol	C <sub>5</sub> H <sub>12</sub> O	74.7 to 156.0	7.18246	1287.625	161.330
1-Pentene	C <sub>5</sub> H <sub>10</sub>	12.8 to 30.7	6.84268	1043.206	233.344
Phenol	C <sub>6</sub> H <sub>6</sub> O	107.2 to 181.8	7.13301	1516.790	174.954
1-Propanol	C <sub>3</sub> H <sub>8</sub> O	60.2 to 104.6	7.74416	1437.686	198.463
2-Propanol	C <sub>3</sub> H <sub>8</sub> O	52.3 to 89.3	7.74021	1359.517	197.527
Propionic acid	C <sub>3</sub> H <sub>6</sub> O <sub>2</sub>	72.4 to 128.3	7.71423	1733.418	217.724
Propylene oxide	C <sub>3</sub> H <sub>6</sub> O	-24.2 to 34.8	7.01443	1086.369	228.594
Pyridine	C <sub>5</sub> H <sub>5</sub> N	67.3 to 152.9	7.04115	1373.799	214.979
Styrene	C <sub>8</sub> H <sub>8</sub>	29.9 to 144.8	7.06623	1507.434	214.985
Toluene	C <sub>7</sub> H <sub>8</sub>	35.3 to 111.5	6.95805	1346.773	219.693
1,1,1-Trichloroethane	C <sub>2</sub> H <sub>3</sub> Cl <sub>3</sub>	-5.4 to 16.9	8.64344	2136.621	302.769
1,1,2-Trichloroethane	C <sub>2</sub> H <sub>3</sub> Cl <sub>3</sub>	50.0 to 113.7	6.95185	1314.410	209.197
Trichloroethylene	C <sub>2</sub> HCl <sub>3</sub>	17.8 to 86.5	6.51827	1018.603	192.731
Vinyl acetate	C <sub>4</sub> H <sub>6</sub> O <sub>2</sub>	21.8 to 72.0	7.21010	1296.130	226.655
Water*	H <sub>2</sub> O	0 to 60	8.10765	1750.286	235.000
Water*	H <sub>2</sub> O	60 to 150	7.96681	1668.210	228.000
<i>m</i> -Xylene	<i>m</i> -C <sub>8</sub> H <sub>10</sub>	59.2 to 140.0	7.00646	1460.183	214.827
<i>o</i> -Xylene	<i>o</i> -C <sub>8</sub> H <sub>10</sub>	63.5 to 145.4	7.00154	1476.393	213.872
<i>p</i> -Xylene	<i>p</i> -C <sub>8</sub> H <sub>10</sub>	58.3 to 139.3	6.98820	1451.792	215.111

**Table B.5** Properties of Saturated Steam: Temperature Table<sup>a</sup>

T(°C)	P(bar)	$\hat{V}(\text{m}^3/\text{kg})$		$\hat{U}(\text{kJ/kg})$		$\hat{H}(\text{kJ/kg})$		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
0.01	0.00611	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
2	0.00705	0.001000	179.9	8.4	2378.3	8.4	2496.8	2505.2
4	0.00813	0.001000	157.3	16.8	2381.1	16.8	2492.1	2508.9
6	0.00935	0.001000	137.8	25.2	2383.8	25.2	2487.4	2512.6
8	0.01072	0.001000	121.0	33.6	2386.6	33.6	2482.6	2516.2
10	0.01227	0.001000	106.4	42.0	2389.3	42.0	2477.9	2519.9
12	0.01401	0.001000	93.8	50.4	2392.1	50.4	2473.2	2523.6
14	0.01597	0.001001	82.9	58.8	2394.8	58.8	2468.5	2527.2
16	0.01817	0.001001	73.4	67.1	2397.6	67.1	2463.8	2530.9
18	0.02062	0.001001	65.1	75.5	2400.3	75.5	2459.0	2534.5
20	0.0234	0.001002	57.8	83.9	2403.0	83.9	2454.3	2538.2
22	0.0264	0.001002	51.5	92.2	2405.8	92.2	2449.6	2541.8
24	0.0298	0.001003	45.9	100.6	2408.5	100.6	2444.9	2545.5
25	0.0317	0.001003	43.4	104.8	2409.9	104.8	2442.5	2547.3
26	0.0336	0.001003	41.0	108.9	2411.2	108.9	2440.2	2549.1
28	0.0378	0.001004	36.7	117.3	2414.0	117.3	2435.4	2552.7
30	0.0424	0.001004	32.9	125.7	2416.7	125.7	2430.7	2556.4
32	0.0475	0.001005	29.6	134.0	2419.4	134.0	2425.9	2560.0
34	0.0532	0.001006	26.6	142.4	2422.1	142.4	2421.2	2563.6
36	0.0594	0.001006	24.0	150.7	2424.8	150.7	2416.4	2567.2
38	0.0662	0.001007	21.6	159.1	2427.5	159.1	2411.7	2570.8
40	0.0738	0.001008	19.55	167.4	2430.2	167.5	2406.9	2574.4
42	0.0820	0.001009	17.69	175.8	2432.9	175.8	2402.1	2577.9
44	0.0910	0.001009	16.04	184.2	2435.6	184.2	2397.3	2581.5
46	0.1009	0.001010	14.56	192.5	2438.3	192.5	2392.5	2585.1
48	0.1116	0.001011	13.23	200.9	2440.9	200.9	2387.7	2588.6
50	0.1234	0.001012	12.05	209.2	2443.6	209.3	2382.9	2592.2
52	0.1361	0.001013	10.98	217.7	2446	217.7	2377	2595
54	0.1500	0.001014	10.02	226.0	2449	226.0	2373	2599
56	0.1651	0.001015	9.158	234.4	2451	234.4	2368	2602
58	0.1815	0.001016	8.380	242.8	2454	242.8	2363	2606
60	0.1992	0.001017	7.678	251.1	2456	251.1	2358	2609
62	0.2184	0.001018	7.043	259.5	2459	259.5	2353	2613
64	0.2391	0.001019	6.468	267.9	2461	267.9	2348	2616
66	0.2615	0.001020	5.947	276.2	2464	276.2	2343	2619
68	0.2856	0.001022	5.475	284.6	2467	284.6	2338	2623

