

Section IV

Appendices

Appendix A

Common Conversions

1 Btu =	252.0 cal	1 in. =	2.540 cm
	1055 J		25.40 mm
1 Btu/ft ³ =	0.00890 cal/cm ³	1 J =	0.000948 Btu
	0.0373 MJ/m ³		0.239 cal
1 Btu/hr =	0.0003931 hp		1 W/sec
	0.2520 kcal/hr	1 kcal =	3.968 Btu
	0.2931 W		1000 cal
1,000,000 Btu/hr =	0.293 MW		4187 J
1 Btu/hr-ft ² =	0.003153 kW/m ²	1 kcal/hr =	3.968 Btu/hr
1 Btu/hr-ft-°F =	1.730 W/m-K		1.162 J/sec
1 Btu/hr-ft ² -°F =	5.67 W/m ² -K	1 kcal/m ³ =	0.1124 Btu/ft ³
1 Btu/lb =	0.5556 cal/g		4187 J/m ³
	2326 J/kg	1 kg =	2.205 lb
1 Btu/lb-°F =	1 cal/g-°C	1 kg/hr-m =	0.00278 g/sec-cm
	4187 J/kg-K		0.672 lb/hr-ft
1 cal =	0.003968 Btu	1 kg/m ³ =	0.06243 lb/ft ³
	4.187 J	1 kW =	3413 Btu/hr
1 cal/cm ² -sec =	3.687 Btu/ft ² -sec		1.341 hp
	41.87 kW/m ²		660.6 kcal/hr
1 cal/cm-sec-°C =	241.9 Btu/ft-hr-°F	1 kW/m ² =	317.2 Btu/hr-ft ²
	418.7 W/m-K	1 kW/m ² -°C =	176.2 Btu/hr-ft ² -°F
1 cal/g =	1.80 Btu/lb	1 lb =	0.4536 kg
	4187 J/kg	1 lb/ft ³ =	0.0160 g/cm ³
1 cal/g-°C =	1 Btu/lb-°F		16.02 kg/m ³
	4187 J/kg-K	1 lbm/hr-ft =	0.413 centipoise
1 centipoise =	2.421 lbm/hr-ft	1 m =	3.281 ft
1 cm ² /sec =	100 centistokes	1 mm =	0.03937 in.
	3.874 ft ² /hr	1 m ² /sec =	10.76 ft ² /sec
1 ft =	0.3048 m	1 mton =	1000 kg
1 ft ² /sec =	0.0929 m ² /sec		2205 lb
1 g/cm ³ =	1000 kg/m ³	1 MW =	3,413,000 Btu/hr
	62.43 lb/ft ³		1000 kW
	0.03613 lb/in. ³	1 therm =	100,000 Btu
1 hp =	33,000 ft-lb/min	1 W =	1 J/sec
	550 ft-lb/sec	1 W/m-K =	0.5778 Btu/ft-hr-°F
	641.4 kcal/hr		
	745.7 W		

TEMPERATURE CONVERSIONS

$$\begin{aligned} ^\circ\text{C} &= 5/9 (^\circ\text{F} - 32) & ^\circ\text{F} &= 9/5 (^\circ\text{C} + 32) \\ \text{K} &= ^\circ\text{C} + 273.15 & ^\circ\text{R} &= ^\circ\text{F} + 459.67 \end{aligned}$$

From: Baukal, C.E., *Heat Transfer in Industrial Combustion*, CRC Press, Boca Raton, FL, 2000.

Appendix B

Design Data

TABLE B.1
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
80	0.0135	0.042 41	0.000 143	0.000 000 9
79	0.0145	0.045 55	0.000 165	0.000 001 1
1/64"	0.0156	0.049 09	0.000 191	0.000 001 3
78	0.0160	0.050 27	0.000 201	0.000 001 4
77	0.0180	0.056 55	0.000 254	0.000 001 8
76	0.0200	0.062 83	0.000 314	0.000 002 2
75	0.0210	0.065 97	0.000 346	0.000 002 4
74	0.0225	0.070 69	0.000 398	0.000 002 8
73	0.0240	0.075 40	0.000 452	0.000 003 1
72	0.0250	0.078 54	0.000 491	0.000 003 4
71	0.0260	0.081 68	0.000 531	0.000 003 7
70	0.0280	0.087 96	0.000 616	0.000 004 3
69	0.0292	0.091 73	0.000 670	0.000 004 7
68	0.0310	0.097 39	0.000 755	0.000 005 2
1/12"	0.0313	0.098 18	0.000 765	0.000 005 3
67	0.0320	0.100 53	0.000 804	0.000 005 6
66	0.0330	0.103 67	0.000 855	0.000 005 9
65	0.0350	0.109 96	0.000 962	0.000 006 7
64	0.0360	0.113 10	0.001 018	0.000 007 1
63	0.0370	0.116 24	0.001 075	0.000 007 5
62	0.0380	0.119 38	0.001 134	0.000 007 9
61	0.0390	0.122 52	0.001 195	0.000 008 3
60	0.0400	0.125 66	0.001 257	0.000 008 7
59	0.0410	0.128 81	0.001 320	0.000 009 2
58	0.0420	0.131 95	0.001 385	0.000 009 6
57	0.0430	0.135 09	0.001 452	0.000 010 1
56	0.0465	0.146 08	0.001 698	0.000 011 8
3/64"	0.0469	0.147 26	0.001 73	0.000 012 0
55	0.0520	0.163 36	0.002 12	0.000 014 7
54	0.0550	0.172 79	0.002 38	0.000 016 5
53	0.0595	0.186 93	0.002 78	0.000 019 3
1/16"	0.0625	0.196 35	0.003 07	0.000 021 3

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
52	0.0635	0.199 49	0.003 17	0.000 022 0
51	0.0670	0.210 49	0.003 53	0.000 024 5
50	0.0700	0.219 91	0.003 85	0.000 026 7
49	0.0730	0.229 34	0.004 19	0.000 029 1
48	0.0760	0.238 76	0.004 54	0.000 031 5
5/64"	0.0781	0.245 44	0.004 79	0.000 033 3
47	0.0785	0.246 62	0.004 84	0.000 033 6
46	0.0810	0.254 47	0.005 15	0.000 035 8
45	0.0820	0.257 61	0.005 28	0.000 036 7
44	0.0860	0.270 18	0.005 81	0.000 040 3
43	0.0890	0.279 60	0.006 22	0.000 043 2
42	0.0935	0.293 74	0.006 87	0.000 047 7
3/32"	0.0937	0.294 52	0.006 90	0.000 047 9
41	0.0960	0.301 59	0.007 24	0.000 050 3
40	0.0980	0.307 88	0.007 54	0.000 052 4
39	0.0995	0.312 59	0.007 78	0.000 054 0
38	0.1015	0.318 87	0.008 09	0.000 056 2
37	0.1040	0.326 73	0.008 49	0.000 059 0
36	0.1065	0.334 58	0.008 91	0.000 061 9
7/64"	0.1094	0.343 61	0.009 40	0.000 065 2
35	0.1100	0.345 58	0.009 50	0.000 066 0
34	0.1110	0.348 72	0.009 68	0.000 067 2
33	0.1130	0.355 00	0.010 03	0.000 069 6
32	0.1160	0.364 43	0.010 57	0.000 073 4
31	0.1200	0.376 99	0.011 31	0.000 078 5
1/8"	0.1250	0.392 70	0.012 27	0.000 085 2
30	0.1285	0.403 70	0.012 96	0.000 090 1
29	0.1360	0.427 26	0.014 53	0.000 100 9
28	0.1405	0.441 39	0.015 49	0.000 107 7
9/64"	0.1406	0.441 79	0.015 53	0.000 107 9
27	0.1440	0.442 39	0.016 29	0.000 113 1
26	0.1470	0.461 82	0.016 97	0.000 117 9
25	0.1495	0.469 67	0.017 55	0.000 121 9
24	0.1520	0.477 52	0.018 15	0.000 126 0
23	0.1540	0.483 81	0.018 63	0.000 129 4
5/32"	0.1562	0.490 87	0.019 17	0.000 133 1
22	0.1570	0.493 23	0.019 36	0.000 134 4
21	0.1590	0.499 51	0.019 86	0.000 137 9
20	0.1610	0.505 80	0.020 36	0.000 141 4
19	0.1660	0.521 51	0.021 64	0.000 150 3
18	0.1695	0.532 50	0.022 56	0.000 156 7
11/64"	0.1719	0.539 96	0.023 20	0.000 161 1
17	0.1730	0.543 50	0.023 51	0.000 163 2
16	0.1770	0.556 06	0.024 61	0.000 170 9

