UNIVERSITI SAINS MALAYSIA

Peperiksaan Semester Kedua
Sidang Akademik 1994/95

April 1995

EKC 111 - UNSUR-UNSUR KEJURUTERAAN KIMIA

Masa: [3 jam]

ARAHAN KEPADA CALON:

Sila pastikan bahawa kertas peperiksaan ini mengandungi **EMPAT** (4) muka surat dan **DUA PULUH SATU** (21) lampiran yang bercetak sebelum anda memulakan peperiksaan ini.

Kertas ini mengandungi **LIMA** (5) soalan.

Jawab mana-mana **EMPAT** (4) soalan.

Jawab mana-mana **SATU** soalan dalam Bahasa Inggeris.

Soalan terjemahan Bahasa Inggeris ditaip dalam bentuk tulisan Italic.

..2/-

1. Udara di dalam sebuah bilik 55m^3 ingin disejukkan dari 37°C, 1 atm dan 80% kelembapan relatif kepada takat embunnya pada 1 atm.

The air in a 55 m^3 room is to be cooled from 37°C, 1 atm, and 80% relative humidity to its dew point at 1 atm.

[a] Hitungkan berat udara kering dan wap air yang hadir di dalam bilik tersebut apabila penyejukan selesai.

Calculate the masses of dry air and water vapor present in the room when the cooling has been accomplished.

[b] Hitung haba (kJ) yang perlu dipindahkan untuk membolehkan penyejukan kuantiti udara yang dikirakan di (a), dengan mengandaikan Q = ΔH untuk proses ini.

Calculate the heat (kJ) that must be transferred to cool the quantity of air calculated in part (a), assuming Q = ΔH for this process.

(25 markah)

2. Suatu campuran cecair mengandungi 30.0 mol % benzena dan 70.0% stirena akan dipisahkan di dalam sebuah turus penyulingan. Turus tersebut menghasilkan keluaran atas (overhead product) dan keluaran bawah (bottoms product). Keluaran bawah adalah 99 mol% stirena serta mengandungi 2.0% daripada benzena yang disuapkan ke turus.

Aliran cecair yang meninggalkan bahagian bawah turus (bukan keluaran bawah) akan pergi ke sebuah pemanas semula separa (partial reboiler) dimana sebahagian cecair akan diwapkan pada 150°C dan disuap balik ke bahagian bawah turus. Sisa cecair daripada pemanas semula merupakan hasil keluaran bawah. Aliran wap dan cecair yang meninggalkan pemanas semula adalah seimbang. **Nisbah pendidihan** atau nisbah mol aliran wap dan cecair yang meninggalkan pemanas semula adalah 2.5:1.

Dengan menggunakan hukum Raoult's dimana perlu, kirakan komposisi pecahan mol komponen hasil penyulingan, wap yang balik ke turus dari pemanas semula, cecair yang disuapkan ke pemanas semula dan anggarkan tekanan yang perlu untuk pengoperasian pemanas semula.

..3/-

A liquid mixture containing 30.0 mole% benzene and 70.0% styrene is to be separated in a distillation column. The column produces an overhead product (distillate) and a bottoms product. The bottoms product is 99 mole% styrene and contains 2.0% of the benzene fed to the column.

The liquid stream leaving the bottom of the column (not the bottoms product) goes to a partial reboiler, in which a portion of it is vaporized at 150°C and returned to the bottom of the column. The residual liquid from the reboiler is the bottoms product. The vapor and liquid streams exiting the reboiler are in equilibrium. The ***boilup ratio****, or mole ratio of the vapor and liquid streams leaving the reboiler, is 2.5:1.*

Using Raoult's law where appropriate, calculate the compositions (component mole fractions) of the distillate product, the vapor returned to the column from the reboiler, and the liquid feed to the reboiler, and estimate the required operating pressure of the reboiler.

(25 markah)

3. n-Hexana dibakar dengan udara berlebihan. Satu analisis gas hasil memberi komposisi mol asas kering seperti berikut:

n-Hexane is burned with excess air. An analysis of the product gas yields the following dry-basis molar composition:

N_2 — 82.1%, CO_2 — 6.9%, CO — 2.1%, O_2 — 8.6%, C_6H_{14} — 0.265%.

Gas sisa muncul pada 500°C dan 1.00 atm. Hitungkan peratus penukaran bagi Hexana, peratus udara lebihan yang disuapkan ke reaktor dan takat embun gas sisa.

The stack gas emerges at 500°C and 1.00 atm. Calculate the percentage conversion of hexane, the percentage excess air fed to the reactor, and the dew point of the stack gas.

(25 markah)

4. Satu aliran yang mengandungi jumlah mol seimbang benzena dan toluena pada 60°C disuapkan ke sebuah penyejat satu peringkat selanjar. 60% daripada benzena di dalam suapan disejatkan. Wap tersebut dianalisis dan didapati mengandungi 63.1 mol% benzena. Kedua-dua cecair dan hasil aliran wap muncul pada 150°C. Kirakan keperluan haba bagi proses ini dalam kJ/kg.

A stream containing equimolar amounts of benzene and toluene at 60°C is fed to a continuous single-stage evaporator. Sixty percent of the benzene in the feed is vaporized. The vapor is analyzed and is found to contain 63.1 mole% benzene. Both the liquid and vapor product streams emerge at 150°C. Calculate the heat requirement for this process in kJ/kg feed.

(25 markah)

5. Sebuah silinder gas 100 liter mengandungi 97 mol.% CO dan 3% CO_2 dihantar ke loji anda. Anda menandatangani resit penerimaan dengan mengesahkan bahawa bacaan tekanan pada tolok tangki menepati 2000 psi. Beberapa hari kemudian anda dapati bacaan tolok hanya 1875 psi bererti satu kebocoran berlaku. Stor menyimpan silinder tersebut mempunyai isipadu 21.4 m^3 dan sistem pengudaraannya amat buruk. Kirakan mol% maksimum bagi CO dalam stor tersebut pada masa kebocoran itu dikesan, dengan andaian gas yang bocor tersebar sama rata di dalam stor tersebut dan suhu stor adalah tetap 30°C. Gunakan Hukum Kay's dimana perlu.

A 100.0 liter cylinder containing a gas 97 mole% CO and 3% CO_2 is delivered to your plant. You sign the receipt for it, noting that the pressure gauge on the cylinder reads 2000 psi. Several days later you notice that the gauge reads 1875 psi, indicating a serious leak. The storage room in which the cylinder is kept has a volume of 21.4 m^3 and is very poorly ventilated. Calculate the maximum mole% of CO in the room at the time the leak is discovered, assuming that the leaking gas spreads uniformly throughout the room and that the room temperature is a constant 30°C, using Kay's rule when appropriate.

(25 markah)

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FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5×10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms (Å) = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 liters = 10^6 cm^3 = 10^6 ml = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft^3 = 1728 $in.^3$ = 7.4805 gal = 0.028317 m^3 = 28.317 liters = 28 317 cm^3
Force	1 N = 1 $kg \cdot m/s^2$ = 10^5 dynes = 10^5 $g \cdot cm/s^2$ = 0.22481 lb_f 1 lb_f = 32.174 $lb_m \cdot ft/s^2$ = 4.4482 N = 4.4482×10^5 dynes
Pressure	1 atm = 1.01325×10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bars = 1.01325×10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 $lb_f/in.^2$ (psi) = 33.9 ft H_2O at 4°C = 29.921 in Hg at 0°C
Energy	1 J = 1 $N \cdot m$ = 10^7 ergs = 10^7 dyne·cm = 2.778×10^{-7} kW·h = 0.23901 cal = 0.7376 ft-lb_f = 9.486×10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb_f/s = 9.486×10^{-4} Btu/s = 1.341×10^{-3} hp

Example: The factor to convert grams to lb_m is $\left(\frac{2.20462\ lb_m}{1000\ g}\right)$

Standard Conditions for Gases

System	T_s	P_s	V_s	n_s
SI	273 K	1 atm	0.022415 m^3	1 mol
CGS	273 K	1 atm	22.415 liters	1 mol
American Engineering	492°R	1 atm	359.05 ft^3	1 lb-mole

ATOMIC WEIGHTS AND NUMBERS

Atomic weights apply to naturally occurring isotopic compositions and are based on an atomic mass of $^{12}C = 12$

