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**TABLE A-1** Atomic or Molecular Weights and Critical Properties of Selected Elements and Compounds

Substance	Chemical Formula	$M$ (kg/kmol)	$T_c$ (K)	$P_c$ (bar)	$Z_c = \frac{P_c V_c}{RT_c}$
Acetylene	$C_2H_2$	26.04	309	62.8	0.274
Air (equivalent)	—	28.97	133	37.7	0.284
Ammonia	$NH_3$	17.03	406	112.8	0.242
Argon	Ar	39.94	151	48.6	0.290
Benzene	$C_6H_6$	78.11	563	49.3	0.274
Butane	$C_4H_{10}$	58.12	425	38.0	0.274
Carbon	C	12.01	—	—	—
Carbon dioxide	$CO_2$	44.01	304	73.9	0.276
Carbon monoxide	CO	28.01	133	35.0	0.294
Copper	Cu	63.54	—	—	—
Ethane	$C_2H_6$	30.07	305	48.8	0.285
Ethyl alcohol	$C_2H_5OH$	46.07	516	63.8	0.249
Ethylene	$C_2H_4$	28.05	283	51.2	0.270
Helium	He	4.003	5.2	2.3	0.300
Hydrogen	$H_2$	2.016	33.2	13.0	0.304
Methane	$CH_4$	16.04	191	46.4	0.290
Methyl alcohol	$CH_3OH$	32.04	513	79.5	0.220
Nitrogen	$N_2$	28.01	126	33.9	0.291
Octane	$C_8H_{18}$	114.22	569	24.9	0.258
Oxygen	$O_2$	32.00	154	50.5	0.290
Propane	$C_3H_8$	44.09	370	42.7	0.276
Propylene	$C_3H_6$	42.08	365	46.2	0.276
Refrigerant 12	$CCl_2F_2$	120.92	385	41.2	0.278
Refrigerant 22	$CHClF_2$	86.48	369	49.8	0.267
Refrigerant 134a	$CF_3CH_2F$	102.03	374	40.7	0.260
Sulfur dioxide	$SO_2$	64.06	431	78.7	0.268
Water	$H_2O$	18.02	647.3	220.9	0.233

Sources: Adapted from *International Critical Tables* and L. C. Nelson and E. F. Obert, Generalized Compressibility Charts, *Chem. Eng.*, 61: 203 (1954).

**TABLE A-2** Properties of Saturated Water (Liquid–Vapor): Temperature Table

H <sub>2</sub> O	Temp. °C	Press. bar	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Temp. °C	
			Sat. Liquid <i>v<sub>f</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>f</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Vapor <i>h<sub>g</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>		
	.01	0.00611	1.0002	206.136	0.00	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	.01
4	0.00813	1.0001	157.232	16.77	2380.9	16.78	2491.9	2508.7	0.0610	9.0514	4	5
5	0.00872	1.0001	147.120	20.97	2382.3	20.98	2489.6	2510.6	0.0761	9.0257	5	6
6	0.00935	1.0001	137.734	25.19	2383.6	25.20	2487.2	2512.4	0.0912	9.0003	6	8
8	0.01072	1.0002	120.917	33.59	2386.4	33.60	2482.5	2516.1	0.1212	8.9501	8	
10	0.01228	1.0004	106.379	42.00	2389.2	42.01	2477.7	2519.8	0.1510	8.9008	10	
11	0.01312	1.0004	99.857	46.20	2390.5	46.20	2475.4	2521.6	0.1658	8.8765	11	
12	0.01402	1.0005	93.784	50.41	2391.9	50.41	2473.0	2523.4	0.1806	8.8524	12	
13	0.01497	1.0007	88.124	54.60	2393.3	54.60	2470.7	2525.3	0.1953	8.8285	13	
14	0.01598	1.0008	82.848	58.79	2394.7	58.80	2468.3	2527.1	0.2099	8.8048	14	
15	0.01705	1.0009	77.926	62.99	2396.1	62.99	2465.9	2528.9	0.2245	8.7814	15	
16	0.01818	1.0011	73.333	67.18	2397.4	67.19	2463.6	2530.8	0.2390	8.7582	16	
17	0.01938	1.0012	69.044	71.38	2398.8	71.38	2461.2	2532.6	0.2535	8.7351	17	
18	0.02064	1.0014	65.038	75.57	2400.2	75.58	2458.8	2534.4	0.2679	8.7123	18	
19	0.02198	1.0016	61.293	79.76	2401.6	79.77	2456.5	2536.2	0.2823	8.6897	19	
20	0.02339	1.0018	57.791	83.95	2402.9	83.96	2454.1	2538.1	0.2966	8.6672	20	
21	0.02487	1.0020	54.514	88.14	2404.3	88.14	2451.8	2539.9	0.3109	8.6450	21	
22	0.02645	1.0022	51.447	92.32	2405.7	92.33	2449.4	2541.7	0.3251	8.6229	22	
23	0.02810	1.0024	48.574	96.51	2407.0	96.52	2447.0	2543.5	0.3393	8.6011	23	
24	0.02985	1.0027	45.883	100.70	2408.4	100.70	2444.7	2545.4	0.3534	8.5794	24	
25	0.03169	1.0029	43.360	104.88	2409.8	104.89	2442.3	2547.2	0.3674	8.5580	25	
26	0.03363	1.0032	40.994	109.06	2411.0	109.07	2439.9	2549.0	0.3814	8.5367	26	
27	0.03567	1.0035	38.774	113.25	2412.5	113.25	2437.6	2550.8	0.3954	8.5156	27	
28	0.03782	1.0037	36.690	117.42	2413.9	117.43	2435.2	2552.6	0.4093	8.4946	28	
29	0.04008	1.0040	34.733	121.60	2415.2	121.61	2432.8	2554.5	0.4231	8.4739	29	
30	0.04246	1.0043	32.894	125.78	2416.6	125.79	2430.5	2556.3	0.4369	8.4533	30	
31	0.04496	1.0046	31.165	129.96	2418.0	129.97	2428.1	2558.1	0.4507	8.4329	31	
32	0.04759	1.0050	29.540	134.14	2419.3	134.15	2425.7	2559.9	0.4644	8.4127	32	
33	0.05034	1.0053	28.011	138.32	2420.7	138.33	2423.4	2561.7	0.4781	8.3927	33	
34	0.05324	1.0056	26.571	142.50	2422.0	142.50	2421.0	2563.5	0.4917	8.3728	34	
35	0.05628	1.0060	25.216	146.67	2423.4	146.68	2418.6	2565.3	0.5053	8.3531	35	
36	0.05947	1.0063	23.940	150.85	2424.7	150.86	2416.2	2567.1	0.5188	8.3336	36	
38	0.06632	1.0071	21.602	159.20	2427.4	159.21	2411.5	2570.7	0.5458	8.2950	38	
40	0.07384	1.0078	19.523	167.56	2430.1	167.57	2406.7	2574.3	0.5725	8.2570	40	
45	0.09593	1.0099	15.258	188.44	2436.8	188.45	2394.8	2583.2	0.6387	8.1648	45	

**TABLE A-2** (Continued)

H <sub>2</sub> O	Temp. °C	Press. bar	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Temp. °C	
			Sat. Liquid <i>v<sub>f</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>f</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>	Sat. Vapor <i>s<sub>g</sub></i>		
	50	.1235	1.0121	12.032	209.32	2443.5	209.33	2382.7	2592.1	.7038	8.0763	50
55	.1576	1.0146	9.568	230.21	2450.1	230.23	2370.7	2600.9	.7679	7.9913	55	
60	.1994	1.0172	7.671	251.11	2456.6	251.13	2358.5	2609.6	.8312	7.9096	60	
65	.2503	1.0199	6.197	272.02	2463.1	272.06	2346.2	2618.3	.8935	7.8310	65	
70	.3119	1.0228	5.042	292.95	2469.6	292.98	2333.8	2626.8	.9549	7.7553	70	
75	.3858	1.0259	4.131	313.90	2475.9	313.93	2321.4	2635.3	1.0155	7.6824	75	
80	.4739	1.0291	3.407	334.86	2482.2	334.91	2308.8	2643.7	1.0753	7.6122	80	
85	.5783	1.0325	2.828	355.84	2488.4	355.90	2296.0	2651.9	1.1343	7.5445	85	
90	.7014	1.0360	2.361	376.85	2494.5	376.92	2283.2	2660.1	1.1925	7.4791	90	
95	.8455	1.0397	1.982	397.88	2500.6	397.96	2270.2	2668.1	1.2500	7.4159	95	
100	1.014	1.0435	1.673	418.94	2506.5	419.04	2257.0	2676.1	1.3069	7.3549	100	
110	1.433	1.0516	1.210	461.14	2518.1	461.30	2230.2	2691.5	1.4185	7.2387	110	
120	1.985	1.0603	0.8919	503.50	2529.3	503.71	2206.2	2706.3	1.5276	7.1296	120	
130	2.701	1.0697	0.6685	546.02	2539.9	546.31	2174.2	2720.5	1.6344	7.0269	130	
140	3.613	1.0797	0.5089	588.74	2550.0	589.13	2144.7	2733.9	1.7391	6.9299	140	
150	4.758	1.0905	0.3928	631.68	2559.5	632.20	2114.3	2746.5	1.8418	6.8379	150	
160	6.178	1.1020	0.3071	674.86	2568.4	675.55	2082.6	2758.1	1.9427	6.7502	160	
170	7.917	1.1143	0.2428	718.33	2576.5	719.21	2049.5	2768.7	2.0419	6.6663	170	
180	10.02	1.1274	0.1941	762.09	2583.7	763.22	2015.0	2778.2	2.1396	6.5857	180	
190	12.54	1.1414	0.1565	806.19	2590.0	807.62	1978.8	2786.4	2.2359	6.5079	190	
200	15.54	1.1565	0.1274	850.65	2595.3	852.45	1940.7	2793.2	2.3309	6.4323	200	
210	19.06	1.1726	0.1044	895.53	2599.5	897.76	1900.7	2798.5	2.4248	6.3585	210	
220	23.18	1.1900	0.08619	940.87	2602.4	943.62	1946.2	2805.8	2.5178	6.2861	220	
230	27.95	1.2088	0.07158	986.74	2603.9	990.12	1813.8	2804.0	2.6099	6.2146	230	
240	33.44	1.2291	0.05976	1033.2	2604.0	1037.3	1766.5	2803.8	2.7015	6.1437	240	
250	39.73	1.2512	0.05013	1080.4	2602.4	1085.4	1716.2	2801.5	2.7927	6.0730	250	
260	46.88	1.2755	0.04221	1128.4	2599.0	1134.4	1662.5	2796.6	2.8838	6.0019	260	
270	54.99	1.3023	0.03564	1177.4	2593.7	1184.5	1605.2	2789.7	2.9751	5.9301	270	
280	64.12	1.3321	0.03017	1227.5	2586.1	1236.0	1543.6	2779.6	3.0668	5.8571	280	
290	74.36	1.3656	0.02557	1278.9	2576.0	1289.1	1477.1	2766.2	3.1594	5.7821	290	
300	85.81	1.4036	0.02167	1332.0	2563.0	1344.0	1404.9	2749.0	3.2534	5.7045	300	
320	112.7	1.4988	0.01549	1444.6	2525.5	1461.5	1238.6	2700.1	3.			

**TABLE A-3** Properties of Saturated Water (Liquid–Vapor): Pressure Table

H <sub>2</sub> O	Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Press. bar	
			Sat. Liquid <i>v<sub>f</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>f</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>	Sat. Vapor <i>s<sub>g</sub></i>		
	0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
	0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
	0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
	0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
	0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
	0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30
	0.40	75.87	1.0265	3.993	317.53	2477.0	317.58	2319.2	2636.8	1.0259	7.6700	0.40
	0.50	81.33	1.0300	3.240	340.44	2483.9	340.49	2305.4	2645.9	1.0910	7.5939	0.50
	0.60	85.94	1.0331	2.732	359.79	2489.6	359.86	2293.6	2653.5	1.1453	7.5320	0.60
	0.70	89.95	1.0360	2.365	376.63	2494.5	376.70	2283.3	2660.0	1.1919	7.4797	0.70
	0.80	93.50	1.0380	2.087	391.58	2498.8	391.66	2274.1	2665.8	1.2329	7.4346	0.80
	0.90	96.71	1.0410	1.869	405.06	2502.6	405.15	2265.7	2670.9	1.2695	7.3949	0.90
	1.00	99.63	1.0432	1.694	417.36	2506.1	417.46	2258.0	2675.5	1.3026	7.3594	1.00
	1.50	111.4	1.0528	1.159	466.94	2519.7	467.11	2226.5	2693.6	1.4336	7.2233	1.50
	2.00	120.2	1.0605	0.8857	504.49	2529.5	504.70	2201.9	2706.7	1.5301	7.1271	2.00
	2.50	127.4	1.0672	0.7187	535.10	2537.2	535.37	2181.5	2716.9	1.6072	7.0527	2.50
	3.00	133.6	1.0732	0.6058	561.15	2543.6	561.47	2163.8	2725.3	1.6718	6.9919	3.00
	3.50	138.9	1.0786	0.5243	583.95	2546.9	584.33	2148.1	2732.4	1.7275	6.9405	3.50
	4.00	143.6	1.0836	0.4625	604.31	2553.6	604.74	2133.8	2738.6	1.7766	6.8959	4.00
	4.50	147.9	1.0882	0.4140	622.25	2557.6	623.25	2120.7	2743.9	1.8207	6.8565	4.50
	5.00	151.9	1.0926	0.3749	639.68	2561.2	640.23	2108.5	2748.7	1.8607	6.8212	5.00
	6.00	158.9	1.1006	0.3157	669.90	2567.4	670.56	2086.3	2756.8	1.9312	6.7600	6.00
	7.00	165.0	1.1080	0.2729	696.44	2572.5	697.22	2066.3	2763.5	1.9922	6.7080	7.00
	8.00	170.4	1.1148	0.2404	720.22	2576.8	721.11	2048.0	2769.1	2.0462	6.6628	8.00
	9.00	175.4	1.1212	0.2150	741.83	2580.5	742.83	2031.1	2773.9	2.0946	6.6226	9.00
	10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863	10.0
	15.0	198.3	1.1539	0.1318	843.16	2594.5	844.84	1947.3	2792.2	2.3150	6.4448	15.0
	20.0	212.4	1.1767	0.0963	906.44	2600.3	908.79	1890.7	2799.5	2.4474	6.3409	20.0
	25.0	224.0	1.1973	0.07998	959.11	2603.1	962.11	1841.0	2803.1	2.5547	6.2575	25.0
	30.0	233.9	1.2165	0.06668	1004.8	2604.1	1008.4	1795.7	2804.2	2.6457	6.1869	30.0
	35.0	242.6	1.2347	0.05707	1045.4	2603.7	1049.8	1753.7	2803.4	2.7253	6.1253	35.0
	40.0	250.4	1.2522	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7964	6.0701	40.0
	45.0	257.5	1.2692	0.04406	1116.2	2600.1	1121.9	1676.4	2798.3	2.8610	6.0199	45.0
	50.0	264.0	1.2859	0.03944	1147.8	2597.1	1154.2	1640.1	2794.3	2.9202	5.9734	50.0
	60.0	275.6	1.3187	0.03244	1205.4	2589.7	1213.4	1571.0	2784.3	3.0267	5.8892	60.0
	70.0	285.9	1.3513	0.02737	1257.6	2580.5	1267.0	1505.1	2772.1	3.1211	5.8133	70.0
	80.0	295.1	1.3842	0.02352	1305.6	2569.8	1316.6	1441.3	2758.0	3.2068	5.7432	80.0
	90.0	303.4	1.4178	0.02048	1350.5	2557.8	1363.3	1378.9	2742.1	3.2858	5.6772	90.0
	100.	311.1	1.4524	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3596	5.6141	100.
	110.	318.2	1.4886	0.01599	1433.7	2529.8	1450.1	1255.5	2705.6	3.4295	5.5527	110.

**TABLE A-3 (Continued)**

H <sub>2</sub> O	Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Press. bar	
			Sat. Liquid <i>v<sub>f</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>f</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>	Sat. Vapor <i>s<sub>g</sub></i>		
	120.	324.8	1.5267	0.01426	1473.0	2513.7	1491.3	1193.6	2684.9	3.4962	5.4924	120.
	130.	330.9	1.5671	0.01278	1511.1	2496.1	1531.5	1130.7	2662.2	3.5606	5.4323	130.
	140.	336.8	1.6107	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6232	5.3717	140.
	150.	342.2	1.6581	0.01034	1585.6	2455.5	1610.5	1000.0	2610.5	3.6848	5.3098	150.
	160.	347.4	1.7107	0.009306	1622.7	2431.7	1650.1	930.6	2580.6	3.7461	5.2455	160.
	170.	352.4	1.7702	0.008364	1660.2	2405.0	1690.3	856.9	2547.2	3.8079	5.1777	170.
	180.	357.1	1.8397	0.007489	1698.9	2374.3	1732.0	777.1	2509.1	3.8715	5.1044	180.
	190.	361.5	1.9243	0.006657	1739.9	2338.1	1776.5	688.0	2464.5	3.9388	5.0228	190.
	200.	365.8	2.036	0.005834	1785.6	2293.0	1826.3	583.4	2409.7	4.0139	4.9269	200.
	220.9	374.1	3.155	0.003155	2029.6	2029.6	2099.3	0	2099.3	4.4298	4.4298	220.9

**TABLE A-4** Properties of Superheated Water Vapor

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 0.06 bar = 0.006 MPa ( <i>T</i> <sub>sat</sub> = 36.16°C)								
<i>p</i> = 0.35 bar = 0.035 MPa ( <i>T</i> <sub>sat</sub> = 72.69°C)								
Sat.	23.739	2425.0	2567.4	8.3304	4.526	2473.0	2631.4	7.7158
80	27.132	2487.3	2650.1	8.5804	4.625	2483.7	2645.6	7.7564
120	30.219	2544.7	2726.0	8.7840	5.163	2542.4	2723.1	7.9644
160	33.302	2602.7	2802.5	8.9693	5.696	2601.2	2800.6	8.1519
200	36.383	2661.4	2879.7	9.1398	6.228	2660.4	2878.4	8.3237
240	39.462	2721.0	2957.8	9.2982	6.758	2720.3	2956.8	8.4828
280	42.540	2781.5	3036.8	9.4464	7.287	2780.9	3036.0	8.6314
320	45.618	2843.0	3116.7	9.5859	7.815	2842.5	3116.1	8.7712
360	48.696	2905.5	3197.7	9.7180	8.344	2905.1	3197.1	8.9034
400	51.774	2969.0	3279.6	9.8435	8.872	2968.6	3279.2	9.0291
440	54.851	3033.5	3362.6	9.9633	9.400	3033.2	3362.2	9.1490
500	59.467	3132.3	3489.1	10.1336	10.192	3132.1	3488.8	9.3194
<i>p</i> = 0.70 bar = 0.07 MPa ( <i>T</i> <sub>sat</sub> = 89.95°C)								
<i>p</i> = 1.0 bar = 0.10 MPa ( <i>T</i> <sub>sat</sub> = 99.63°C)								
Sat.	2.365	2494.5	2660.0	7.4797	1.694	2506.1	2675.5	7.3594
100	2.434	2509.7	2680.0	7.5341	1.696	2506.7	2676.2	7.3614
120	2.571	2539.7	2719.6	7.6375	1.793	2537.3	2716.6	7.4668
160	2.841	2599.4	2798.2	7.8279	1.984	2597.8	2796.2	7.6597
200	3.108	2659.1	2876.7	8.0012	2.172	2658.1	2875.3	7.8343
240	3.374	2719.3	2955.5	8.1611	2.359	2718.5	2954.5	7.9949
280	3.640	2780.2	3035.0	8.3162	2.546	2779.6	3034.2	8.1445
320	3.905	2842.0	3115.3	8.4504	2.732	2841.5	3114.6	8.2849
360	4.170	2904.6	3196.5	8.5828	2.917	2904.2	3195.9	8.4175
400	4.434	2968.2	3278.6	8.7086	3.103	2967.9	3278.2	8.5435
440	4.698	3032.9	3361.8	8.8286	3.288	3032.6	3361.4	8.6636
500	5.095	3131.8	3488.5	8.9991	3.565	3131.6	3488.1	8.8342
<i>p</i> = 1.5 bar = 0.15 MPa ( <i>T</i> <sub>sat</sub> = 111.37°C)								
<i>p</i> = 3.0 bar = 0.30 MPa ( <i>T</i> <sub>sat</sub> = 133.55°C)								
Sat.	1.159	2519.7	2693.6	7.2233	0.606	2543.6	2725.3	6.9919
120	1.188	2533.3	2711.4	7.2693	0.651	2587.1	2782.3	7.1276
160	1.317	2595.2	2792.8	7.4665	0.716	2650.7	2865.5	7.3115
200	1.444	2656.2	2872.9	7.6433	0.781	2713.1	2947.3	7.4774
240	1.570	2717.2	2952.7	7.8052	0.844	2775.4	3028.6	7.6299
280	1.695	2778.6	3032.8	7.9555	0.907	2838.1	3110.1	7.7722
320	1.819	2840.6	3113.5	8.0964	0.969	2901.4	3192.2	7.9061
360	1.943	2903.5	3195.0	8.2293	1.032	2965.6	3275.0	8.0330
400	2.067	2967.3	3277.4	8.3555	1.094	3030.6	3358.7	8.1538
440	2.191	3032.1	3360.7	8.4757	1.187	3130.0	3486.0	8.3251
500	2.376	3131.2	3487.6	8.6466	1.341	3300.8	3703.2	8.5892