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
15	0.1800	0.565 49	0.025 45	0.000 176 7
14	0.1820	0.571 77	0.026 02	0.000 180 7
13	0.1850	0.581 20	0.026 88	0.000 186 7
3/16"	0.1875	0.589 05	0.027 61	0.000 191 7
12	0.1890	0.593 76	0.028 06	0.000 194 8
11	0.1910	0.600 05	0.028 65	0.000 199 0
10	0.1930	0.606 33	0.029 40	0.000 203 2
9	0.1960	0.615 75	0.030 17	0.000 209 5
8	0.1990	0.625 18	0.031 10	0.000 216 0
7	0.2010	0.631 46	0.031 73	0.000 220 4
13/64"	0.2031	0.638 14	0.032 41	0.000 224 8
6	0.2040	0.640 89	0.032 69	0.000 227 0
5	0.2055	0.645 60	0.033 17	0.000 230 3
4	0.2090	0.656 59	0.034 31	0.000 238 2
3	0.2130	0.669 16	0.035 63	0.000 247 5
7/32"	0.2187	0.687 22	0.037 58	0.000 261 0
2	0.2210	0.694 29	0.038 36	0.000 266 4
1	0.2280	0.716 28	0.040 83	0.000 283 5
A	0.2340	0.735 13	0.043 01	0.000 298 7
15/64"	0.2344	0.736 31	0.043 14	0.000 299 6
B	0.2380	0.747 70	0.044 49	0.000 308 9
C	0.2420	0.760 27	0.046 00	0.000 319 4
D	0.2460	0.772 83	0.047 53	0.000 330 1
E = 1/4"	0.2500	0.785 40	0.049 09	0.000 340 9
F	0.2570	0.807 39	0.051 87	0.000 360 2
G	0.2610	0.819 96	0.053 50	0.000 371 5
17/64"	0.2656	0.834 41	0.055 42	0.000 384 9
H	0.2660	0.835 67	0.055 57	0.000 385 9
I	0.2720	0.854 52	0.058 11	0.000 403 5
J	0.2770	0.870 22	0.060 26	0.000 418 5
K	0.2810	0.882 79	0.062 02	0.000 430 7
9/32"	0.2812	0.883 57	0.062 13	0.000 431 5
L	0.2900	0.911 06	0.066 05	0.000 458 7
M	0.2950	0.926 77	0.068 35	0.000 474 7
19/64"	0.2969	0.932 66	0.069 22	0.000 480 7
N	0.3030	0.951 90	0.071 63	0.000 500 7
5/16"	0.3125	0.981 75	0.076 70	0.000 532 6
O	0.3160	0.992 75	0.078 43	0.000 544 6
P	0.3230	1.014 74	0.081 94	0.000 569 0
21/64"	0.3281	1.030 8	0.084 56	0.000 587 2
Q	0.3320	1.043 0	0.086 57	0.000 601 2
R	0.3390	1.065 0	0.090 26	0.000 626 8
11/32"	0.3437	1.079 8	0.092 81	0.000 644 5
S	0.3480	1.093 3	0.095 11	0.000 660 5

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
T	0.3580	1.124 7	0.100 6	0.000 699 0
23/64"	0.3594	1.129 0	0.101 4	0.000 704 4
U	0.3680	1.156 1	0.106 4	0.000 738 6
3/8"	0.3750	1.178 1	0.110 5	0.000 767 0
V	0.3770	1.184 4	0.111 6	0.000 775 2
W	0.3860	1.212 7	0.117 0	0.000 812 7
25/64"	0.3906	1.227 2	0.119 8	0.000 832 2
X	0.3970	1.247 2	0.123 8	0.000 859 6
Y	0.4040	1.269 2	0.128 2	0.000 890 2
13/32"	0.4062	1.276 3	0.129 6	0.000 900 1
Z	0.4130	1.297 5	0.134 0	0.000 930 3
27/64"	0.4219	1.325 4	0.139 8	0.000 970 8
7/16"	0.4375	1.3745	0.1503	0.001 044
29/64"	0.4531	1.4235	0.1613	0.001 120
15/32"	0.4687	1.4726	0.1726	0.001 198
31/64"	0.4844	1.5217	0.1843	0.001 280
1/2"	0.5000	1.5708	0.1964	0.001 364
33/64"	0.5156	1.6199	0.2088	0.001 450
17/32"	0.5313	1.6690	0.2217	0.001 539
35/64"	0.5469	1.7181	0.2349	0.001 631
9/16"	0.5625	1.7672	0.2485	0.001 726
37/64"	0.5781	1.8162	0.2625	0.001 823
19/32"	0.5938	1.8653	0.2769	0.001 923
39/64"	0.6094	1.9144	0.2917	0.002 025
5/8"	0.6250	1.9635	0.3068	0.002 131
41/64"	0.6406	2.0126	0.3223	0.002 238
21/32"	0.6562	2.0617	0.3382	0.002 350
43/64"	0.6719	2.1108	0.3545	0.002 462
11/16"	0.6875	2.1598	0.3712	0.002 578
23/32"	0.7188	2.2580	0.4057	0.002 818
3/4"	0.7500	2.3562	0.4418	0.003 068
25/32"	0.7812	2.4544	0.4794	0.003 329
13/16"	0.8125	2.5525	0.5185	0.003 601
27/32"	0.8438	2.6507	0.5591	0.003 883
7/8"	0.8750	2.7489	0.6013	0.004 176
29/32"	0.9062	2.8471	0.6450	0.004 479
15/16"	0.9375	2.9452	0.6903	0.004 794
31/32"	0.9688	3.0434	0.7371	0.005 119
1"	1.0000	3.1416	0.7854	0.005 454
1 1/16"	1.0625	3.3379	0.8866	0.006 157
1 1/8"	1.1250	3.5343	0.9940	0.006 903
1 3/16"	1.1875	3.7306	1.1075	0.007 691
1 1/4"	1.2500	3.9270	1.2272	0.008 522
1 5/16"	1.3125	4.1233	1.3530	0.009 396

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
1 3/8"	1.3750	4.3170	1.4849	0.010 31
1 7/16"	1.4375	4.5160	1.6230	0.011 27
1 1/2"	1.5000	4.7124	1.7671	0.012 27
1 9/16"	1.5625	4.9087	1.9175	0.013 32
1 5/8"	1.6250	5.1051	2.0739	0.014 40
1 11/16"	1.6875	5.3014	2.2365	0.015 53
1 3/4"	1.7500	5.4978	2.4053	0.016 70
1 13/16"	1.8125	5.6941	2.5802	0.017 92
1 7/8"	1.8750	5.8905	2.7612	0.019 18
1 15/16"	1.9375	6.0868	2.9483	0.020 47
2"	2.0000	6.2832	3.1416	0.021 82
2 1/16"	2.0625	6.4795	3.3410	0.023 20
2 1/8"	2.1250	6.6759	3.5466	0.024 63
2 3/16"	2.1875	6.8722	3.7583	0.026 10
2 1/4"	2.2500	7.0686	3.9761	0.027 61
2 5/16"	2.3125	7.2649	4.2000	0.029 17
2 3/8"	2.3750	7.4613	4.4301	0.030 76
2 7/16"	2.4375	7.6576	4.6664	0.032 41
2 1/2"	2.5000	7.8540	4.9087	0.034 09
2 9/16"	2.5625	8.0503	5.1572	0.035 81
2 5/8"	2.6250	8.2467	5.4119	0.037 58
2 11/16"	2.6875	8.4430	5.6727	0.039 39
2 3/4"	2.7500	8.6394	5.9396	0.041 25
2 13/16"	2.8125	8.8357	6.2126	0.043 14
2 7/8"	2.8750	9.0323	6.4918	0.045 08
2 15/16"	2.9375	9.2284	6.7771	0.047 06
3"	3.0000	9.4248	7.0686	0.049 09
3 1/16"	3.0625	9.6211	7.3662	0.051 15
3 1/8"	3.1250	9.8175	7.6699	0.053 26
3 3/16"	3.1875	10.014	7.9798	0.055 42
3 1/4"	3.2500	10.210	8.2958	0.057 36
3 5/16"	3.3125	10.407	8.6179	0.059 85
3 3/8"	3.3750	10.603	8.9462	0.062 13
3 7/16"	3.4375	10.799	9.2806	0.064 45
3 1/2"	3.5000	10.996	9.6211	0.066 81
3 9/16"	3.5625	11.192	9.9678	0.069 22
3 5/8"	3.6250	11.388	10.321	0.071 67
3 11/16"	3.6875	11.585	10.680	0.074 17
3 3/4"	3.7500	11.781	11.045	0.076 70
3 13/16"	3.8125	11.977	11.416	0.079 28
3 7/8"	3.8750	12.174	11.793	0.081 90
3 15/16"	3.9375	12.370	12.177	0.084 56
4"	4.0000	12.566	12.566	0.087 26
4 1/16"	4.0625	12.763	12.962	0.090 02