Element	Symbol	Atomic number	Atomic weight	Element	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	—	Iridium	Ir	77	192.2
Aluminum	Al	13	26.9815	Iron	Fe	26	55.847
Americium	Am	95	—	Krypton	Kr	36	83.80
Antimony	Sb	51	121.75	Lanthanum	La	57	138.91
Argon	Ar	18	39.948	Lawrencium	Lr	103	—
Arsenic	As	33	74.9216	Lead	Pb	82	207.19
Astatine	At	85	—	Lithium	Li	3	6.939
Barium	Ba	56	137.34	Lutetium	Lu	71	174.97
Berkelium	Bk	97	—	Magnesium	Mg	12	24.312
Beryllium	Be	4	9.0122	Manganese	Mn	25	54.9380
Bismuth	Bi	83	208.980	Mendelevium	Md	101	—
Boron	B	5	10.811	Mercury	Hg	80	200.59
Bromine	Br	35	79.904	Molybdenum	Mo	42	95.94
Cadmium	Cd	48	112.40	Neodymium	Nd	60	144.24
Calcium	Ca	20	40.08	Neon	Ne	10	20.183
Californium	Cf	98	—	Neptunium	Np	93	—
Carbon	C	6	12.01115	Nickel	Ni	28	58.71
Cerium	Ce	58	140.12	Niobium	Nb	41	92.906
Cesium	Cs	55	132.905	Nitrogen	N	7	14.0067
Chlorine	Cl	17	35.453	Nobelium	No	102	—
Chromium	Cr	24	51.996	Osmium	Os	75	190.2
Cobalt	Co	27	58.9332	Oxygen	O	8	15.9994
Copper	Cu	29	63.546	Palladium	Pd	46	106.4
Curium	Cm	96	—	Phosphorus	P	15	30.9738
Dysprosium	Dy	66	162.50	Platinum	Pt	78	195.09
Einsteinium	Es	99	—	Plutonium	Pu	94	—
Erbium	Er	68	167.26	Polonium	Po	84	—
Europium	Eu	63	151.96	Potassium	K	19	39.102
Fermium	Fm	100	—	Praseodymium	Pr	59	140.907
Fluorine	F	9	18.9984	Promethium	Pm	61	—
Francium	Fr	87	—	Protactinium	Pa	91	—
Gadolinium	Gd	64	157.25	Radium	Ra	88	—
Gallium	Ga	31	69.72	Radon	Rn	86	
Germanium	Ge	32	72.59	Rhenium	Re	75	186.2
Gold	Au	79	196.967	Rhodium	Rh	45	102.905
Hafnium	Hf	72	178.49	Rubidium	Rb	37	84.57
Helium	He	2	4.0026	Ruthenium	Ru	44	101.07
Holmium	Ho	67	164.930	Samarium	Sm	62	150.35
Hydrogen	H	1	1.00797	Scandium	Sc	21	44.956
Indium	In	49	114.82	Selenium	Se	34	78.96
Iodine	I	53	126.9044	Silicon	Si	14	28.086

Atomic weights apply to naturally occurring isotopic compositions and are based on an atomic mass of $^{12}C = 12$

Element	Symbol	Atomic number	Atomic weight	Element	Symbol	Atomic number	Atomic weight
Silver	Ag	47	107.868	Tin	Sn	50	118.69
Sodium	Na	11	22.9898	Titanium	Ti	22	47.90
Strontium	Sr	38	87.62	Tungsten	W	74	183.85
Sulfur	S	16	32.064	Uranium	U	92	238.03
Tantalum	Ta	73	180.948	Vanadium	V	23	50.942
Technetium	Tc	43	—	Xenon	Xe	54	131.30
Tellurium	Te	52	127.60	Ytterbium	Yb	70	173.04
Terbium	Tb	65	158.924	Yttrium	Y	39	88.905
Thallium	Tl	81	204.37	Zinc	Zn	30	65.37
Thorium	Th	90	232.038	Zirconium	Zr	40	91.22
Thulium	Tm	69	168.934				