<sup>a</sup>From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968.  $\hat{V}$  = specific volume,  $\hat{U}$  = specific internal energy, and  $\hat{H}$  = specific enthalpy. Note:  $\text{kJ/kg} \times 0.4303 = \text{Btu/lb}_m$ .

(continued)

**Table B.5** (Continued)

$T(^{\circ}\text{C})$	$P(\text{bar})$	$\hat{V}(\text{m}^3/\text{kg})$		$\hat{U}(\text{kJ/kg})$		$\hat{H}(\text{kJ/kg})$		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
70	0.3117	0.001023	5.045	293.0	2469	293.0	2333	2626
72	0.3396	0.001024	4.655	301.4	2472	301.4	2329	2630
74	0.3696	0.001025	4.299	309.8	2474	309.8	2323	2633
76	0.4019	0.001026	3.975	318.2	2476	318.2	2318	2636
78	0.4365	0.001028	3.679	326.4	2479	326.4	2313	2639
80	0.4736	0.001029	3.408	334.8	2482	334.9	2308	2643
82	0.5133	0.001030	3.161	343.2	2484	343.3	2303	2646
84	0.5558	0.001032	2.934	351.6	2487	351.7	2298	2650
86	0.6011	0.001033	2.727	360.0	2489	360.1	2293	2653
88	0.6495	0.001034	2.536	368.4	2491	368.5	2288	2656
90	0.7011	0.001036	2.361	376.9	2493	377.0	2282	2659
92	0.7560	0.001037	2.200	385.3	2496	385.4	2277	2662
94	0.8145	0.001039	2.052	393.7	2499	393.8	2272	2666
96	0.8767	0.001040	1.915	402.1	2501	402.2	2267	2669
98	0.9429	0.001042	1.789	410.6	2504	410.7	2262	2673
100	1.0131	0.001044	1.673	419.0	2507	419.1	2257	2676
102	1.0876	0.001045	1.566	427.1	2509	427.5	2251	2679

**Table B.6** Properties of Saturated Steam: Pressure Table<sup>a</sup>

$P$ (bar)	$T$ (°C)	$\hat{V}$ (m <sup>3</sup> /kg)		$\hat{U}$ (kJ/kg)		$\hat{H}$ (kJ/kg)	
		Water	Steam	Water	Steam	Water	Evaporation
0.00611	0.01	0.001000	206.2	zero	2375.6	+0.0	2501.6
0.008	3.8	0.001000	159.7	15.8	2380.7	15.8	2492.6
0.010	7.0	0.001000	129.2	29.3	2385.2	29.3	2485.0
0.012	9.7	0.001000	108.7	40.6	2388.9	40.6	2478.7
0.014	12.0	0.001000	93.9	50.3	2392.0	50.3	2473.2
0.016	14.0	0.001001	82.8	58.9	2394.8	58.9	2468.4
0.018	15.9	0.001001	74.0	66.5	2397.4	66.5	2464.1
0.020	17.5	0.001001	67.0	73.5	2399.6	73.5	2460.2
0.022	19.0	0.001002	61.2	79.8	2401.7	79.8	2456.6
0.024	20.4	0.001002	56.4	85.7	2403.6	85.7	2453.3
0.026	21.7	0.001002	52.3	91.1	2405.4	91.1	2450.2
0.028	23.0	0.001002	48.7	96.2	2407.1	96.2	2447.3
0.030	24.1	0.001003	45.7	101.0	2408.6	101.0	2444.6
0.035	26.7	0.001003	39.5	111.8	2412.2	111.8	2438.5
0.040	29.0	0.001004	34.8	121.4	2415.3	121.4	2433.1
0.045	31.0	0.001005	31.1	130.0	2418.1	130.0	2428.2
0.050	32.9	0.001005	28.2	137.8	2420.6	137.8	2423.8
0.060	36.2	0.001006	23.74	151.5	2425.1	151.5	2416.0
0.070	39.0	0.001007	20.53	163.4	2428.9	163.4	2409.2
0.080	41.5	0.001008	18.10	173.9	2432.3	173.9	2403.2
0.090	43.8	0.001009	16.20	183.3	2435.3	183.3	2397.9
0.10	45.8	0.001010	14.67	191.8	2438.0	191.8	2392.9
0.11	47.7	0.001011	13.42	199.7	2440.5	199.7	2388.4
0.12	49.4	0.001012	12.36	206.9	2442.8	206.9	2384.3
0.13	51.1	0.001013	11.47	213.7	2445.0	213.7	2380.4
0.14	52.6	0.001013	10.69	220.0	2447.0	220.0	2376.7