**TABLE A-4 (Continued)**

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 5.0 bar = 0.50 MPa ( <i>T</i> <sub>sat</sub> = 151.86°C)								
<i>p</i> = 7.0 bar = 0.70 MPa ( <i>T</i> <sub>sat</sub> = 164.97°C)								
Sat.	0.3749	2561.2	2748.7	6.8213	0.2729	2572.5	2763.5	6.7080
180	0.4045	2609.7	2812.0	6.9656	0.2847	2599.8	2799.1	6.7880
200	0.4249	2642.9	2855.4	7.0592	0.2999	2634.8	2844.8	6.8865
240	0.4646	2707.6	2939.9	7.2307	0.3292	2701.8	2932.2	7.0641
280	0.5034	2771.2	3022.9	7.3865	0.3574	2766.9	3017.1	7.2233
320	0.5416	2834.7	3105.6	7.5308	0.3852	2831.3	3100.9	7.3697
360	0.5796	2898.7	3188.4	7.6660	0.4126	2895.8	3184.7	7.5063
400	0.6173	2963.2	3271.9	7.7938	0.4397	2960.9	3268.7	7.6350
440	0.6548	3028.6	3356.0	7.9152	0.4667	3026.6	3353.3	7.7571
500	0.7109	3128.4	3483.9	8.0873	0.5070	3126.8	3481.7	7.9299
600	0.8041	3299.6	3701.7	8.3522	0.5738	3298.5	3700.2	8.1956
700	0.8969	3477.5	3925.9	8.5952	0.6403	3476.6	3924.8	8.4391
<i>p</i> = 10.0 bar = 1.0 MPa ( <i>T</i> <sub>sat</sub> = 179.91°C)								
<i>p</i> = 15.0 bar = 1.5 MPa ( <i>T</i> <sub>sat</sub> = 198.32°C)								
Sat.	0.1944	2583.6	2778.1	6.5865	0.1318	2594.5	2792.2	6.4448
200	0.2060	2621.9	2827.9	6.6940	0.1325	2598.1	2796.8	6.4546
240	0.2275	2692.9	2920.4	6.8817	0.1483	2676.9	2899.3	6.6628
280	0.2480	2760.2	3008.2	7.0465	0.1627	2748.6	2992.7	6.8381
320	0.2678	2826.1	3093.9	7.1962	0.1765	2817.1	3081.9	6.9938
360	0.2873	2891.6	3178.9	7.3349	0.1899	2884.4	3169.2	7.1363
400	0.3066	2957.3	3263.9	7.4651	0.2030	2951.3	3255.8	7.2690
440	0.3257	3023.6	3349.3	7.5883	0.2160	3018.5	3342.5	7.3940
500	0.3541	3124.4	3478.5	7.7622	0.2352	3120.3	3473.1	7.5698
540	0.3729	3192.6	3565.6	7.8720	0.2478	3189.1	3560.9	7.6805
600	0.4011	3296.8	3697.9	8.0290	0.2668	3293.9	3694.0	7.8385
640	0.4198	3367.4	3787.2	8.1290	0.2793	3364.8	3783.8	7.9391
<i>p</i> = 20.0 bar = 2.0 MPa ( <i>T</i> <sub>sat</sub> = 212.42°C)								
<i>p</i> = 30.0 bar = 3.0 MPa ( <i>T</i> <sub>sat</sub> = 233.90°C)								
Sat.	0.0996	2600.3	2799.5	6.3409	0.0667	2604.1	2804.2	6.1869
240	0.1085	2659.6	2876.5	6.4952	0.0682	2619.7	2824.3	6.2265
280	0.1200	2736.4	2976.4	6.6828	0.0771	2709.9	2941.3	6.4462
320	0.1308	2807.9	3069.5	6.8452	0.0850	2788.4	3043.4	6.6245
360	0.1411	2877.0	3159.3	6.9917	0.0923	2861.7	3138.7	6.7801
400	0.1512	2945.2	3247.6	7.1271	0.0994	2932.8	3230.9	6.9212
440	0.1611	3013.4	3335.5	7.2540	0.1062	3002.9	3321.5	7.0520
500	0.1757	3116.2	3467.6	7.4317	0.1162	3108.0	3456.5	7.2338
540	0.1853	3185.6	3556.1	7.5434	0.1227	3178.4	3546.6	7.3474
600	0.1996	3290.9	3690.1	7.7024	0.1324	3285.0	3682.3	7.5085
640	0.2091	3362.2	3780.4	7.8035	0.1388	3357.0	3773.5	7.6106
700	0.2232	3470.9	3917.4	7.9487	0.1484	3466.5	3911.7	7.7571

**TABLE A-4** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 40 bar = 4.0 MPa ( <i>T</i> <sub>sat</sub> = 250.4°C)								
<i>p</i> = 60 bar = 6.0 MPa ( <i>T</i> <sub>sat</sub> = 275.64°C)								
Sat.	0.04978	2602.3	2801.4	6.0701	0.03244	2589.7	2784.3	5.8892
280	0.05546	2680.0	2901.8	6.2568	0.03317	2605.2	2804.2	5.9252
320	0.06199	2767.4	3015.4	6.4553	0.03876	2720.0	2952.6	6.1846
360	0.06788	2845.7	3117.2	6.6215	0.04331	2811.2	3071.1	6.3782
400	0.07341	2919.9	3213.6	6.7690	0.04739	2892.9	3177.2	6.5408
440	0.07872	2992.2	3307.1	6.9041	0.05122	2970.0	3277.3	6.6853
500	0.08643	3099.5	3445.3	7.0901	0.05665	3082.2	3422.2	6.8803
540	0.09145	3171.1	3536.9	7.2056	0.06015	3156.1	3517.0	6.9999
600	0.09885	3279.1	3674.4	7.3688	0.06525	3266.9	3658.4	7.1677
640	0.1037	3351.8	3766.6	7.4720	0.06859	3341.0	3752.6	7.2731
700	0.1110	3462.1	3905.9	7.6198	0.07352	3453.1	3894.1	7.4234
740	0.1157	3536.6	3999.6	7.7141	0.07677	3528.3	3989.2	7.5190
<i>p</i> = 80 bar = 8.0 MPa ( <i>T</i> <sub>sat</sub> = 295.06°C)								
<i>p</i> = 100 bar = 10.0 MPa ( <i>T</i> <sub>sat</sub> = 311.06°C)								
Sat.	0.02352	2569.8	2758.0	5.7432	0.01803	2544.4	2724.7	5.6141
320	0.02682	2662.7	2877.2	5.9489	0.01925	2588.8	2781.3	5.7103
360	0.03089	2772.7	3019.8	6.1819	0.02331	2729.1	2962.1	6.0060
400	0.03432	2863.8	3138.3	6.3634	0.02641	2832.4	3096.5	6.2120
440	0.03742	2946.7	3246.1	6.5190	0.02911	2922.1	3213.2	6.3805
480	0.04034	3025.7	3348.4	6.6586	0.03160	3005.4	3321.4	6.5282
520	0.04313	3102.7	3447.7	6.7871	0.03394	3085.6	3425.1	6.6622
560	0.04582	3178.7	3545.3	6.9072	0.03619	3164.1	3526.0	6.7864
600	0.04845	3254.4	3642.0	7.0206	0.03837	3241.7	3625.3	6.9029
640	0.05102	3330.1	3738.3	7.1283	0.04048	3318.9	3723.7	7.0131
700	0.05481	3443.9	3882.4	7.2812	0.04358	3434.7	3870.5	7.1687
740	0.05729	3520.4	3978.7	7.3782	0.04560	3512.1	3968.1	7.2670
<i>p</i> = 120 bar = 12.0 MPa ( <i>T</i> <sub>sat</sub> = 324.75°C)								
<i>p</i> = 140 bar = 14.0 MPa ( <i>T</i> <sub>sat</sub> = 336.75°C)								
Sat.	0.01426	2513.7	2684.9	5.4924	0.01149	2476.8	2637.6	5.3717
360	0.01811	2678.4	2895.7	5.8361	0.01422	2617.4	2816.5	5.6602
400	0.02108	2798.3	3051.3	6.0747	0.01722	2760.9	3001.9	5.9448
440	0.02355	2896.1	3178.7	6.2586	0.01954	2868.6	3142.2	6.1474
480	0.02576	2984.4	3293.5	6.4154	0.02157	2962.5	3264.5	6.3143
520	0.02781	3068.0	3401.8	6.5555	0.02343	3049.8	3377.8	6.4610
560	0.02977	3149.0	3506.2	6.6840	0.02517	3133.6	3486.0	6.5941
600	0.03164	3228.7	3608.3	6.8037	0.02683	3215.4	3591.1	6.7172
640	0.03345	3307.5	3709.0	6.9164	0.02843	3296.0	3694.1	6.8326
700	0.03610	3425.2	3858.4	7.0749	0.03075	3415.7	3846.2	6.9939
740	0.03781	3503.7	3957.4	7.1746	0.03225	3495.2	3946.7	7.0952

**TABLE A-4** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 160 bar = 16.0 MPa ( <i>T</i> <sub>sat</sub> = 347.44°C)								
<i>p</i> = 180 bar = 18.0 MPa ( <i>T</i> <sub>sat</sub> = 357.06°C)								
Sat.	0.00931	2431.7	2580.6	5.2455	0.00749	2374.3	2509.1	5.1044
360	0.01105	2539.0	2715.8	5.4614	0.00809	2418.9	2564.5	5.1922
400	0.01426	2719.4	2947.6	5.8175	0.01190	2672.8	2887.0	5.6887
440	0.01652	2839.4	3103.7	6.0429	0.01414	2808.2	3062.8	5.9428
480	0.01842	2939.7	3234.4	6.2215	0.01596	2915.9	3203.2	6.1345
520	0.02013	3031.1	3353.3	6.3752	0.01757	3011.8	3378.0	6.2960
560	0.02172	3117.8	3465.4	6.5132	0.01904	3101.7	3444.4	6.4392
600	0.02323	3201.8	3573.5	6.6399	0.02042	3188.0	3555.6	6.5696
640	0.02467	3284.2	3678.9	6.7580	0.02174	3272.3	3663.6	6.6905
700	0.02674	3406.0	3833.9	6.9224	0.02362	3396.3	3821.5	6.8580
740	0.02808	3486.7	3935.9	7.0251	0.02483	3478.0	3925.0	6.9623
<i>p</i> = 200 bar = 20.0 MPa ( <i>T</i> <sub>sat</sub> = 365.81°C)								
<i>p</i> = 240 bar = 24.0 MPa								
Sat.	0.00583	2293.0	2409.7	4.9269	0.00673	2477.8	2639.4	5.2393
400	0.00994	2619.3	2818.1	5.5540	0.00929	2700.6	2923.4	5.6506
440	0.01222	2774.9	3019.4	5.8450	0.01366	3051.1	3379.0	6.2448
480	0.01399	2891.2	3170.8	6.0518	0.01100	2838.3	3102.3	5.8950
520	0.01551	2992.0	3302.2	6.2218	0.01241	2950.5	3248.5	6.0842
560	0.01689	3085.2	3423.0	6.3705	0.01739	3366.4	3783.8	6.6947
600	0.01818	3174.0	3537.6	6.5048	0.01481	3145.2	3500.7	6.3875
640	0.01940	3260.2	3648.1	6.6286	0.01588	3235.5	3616.7	6.5174
700	0.02113	3386.4	3809.0	6.7993	0.01739	3366.4	3783.8	6.6947
740	0.02224	3469.3	3914.1	6.9052	0.01835	3451.7	3892.1	6.8038
800	0.02385	3592.7	4069.7	7.0544	0.01974	3578.0	4051.6	6.9567
<i>p</i> = 280 bar = 28.0 MPa								
<i>p</i> = 320 bar = 32.0 MPa								
400	0.00383	2223.5	2330.7	4.7494	0.00236	1980.4	2055.9	4.3239
440	0.00712	2613.2	2812.6	5.4494	0.00544	2509.0	2683.0	5.2327
480	0.00885	2780.8	3028.5	5.7446	0.00722	2718.1	2949.2	5.5968
520	0.01020	2906.8	3192.3	5.9566	0.00853	2860.7	3133.7	5.8357
560	0.01136	3015.7	3333.7	6.1307	0.00963	2979.0	3287.2	6.0246
600	0.01241	3115.6	3463.0	6.2823	0.01061	3085.3	3424.6	6.1858
640	0.01338	3210.3	3584.8	6.4187	0.01150	3184.5	3552.5	6.3290
700	0.01473	3346.1	3758.4	6.6029	0.01273	3325.4	3732.8	6.5203
740	0.01558	3433.9	3870.0	6.7153	0.01350	3415.9	3847.8	6.6361
800	0.01680	3563.1	4033.4	6.8720	0.01460	3548.0	4015.1	6.7966
900	0.01873	3774.3	4298.8	7.1084	0.01633	3762.7	4285.1	7.0372

**TABLE A-5** Properties of Compressed Liquid Water

<i>T</i> °C	<i>v</i> × 10 <sup>3</sup> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> × 10 <sup>3</sup> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 25 bar = 2.5 MPa ( <i>T</i> <sub>sat</sub> = 223.99°C)								
20	1.006	83.80	86.30	.2961	.9995	83.65	88.65	.2956
40	1.0067	167.25	169.77	.5715	1.0056	166.95	171.97	.5705
80	1.0280	334.29	336.86	1.0737	1.0268	333.72	338.85	1.0720
100	1.0423	418.24	420.85	1.3050	1.0410	417.52	422.72	1.3030
140	1.0784	587.82	590.52	1.7369	1.0768	586.76	592.15	1.7343
180	1.1261	761.16	763.97	2.1375	1.1240	759.63	765.25	2.1341
200	1.1555	849.9	852.8	2.3294	1.1530	848.1	853.9	2.3255
220	1.1898	940.7	943.7	2.5174	1.1866	938.4	944.4	2.5128
Sat.	1.1973	959.1	962.1	2.5546	1.2859	1147.8	1154.2	2.9202
<i>p</i> = 75 bar = 7.5 MPa ( <i>T</i> <sub>sat</sub> = 290.59°C)								
20	.9984	83.50	90.99	.2950	.9972	83.36	93.33	.2945
40	1.0045	166.64	174.18	.5696	1.0034	166.35	176.38	.5686
80	1.0256	333.15	340.84	1.0704	1.0245	332.59	342.83	1.0688
100	1.0397	416.81	424.62	1.3011	1.0385	416.12	426.50	1.2992
140	1.0752	585.72	593.78	1.7317	1.0737	584.68	595.42	1.7292
180	1.1219	758.13	766.55	2.1308	1.1199	756.65	767.84	2.1275
220	1.1835	936.2	945.1	2.5083	1.1805	934.1	945.9	2.5039
260	1.2696	1124.4	1134.0	2.8763	1.2645	1121.1	1133.7	2.8699
Sat.	1.3677	1282.0	1292.2	3.1649	1.4524	1393.0	1407.6	3.3596
<i>p</i> = 150 bar = 15.0 MPa ( <i>T</i> <sub>sat</sub> = 342.24°C)								
20	.9950	83.06	97.99	.2934	.9928	82.77	102.62	.2923
40	1.0013	165.76	180.78	.5666	.9992	165.17	185.16	.5646
80	1.0222	331.48	346.81	1.0656	1.0199	330.40	350.80	1.0624
100	1.0361	414.74	430.28	1.2955	1.0337	413.39	434.06	1.2917
140	1.0707	582.66	598.72	1.7242	1.0678	580.69	602.04	1.7193
180	1.1159	753.76	770.50	2.1210	1.1120	750.95	773.20	2.1147
220	1.1748	929.9	947.5	2.4953	1.1693	925.9	949.3	2.4870
260	1.2550	1114.6	1133.4	2.8576	1.2462	1108.6	1133.5	2.8459
300	1.3770	1316.6	1337.3	3.2260	1.3596	1306.1	1333.3	3.2071
Sat.	1.6581	1585.6	1610.5	3.6848	2.036	1785.6	1826.3	4.0139
<i>p</i> = 250 bar = 25 MPa								
20	.9907	82.47	107.24	.2911	.9886	82.17	111.84	.2899
40	.9971	164.60	189.52	.5626	.9951	164.04	193.89	.5607
100	1.0313	412.08	437.85	1.2881	1.0290	410.78	441.66	1.2844
200	1.1344	834.5	862.8	2.2961	1.1302	831.4	865.3	2.2893
300	1.3442	1296.6	1330.2	3.1900	1.3304	1287.9	1327.8	3.1741
<i>p</i> = 300 bar = 30.0 MPa								
20	.9907	82.47	107.24	.2911	.9886	82.17	111.84	.2899
40	.9971	164.60	189.52	.5626	.9951	164.04	193.89	.5607
100	1.0313	412.08	437.85	1.2881	1.0290	410.78	441.66	1.2844

**TABLE A-6** Properties of Saturated Water (Solid-Vapor): Temperature Table

Temp. °C	Pressure kPa	Specific Volume m <sup>3</sup> /kg				Internal Energy kJ/kg				Enthalpy kJ/kg				Entropy kJ/kg · K			
		Sat. Solid <i>v</i> <sub>l</sub> × 10 <sup>3</sup>	Sat. Vapor <i>v</i> <sub>g</sub>	Sat. Solid <i>u</i> <sub>l</sub>	Sat. Vapor <i>u</i> <sub>g</sub>	Sat. Solid <i>h</i> <sub>l</sub>	Sat. Vapor <i>h</i> <sub>g</sub>	Subl. <i>h</i> <sub>lg</sub>	Subl. <i>h</i> <sub>g</sub>	Sat. Solid <i>s</i> <sub>l</sub>	Sat. Vapor <i>s</i> <sub>g</sub>	Sat. Solid <i>s</i> <sub>fg</sub>	Sat. Vapor <i>s</i> <sub>fg</sub>	Sat. Vapor <i>s</i> <sub>fg</sub>			
.01	.6113	1.0908	206.1	−333.40	2708.7	2375.3	−333.40	2834.8	2501.4	−1.221	10.378	9.156					
0	.6108	1.0908	206.3	−333.43	2708.8	2375.3	−333.43	2834.8	2501.3	−1.221	10.378	9.157					
−2	.5176	1.0904	241.7	−337.62	2710.2	2372.6	−337.62	2835.3	2497.7	−1.237	10.456	9.219					
−4	.4375	1.0901	283.8	−341.78	2711.6	2369.8	−341.78	2835.7	2494.0	−1.253	10.536	9.283					
−6	.3689	1.0898	334.2	−345.91	2712.9	2367.0	−345.91	2836.2	2490.3	−1.268	10.616	9.348					
−8	.3102	1.0894	394.4	−350.02	2714.2	2364.2	−350.02	2836.6	2486.6	−1.284	10.698	9.414					
−10	.2602	1.0891	466.7	−354.09	2715.5	2361.4	−354.09	2837.0	2482.9	−1.299	10.781	9.481					
−12	.2176	1.0888	553.7	−358.14	2716.8	2358.7	−358.14	2837.3	2479.2	−1.315	10.865	9.550					
−14	.1815	1.0884	658.8	−362.15	2718.0	2355.9	−362.15	2837.6	2475.5	−1.331	10.950	9.619					
−16	.1510	1.0881	786.0	−366.14	2719.2	2353.1	−366.14	2837.9	2471.8	−1.346	11.036	9.690					
−18	.1252	1.0878	940.5	−370.10	2720.4	2350.3	−370.10	2838.2	2468.1	−1.362	11.123	9.762					
−20	.1035	1.0874	1128.6	−374.03	2721.6	2347.5	−374.03	2838.4	2464.3	−1.377	11.212	9.835					
−22	.0853	1.0871	1358.4	−377.93	2722.7	2344.7	−377.93	2838.6	2460.6	−1.393	11.302	9.909					
−24	.0701	1.0868	1640.1	−381.80	2723.7	2342.0	−381.80	2838.7	2456.9	−1.408	11.394	9.985					
−26	.0574	1.0864	1986.4	−385.64	2724.8	2339.2	−385.64	2838.9	2453.2	−1.424	11.486	10.062					
−28	.0469	1.0861	241.37	−389.45	2725.8	2336.4	−389.45	2839.0	2449.5	−1.439	11.580	10.141					
−30	.0381	1.0858	294.3	−393.23	2726.8	2336.6	−393.23	2839.0	2445.8	−1.455	11.676	10.221					
−32	.0309	1.0854	3600	−396.98	2727.8	2330.8	−396.98	2839.1	2442.1	−1.471	11.773	10.303					
−34	.0250	1.0851	4419	−400.71	2728.7	2328.0	−400.71	2839.1	2438.4	−1.486	11.872	10.386					
−36	.0201	1.0848	5444	−404.40	2729.6	2325.2	−404.40	2839.1	2434.7	−1.501	11.972	10.470					
−38	.0161	1.0844	6731	−408.06	2730.5	2322.4	−408.06	2839.0	2430.9	−1.517	12.073	10.556					
−40	.0129	1.0841	8354	−411.70	2731.3	2319.6	−411.70	2838.9	2427.2	−1.532	12.176	10.644					

Source: J. H. Keenan, F. G. Keyes, P. G. Hill, and J. G. Moore, *Steam Tables*, Wiley, New York, 1978.

**TABLE A-7** Properties of Saturated Refrigerant 22 (Liquid–Vapor): Temperature Table

Temp. °C	Press. bar	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Temp. °C	
		Sat. Liquid $v_l \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Evap. $h_{fg}$	Sat. Vapor $h_g$	Sat. Liquid $s_f$		
-60	0.3749	0.6833	0.5370	-21.57	203.67	-21.55	245.35	223.81	-0.0964	1.0547	-60
-50	0.6451	0.6966	0.3239	-10.89	207.70	-10.85	239.44	228.60	-0.0474	1.0256	-50
-45	0.8290	0.7037	0.2564	-5.50	209.70	-5.44	236.39	230.95	-0.0235	1.0126	-45
-40	1.0522	0.7109	0.2052	-0.07	211.68	0.00	233.27	233.27	0.0000	1.0005	-40
-36	1.2627	0.7169	0.1730	4.29	213.25	4.38	230.71	235.09	0.0186	0.9914	-36
-32	1.5049	0.7231	0.1468	8.68	214.80	8.79	228.10	236.89	0.0369	0.9828	-32
-30	1.6389	0.7262	0.1355	10.88	215.58	11.00	226.77	237.78	0.0460	0.9787	-30
-28	1.7819	0.7294	0.1252	13.09	216.34	13.22	225.43	238.66	0.0551	0.9746	-28
-26	1.9345	0.7327	0.1159	15.31	217.11	15.45	224.08	239.53	0.0641	0.9707	-26
-22	2.2698	0.7393	0.0997	19.76	218.62	19.92	221.32	241.24	0.0819	0.9631	-22
-20	2.4534	0.7427	0.0926	21.99	219.37	22.17	219.91	242.09	0.0908	0.9595	-20
-18	2.6482	0.7462	0.0861	24.23	220.11	24.43	218.49	242.92	0.0996	0.9559	-18
-16	2.8547	0.7497	0.0802	26.48	220.85	26.69	217.05	243.74	0.1084	0.9525	-16
-14	3.0733	0.7533	0.0748	28.73	221.58	28.97	215.59	244.56	0.1171	0.9490	-14
-12	3.3044	0.7569	0.0698	31.00	222.30	31.25	214.11	245.36	0.1258	0.9457	-12
-10	3.5485	0.7606	0.0652	33.27	223.02	33.54	212.62	246.15	0.1345	0.9424	-10
-8	3.8062	0.7644	0.0610	35.54	223.73	35.83	211.10	246.93	0.1431	0.9392	-8
-6	4.0777	0.7683	0.0571	37.83	224.43	38.14	209.56	247.70	0.1517	0.9361	-6
-4	4.3638	0.7722	0.0535	40.12	225.13	40.46	208.00	248.45	0.1602	0.9330	-4
-2	4.6647	0.7762	0.0501	42.42	225.82	42.78	206.41	249.20	0.1688	0.9300	-2
0	4.9811	0.7803	0.0470	44.73	226.50	45.12	204.81	249.92	0.1773	0.9271	0
2	5.3133	0.7844	0.0442	47.04	227.17	47.46	203.18	250.64	0.1857	0.9241	2
4	5.6619	0.7887	0.0415	49.37	227.83	49.82	201.52	251.34	0.1941	0.9213	4
6	6.0275	0.7930	0.0391	51.71	228.48	52.18	199.84	252.03	0.2025	0.9184	6
8	6.4105	0.7974	0.0368	54.05	229.13	54.56	198.14	252.70	0.2109	0.9157	8
10	6.8113	0.8020	0.0346	56.40	229.76	56.95	196.40	253.35	0.2193	0.9129	10
12	7.2307	0.8066	0.0326	58.77	230.38	59.35	194.64	253.99	0.2276	0.9102	12
16	8.1268	0.8162	0.0291	63.53	231.59	64.19	191.02	255.21	0.2442	0.9048	16
20	9.1030	0.8263	0.0259	68.33	232.76	69.09	187.28	256.37	0.2607	0.8996	20
24	10.164	0.8369	0.0232	73.19	233.87	74.04	183.40	257.44	0.2772	0.8944	24
28	11.313	0.8480	0.0208	78.09	234.92	79.05	179.37	258.43	0.2936	0.8893	28
32	12.556	0.8599	0.0186	83.06	235.91	84.14	175.18	259.32	0.3101	0.8842	32
36	13.897	0.8724	0.0168	88.08	236.83	89.29	170.82	260.11	0.3265	0.8790	36
40	15.341	0.8858	0.0151	93.18	237.66	94.53	166.25	260.79	0.3429	0.8738	40
45	17.298	0.9039	0.0132	99.65	238.59	101.21	160.24	261.46	0.3635	0.8672	45
50	19.433	0.9238	0.0116	106.26	239.34	108.06	153.84	261.90	0.3842	0.8603	50
60	24.281	0.9705	0.0089	120.00	240.24	122.35	139.61	261.96	0.4264	0.8455	60

Source: Tables A-7 through A-9 are calculated based on equations from A. Kamei and S. W. Beyerlein, "A Fundamental Equation for Chlorodifluoromethane (R-22)," *Fluid Phase Equilibria*, Vol. 80, No. 11, 1992, pp. 71–86.