THE GAS CONSTANT

$8.314\ m^3 \cdot Pa/mol \cdot K$

0.08314 liter·bar/mol·K

0.08206 liter·atm/mol·K

62.36 liter·mm Hg/mol·K

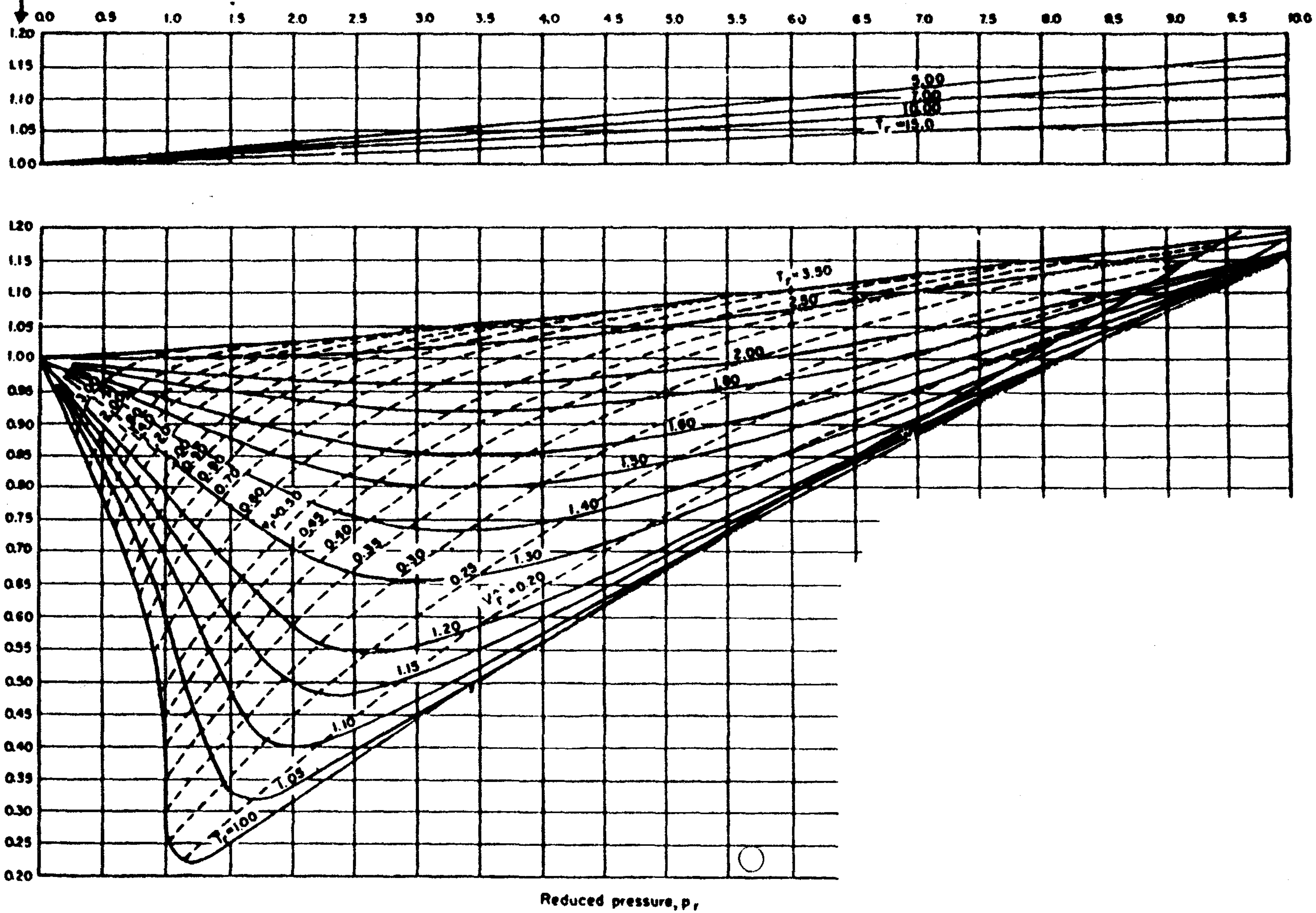
$0.7302\ ft^3 \cdot$atm/lb-mole·°R

$10.73\ ft^3 \cdot$psia/lb-mole·°R

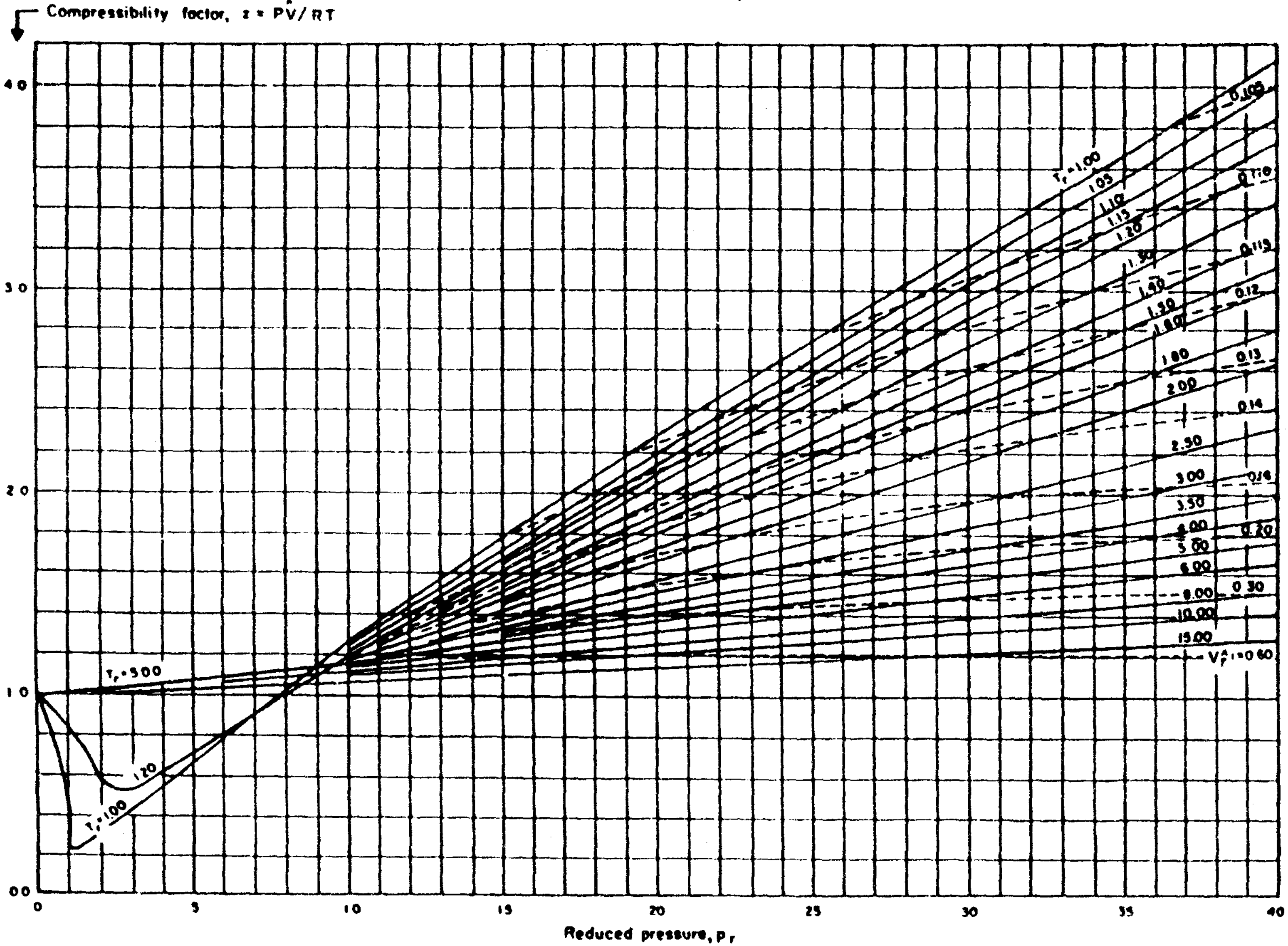
8.314 J/mol·K

1.987 cal/mol·K

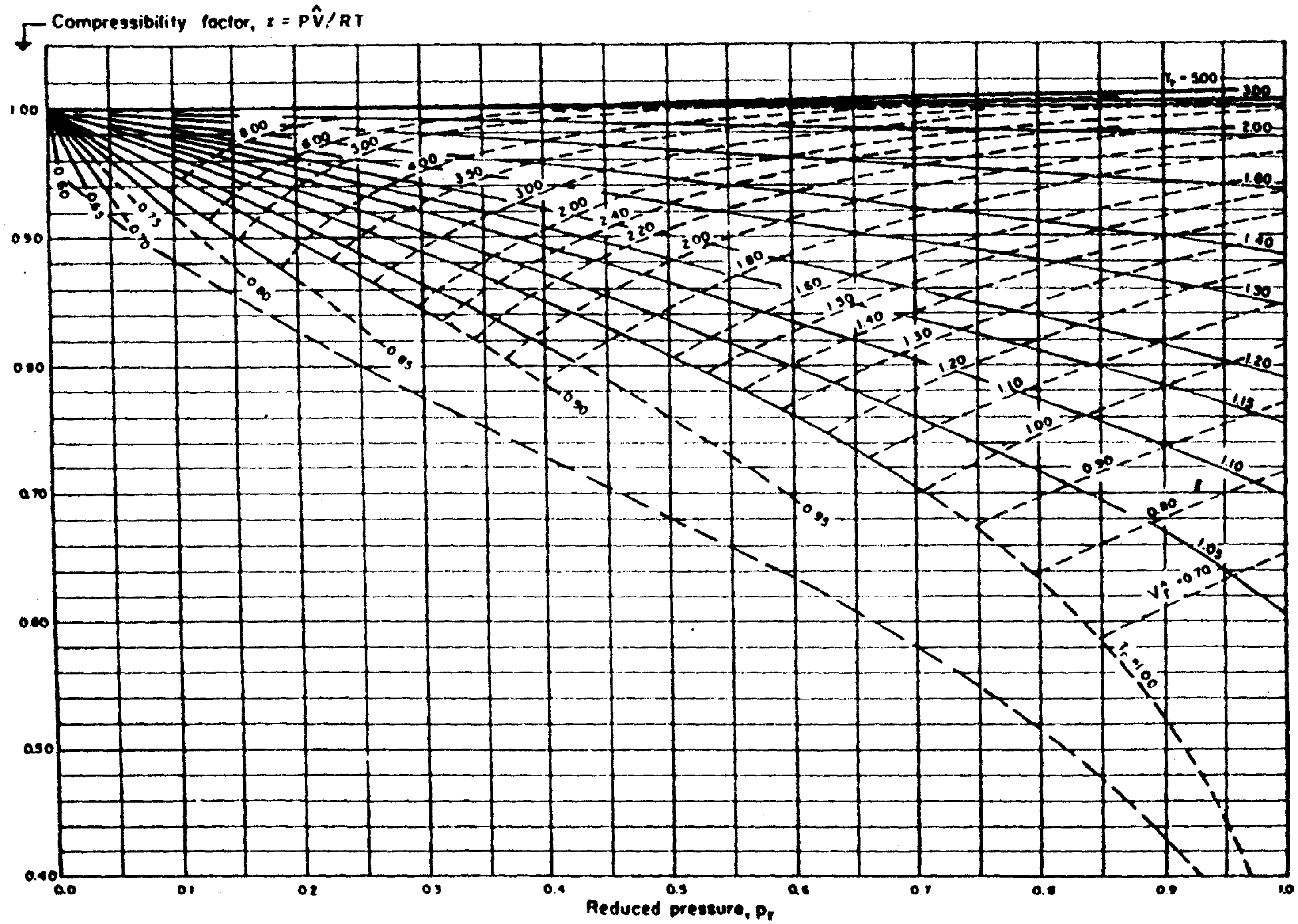
1.987 Btu/lb-mole·°R



Generalized compressibility chart, medium pressures.



Generalized compressibility chart, high pressures. (From D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd edition, copyright © 1974, p. 177. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, N.J.)



Generalized compressibility chart, low pressures. (From D. M. Himmelblau, ***Basic Principles and Calculations in Chemical Engineering***, 3rd edition, copyright © 1974, p. 175. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, N.J.)

TABLE 6.1-1

Antoine Equation Constants[a]

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

Substance	Formula	Range, °C	A	B	C
Acetaldehyde	C_2H_4O	−45 to +70	6.81089	992.0	230
Acetic acid	$C_2H_4O_2$	0 to +36	7.80307	1651.2	225
		+36 to +170	7.18807	1416.7	211
Acetone	C_3H_6O	—	7.02447	1161.0	224
Ammonia	NH_3	−83 to +60	7.55466	1002.711	247.885
Benzene	C_6H_6	—	6.90565	1211.033	220.790
Carbon tetrachloride	CCl_4	—	6.93390	1242.43	230.0
Chlorobenzene	C_6H_5Cl	0 to +42	7.10690	1500.0	224.0
		+42 to +230	6.94504	1413.12	216.0
Chloroform	$CHCl_3$	−30 to +150	6.90328	1163.03	227.4
Cyclohexane	C_6H_{12}	−50 to +200	6.84498	1203.526	222.863
Ethyl acetate	$C_4H_8O_2$	−20 to +150	7.09808	1238.71	217.0
Ethyl alcohol	C_2H_6O	—	8.04494	1554.3	222.65
Ethylbenzene	C_8H_{10}	—	6.95719	1424.255	213.206
n-Heptane	C_7H_{16}	—	6.90240	1268.115	216.900
n-Hexane	C_6H_{14}	—	6.87776	1171.530	224.366
Methyl alcohol	CH_4O	−20 to +140	7.87863	1473.11	230.0
Methyl ethyl ketone	C_4H_8O	—	6.97421	1209.6	216
n-Pentane	C_5H_{12}	—	6.85221	1064.63	232.000
Isopentane	C_5H_{12}	—	6.78967	1020.012	233.097
Styrene	C_8H_8	—	6.92409	1420.0	206
Toluene	C_7H_8	—	6.95334	1343.943	219.377
Water	H_2O	0 to 60	8.10765	1750.286	235.0
		60 to 150	7.96681	1668.21	228.0

[a] Reprinted from *Lange's Handbook of Chemistry*, 9th Edition, Handbook Publishers, Inc., Sandusky, Ohio, 1956. For an expanded list of Antoine constants see J. A. Dean, *Lange's Handbook of Chemistry*, 12th Edition, McGraw-Hill, New York, 1979, pp. 10–29 through 10–54.