0.15	54.0	0.001014	10.02	226.0	2448.9	226.0	2373.2	2599.2
0.16	55.3	0.001015	9.43	231.6	2450.6	231.6	2370.0	2601.6
0.17	56.6	0.001015	8.91	236.9	2452.3	236.9	2366.9	2603.8
0.18	57.8	0.001016	8.45	242.0	2453.9	242.0	2363.9	2605.9
0.19	59.0	0.001017	8.03	246.8	2455.4	246.8	2361.1	2607.9
0.20	60.1	0.001017	7.65	251.5	2456.9	251.5	2358.4	2609.9
0.22	62.2	0.001018	7.00	260.1	2459.6	260.1	2353.3	2613.5
0.24	64.1	0.001019	6.45	268.2	2462.1	268.2	2348.6	2616.8
0.26	65.9	0.001020	5.98	275.6	2464.4	275.7	2344.2	2619.9
0.28	67.5	0.001021	5.58	282.7	2466.5	282.7	2340.0	2622.7
0.30	69.1	0.001022	5.23	289.3	2468.6	289.3	2336.1	2625.4
0.35	72.7	0.001025	4.53	304.3	2473.1	304.3	2327.2	2631.5
0.40	75.9	0.001027	3.99	317.6	2477.1	317.7	2319.2	2636.9
0.45	78.7	0.001028	3.58	329.6	2480.7	329.6	2312.0	2641.7
0.50	81.3	0.001030	3.24	340.5	2484.0	340.6	2305.4	2646.0
0.55	83.7	0.001032	2.96	350.6	2486.9	350.6	2299.3	2649.9
0.60	86.0	0.001033	2.73	359.9	2489.7	359.9	2293.6	2653.6
0.65	88.0	0.001035	2.53	368.5	2492.2	368.6	2288.3	2656.9
0.70	90.0	0.001036	2.36	376.7	2494.5	376.8	2283.3	2660.1
0.75	91.8	0.001037	2.22	384.4	2496.7	384.5	2278.6	2663.0
0.80	93.5	0.001039	2.087	391.6	2498.8	391.7	2274.1	2665.8
0.85	95.2	0.001040	1.972	398.5	2500.8	398.6	2269.8	2668.4
0.90	96.7	0.001041	1.869	405.1	2502.6	405.2	2265.6	2670.9
0.95	98.2	0.001042	1.777	411.4	2504.4	411.5	2261.7	2673.2
1.00	99.6	0.001043	1.694	417.4	2506.1	417.5	2257.9	2675.4
1.01325	100.0	0.001044	1.673	419.0	2506.5	419.1	2256.9	2676.0
(1 atm)								

<sup>a</sup>From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968.  $\hat{V}$  = specific volume,  $\hat{U}$  = specific internal energy, and  $\hat{H}$  = specific enthalpy. Note:  $\text{kJ/kg} \times 0.4303 = \text{Btu/lb}_m$ .

(continued)

**Table B.6** (Continued)

$P$ (bar)	$T$ (°C)	$\hat{V}$ (m <sup>3</sup> /kg)			$\hat{U}$ (kJ/kg)			$\hat{H}$ (kJ/kg)
		Water	Steam	Water	Steam	Water	Evaporation	
1.1	102.3	0.001046	1.549	428.7	2509.2	428.8	2250.8	2679.6
1.2	104.8	0.001048	1.428	439.2	2512.1	439.4	2244.1	2683.4
1.3	107.1	0.001049	1.325	449.1	2514.7	449.2	2237.8	2687.0
1.4	109.3	0.001051	1.236	458.3	2517.2	458.4	2231.9	2690.3
1.5	111.4	0.001053	1.159	467.0	2519.5	467.1	2226.2	2693.4
1.6	113.3	0.001055	1.091	475.2	2521.7	475.4	2220.9	2696.2
1.7	115.2	0.001056	1.031	483.0	2523.7	483.2	2215.7	2699.0
1.8	116.9	0.001058	0.977	490.5	2525.6	490.7	2210.8	2701.5
1.9	118.6	0.001059	0.929	497.6	2527.5	497.8	2206.1	2704.0
2.0	120.2	0.001061	0.885	504.5	2529.2	504.7	2201.6	2706.3
2.2	123.3	0.001064	0.810	517.4	2532.4	517.6	2193.0	2710.6
2.4	126.1	0.001066	0.746	529.4	2535.4	529.6	2184.9	2714.5
2.6	128.7	0.001069	0.693	540.6	2538.1	540.9	2177.3	2718.2
2.8	131.2	0.001071	0.646	551.1	2540.6	551.4	2170.1	2721.5
3.0	133.5	0.001074	0.606	561.1	2543.0	561.4	2163.2	2724.7
3.2	135.8	0.001076	0.570	570.6	2545.2	570.9	2156.7	2727.6
3.4	137.9	0.001078	0.538	579.6	2547.2	579.9	2150.4	2730.3
3.6	139.9	0.001080	0.510	588.1	2549.2	588.5	2144.4	2732.9
3.8	141.8	0.001082	0.485	596.4	2551.0	596.8	2138.6	2735.3
4.0	143.6	0.001084	0.462	604.2	2552.7	604.7	2133.0	2737.6
4.2	145.4	0.001086	0.442	611.8	2554.4	612.3	2127.5	2739.8
4.4	147.1	0.001088	0.423	619.1	2555.9	619.6	2122.3	2741.9
4.6	148.7	0.001089	0.405	626.2	2557.4	626.7	2117.2	2743.9
4.8	150.3	0.001091	0.389	633.0	2558.8	633.5	2112.2	2745.7
5.0	151.8	0.001093	0.375	639.6	2560.2	640.1	2107.4	2747.5
5.5	155.5	0.001097	0.342	655.2	2563.3	655.8	2095.9	2751.7
6.0	158.8	0.001101	0.315	669.8	2566.2	670.4	2085.0	2755.5
6.5	162.0	0.001105	0.292	683.4	2568.7	684.1	2074.7	2758.9
7.0	165.0	0.001108	0.273	696.3	2571.1	697.1	2064.9	2762.0