**TABLE A-8** Properties of Saturated Refrigerant 22 (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Press. bar	
		Sat. Liquid $v_l \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Sat. Vapor $h_g$	Sat. Liquid $s_f$	Sat. Vapor $s_g$		
0.40	-58.86	0.6847	0.5056	-20.36	204.13	-20.34	244.69	224.36	-0.0907	1.0512	0.40
0.50	-54.83	0.6901	0.4107	-16.07	205.76	-16.03	242.33	226.30	-0.0709	1.0391	0.50
0.60	-51.40	0.6947	0.3466	-12.39	207.14	-12.35	240.28	227.93	-0.0542	1.0294	0.60
0.70	-48.40	0.6989	0.3002	-9.17	208.34	-9.12	238.47	229.35	-0.0397	1.0213	0.70
0.80	-45.73	0.7026	0.2650	-6.28	209.41	-6.23	236.84	230.61	-0.0270	1.0144	0.80
0.90	-43.30	0.7061	0.2374	-3.66	210.37	-3.60	235.34	231.74	-0.0155	1.0084	0.90
1.00	-41.09	0.7093	0.2152	-1.26	211.25	-1.19	233.95	232.77	-0.0051	1.0031	1.00
1.25	-36.23	0.7166	0.1746	4.04	213.16	4.13	230.86	234.99	0.0175	0.9919	1.25
1.50	-32.08	0.7230	0.1472	8.60	214.77	8.70	228.15	236.86	0.0366	0.9830	1.50
1.75	-28.44	0.7287	0.1274	12.61	216.18	12.74	225.73	238.47	0.0531	0.9755	1.75
2.00	-25.18	0.7340	0.1123	16.22	217.42	16.37	223.52	239.88	0.0678	0.9691	2.00
2.25	-22.22	0.7389	0.1005	19.51	218.53	19.67	221.47	241.15	0.0809	0.9636	2.25
2.50	-19.51	0.7436	0.0910	22.54	219.55	22.72	219.57	242.29	0.0930	0.9586	2.50
2.75	-17.00	0.7479	0.0831	25.36	220.48	25.56	217.77	243.33	0.1040	0.9542	2.75
3.00	-14.66	0.7521	0.0765	27.99	221.34	28.22	216.07	244.29	0.1143	0.9502	3.00
3.25	-12.46	0.7561	0.0709	30.47	222.13	30.72	214.46	245.18	0.1238	0.9465	3.25
3.50	-10.39	0.7599	0.0661	32.82	222.88	33.09	212.91	246.00	0.1328	0.9431	3.50
3.75	-8.43	0.7636	0.0618	35.06	223.58	35.34	211.42	246.77	0.1413	0.9399	3.75
4.00	-6.56	0.7672	0.0581	37.18	224.24	37.49	209.99	247.48	0.1493	0.9370	4.00
4.25	-4.78	0.7706	0.0548	39.22	224.86	39.55	208.61	248.16	0.1569	0.9342	4.25
4.50	-3.08	0.7740	0.0519	41.17	225.45	41.52	207.27	248.80	0.1642	0.9316	4.50
4.75	-1.45	0.7773	0.0492	43.05	226.00	43.42	205.98	249.40	0.1711	0.9292	4.75
5.00	0.12	0.7805	0.0469	44.86	226.54	45.25	204.71	249.97	0.1777	0.9269	5.00
5.25	1.63	0.7836	0.0447	46.61	227.04	47.02	203.48	250.51	0.1841	0.9247	5.25
5.50	3.08	0.7867	0.0427	48.30	227.53	48.74	202.28	251.02	0.1903	0.9226	5.50
5.75	4.49	0.7897	0.0409	49.94	227.99	50.40	201.11	251.51	0.1962	0.9206	5.75
6.00	5.85	0.7927	0.0392	51.53	228.44	52.01	199.97	251.98	0.2019	0.9186	6.00
7.00	10.91	0.8041	0.0337	57.48	230.04	58.04	195.60	253.64	0.2231	0.9117	7.00
8.00	15.45	0.8149	0.0295	62.88	231.43	63.53	191.52	255.05	0.2419	0.9056	8.00
9.00	19.59	0.8252	0.0262	67.84	232.64	68.59	187.67	256.25	0.2591	0.9001	9.00
10.00	23.40	0.8352	0.0236	72.46	233.71	73.30	183.99	257.28	0.2748	0.8952	10.00
12.00	30.25	0.8546	0.0195	80.87	235.48	81.90	177.04	258.94	0.3029	0.8864	12.00
14.00	36.29	0.8734	0.0166	88.45	236.89	89.68	170.49	260.16	0.3277	0.8786	14.00
16.00	41.73	0.8919	0.0144	95.41	238.00	96.83	164.21	261.04	0.3500	0.8715	16.00
18.00	46.69	0.9104	0.0127	1							

**TABLE A-9** Properties of Superheated Refrigerant 22 Vapor

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 0.4 bar = 0.04 MPa ( <i>T</i> <sub>sat</sub> = -58.86°C)								
<i>p</i> = 0.6 bar = 0.06 MPa ( <i>T</i> <sub>sat</sub> = -51.40°C)								
Sat.	0.50559	204.13	224.36	1.0512	0.34656	207.14	227.93	1.0294
-55	0.51532	205.92	226.53	1.0612				
-50	0.52787	208.26	229.38	1.0741	0.34895	207.80	228.74	1.0330
-45	0.54037	210.63	232.24	1.0868	0.35747	210.20	231.65	1.0459
-40	0.55284	213.02	235.13	1.0993	0.36594	212.62	234.58	1.0586
-35	0.56526	215.43	238.05	1.1117	0.37437	215.06	237.52	1.0711
-30	0.57766	217.88	240.99	1.1239	0.38277	217.53	240.49	1.0835
-25	0.59002	220.35	243.95	1.1360	0.39114	220.02	243.49	1.0956
-20	0.60236	222.85	246.95	1.1479	0.39948	222.54	246.51	1.1077
-15	0.61468	225.38	249.97	1.1597	0.40779	225.08	249.55	1.1196
-10	0.62697	227.93	253.01	1.1714	0.41608	227.65	252.62	1.1314
-5	0.63925	230.52	256.09	1.1830	0.42436	230.25	255.71	1.1430
0	0.65151	233.13	259.19	1.1944	0.43261	232.88	258.83	1.1545
<i>p</i> = 0.8 bar = 0.08 MPa ( <i>T</i> <sub>sat</sub> = -45.73°C)								
<i>p</i> = 1.0 bar = 0.10 MPa ( <i>T</i> <sub>sat</sub> = -41.09°C)								
Sat.	0.26503	209.41	230.61	1.0144	0.21518	211.25	232.77	1.0031
-45	0.26597	209.76	231.04	1.0163				
-40	0.27245	212.21	234.01	1.0292	0.21633	211.79	233.42	1.0059
-35	0.27890	214.68	236.99	1.0418	0.22158	214.29	236.44	1.0187
-30	0.28530	217.17	239.99	1.0543	0.22679	216.80	239.48	1.0313
-25	0.29167	219.68	243.02	1.0666	0.23197	219.34	242.54	1.0438
-20	0.29801	222.22	246.06	1.0788	0.23712	221.90	245.61	1.0560
-15	0.30433	224.78	249.13	1.0908	0.24224	224.48	248.70	1.0681
-10	0.31062	227.37	252.22	1.1026	0.24734	227.08	251.82	1.0801
-5	0.31690	229.98	255.34	1.1143	0.25241	229.71	254.95	1.0919
0	0.32315	232.62	258.47	1.1259	0.25747	232.36	258.11	1.1035
5	0.32939	235.29	261.64	1.1374	0.26251	235.04	261.29	1.1151
10	0.33561	237.98	264.83	1.1488	0.26753	237.74	264.50	1.1265
<i>p</i> = 1.5 bar = 0.15 MPa ( <i>T</i> <sub>sat</sub> = -32.08°C)								
<i>p</i> = 2.0 bar = 0.20 MPa ( <i>T</i> <sub>sat</sub> = -25.18°C)								
Sat.	0.14721	214.77	236.86	0.9830	0.11232	217.42	239.88	0.9691
-30	0.14872	215.85	238.16	0.9883				
-25	0.15232	218.45	241.30	1.0011	0.11242	217.51	240.00	0.9696
-20	0.15588	221.07	244.45	1.0137	0.11520	220.19	243.23	0.9825
-15	0.15941	223.70	247.61	1.0260	0.11795	222.88	246.47	0.9952
-10	0.16292	226.35	250.78	1.0382	0.12067	225.58	249.72	1.0076
-5	0.16640	229.02	253.98	1.0502	0.12336	228.30	252.97	1.0199
0	0.16987	231.70	257.18	1.0621	0.12603	231.03	256.23	1.0310
5	0.17331	234.42	260.41	1.0738	0.12868	233.78	259.51	1.0438
10	0.17674	237.15	263.66	1.0854	0.13132	236.54	262.81	1.0555
15	0.18015	239.91	266.93	1.0968	0.13393	239.33	266.12	1.0671
20	0.18355	242.69	270.22	1.1081	0.13653	242.14	269.44	1.0786
25	0.18693	245.49	273.53	1.1193	0.13912	244.97	272.79	1.0899

**TABLE A-9 (Continued)**

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	
<i>p</i> = 2.5 bar = 0.25 MPa ( <i>T</i> <sub>sat</sub> = -19.51°C)									
<i>p</i> = 3.0 bar = 0.30 MPa ( <i>T</i> <sub>sat</sub> = -14.66°C)									
Sat.	0.09097	219.55	242.29	0.9586		0.07651	221.34	244.29	0.9502
-15	0.09303	222.03	245.29	0.9703		0.07833	223.96	247.46	0.9623
-10	0.09528	224.79	248.61	0.9831		0.08025	226.78	250.86	0.9751
-5	0.09751	227.55	251.93	0.9956		0.08214	229.61	254.25	0.9876
0	0.09971	230.33	255.26	1.0078		0.08400	232.44	257.64	0.9999
5	0.10189	233.12	258.59	1.0199		0.08660	235.66	261.64	1.0157
10	0.10405	235.92	261.93	1.0318		0.08858	238.28	264.44	1.0239
15	0.10619	238.74	265.29	1.0436		0.09076	241.14	267.85	1.0357
20	0.10831	241.58	268.66	1.0552		0.09294	244.01	270.50	1.0472
25	0.11043	244.44	272.04	1.0666		0.09512	246.89	274.72	1.0587
30	0.11253	247.31	275.44	1.0779		0.09730	249.80	278.17	1.0700
35	0.11461	250.21	278.86	1.0891		0.09948	251.72	280.28	1.0804
40	0.11669	253.13	282.30	1.1002		0.07282	254.70	283.83	1.0616
<i>p</i> = 3.5 bar = 0.35 MPa ( <i>T</i> <sub>sat</sub> = -10.39°C)									
<i>p</i> = 4.0 bar = 0.40 MPa ( <i>T</i> <sub>sat</sub> = -6.56°C)									
Sat.	0.06605	222.88	246.00	0.9431		0.05812	224.24	247.48	0.9370
-10	0.06619	223.10	246.27	0.9441		0.05860	225.16	248.60	0.9411
-5	0.06789	225.99	249.75	0.9572		0.06011	228.09	252.14	0.9542
0	0.06956	228.86	253.21	0.9700		0.06160	231.02	225.66	0.9670
5	0.07121	231.74	256.67	0.9825		0.06306	233.95	259.18	0.9795
10	0.07284	234.63	260.12	0.9948		0.07450	236.89	262.69	0.9918
15	0.07444	237.52	263.57	1.0069		0.07672	240.73	273.22	1.0274
20	0.07603	240.42	267.03	1.0188		0.07810	248.71	276.75	1.0390
25	0.07760	243.34	270.50	1.0305		0.07948	251.70	280.28	1.0504
30	0.07916	246.27	273.97	1.0421		0.08186	254.73	277.22	1.0724
35	0.08070	249.22	277.46	1.0535		0.08424	258.71	281.68	1.0803
40	0.08224	252.18	280.97	1.0648		0.08662	261.70	285.00	1.0923
45	0.08376	255.17	284.48	1.0759		0.08900	264.70	288.33	1.1041
<i>p</i> = 4.5 bar = 0.45 MPa ( <i>T</i> <sub>sat</sub> = -3.08°C)									
<i>p</i> = 5.0 bar = 0.50 MPa ( <i>T</i> <sub>sat</sub> = 0.12°C)									
Sat.	0.05189	225.45	248.80	0.9316		0.04686	226.54	249.97	0.9269
0	0.05275	227.29	251.03	0.9399		0.04810	229.52	253.57	0.9399
5	0.05411	230.28	254.63	0.9529		0.05044	232.50	257.22	0.9530
10	0.05545	233.26	258.21	0.9657		0.05278	235.57	260.85	0.9657
15	0.05676	236.24	261.78	0.9782		0.05512	238.59	264.47	0.9781
20	0.05805	239.22	265.34	0.9904		0.05746	241.61	268.07	0.9903
25	0.05933	242.20	268.90	1.0025		0.05980	244.63	271.68	1.0023
30	0.06059	245.19	272.46	1.0143		0.06214	247.66	275.28	1.0141
35	0.06184	248.19	276.02	1.0259		0.06452	250.70	280.89	1.0257
40	0.06308	251.20	279.59	1.0374		0.06686	253.76	282.50	1.0371
45	0.06430	254.23	283.17	1.0488		0.06924	256.82	286.12	1.0484
50	0.06552	257.28	286.76	1.0600		0.07162	259.90	289.75	1.0595

TABLE A-9 (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 5.5 bar = 0.55 MPa ( <i>T</i> <sub>sat</sub> = 3.08°C)								
<i>p</i> = 6.0 bar = 0.60 MPa ( <i>T</i> <sub>sat</sub> = 5.85°C)								
Sat.	0.04271	227.53	251.02	0.9226	0.03923	228.44	251.98	0.9186
5	0.04317	228.72	252.46	0.9278				
10	0.04433	231.81	256.20	0.9411	0.04015	231.05	255.14	0.9299
15	0.04547	234.89	259.90	0.9540	0.04122	234.18	258.91	0.9431
20	0.04658	237.95	263.57	0.9667	0.04227	237.29	262.65	0.9560
25	0.04768	241.01	267.23	0.9790	0.04330	240.39	266.37	0.9685
30	0.04875	244.07	270.88	0.9912	0.04431	243.49	270.07	0.9808
35	0.04982	247.13	274.53	1.0031	0.04530	246.58	273.76	0.9929
40	0.05086	250.20	278.17	1.0148	0.04628	249.68	277.45	1.0048
45	0.05190	253.27	281.82	1.0264	0.04724	252.78	281.13	1.0164
50	0.05293	256.36	285.47	1.0378	0.04820	255.90	284.82	1.0279
55	0.05394	259.46	289.13	1.0490	0.04914	259.02	288.51	1.0393
60	0.05495	262.58	292.80	1.0601	0.05008	262.15	292.20	1.0504
<i>p</i> = 7.0 bar = 0.70 MPa ( <i>T</i> <sub>sat</sub> = 10.91°C)								
<i>p</i> = 8.0 bar = 0.80 MPa ( <i>T</i> <sub>sat</sub> = 15.45°C)								
Sat.	0.03371	230.04	253.64	0.9117	0.02953	231.43	255.05	0.9056
15	0.03451	232.70	256.86	0.9229				
20	0.03547	235.92	260.75	0.9363	0.03033	234.47	258.74	0.9182
25	0.03639	239.12	264.59	0.9493	0.03118	237.76	262.70	0.9315
30	0.03730	242.29	268.40	0.9619	0.03202	241.04	266.66	0.9448
35	0.03819	245.46	272.19	0.9743	0.03283	244.28	270.54	0.9574
40	0.03906	248.62	275.96	0.9865	0.03363	247.52	274.42	0.9700
45	0.03992	251.78	279.72	0.9984	0.03440	250.74	278.26	0.9821
50	0.04076	254.94	283.48	1.0101	0.03517	253.96	282.10	0.9941
55	0.04160	258.11	287.23	1.0216	0.03592	257.18	285.92	1.0058
60	0.04242	261.29	290.99	1.0330	0.03667	260.40	289.74	1.0174
65	0.04324	264.48	294.75	1.0442	0.03741	263.64	293.56	1.0287
70	0.04405	267.68	298.51	1.0552	0.03814	266.87	297.38	1.0400
<i>p</i> = 9.0 bar = 0.90 MPa ( <i>T</i> <sub>sat</sub> = 19.59°C)								
<i>p</i> = 10.0 bar = 1.00 MPa ( <i>T</i> <sub>sat</sub> = 23.40°C)								
Sat.	0.02623	232.64	256.25	0.9001	0.02358	233.71	257.28	0.8952
20	0.02630	232.92	256.59	0.9013				
30	0.02789	239.73	264.83	0.9289	0.02457	238.34	262.91	0.9139
40	0.02939	246.37	272.82	0.9549	0.02598	245.18	271.17	0.9407
50	0.03082	252.95	280.68	0.9795	0.02732	251.90	279.22	0.9660
60	0.03219	259.49	288.46	1.0033	0.02860	258.56	287.15	0.9902
70	0.03353	266.04	296.21	1.0262	0.02984	265.19	295.03	1.0135
80	0.03483	272.62	303.96	1.0484	0.03104	271.84	302.88	1.0361
90	0.03611	279.23	311.73	1.0701	0.03221	278.52	310.74	1.0580
100	0.03736	285.90	319.53	1.0913	0.03337	285.24	318.61	1.0794
110	0.03860	292.63	327.37	1.1120	0.03450	292.02	326.52	1.1003
120	0.03982	299.42	335.26	1.1323	0.03562	298.85	334.46	1.1207
130	0.04103	306.28	343.21	1.1523	0.03672	305.74	342.46	1.1408
140	0.04223	313.21	351.22	1.1719	0.03781	312.70	350.51	1.1605
150	0.04342	320.21	359.29	1.1912	0.03889	319.74	358.63	1.1790

TABLE A-9 (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 12.0 bar = 1.20 MPa ( <i>T</i> <sub>sat</sub> = 30.25°C)								
<i>p</i> = 14.0 bar = 1.40 MPa ( <i>T</i> <sub>sat</sub> = 36.29°C)								
Sat.	0.01955	235.48	258.94	0.8864	0.01662	236.89	260.16	0.8786
40	0.02083	242.63	267.62	0.9146	0.01708	239.78	263.70	0.8900
50	0.02204	249.69	276.14	0.9413	0.01823	247.29	272.81	0.9186
60	0.02319	256.60	284.43	0.9666	0.01929	254.52	281.53	0.9452
70	0.02428	263.44	292.58	0.9907	0.02029	261.60	290.01	0.9703
80	0.02534	270.25	300.66	1.0139	0.02125	268.60	298.34	0.9942
90	0.02636	277.07	308.70	1.0363	0.02217	275.56	306.60	1.0172
100	0.02736	283.90	316.73	1.0582	0.02306	282.52	314.80	1.0395
110	0.02834	290.77	324.78	1.0794	0.02393	289.49	323.00	1.0612
120	0.02930	297.69	332.85	1.1002	0.02478	296.50	331.19	1.0823
130	0.03024	304.65	340.95	1.1205	0.02562	303.55	339.41	1.1029
140	0.03118	311.68	349.09	1.1405	0.02644	310.64	347.65	1.1231
150	0.03210	318.77	357.29	1.1601	0.02725	317.79	355.94	1.1429
160	0.03301	325.92	365.54	1.1793	0.02805	324.99	364.26	1.1624
170	0.03392	333.14	373.84	1.1983	0.02884	332.26	372.64	1.1815
<i>p</i> = 16.0 bar = 1.60 MPa ( <i>T</i> <sub>sat</sub> = 41.73°C)								
<i>p</i> = 18.0 bar = 1.80 MPa ( <i>T</i> <sub>sat</sub> = 46.69°C)								
Sat.	0.01440	238.00	261.04	0.8715	0.01265	238.86	261.64	0.8649
50	0.01533	244.66	269.18	0.8971	0.01301	241.72	265.14	0.8758
60	0.01634	252.29	278.43	0.9252	0.01401	249.86	275.09	0.9061
70	0.01728	259.65	287.30	0.9515	0.01492	257.57	284.43	0.9337
80	0.01817	266.86	295.93	0.9762	0.01576	265.04	293.40	0.9595
90	0.01901	274.00	304.42	0.9999	0.01655	272.37	302.16	0.9839
100	0.01983	281.09	312.82	1.0228	0.01731	279.62	310.77	1.0073
110	0.02062	288.18	321.17	1.0448	0.01804	286.83	319.30	1.0299
120	0.02139	295.28	329.51	1.0663	0.01874	294.04	327.78	1.0517
130	0.02214	302.41	337.84	1.0872	0.01943	301.26	336.24	1.0730
140	0.02288	309.58	346.19	1.1077	0.02011	308.50	344.70	1.0937
150	0.02361	316.79	354.56	1.1277	0.02077	315.78	353.17	1.1139
160	0.02432	324.05	362.97	1.1473	0.02142	323.10	361.66	1.1338
170	0.02503	331.37	371.42	1.1666	0.02207	330.47	370.19	1.1532
<i>p</i> = 20.0 bar = 2.00 MPa ( <i>T</i> <sub>sat</sub> = 51.26°C)								
<i>p</i> = 24.0 bar = 2.4 MPa ( <i>T</i> <sub>sat</sub> = 59.46°C)								
Sat.	0.01124	239.51	261.98	0.8586	0.00907	240.22	261.99	0.8463
60	0.01212	247.20	271.43	0.8873	0.00913	240.78	262.68	0.8484
70	0.01300	255.35	281.36	0.9167	0.01006	250.30	274.43	0.8831
80	0.01381	263.12	290.74	0.9436	0.01085	258.89	284.93	0.9133
90	0.01457	270.67	299.80	0.9689	0.01156	267.01	294.75	0.9407
100	0.01528	278.09	308.65	0.9929	0.01222	274.85	304.18	0.9663
110	0.01596	285.44	317.37	1.0160	0.01284	282.53	313.35	0.9906
120	0.01663	292.76	326.01	1.0383	0.01343	290.11	322.35	1.0137
130	0.01727	300.08	334.61	1.0598	0.01400	297.64	331.25	1.0361
140	0.01789	307.40	343.19	1.0808	0.01456	305.14	340.08	1.0577
150	0.01850	314.75	351.76	1.1013	0.01509	312.64	348.87	1.0787
160	0.01910	322.14	360.34	1.1214	0.01562	320.16	357.64	1.0992
170	0.01969	329.56	368.95	1.1410	0.01613	327.70	366.41	1.1192
180	0.02027	337.03	377.58	1.1603	0.01663	335.27	375.20</td	