Mean Heat Capacities of Ideal Combustion Gases: SI Units*

$\bar{C}_p$(J/mol·°C) Reference state: P_{ref} = 1 atm, T_{ref} = 25°C								
T(°C)	Air	O_2	N_2	H_2	CO	CO_2	H_2O
0	28.94	29.24	29.03	28.84	29.00	36.63	33.55
25	29.05	29.39	29.06	28.84	29.06	37.15	33.63
100	29.21	29.80	29.16	28.86	29.23	38.63	33.92
200	29.45	30.32	29.32	28.90	29.47	40.45	34.34
300	29.71	30.80	29.52	28.95	29.72	42.10	34.80
400	29.97	31.24	29.74	29.03	29.99	43.59	35.29
500	30.25	31.65	29.98	29.12	30.27	44.93	35.81
600	30.53	32.02	30.24	29.23	30.56	46.14	36.36
700	30.81	32.39	30.51	29.35	30.85	47.23	36.92
800	31.10	32.71	30.79	29.48	31.14	48.20	37.49
900	31.38	33.02	31.07	29.63	31.42	49.07	38.08
1000	31.65	33.30	31.34	29.78	31.70	49.85	38.66
1100	31.92	33.55	31.62	29.94	31.97	50.54	39.24
1200	32.18	33.79	31.88	30.12	32.23	51.18	39.81
1300	32.42	34.02	32.13	30.29	32.47	51.75	40.37
1400	32.65	34.23	32.37	30.47	32.69	52.28	40.91
1500	32.85	34.42	32.58	30.66	32.89	52.77	41.42

*Calculated from the heat capacity formulas of Table B.2.

Example: The enthalpy of oxygen at 700°C relative to O_2 at 25°C [or the enthalpy change for the process $O_2(25°C) \to O_2(700°C)$] is

$$\hat{H}_{O_2}(700°C) = (\bar{C}_p)_{700°C}(700°C - 25°C)$$
$$= \left(32.39 \frac{J}{mol \cdot °C}\right)(675°C) = 21\,860 \text{ J/mol}$$

Mean Heat Capacities of Ideal Combustion Gases: American Engineering Units*

$\bar{C}_p$(Btu/lb-mole·°F) Reference state: P_{ref} = 1 atm, T_{ref} = 77°F								
T(°F)	Air	O_2	N_2	H_2	CO	CO_2	H_2O
32	6.942	6.989	6.938	6.893	6.931	8.755	8.019
77	6.943	7.024	6.944	6.895	6.945	8.879	8.038
100	6.949	7.041	6.948	6.895	6.952	8.941	8.049
200	6.979	7.114	6.967	6.898	6.981	9.203	8.100
300	7.010	7.184	6.988	6.902	7.013	9.451	8.154
400	7.042	7.251	7.011	6.908	7.045	9.686	8.211
500	7.075	7.315	7.036	6.915	7.079	9.909	8.271
600	7.110	7.377	7.063	6.923	7.113	10.12	8.334
700	7.145	7.437	7.092	6.933	7.149	10.32	8.399
800	7.181	7.494	7.123	6.944	7.186	10.51	8.467
900	7.217	7.548	7.155	6.956	7.223	10.68	8.536
1000	7.254	7.600	7.189	6.970	7.261	10.85	8.607
1100	7.291	7.650	7.233	6.984	7.299	11.01	8.680
1200	7.329	7.698	7.258	7.000	7.337	11.16	8.754
1300	7.367	7.744	7.295	7.016	7.376	11.30	8.83[illegible]
1400	7.405	7.788	7.331	7.034	7.414	11.43	8.90[illegible]
1500	7.442	7.830	7.368	7.052	7.453	11.55	8.983
1600	7.480	7.871	7.405	7.071	7.491	11.67	9.060
1700	7.517	7.909	7.443	7.091	7.529	11.78	9.138
1800	7.554	7.946	7.480	7.112	7.566	11.88	9.215
1900	7.590	7.982	7.516	7.133	7.602	11.98	9.293
2000	7.625	8.016	7.553	7.155	7.638	12.07	9.370

*Calculated from the heat capacity formulas of Table B.2.

Example: The enthalpy of water vapor at 1500°F relative to $H_2O(v)$ at 77°F is

$$\hat{H}_{H_2O(v)}(1500°F) = \bar{C}_p(1500°F)(1500°F - 77°F)$$
$$= \left(8.983 \frac{Btu}{lb\text{-}mole \cdot °F}\right)(1423°F) = 12\,780 \text{ Btu/lb-mole}$$

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The energy balance, neglecting kinetic energy changes, is

$$Q = \Delta H = n\Delta\hat{H}$$

$$= \frac{15 \text{ kmol}}{s} \bigg| \frac{-9980 \text{ kJ}}{\text{kmol}} \bigg| \frac{1 \text{ kW}}{1 \text{ kJ/s}} = \boxed{-1.497 \times 10^5 \text{ kW}}$$

Note: The mean heat capacities of the two preceding tables (and for that matter, the heat capacity formulas of Table B.2) apply strictly to heating or cooling at a constant pressure of 1 atm. The tabulated capacities may also be used for nonisobaric heating or cooling of ideal or nearly ideal gases. However, at pressures high enough for the gases to be highly nonideal, enthalpy tables or more precise heat capacity formulas should be used.

Selected Physical Property Data

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta\hat{H}_c^\circ)$[i,j] kJ/mol
Acetaldehyde	CH_3CHO	44.05	0.783[18°]	−123.7	—	20.2	25.1	461.0	—	−166.2(g)	−1192.4(g)
Acetic acid	CH_3COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	−486.18(l) −438.15(g)	−871.69(l) −919.73(g)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−248.2(l) −216.7(g)	−1785.7(l) −1821.4(g)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	+226.75(g)	−1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l) −46.19(g)	 −382.58(g)
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−366.48(aq)	—
Ammonium nitrate	NH_4NO_3	80.05	1.725[25°]	169.6	5.4	Decomposes at 210°C				−365.14(c) −339.36(aq)	—
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—	Decomposes at 513°C after melting				−1179.3(c) −1173.1(aq)	— —
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l) −40.04(g)	−3520.0(l) —
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l) +82.93(g)	−3267.6(l) −3301.5(g)

[a] 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, N. J.

[b] Melting point at 1 atm.

[c] Heat of fusion at T_m and 1 atm.

[d] Boiling point at 1 atm.

[e] Heat of vaporization at T_b and 1 atm.

[f] Critical temperature.

[g] Critical pressure.

[h] Heat of formation at 25°C and 1 atm.

[i] Heat of combustion at 25°C and 1 atm. Standard states of products are CO_2(g), H_2O(l), SO_2(g), HCl(aq), and N_2(g). To calculate $\Delta\hat{H}_c^\circ$ with H_2O(g) as a product, add $44.01n_w$ to the tabulated value, where n_w = moles H_2O formed/mole fuel burned.