7.5	167.8	0.001112	0.2554	708.5	2573.3	709.3	2055.5	2764.8
8.0	170.4	0.001115	0.2403	720.0	2575.5	720.9	2046.5	2767.5
8.5	172.9	0.001118	0.2268	731.1	2577.1	732.0	2037.9	2769.9
9.0	175.4	0.001121	0.2148	741.6	2578.8	742.6	2029.5	2772.1
9.5	177.7	0.001124	0.2040	751.8	2580.4	752.8	2021.4	2774.2
10.0	179.9	0.001127	0.1943	761.5	2581.9	762.6	2013.6	2776.2
10.5	182.0	0.001130	0.1855	770.8	2583.3	772.0	2005.9	2778.0
11.0	184.1	0.001133	0.1774	779.9	2584.5	781.1	1998.5	2779.7
11.5	186.0	0.001136	0.1700	788.6	2585.8	789.9	1991.3	2781.3
12.0	188.0	0.001139	0.1632	797.1	2586.9	798.4	1984.3	2782.7
12.5	189.8	0.001141	0.1569	805.3	2588.0	806.7	1977.4	2784.1
13.0	191.6	0.001144	0.1511	813.2	2589.0	814.7	1970.7	2785.4
14	195.0	0.001149	0.1407	828.5	2590.8	830.1	1957.7	2787.8
15	198.3	0.001154	0.1317	842.9	2592.4	844.7	1945.2	2789.9
16	201.4	0.001159	0.1237	856.7	2593.8	858.6	1933.2	2791.7
17	204.3	0.001163	0.1166	869.9	2595.1	871.8	1921.5	2793.4
18	207.1	0.001168	0.1103	882.5	2596.3	884.6	1910.3	2794.8
19	209.8	0.001172	0.1047	894.6	2597.3	896.8	1899.3	2796.1
20	212.4	0.001177	0.0995	906.2	2598.2	908.6	1888.6	2797.2
21	214.9	0.001181	0.0949	917.5	2598.9	920.0	1878.2	2798.2
22	217.2	0.001185	0.0907	928.3	2599.6	931.0	1868.1	2799.1
23	219.6	0.001189	0.0868	938.9	2600.2	941.6	1858.2	2799.8
24	221.8	0.001193	0.0832	949.1	2600.7	951.9	1848.5	2800.4
25	223.9	0.001197	0.0799	959.0	2601.2	962.0	1839.0	2800.9
26	226.0	0.001201	0.0769	968.6	2601.5	971.7	1829.6	2801.4
27	228.1	0.001205	0.0740	978.0	2601.8	981.2	1820.5	2801.7
28	230.0	0.001209	0.0714	987.1	2602.1	990.5	1811.5	2802.0
29	232.0	0.001213	0.0689	996.0	2602.3	999.5	1802.6	2802.2
30	233.8	0.001216	0.0666	1004.7	2602.4	1008.4	1793.9	2802.3
32	237.4	0.001224	0.0624	1021.5	2602.5	1025.4	1776.9	2802.3
34	240.9	0.001231	0.0587	1037.6	2602.5	1041.8	1760.3	2802.1
36	244.2	0.001238	0.0554	1053.1	2602.2	1057.6	1744.2	2801.7
38	247.3	0.001245	0.0524	1068.0	2601.9	1072.7	1728.4	2801.1

(continued)