**TABLE A-10** Properties of Saturated Refrigerant 134a (Liquid–Vapor): Temperature Table

Temp. °C	Press. bar	Specific Volume $m^3/kg$		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Temp. °C	
		Sat. Liquid $v_f \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Sat. Vapor $h_g$	Sat. Liquid $s_f$	Sat. Vapor $s_g$		
-40	0.5164	0.7055	0.3569	-0.04	204.45	0.00	222.88	222.88	0.0000	0.9560	-40
-36	0.6332	0.7113	0.2947	4.68	206.73	4.73	220.67	225.40	0.0201	0.9506	-36
-32	0.7704	0.7172	0.2451	9.47	209.01	9.52	218.37	227.90	0.0401	0.9456	-32
-28	0.9305	0.7233	0.2052	14.31	211.29	14.37	216.01	230.38	0.0600	0.9411	-28
-26	1.0199	0.7265	0.1882	16.75	212.43	16.82	214.80	231.62	0.0699	0.9390	-26
-24	1.1160	0.7296	0.1728	19.21	213.57	19.29	213.57	232.85	0.0798	0.9370	-24
-22	1.2192	0.7328	0.1590	21.68	214.70	21.77	212.32	234.08	0.0897	0.9351	-22
-20	1.3299	0.7361	0.1464	24.17	215.84	24.26	211.05	235.31	0.0996	0.9332	-20
-18	1.4483	0.7395	0.1350	26.67	216.97	26.77	209.76	236.53	0.1094	0.9315	-18
-16	1.5748	0.7428	0.1247	29.18	218.10	29.30	208.45	237.74	0.1192	0.9298	-16
-12	1.8540	0.7498	0.1068	34.25	220.36	34.39	205.77	240.15	0.1388	0.9267	-12
-8	2.1704	0.7569	0.0919	39.38	222.60	39.54	203.00	242.54	0.1583	0.9239	-8
-4	2.5274	0.7644	0.0794	44.56	224.84	44.75	200.15	244.90	0.1777	0.9213	-4
0	2.9282	0.7721	0.0689	49.79	227.06	50.02	197.21	247.23	0.1970	0.9190	0
4	3.3765	0.7801	0.0600	55.08	229.27	55.35	194.19	249.53	0.2162	0.9169	4
8	3.8756	0.7884	0.0525	60.43	231.46	60.73	191.07	251.80	0.2354	0.9150	8
12	4.4294	0.7971	0.0460	65.83	233.63	66.18	187.85	254.03	0.2545	0.9132	12
16	5.0416	0.8062	0.0405	71.29	235.78	71.69	184.52	256.22	0.2735	0.9116	16
20	5.7160	0.8157	0.0358	76.80	237.91	77.26	181.09	258.36	0.2924	0.9102	20
24	6.4566	0.8257	0.0317	82.37	240.01	82.90	177.55	260.45	0.3113	0.9089	24
26	6.8530	0.8309	0.0298	85.18	241.05	85.75	175.73	261.48	0.3208	0.9082	26
28	7.2675	0.8362	0.0281	88.00	242.08	88.61	173.89	262.50	0.3302	0.9076	28
30	7.7006	0.8417	0.0265	90.84	243.10	91.49	172.00	263.50	0.3396	0.9070	30
32	8.1528	0.8473	0.0250	93.70	244.12	94.39	170.09	264.48	0.3490	0.9064	32
34	8.6247	0.8530	0.0236	96.58	245.12	97.31	168.14	265.45	0.3584	0.9058	34
36	9.1168	0.8590	0.0223	99.47	246.11	100.25	166.15	266.40	0.3678	0.9053	36
38	9.6298	0.8651	0.0210	102.38	247.09	103.21	164.12	267.33	0.3772	0.9047	38
40	10.164	0.8714	0.0199	105.30	248.06	106.19	162.05	268.24	0.3866	0.9041	40
42	10.720	0.8780	0.0188	108.25	249.02	109.19	159.94	269.14	0.3960	0.9035	42
44	11.299	0.8847	0.0177	111.22	249.96	112.22	157.79	270.01	0.4054	0.9030	44
48	12.526	0.8989	0.0159	117.22	251.79	118.35	153.33	271.68	0.4243	0.9017	48
52	13.851	0.9142	0.0142	123.31	253.55	124.58	148.66	273.24	0.4432	0.9004	52
56	15.278	0.9308	0.0127	129.51	255.23	130.93	143.75	274.68	0.4622	0.8990	56
60	16.813	0.9488	0.0114	135.82	256.81	137.42	138.57	275.99	0.4814	0.8973	60
70	21.162	1.0027	0.0086	152.22	260.15	154.34	124.08	278.43	0.5302	0.8918	70
80	26.324	1.0766	0.0064	169.88	262.14	172.71	106.41	279.12	0.5814	0.8827	80
90	32.435	1.1949	0.0046	189.82	261.34	193.69	82.63	276.32	0.6380	0.8655	90
100	39.742	1.5443	0.0027	218.60	248.49	224.74	34.40	259.13	0.7196	0.8117	100

Source: Tables A-10 through A-12 are calculated based on equations from D. P. Wilson and R. S. Basu, "Thermodynamic Properties of a New Stratospherically Safe Working Fluid—Refrigerant 134a," *ASHRAE Trans.*, Vol. 94, Pt. 2, 1988, pp. 2095–2118.

**TABLE A-11** Properties of Saturated Refrigerant 134a (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume $m^3/kg$		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Press. bar	
		Sat. Liquid $v_f \times 10^3$	Sat. Vapor $v_g$	Sat. Liquid $u_f$	Sat. Vapor $u_g$	Sat. Liquid $h_f$	Sat. Vapor $h_g$	Sat. Liquid $s_f$	Sat. Vapor $s_g$		
0.6	-37.07	0.7097	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520	0.6
0.8	-31.21	0.7184	0.2366	10.41	209.46	10.47	217.92	228.39	0.0440	0.9447	0.8
1.0	-26.43	0.7258	0.1917	16.22	212.18	16.29	215.06	231.35	0.0678	0.9395	1.0
1.2	-22.36	0.7323	0.1614	21.23	214.50	21.32	212.54	233.86	0.0879	0.9354	1.2
1.4	-18.80	0.7381	0.1395	25.66	216.52	25.77	210.27	236.04	0.1055	0.9322	1.4
1.6	-15.62	0.7435	0.1229	29.66	218.32	29.78	208.19	237.97	0.1211	0.9295	1.6
1.8	-12.73	0.7485	0.1098	33.31	219.94	33.45	206.26	239.71	0.1352	0.9273	1.8
2.0	-10.09	0.7532	0.0993	36.69	221.43	36.84	204.46	241.30	0.1481	0.9253	2.0
2.4	-5.37	0.7618	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222	2.4
2.8	-1.23	0.7697	0.0719	48.18	226.38	48.39	198.13	246.52	0.1911	0.9197	2.8
3.2	2.48	0.7770	0.0632	53.06	228.43	53.31	195.35	248.66	0.2089	0.9177	3.2
3.6	5.84	0.7839	0.0564	57.54	230.28	57.82	192.76	250.58	0.2251	0.9160	3.6
4.0	8.93	0.7904	0.0509	61.69	231.97	62.00	190.32	252.32	0.2399	0.9145	4.0
5.0	15.74	0.8056	0.0409	70.93	235.64	71.33	184.74	256.07	0.2723	0.9117	5.0
6.0	21.58	0.8196	0.0341	78.99	238.74	79.48	179.71	259.19	0.2999	0.9097	6.0
7.0	26.72	0.8328	0.0292	86.19	241.42	86.78	175.07	261.85	0.3242	0.9080	7.0
8.0	31.33	0.8454	0.0255	92.75	243.78	93.42	170.73	264.15	0.3459	0.9066	8.0
9.0	35.53	0.8576	0.0226	98.79	245.88	99.56	166.62	266.18	0.3656	0.9054	9.0
10.0	39.39	0.8695	0.0202	104.42	247.77	105.29	162.68	267.97	0.3838	0.9043	10.0
12.0	46.32	0.8928	0.0166	114.69	251.03	115.76	155.23	270.99	0.4164	0.9023	12.0
14.0	52.43	0.9159	0.0140	123.98	253.74	125.26	148.14	273.40	0.4453	0.9003	14.0
16.0	57.92	0.9392	0.0121	132.52	256.00	134.02	141.31	275.33	0.4714	0.8982	16.0
18.0	62.91	0.9631	0.0105	140.49	257.88	142.22	134.60	276.83	0.4954	0.8959	18.0
20.0	67.49	0.9878	0.0093	148.02	259.41	149.99	127.95	277.94	0.5178	0.8934	20.0
25.0	77.59	1.0562	0.0069	165.48	261.84	168.12	111.06	279.17	0.5687	0.8854	25.0
30.0	86.22	1.1416	0.0053	181.88	262.16	185.30	92.71	278.01	0.6156	0.8735	30.0

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**TABLE A-12** Properties of Superheated Refrigerant 134a Vapor

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 0.6 bar = 0.06 MPa ( <i>T</i> <sub>sat</sub> = -37.07°C)								
<i>p</i> = 1.0 bar = 0.10 MPa ( <i>T</i> <sub>sat</sub> = -26.43°C)								
Sat.	0.31003	206.12	224.72	0.9520	0.19170	212.18	231.35	0.9395
-20	0.33536	217.86	237.98	1.0062	0.19770	216.77	236.54	0.9602
-10	0.34992	224.97	245.96	1.0371	0.20686	224.01	244.70	0.9918
0	0.36433	232.24	254.10	1.0675	0.21587	231.41	252.99	1.0227
10	0.37861	239.69	262.41	1.0973	0.22473	238.96	261.43	1.0531
20	0.39279	247.32	270.89	1.1267	0.23349	246.67	270.02	1.0829
30	0.40688	255.12	279.53	1.1557	0.24216	254.54	278.76	1.1122
40	0.42091	263.10	288.35	1.1844	0.25076	262.58	287.66	1.1411
50	0.43487	271.25	297.34	1.2126	0.25930	270.79	296.72	1.1696
60	0.44879	279.58	306.51	1.2405	0.26779	279.16	305.94	1.1977
70	0.46266	288.08	315.84	1.2681	0.27623	287.70	315.32	1.2254
80	0.47650	296.75	325.34	1.2954	0.28464	296.40	324.87	1.2528
90	0.49031	305.58	335.00	1.3224	0.29302	305.27	334.57	1.2799
<i>p</i> = 1.4 bar = 0.14 MPa ( <i>T</i> <sub>sat</sub> = -18.80°C)								
<i>p</i> = 1.8 bar = 0.18 MPa ( <i>T</i> <sub>sat</sub> = -12.73°C)								
Sat.	0.13945	216.52	236.04	0.9322	0.10983	219.94	239.71	0.9273
-10	0.14549	223.03	243.40	0.9606	0.11135	222.02	242.06	0.9362
0	0.15219	230.55	251.86	0.9922	0.11678	229.67	250.69	0.9684
10	0.15875	238.21	260.43	1.0230	0.12207	237.44	259.41	0.9998
20	0.16520	246.01	269.13	1.0532	0.12723	245.33	268.23	1.0304
30	0.17155	253.96	277.97	1.0828	0.13230	253.36	277.17	1.0604
40	0.17783	262.06	286.96	1.1120	0.13730	261.53	286.24	1.0898
50	0.18404	270.32	296.09	1.1407	0.14222	269.85	295.45	1.1187
60	0.19020	278.74	305.37	1.1690	0.14710	278.31	304.79	1.1472
70	0.19633	287.32	314.80	1.1969	0.15193	286.93	314.28	1.1753
80	0.20241	296.06	324.39	1.2244	0.15672	295.71	323.92	1.2030
90	0.20846	304.95	334.14	1.2516	0.16148	304.63	333.70	1.2303
100	0.21449	314.01	344.04	1.2785	0.16622	313.72	343.63	1.2573
<i>p</i> = 2.0 bar = 0.20 MPa ( <i>T</i> <sub>sat</sub> = -10.09°C)								
<i>p</i> = 2.4 bar = 0.24 MPa ( <i>T</i> <sub>sat</sub> = -5.37°C)								
Sat.	0.09933	221.43	241.30	0.9253	0.08343	224.07	244.09	0.9222
-10	0.09938	221.50	241.38	0.9256	0.08574	228.31	248.89	0.9399
0	0.10438	229.23	250.10	0.9582				
10	0.10922	237.05	258.89	0.9898	0.08993	236.26	257.84	0.9721
20	0.11394	244.99	267.78	1.0206	0.09399	244.30	266.85	1.0034
30	0.11856	253.06	276.77	1.0508	0.09794	252.45	275.95	1.0339
40	0.12311	261.26	285.88	1.0804	0.10181	260.72	285.16	1.0637
50	0.12758	269.61	295.12	1.1094	0.10562	269.12	294.47	1.0930
60	0.13201	278.10	304.50	1.1380	0.10937	277.67	303.91	1.1218
70	0.13639	286.74	314.02	1.1661	0.11307	286.35	313.49	1.1501
80	0.14073	295.53	323.68	1.1939	0.11674	295.18	323.19	1.1780
90	0.14504	304.47	333.48	1.2212	0.12037	304.15	333.04	1.2055
100	0.14932	313.57	343.43	1.2483	0.12398	313.27	343.03	1.2326

**TABLE A-12** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 2.8 bar = 0.28 MPa ( <i>T</i> <sub>sat</sub> = -1.23°C)								
<i>p</i> = 3.2 bar = 0.32 MPa ( <i>T</i> <sub>sat</sub> = 2.48°C)								
Sat.	0.07193	226.38	246.52	0.9197	0.06322	228.43	248.66	0.9177
0	0.07240	227.37	247.64	0.9238	0.06576	234.61	255.65	0.9427
10	0.07613	235.44	256.76	0.9566				
20	0.07972	243.59	265.91	0.9883	0.06901	242.87	264.95	0.9749
30	0.08320	251.83	275.12	1.0192	0.07214	251.19	274.28	1.0062
40	0.08660	260.17	284.42	1.0494	0.07518	259.61	283.67	1.0367
50	0.08992	268.64	293.81	1.0789	0.07815	268.14	293.15	1.0665
60	0.09319	277.23	303.32	1.1079	0.08106	276.79	302.72	1.0957
70	0.09641	285.96	312.95	1.1364	0.08392	285.56	312.41	1.1243
80	0.09960	294.82	322.71	1.1644	0.08674	294.46	322.22	1.1525
90	0.10275	303.83	332.60	1.1920	0.08953	303.50	332.15	1.1802
100	0.10587	312.98	342.62	1.2193	0.09229	312.68	342.21	1.2076
110	0.10897	322.27	352.78	1.2461	0.09503	322.00	352.40	1.2345
120	0.11205	331.71	363.08	1.2727	0.09774	331.45	362.73	1.2611
<i>p</i> = 4.0 bar = 0.40 MPa ( <i>T</i> <sub>sat</sub> = 8.93°C)								
<i>p</i> = 5.0 bar = 0.50 MPa ( <i>T</i> <sub>sat</sub> = 15.74°C)								
Sat.	0.05089	231.97	252.32	0.9145	0.04086	235.64	256.07	0.9117
10	0.05119	232.87	253.35	0.9182				
20	0.05397	241.37	262.96	0.9515	0.04188	239.40	260.34	0.9264
30	0.05662	249.89	272.54	0.9837	0.04416	248.20	270.28	0.9597
40	0.05917	258.47	282.14	1.0148	0.04633	256.99	280.16	0.9918
50	0.06164	267.13	291.79	1.0452	0.04842	265.83	290.04	1.0229
60	0.06405	275.89	301.51	1.0748	0.05043	274.73	299.95	1.0531
70	0.06641	284.75	311.32	1.1038	0.05240	283.72	309.92	1.0825
80	0.06873	293.73	321.23	1.1322	0.05432	292.80	319.96	1.1114
90	0.07102	302.84	331.25	1.1602	0.05620	302.00	330.10	1.1397
100	0.07327	312.07	341.38	1.1878	0.05805	311.31	340.33	1.1675
110	0.07550	321.44	351.64	1.2149	0.05988	320.74	350.68	1.1949
120	0.07771	330.94	362.03	1.2417	0.06168	330.30	361.14	1.2218
130	0.07991	340.58	372.54	1.2681	0.06347	339.98	371.72	1.2484
140	0.08208	350.35	383.18	1.2941	0.06524	349.79	382.42	1.2746
<i>p</i> = 6.0 bar = 0.60 MPa ( <i>T</i> <sub>sat</sub> = 21.58°C)								
<i>p</i> = 7.0 bar = 0.70 MPa ( <i>T</i> <sub>sat</sub> = 26.72°C)								
Sat.	0.03408	238.74	259.19	0.9097	0.02918	241.42	261.85	0.9080
30	0.03581	246.41	267.89	0.9388	0.02979	244.51	265.37	0.9197
40	0.03774	255.45	278.09	0.9719	0.03157	253.83	275.93	0.9539
50	0.03958	264.48	288.23	1.0037	0.03324	263.08	286.35	0.9867
60	0.04134	273.54	298.35	1.0346	0.03482	272.31	296.69	1.0182
70	0.04304	282.66	308.48	1.0645	0.03634	281.57	307.01	1.0487
80	0.04469	291.86	318.67	1.0938	0.03781	290.88	317.35	1.0784
90	0.04631	301.14	328.93	1.1225	0.03924	300.27	327.74	1.1074
100	0.04790	310.53	339.27	1.1505	0.04064	309.74	338.19	1.1358
110	0.04946	320.03	349.70	1.1781	0.04201	319.31	348.71	1.1637
120	0.05099	329.64	360.24	1.2053	0.04335	328.98	359.33	1.1910
130	0.05251	339.38	370.88	1.2320	0.04468	338.76	370.04	1.2179
140	0.05402	349.23	381.64	1.2584	0.04599	348.66	380.86	1.2444
150	0.05550	359.21	392.52	1.2844	0.04729	358.68	391.79	1.2706
160	0.05698	369.32	403.51	1.3100	0.04857	368.82	402.82	1.2963

TABLE A-12 (Continued)

$T$ °C	$v$ $\text{m}^3/\text{kg}$	$u$ $\text{kJ/kg}$	$h$ $\text{kJ/kg}$	$s$ $\text{kJ/kg} \cdot \text{K}$	$v$ $\text{m}^3/\text{kg}$	$u$ $\text{kJ/kg}$	$h$ $\text{kJ/kg}$	$s$ $\text{kJ/kg} \cdot \text{K}$
$p = 8.0 \text{ bar} = 0.80 \text{ MPa}$ ( $T_{\text{sat}} = 31.33^\circ\text{C}$ )								
Sat.	0.02547	243.78	264.15	0.9066	0.02255	245.88	266.18	0.9054
40	0.02691	252.13	273.66	0.9374	0.02325	250.32	271.25	0.9217
50	0.02846	261.62	284.39	0.9711	0.02472	260.09	282.34	0.9566
60	0.02992	271.04	294.98	1.0034	0.02609	269.72	293.21	0.9897
70	0.03131	280.45	305.50	1.0345	0.02738	279.30	303.94	1.0214
80	0.03264	289.89	316.00	1.0647	0.02861	288.87	314.62	1.0521
90	0.03393	299.37	326.52	1.0940	0.02980	298.46	325.28	1.0819
100	0.03519	308.93	337.08	1.1227	0.03095	308.11	335.96	1.1109
110	0.03642	318.57	347.71	1.1508	0.03207	317.82	346.68	1.1392
120	0.03762	328.31	358.40	1.1784	0.03316	327.62	357.47	1.1670
130	0.03881	338.14	369.19	1.2055	0.03423	337.52	368.33	1.1943
140	0.03997	348.09	380.07	1.2321	0.03529	347.51	379.27	1.2211
150	0.04113	358.15	391.05	1.2584	0.03633	357.61	390.31	1.2475
160	0.04227	368.32	402.14	1.2843	0.03736	367.82	401.44	1.2735
170	0.04340	378.61	413.33	1.3098	0.03838	378.14	412.68	1.2992
180	0.04452	389.02	424.63	1.3351	0.03939	388.57	424.02	1.3245
$p = 10.0 \text{ bar} = 1.00 \text{ MPa}$ ( $T_{\text{sat}} = 39.39^\circ\text{C}$ )								
Sat.	0.02020	247.77	267.97	0.9043	0.01663	251.03	270.99	0.9023
40	0.02029	248.39	268.68	0.9066				
50	0.02171	258.48	280.19	0.9428	0.01712	254.98	275.52	0.9164
60	0.02301	268.35	291.36	0.9768	0.01835	265.42	287.44	0.9527
70	0.02423	278.11	302.34	1.0093	0.01947	275.59	298.96	0.9868
80	0.02538	287.82	313.20	1.0405	0.02051	285.62	310.24	1.0192
90	0.02649	297.53	324.01	1.0707	0.02150	295.59	321.39	1.0503
100	0.02755	307.27	334.82	1.1000	0.02244	305.54	332.47	1.0804
110	0.02858	317.06	345.65	1.1286	0.02335	315.50	343.52	1.1096
120	0.02959	326.93	356.52	1.1567	0.02423	325.51	354.58	1.1381
130	0.03058	336.88	367.46	1.1841	0.02508	335.58	365.68	1.1660
140	0.03154	346.92	378.46	1.2111	0.02592	345.73	376.83	1.1933
150	0.03250	357.06	389.56	1.2376	0.02674	355.95	388.04	1.2201
160	0.03344	367.31	400.74	1.2638	0.02754	366.27	399.33	1.2465
170	0.03436	377.66	412.02	1.2895	0.02834	376.69	410.70	1.2724
180	0.03528	388.12	423.40	1.3149	0.02912	387.21	422.16	1.2980
$p = 14.0 \text{ bar} = 1.40 \text{ MPa}$ ( $T_{\text{sat}} = 52.43^\circ\text{C}$ )								
Sat.	0.01405	253.74	273.40	0.9003	0.01208	256.00	275.33	0.8982
60	0.01495	262.17	283.10	0.9297	0.01233	258.48	278.20	0.9069
70	0.01603	272.87	295.31	0.9658	0.01340	269.89	291.33	0.9457
80	0.01701	283.29	307.10	0.9997	0.01435	280.78	303.74	0.9813
90	0.01792	293.55	318.63	1.0319	0.01521	291.39	315.72	1.0148
100	0.01878	303.73	330.02	1.0628	0.01601	301.84	327.46	1.0467
110	0.01960	313.88	341.32	1.0927	0.01677	312.20	339.04	1.0773
120	0.02039	324.05	352.59	1.1218	0.01750	322.53	350.53	1.1069
130	0.02115	334.25	363.86	1.1501	0.01820	332.87	361.99	1.1357
140	0.02189	344.50	375.15	1.1777	0.01887	343.24	373.44	1.1638
150	0.02262	354.82	386.49	1.2048	0.01953	353.66	384.91	1.1912
160	0.02333	365.22	397.89	1.2315	0.02017	364.15	396.43	1.2181
170	0.02403	375.71	409.36	1.2576	0.02080	374.71	407.99	1.2445
180	0.02472	386.29	420.90	1.2834	0.02142	385.35	419.62	1.2704
190	0.02541	396.96	432.53	1.3088	0.02203	396.08	431.33	1.2960
200	0.02608	407.73	444.24	1.3338	0.02263	406.90	443.11	1.3212
$p = 16.0 \text{ bar} = 1.60 \text{ MPa}$ ( $T_{\text{sat}} = 57.92^\circ\text{C}$ )								

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TABLE A-13 Properties of Saturated Ammonia (Liquid-Vapor): Temperature Table