[j] 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)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta\hat{H}_c^\circ)$[i,j] kJ/mol
Benzoic acid	$C_7H_6O_2$	122.12	1.266^{15}	122.2	—	249.8	—	—	—	—	−3226.7(g)
Benzyl alcohol	C_7H_8O	108.13	1.045	−15.4	—	205.2	—	—	—		−3741.8(l)
Bromine	Br_2	159.83	3.119	−7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C_4H_6	54.09	—	−136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C_4H_6	54.09	—	−109.1	—	−4.6	—	425	42.7	—	—
n-Butane	C_4H_{10}	58.12	—	−138.3	4.661	−0.6	22.305	425.17	37.47	−147.0(l) −124.7(g)	−2855.6(l) −2878.5(g)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−158.4(l) −134.5(g)	−2849.0(l) −2868.8(g)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	+1.17(g)	−2718.6(g)
Calcium carbide	CaC_2	64.10	$2.22^{18°}$	2300	—	—	—	—	—	−62.76(c)	—
Calcium carbonate	$CaCO_3$	100.09	2.93	Decomposes at 825°C						−1206.9(c)	—
Calcium chloride	$CaCl_2$	110.99	2.152^{15}	782	28.37	> 1600	—	—	—	−794.96(c)	—
Calcium hydroxide	$Ca(OH)_2$	74.10	2.24	$(-H_2O$ at 580°C)						−986.59(c)	—
Calcium oxide	CaO	56.08	3.32	2570	50	2850	—	—	—	−635.6(c)	—
Calcium phosphate	$Ca_3(PO_4)_2$	310.19	3.14	1670	—	—	—	—	-	−4138(c)	—
Calcium silicate	$CaSiO_3$	116.17	2.915	1530	48.62	—	—	—	—	−1584(c)	—
Calcium sulfate	$CaSO_4$	136.15	2.96	—	—	—	—	—	-	−1432.7(c) −1450.4(aq)	—
Calcium sulfate (gypsum)	$CaSO_4 \cdot 2H_2O$	172.18	2.32	$(-1.5\ H_2O$ at 128°C)			—	—	—	−2021(c)	—
Carbon (graphite)	C	12.010	2.26	3600	46.0	4200	—	—	—	0(c)	−393.51(c)
Carbon dioxide	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	CS_2	76.14	$1.261^{22°/20°}$	−112.1	4.39	46.25	26.8	552.0	78.0	−87.9(l) −115.3(g)	−1075.2(l) −1102.6(g)
Carbon monoxide	CO	28.01	—	−205.1	0.837	−191.5	6.042	133.0	34.5	−110.52(g)	−282.99(g)
Carbon tetrachloride	CCl_4	153.84	1.595	−22.9	2.51	76.7	30.0	556.4	45.0	−139.5(l) −106.7(g)	−352.2(l) −385.0(g)
Chlorine	Cl_2	70.91	—	−101.00	6.406	−34.06	20.4	417.0	76.1	0(g)	—
Chlorobenzene	C_6H_5Cl	112.56	1.107	−45	—	132.10	36.5	632.4	44.6	—	—
Chloroethane	C_2H_5Cl	See ethyl chloride									
Chloroform	$CHCl_3$	119.39	1.489	−63.7	—	61.0		536.0	54.0	−131.8(l)	−373(l)
Copper	Cu	63.54	8.92	1083	13.01	2595	304.6	—		0(c)	—
Cupric sulfate	$CuSO_4$	159.61	3.606^{15}	Decomposes > 600°C						−769.9(c) −843.1(aq)	— —
Cyclohexane	C_6H_{12}	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_5H_{10}	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)
n-Decane	$C_{10}H_{22}$	142.28	0.730	−29.9	—	173.8	—	619.0	20.8	−249.7(l) —	−6778.3(l) −6829.7(g)
Diethyl ether	$(C_2H_5)_2O$	74.12	$0.708^{25°}$	−116.3	7.30	34.6	26.05	467	35.6	−272.8(l)	−2726.7(l)
Ethane	C_2H_6	30.07	—	−183.3	2.859	−88.6	14.72	305.4	48.2	−84.67(g)	−1559.9(g)
Ethyl acetate	$C_4H_8O_2$	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_2H_5OH	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_8H_{10}	106.16	0.867	−94.97	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_2H_5Br	108.98	1.460	−119.1	—	38.2	—	504	61.5	−54.4(g)	—
Ethyl chloride	C_2H_5Cl	64.52	0.903^{15}	−138.3	4.452	13.1	24.7	460.4	52.0	−105.0(g)	—
3-Ethyl hexane	C_8H_{18}	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_2H_4	28.05	—	−169.2	3.350	−103.7	13.54	283.1	50.5	−52.28(g)	−1410.99(g)
Ethylene glycol	$C_2H_6O_2$	62.07	1.113^{19}	−13	11.23	197.2	56.9	—	—	−451.5(l) −387.1(g)	−1179.5(l) —
Ferric oxide	Fe_2O_3	159.70	5.12	Decomposes at 1560°C						−822.2(c)	—
Ferrous oxide	FeO	71.85	5.7	—	—	—		--	—	−266.5(c)	—

(continued)

TABLE B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta\hat{H}_c^\circ)$[i,j] kJ/mol
Ferrous sulfide	FeS	87.92	4.84	1193	—	—	—	—	—	−95.1(c)	—
Formaldehyde	H_2CO	30.03	0.815^{-20}	−92	—	−19.3	24.48	—	—	−115.90(g)	−563.46(g)
Formic acid	CH_2O_2	46.03	1.220	8.30	12.68	100.5	22.25	—	—	−409.2(l) −362.6(g)	−262.8(l) —
Glycerol	$C_3H_8O_3$	92.09	1.260^{50}	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)	—
n-Heptane	C_7H_{16}	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)
n-Hexane	C_6H_{14}	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_2	2.016	—	−259.19	0.12	−252.76	0.904	33.3	12.8	0(g)	−285.84(g)
Hydrogen bromide	HBr	80.92	—	−86	—	−67	—	—	—	−36.23(g)	—
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_2S	34.08	—	−85.5	2.38	−60.3	18.67	373.6	88.9	−19.96(g)	−562.59(g)
Iodine	I_2	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	$11.337^{20/20}$	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	$MgCl_2$	95.23	2.325^{25}	714	43.1	1418	136.8	—	—	−641.8(c)	—
Magnesium hydroxide	$Mg(OH)_2$	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_4	16.04	—	−182.5	0.94	−161.5	8.179	190.70	45.8	−74.85(g)	−890.36(g)
Methyl acetate	$C_3H_6O_2$	74.08	0.933	−98.9	—	57.1	—	506.7	46.30	−409.4(l)	−1595(l)
Methyl alcohol (Methanol)	CH_3OH	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_5N	31.06	0.699^{-11}	−92.7	—	−6.9	—	429.9	73.60	−28.0(g)	−1071.5(l)
Methyl chloride	CH_3Cl	50.49	—	−97.9	—	−24	—	416.1	65.80	−81.92(g)	—
Methyl ethyl ketone	C_4H_8O	72.10	0.805	−87.1	—	78.2	32.0	—	—	—	−2436(l)
Naphthalene	$C_{10}H_8$	128.16	1.145	80.0	—	217.8	—	—	—	—	−5157(g)
Nickel	Ni	58.69	8.90	1452	—	2900	—	—	—	0(c)	—
Nitric acid	HNO_3	63.02	1.502	−41.6	10.47	86	30.30	—	—	−173.23(l) −206.57(aq)	—
Nitrobenzene	$C_6H_5O_2N$	123.11	1.203	5.5	—	210.7	—	—	—	—	−3092.8(l)
Nitrogen	N_2	28.02	—	−210.0	0.720	−195.8	5.577	126.20	33.5	0(g)	—
Nitrogen dioxide	NO_2	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_2O_5	108.02	$1.63^{18°}$	30	—	47	—	—	—	—	—
Nitrogen tetraoxide	N_2O_4	92.0	1.448	−9.5	—	21.1	—	431.0	99.0	+9.3(g)	—
Nitrous oxide	N_2O	44.02	1.226^{-89}	−91.1	—	−88.8	—	309.5	71.70	+81.5(g)	—
n-Nonane	C_9H_{20}	128.25	0.718	−53.8	—	150.6	—	595	23.0	−229.0(l) —	−6124.5(l) −6171.0(g)
n-Octane	C_8H_{18}	114.22	0.703	−57.0	—	125.5	—	595.0	22.5	−249.9(l) −208.4(g)	−5470.7(l) −5512.2(g)
Oxalic acid	$C_2H_2O_4$	90.04	1.90		Decomposes at 186°C			—	—	−826.8(c)	−251.9(s)
Oxygen	O_2	32.00	—	−218.75	0.444	−182.97	6.82	154.4	49.7	0(g)	—
n-Pentane	C_5H_{12}	72.15	$0.63^{18°}$	−129.6	8.393	36.07	25.77	469.80	33.3	−173.0(l) −146.4(g)	−3509.5(l) −3536.1(g)

(continued)