**Table B.6** (Continued)

$P$ (bar)	$T$ (°C)	$\hat{V}$ (m <sup>3</sup> /kg)			$\hat{U}$ (kJ/kg)			$\hat{H}$ (kJ/kg)	
		Water	Steam	Water	Steam	Water	Evaporation	Steam	
40	250.3	0.001252	0.0497	1082.4	2601.3	1087.4	1712.9	2800.3	
42	253.2	0.001259	0.0473	1096.3	2600.7	1101.6	1697.8	2799.4	
44	256.0	0.001266	0.0451	1109.8	2599.9	1115.4	1682.9	2798.3	
46	258.8	0.001272	0.0430	1122.9	2599.1	1128.8	1668.3	2797.1	
48	261.4	0.001279	0.0412	1135.6	2598.1	1141.8	1653.9	2795.7	
50	263.9	0.001286	0.0394	1148.0	2597.0	1154.5	1639.7	2794.2	
52	266.4	0.001292	0.0378	1160.1	2595.9	1166.8	1625.7	2792.6	
54	268.8	0.001299	0.0363	1171.9	2594.6	1178.9	1611.9	2790.8	
56	271.1	0.001306	0.0349	1183.5	2593.3	1190.8	1598.2	2789.0	
58	273.3	0.001312	0.0337	1194.7	2591.9	1202.3	1584.7	2787.0	
60	275.6	0.001319	0.0324	1205.8	2590.4	1213.7	1571.3	2785.0	
62	277.7	0.001325	0.0313	1216.6	2588.8	1224.8	1558.0	2782.9	
64	279.8	0.001332	0.0302	1227.2	2587.2	1235.7	1544.9	2780.6	
66	281.8	0.001338	0.0292	1237.6	2585.5	1246.5	1531.9	2778.3	
68	283.8	0.001345	0.0283	1247.9	2583.7	1257.0	1518.9	2775.9	
70	285.8	0.001351	0.0274	1258.0	2581.8	1267.4	1506.0	2773.5	
72	287.7	0.001358	0.0265	1267.9	2579.9	1277.6	1493.3	2770.9	
74	289.6	0.001364	0.0257	1277.6	2578.0	1287.7	1480.5	2768.3	
76	291.4	0.001371	0.0249	1287.2	2575.9	1297.6	1467.9	2765.5	
78	293.2	0.001378	0.0242	1296.7	2573.8	1307.4	1455.3	2762.8	
80	295.0	0.001384	0.0235	1306.0	2571.7	1317.1	1442.8	2759.9	
82	296.7	0.001391	0.0229	1315.2	2569.5	1326.6	1430.3	2757.0	
84	298.4	0.001398	0.0222	1324.3	2567.2	1336.1	1417.9	2754.0	
86	300.1	0.001404	0.0216	1333.3	2564.9	1345.4	1405.5	2750.9	
88	301.7	0.001411	0.0210	1342.2	2562.6	1354.6	1393.2	2747.8	
90	303.3	0.001418	0.02050	1351.0	2560.1	1363.7	1380.9	2744.6	
92	304.9	0.001425	0.01996	1359.7	2557.7	1372.8	1368.6	2741.4	
94	306.4	0.001432	0.01945	1368.2	2555.2	1381.7	1356.3	2738.0	