Temp. °C	Press. bar	Specific Volume $\text{m}^3/\text{kg}$		Internal Energy $\text{kJ/kg}$		Enthalpy $\text{kJ/kg}$		Entropy $\text{kJ/kg} \cdot \text{K}$		Temp. °C
		Sat. $v_l \times 10^3$	Sat. $v_g$	Sat. $u_l$	Sat. $u_g$	Sat. $h_l$	Sat. $h_g$	Sat. $s_f$	Sat. $s_g$	
-50	0.4086	1.4245	2.6265	-43.94	1264.99	-43.88	1416.20	1372.32	-0.1922	6.1543
-45	0.5453	1.4367	2.0060	-22.03	1271.19	-21.95	1402.52	1380.57	-0.0951	6.0523
-40	0.7174	1.4493	1.5524	-10.10	1277.20	0.00	1388.56	1388.56	0.0000	5.9557
-36	0.8850	1.4597	1.2757	17.47	1281.87	17.60	1377.17	1394.77	0.0747	5.8819
-32	1.0832	1.4703	1.0561	35.09	1286.41	35.25	1365.55	1400.81	0.1484	5.8111
-30	1.1950	1.4757	0.9634	43.93	1288.63	44.10	1359.65	1403.75	0.1849	5.7767
-28	1.3159	1.4812	0.8803	52.78	1290.82	52.97	1353.68	1406.66	0.2212	5.7430
-26	1.4465	1.4867	0.8056	61.65	1292.97	61.86	1347.65	1409.51	0.2572	5.7100
-22	1.7390	1.4980	0.6780	79.46	1297.18	79.72	1335.36	1415.08	0.3287	5.6457
-20	1.9019	1.5038	0.6233	88.40	1299.23	88.68	1329.10	1417.79	0.3642	5.6144
-18	2.0769	1.5096	0.5739	97.36	1301.25	97.68	1322.77	1420.45	0.3994	5.5837
-16	2.2644	1.5155	0.5291	106.36	1303.23	106.70	1316.35	1423.05	0.4346	5.5536
-14	2.4652	1.5215	0.4885	115.37	1305.17	115.75	1309.86	1425.61	0.4695	5.5239
-12	2.6798	1.5276	0.4516	124.42	1307.08	124.83	1303.28	1428.11	0.5043	5.4948
-10	2.9089	1.5338	0.4180	133.50	1308.95	133.94	1296.61	1430.55	0.5389	5.4662
-8	3.1532	1.5400	0.3874	142.60	1310.78	143.09	1289.86	1432.95	0.5734	5.4380
-6	3.4134	1.5464	0.3595	151.74	1312.57	152.26	1283.02	1435.28	0.6077	5.4103
-4	3.6901	1.5528	0.3340	160.88	1314.32	161.46	1276.10	1437.56	0.6418	5.3831
-2	3.9842	1.5594	0.3106	170.07	1316.04	170.69	1269.08	1439.78	0.6759	5.3562
0	4.2962	1.5660	0.2892	179.29	1317.71	179.96	1261.97	1441.94	0.7097	5.3298
2	4.6270	1.5727	0.2695	188.53	1319.34	189.26	1254.77	1444.03	0.7435	5.3038
4	4.9773	1.5796	0.2514	197.80	1320.92	198.59	1247.48	1446.07	0.7770	5.2781
6	5.3479	1.5866	0.2348	207.10	1322.47	207.95	1240.09	1448.04	0.8105	5.2529
8	5.7395	1.5936	0.2195	216.42	1323.96	217.34	1232.61	1449.94	0.8438	5.2279
10	6.1529	1.6008	0.2054	225.77	1325.42	226.75	1225.03	1451.78	0.8769	5.2033
12	6.5890	1.6081	0.1923	235.14	1326.82	236.20	1217.35	1453.55	0.9099	5.1791
16	7.5324	1.6231	0.1691	253.95	1329.48	255.18	1201.70	1456.87	0.9755	5.1314
20	8.5762	1.6386	0.1492	272.86	1331.94	274.26	1185.64	1459.90	1.0404	5.0849
24	9.7274	1.6547	0.1320	291.84	1334.19	293.45	1169.16	1462.61	1.1048	5.0394
28	10.993	1.6714	0.1172	310.92	1336.20	312.75	1152.24	1465.00	1.1686	4.9948
32	12.380	1.6887	0.1043	330.07	1337.97	332.17	1134.87	1467.03	1.2319	4.9509
36	13.896	1.7068	0.0930	349.32	1339.47	351.69	1117.00	1468.70	1.2946	4.9078
40	15.549	1.7256	0.0831	368.67	1340.70	371.35	1098.62	1469.97	1.3569	4.8652
45	17.819	1.7503	0.0							

**TABLE A-14** Properties of Saturated Ammonia (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Press. bar	
		Sat. Liquid <i>v<sub>l</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>l</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Vapor <i>h<sub>g</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>		
0.40	-50.36	1.4236	2.6795	-45.52	1264.54	-45.46	1417.18	1371.72	-0.1992	6.1618	0.40
0.50	-46.53	1.4330	2.1752	-28.73	1269.31	-28.66	1406.73	1378.07	-0.1245	6.0829	0.50
0.60	-43.28	1.4410	1.8345	-14.51	1273.27	-14.42	1397.76	1383.34	-0.0622	6.0186	0.60
0.70	-40.46	1.4482	1.5884	-2.11	1276.66	-2.01	1389.85	1387.84	-0.0086	5.9643	0.70
0.80	-37.94	1.4546	1.4020	8.93	1279.61	9.04	1382.73	1391.78	0.0386	5.9174	0.80
0.90	-35.67	1.4605	1.2559	18.91	1282.24	19.04	1376.23	1395.27	0.0808	5.8760	0.90
1.00	-33.60	1.4660	1.1381	28.03	1284.61	28.18	1370.23	1398.41	0.1191	5.8391	1.00
1.25	-29.07	1.4782	0.9237	48.03	1289.65	48.22	1356.89	1405.11	0.2018	5.7610	1.25
1.50	-25.22	1.4889	0.7787	65.10	1293.80	65.32	1345.28	1410.61	0.2712	5.6973	1.50
1.75	-21.86	1.4984	0.6740	80.08	1297.33	80.35	1334.92	1415.27	0.3312	5.6435	1.75
2.00	-18.86	1.5071	0.5946	93.50	1300.39	93.80	1325.51	1419.31	0.3843	5.5969	2.00
2.25	-16.15	1.5151	0.5323	105.68	1303.08	106.03	1316.83	1422.86	0.4319	5.5558	2.25
2.50	-13.67	1.5225	0.4821	116.88	1305.49	117.26	1308.76	1426.03	0.4753	5.5190	2.50
2.75	-11.37	1.5295	0.4408	127.26	1307.67	127.68	1301.20	1428.88	0.5152	5.4858	2.75
3.00	-9.24	1.5361	0.4061	136.96	1309.65	137.42	1294.05	1431.47	0.5520	5.4554	3.00
3.25	-7.24	1.5424	0.3765	146.06	1311.46	146.57	1287.27	1433.84	0.5864	5.4275	3.25
3.50	-5.36	1.5484	0.3511	154.66	1313.14	155.20	1280.81	1436.01	0.6186	5.4016	3.50
3.75	-3.58	1.5542	0.3289	162.80	1314.68	163.38	1274.64	1438.03	0.6489	5.3774	3.75
4.00	-1.90	1.5597	0.3094	170.55	1316.12	171.18	1268.71	1439.89	0.6776	5.3548	4.00
4.25	-0.29	1.5650	0.2921	177.96	1317.47	178.62	1263.01	1441.63	0.7048	5.3336	4.25
4.50	1.25	1.5702	0.2767	185.04	1318.73	185.75	1257.50	1443.25	0.7308	5.3135	4.50
4.75	2.72	1.5752	0.2629	191.84	1319.91	192.59	1252.18	1444.77	0.7555	5.2946	4.75
5.00	4.13	1.5800	0.2503	198.39	1321.02	199.18	1247.02	1446.19	0.7791	5.2765	5.00
5.25	5.48	1.5847	0.2390	204.69	1322.07	205.52	1242.01	1447.53	0.8018	5.2594	5.25
5.50	6.79	1.5893	0.2286	210.78	1323.06	211.65	1237.15	1448.80	0.8236	5.2430	5.50
5.75	8.05	1.5938	0.2191	216.66	1324.00	217.58	1232.41	1449.99	0.8446	5.2273	5.75
6.00	9.27	1.5982	0.2104	222.37	1324.89	223.32	1227.79	1451.12	0.8649	5.2122	6.00
7.00	13.79	1.6148	0.1815	243.56	1328.04	244.69	1210.38	1455.07	0.9394	5.1576	7.00
8.00	17.84	1.6302	0.1596	262.64	1330.64	263.95	1194.36	1458.30	1.0054	5.1099	8.00
9.00	21.52	1.6446	0.1424	280.05	1332.82	281.53	1179.44	1460.97	1.0649	5.0675	9.00
10.00	24.89	1.6584	0.1285	296.10	1334.66	297.76	1165.42	1463.18	1.1191	5.0294	10.00
12.00	30.94	1.6841	0.1075	324.99	1337.52	327.01	1139.52	1466.53	1.2152	4.9625	12.00
14.00	36.26	1.7080	0.0923	350.58	1339.56	352.97	1115.82	1468.79	1.2987	4.9050	14.00
16.00	41.03	1.7306	0.0808	373.69	1340.97	376.46	1093.77	1470.23	1.3729	4.8542	16.00
18.00	45.38	1.7522	0.0717	394.85	1341.88	398.00	1073.01	1471.01	1.4399	4.8086	18.00
20.00	49.37	1.7731	0.0644	414.44	1342.37	417.99	1053.27	1471.26	1.5012	4.7670	20.00

Ammonia

**TABLE A-15** Properties of Superheated Ammonia Vapor

T °C	v m <sup>3</sup> /kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m <sup>3</sup> /kg	u kJ/kg	h kJ/kg	s kJ/kg · K
<i>p</i> = 0.4 bar = 0.04 MPa (T <sub>sat</sub> = -50.36°C)					<i>p</i> = 0.6 bar = 0.06 MPa (T <sub>sat</sub> = -43.28°C)			
Sat.	2.6795	1264.54	1371.72	6.1618	1.8345	1273.27	1383.34	6.0186
-50	2.6841	1265.11	1372.48	6.1652				
-45	2.7481	1273.05	1382.98	6.2118				
-40	2.8118	1281.01	1393.48	6.2573	1.8630	1278.62	1390.40	6.0490
-35	2.8753	1288.96	1403.98	6.3018	1.9061	1286.75	1401.12	6.0946
-30	2.9385	1296.93	1414.47	6.3455	1.9491	1294.88	1411.83	6.1390
-25	3.0015	1304.90	1424.96	6.3882	1.9918	1303.01	1422.52	6.1826
-20	3.0644	1312.88	1435.46	6.4300	2.0343	1311.13	1433.19	6.2251
-15	3.1271	1320.87	1445.95	6.4711	2.0766	1319.25	1443.85	6.2668
-10	3.1896	1328.87	1456.45	6.5114	2.1188	1327.37	1454.50	6.3077
-5	3.2520	1336.88	1466.95	6.5509	2.1609	1335.49	1465.14	6.3478
0	3.3142	1344.90	1477.47	6.5898	2.2028	1343.61	1475.78	6.3871
5	3.3764	1352.95	1488.00	6.6280	2.2446	1351.75	1486.43	6.4257
<i>p</i> = 0.8 bar = 0.08 MPa (T <sub>sat</sub> = -37.94°C)					<i>p</i> = 1.0 bar = 0.10 MPa (T <sub>sat</sub> = -33.60°C)			
Sat.	1.4021	1279.61	1391.78	5.9174	1.1381	1284.61	1398.41	5.8391
-35	1.4215	1284.51	1398.23	5.9446				
-30	1.4543	1292.81	1409.15	5.9900	1.1573	1290.71	1406.44	5.8723
-25	1.4868	1301.09	1420.04	6.0343	1.1838	1299.15	1417.53	5.9175
-20	1.5192	1309.36	1430.90	6.0777	1.2101	1307.57	1428.58	5.9616
-15	1.5514	1317.61	1441.72	6.1200	1.2362	1315.96	1439.58	6.0046
-10	1.5834	1325.85	1452.53	6.1615	1.2621	1324.33	1450.54	6.0467
-5	1.6153	1334.09	1463.31	6.2021	1.2880	1332.67	1461.47	6.0878
0	1.6471	1342.31	1474.08	6.2419	1.3136	1341.00	1472.37	6.1281
5	1.6788	1350.54	1484.84	6.2809	1.3392	1349.33	1483.25	6.1676
10	1.7103	1358.77	1495.60	6.3192	1.3647	1357.64	1494.11	6.2063
15	1.7418	1367.01	1506.35	6.3568	1.3900	1365.95	1504.96	6.2442
20	1.7732	1375.25	1517.10	6.3939	1.4153	1374.27	1515.80	6.2816
<i>p</i> = 1.5 bar = 0.15 MPa (T <sub>sat</sub> = -25.22°C)					<i>p</i> = 2.0 bar = 0.20 MPa (T <sub>sat</sub> = -18.86°C)			
Sat.	0.7787	1293.80	1410.61	5.9673	0.59460	1300.39	1419.31	5.5969
-25	0.7795	1294.20	1411.13	5.9694				
-20	0.7978	1303.00	1422.67	5.7454				
-15	0.8158	1311.75	1434.12	5.7902	0.60542	1307.43	1428.51	5.6328
-10	0.8336	1320.44	1445.49	5.8338	0.61926	1316.46	1440.31	5.6781
-5	0.8514	1329.08	1456.79	5.8764	0.63294	1325.41	1452.00	5.7221
0	0.8689	1337.68	1468.02	5.9179	0.64648	1334.29	1463.59	5.7649
5	0.8864	1346.25	1479.20	5.9585	0.65989	1343.11	1475.09	5.8066
10	0.9037	1354.78	1490.34	5.9981	0.67320	1351.87	1486.51	5.8473
15	0.9210	1363.29	1501.44	6.0370	0.68640	1360.59	1497.87	5.8871
20	0.9382	1371.79	1512.51	6.0751	0.69952	1369.28	1509.18	5.9260
25	0.9553	1380.28	1523.56	6.1125	0.71256	1377.93	1520.44	5.9641
30	0.9723	1388.76	1534.60	6.1492	0.72553	1386.56	1531.67	6.0014

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**TABLE A-15** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 2.5 bar = 0.25 MPa ( <i>T</i> <sub>sat</sub> = -13.67°C)								
<i>p</i> = 3.0 bar = 0.30 MPa ( <i>T</i> <sub>sat</sub> = -9.24°C)								
Sat.	0.48213	1305.49	1426.03	5.5190	0.40607	1309.65	1431.47	5.4554
-10	0.49051	1312.37	1435.00	5.5534				
-5	0.50180	1321.65	1447.10	5.5989	0.41428	1317.80	1442.08	5.4953
0	0.51293	1330.83	1459.06	5.6431	0.42382	1327.28	1454.43	5.5409
5	0.52393	1339.91	1470.89	5.6860	0.43323	1336.64	1466.61	5.5851
10	0.53482	1348.91	1482.61	5.7278	0.44251	1345.89	1478.65	5.6280
15	0.54560	1357.84	1494.25	5.7685	0.45169	1355.05	1490.56	5.6697
20	0.55630	1366.72	1505.80	5.8083	0.46078	1364.13	1502.36	5.7103
25	0.56691	1375.55	1517.28	5.8471	0.46978	1373.14	1514.07	5.7499
30	0.57745	1384.34	1528.70	5.8851	0.47870	1382.09	1525.70	5.7886
35	0.58793	1393.10	1540.08	5.9223	0.48756	1391.00	1537.26	5.8264
40	0.59835	1401.84	1551.42	5.9589	0.49637	1399.86	1548.77	5.8635
45	0.60872	1410.56	1562.74	5.9947	0.50512	1408.70	1560.24	5.8998
<i>p</i> = 3.5 bar = 0.35 MPa ( <i>T</i> <sub>sat</sub> = -5.36°C)								
<i>p</i> = 4.0 bar = 0.40 MPa ( <i>T</i> <sub>sat</sub> = -1.90°C)								
Sat.	0.35108	1313.14	1436.01	5.4016	0.30942	1316.12	1439.89	5.3548
0	0.36011	1323.66	1449.70	5.4522	0.31227	1319.95	1444.86	5.3731
10	0.37654	1342.82	1474.61	5.5417	0.32701	1339.68	1470.49	5.4652
20	0.39251	1361.49	1498.87	5.6259	0.34129	1358.81	1495.33	5.5515
30	0.40814	1379.81	1522.66	5.7057	0.35520	1377.49	1519.57	5.6328
40	0.42350	1397.87	1546.09	5.7818	0.36884	1395.85	1543.38	5.7101
60	0.45363	1433.55	1592.32	5.9249	0.39550	1431.97	1590.17	5.8549
80	0.48320	1469.06	1638.18	6.0586	0.42160	1467.77	1636.41	5.9897
100	0.51240	1504.73	1684.07	6.1850	0.44733	1503.64	1682.58	6.1169
120	0.54136	1540.79	1730.26	6.3056	0.47280	1539.85	1728.97	6.2380
140	0.57013	1577.38	1776.92	6.4213	0.49808	1576.79	1775.79	6.3541
160	0.59876	1614.60	1824.16	6.5330	0.52323	1613.86	1823.16	6.4661
180	0.62728	1652.51	1872.06	6.6411	0.54827	1651.85	1871.16	6.5744
200	0.65572	1691.15	1920.65	6.7460	0.57322	1690.56	1919.85	6.6796
<i>p</i> = 4.5 bar = 0.45 MPa ( <i>T</i> <sub>sat</sub> = 1.25°C)								
<i>p</i> = 5.0 bar = 0.50 MPa ( <i>T</i> <sub>sat</sub> = 4.13°C)								
Sat.	0.27671	1318.73	1443.25	5.3135	0.25034	1321.02	1446.19	5.2765
10	0.28846	1336.48	1466.29	5.3962	0.25757	1333.22	1462.00	5.3330
20	0.30142	1356.09	1491.72	5.4845	0.26949	1353.32	1488.06	5.4234
30	0.31401	1375.15	1516.45	5.5674	0.28103	1372.76	1513.28	5.5080
40	0.32631	1393.80	1540.64	5.6460	0.29227	1391.74	1537.87	5.5878
60	0.35029	1430.37	1588.00	5.7926	0.31410	1428.76	1585.81	5.7362
80	0.37369	1466.47	1634.63	5.9285	0.33535	1465.16	1632.84	5.8733
100	0.39671	1502.55	1681.07	6.0564	0.35621	1501.46	1679.56	6.0020
120	0.41947	1538.91	1727.67	6.1781	0.37681	1537.97	1726.37	6.1242
140	0.44205	1575.73	1774.65	6.2946	0.39722	1574.90	1773.51	6.2412
160	0.46448	1613.13	1822.15	6.4069	0.41749	1612.40	1821.14	6.3537
180	0.48681	1651.20	1870.26	6.5155	0.43765	1650.54	1869.36	6.4626
200	0.50905	1689.97	1919.04	6.6208	0.45771	1689.38	1918.24	6.5681

**TABLE A-15** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 5.5 bar = 0.55 MPa ( <i>T</i> <sub>sat</sub> = 6.79°C)								
Sat.	0.22861	1323.06	1448.80	5.2430	0.21038	1324.89	1451.12	5.2122
10	0.23227	1329.88	1457.63	5.2743	0.21115	1326.47	1453.16	5.2195
20	0.24335	1350.50	1484.34	5.3671	0.22155	1347.62	1480.55	5.3145
30	0.25404	1370.35	1510.07	5.4534	0.23152	1367.90	1506.81	5.4026
40	0.26441	1389.64	1535.07	5.5345	0.24118	1387.52	1532.23	5.4851
50	0.27454	1408.53	1559.53	5.6114	0.25059	1406.67	1557.03	5.5631
60	0.28449	1427.13	1583.60	5.6848	0.25981	1425.49	1581.38	5.6373
80	0.30398	1463.85	1631.04	5.8230	0.27783	1462.52	1629.22	5.7768
100	0.32307	1500.36	1678.05	5.9525	0.29546	1499.25	1676.52	5.9071
120	0.34190	1537.02	1725.07	6.0753	0.31281	1536.07	1723.76	6.0304
140	0.36054	1574.07	1772.37	6.1926	0.32997	1573.24	1771.22	6.1481
160	0.37903	1611.66	1820.13	6.3055	0.34699	1610.92	1819.12	6.2613
180	0.39742	1649.88	1868.46	6.4146	0.36390	1649.22	1867.56	6.3707
200	0.41571	1688.79	1917.43	6.5203	0.38071	1688.20	1916.63	6.4766
<i>p</i> = 7.0 bar = 0.70 MPa ( <i>T</i> <sub>sat</sub> = 13.79°C)								
<i>p</i> = 8.0 bar = 0.80 MPa ( <i>T</i> <sub>sat</sub> = 17.84°C)								
Sat.	0.18148	1328.04	1455.07	5.1576	0.15958	1330.64	1458.30	5.1099
20	0.18721	1341.72	1472.77	5.2186	0.16138	1335.59	1464.70	5.1318
30	0.19610	1362.88	1500.15	5.3104	0.16948	1357.71	1493.29	5.2277
40	0.20464	1383.20	1526.45	5.3958	0.17720	1378.77	1520.53	5.3161
50	0.21293	1402.90	1551.95	5.4760	0.18465	1399.05	1546.77	5.3986
60	0.22101	1422.16	1576.87	5.5519	0.19189	1418.77	1572.28	5.4763
80	0.23674	1459.85	1625.56	5.6939	0.20590	1457.14	1621.86	5.6209
100	0.25205	1497.02	1673.46	5.8258	0.21949	1494.77	1670.37	5.7545
120	0.26709	1534.16	1721.12	5.9502	0.23280	1532.24	1718.48	5.8801
140	0.28193	1571.57	1768.92	6.0688	0.24590	1569.89	1766.61	5.9995
160	0.29663	1609.44	1817.08	6.1826	0.25886	1607.96	1815.04	6.1140
180	0.31121	1647.90	1865.75	6.2925	0.27170	1646.57	1863.94	6.2243
200	0.32571	1687.02	1915.01	6.3988	0.28445	1685.83	1913.39	6.3311
<i>p</i> = 9.0 bar = 0.90 MPa ( <i>T</i> <sub>sat</sub> = 21.52°C)								
<i>p</i> = 10.0 bar = 1.00 MPa ( <i>T</i> <sub>sat</sub> = 24.89°C)								
Sat.	0.14239	1332.82	1460.97	5.0675	0.12852	1334.66	1463.18	5.0294
30	0.14872	1352.36	1486.20	5.1520	0.13206	1346.82	1478.88	5.0816
40	0.15582	1374.21	1514.45	5.2436	0.13868	1369.52	1508.20	5.1768
50	0.16263	1395.11	1541.47	5.3286	0.14499	1391.07	1536.06	5.2644
60	0.16922	1415.32	1567.61	5.4083	0.15106	1411.79	1562.86	5.3460
80	0.18191	1454.39	1618.11	5.5555	0.16270	1451.60	1614.31	5.4960
100	0.19416	1492.50	1667.24	5.6908	0.17389	1490.20	1664.10	5.6332
120	0.20612	1530.30	1715.81	5.8176	0.18478	1528.35	1713.13	5.7612
140	0.21788	1568.20	1764.29	5.9379	0.19545	1566.51	1761.96	5.8823
160	0.22948	1606.46	1813.00	6.0530	0.20598	1604.97	1810.94	5.9981
180	0.24097	1645.24	1862.12	6.1639	0.21638	1643.91	1860.29	6.1095
200	0.25237	1684.64	1911.77	6.2711	0.22670	1683.44	1910.14	6.2171