TABLE B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta \hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta \hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta \hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta \hat{H}_c^\circ)$[i,j] kJ/mol
Isopentane	C_5H_{12}	72.15	0.62[19]	−160.1	—	27.7	— —	461.00	32.9	−179.3(l) −152.0(g)	−3507.5(l) −3529.2(g)
1-Pentene	C_5H_{10}	70.13	0.641	−165.2	4.94	29.97		474	39.9	−20.9(g)	−3375.8(g)
Phenol	C_6H_5OH	94.11	1.071[25]	42.5	11.43	181.4	—	692.1	60.5	−158.1(l) −90.8(g)	−3063.5(s) —
Phosphoric acid	H_3PO_4	98.00	1.834[18]	42.3	10.54	(−½H_2O at 213°C)		—	—	−1281.1(c) −1278.6(aq, 1H_2O)	— —
Phosphorus (red)	P_4	123.90	2.20	590[43 atm]	81.17	Ignites in air, 725°C		—	—	−17.6(c) 0(c)	—
Phosphorus (white)	P_4	123.90	1.82	44.2	2.51	280	49.71	—	—		—
Phosphorus pentoxide	P_2O_5	141.95	2.387			Sublimes at 250°C		—	—	−1506.2(c)	—
Propane	C_3H_8	44.09	—	−187.69	3.52	−42.07	18.77	369.9	42.0	−119.8(l) −103.8(g)	−2204.0(l) −2220.0(g)
Propylene	C_3H_6	42.08	—	−185.2	3.00	−47.70	18.42	365.1	45.4	−20.41(g)	−2058.4(g)
n-Propyl alcohol	C_3H_7OH	60.09	0.804	−127	—	97.04	—	536.7	49.95	−300.70(l) −255.2(g)	−2010.4(l) −2068.6(g)
Isopropyl alcohol	C_3H_8O	60.09	0.785	−89.7	—	82.24	—	508.8	53.0	−310.9(l)	−1986.6(l)
n-Propyl benzene	C_9H_{12}	120.19	0.862	−99.50	8.54	159.2	38.24	638.7	31.3	−38.40(l) −7.82(g)	−5218.2(l) −5264.48(g)
Silicon dioxide	SiO_2	60.09	2.25	1710	14.2	2230	-	—	—	−851.0(c)	—
Sodium bicarbonate	$NaHCO_3$	84.01	2.20			Decomposes at 270°C		—	—	−945.6(c)	—
Sodium bisulfate	$NaHSO_4$	120.07	2.742	—	—	—	—	—	—	−1126.3(c)	—
Sodium carbonate	Na_2CO_3	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	$NaNO_3$	85.00	2.257	310	15.9	Decomposes at 380°C			—	−466.7(c)	—
Sodium nitrite	$NaNO_2$	69.00	2.168[0°]	271	—	Decomposes at 320°C			—	−359.4(c)	—
Sodium sulfate	Na_2SO_4	142.05	2.698	890	24.3	—	—	—	—	−1384.5(c)	—
Sodium sulfide	Na_2S	78.05	1.856	950	6.7	—	—	—	—	−373.2(c)	—
Sodium sulfite	Na_2SO_3	126.05	2.633[15°]		Decomposes			—	—	−1090.3(c)	
Sodium thiosulfate	$Na_2S_2O_3$	158.11	1.667	—	—	—	—	—	—	−1117.1(c)	—
Sulfur (rhombic)	S_8	256.53	2.07	113	10.04	444.6	83.7	—	—	0(c)	—
Sulfur (monoclinic)	S_8	256.53	1.96	119	14.17	444.6	83.7	—	—	+0.30(c)	—
Sulfur dioxide	SO_2	64.07	—	−75.48	7.402	−10.02	24.91	430.7	77.8	−296.90(g)	—
Sulfur trioxide	SO_3	80.07	—	16.84	25.48	43.3	41.80	491.4	83.8	−395.18(g)	—
Sulfuric acid	H_2SO_4	98.08	1.834[18°]	10.35	9.87	Decomposes at 340°C		—	—	−811.32(l) −907.51(aq)	— —
Toluene	C_7H_8	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_2O	18.016	1.00[4°]	0.00	6.0095	100.00	40.656	647.4	218.3	−285.84(l) −241.83(g)	— —
m-Xylene	C_8H_{10}	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)
o-Xylene	C_8H_{10}	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)
p-Xylene	C_8H_{10}	106.16	0.861	13.26	17.11	138.35	36.07	618	33.9	−24.43(l) 17.95(g)	−4552.9(l) −4595.2(g)
Zinc	Zn	65.38	7.140	419.5	6.674	907	114.77	—	—	0(c)	—

TABLE B.2
Heat Capacities[a]

Form 1: C_p(J/mol·°C) or (J/mol·K) $= a + bT + cT^2 + dT^3$
Form 2: C_p(J/mol·°C) or (J/mol·K) $= a + bT + cT^{-2}$

Example: $(C_p)_{\text{acetone(g)}} = 71.96 + (20.10 \times 10^{-2})T - (12.78 \times 10^{-5})T^2 + (34.76 \times 10^{-9})T^3$, where T is in °C.

Note: The formulas for gases are strictly applicable at pressures low enough for the ideal gas law to apply.

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	a	$b \cdot 10^2$	$c \cdot 10^5$	$d \cdot 10^9$	Range (Units of T)
Acetone	CH_3COCH_3	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_2H_2	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_3	17.03	g	1	°C	35.15	2.954	0.4421	−6.686	0–1200
Ammonium sulfate	$(NH_4)_2SO_4$	132.15	c	1	K	215.9				275–328
Benzene	C_6H_6	78.11	l	1	K	62.55	23.4			279–350
			g	1	°C	74.06	32.95	−25.20	77.57	0–1200
Isobutane	C_4H_{10}	58.12	g	1	°C	89.46	30.13	−18.91	49.87	0–1200
n-Butane	C_4H_{10}	58.12	g	1	°C	92.30	27.88	−15.47	34.98	0–1200
Isobutene	C_4H_8	56.10	g	1	°C	82.88	25.64	−17.27	50.50	0–1200
Calcium carbide	CaC_2	64.10	c	2	K	68.62	1.19	-8.66×10^{10}	—	298–720
Calcium carbonate	$CaCO_3$	100.09	c	2	K	82.34	4.975	-12.87×10^{10}	—	273–1033
Calcium hydroxide	$Ca(OH)_2$	74.10	c	1	K	89.5				276–373
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52×10^{10}		273–1173
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891×10^{10}		273–1373
Carbon dioxide	CO_2	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_4	153.84	l	1	K	93.39	12.98			273–343
Chlorine	Cl_2	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
Cumene (Isopropyl benzene)	C_9H_{12}	120.19	g	1	°C	139.2	53.76	−39.79	120.5	0–1200
Cyclohexane	C_6H_{12}	84.16	g	1	°C	94.140	49.62	−31.90	80.63	0–1200
Cyclopentane	C_5H_{10}	70.13	g	1	°C	73.39	39.28	−25.54	68.66	0–1200
Ethane	C_2H_6	30.07	g	1	°C	49.37	13.92	−5.816	7.280	0–1200
Ethyl alcohol (Ethanol)	C_2H_5OH	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_2H_4	28.05	g	1	°C	40.75	11.47	−6.891	17.66	0–1200
Ferric oxide	Fe_2O_3	159.70	c	2	K	103.4	6.711	-17.72×10^{10}	—	273–1097
Formaldehyde	CH_2O	30.03	g	1	°C	34.28	4.268	0.0000	−8.694	0–1200
Helium	He	4.00	g	1	°C	20.8				All
n-Hexane	C_6H_{14}	86.17	l	1	°C	216.3				20–100
			g	1	°C	137.44	40.85	−23.92	57.66	0–1200
Hydrogen	H_2	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_2S	34.08	g	1	°C	33.51	1.547	0.3012	−3.292	0–1500
Magnesium chloride	$MgCl_2$	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^{10}		273–2073
Methane	CH_4	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_3OH	32.04	l	1	°C	75.86				0
						82.59				40
			g	1	°C	42.93	8.301	−1.87	−8.03	0–700
Methyl cyclohexane	C_7H_{14}	98.18	g	1	°C	121.3	56.53	−37.72	100.8	0–1200
Methyl cyclopentane	C_6H_{12}	84.16	g	1	°C	98.83	45.857	−30.44	83.81	0–1200
Nitric acid	HNO_3	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

[a] 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, N.J.

(continued)

TABLE B.2 (Continued)

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	a	$b \cdot 10^2$	$c \cdot 10^5$	$d \cdot 10^9$	Range (Units of T)
Nitrogen	N_2	28.02	g	1	°C	29.00	0.2199	0.5723	−2.871	0–1500
Nitrogen dioxide	NO_2	46.01	g	1	°C	36.07	3.97	−2.88	7.87	0–1200
Nitrogen tetraoxide	N_2O_4	92.02	g	1	°C	75.7	12.5	−11.3		0–300
Nitrous oxide	N_2O	44.02	g	1	°C	37.66	4.151	−2.694	10.57	0–1200
Oxygen	O_2	32.00	g	1	°C	29.10	1.158	−0.6076	1.311	0–1500
n-Pentane	C_5H_{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	C_3H_8	44.09	g	1	°C	68.032	22.59	−13.11	31.71	0–1200
Propylene	C_3H_6	42.08	g	1	°C	59.580	17.71	−10.17	24.60	0–1200
Sodium carbonate	Na_2CO_3	105.99	c	1	K	121				288–371
Sodium carbonate decahydrate	$Na_2CO_3 \cdot 10H_2O$	286.15	c	1	K	535.6				298
Sulfur	S	32.07	c (Rhombic)	1	K	15.2	2.68			273–368
			c (Monoclinic)	1	K	18.3	1.84			368–392
Sulfuric acid	H_2SO_4	98.08	l	1	°C	139.1	15.59			10–45
Sulfur dioxide	SO_2	64.07	g	1	°C	38.91	3.904	−3.104	8.606	0–1500
Sulfur trioxide	SO_3	80.07	g	1	°C	48.50	9.188	−8.540	32.40	0–1000
Toluene	C_7H_8	92.13	l	1	°C	148.8				0
			l	1	°C	181.2				100
			g	1	°C	94.18	38.00	−27.86	80.33	0–1200
Water	H_2O	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[a]

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	2.112	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	6.525	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

[a] 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)

T(°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
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
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	33.584	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
T(°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
T(°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
Properties of Saturated Steam: Temperature Table[a]

T(°C)	P(bar)	$\hat{V}$(m³/kg) Water	Steam	$\hat{U}$(kJ/kg) Water	Steam	$\hat{H}$(kJ/kg) 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

[a] 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:* kJ/kg × 0.4303 = Btu/lb$_m$.