**Table B.7** Properties of Superheated Steam<sup>a</sup>

$P$ (bar) ( $T_{\text{sat.}}$ °C)	Sat'd Water	Sat'd Steam	Temperature (°C) →							
			50	75	100	150	200	250	300	350
0.0	$\hat{H}$	—	2595	2642	2689	2784	2880	2978	3077	3177
(—)	$\hat{U}$	—	2446	2481	2517	2589	2662	2736	2812	2890
	$\hat{V}$	—	—	—	—	—	—	—	—	—
0.1	$\hat{H}$	191.8	2584.8	2593	2640	2688	2783	2880	2977	3077
(45.8)	$\hat{U}$	191.8	2438.0	2444	2480	2516	2588	2661	2736	2812
	$\hat{V}$	0.00101	14.7	14.8	16.0	17.2	19.5	21.8	24.2	28.7
0.5	$\hat{H}$	340.6	2646.0	209.3	313.9	2683	2780	2878	2979	3076
(81.3)	$\hat{U}$	340.6	2484.0	209.2	313.9	2512	2586	2660	2735	2811
	$\hat{V}$	0.00103	3.24	0.00101	0.00103	3.41	3.89	4.35	4.83	5.75
1.0	$\hat{H}$	417.5	2675.4	209.3	314.0	2676	2776	2875	2975	3074
(99.6)	$\hat{U}$	417.5	2506.1	209.2	313.9	2507	2583	2658	2734	2811
	$\hat{V}$	0.00104	1.69	0.00101	0.00103	1.69	1.94	2.17	2.40	2.87
5.0	$\hat{H}$	640.1	2747.5	209.7	314.3	419.4	632.2	2855	2961	3065
(151.8)	$\hat{U}$	639.6	2560.2	209.2	313.8	418.8	631.6	2643	2724	2803
	$\hat{V}$	0.00109	0.375	0.00101	0.00103	0.00104	0.00109	0.425	0.474	0.522
10	$\hat{H}$	762.6	2776.2	210.1	314.7	419.7	632.5	2827	2943	3052
(179.9)	$\hat{U}$	761.5	2582	209.1	313.7	418.7	631.4	2621	2710	2794
	$\hat{V}$	0.00113	0.194	0.00101	0.00103	0.00104	0.00109	0.206	0.233	0.258
20	$\hat{H}$	908.6	2797.2	211.0	315.5	420.5	633.1	852.6	2902	3025
(212.4)	$\hat{U}$	906.2	2598.2	209.0	313.5	418.4	603.9	850.2	2679	2774
	$\hat{V}$	0.00118	0.09950	0.00101	0.00102	0.00104	0.00109	0.00116	0.111	0.125
40	$\hat{H}$	1087.4	2800.3	212.7	317.1	422.0	634.3	853.4	1085.8	2962
(250.3)	$\hat{U}$	1082.4	2601.3	208.6	313.0	417.8	630.0	848.8	1080.8	2727
	$\hat{V}$	0.00125	0.04975	0.00101	0.00102	0.00104	0.00109	0.00115	0.00125	0.0588
60	$\hat{H}$	1213.7	2785.0	214.4	318.7	423.5	635.6	854.2	1085.8	2885
(275.6)	$\hat{U}$	1205.8	2590.4	208.3	312.6	417.3	629.1	847.3	1078.3	2668
	$\hat{V}$	0.00132	0.0325	0.00101	0.00103	0.00104	0.00109	0.00115	0.00125	0.0361
80	$\hat{H}$	1317.1	2759.9	216.1	320.3	425.0	636.8	855.1	1085.8	2787
(295.0)	$\hat{U}$	1306.0	2571.7	208.1	312.3	416.7	628.2	845.9	1075.8	2593
	$\hat{V}$	0.00139	0.0235	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.0243
100	$\hat{H}$	1408.0	2727.7	217.8	322.9	426.5	638.1	855.9	1085.8	1343.4
(311.0)	$\hat{U}$	1393.5	2547.3	207.8	311.7	416.1	627.3	844.4	1073.4	1329.4
	$\hat{V}$	0.00145	0.0181	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.00140
150	$\hat{H}$	1611.0	2615.0	222.1	326.0	430.3	641.3	858.1	1086.2	1338.2
(342.1)	$\hat{U}$	1586.1	2459.9	207.0	310.7	414.7	625.0	841.0	1067.7	1317.6
	$\hat{V}$	0.00166	0.0103	0.00101	0.00102	0.00104	0.00108	0.00114	0.00123	0.00138
200	$\hat{H}$	1826.5	2418.4	226.4	330.0	434.0	644.5	860.4	1086.7	1334.3
(365.7)	$\hat{U}$	1785.7	2300.8	206.3	309.7	413.2	622.9	837.7	1062.2	1307.1
	$\hat{V}$	0.00204	0.005875	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00136
221.2( $P_c$ )	$\hat{H}$	2108	2108	228.2	331.7	435.7	645.8	861.4	1087.0	1332.8
(374.15)( $T_c$ )	$\hat{U}$	2037.8	2037.8	206.0	309.2	412.8	622.0	836.3	1060.0	1302.9
	$\hat{V}$	0.00317	0.00317	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00135
250	$\hat{H}$	—	—	230.7	334.0	437.8	647.7	862.8	1087.5	1331.1
(—)	$\hat{U}$	—	—	205.7	308.7	412.1	620.8	834.4	1057.0	1297.5
	$\hat{V}$	—	—	0.00100	0.00101	0.00103	0.00108	0.00113	0.00122	0.00135
300	$\hat{H}$	—	—	235.0	338.1	441.6	650.9	865.2	1088.4	1328.7
(—)	$\hat{U}$	—	—	205.0	307.7	410.8	618.7	831.3	1052.1	1288.7
	$\hat{V}$	—	—	0.0009990	0.00101	0.00103	0.00107	0.00113	0.00121	0.00133
500	$\hat{H}$	—	—	251.9	354.2	456.8	664.1	875.4	1093.6	1323.7
(—)	$\hat{U}$	—	—	202.4	304.0	405.8	611.0	819.7	1034.3	1259.3
	$\hat{V}$	—	—	0.0009911	0.00100	0.00102	0.00106	0.00111	0.00119	0.00129
1000	$\hat{H}$	—	—	293.9	394.3	495.1	698.0	903.5	1113.0	1328.7
(—)	$\hat{U}$	—	—	196.5	295.7	395.1	594.4	795.3	999.0	1207.1
	$\hat{V}$	—	—	0.0009737	0.0009852	0.001000	0.00104	0.00108	0.00114	0.00122

<sup>a</sup> Adapted from R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968. Water is a liquid in the enclosed region between 50°C and 350°C.  $\hat{H}$  = specific enthalpy (kJ/kg),  $\hat{U}$  = specific internal energy (kJ/kg),  $\hat{V}$  = specific volume ( $\text{m}^3/\text{kg}$ ). Note: kJ/kg × 0.4303 = Btu/lb<sub>m</sub>.

(continued)