**TABLE A-15** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 12.0 bar = 1.20 MPa ( <i>T</i> <sub>sat</sub> = 30.94°C)								
<i>p</i> = 14.0 bar = 1.40 MPa ( <i>T</i> <sub>sat</sub> = 36.26°C)								
Sat.	0.10751	1337.52	1466.53	4.9625	0.09231	1339.56	1468.79	4.9050
40	0.11287	1359.73	1495.18	5.0553	0.09432	1349.29	1481.33	4.9453
60	0.12378	1404.54	1553.07	5.2347	0.10423	1396.97	1542.89	5.1360
80	0.13387	1445.91	1606.56	5.3906	0.11324	1440.06	1598.59	5.2984
100	0.14347	1485.55	1657.71	5.5315	0.12172	1480.79	1651.20	5.4433
120	0.15275	1524.41	1707.71	5.6620	0.12986	1520.41	1702.21	5.5765
140	0.16181	1563.09	1757.26	5.7850	0.13777	1559.63	1752.52	5.7013
160	0.17072	1601.95	1806.81	5.9021	0.14552	1598.92	1802.65	5.8198
180	0.17950	1641.23	1856.63	6.0145	0.15315	1638.53	1852.94	5.9333
200	0.18819	1681.05	1906.87	6.1230	0.16068	1678.64	1903.59	6.0427
220	0.19680	1721.50	1957.66	6.2282	0.16813	1719.35	1954.73	6.1485
240	0.20534	1762.63	2009.04	6.3303	0.17551	1760.72	2006.43	6.2513
260	0.21382	1804.48	2061.06	6.4297	0.18283	1802.78	2058.75	6.3513
280	0.22225	1847.04	2113.74	6.5267	0.19010	1845.55	2111.69	6.4488
<i>p</i> = 16.0 bar = 1.60 MPa ( <i>T</i> <sub>sat</sub> = 41.03°C)								
<i>p</i> = 18.0 bar = 1.80 MPa ( <i>T</i> <sub>sat</sub> = 45.38°C)								
Sat.	0.08079	1340.97	1470.23	4.8542	0.07174	1341.88	1471.01	4.8086
60	0.08951	1389.06	1532.28	5.0461	0.07801	1380.77	1521.19	4.9627
80	0.09774	1434.02	1590.40	5.2156	0.08565	1427.79	1581.97	5.1399
100	0.10539	1475.93	1644.56	5.3648	0.09267	1470.97	1637.78	5.2937
120	0.11268	1516.34	1696.64	5.5008	0.09931	1512.22	1690.98	5.4326
140	0.11974	1556.14	1747.72	5.6276	0.10570	1552.61	1742.88	5.5614
160	0.12663	1595.85	1798.45	5.7475	0.11192	1592.76	1794.23	5.6828
180	0.13339	1635.81	1849.23	5.8621	0.11801	1633.08	1845.50	5.7985
200	0.14005	1676.21	1900.29	5.9723	0.12400	1673.78	1896.98	5.9096
<i>p</i> = 20.0 bar = 2.00 MPa ( <i>T</i> <sub>sat</sub> = 49.37°C)								
Sat.	0.06445	1342.37	1471.26	4.7670				
60	0.06875	1372.05	1509.54	4.8838				
80	0.07596	1421.36	1573.27	5.0696				
100	0.08248	1465.89	1630.86	5.2283				
120	0.08861	1508.03	1685.24	5.3703				
140	0.09447	1549.03	1737.98	5.5012				
160	0.10016	1589.65	1789.97	5.6241				
180	0.10571	1630.32	1841.74	5.7409				
200	0.11116	1671.33	1893.64	5.8530				
220	0.11652	1712.82	1945.87	5.9611				
240	0.12182	1754.90	1998.54	6.0658				
260	0.12706	1797.63	2051.74	6.1675				
280	0.13224	1841.03	2105.50	6.2665				

**TABLE A-16** Properties of Saturated Propane (Liquid–Vapor): Temperature Table

Temp. °C	Press. bar	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Temp. °C
		Sat. Liquid <i>v<sub>f</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>f</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Sat. Vapor <i>h<sub>g</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>	Sat. Vapor <i>s<sub>g</sub></i>	
-100	0.02888	1.553	11.27	-128.4	319.5	-128.4	480.4	352.0	-0.634	2.140
-90	0.06426	1.578	5.345	-107.8	329.3	-107.8	471.4	363.6	-0.519	2.055
-80	0.1301	1.605	2.774	-87.0	339.3	-87.0	462.4	375.4	-0.408	1.986
-70	0.2434	1.633	1.551	-65.8	349.5	-65.8	453.1	387.3	-0.301	1.929
-60	0.4261	1.663	0.9234	-44.4	359.9	-44.4	443.5	399.2	-0.198	1.883
-50	0.7046	1.694	0.5793	-22.5	370.4	-22.5	433.6	411.2	-0.098	1.845
-40	1.110	1.728	0.3798	-0.2	381.0	0.0	423.2	423.2	0.000	1.815
-30	1.677	1.763	0.2585	22.6	391.6	22.9	412.1	435.0	0.096	1.791
-20	2.444	1.802	0.1815	45.9	402.4	46.3	400.5	446.8	0.190	1.772
-10	3.451	1.844	0.1309	69.8	413.2	70.4	388.0	458.4	0.282	1.757
0	4.743	1.890	0.09653	94.2	423.8	95.1	374.5	469.6	0.374	1.745
4	5.349	1.910	0.08591	104.2	428.1	105.3	368.8	474.1	0.410	1.741
8	6.011	1.931	0.07666	114.3	432.3	115.5	362.9	478.4	0.446	1.737
12	6.732	1.952	0.06858	124.6	436.5	125.9	356.8	482.7	0.482	1.734
16	7.515	1.975	0.06149	135.0	440.7	136.4	350.5	486.9	0.519	1.731
20	8.362	1.999	0.05525	145.4	444.8	147.1	343.9	491.0	0.555	1.728
24	9.278	2.024	0.04973	156.1	448.9	158.0	337.0	495.0	0.591	1.725
28	10.27	2.050	0.04483	166.9	452.9	169.0	329.9	498.9	0.627	1.722
32	11.33	2.078	0.04048	177.8	456.7	180.2	322.4	502.6	0.663	1.720
36	12.47	2.108	0.03659	188.9	460.6	191.6	314.6	506.2	0.699	1.717
40	13.69	2.140	0.03310	200.2	464.3	203.1	306.5	509.6	0.736	1.715
44	15.00	2.174	0.02997	211.7	467.9	214.9	298.0	512.9	0.772	1.712
48	16.40	2.211	0.02714	223.4	471.4	227.0	288.9	515.9	0.809	1.709
52	17.89	2.250	0.02459	235.3	474.6	239.3	279.3	518.6	0.846	1.705
56	19.47	2.293	0.02227	247.4	477.7	251.9	269.2	521.1	0.884	1.701
60	21.16	2.340	0.02015	259.8	480.6	264.8	258.4	523.2	0.921	1.697
65	23.42	2.406	0.01776	275.7	483.6	281.4	243.8	525.2	0.969	1.690
70	25.86	2.483	0.01560	292.3	486.1	298.7	227.7	526.4	1.018	1.682
75	28.49	2.573	0.01363	309.5	487.8	316.8	209.8	526.6	1.069	1.671
80	31.31	2.683	0.01182	327.6	488.2	336.0	189.2	525.2	1.122	1.657
85	34.36	2.827	0.01011	347.2	486.9	356.9	164.7	521.6	1.178	1.638
90	37.64	3.038	0.008415	369.4	482.2	380.8	133.1	513.9	1.242	1.608
95	41.19	3.488	0.006395	399.8	467.4	414.2	79.5	493.7	1.330	1.546
96.7	42.48	4.535	0.004535	434.9	434.9	454.2	0.0	457.2	1.437	1.437
										96.7

Source: Tables A-16 through A-18 are calculated based on B. A. Younglove and J. F. Ely, "Thermophysical Properties of Liquids. II. Methane, Ethane, Propane, Isobutane and Normal Butane," *J. Phys. Chem. Ref. Data*, Vol. 16, No. 4, 1987, pp. 577–598.

**TABLE A-17** Properties of Saturated Propane (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m <sup>3</sup> /kg		Internal Energy kJ/kg		Enthalpy kJ/kg		Entropy kJ/kg · K		Press. bar	
		Sat. Liquid <i>v<sub>f</sub></i> × 10 <sup>3</sup>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>u<sub>f</sub></i>	Sat. Vapor <i>u<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Vapor <i>h<sub>g</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>		
0.05	-93.28	1.570	6.752	-114.6	326.0	-114.6	474.4	359.8	-0.556	2.081	0.05
0.10	-83.87	1.594	3.542	-95.1	335.4	-95.1	465.9	370.8	-0.450	2.011	0.10
0.25	-69.55	1.634	1.513	-64.9	350.0	-64.9	452.7	387.8	-0.297	1.927	0.25
0.50	-56.93	1.672	0.7962	-37.7	363.1	-37.6	440.5	402.9	-0.167	1.871	0.50
0.75	-48.68	1.698	0.5467	-19.6	371.8	-19.5	432.3	412.8	-0.085	1.841	0.75
1.00	-42.38	1.719	0.4185	-5.6	378.5	-5.4	425.7	420.3	-0.023	1.822	1.00
2.00	-25.43	1.781	0.2192	33.1	396.6	33.5	406.9	440.4	0.139	1.782	2.00
3.00	-14.16	1.826	0.1496	59.8	408.7	60.3	393.3	453.6	0.244	1.762	3.00
4.00	-5.46	1.865	0.1137	80.8	418.0	81.5	382.0	463.5	0.324	1.751	4.00
5.00	1.74	1.899	0.09172	98.6	425.7	99.5	372.1	471.6	0.389	1.743	5.00
6.00	7.93	1.931	0.07680	114.2	432.2	115.3	363.0	478.3	0.446	1.737	6.00
7.00	13.41	1.960	0.06598	128.2	438.0	129.6	354.6	484.2	0.495	1.733	7.00
8.00	18.33	1.989	0.05776	141.0	443.1	142.6	346.7	489.3	0.540	1.729	8.00
9.00	22.82	2.016	0.05129	152.9	447.6	154.7	339.1	493.8	0.580	1.726	9.00
10.00	26.95	2.043	0.04606	164.0	451.8	166.1	331.8	497.9	0.618	1.723	10.00
11.00	30.80	2.070	0.04174	174.5	455.6	176.8	324.7	501.5	0.652	1.721	11.00
12.00	34.39	2.096	0.03810	184.4	459.1	187.0	317.8	504.8	0.685	1.718	12.00
13.00	37.77	2.122	0.03499	193.9	462.2	196.7	311.0	507.7	0.716	1.716	13.00
14.00	40.97	2.148	0.03231	203.0	465.2	206.0	304.4	510.4	0.745	1.714	14.00
15.00	44.01	2.174	0.02997	211.7	467.9	215.0	297.9	512.9	0.772	1.712	15.00
16.00	46.89	2.200	0.02790	220.1	470.4	223.6	291.4	515.0	0.799	1.710	16.00
17.00	49.65	2.227	0.02606	228.3	472.7	232.0	285.0	517.0	0.824	1.707	17.00
18.00	52.30	2.253	0.02441	236.2	474.9	240.2	278.6	518.8	0.849	1.705	18.00
19.00	54.83	2.280	0.02292	243.8	476.9	248.2	272.2	520.4	0.873	1.703	19.00
20.00	57.27	2.308	0.02157	251.3	478.7	255.9	265.9	521.8	0.896	1.700	20.00
22.00	61.90	2.364	0.01921	265.8	481.7	271.0	253.0	524.0	0.939	1.695	22.00
24.00	66.21	2.424	0.01721	279.7	484.3	285.5	240.1	525.6	0.981	1.688	24.00
26.00	70.27	2.487	0.01549	293.1	486.2	299.6	226.9	526.5	1.021	1.681	26.00
28.00	74.10	2.555	0.01398	306.2	487.5	313.4	213.2	526.6	1.060	1.673	28.00
30.00	77.72	2.630	0.01263	319.2	488.1	327.1	198.9	526.0	1.097	1.664	30.00
35.00	86.01	2.862	0.009771	351.4	486.3	361.4	159.1	520.5	1.190	1.633	35.00
40.00	93.38	3.279	0.007151	387.9	474.7	401.0	102.3	503.3	1.295	1.574	40.00
42.48	96.70	4.535	0.004535	434.9	434.9	454.2	0.0	454.2	1.437	1.437	42.48

Propane

**TABLE A-18** Properties of Superheated Propane

T °C	v m <sup>3</sup> /kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m <sup>3</sup> /kg		u kJ/kg		h kJ/kg		s kJ/kg · K		
					p = 0.05 bar = 0.005 MPa (T <sub>sat</sub> = -93.28°C)	p = 0.1 bar = 0.01 MPa (T <sub>sat</sub> = -83.87°C)	p = 0.5 bar = 0.05 MPa (T <sub>sat</sub> = -56.93°C)	p = 1.0 bar = 0.1 MPa (T <sub>sat</sub> = -42.38°C)	p = 2.0 bar = 0.2 MPa (T <sub>sat</sub> = -25.43°C)	p = 3.0 bar = 0.3 MPa (T <sub>sat</sub> = -14.16°C)			
Sat.	6.752	326.0	359.8	2.081	3.542	367.3	370.8	2.011	0.4185	378.5	420.3	1.822	
-90	6.877	329.4	363.8	2.103	3.617	339.5	375.7	2.037	0.4234	381.5	423.8	1.837	
-80	7.258	339.8	376.1	2.169	0	436.8	488.2	2.652	0.4439	394.2	438.6	1.899	
-70	7.639	350.6	388.8	2.233	10	450.8	504.1	2.709	0.4641	407.3	453.7	1.960	
-60	8.018	361.8	401.9	2.296	10	470.0	520.4	2.765	0.4842	420.7	469.1	2.019	
-50	8.397	373.3	415.3	2.357	20	470.6	526.7	2.811	0.5040	434.4	484.8	2.078	
					0	410.0	457.6	2.405	0.5238	448.6	501.0	2.136	
					10	449.8	502.7	2.271	0.5434	463.3	517.6	2.194	
					20	464.3	519.1	2.328	0.5629	478.2	534.5	2.251	
					30	479.2	535.9	2.384	0.5824	493.7	551.9	2.307	
					40	494.6	553.2	2.440	0.6018	509.5	569.7	2.363	
					50	510.4	570.9	2.496	0.6211	525.8	587.9	2.419	
					60	526.7	589.1	2.551					
					30	1.135	479.2	535.9	2.384	0.1496	408.7	453.6	1.762
					40	1.173	494.6	553.2	2.440	0.1527	414.7	460.5	1.789
					50	1.211	510.4	570.9	2.496	0.1602	429.0	477.1	1.851
					60	1.249	526.7	589.1	2.551	0.1674	443.8	494.0	1.912
					70	1.287	491.9	549.3	2.170	0.1746	458.8	511.2	1.971
					80	1.326	558.4	623.7	2.394	0.1816	474.2	528.7	2.030
					90	1.365	576.1	643.4	2.449	0.1885	490.1	546.6	2.088
									0.1954	506.2	564.8	2.145	
									0.2022	522.7	583.4	2.202	
									0.2090	539.6	602.3	2.258	
									0.2157	557.0	621.7	2.314	
									0.2223	574.8	641.5	2.369	

Propane

**TABLE A-18** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 4.0 bar = 0.4 MPa ( <i>T</i> <sub>sat</sub> = -5.46°C)								
<i>p</i> = 5.0 bar = 0.5 MPa ( <i>T</i> <sub>sat</sub> = 1.74°C)								
Sat.	0.1137	418.0	463.5	1.751	0.09172	425.7	471.6	1.743
0	0.1169	426.1	472.9	1.786				
10	0.1227	441.2	490.3	1.848	0.09577	438.4	486.3	1.796
20	0.1283	456.6	507.9	1.909	0.1005	454.1	504.3	1.858
30	0.1338	472.2	525.7	1.969	0.1051	470.0	522.5	1.919
40	0.1392	488.1	543.8	2.027	0.1096	486.1	540.9	1.979
50	0.1445	504.4	562.2	2.085	0.1140	502.5	559.5	2.038
60	0.1498	521.1	581.0	2.143	0.1183	519.4	578.5	2.095
70	0.1550	538.1	600.1	2.199	0.1226	536.6	597.9	2.153
80	0.1601	555.7	619.7	2.255	0.1268	554.1	617.5	2.209
90	0.1652	573.5	639.6	2.311	0.1310	572.1	637.6	2.265
100	0.1703	591.8	659.9	2.366	0.1351	590.5	658.0	2.321
110	0.1754	610.4	680.6	2.421	0.1392	609.3	678.9	2.376
<i>p</i> = 6.0 bar = 0.6 MPa ( <i>T</i> <sub>sat</sub> = 7.93°C)								
<i>p</i> = 7.0 bar = 0.7 MPa ( <i>T</i> <sub>sat</sub> = 13.41°C)								
Sat.	0.07680	432.2	478.3	1.737	0.06598	438.0	484.2	1.733
10	0.07769	435.6	482.2	1.751				
20	0.08187	451.5	500.6	1.815	0.06847	448.8	496.7	1.776
30	0.08588	467.7	519.2	1.877	0.07210	465.2	515.7	1.840
40	0.08978	484.0	537.9	1.938	0.07558	481.9	534.8	1.901
50	0.09357	500.7	556.8	1.997	0.07896	498.7	554.0	1.962
60	0.09729	517.6	576.0	2.056	0.08225	515.9	573.5	2.021
70	0.1009	535.0	595.5	2.113	0.08547	533.4	593.2	2.079
80	0.1045	552.7	615.4	2.170	0.08863	551.2	613.2	2.137
90	0.1081	570.7	635.6	2.227	0.09175	569.4	633.6	2.194
100	0.1116	589.2	656.2	2.283	0.09482	587.9	654.3	2.250
110	0.1151	608.0	677.1	2.338	0.09786	606.8	675.3	2.306
120	0.1185	627.3	698.4	2.393	0.1009	626.2	696.8	2.361
<i>p</i> = 8.0 bar = 0.8 MPa ( <i>T</i> <sub>sat</sub> = 18.33°C)								
<i>p</i> = 9.0 bar = 0.9 MPa ( <i>T</i> <sub>sat</sub> = 22.82°C)								
Sat.	0.05776	443.1	489.3	1.729	0.05129	447.2	493.8	1.726
20	0.05834	445.9	492.6	1.740				
30	0.06170	462.7	512.1	1.806	0.05355	460.0	508.2	1.774
40	0.06489	479.6	531.5	1.869	0.05653	477.2	528.1	1.839
50	0.06796	496.7	551.1	1.930	0.05938	494.7	548.1	1.901
60	0.07094	514.0	570.8	1.990	0.06213	512.2	568.1	1.962
70	0.07385	531.6	590.7	2.049	0.06479	530.0	588.3	2.022
80	0.07669	549.6	611.0	2.107	0.06738	548.1	608.7	2.081
90	0.07948	567.9	631.5	2.165	0.06992	566.5	629.4	2.138
100	0.08222	586.5	652.3	2.221	0.07241	585.2	650.4	2.195
110	0.08493	605.6	673.5	2.277	0.07487	604.3	671.7	2.252
120	0.08761	625.0	695.1	2.333	0.07729	623.7	693.3	2.307
130	0.09026	644.8	717.0	2.388	0.07969	643.6	715.3	2.363
140	0.09289	665.0	739.3	2.442	0.08206	663.8	737.7	2.418

**TABLE A-18** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 10.0 bar = 1.0 MPa ( <i>T</i> <sub>sat</sub> = 26.95°C)								
<i>p</i> = 12.0 bar = 1.2 MPa ( <i>T</i> <sub>sat</sub> = 34.39°C)								
Sat.	0.04606	451.8	497.9	1.723	0.03810	459.1	504.8	1.718
30	0.04696	457.1	504.1	1.744				
40	0.04980	474.8	524.6	1.810	0.03957	469.4	516.9	1.757
50	0.05248	492.4	544.9	1.874	0.04204	487.8	538.2	1.824
60	0.05505	510.2	565.2	1.936	0.04436	506.1	559.3	1.889
70	0.05752	528.2	585.7	1.997	0.04657	524.4	580.3	1.951
80	0.05992	546.4	606.3	2.056	0.04869	543.1	601.5	2.012
90	0.06226	564.9	627.2	2.114	0.05075	561.8	622.7	2.071
100	0.06456	583.7	648.3	2.172	0.05275	580.9	644.2	2.129
110	0.06681	603.0	669.8	2.228	0.05470	600.4	666.0	2.187
120	0.06903	622.6	691.6	2.284	0.05662	620.1	688.0	2.244
130	0.07122	642.5	713.7	2.340	0.05851	640.1	710.3	2.300
140	0.07338	662.8	736.2	2.395	0.06037	660.6	733.0	2.355
<i>p</i> = 14.0 bar = 1.4 MPa ( <i>T</i> <sub>sat</sub> = 40.97°C)								
<i>p</i> = 16.0 bar = 1.6 MPa ( <i>T</i> <sub>sat</sub> = 46.89°C)								
Sat.	0.03231	465.2	510.4	1.714	0.02790	470.4	515.0	1.710
50	0.03446	482.6	530.8	1.778	0.02861	476.7	522.5	1.733
60	0.03664	501.6	552.9	1.845	0.03075	496.6	545.8	1.804
70	0.03869	520.4	574.6	1.909	0.03270	516.2	568.5	1.871
80	0.04063	539.4	596.3	1.972	0.03453	535.7	590.9	1.935
90	0.04249	558.6	618.1	2.033	0.03626	555.2	613.2	1.997
100	0.04429	577.9	639.9	2.092	0.03792	574.8	635.5	2.058
110	0.04604	597.5	662.0	2.150	0.03952	594.7	657.9	2.117
120	0.04774	617.5	684.3	2.208	0.04107	614.8	680.5	2.176
130	0.04942	637.7	706.9	2.265	0.04259	635.3	703.4	2.233
140	0.05106	658.3	729.8	2.321	0.04407	656.0	726.5	2.290
150	0.05268	679.2	753.0	2.376	0.04553	677.1	749.9	2.346
160	0.05428	700.5	776.5	2.431	0.04696	698.5	773.6	2.401
<i>p</i> = 18.0 bar = 1.8 MPa ( <i>T</i> <sub>sat</sub> = 52.30°C)								
<i>p</i> = 20.0 bar = 2.0 MPa ( <i>T</i> <sub>sat</sub> = 57.27°C)								
Sat.	0.02441	474.9	518.8	1.705	0.02157	478.7	521.8	1.700
60	0.02606	491.1	538.0	1.763	0.02216	484.8	529.1	1.722
70	0.02798	511.4	561.8	1.834	0.02412	506.3	554.5	1.797
80	0.02974	531.6	585.1	1.901	0.02585	527.1	578.8	1.867
90	0.03138	551.5	608.0	1.965	0.02744	547.6	602.5	1.933
100	0.03293	571.5	630.8	2.027	0.02892	568.1	625.9	1.997
110	0.03443	591.7	653.7	2.087	0.03033	588.5	649.2	2.059
120	0.03586	612.1	676.6	2.146	0.03169	609.2	672.6	2.119
130	0.03726	632.7	699.8	2.204	0.03299	630.0	696.0	2.178
140	0.03863	653.6	723.1	2.262	0.03426	651.2	719.7	2.236
150	0.03996	674.8	746.7	2.318	0.03550	672.5	743.5	2.293
160	0.04127	696.3	770.6	2.374	0.03671	694.2	767.6	2.349
170	0.04256	718.2	794.8	2.429	0.03790	716.2	792.0	2.404
180	0.04383	740.4	819.3	2.484	0.03907	738.5	816.6	2.459