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
4 1/8"	4.1250	12.959	13.364	0.092 81
4 3/16"	4.1875	13.155	13.772	0.095 64
4 1/4"	4.2500	13.352	14.186	0.098 52
4 5/16"	4.3125	13.548	14.607	0.101 4
4 3/8"	4.3750	13.745	15.033	0.104 3
4 7/16"	4.4375	13.941	15.466	0.107 4
4 1/2"	4.5000	14.137	15.904	0.110 4
4 9/16"	4.5625	14.334	16.349	0.113 5
4 5/8"	4.6250	14.530	16.800	0.1167
4 11/16"	4.6875	14.726	17.257	0.1198
4 3/4"	4.7500	14.923	17.721	0.1231
4 13/16"	4.8125	15.119	18.190	0.1263
4 7/8"	4.8750	15.315	18.665	0.1296
4 15/16"	4.9375	15.512	19.147	0.1330
5"	5.0000	15.708	19.635	0.1364
5 1/16"	5.0625	15.904	20.129	0.1398
5 1/8"	5.1250	16.101	20.629	0.1433
5 3/16"	5.1875	16.297	21.135	0.1468
5 1/4"	5.2500	16.493	21.648	0.1503
5 5/16"	5.3125	16.690	22.166	0.1539
5 3/8"	5.3750	16.886	22.691	0.1576
5 7/16"	5.4375	17.082	23.221	0.1613
5 1/2"	5.5000	17.279	23.758	0.1650
5 9/16"	5.5625	17.475	24.301	0.1688
5 5/8"	5.6250	17.671	24.851	0.1726
5 11/16"	5.6875	17.868	25.406	0.1764
5 3/4"	5.7500	18.064	25.967	0.1803
5 13/16"	5.8125	18.261	26.535	0.1843
5 7/8"	5.8750	18.457	27.109	0.1883
5 15/16"	5.9375	18.653	27.688	0.1923
6"	6.0000	18.850	28.274	0.1963
6 1/8"	6.1250	19.242	29.465	0.2046
6 1/4"	6.2500	19.649	30.680	0.2131
6 3/8"	6.3750	20.028	31.919	0.2217
6 1/2"	6.5000	20.420	33.183	0.2304
6 5/8"	6.6250	20.813	34.472	0.2394
6 3/4"	6.7500	21.206	35.785	0.2485
6 7/8"	6.8750	21.598	37.122	0.2578
7"	7.0000	21.991	38.485	0.2673
7 1/8"	7.1250	22.384	39.871	0.2769
7 1/4"	7.2500	22.777	41.283	0.2867
7 3/8"	7.3750	23.169	42.718	0.2967
7 1/2"	7.5000	23.562	44.179	0.3068
7 5/8"	7.6250	23.955	45.664	0.3171

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
7 3/4"	7.7500	24.347	47.173	0.3276
7 7/8"	7.8750	24.740	48.707	0.3382
8"	8.0000	25.133	50.266	0.3491
8 1/8"	8.1250	25.525	51.849	0.3601
8 1/4"	8.2500	25.918	53.456	0.3712
8 3/8"	8.3750	26.301	55.088	0.3826
8 1/2"	8.5000	26.704	56.745	0.3941
8 5/8"	8.6250	27.096	58.426	0.4057
8 3/4"	8.7500	27.489	60.132	0.4176
8 7/8"	8.8750	27.882	61.862	0.4296
9"	9.0000	28.274	63.617	0.4418
9 1/8"	9.1250	28.667	65.397	0.4541
9 1/4"	9.2500	29.060	67.201	0.4667
9 3/8"	9.3750	29.452	69.029	0.4794
9 1/2"	9.5000	29.845	70.882	0.4922
9 5/8"	9.6250	30.238	72.760	0.5053
9 3/4"	9.7500	30.631	74.662	0.5185
9 7/8"	9.8750	31.023	76.589	0.5319
10"	10.0000	31.416	78.540	0.5454
10 1/8"	10.1250	31.809	80.516	0.5591
10 1/4"	10.2500	32.201	82.516	0.5730
10 3/8"	10.3750	32.594	84.541	0.5871
10 1/2"	10.5000	32.987	86.590	0.6013
10 5/8"	10.6250	33.379	88.664	0.6157
10 3/4"	10.7500	33.772	90.763	0.6303
10 7/8"	10.8750	34.165	92.886	0.6450
11"	11.0000	34.558	95.033	0.6600
11 1/8"	11.1250	34.950	97.205	0.6750
11 1/4"	11.2500	35.343	99.402	0.6903
11 3/8"	11.3750	35.736	101.6	0.7056
11 1/2"	11.5000	36.128	103.9	0.7213
11 5/8"	11.6250	36.521	106.1	0.7371
11 3/4"	11.7500	36.914	108.4	0.7530
11 7/8"	11.8750	37.306	110.8	0.7691
12"	12.0000	37.699	113.1	0.7854
12 1/4"	12.2500	38.485	117.9	0.819
12 1/2"	12.5000	39.269	122.7	0.851
12 3/4"	12.7500	40.055	127.7	0.886
13"	13.0000	40.841	132.7	0.921
13 1/4"	13.2500	41.626	137.9	0.957
13 1/2"	13.5000	42.412	143.1	0.995
13 3/4"	13.7500	43.197	148.5	1.031
14"	14.0000	43.982	153.9	1.069
14 1/4"	14.2500	44.768	159.5	1.109

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
14 1/2"	14.5000	45.553	165.1	1.149
14 3/4"	14.7500	46.339	170.9	1.185
15"	15.0000	47.124	176.7	1.228
15 1/4"	15.2500	47.909	182.7	1.269
15 1/2"	15.5000	48.695	188.7	1.309
15 3/4"	15.7500	49.480	194.8	1.352
16"	16.0000	50.266	201.1	1.398
16 1/4"	16.2500	51.051	207.4	1.440
16 1/2"	16.5000	51.836	213.8	1.485
16 3/4"	16.7500	52.622	220.4	1.531
17"	17.0000	53.407	227.0	1.578
17 1/4"	17.2500	54.193	233.7	1.619
17 1/2"	17.5000	54.978	240.5	1.673
17 3/4"	17.7500	55.763	247.5	1.719
18"	18.0000	56.548	254.5	1.769
18 1/4"	18.2500	57.334	261.6	1.816
18 1/2"	18.5000	58.120	268.8	1.869
18 3/4"	18.7500	58.905	276.1	1.920
19"	19.0000	59.690	283.5	1.969
19 1/4"	19.2500	60.476	291.0	2.022
19 1/2"	19.5000	61.261	298.7	2.075
19 3/4"	19.7500	62.047	306.4	2.125
20"	20.0000	62.832	314.2	2.182
20 1/4"	20.2500	63.617	322.1	2.237
20 1/2"	20.5000	64.403	330.1	2.292
20 3/4"	20.7500	65.188	338.2	2.348
21"	21.0000	65.974	346.4	2.405
21 1/4"	21.2500	66.759	354.7	2.463
21 1/2"	21.5000	67.544	363.1	2.521
21 3/4"	21.7500	68.330	371.5	2.580
22"	22.0000	69.115	380.1	2.640
22 1/4"	22.2500	69.901	388.8	2.700
22 1/2"	22.5000	70.686	397.6	2.761
22 3/4"	22.7500	71.471	406.5	2.823
23"	23.0000	72.257	415.5	2.885
23 1/4"	23.2500	73.042	424.6	2.948
23 1/2"	23.5000	73.828	433.7	3.012
23 3/4"	23.7500	74.613	443.0	3.076
24"	24.0000	75.398	452.4	3.142
24 1/4"	24.2500	76.184	461.9	3.207
24 1/2"	24.5000	76.969	471.4	3.274
24 3/4"	24.7500	77.755	481.1	3.341
25"	25.0000	78.540	490.9	3.409
25 1/4"	25.2500	79.325	500.7	3.477