**Table B.7** (Continued)

$P(\text{bar})$ ( $T_{\text{sat}}, ^\circ\text{C}$ )	Temperature ( $^\circ\text{C}$ ) →								
	400	450	500	550	600	650	700	750	
0.0	$\hat{H}$	3280	3384	3497	3597	3706	3816	3929	4043
(—)	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3591
	$\hat{V}$	—	—	—	—	—	—	—	—
0.1	$\hat{H}$	3280	3384	3489	3596	3706	3816	3929	4043
(45.8)	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3571
	$\hat{V}$	21.1	33.3	35.7	38.0	40.3	42.6	44.8	47.2
0.5	$\hat{H}$	3279	3383	3489	3596	3705	3816	3929	4043
(81.3)	$\hat{U}$	2969	3049	3132	3216	3302	3390	3480	3571
	$\hat{V}$	6.21	6.67	7.14	7.58	8.06	8.55	9.01	9.43
1.0	$\hat{H}$	3278	3382	3488	3596	3705	3816	3928	4042
(99.6)	$\hat{U}$	2968	3049	3132	3216	3302	3390	3479	3570
	$\hat{V}$	3.11	3.33	3.57	3.80	4.03	4.26	4.48	4.72
5.0	$\hat{H}$	3272	3379	3484	3592	3702	3813	3926	4040
(151.8)	$\hat{U}$	2964	3045	3128	3213	3300	3388	3477	3569
	$\hat{V}$	0.617	0.664	0.711	0.758	0.804	0.850	0.897	0.943
10	$\hat{H}$	3264	3371	3478	3587	3697	3809	3923	4038
(179.9)	$\hat{U}$	2958	3041	3124	3210	3296	3385	3475	3567
	$\hat{V}$	0.307	0.330	0.353	0.377	0.402	0.424	0.448	0.472
20	$\hat{H}$	3249	3358	3467	3578	3689	3802	3916	4032
(212.4)	$\hat{U}$	2946	3031	3115	3202	3290	3379	3470	3562
	$\hat{V}$	0.151	0.163	0.175	0.188	0.200	0.211	0.223	0.235
40	$\hat{H}$	3216	3331	3445	3559	3673	3788	3904	4021
(250.3)	$\hat{U}$	2922	3011	3100	3188	3278	3368	3460	3554
	$\hat{V}$	0.0734	0.0799	0.0864	0.0926	0.0987	0.105	0.111	0.117
60	$\hat{H}$	3180	3303	3422	3539	3657	3774	3892	4011
(275.6)	$\hat{U}$	2896	2991	3083	3174	3265	3357	3451	3545
	$\hat{V}$	0.0474	0.0521	0.0566	0.0609	0.0652	0.0693	0.0735	0.0776
80	$\hat{H}$	3142	3274	3399	3520	3640	3759	3879	4000
(295.0)	$\hat{U}$	2867	2969	3065	3159	3252	3346	3441	3537
	$\hat{V}$	0.0344	0.0382	0.0417	0.0450	0.0483	0.0515	0.0547	0.0578
100	$\hat{H}$	3100	3244	3375	3500	3623	3745	3867	3989
(311.0)	$\hat{U}$	2836	2946	3047	3144	3240	3335	3431	3528
	$\hat{V}$	0.0264	0.0298	0.0328	0.0356	0.0383	0.0410	0.0435	0.0461
150	$\hat{H}$	2975	3160	3311	3448	3580	3708	3835	3962
(342.1)	$\hat{U}$	2744	2883	2999	3105	3207	3307	3407	3507
	$\hat{V}$	0.0157	0.0185	0.0208	0.0229	0.0249	0.0267	0.0286	0.0304
200	$\hat{H}$	2820	3064	3241	3394	3536	3671	3804	3935
(365.7)	$\hat{U}$	2622	2810	2946	3063	3172	3278	3382	3485
	$\hat{V}$	0.009950	0.0127	0.0148	0.0166	0.0182	0.197	0.211	0.0225
221.2( $P_c$ )	$\hat{H}$	2733	3020	3210	3370	3516	3655	3790	3923
(374.15)( $T_c$ )	$\hat{U}$	2553	2776	2922	3045	3157	3265	3371	3476
	$\hat{V}$	0.008157	0.0110	0.0130	0.0147	0.0162	0.0176	0.0190	0.0202
250	$\hat{H}$	2582	2954	3166	3337	3490	3633	3772	3908
(—)	$\hat{U}$	2432	2725	2888	3019	3137	3248	3356	3463
	$\hat{V}$	0.006013	0.009174	0.0111	0.0127	0.0141	0.0143	0.0166	0.0178
300	$\hat{H}$	2162	2826	3085	3277	3443	3595	3740	3880
(—)	$\hat{U}$	2077	2623	2825	2972	3100	3218	3330	3441
	$\hat{V}$	0.002830	0.006734	0.008680	0.0102	0.0114	0.0126	0.0136	0.0147
500	$\hat{H}$	1878	2293	2723	3021	3248	3439	3610	3771
(—)	$\hat{U}$	1791	2169	2529	2765	2946	3091	3224	3350
	$\hat{V}$	0.001726	0.002491	0.003882	0.005112	0.006112	0.007000	0.007722	0.008418
1000	$\hat{H}$	1798	2051	2316	2594	2857	3105	3324	3526
(—)	$\hat{U}$	1653	1888	2127	2369	2591	2795	2971	3131
	$\hat{V}$	0.001446	0.001628	0.001893	0.002246	0.002668	0.003106	0.003536	0.003953