**TABLE A-18** (Continued)

<i>T</i> °C	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K	<i>v</i> m <sup>3</sup> /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg · K
<i>p</i> = 22.0 bar = 2.2 MPa ( <i>T</i> <sub>sat</sub> = 61.90°C)								
<i>p</i> = 24.0 bar = 2.4 MPa ( <i>T</i> <sub>sat</sub> = 66.21°C)								
Sat.	0.01921	481.8	524.0	1.695	0.01721	484.3	525.6	1.688
70	0.02086	500.5	546.4	1.761	0.01802	493.7	536.9	1.722
80	0.02261	522.4	572.1	1.834	0.01984	517.0	564.6	1.801
90	0.02417	543.5	596.7	1.903	0.02141	539.0	590.4	1.873
100	0.02561	564.5	620.8	1.969	0.02283	560.6	615.4	1.941
110	0.02697	585.3	644.6	2.032	0.02414	581.9	639.8	2.006
120	0.02826	606.2	668.4	2.093	0.02538	603.2	664.1	2.068
130	0.02949	627.3	692.2	2.153	0.02656	624.6	688.3	2.129
140	0.03069	648.6	716.1	2.211	0.02770	646.0	712.5	2.188
150	0.03185	670.1	740.2	2.269	0.02880	667.8	736.9	2.247
160	0.03298	691.9	764.5	2.326	0.02986	689.7	761.4	2.304
170	0.03409	714.1	789.1	2.382	0.03091	711.9	786.1	2.360
180	0.03517	736.5	813.9	2.437	0.03193	734.5	811.1	2.416
<i>p</i> = 26.0 bar = 2.6 MPa ( <i>T</i> <sub>sat</sub> = 70.27°C)								
<i>p</i> = 30.0 bar = 3.0 MPa ( <i>T</i> <sub>sat</sub> = 77.72°C)								
Sat.	0.01549	486.2	526.5	1.681	0.01263	488.2	526.0	1.664
80	0.01742	511.0	556.3	1.767	0.01318	495.4	534.9	1.689
90	0.01903	534.2	583.7	1.844	0.01506	522.8	568.0	1.782
100	0.02045	556.4	609.6	1.914	0.01654	547.2	596.8	1.860
110	0.02174	578.3	634.8	1.981	0.01783	570.4	623.9	1.932
120	0.02294	600.0	659.6	2.045	0.01899	593.0	650.0	1.999
130	0.02408	621.6	684.2	2.106	0.02007	615.4	675.6	2.063
140	0.02516	643.4	708.8	2.167	0.02109	637.7	701.0	2.126
150	0.02621	665.3	733.4	2.226	0.02206	660.1	726.3	2.186
160	0.02723	687.4	758.2	2.283	0.02300	682.6	751.6	2.245
170	0.02821	709.9	783.2	2.340	0.02390	705.4	777.1	2.303
180	0.02918	732.5	808.4	2.397	0.02478	728.3	802.6	2.360
190	0.03012	755.5	833.8	2.452	0.02563	751.5	828.4	2.417
<i>p</i> = 35.0 bar = 3.5 MPa ( <i>T</i> <sub>sat</sub> = 86.01°C)								
<i>p</i> = 40.0 bar = 4.0 MPa ( <i>T</i> <sub>sat</sub> = 93.38°C)								
Sat.	0.00977	486.3	520.5	1.633	0.00715	474.7	503.3	1.574
90	0.01086	502.4	540.5	1.688				
100	0.01270	532.9	577.3	1.788	0.00940	512.1	549.7	1.700
110	0.01408	558.9	608.2	1.870	0.01110	544.7	589.1	1.804
120	0.01526	583.4	636.8	1.944	0.01237	572.1	621.6	1.887
130	0.01631	607.0	664.1	2.012	0.01344	597.4	651.2	1.962
140	0.01728	630.2	690.7	2.077	0.01439	621.9	679.5	2.031
150	0.01819	653.3	717.0	2.140	0.01527	645.9	707.0	2.097
160	0.01906	676.4	743.1	2.201	0.01609	669.7	734.1	2.160
170	0.01989	699.6	769.2	2.261	0.01687	693.4	760.9	2.222
180	0.02068	722.9	795.3	2.319	0.01761	717.3	787.7	2.281
190	0.02146	746.5	821.6	2.376	0.01833	741.2	814.5	2.340
200	0.02221	770.3	848.0	2.433	0.01902	765.3	841.4	2.397

**TABLE A-19** Properties of Selected Solids and Liquids: *c<sub>p</sub>*, *p*, and *κ*

Substance	Specific Heat, <i>c<sub>p</sub></i> (kJ/kg · K)	Density, <i>ρ</i> (kg/m <sup>3</sup> )	Thermal Conductivity, <i>κ</i> (W/m · K)
<b>Selected Solids, 300K</b>			
Aluminium	0.903	2700	237
Coal, anthracite	1.260	1350	0.26
Copper	0.385	8930	401
Granite	0.775	2630	2.79
Iron	0.447	7870	80.2
Lead	0.129	11300	35.3
Sand	0.800	1520	0.27
Silver	0.235	10500	429
Soil	1.840	2050	0.52
Steel (AISI 302)	0.480	8060	15.1
Tin	0.227	7310	66.6
<b>Building Materials, 300K</b>			
Brick, common	0.835	1920	0.72
Concrete (stone mix)	0.880	2300	1.4
Glass, plate	0.750	2500	1.4
Hardboard, siding	1.170	640	0.094
Limestone	0.810	2320	2.15
Plywood	1.220	545	0.12
Softwoods (fir, pine)	1.380	510	0.12
<b>Insulating Materials, 300K</b>			
Blanket (glass fiber)	—	16	0.046
Cork	1.800	120	0.039
Duct liner (glass fiber, coated)	0.835	32	0.038
Polystyrene (extruded)	1.210	55	0.027
Vermiculite fill (flakes)	0.835	80	0.068
<b>Saturated Liquids</b>			
Ammonia, 300K	4.818	599.8	0.465
Mercury, 300K	0.139	13529	8.540
Refrigerant 22, 300K	1.267	1183.1	0.085
Refrigerant 134a, 300K	1.434	1199.7	0.081
Unused Engine Oil, 300K	1.909	884.1	0.145
Water, 275K	4.211	999.9	0.574
300K	4.179	996.5	0.613
325K	4.182	987.1	0.645
350K	4.195	973.5	0.668
375K	4.220	956.8	0.681
400K	4.256	937.4	0.688

Source: Drawn from several sources, these data are only representative. Values can vary depending on temperature, purity, moisture content, and other factors.

**TABLE A-20** Ideal Gas Specific Heats of Some Common Gases (kJ/kg · K)

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

Source: Adapted from K. Wark, *Thermodynamics*, 4th ed., McGraw-Hill, New York, 1983, as based on "Tables of Thermal Properties of Gases," NBS Circular 564, 1955.

Table A-20

**TABLE A-21** Variation of  $\bar{c}_p$  with Temperature for Selected Ideal Gases

Gas	$\alpha$	$\beta \times 10^3$	$\gamma \times 10^6$	$\delta \times 10^9$	$\varepsilon \times 10^{12}$
CO	3.710	-1.619	3.692	-2.032	0.240
CO <sub>2</sub>	2.401	8.735	-6.607	2.002	0
H <sub>2</sub>	3.057	2.677	-5.810	5.521	-1.812
H <sub>2</sub> O	4.070	-1.108	4.152	-2.964	0.807
O <sub>2</sub>	3.626	-1.878	7.055	-6.764	2.156
N <sub>2</sub>	3.675	-1.208	2.324	-0.632	-0.226
Air	3.653	-1.337	3.294	-1.913	0.2763
SO <sub>2</sub>	3.267	5.324	0.684	-5.281	2.559
CH <sub>4</sub>	3.826	-3.979	24.558	-22.733	6.963
C <sub>2</sub> H <sub>2</sub>	1.410	19.057	-24.501	16.391	-4.135
C <sub>2</sub> H <sub>4</sub>	1.426	11.383	7.989	-16.254	6.749
Monatomic gases <sup>a</sup>	2.5	0	0	0	0

<sup>a</sup>For monatomic gases, such as He, Ne, and Ar,  $\bar{c}_p$  is constant over a wide temperature range and is very nearly equal to  $5/2 \bar{R}$ .

Source: Adapted from K. Wark, *Thermodynamics*, 4th ed., McGraw-Hill, New York, 1983, as based on NASA SP-273, U.S. Government Printing Office, Washington, DC, 1971.

Table A-21

Table A-22

TABLE A-22 Ideal Gas Properties of Air

T	h	u	$s^o$	when $\Delta s = 0^1$		when $\Delta s = 0$					
				$p_r$	$v_r$	T	h	u	$s^o$	$p_r$	$v_r$
200	199.97	142.56	1.29559	0.3363	1707.	450	451.80	322.62	2.11161	5.775	223.6
210	209.97	149.69	1.34444	0.3987	1512.	460	462.02	329.97	2.13407	6.245	211.4
220	219.97	156.82	1.39105	0.4690	1346.	470	472.24	337.32	2.15604	6.742	200.1
230	230.02	164.00	1.43557	0.5477	1205.	480	482.49	344.70	2.17760	7.268	189.5
240	240.02	171.13	1.47824	0.6355	1084.	490	492.74	352.08	2.19876	7.824	179.7
250	250.05	178.28	1.51917	0.7329	979.	500	503.02	359.49	2.21952	8.411	170.6
260	260.09	185.45	1.55848	0.8405	887.8	510	513.32	366.92	2.23993	9.031	162.1
270	270.11	192.60	1.59634	0.9590	808.0	520	523.63	374.36	2.25997	9.684	154.1
280	280.13	199.75	1.63279	1.0889	738.0	530	533.98	381.84	2.27967	10.37	146.7
285	285.14	203.33	1.65055	1.1584	706.1	540	544.35	389.34	2.29906	11.10	139.7
290	290.16	206.91	1.66802	1.2311	676.1	550	554.74	396.86	2.31809	11.86	133.1
295	295.17	210.49	1.68515	1.3068	647.9	560	565.17	404.42	2.33685	12.66	127.0
300	300.19	214.07	1.70203	1.3860	621.2	570	575.59	411.97	2.35531	13.50	121.2
305	305.22	217.67	1.71865	1.4686	596.0	580	586.04	419.55	2.37348	14.38	115.7
310	310.24	221.25	1.73498	1.5546	572.3	590	596.52	427.15	2.39140	15.31	110.6
315	315.27	224.85	1.75106	1.6442	549.8	600	607.02	434.78	2.40902	16.28	105.8
320	320.29	228.42	1.76690	1.7375	528.6	610	617.53	442.42	2.42644	17.30	101.2
325	325.31	232.02	1.78249	1.8345	508.4	620	628.07	450.09	2.44356	18.36	96.92
330	330.34	235.61	1.79783	1.9352	489.4	630	638.63	457.78	2.46048	19.84	92.84
340	340.42	242.82	1.82790	2.149	454.1	640	649.22	465.50	2.47716	20.64	88.99
350	350.49	250.02	1.85708	2.379	422.2	650	659.84	473.25	2.49364	21.86	85.34
360	360.58	257.24	1.88543	2.626	393.4	660	670.47	481.01	2.50985	23.13	81.89
370	370.67	264.46	1.91313	2.892	367.2	670	681.14	488.81	2.52589	24.46	78.61
380	380.77	271.69	1.94001	3.176	343.4	680	691.82	496.62	2.54175	25.85	75.50
390	390.88	278.93	1.96633	3.481	321.5	690	702.52	504.45	2.55731	27.29	72.56
400	400.98	286.16	1.99194	3.806	301.6	700	713.27	512.33	2.57277	28.80	69.76
410	411.12	293.43	2.01699	4.153	283.3	710	724.04	520.23	2.58810	30.38	67.07
420	421.26	300.69	2.04142	4.522	266.6	720	734.82	528.14	2.60319	32.02	64.53
430	431.43	307.99	2.06533	4.915	251.1	730	745.62	536.07	2.61803	33.72	62.13
440	441.61	315.30	2.08870	5.332	236.8	740	756.44	544.02	2.63280	35.50	59.82

1.  $p_r$  and  $v_r$  data for use with Eqs. 6.43 and 6.44, respectively.

TABLE A-22 (Continued)

T	h	u	$s^o$	when $\Delta s = 0^1$		when $\Delta s = 0$					
				$p_r$	$v_r$	T	h	u	$s^o$	$p_r$	$v_r$
750	767.29	551.99	2.64737	37.35	57.63	1300	1395.97	1022.82	3.27345	330.9	112.75
760	778.18	560.01	2.66176	39.27	55.54	1320	1419.76	1040.88	3.29160	352.5	10.747
770	789.11	568.07	2.67595	41.31	53.39	1340	1443.60	1058.94	3.30959	375.3	10.247
780	800.03	576.12	2.69013	43.35	51.64	1360	1467.49	1077.10	3.32724	399.1	9.780
790	810.99	584.21	2.70400	45.55	49.86	1380	1491.44	1095.26	3.34474	424.2	9.337
800	821.95	592.30	2.71787	47.75	48.08	1400	1515.42	1113.52	3.36200	450.5	8.919
820	843.98	608.59	2.74504	52.59	44.84	1420	1539.44	1131.77	3.37901	478.0	8.526
840	866.08	624.95	2.77170	57.60	41.85	1440	1563.51	1150.13	3.39586	506.9	8.153
860	888.27	641.40	2.79783	63.09	39.12	1460	1587.63	1168.49	3.41247	537.1	7.801
880	910.56	657.95	2.82344	68.98	36.61	1480	1611.79	1186.95	3.42892	568.8	7.468
900	932.93	674.58	2.84856	75.29	34.31	1500	1635.97	1205.41	3.44516	601.9	7.152
920	955.38	691.28	2.87324	82.05	32.18	1520	1660.23	1223.87	3.46120	636.5	6.854
940	977.92	708.08	2.89748	89.28	30.22	1540	1684.51	1242.43	3.47712	672.8	6.569
960	1000.55	725.02	2.92128	97.00	28.40	1560	1708.82	1260.99	3.49276	710.5	6.301
980	1023.25	741.98	2.94468	105.2	26.73	1580	1733.17	1279.65	3.50829	750.0	6.046
1000	1046.04	758.94	2.96770	114.0	25.17	1600	1757.57	1298.30	3.52364	791.2	5.804
1020	1068.89	776.10	2.99034	123.4	23.72	1620	1782.00	1316.96	3.53879	834.1	5.574
1040	1091.85	793.36	3.01260	133.3	22.39	1640	1806.46	1335.72	3.55381	878.9	5.355
1060	1114.86	810.62	3.03449	143.9	21.14	1660	1830.96	1354.48	3.56867	925.6	5.147
1080	1137.89	827.88	3.05608	155.2	19.98	1680	1855.50	1373.24	3.58335	974.2	4.949
1100	1161.07	845.33	3.07732	167.1	18.896	1700	1880.1	1392.7	3.5979	1025	4.761
1120	1184.28	862.79	3.09825	179.7	17.886	1750	1941.6	1439.8	3.6336	1161	4.328
1140	1207.57	880.35	3.11883	193.1	16.946	1800	2003.3	1487.2	3.6684	1310	3.944
1160	1230.92	897.91	3.13916	207.2	16.064	1850	2065.3	1534.9	3.7023	1475	3.601
1180	1254.34	915.57	3.15916	222.2	15.241	1900	2127.4	1582.6	3.7354	1655	3.295
1200	1277.79	933.33	3.17888	238.0	14.470	1950	2189.7	1630.6	3.7677	1852	3.022
1220	1301.31	951.09	3.19834	254.7	13.747	2000	2252.1	1678.7	3.7994	2068	2.776
1240	1324.93	968.95	3.21751	272.3	13.069	2050	2314.6	1726.8	3.8303	2303	2.555
1260	1348.55	986.90	3.23638	290.8	12.435	2100	2377.4	1775.3	3.8605	2559	2.356
1280	1372.24	1004.76	3.25510	310.4	11.835	2150	2440.3	1823.8	3.8901	2837	2.175
						2200	2503.2	1872.4	3.9191	3138	2.012
						2250	2566.4	1921.3	3.9474	3464	1.864

Source: Tables A-22 are based on J. H. Keenan and J. Kaye, *Gas Tables*, Wiley, New York, 1945.

Table A-22

Table A-23

TABLE A-23 Ideal Gas Properties of Selected Gases

$T$	Carbon Dioxide, CO <sub>2</sub> ( $\bar{h}_f^o = -393,520 \text{ kJ/kmol}$ )				Carbon Monoxide, CO ( $\bar{h}_f^o = -110,530 \text{ kJ/kmol}$ )				Water Vapor, H <sub>2</sub> O ( $\bar{h}_f^o = -241,820 \text{ kJ/kmol}$ )				$\bar{v}^o$ (kJ/kmol)				Oxygen, O <sub>2</sub> ( $\bar{h}_f^o = 0 \text{ kJ/kmol}$ )				Nitrogen, N <sub>2</sub> ( $\bar{h}_f^o = 0 \text{ kJ/kmol}$ )					
	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$		
0	0	0	0	0	0	0	0	0	0	5,466	5,466	178,576	6,404	4,575	196,171	0	0	0	6,391	4,562	0	0	0	0		
220	6,601	4,772	202,966	6,391	4,562	188,683	7,295	6,671	180,054	8,621	6,694	4,752	197,461	6,683	4,770	183,938	220	182,638	4,562	0	0	0	0	0		
230	6,938	5,026	204,464	6,683	4,771	189,380	7,628	5,715	181,471	7,961	6,984	4,939	198,696	6,975	4,979	185,180	230	183,938	4,770	0	0	0	0	0		
240	7,280	5,285	205,920	6,975	4,979	191,221	7,961	5,965	181,471	8,294	8,215	182,831	7,275	5,197	199,885	7,266	5,188	186,370	240	185,180	4,979	0	0	0	0	0
250	7,627	5,548	207,337	7,266	5,188	192,411	8,294	6,215	182,831	8,294	8,215	182,831	7,275	5,197	199,885	7,266	5,188	186,370	250	186,370	5,188	0	0	0	0	0
260	7,979	5,817	208,717	7,558	5,396	193,554	8,627	6,466	184,139	7,566	7,566	201,027	7,558	5,405	201,027	7,558	5,405	187,514	260	187,514	5,405	0	0	0	0	0
270	8,335	6,091	210,062	7,849	5,604	194,654	8,964	7,616	185,399	7,958	7,958	5,613	202,128	7,849	5,604	188,614	270	188,614	5,604	0	0	0	0	0		
280	8,697	6,369	211,376	8,140	5,812	195,173	9,296	8,661	186,616	8,150	8,150	5,822	203,191	8,141	5,813	189,673	280	189,673	5,813	0	0	0	0	0		
290	9,063	6,651	212,660	8,432	6,020	196,735	9,631	9,219	188,720	8,443	8,204	218	8,432	6,021	190,695	290	190,695	6,021	0	0	0	0	0			
298	9,364	6,885	213,685	8,669	6,190	197,543	9,904	9,725	188,928	8,682	8,620	205,033	8,669	6,190	191,502	298	191,502	6,190	0	0	0	0	0			
300	9,431	6,939	213,915	8,723	6,229	197,723	9,966	9,742	188,928	8,736	8,642	205,213	8,723	6,229	191,682	300	191,682	6,229	0	0	0	0	0			
310	9,807	7,230	215,146	9,014	6,437	198,678	10,302	7,725	190,030	9,030	9,030	9,325	207,112	9,306	6,645	193,562	310	193,562	6,645	0	0	0	0	0		
320	10,186	7,526	216,351	9,306	6,645	199,603	10,639	7,978	191,098	10,639	10,639	9,664	207,112	10,736	6,849	194,459	320	194,459	6,849	0	0	0	0	0		
330	10,570	7,826	217,534	9,597	6,854	200,500	10,976	8,232	192,136	10,976	10,976	9,677	208,020	10,957	6,885	195,328	330	195,328	6,885	0	0	0	0	0		
340	10,959	8,131	218,694	9,889	7,062	201,371	11,314	8,487	193,144	9,916	9,916	10,049	208,904	9,888	7,061	195,328	340	195,328	7,061	0	0	0	0	0		
350	11,351	8,439	219,831	10,181	7,442	202,217	11,652	9,415	194,125	10,213	10,213	10,451	209,765	10,180	7,207	196,173	350	196,173	7,207	0	0	0	0	0		
360	11,748	8,752	220,948	10,473	7,480	203,040	12,092	9,898	195,081	10,551	10,551	10,809	210,604	10,471	7,447	196,995	360	196,995	7,447	0	0	0	0	0		
370	12,148	9,068	222,044	10,765	7,689	203,842	12,331	9,255	196,012	10,912	10,912	11,109	211,423	10,763	7,687	197,794	370	197,794	7,687	0	0	0	0	0		
380	12,552	9,392	223,122	11,058	7,999	204,882	12,672	9,513	196,920	11,304	11,304	11,500	212,222	11,055	7,895	198,572	380	198,572	7,895	0	0	0	0	0		
390	12,960	9,718	224,182	11,351	8,108	205,383	13,014	9,711	197,807	11,409	11,409	11,606	213,002	11,347	8,104	199,331	390	199,331	8,104	0	0	0	0	0		
400	13,372	10,046	225,225	11,644	8,319	206,125	13,356	10,030	198,673	11,711	11,711	11,904	213,765	11,304	8,314	200,071	400	200,071	8,314	0	0	0	0	0		
410	13,787	10,344	226,080	12,044	8,600	207,850	13,699	12,090	199,521	12,012	12,012	12,314	204,982	11,932	8,225	200,794	410	200,794	8,225	0	0	0	0	0		
420	14,206	10,714	227,258	12,432	8,722	208,525	12,526	12,672	208,525	12,438	12,438	12,640	205,705	12,400	8,244	201,499	420	201,499	8,244	0	0	0	0	0		
430	14,628	11,053	228,252	12,821	9,163	208,929	13,744	11,075	201,955	12,923	12,923	13,204	216,656	12,811	9,153	202,863	430	202,863	9,153	0	0	0	0	0		
440	15,054	11,393	229,230	13,208	9,478	209,593	13,975	12,300	203,497	13,339	13,339	13,734	212,342	13,202	9,480	204,033	440	204,033	9,480	0	0	0	0	0		
450	15,483	11,742	230,194	13,116	9,587	209,828	14,052	12,488	210,243	13,524	13,524	13,969	204,247	13,842	9,935	204,803	450	204,803	9,935	0	0	0	0	0		
460	15,916	12,091	231,144	13,412	9,874	213,890	14,093	12,616	214,460	13,889	13,889	14,260	204,982	14,151	10,160	205,424	460	205,424	10,160	0	0	0	0	0		
470	16,351	12,444	232,080	13,708	10,090	214,460	14,052	12,155	215,020	13,755	13,755	14,220	205,705	14,460	10,386	206,033	470	206,033	10,386	0	0	0	0	0		
480	16,791	14,985	238,292	14,302	10,228	212,117	16,477	12,447	212,117	16,477	16,477	16,804	209,139	16,022	11,533	208,914	480	208,914	11,533	0	0	0	0	0		
490	17,232	15,352	239,135	16,097	11,524	215,572	18,601	14,028	209,795	16,338	16,338	17,765	223,576	15,766	11,277	208,914	490	208,914	11,277	0	0	0	0	0		
500	17,678	15,521	239,962	16,399	11,743	216,115	18,959	14,303	210,440	16,654	16,654	17,908	224,146	16,064	11,492	209,461	500	209,461	11,492	0	0	0	0	0		
560	20,407	17,751	240,789	16,701	11,961	216,649	19,318	15,044	207,112	17,940	17,940	18,626	221,206	17,633	11,707	209,999	560	209,999	11,707	0	0	0	0	0		
570	20,870	16,131	240,789	16,701	11,961	216,649	19,318	15,044	207,112	17,940	17,940	18,626	221,206	17,633	11,707	209,999	570	209,999	11,707	0	0	0	0	0		
580	21,337	16,515	241,602	17,033	12,181	217,175	19,678	14,856	211,702	17,967	17,967	18,626	224,167	17,692	12,139	211,049	580	211,049	12,139	0	0	0	0	0		
590	21,807	16,902	242,405	17,307	12,401	217,693	20,039	15,134	20,702	17,902	17,902	18,626	225,808	17,703	12,703	217,262	590	217,262	12,703	0	0	0	0	0		
700	27,125	21,305	250,663	20,690	14,870	222,936	21,002	16,488	225,947	26,741	26,741	20,339	222,221	23,513	17,111	234,528	700	234,528	17,111	0	0	0	0	0		
710	27,622	21,719	251,368	21,449	19,362	221,127	21,843	18,260	224,840	21,843	21,843	21,843	221,179	21,351	17,111	234,528	710	234,528	17,111	0	0	0	0	0		
720	28,121	22,134	252,065	21,315	15,328	223,833	21,824	18,548	21,824	21,824	21,824	21,824	221,179	21,351	17,111	234,528	720	234,528	17,111	0	0	0	0	0		
730	28,622	22,552	252,755	21,628	15,538	224,265	22,308	19,246	21,824	21,824	21,824															