TABLE B.1 (Continued)
Areas and Circumferences of Circles and Drill Sizes

Drill Size	Diameter (in.)	Circumference (in.)	Area (in.)	Area (ft)
25 1/2"	25.5000	80.111	510.7	3.547
25 3/4"	25.7500	80.896	520.8	3.616
26"	26.0000	81.682	530.9	3.687
26 1/4"	26.2500	82.467	541.2	3.758
26 1/2"	26.5000	83.252	551.6	3.830
26 3/4"	26.7500	84.038	562.0	3.903
27"	27.0000	84.823	572.6	3.976
27 1/4"	27.2500	85.609	583.2	4.050
27 1/2"	27.5000	86.394	594.0	4.125
27 3/4"	27.7500	87.179	604.8	4.200
28"	28.0000	87.965	615.8	4.276
28 1/4"	28.2500	88.750	626.8	4.353
28 1/2"	28.5000	89.536	637.9	4.430
28 3/4"	28.7500	90.321	649.2	4.508
29"	29.0000	91.106	660.5	4.587
29 1/4"	29.2500	91.892	672.0	4.666
29 1/2"	29.5000	92.677	683.5	4.746
29 3/4"	29.7500	93.463	695.1	4.827
30"	30.0000	94.248	706.9	4.909
31"	31.0000	97.390	754.8	5.241
32"	32.0000	100.53	804.3	5.585
33"	33.0000	103.67	855.3	5.940
34"	34.0000	106.81	907.9	6.305
35"	35.0000	109.96	962.1	6.681
36"	36.0000	113.10	1017.9	7.069
37"	37.0000	116.24	1075.2	7.467
38"	38.0000	119.38	1134.1	7.876
39"	39.0000	122.52	1194.6	8.296
40"	40.0000	125.66	1256.6	8.727
41"	41.0000	128.81	1320.3	9.168
42"	42.0000	131.95	1385.4	9.621
43"	43.0000	135.09	1452.2	10.08
44"	44.0000	138.23	1520.5	10.56
45"	45.0000	141.37	1590.4	11.04
46"	46.0000	144.51	1661.9	11.54
47"	47.0000	147.66	1734.9	12.04
48"	48.0000	150.80	1809.6	12.57
49"	49.0000	153.94	1885.7	13.10
50"	50.0000	157.08	1963.5	13.64

TABLE B.2
Physical Properties of Pipe

Nominal Pipe Size, OD, in.	Schedule Number			Wall Thick- ness, in.	I.D., in.	Inside Area, sq. in.	Metal Area, sq. in.	Sq. Ft. Outside Surface, per ft	Sq. Ft. Inside Surface, per ft	Weight per ft, lb	Weight of Water per ft, lb	Moment of Inertia, in. ⁴	Section Modulus, in. ³	Radius Gyration, in.
	a	b	c											
1/8 0.405	...	.....	10S	0.049	0.307	0.0740	0.0548	0.106	0.0804	0.186	0.0321	0.00088	0.00437	0.1271
	40	Std	40S	0.068	0.269	0.0568	0.0720	0.106	0.0705	0.245	0.0246	0.00106	0.00525	0.1215
	80	XS	80S	0.095	0.215	0.0364	0.0925	0.106	0.0563	0.315	0.0157	0.00122	0.00600	0.1146
1/4 0.540	...	.....	10S	0.065	0.410	0.1320	0.0970	0.141	0.1073	0.330	0.0572	0.00279	0.01032	0.1694
	40	Std	40S	0.088	0.364	0.1041	0.1250	0.141	0.0955	0.425	0.0451	0.00331	0.01230	0.1628
	80	XS	80S	0.119	0.302	0.0716	0.1574	0.141	0.0794	0.535	0.0310	0.00378	0.01395	0.1547
3/8 0.675	...	.....	10S	0.065	0.545	0.2333	0.1246	0.177	0.1427	0.423	0.1011	0.00586	0.01737	0.2169
	40	Std	40S	0.091	0.493	0.1910	0.1670	0.177	0.1295	0.568	0.0827	0.00730	0.02160	0.2090
	80	XS	80S	0.126	0.423	0.1405	0.2173	0.177	0.1106	0.739	0.0609	0.00862	0.02554	0.1991
1/2 0.840	...	.....	10S	0.083	0.674	0.3570	0.1974	0.220	0.1765	0.671	0.1547	0.01431	0.0341	0.2692
	40	Std	40S	0.109	0.622	0.3040	0.2503	0.220	0.1628	0.851	0.1316	0.01710	0.0407	0.2613
	80	XS	80S	0.147	0.546	0.2340	0.3200	0.220	0.1433	1.088	0.1013	0.02010	0.0478	0.2505
	160	.....	...	0.187	0.466	0.1706	0.3830	0.220	0.1220	1.304	0.0740	0.02213	0.0527	0.2402
	...	XXS	...	0.294	0.252	0.0499	0.5040	0.220	0.0660	1.714	0.0216	0.02425	0.0577	0.2192
3/4 1.050	...	.....	5S	0.065	0.920	0.6650	0.2011	0.275	0.2409	0.684	0.2882	0.02451	0.0467	0.349
	...	.....	10S	0.083	0.884	0.6140	0.2521	0.275	0.2314	0.857	0.2661	0.02970	0.0566	0.343
	40	Std	40S	0.113	0.824	0.5330	0.3330	0.275	0.2157	1.131	0.2301	0.0370	0.0706	0.334
	80	XS	80S	0.154	0.742	0.4320	0.4350	0.275	0.1943	1.474	0.1875	0.0448	0.0853	0.321
	160	.....	...	0.218	0.614	0.2961	0.5700	0.275	0.1607	1.937	0.1284	0.0527	0.1004	0.304
	...	XXS	...	0.308	0.434	0.1479	0.7180	0.275	0.1137	2.441	0.0641	0.0579	0.1104	0.284