(continued)

TABLE B.4 (Continued)

T(°C)	P(bar)	$\hat{V}$(m³/kg) Water	Steam	$\hat{U}$(kJ/kg) Water	Steam	$\hat{H}$(kJ/kg) 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

[redacted]

TABLE B.5

Properties of Saturated Steam: Pressure Table[a]

P(bar)	T(°C)	$\hat{V}$(m^3/kg) Water	$\hat{V}$(m^3/kg) Steam	$\hat{U}$(kJ/kg) Water	$\hat{U}$(kJ/kg) Steam	$\hat{H}$(kJ/kg) Water	$\hat{H}$(kJ/kg) Evaporation	$\hat{H}$(kJ/kg) Steam
0.00611	0.01	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
0.008	3.8	0.001000	159.7	15.8	2380.7	15.8	2492.6	2508.5
0.010	7.0	0.001000	129.2	29.3	2385.2	29.3	2485.0	2514.4
0.012	9.7	0.001000	108.7	40.6	2388.9	40.6	2478.7	2519.3
0.014	12.0	0.001000	93.9	50.3	2392.0	50.3	2473.2	2523.5
0.016	14.0	0.001001	82.8	58.9	2394.8	58.9	2468.4	2527.3
0.018	15.9	0.001001	74.0	66.5	2397.4	66.5	2464.1	2530.6
0.020	17.5	0.001001	67.0	73.5	2399.6	73.5	2460.2	2533.6
0.022	19.0	0.001002	61.2	79.8	2401.7	79.8	2456.6	2536.4
0.024	20.4	0.001002	56.4	85.7	2403.6	85.7	2453.3	2539.0
0.026	21.7	0.001002	52.3	91.1	2405.4	91.1	2450.2	2541.3
0.028	23.0	0.001002	48.7	96.2	2407.1	96.2	2447.3	2543.6
0.030	24.1	0.001003	45.7	101.0	2408.6	101.0	2444.6	2545.6
0.035	26.7	0.001003	39.5	111.8	2412.2	111.8	2438.5	2550.4
0.040	29.0	0.001004	34.8	121.4	2415.3	121.4	2433.1	2554.5
0.045	31.0	0.001005	31.1	130.0	2418.1	130.0	2428.2	2558.2
0.050	32.9	0.001005	28.2	137.8	2420.6	137.8	2423.8	2561.6
0.060	36.2	0.001006	23.74	151.5	2425.1	151.5	2416.0	2567.5
0.070	39.0	0.001007	20.53	163.4	2428.9	163.4	2409.2	2572.6
0.080	41.5	0.001008	18.10	173.9	2432.3	173.9	2403.2	2577.1
0.090	43.8	0.001009	16.20	183.3	2435.3	183.3	2397.9	2581.1
0.10	45.8	0.001010	14.67	191.8	2438.0	191.8	2392.9	2584.8
0.11	47.7	0.001011	13.42	199.7	2440.5	199.7	2388.4	2588.1
0.12	49.4	0.001012	12.36	206.9	2442.8	206.9	2384.3	2591.2
0.13	51.1	0.001013	11.47	213.7	2445.0	213.7	2380.4	2594.0
0.14	52.6	0.001013	10.69	220.0	2447.0	220.0	2376.7	2596.7
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 (1 atm)	100.0	0.001044	1.673	419.0	2506.5	419.1	2256.9	2676.0

[a] 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:* kJ/kg × 0.4303 = Btu/lb$_m$.

(continued)

P(bar)	T(°C)	$\hat{V}$(m³/kg) Water	Steam	$\hat{U}$(kJ/kg) Water	Steam	$\hat{H}$(kJ/kg) Water	Evaporation	Steam
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

(continued)

TABLE B.5 (Continued)

		$\hat{V}$(m^3/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
P(bar)	T(°C)	Water	Steam	Water	Steam	Water	Evaporation	Steam
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
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
96	308.0	0.001439	0.01897	1376.7	2552.6	1390.6	1344.1	2734.7
98	309.5	0.001446	0.01849	1385.2	2550.0	1399.3	1331.9	2731.2
100	311.0	0.001453	0.01804	1393.5	2547.3	1408.0	1319.7	2727.7
105	314.6	0.001470	0.01698	1414.1	2540.4	1429.5	1289.2	2718.7
110	318.0	0.001489	0.01601	1434.2	2533.2	1450.6	1258.7	2709.3
115	321.4	0.001507	0.01511	1454.0	2525.7	1471.3	1228.2	2699.5
120	324.6	0.001527	0.01428	1473.4	2517.8	1491.8	1197.4	2689.2
125	327.8	0.001547	0.01351	1492.7	2509.4	1512.0	1166.4	2678.4
130	330.8	0.001567	0.01280	1511.6	2500.6	1532.0	1135.0	2667.0
135	333.8	0.001588	0.01213	1530.4	2491.3	1551.9	1103.1	2655.0
140	336.6	0.001611	0.01150	1549.1	2481.4	1571.6	1070.7	2642.4
145	339.4	0.001634	0.01090	1567.5	2471.0	1591.3	1037.7	2629.1
150	342.1	0.001658	0.01034	1586.1	2459.9	1611.0	1004.0	2615.0
155	344.8	0.001683	0.00981	1604.6	2448.2	1630.7	969.6	2600.3
160	347.3	0.001710	0.00931	1623.2	2436.0	1650.5	934.3	2584.9
165	349.8	0.001739	0.00883	1641.8	2423.1	1670.5	898.3	2568.8
170	352.3	0.001770	0.00837	1661.6	2409.3	1691.7	859.9	2551.6
175	354.6	0.001803	0.00793	1681.8	2394.6	1713.3	820.0	2533.3
180	357.0	0.001840	0.00750	1701.7	2378.9	1734.8	779.1	2513.9
185	359.2	0.001881	0.00708	1721.7	2362.1	1756.5	736.6	2493.1
190	361.4	0.001926	0.00668	1742.1	2343.8	1778.7	692.0	2470.6
195	363.6	0.001977	0.00628	1763.2	2323.6	1801.8	644.2	2446.0
200	365.7	0.00204	0.00588	1785.7	2300.8	1826.5	591.9	2418.4
205	367.8	0.00211	0.00546	1810.7	2274.4	1853.9	532.5	2386.4
210	369.8	0.00220	0.00502	1840.0	2242.1	1886.3	461.3	2347.6
215	371.8	0.00234	0.00451	1878.6	2198.1	1928.9	366.2	2295.2
220	373.7	0.00267	0.00373	1952	2114	2011	185	2196
221.2 (Critical point)	374.15	0.00317	0.00317	2038	2038	2108	0	2108