**Table B.8** Specific Enthalpies of Selected Gases: SI Units

<i>T</i>	$\hat{H}$ (kJ/mol)						
	Air	O <sub>2</sub>	N <sub>2</sub>	H <sub>2</sub>	CO	CO <sub>2</sub>	H <sub>2</sub> O
<b>0</b>	-0.72	-0.73	-0.73	-0.72	-0.73	-0.92	-0.84
<b>25</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>100</b>	2.19	2.24	2.19	2.16	2.19	2.90	2.54
<b>200</b>	5.15	5.31	5.13	5.06	5.16	7.08	6.01
<b>300</b>	8.17	8.47	8.12	7.96	8.17	11.58	9.57
<b>400</b>	11.24	11.72	11.15	10.89	11.25	16.35	13.23
<b>500</b>	14.37	15.03	14.24	13.83	14.38	21.34	17.01
<b>600</b>	17.55	18.41	17.39	16.81	17.57	26.53	20.91
<b>700</b>	20.80	21.86	20.59	19.81	20.82	31.88	24.92
<b>800</b>	24.10	25.35	23.86	22.85	24.13	37.36	29.05
<b>900</b>	27.46	28.89	27.19	25.93	27.49	42.94	33.32
<b>1000</b>	30.86	32.47	30.56	29.04	30.91	48.60	37.69
<b>1100</b>	34.31	36.07	33.99	32.19	34.37	54.33	42.18
<b>1200</b>	37.81	39.70	37.46	35.39	37.87	60.14	46.78
<b>1300</b>	41.34	43.38	40.97	38.62	41.40	65.98	51.47
<b>1400</b>	44.89	47.07	44.51	41.90	44.95	71.89	56.25
<b>1500</b>	48.45	50.77	48.06	45.22	48.51	77.84	61.09

**Table B.9** Specific Enthalpies of Selected Gases: American Engineering Units

<i>T</i>	$\hat{H}$ (Btu/lb-mole)						
	Air	O <sub>2</sub>	N <sub>2</sub>	H <sub>2</sub>	CO	CO <sub>2</sub>	H <sub>2</sub> O
<b>32</b>	-312	-315	-312	-310	-312	-394	-361
<b>77</b>	0	0	0	0	0	0	0
<b>100</b>	160	162	160	159	160	206	185
<b>200</b>	858	875	857	848	859	1132	996
<b>300</b>	1563	1602	1558	1539	1564	2108	1818
<b>400</b>	2275	2342	2265	2231	2276	3129	2652
<b>500</b>	2993	3094	2976	2925	2994	4192	3499
<b>600</b>	3719	3858	3694	3621	3720	5293	4359
<b>700</b>	4451	4633	4418	4319	4454	6429	5233
<b>800</b>	5192	5418	5150	5021	5195	7599	6122
<b>900</b>	5940	6212	5889	5725	5945	8790	7025
<b>1000</b>	6695	7015	6635	6433	6702	10015	7944
<b>1100</b>	7459	7826	7399	7145	7467	11263	8880
<b>1200</b>	8230	8645	8151	7861	8239	12533	9831
<b>1300</b>	9010	9471	8922	8581	9021	13820	10799
<b>1400</b>	9797	10304	9699	9306	9809	15122	11783
<b>1500</b>	10590	11142	10485	10035	10606	16436	12783
<b>1600</b>	11392	11988	11278	10769	11409	17773	13798
<b>1700</b>	12200	12836	12080	11509	12220	19119	14831
<b>1800</b>	13016	13691	12888	12254	13036	20469	15877
<b>1900</b>	13837	14551	13702	13003	13858	21840	16941
<b>2000</b>	14663	15415	14524	13759	14688	23211	18019

**Table B.10** Atomic Heat Capacities for Kopp's Rule<sup>a</sup>

Element	$C_{pa}$ [J/(g-atom·°C)]	
	Solids	Liquids
C	7.5	12
H	9.6	18
B	11	20
Si	16	24
O	17	25
F	21	29
P	23	31
S	26	31
All Others	26	33

<sup>a</sup>D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, Prentice-Hall, Englewood Cliffs, NJ, 1974, p. 270.

**Table B.11** Integral Heats of Solution and Mixing at 25°C

$r$ (mol H <sub>2</sub> O/mol solute)	$(\Delta\hat{H}_s)_{\text{HCl(g)}}$ kJ/mol HCl	$(\Delta\hat{H}_s)_{\text{NaOH(s)}}$ kJ/mol NaOH	$(\Delta\hat{H}_m)_{\text{H}_2\text{SO}_4}$ kJ/mol H <sub>2</sub> SO <sub>4</sub>
0.5	—	—	-15.73
1	-26.22	—	-28.07
1.5	—	—	-36.90
2	-48.82	—	-41.92
3	-56.85	-28.87	-48.99
4	-61.20	-34.43	-54.06
5	-64.05	-37.74	-58.03
10	-69.49	-42.51	-67.03
20	-71.78	-42.84	—
25	—	—	-72.30
30	-72.59	-42.72	—
40	-73.00	-42.59	—
50	-73.26	-42.51	-73.34
100	-73.85	-42.34	-73.97
200	-74.20	-42.26	—
500	-74.52	-42.38	-76.73
1 000	-74.68	-42.47	-78.57
2 000	-74.82	-42.55	—
5 000	-74.93	-42.68	-84.43
10 000	-74.99	-42.72	-87.07
50 000	-75.08	-42.80	—
100 000	-75.10	—	-93.64
500 000	—	—	-95.31
$\infty$	-75.14	-42.89	-96.19

<sup>a</sup>From J. C. Whitwell and R. K. Toner, *Conservation of Mass and Energy*, pp. 344–346. Copyright © 1969 by McGraw-Hill, Inc. Used with permission of McGraw-Hill.