1 1.315	...	.....	5S	0.065	1.185	1.1030	0.2553	0.344	0.3100	0.868	0.478	0.0500	0.0760	0.443
	...	.....	10S	0.109	1.097	0.9450	0.4130	0.344	0.2872	1.404	0.409	0.0757	0.1151	0.428
	40	Std	40S	0.133	1.049	0.8640	0.4940	0.344	0.2746	1.679	0.374	0.0874	0.1329	0.421
	80	XS	80S	0.179	0.957	0.7190	0.6390	0.344	0.2520	2.172	0.311	0.1056	0.1606	0.407
	160	.....	...	0.250	0.815	0.5220	0.8360	0.344	0.2134	2.844	0.2261	0.1252	0.1903	0.387
1-1/4 1.660	...	XXS	...	0.358	0.599	0.2818	1.0760	0.344	0.1570	3.659	0.1221	0.1405	0.2137	0.361
	...	.....	5S	0.065	1.530	1.839	0.326	0.434	0.401	1.107	0.797	0.1038	0.1250	0.564
	...	.....	10S	0.109	1.442	1.633	0.531	0.434	0.378	1.805	0.707	0.1605	0.1934	0.550
	40	Std	40S	0.140	1.380	1.496	0.669	0.434	0.361	2.273	0.648	0.1948	0.2346	0.540
	80	XS	80S	0.191	1.278	1.283	0.881	0.434	0.335	2.997	0.555	0.2418	0.2913	0.524
1-1/2 1.900	160	.....	...	0.250	1.160	1.057	1.107	0.434	0.304	3.765	0.458	0.2839	0.342	0.506
	...	XXS	...	0.382	0.896	0.631	1.534	0.434	0.2346	5.214	0.2732	0.341	0.411	0.472
	...	.....	5S	0.065	1.770	2.461	0.375	0.497	0.463	1.274	1.067	0.1580	0.1663	0.649
	...	.....	10S	0.109	1.682	2.222	0.613	0.497	0.440	2.085	0.962	0.2469	0.2599	0.634
	40	Std	40S	0.145	1.610	2.036	0.799	0.497	0.421	2.718	0.882	0.310	0.326	0.623
2 2.375	80	XS	80S	0.200	1.500	1.767	1.068	0.497	0.393	3.631	0.765	0.391	0.412	0.605
	160	.....	...	0.281	1.338	1.406	1.429	0.497	0.350	4.859	0.608	0.483	0.508	0.581
	...	XXS	...	0.400	1.100	0.950	1.885	0.497	0.288	6.408	0.412	0.568	0.598	0.549
	...	.....	5S	0.065	2.245	3.960	0.472	0.622	0.588	1.604	1.716	0.315	0.2652	0.817
	...	.....	10S	0.109	2.157	3.650	0.776	0.622	0.565	2.638	1.582	0.499	0.420	0.802
2-1/2 2.875	40	Std	40S	0.154	2.067	3.360	1.075	0.622	0.541	3.653	1.455	0.666	0.561	0.787
	80	XS	80S	0.218	1.939	2.953	1.477	0.622	0.508	5.022	1.280	0.868	0.731	0.766
	160	.....	...	0.343	1.689	2.240	2.190	0.622	0.442	7.444	0.971	1.163	0.979	0.729
	...	XXS	...	0.436	1.503	1.774	2.656	0.622	0.393	9.029	0.769	1.312	1.104	0.703
	...	.....	5S	0.083	2.709	5.76	0.728	0.753	0.709	2.475	2.499	0.710	0.494	0.988
	...	.....	10S	0.120	2.635	5.45	1.039	0.753	0.690	3.531	2.361	0.988	0.687	0.975
	40	Std	40S	0.203	2.469	4.79	1.704	0.753	0.646	5.793	2.076	1.530	1.064	0.947
	80	XS	80S	0.276	2.323	4.24	2.254	0.753	0.608	7.661	1.837	0.193	1.339	0.924
	160	.....	...	0.375	2.125	3.55	2.945	0.753	0.556	10.01	1.535	2.353	1.637	0.894
	...	XXS	...	0.552	1.771	2.46	4.030	0.753	0.464	13.70	1.067	2.872	1.998	0.844

TABLE B.2 (Continued)
Physical Properties of Pipe

Nominal Pipe Size, OD, in.	Schedule Number			Wall Thick- ness, in.	I.D., in.	Inside Area, sq. in.	Metal Area, sq. in.	Sq. Ft. Outside Surface, per ft	Sq. Ft. Inside Surface, per ft	Weight per ft, lb	Weight of Water per ft, lb	Moment of Inertia, in. ⁴	Section Modulus, in. ³	Radius Gyration, in.
	a	b	c											
3 3.500	...	.....	5S	0.083	3.334	8.73	0.891	0.916	0.873	3.03	3.78	1.301	0.744	1.208
	...	.....	10S	0.120	3.260	8.35	1.274	0.916	0.853	4.33	3.61	1.822	1.041	1.196
	40	Std	40S	0.216	3.068	7.39	2.228	0.916	0.803	7.58	3.20	3.02	1.724	1.164
	80	XS	80S	0.300	2.900	6.61	3.020	0.916	0.759	10.25	2.864	3.90	2.226	1.136
	160	.....	...	0.437	2.626	5.42	4.210	0.916	0.687	14.32	2.348	5.03	2.876	1.094
3-1/2 4.000	...	XXS	...	0.600	2.300	4.15	5.470	0.916	0.602	18.58	1.801	5.99	3.43	1.047
	...	.....	5S	0.083	3.834	11.55	1.021	1.047	1.004	3.47	5.01	1.960	0.980	1.385
	...	.....	10S	0.120	3.760	11.10	1.463	1.047	0.984	4.97	4.81	2.756	1.378	1.372
	40	Std	40S	0.226	3.548	9.89	2.68	1.047	0.929	9.11	4.28	4.79	2.394	1.337
	80	XS	80S	0.318	3.364	8.89	3.68	1.047	0.881	12.51	3.85	6.28	3.14	1.307
4 4.500	...	.....	5S	0.083	4.334	14.75	1.152	1.178	1.135	3.92	6.40	2.811	1.249	1.562
	...	.....	10S	0.120	4.260	14.25	1.651	1.178	1.115	5.61	6.17	3.96	1.762	1.549
	40	Std	40S	0.237	4.026	12.73	3.17	1.178	1.054	10.79	5.51	7.23	3.21	1.510
	80	XS	80S	0.337	3.826	11.50	4.41	1.178	1.002	14.98	4.98	9.61	4.27	1.477
	120	.....	...	0.437	3.626	10.33	5.58	1.178	0.949	18.96	4.48	11.65	5.18	1.445
	160	.....	...	0.531	3.438	9.28	6.62	1.178	0.900	22.51	4.02	13.27	5.90	1.416
	...	XXS	...	0.674	3.152	7.80	8.10	1.178	0.825	27.54	3.38	15.29	6.79	1.374
5 5.563	...	.....	5S	0.109	5.345	22.44	1.868	1.456	1.399	6.35	9.73	6.95	2.498	1.929
	...	.....	10S	0.134	5.295	22.02	2.285	1.456	1.386	7.77	9.53	8.43	3.03	1.920
	40	Std	40S	0.258	5.047	20.01	4.30	1.456	1.321	14.62	8.66	15.17	5.45	1.878
	80	XS	80S	0.375	4.813	18.19	6.11	1.456	1.260	20.78	7.89	20.68	7.43	1.839
	120	.....	...	0.500	4.563	16.35	7.95	1.456	1.195	27.04	7.09	25.74	9.25	1.799
	160	.....	...	0.625	4.313	14.61	9.70	1.456	1.129	32.96	6.33	30	10.8	1.760
	...	XXS	...	0.750	4.063	12.97	11.34	1.456	1.064	38.55	5.62	33.6	12.1	1.722

6 6.625	...	.....	5S	0.109	6.407	32.20	2.231	1.734	1.677	5.37	13.98	11.85	3.58	2.304
	...	.....	10S	0.134	6.357	31.70	2.733	1.734	1.664	9.29	13.74	14.4	4.35	2.295
	40	Std	40S	0.280	6.065	28.89	5.58	1.734	1.588	18.97	12.51	28.14	8.5	2.245
	80	XS	80S	0.432	5.761	26.07	8.40	1.734	1.508	28.57	11.29	40.5	12.23	2.195
	120	.....	...	0.562	5.501	23.77	10.70	1.734	1.440	36.39	10.30	49.6	14.98	2.153
	160	.....	...	0.718	5.189	21.15	13.33	1.734	1.358	45.30	9.16	59	17.81	2.104
	...	XXS	...	0.864	4.897	18.83	15.64	1.734	1.282	53.16	8.17	66.3	20.03	2.060
8 8.625	...	.....	5S	0.109	8.407	55.5	2.916	2.258	2.201	9.91	24.07	26.45	6.13	3.01
	...	.....	10S	0.148	8.329	54.5	3.94	2.258	2.180	13.40	23.59	35.4	8.21	3.00
	20	.....	...	0.250	8.125	51.8	6.58	2.258	2.127	22.36	22.48	57.7	13.39	2.962
	30	.....	...	0.277	8.071	51.2	7.26	2.258	2.113	24.70	22.18	63.4	14.69	2.953
	40	Std	40S	0.322	7.981	50.0	8.40	2.258	2.089	28.55	21.69	72.5	16.81	2.938
	60	.....	...	0.406	7.813	47.9	10.48	2.258	2.045	35.64	20.79	88.8	20.58	2.909
	80	XS	80S	0.500	7.625	45.7	12.76	2.258	1.996	43.39	19.80	105.7	24.52	2.878
	100	.....	...	0.593	7.439	43.5	14.96	2.258	1.948	50.87	18.84	121.4	28.14	2.847
	120	.....	...	0.718	7.189	40.6	17.84	2.258	1.882	60.63	17.60	140.6	32.6	2.807
	140	.....	...	0.812	7.001	38.5	19.93	2.258	1.833	67.76	16.69	153.8	35.7	2.777
10 10.750	...	XXS	...	0.875	6.875	37.1	21.30	2.258	1.800	72.42	16.09	162	37.6	2.757
	160	....	...	0.906	6.813	36.5	21.97	2.258	1.784	74.69	15.80	165.9	38.5	2.748
	...	.....	5S	0.134	10.482	86.3	4.52	2.815	2.744	15.15	37.4	63.7	11.85	3.75
	...	.....	10S	0.165	10.420	85.3	5.49	2.815	2.728	18.70	36.9	76.9	14.3	3.74
	20	.....	...	0.250	10.250	82.5	8.26	2.815	2.683	28.04	35.8	113.7	21.16	3.71
	...	.....	...	0.279	10.192	81.6	9.18	2.815	2.668	31.20	35.3	125.9	23.42	3.70
	30	.....	...	0.307	10.136	80.7	10.07	2.815	2.654	34.24	35.0	137.5	25.57	3.69
	40	Std	40S	0.365	10.020	78.9	11.91	2.815	2.623	40.48	34.1	160.8	29.9	3.67
	60	XS	80S	0.500	9.750	74.7	16.10	2.815	2.553	54.74	32.3	212	39.4	3.63
	80	.....	...	0.593	9.564	71.8	18.92	2.815	2.504	64.33	31.1	244.9	45.6	3.60
	100	.....	...	0.718	9.314	68.1	22.63	2.815	2.438	76.93	29.5	286.2	53.2	3.56
	120	.....	...	0.843	9.064	64.5	26.24	2.815	2.373	89.20	28.0	324	60.3	3.52
	140	.....	...	1.000	8.750	60.1	30.6	2.815	2.291	104.13	26.1	368	68.4	3.47
	160	.....	...	1.125	8.500	56.7	34.0	2.815	2.225	115.65	24.6	399	74.3	3.43