TABLE B.6

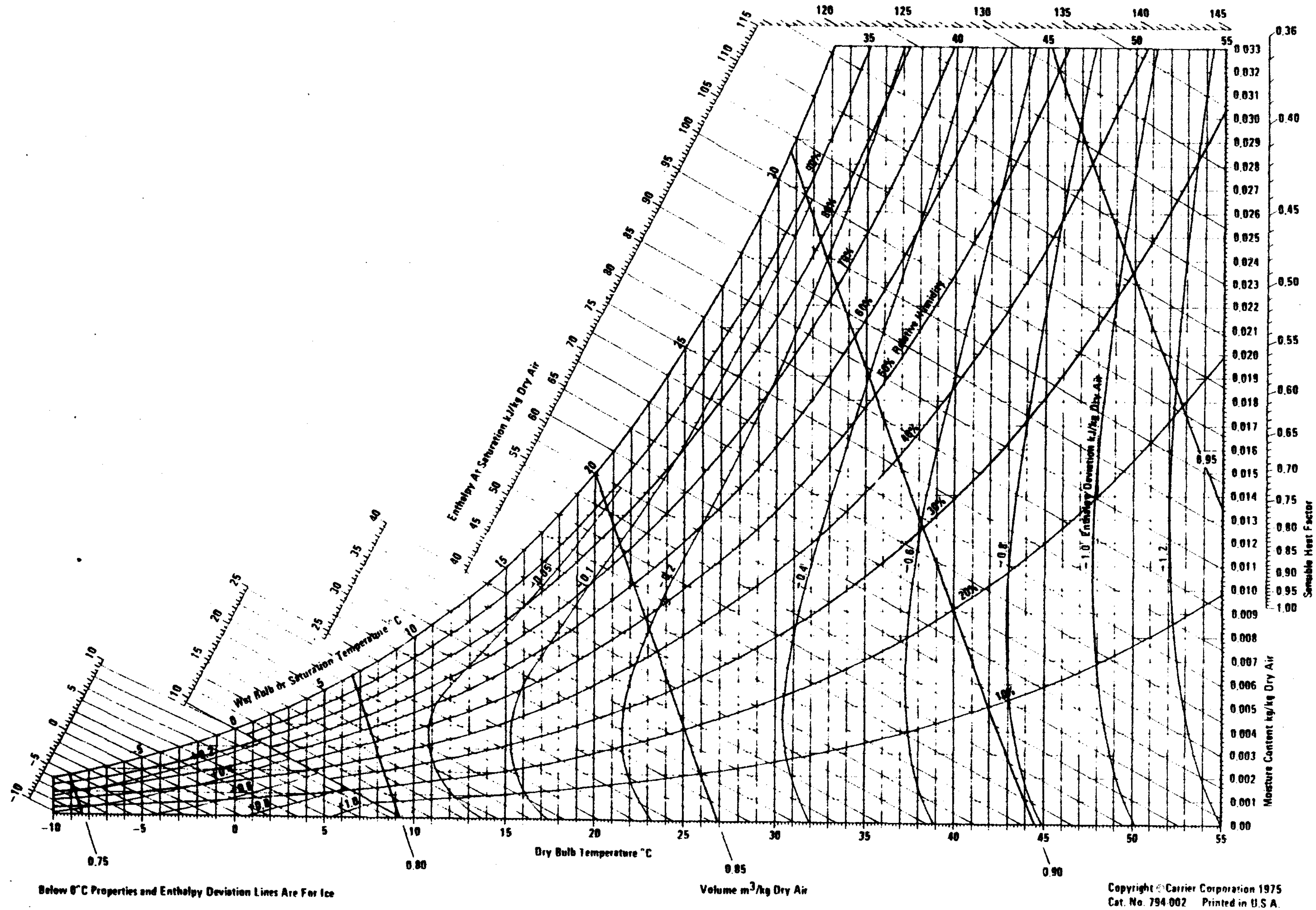
Properties of Superheated Steam[a]

P(bar) (T_{sat}, °C)		Sat'd Water	Sat'd Steam	50	75	100	150	200	250	300	350
				Temperature (°C)→							
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	3177
(45.8)	$\hat{U}$	191.8	2438.0	2444	2480	2516	2588	2661	2736	2812	2890
	$\hat{V}$	0.00101	14.7	14.8	16.0	17.2	19.5	21.8	24.2	26.5	28.7
0.5	$\hat{H}$	340.6	2446.0	209.3	313.9	2683	2780	2878	2979	3076	3177
(81.3)	$\hat{U}$	340.6	2484.0	209.2	313.9	2512	2586	2660	2735	2811	2889
	$\hat{V}$	0.00103	3.24	0.00101	0.00103	3.41	3.89	4.35	4.83	5.29	5.75
1.0	$\hat{H}$	417.5	2675.4	209.3	314.0	2676	2776	2875	2975	3074	3176
(99.6)	$\hat{U}$	417.5	2506.1	209.2	313.9	2507	2583	2658	2734	2811	2889
	$\hat{V}$	0.00104	1.69	0.00101	0.00103	1.69	1.94	2.17	2.40	2.64	2.87
5.0	$\hat{H}$	640.1	2747.5	209.7	314.3	419.4	632.2	2855	2961	3065	3168
(151.8)	$\hat{U}$	639.6	2560.2	209.2	313.8	418.8	631.6	2643	2724	2803	2883
	$\hat{V}$	0.00109	0.375	0.00101	0.00103	0.00104	0.00109	0.425	0.474	0.522	0.571
10	$\hat{H}$	762.6	2776.2	210.1	314.7	419.7	632.5	2827	2943	3052	3159
(179.9)	$\hat{U}$	761.5	2582	209.1	313.7	418.7	631.4	2621	2710	2794	2876
	$\hat{V}$	0.00113	0.194	0.00101	0.00103	0.00104	0.00109	0.206	0.233	0.258	0.282
20	$\hat{H}$	908.6	2797.2	211.0	315.5	420.5	633.1	852.6	2902	3025	3139
(212.4)	$\hat{U}$	906.2	2598.2	209.0	313.5	418.4	603.9	850.2	2679	2774	2862
	$\hat{V}$	0.00118	0.09950	0.00101	0.00102	0.00104	0.00109	0.00116	0.111	0.125	0.139
40	$\hat{H}$	1087.4	2800.3	212.7	317.1	422.0	634.3	853.4	1085.8	2962	3095
(250.3)	$\hat{U}$	1082.4	2601.3	208.6	313.0	417.8	630.0	848.8	1080.8	2727	2829
	$\hat{V}$	0.00125	0.04975	0.00101	0.00102	0.00104	0.00109	0.00115	0.00125	0.0588	0.0665
60	$\hat{H}$	1213.7	2785.0	214.4	318.7	423.5	635.6	854.2	1085.8	2885	3046
(275.6)	$\hat{U}$	1205.8	2590.4	208.3	312.6	417.3	629.1	847.3	1078.3	2668	2792
	$\hat{V}$	0.00132	0.0325	0.00101	0.00103	0.00104	0.00109	0.00115	0.00125	0.0361	0.0422
80	$\hat{H}$	1317.1	2759.9	216.1	320.3	425.0	636.8	855.1	1085.8	2787	2990
(295.0)	$\hat{U}$	1306.0	2571.7	208.1	312.3	416.7	628.2	845.9	1075.8	2593	2750
	$\hat{V}$	0.00139	0.0235	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.0243	0.0299
100	$\hat{H}$	1408.0	2727.7	217.8	322.9	426.5	638.1	855.9	1085.8	1343.4	2926
(311.0)	$\hat{U}$	1393.5	2547.3	207.8	311.7	416.1	627.3	844.4	1073.4	1329.4	2702
	$\hat{V}$	0.00145	0.0181	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.00140	0.0224
150	$\hat{H}$	1611.0	2615.0	222.1	326.0	430.3	641.3	858.1	1086.2	1338.2	2695
(342.1)	$\hat{U}$	1586.1	2459.9	207.0	310.7	414.7	625.0	841.0	1067.7	1317.6	2523
	$\hat{V}$	0.00166	0.0103	0.00101	0.00102	0.00104	0.00108	0.00114	0.00123	0.00138	0.0115
200	$\hat{H}$	1826.5	2418.4	226.4	330.0	434.0	644.5	860.4	1086.7	1334.3	1647.1
(365.7)	$\hat{U}$	1785.7	2300.8	206.3	309.7	413.2	622.9	837.7	1062.2	1307.1	1613.7
	$\hat{V}$	0.00204	0.005875	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00136	0.00167
221.2(P_c)	$\hat{H}$	2108	2108	228.2	331.7	435.7	645.8	861.4	1087.0	1332.8	1635.5
(374.15)(T_c)	$\hat{U}$	2037.8	2037.8	206.0	309.2	412.8	622.0	836.3	1060.0	1302.9	1600.3
	$\hat{V}$	0.00317	0.00317	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00135	0.00163
250	$\hat{H}$	—	—	230.7	334.0	437.8	647.7	862.8	1087.5	1331.1	1625.0
(—)	$\hat{U}$	—	—	205.7	308.7	412.1	620.8	834.4	1057.0	1297.5	1585.0
	$\hat{V}$	—	—	0.00100	0.00101	0.00103	0.00108	0.00113	0.00122	0.00135	0.00160
300	$\hat{H}$	—	—	235.0	338.1	441.6	650.9	865.2	1088.4	1328.7	1609.9
(—)	$\hat{U}$	—	—	205.0	307.7	410.8	618.7	831.3	1052.1	1288.7	1563.3
	$\hat{V}$	—	—	0.0009990	0.00101	0.00103	0.00107	0.00113	0.00121	0.00133	0.00155
500	$\hat{H}$	—	—	251.9	354.2	456.8	664.1	875.4	1093.6	1323.7	1576.3
(—)	$\hat{U}$	—	—	202.4	304.0	405.8	611.0	819.7	1034.3	1259.3	1504.1
	$\hat{V}$	—	—	0.0009911	0.00100	0.00102	0.00106	0.00111	0.00119	0.00129	0.00144
1000	$\hat{H}$	—	—	293.9	394.3	495.1	698.0	903.5	1113.0	1328.7	1550.5
(—)	$\hat{U}$	—	—	196.5	295.7	395.1	594.4	795.3	999.0	1207.1	1419.0
	$\hat{V}$	—	—	0.0009737	0.0009852	0.001000	0.00104	0.00108	0.00114	0.00122	0.00131

[a] Adapted from 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 (m^3/kg). *Note:* kJ/kg × 0.4303 = Btu/lb_m

Physical Properties Table

P(bar) (T_{sat} °C)		Temperature (°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	0.0197	0.0211	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



Psychrometric chart—SI units. (Reprinted with permission of Carrier Corporation.)