TABLE A-23 (Continued)

$T$	Carbon Dioxide, CO <sub>2</sub> ( $\bar{h}_f^o = -393,520 \text{ kJ/kmol}$ )			Carbon Monoxide, CO ( $\bar{h}_f^o = -110,530 \text{ kJ/kmol}$ )			Water Vapor, H <sub>2</sub> O ( $\bar{h}_f^o = -241,820 \text{ kJ/kmol}$ )			Oxygen, O <sub>2</sub> ( $\bar{h}_f^o = 0 \text{ kJ/kmol}$ )			Nitrogen, N <sub>2</sub> ( $\bar{h}_f^o = 0 \text{ kJ/kmol}$ )		
	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$
1000	42,769	34,455	269,215	30,355	22,041	234,421	35,882	27,568	232,597	31,389	23,075	243,471	30,129	21,815	228,057
1020	43,859	35,378	270,293	31,020	22,540	235,079	36,709	28,228	233,415	32,088	23,607	244,164	30,784	22,404	228,706
1040	44,953	36,306	271,354	31,688	31,041	235,728	37,542	28,895	232,223	32,789	24,142	244,844	31,442	22,795	229,344
1060	46,051	37,238	272,400	32,357	32,544	236,564	38,380	29,567	235,020	33,490	24,677	245,513	32,101	23,288	229,973
1080	47,153	38,174	273,430	33,029	24,049	236,992	39,223	30,243	235,806	34,194	25,214	246,711	32,762	23,782	230,591
1100	48,258	39,112	274,445	33,702	24,557	237,609	40,071	30,925	236,584	34,899	25,753	246,818	33,426	24,280	231,199
1120	49,369	40,057	275,444	34,377	20,065	238,217	41,923	31,611	237,352	35,106	26,294	247,454	34,092	24,780	231,799
1140	50,484	41,006	276,430	35,054	25,575	238,817	41,780	32,301	238,110	36,314	26,836	248,081	34,760	25,282	232,391
1160	51,602	41,957	277,403	35,733	26,088	239,407	42,642	32,997	238,859	37,023	27,379	248,698	35,430	25,786	232,973
1180	52,724	42,913	278,362	36,406	26,602	239,898	43,509	33,698	239,600	37,734	27,923	249,307	36,104	26,291	233,549
1200	53,848	43,871	279,307	37,095	27,118	240,663	44,380	34,403	240,533	38,447	28,469	249,906	36,777	26,799	231,195
1220	54,977	44,834	280,238	37,780	27,637	241,128	45,256	35,112	241,057	39,162	29,018	250,497	37,452	27,308	234,673
1240	56,108	45,799	281,158	38,466	28,426	241,686	46,137	35,827	241,773	39,877	29,568	251,079	38,129	27,819	235,223
1260	57,244	46,768	282,066	39,154	28,678	242,236	47,022	36,546	242,482	40,594	30,118	251,653	39,760	28,331	235,766
1280	58,381	47,739	282,962	39,884	29,201	242,780	47,912	37,270	243,183	41,512	30,670	252,219	39,488	28,845	236,302
1300	59,522	48,713	283,847	40,534	29,725	243,316	48,807	38,000	243,877	42,033	31,224	252,776	40,170	29,361	236,831
1320	60,666	49,691	284,722	41,266	30,251	243,844	49,707	38,732	244,564	42,753	31,778	253,325	40,853	29,878	237,353
1340	61,813	50,672	285,586	41,919	30,778	244,366	50,612	39,470	245,243	43,475	32,334	253,868	41,559	30,398	237,867
1360	62,963	51,656	286,439	42,613	31,306	244,880	51,521	40,213	245,915	44,198	32,891	254,404	42,227	30,919	238,767
1380	64,116	52,643	287,283	43,309	31,836	245,388	52,434	40,960	246,582	44,923	33,449	254,932	42,915	31,441	238,878
1400	65,271	53,631	288,106	44,007	32,367	246,889	53,351	41,711	247,241	45,648	34,008	255,454	43,605	32,964	239,375
1420	66,427	54,621	288,934	44,716	32,990	246,385	54,273	42,466	247,895	46,374	34,567	255,968	44,249	32,489	242,685
1440	67,586	55,614	289,743	45,408	33,434	246,876	55,198	43,226	248,543	47,102	35,129	256,475	46,221	33,014	240,350
1460	68,748	56,609	290,533	46,110	33,971	247,360	56,128	43,989	249,185	47,831	35,692	256,978	45,682	33,543	240,827
1480	69,911	57,606	291,333	46,813	34,504	247,839	57,062	44,762	249,820	48,561	36,226	257,474	46,377	34,071	241,301
1500	70,978	58,606	292,114	47,517	35,046	248,312	57,999	45,528	250,450	49,292	36,821	257,965	47,073	34,601	241,768
1520	72,246	60,613	292,888	48,222	35,584	248,778	58,942	46,304	251,074	50,024	37,387	258,450	47,771	35,133	242,228
1540	73,417	61,613	293,632	48,928	36,124	249,240	59,888	47,084	251,693	51,434	40,227	258,928	48,470	35,665	242,685
1560	74,590	62,620	294,411	49,635	36,665	249,695	60,838	48,592	252,305	51,490	38,520	259,402	49,168	36,197	243,137
1580	76,767	62,630	295,161	50,344	37,207	250,147	61,792	48,655	252,912	52,224	39,088	259,870	49,869	36,732	243,585
1600	76,944	63,741	295,901	51,053	37,750	250,592	62,748	49,445	253,513	52,961	39,658	260,333	50,571	37,268	244,028
1620	78,123	64,653	296,632	51,763	38,293	251,033	63,709	50,339	254,703	54,696	40,227	260,791	51,275	37,806	244,464
1640	79,303	65,668	297,356	52,472	38,837	251,470	64,675	51,039	254,703	54,329	40,799	261,242	51,980	38,444	244,896
1660	80,486	66,592	298,072	53,184	39,382	251,901	65,643	51,841	255,290	55,172	41,370	261,690	52,686	38,884	245,324
1680	81,670	67,702	298,781	53,895	39,927	252,329	66,614	52,646	255,873	55,912	41,944	262,132	53,393	39,424	245,747
1700	82,856	68,721	299,482	54,609	40,474	252,751	67,589	53,455	256,450	56,652	42,517	262,571	54,099	39,965	246,166
1720	84,043	69,742	300,177	55,323	41,023	253,169	68,567	54,267	257,022	57,394	43,093	263,603	54,807	40,507	246,580
1740	85,231	70,764	300,863	56,039	41,572	253,582	69,550	55,083	257,589	58,136	43,669	263,435	55,516	41,049	246,990

TABLE A-23 (Continued)

$T$	Carbon Dioxide, CO <sub>2</sub> ( $\bar{h}_f^o = -110,530 \text{ kJ/kmol}$ )			Carbon Monoxide, CO ( $\bar{h}_f^o = -110,530 \text{ kJ/kmol}$ )			Water Vapor, H <sub>2</sub> O ( $\bar{h}_f^o = -241,820 \text{ kJ/kmol}$ )			Oxygen, O <sub>2</sub> ( $\bar{h}_f^o = 0 \text{ kJ/kmol}$ )			Nitrogen, N <sub>2</sub> ( $\bar{h}_f^o = 0 \text{ kJ/kmol}$ )		
	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$	$\bar{h}$	$\bar{u}$	$\bar{s}^o$
1760	86,420	71,787	301,543	56,756	42,123	253,399	70,535	55,902	258,151	58,800	44,247	263,861	56,227	41,594	247,396
1780	87,612	72,812	302,271	57,473	42,673	254,398	71,523	56,723	258,708	59,624	44,825	264,283	56,938	42,139	247,798
1800	88,806	73,840	302,884	58,191	43,225	254,797	72,513	57,547	259,262	60,371	45,405	264,701	57,651	42,685	248,195
1820	90,000	74,866	303,544	58,916	43,974	255,194	73,503	58,375	259,811	61,518	45,986	265,113	58,363	43,231	248,589
1840	91,196	75,897	304,897	59,629	44,331	255,587	74,506	59,207	260,357	61,866	46,558	265,521	59,079	43,777	248,979
1860	92,394	76,929	304,845	60,351	44,886	255,976	75,506	60,042	260,898	62,616	47,151	266,925	59,790	44,324	249,365
1880	93,593	77,962	305,487	61,072	45,441	256,474	76,511	60,880	261,436	63,365	47,734	266,326	60,504	45,873	249,748
1900	94,793	78,996	306,122	61,794	45,977	256,743	77,511	61,720	261,969	64,116	48,319	266,722	61,220	45,423	250,128
1920	95,995	80,031	306,751	62,516	46,552	257,122	78,527	62,564	262,497	64,868	48,904	267,115	61,936	45,973	250,502
1940	97,197	81,067	307,374	63,238	47,10										

Table A-24

TABLE A-24 Constants for the van der Waals, Redlich-Kwong, and Benedict-Webb-Rubin Equations of State

Substance	van der Waals		Redlich-Kwong	
	$a$ bar $(\frac{m^3}{kmol})^2$	$b$ kmol	$a$ bar $(\frac{m^3}{kmol})^2$	$b$ kmol
Air	1.368	0.0367	15.989	0.02541
Butane ( $C_4H_{10}$ )	13.86	0.1162	289.55	0.08060
Carbon dioxide ( $CO_2$ )	3.647	0.0428	64.43	0.02963
Carbon monoxide ( $CO$ )	1.474	0.0395	17.22	0.02737
Methane ( $CH_4$ )	2.293	0.0428	32.11	0.02965
Nitrogen ( $N_2$ )	1.366	0.0386	15.53	0.02677
Oxygen ( $O_2$ )	1.369	0.0317	17.22	0.02197
Propane ( $C_3H_8$ )	9.349	0.0901	182.23	0.06242
Refrigerant 12	10.49	0.0971	208.59	0.06731
Sulfur dioxide ( $SO_2$ )	6.883	0.0569	144.80	0.03945
Water ( $H_2O$ )	5.531	0.0305	142.59	0.02111

Source: Calculated from critical data.

2. Benedict-Webb-Rubin: Constants for pressure in bar, specific volume in  $m^3/kmol$ , and temperature in K

Substance	$a$	$A$	$b$	$B$	$c$	$C$	$\alpha$	$\gamma$
$C_4H_{10}$	1.9073	10.218	0.039998	0.12436	$3.206 \times 10^5$	$1.006 \times 10^6$	$1.101 \times 10^{-3}$	0.0340
$CO_2$	0.1386	2.7737	0.007210	0.04991	$1.512 \times 10^4$	$1.404 \times 10^5$	$8.47 \times 10^{-5}$	0.00539
CO	0.0371	1.3590	0.002632	0.05454	$1.054 \times 10^3$	$8.676 \times 10^3$	$1.350 \times 10^{-4}$	0.0060
$CH_4$	0.0501	1.8796	0.003380	0.04260	$2.579 \times 10^3$	$2.287 \times 10^4$	$1.244 \times 10^{-4}$	0.0060
$N_2$	0.0254	1.0676	0.002328	0.04074	$7.381 \times 10^2$	$8.166 \times 10^3$	$1.272 \times 10^{-4}$	0.0053

Source: H. W. Cooper and J. C. Goldfrank, *Hydrocarbon Processing*, 46 (12): 141 (1967).

TABLE A-25 Thermochemical Properties of Selected Substances at 298K and 1 atm

Substance	Formula	Molar Mass, $M$ (kg/kmol)	Enthalpy of Formation, $\bar{H}_f^\circ$ (kJ/kmol)	Gibbs Function of Formation, $\bar{G}_f^\circ$ (kJ/kmol)	Absolute Entropy, $\bar{s}^\circ$ (kJ/kmol · K)	Heating Values	
						Higher, HHV (kJ/kg)	Lower, LHV (kJ/kg)
Carbon	C(s)	12.01	0	0	5.74	32,770	32,770
Hydrogen	$H_2(g)$	2.016	0	0	130.57	141,780	119,950
Nitrogen	$N_2(g)$	28.01	0	0	191.50	—	—
Oxygen	$O_2(g)$	32.00	0	0	205.03	—	—
Carbon monoxide	$CO(g)$	28.01	-110,530	-137,150	197.54	—	—
Carbon dioxide	$CO_2(g)$	44.01	-393,520	-394,380	213.69	—	—
Water	$H_2O(g)$	18.02	-241,820	-228,590	188.72	—	—
Water	$H_2O(l)$	18.02	-285,830	-237,180	69.95	—	—
Hydrogen peroxide	$H_2O_2(g)$	34.02	-136,310	-105,600	232.63	—	—
Ammonia	$NH_3(g)$	17.03	-46,190	-16,590	192.33	—	—
Oxygen	$O(g)$	16.00	249,170	231,770	160.95	—	—
Hydrogen	$H(g)$	1.008	218,000	203,290	114.61	—	—
Nitrogen	$N(g)$	14.01	472,680	455,510	153.19	—	—
Hydroxyl	$OH(g)$	17.01	39,460	34,280	183.75	—	—
Methane	$CH_4(g)$	16.04	-74,850	-50,790	186.16	55,510	50,020
Acetylene	$C_2H_2(g)$	26.04	226,730	209,170	200.85	49,910	48,220
Ethylene	$C_2H_4(g)$	28.05	52,280	68,120	219.83	50,300	47,160
Ethane	$C_2H_6(g)$	30.07	-84,680	-32,890	229.49	51,870	47,480
Propylene	$C_3H_6(g)$	42.08	20,410	62,720	266.94	48,920	45,780
Propane	$C_3H_8(g)$	44.09	-103,850	-23,490	269.91	50,350	46,360
Butane	$C_4H_{10}(g)$	58.12	-126,150	-15,710	310.03	49,500	45,720
Pentane	$C_5H_{12}(g)$	72.15	-146,440	-8,200	348.40	49,010	45,350
Octane	$C_8H_{18}(g)$	114.22	-208,450	17,320	463.67	48,260	44,790
Octane	$C_8H_{18}(l)$	114.22	-249,910	6,610	360.79	47,900	44,430
Benzene	$C_6H_6(g)$	78.11	82,930	129,660	269.20	42,270	40,580
Methyl alcohol	$CH_3OH(g)$	32.04	-200,890	-162,140	239.70	23,850	21,110
Methyl alcohol	$CH_3OH(l)$	32.04	-238,810	-166,290	126.80	22,670	19,920
Ethyl alcohol	$C_2H_5OH(g)$	46.07	-235,310	-168,570	282.59	30,590	27,720
Ethyl alcohol	$C_2H_5OH(l)$	46.07	-277,690	174,890	160.70	29,670	26,800

Source: Based on JANAF Thermochemical Tables, NSRDS-NBS-37, 1971; *Selected Values of Chemical Thermodynamic Properties*, NBS Tech. Note 270-3, 1968; and API Research Project 44, Carnegie Press, 1953. Heating values calculated.

Table A-25

**TABLE A-26** Standard Molar Chemical Exergy,  $\bar{e}^{\text{ch}}$  (kJ/kmol), of Selected Substances at 298 K and  $p_0$

Substance	Formula	Model I <sup>a</sup>	Model II <sup>b</sup>
Nitrogen	N <sub>2</sub> (g)	640	720
Oxygen	O <sub>2</sub> (g)	3,950	3,970
Carbon dioxide	CO <sub>2</sub> (g)	14,175	19,870
Water	H <sub>2</sub> O(g)	8,635	9,500
Water	H <sub>2</sub> O(l)	45	900
Carbon (graphite)	C(s)	404,590	410,260
Hydrogen	H <sub>2</sub> (g)	235,250	236,100
Sulfur	S(s)	598,160	609,600
Carbon monoxide	CO(g)	269,410	275,100
Sulfur dioxide	SO <sub>2</sub> (g)	301,940	313,400
Nitrogen monoxide	NO(g)	88,850	88,900
Nitrogen dioxide	NO <sub>2</sub> (g)	55,565	55,600
Hydrogen sulfide	H <sub>2</sub> S(g)	799,890	812,000
Ammonia	NH <sub>3</sub> (g)	336,685	337,900
Methane	CH <sub>4</sub> (g)	824,350	831,650
Ethane	C <sub>2</sub> H <sub>6</sub> (g)	1,482,035	1,495,840
Methyl alcohol	CH <sub>3</sub> OH(g)	715,070	722,300
Methyl alcohol	CH <sub>3</sub> OH(l)	710,745	718,000
Ethyl alcohol	C <sub>2</sub> H <sub>5</sub> OH(g)	1,348,330	1,363,900
Ethyl alcohol	C <sub>2</sub> H <sub>5</sub> OH(l)	1,342,085	1,357,700

<sup>a</sup>J. Ahrendts, "Die Energie Chemisch Reaktionsfähiger Systeme," *VDI-Forschungsheft*, VDI-Verlag, Dusseldorf, 579, 1977. Also see "Reference States," *Energy—The International Journal*, 5: 667–677, 1980. In Model I,  $p_0 = 1.019$  atm. This model attempts to impose a criterion that the reference environment be in equilibrium. The reference substances are determined assuming restricted chemical equilibrium for nitric acid and nitrates and unrestricted thermodynamic equilibrium for all other chemical components of the atmosphere, the oceans, and a portion of the Earth's crust. The chemical composition of the gas phase of this model approximates the composition of the natural atmosphere.

<sup>b</sup>J. Szargut, D. R. Morris, and F. R. Steward, *Exergy Analysis of Thermal, Chemical, and Metallurgical Processes*, Hemisphere, New York, 1988. In Model II,  $p_0 = 1.0$  atm. In developing this model a reference substance is selected for each chemical element from among substances that contain the element being considered and that are abundantly present in the natural environment, even though the substances are not in completely mutual stable equilibrium. An underlying rationale for this approach is that substances found abundantly in nature have little economic value. On an overall basis, the chemical composition of the exergy reference environment of Model II is closer than Model I to the composition of the natural environment, but the equilibrium criterion is not always satisfied.

**TABLE A-27** Logarithms to the Base 10 of the Equilibrium Constant  $K$

Temp. K	$\log_{10} K$								Temp. °R
	H <sub>2</sub> ⇌ 2H	O <sub>2</sub> ⇌ 2O	N <sub>2</sub> ⇌ 2N	$\frac{1}{2}\text{O}_2 + \frac{1}{2}\text{N}_2 \rightleftharpoons \text{NO}$	H <sub>2</sub> O ⇌ H <sub>2</sub> + $\frac{1}{2}\text{O}_2$	H <sub>2</sub> O ⇌ OH + $\frac{1}{2}\text{H}_2$	CO <sub>2</sub> ⇌ CO + $\frac{1}{2}\text{O}_2$	CO <sub>2</sub> + H <sub>2</sub> ⇌ CO + H <sub>2</sub> O	
298	-71.224	-81.208	-159.600	-15.171	-40.048	-46.054	-45.066	-5.018	537
500	-40.316	-45.880	-92.672	-8.783	-22.886	-26.130	-25.025	-2.139	900
1000	-17.292	-19.614	-43.056	-4.062	-10.062	-11.280	-10.221	-0.159	1800
1200	-13.414	-15.208	-34.754	-3.275	-7.899	-8.811	-7.764	+0.135	2160
1400	-10.630	-12.054	-28.812	-2.712	-6.347	-7.021	-6.014	+0.333	2520
1600	-8.532	-9.684	-24.350	-2.290	-5.180	-5.677	-4.706	+0.474	2880
1700	-7.666	-8.706	-22.512	-2.116	-4.699	-5.124	-4.169	+0.530	3060
1800	-6.896	-7.836	-20.874	-1.962	-4.270	-4.613	-3.693	+0.577	3240
1900	-6.204	-7.058	-19.410	-1.823	-3.886	-4.190	-3.267	+0.619	3420
2000	-5.580	-6.356	-18.092	-1.699	-3.540	-3.776	-2.884	+0.656	3600
2100	-5.016	-5.720	-16.898	-1.586	-3.227	-3.434	-2.539	+0.688	3780
2200	-4.502	-5.142	-15.810	-1.484	-2.942	-3.091	-2.226	+0.716	3960
2300	-4.032	-4.614	-14.818	-1.391	-2.682	-2.809	-1.940	+0.742	4140
2400	-3.600	-4.130	-13.908	-1.305	-2.443	-2.520	-1.679	+0.764	4320
2500	-3.202	-3.684	-13.070	-1.227	-2.224	-2.270	-1.440	+0.784	4500
2600	-2.836	-3.272	-12.298	-1.154	-2.021	-2.038	-1.219	+0.802	4680
2700	-2.494	-2.892	-11.580	-1.087	-1.833	-1.823	-1.015	+0.818	4860
2800	-2.178	-2.536	-10.914	-1.025	-1.658	-1.624	-0.825	+0.833	5040
2900	-1.882	-2.206	-10.294	-0.967	-1.495	-1.438	-0.649	+0.846	5220
3000	-1.606	-1.898	-9.716	-0.913	-1.343	-1.265	-0.485	+0.858	5400
3100	-1.348	-1.610	-9.174	-0.863	-1.201	-1.103	-0.332	+0.869	5580
3200	-1.106	-1.340	-8.664	-0.815	-1.067	-0.951	-0.189	+0.878	5760
3300	-0.878	-1.086	-8.186	-0.771	-0.942	-0.809	-0.054	+0.888	5940
3400	-0.664	-0.846	-7.736	-0.729	-0.824	-0.674	+0.071	+0.895	6120
3500	-0.462	-0.620	-7.312	-0.690	-0.712	-0.547	+0.190	+0.902	6300

Source: Based on data from the JANAF Thermochemical Tables, NSRDS-NBS-37, 1971.