TABLE B.2 (Continued)
Physical Properties of Pipe

Nominal Pipe Size, OD, in.	Schedule Number			Wall Thick- ness, in.	I.D., in.	Inside Area, sq. in.	Metal Area, sq. in.	Sq. Ft. Outside Surface, per ft	Sq. Ft. Inside Surface, per ft	Weight per ft, lb	Weight of Water per ft, lb	Moment of Inertia, in. ⁴	Section Modulus, in. ³	Radius Gyration, in.
	a	b	c											
12 12.750	...	.....	5S	0.165	12.420	121.2	6.52	3.34	3.25	19.56	52.5	129.2	20.27	4.45
	...	.....	10S	0.180	12.390	120.6	7.11	3.34	3.24	24.20	52.2	140.5	22.03	4.44
	20	.....	...	0.250	12.250	117.9	9.84	3.34	3.21	33.38	51.1	191.9	30.1	4.42
	30	.....	...	0.330	12.090	114.8	12.88	3.34	3.17	43.77	49.7	248.5	39.0	4.39
	...	Std	40S	0.375	12.000	113.1	14.58	3.34	3.14	49.56	49.0	279.3	43.8	4.38
	40	.....	...	0.406	11.938	111.9	15.74	3.34	3.13	53.53	48.5	300	47.1	4.37
	...	XS	80S	0.500	11.750	108.4	19.24	3.34	3.08	65.42	47.0	362	56.7	4.33
	60	.....	...	0.562	11.626	106.2	21.52	3.34	3.04	73.16	46.0	401	62.8	4.31
	80	.....	...	0.687	11.376	101.6	26.04	3.34	2.978	88.51	44.0	475	74.5	4.27
	100	.....	...	0.843	11.064	96.1	31.5	3.34	2.897	107.20	41.6	562	88.1	4.22
	120	.....	...	1.000	10.750	90.8	36.9	3.34	2.814	125.49	39.3	642	100.7	4.17
	140	.....	...	1.125	10.500	86.6	41.1	3.34	2.749	139.68	37.5	701	109.9	4.13
	160	.....	...	1.312	10.126	80.5	47.1	3.34	2.651	160.27	34.9	781	122.6	4.07
	10	.....	...	0.250	13.500	143.1	10.80	3.67	3.53	36.71	62.1	255.4	36.5	4.86
14 14.000	20	.....	...	0.312	13.376	140.5	13.42	3.67	3.5	45.68	60.9	314	44.9	4.84
	30	Std	...	0.375	13.250	137.9	16.05	3.67	3.47	54.57	59.7	373	53.3	4.82
	40	.....	...	0.437	13.126	135.3	18.62	3.67	3.44	63.37	58.7	429	61.2	4.80
	...	XS	...	0.500	13.000	132.7	21.21	3.67	3.4	72.09	57.5	484	69.1	4.78
	...	.....	...	0.562	12.876	130.2	23.73	3.67	3.37	80.66	56.5	537	76.7	4.76
	60	.....	...	0.593	12.814	129.0	24.98	3.67	3.35	84.91	55.9	562	80.3	4.74
	...	.....	...	0.625	12.750	127.7	26.26	3.67	3.34	89.28	55.3	589	84.1	4.73
	...	.....	...	0.687	12.626	125.2	28.73	3.67	3.31	97.68	54.3	638	91.2	4.71
	80	.....	...	0.750	12.500	122.7	31.2	3.67	3.27	106.13	53.2	687	98.2	4.69
	...	.....	...	0.875	12.250	117.9	36.1	3.67	3.21	122.66	51.1	781	111.5	4.65
	100	.....	...	0.937	12.126	115.5	38.5	3.67	3.17	130.73	50.0	825	117.8	4.63
	120	.....	...	1.093	11.814	109.6	44.3	3.67	3.09	150.67	47.5	930	132.8	4.58
	140	.....	...	1.250	11.500	103.9	50.1	3.67	3.01	170.22	45.0	1127	146.8	4.53
	160	.....	...	1.406	11.188	98.3	55.6	3.67	2.929	189.12	42.6	1017	159.6	4.48

16 16.000	10	.....	...	0.250	15.500	188.7	12.37	4.19	4.06	42.05	81.8	384	48	5.57
	20	.....	...	0.312	15.376	185.7	15.38	4.19	4.03	52.36	80.5	473	59.2	5.55
	30	Std	...	0.375	15.250	182.6	18.41	4.19	3.99	62.58	79.1	562	70.3	5.53
	...	.....	...	0.437	15.126	179.7	21.37	4.19	3.96	72.64	77.9	648	80.9	5.50
	40	XS	...	0.500	15.000	176.7	24.35	4.19	3.93	82.77	76.5	732	91.5	5.48
	...	.....	...	0.562	14.876	173.8	27.26	4.19	3.89	92.66	75.4	813	106.6	5.46
	...	.....	...	0.625	14.750	170.9	30.2	4.19	3.86	102.63	74.1	894	112.2	5.44
	60	.....	...	0.656	14.688	169.4	31.6	4.19	3.85	107.50	73.4	933	116.6	5.43
	...	.....	...	0.687	14.626	168.0	33.0	4.19	3.83	112.36	72.7	971	121.4	5.42
	...	.....	...	0.750	14.500	165.1	35.9	4.19	3.8	122.15	71.5	1047	130.9	5.40
	80	.....	...	0.842	14.314	160.9	40.1	4.19	3.75	136.46	69.7	1157	144.6	5.37
	...	.....	...	0.875	14.250	159.5	41.6	4.19	3.73	141.35	69.1	1193	154.1	5.36
	100	.....	...	1.031	13.938	152.6	48.5	4.19	3.65	164.83	66.1	1365	170.6	5.30
	120	.....	...	1.218	13.564	144.5	56.6	4.19	3.55	192.29	62.6	1556	194.5	5.24
	140	.....	...	1.437	13.126	135.3	65.7	4.19	3.44	223.50	58.6	1760	220.0	5.17
	160	.....	...	1.593	12.814	129.0	72.1	4.19	3.35	245.11	55.9	1894	236.7	5.12
18 18.000	10	.....	...	0.250	17.500	240.5	13.94	4.71	4.58	47.39	104.3	549	61.0	6.28
	20	.....	...	0.312	17.376	237.1	17.34	4.71	4.55	59.03	102.8	678	75.5	6.25
	...	Std	...	0.375	17.250	233.7	20.76	4.71	4.52	70.59	101.2	807	89.6	6.23
	30	.....	...	0.437	17.126	230.4	24.11	4.71	4.48	82.06	99.9	931	103.4	6.21
	...	XS	...	0.500	17.000	227.0	27.49	4.71	4.45	93.45	98.4	1053	117.0	6.19
	40	.....	...	0.562	16.876	223.7	30.8	4.71	4.42	104.75	97.0	1172	130.2	6.17
	...	.....	...	0.625	16.750	220.5	34.1	4.71	4.39	115.98	95.5	1289	143.3	6.15
	...	.....	...	0.687	16.626	217.1	37.4	4.71	4.35	127.03	94.1	1403	156.3	6.13
	60	.....	...	0.750	16.500	213.8	40.6	4.71	4.32	138.17	92.7	1515	168.3	6.10
	...	.....	...	0.875	16.250	207.4	47.1	4.71	4.25	160.04	89.9	1731	192.8	6.06
	80	.....	...	0.937	16.126	204.2	50.2	4.71	4.22	170.75	88.5	1834	203.8	6.04
	100	.....	...	1.156	15.688	193.3	61.2	4.71	4.11	207.96	83.7	2180	242.2	5.97
	120	.....	...	1.375	15.250	182.6	71.8	4.71	3.99	244.14	79.2	2499	277.6	5.90
	140	.....	...	1.562	14.876	173.8	80.7	4.71	3.89	274.23	75.3	2750	306	5.84
	160	.....	...	1.781	14.438	163.7	90.7	4.71	3.78	308.51	71.0	3020	336	5.77

TABLE B.2 (Continued)
Physical Properties of Pipe

Nominal Pipe Size, OD, in.	Schedule Number			Wall Thick- ness, in.	I.D., in.	Inside Area, sq. in.	Metal Area, sq. in.	Sq. Ft. Outside Surface, per ft	Sq. Ft. Inside Surface, per ft	Weight per ft, lb	Weight of Water per ft, lb	Moment of Inertia, in. ⁴	Section Modulus, in. ³	Radius Gyration, in.
	a	b	c											
20 20.000	10	.....	...	0.250	19.500	298.6	15.51	5.24	5.11	52.73	129.5	757	75.7	6.98
	...	.....	...	0.312	19.376	294.9	19.30	5.24	5.07	65.40	128.1	935	93.5	6.96
	20	Std	...	0.375	19.250	291.0	23.12	5.24	5.04	78.60	126.0	1114	111.4	6.94
	...	.....	...	0.437	19.126	287.3	26.86	5.24	5.01	91.31	124.6	1286	128.6	6.92
	30	XS	...	0.500	19.000	283.5	30.6	5.24	4.97	104.13	122.8	1457	145.7	6.90
	...	.....	...	0.562	18.876	279.8	34.3	5.24	4.94	116.67	121.3	1624	162.4	6.88
	40	.....	...	0.593	18.814	278.0	36.2	5.24	4.93	122.91	120.4	1704	170.4	6.86
	...	.....	...	0.625	18.750	276.1	38.0	5.24	4.91	129.33	119.7	1787	178.7	6.85
	...	.....	...	0.687	18.626	272.5	41.7	5.24	4.88	141.71	118.1	1946	194.6	6.83
	...	.....	...	0.750	18.500	268.8	45.4	5.24	4.84	154.20	116.5	2105	210.5	6.81
	60	.....	...	0.812	18.376	265.2	48.9	5.24	4.81	166.40	115.0	2257	225.7	6.79
	...	.....	...	0.875	18.250	261.6	52.6	5.24	4.78	178.73	113.4	2409	240.9	6.77
	80	.....	...	1.031	17.938	252.7	61.4	5.24	4.70	208.87	109.4	2772	277.2	6.72
	100	.....	...	1.281	17.438	238.8	75.3	5.24	4.57	256.10	103.4	3320	332	6.63
	120	.....	...	1.500	17.000	227.0	87.2	5.24	4.45	296.37	98.3	3760	376	6.56
	140	.....	...	1.750	16.500	213.8	100.3	5.24	4.32	341.10	92.6	4220	422	6.48
	160	.....	...	1.968	16.064	202.7	111.5	5.24	4.21	379.01	87.9	4590	459	6.41

24 24.000	10	.....	...	0.250	23.500	434	18.65	6.28	6.15	63.41	188.0	1316	109.6	8.40
	...	.....	...	0.312	23.376	430	23.20	6.28	6.12	78.93	186.1	1629	135.8	8.38
	20	Std	...	0.375	23.250	425	27.83	6.28	6.09	94.62	183.8	1943	161.9	8.35
	...	.....	...	0.437	23.126	420	32.4	6.28	6.05	109.97	182.1	2246	187.4	8.33
	...	XS	...	0.500	23.000	415	36.9	6.28	6.02	125.49	180.1	2550	212.5	8.31
	30	.....	...	0.562	22.876	411	41.4	6.28	5.99	140.80	178.1	2840	237.0	8.29
	...	.....	...	0.625	22.750	406	45.9	6.28	5.96	156.03	176.2	3140	261.4	8.27
	40	.....	...	0.687	22.626	402	50.3	6.28	5.92	171.17	174.3	3420	285.2	8.25
	...	.....	...	0.750	22.500	398	54.8	6.28	5.89	186.24	172.4	3710	309	8.22
	60	.....	...	0.968	22.064	382	70.0	6.28	5.78	238.11	165.8	4650	388	8.15
	80	.....	...	1.218	21.564	365	87.2	6.28	5.65	296.36	158.3	5670	473	8.07
	100	.....	...	1.531	20.938	344	108.1	6.28	5.48	367.40	149.3	6850	571	7.96
	120	.....	...	1.812	20.376	326	126.3	6.28	5.33	429.39	141.4	7830	652	7.87
	140	.....	...	2.062	19.876	310	142.1	6.28	5.20	483.13	134.5	8630	719	7.79
	160	.....	...	2.343	19.314	293	159.4	6.28	5.06	541.94	127.0	9460	788	7.70
30 30.000	10	.....	...	0.312	29.376	678	29.1	7.85	7.69	98.93	293.8	3210	214	10.50
	20	.....	...	0.500	29.000	661	46.3	7.85	7.59	157.53	286.3	5040	336	10.43
	30	.....	...	0.625	28.750	649	57.6	7.85	7.53	196.08	281.5	6220	415	10.39

a = ASA B36.10 Steel-pipe schedule numbers

b = ASA B36.10 Steel-pipe nominal wall-thickness designations

c = ASA B36.19 Stainless-steel-pipe schedule numbers

TABLE B.3
Physical Properties of Tubing*

The following table gives dimensional data and weights of copper tubing used for automotive, plumbing, refrigeration, and heat exchanger services. For additional data see the standards handbooks of the Copper Development Association, Inc., the ASTM standards, and the "SAE Handbook."

Dimensions in this table are actual specified measurements, subject to accepted tolerances. Trade size designations are usually by actual OD, except for water and drainage tube (plumbing), which measures 1/8-in. larger OD. A 1/2-in. plumbing tube, for example, measures 5/8-in. OD, and a 2-in. plumbing tube measures 2 1/8-in. OD.

KEY TO GAGE SIZES

Standard-gage wall thicknesses are listed by numerical designation (14 to 21), BWG or Stubs gage. These gage sizes are standard for tubular heat exchangers. The letter *A* designates SAE tubing sizes for automotive service. Letter designations *K* and *L* are the common sizes for plumbing services, soft or hard temper.

OTHER MATERIALS

These same dimensional sizes are also common for much of the commercial tubing available in aluminum, mild steel, brass, bronze, and other alloys. Tube weights in this table are based on copper at 0.323 lb/in³. For other materials the weights should be multiplied by the following approximate factors:

aluminum	0.30	monel	0.96
mild steel	0.87	stainless steel	0.89
brass	0.95		

Size, OD		Wall Thickness			Flow Area		Metal Area, in. ²	Surface Area		Weight, lb/ft
in.	mm	in.	mm	gage	in. ²	mm ²		Inside, ft ² /ft	Outside, ft ² /ft	
1/8	3.2	.030	0.76	A	0.003	1.9	0.012	0.017	0.033	0.035
3/16	4.76	.030	0.76	A	0.013	8.4	0.017	0.034	0.049	0.058
1/4	6.4	.030	0.76	A	0.028	18.1	0.021	0.050	0.066	0.080
1/4	6.4	.049	1.24	18	0.018	11.6	0.031	0.038	0.066	0.120
5/16	7.94	.032	0.81	21A	0.048	31.0	0.028	0.065	0.082	0.109
3/8	9.53	.032	0.81	21A	0.076	49.0	0.033	0.081	0.098	0.134
3/8	9.53	.049	1.24	18	0.060	38.7	0.050	0.072	0.098	0.195
1/2	12.7	.032	0.81	21A	0.149	96.1	0.047	0.114	0.131	0.182
1/2	12.7	.035	0.89	20L	0.145	93.6	0.051	0.113	0.131	0.198
1/2	12.7	.049	1.24	18K	0.127	81.9	0.069	0.105	0.131	0.269
1/2	12.7	.065	1.65	16	0.108	69.7	0.089	0.97	0.131	0.344
5/8	15.9	.035	0.89	20A	0.242	156	0.065	0.145	0.164	0.251
5/8	15.9	.040	1.02	L	0.233	150	0.074	0.143	0.164	0.285
5/8	15.9	.049	1.24	18K	0.215	139	0.089	0.138	0.164	0.344
3/4	19.1	.035	0.89	20A	0.363	234	0.079	0.178	0.196	0.305
3/4	19.1	.042	1.07	L	0.348	224	0.103	0.174	0.196	0.362
3/4	19.1	.049	1.24	18K	0.334	215	0.108	0.171	0.196	0.418
3/4	19.1	.065	1.65	16	0.302	195	0.140	0.162	0.196	0.542
3/4	19.1	.083	2.11	14	0.268	173	0.174	0.151	0.196	0.674
7/8	22.2	.045	1.14	L	0.484	312	0.117	0.206	0.229	0.455
7/8	22.2	.065	1.65	16K	0.436	281	0.165	0.195	0.229	0.641
7/8	22.2	.083	2.11	14	0.395	255	0.206	0.186	0.229	0.800
1	25.4	.065	1.65	16	0.594	383	0.181	0.228	0.262	0.740
1	25.4	.083	2.11	14	0.546	352	0.239	0.218	0.262	0.927
1 1/8	28.6	.050	1.27	L	0.825	532	0.176	0.268	0.294	0.655

TABLE B.3 (Continued)
Physical Properties of Tubing*

Size, OD		Wall Thickness			Flow Area		Metal Area, in. ²	Surface Area		Weight, lb/ft
in.	mm	in.	mm	gage	in. ²	mm ²		Inside, ft ² /ft	Outside, ft ² /ft	
1 1/8	28.6	.065	1.65	16K	0.778	502	0.216	0.261	0.294	0.839
1 1/4	31.8	.065	1.65	16	0.985	636	0.242	0.293	0.327	0.938
1 1/4	31.8	.083	2.11	14	0.923	596	0.304	0.284	0.327	1.18
1 3/8	34.9	.055	1.40	L	1.257	811	0.228	0.331	0.360	0.884
1 3/8	34.9	.065	1.65	16K	1.217	785	0.267	0.326	0.360	1.04
1 1/2	38.1	.065	1.65	16	1.474	951	0.294	0.359	0.393	1.14
1 1/2	38.7	.083	2.11	14	1.398	902	0.370	0.349	0.393	1.43
1 5/8	41.3	.060	1.52	L	1.779	1148	0.295	0.394	0.425	1.14
1 5/8	41.3	.072	1.83	K	1.722	1111	0.351	0.388	0.425	1.36
2	50.8	.083	2.11	14	2.642	1705	0.500	0.480	0.628	1.94
2	50.8	.109	2.76	12	2.494	1609	0.620	0.466	0.628	2.51
2 1/8	54.0	.070	1.78	L	3.095	1997	0.449	0.520	0.556	1.75
2 1/8	54.0	.083	2.11	14K	3.016	1946	0.529	0.513	0.556	2.06
2 5/8	66.7	.080	2.03	L	4.77	3078	0.645	0.645	0.687	2.48
2 5/8	66.7	.095	2.41	13K	4.66	3007	0.760	0.637	0.687	2.93
3 1/8	79.4	.090	2.29	L	6.81	4394	0.950	0.771	0.818	3.33
3 1/8	79.4	.109	2.77	12K	6.64	4284	1.034	0.761	0.818	4.00
3 5/8	92.1	.100	2.54	L	9.21	5942	1.154	0.897	0.949	4.29
3 5/8	92.1	.120	3.05	11K	9.00	5807	1.341	0.886	0.949	5.12
4 1/8	104.8	.110	2.79	L	11.92	7691	1.387	1.022	1.080	5.38
4 1/8	104.8	.134	3.40	10K	11.61	7491	1.682	1.009	1.080	6.51

* Compiled and computed.

From: *The CRC Handbook of Mechanical Engineering*, CRC Press, Boca Raton, FL, 1998.

TABLE B.4
SAE Grades for Steel Bolts

SAE grade no.	Size range incl.	Proof strength, † kpsi	Tensile strength, † kpsi	Material	Head marking
1	$\frac{1}{4}$ – $1\frac{1}{4}$			Low- or medium-carbon steel	
2	$\frac{1}{4}$ – $\frac{1}{2}$ $\frac{3}{4}$ – $1\frac{1}{2}$	55 33	74 60		
5	$\frac{1}{4}$ –1 $1\frac{1}{2}$ – $1\frac{1}{2}$	85 74	120 105	Medium-carbon steel, Q & T	
5.2	$\frac{1}{4}$ –1	85	120	Low-carbon martensite steel, Q & T	
7	$\frac{1}{4}$ – $1\frac{1}{2}$	105	133	Medium-carbon alloy steel, Q & T ‡	
8	$\frac{1}{4}$ – $1\frac{1}{2}$	120	150	Medium-carbon alloy steel, Q & T	
8.2	$\frac{1}{4}$ –1	120	150	Low-carbon martensite steel, Q & T	

†Minimum values.

‡Roll threaded after heat treatment.

Sources: See "Helpful Hints," by Russell, Burdall & Ward Corp., Mentor, Ohio 44060; and Chap. 23.

From: The CRC Press Handbook of Mechanical Engineering, CRC Press, Boca Raton, FL, 1998.

TABLE B.5
ASTM Grades for Steel Bolts

ASTM designation	Size range incl.	Proof strength,† kpsi	Tensile strength,† kpsi	Material	Head marking
A307	$\frac{1}{2}$ to 4			Low-carbon steel	
A325 type 1	$\frac{1}{2}$ to 1	85	120	Medium-carbon steel, Q & T	
	$1\frac{1}{8}$ to $1\frac{1}{2}$	74	105		
A325 type 2	$\frac{1}{2}$ to 1	85	120	Low-carbon martensite steel, Q & T	
	$1\frac{1}{8}$ to $1\frac{1}{2}$	74	105		
A325 type 3	$\frac{1}{2}$ to 1	85	120	Weathering steel, Q & T	
	$1\frac{1}{8}$ to $1\frac{1}{2}$	74	105		
A354 grade BC				Alloy steel, Q & T	
A354 grade BD	$\frac{1}{2}$ to 4	120	150	Alloy steel, Q & T	
A449	$\frac{1}{2}$ to 1	85	120	Medium-carbon steel, Q & T	
	$1\frac{1}{8}$ to $1\frac{1}{2}$	74	105		
	$1\frac{1}{2}$ to 3	55	90		
A490 type 1	$\frac{1}{2}$ to $1\frac{1}{2}$	120	150	Alloy steel, Q & T	
A490 type 3				Weathering steel, Q & T	

† Minimum value.

Sources: See "Helpful Hints," by Russell, Burdick & Ward Corp., Mentor, Ohio 44060; and Chapter 23

From: *The CRC Press Handbook of Mechanical Engineering*, CRC Press, Boca Raton, FL, 1998.

TABLE B.6
Properties for Metric Steel Bolts, Screws, and Studs

Property class	Size range incl.	Proof strength, MPa	Tensile strength, MPa	Material	Head marking
4.6	M5–M36	225	400	Low- or medium-carbon steel	
4.8	M1.6–M16	310	420	Low- or medium-carbon steel	
5.8	M5–M24	380	520	Low- or medium-carbon steel	
8.8	M1.6–M36	600	830	Medium-carbon steel, Q & T	
9.8	M1.6–M16	650	900	Medium-carbon steel, Q & T	
10.9	M5–M36	830	1040	Low-carbon martensite steel, Q & T	
12.9	M1.6–M36	970	1220	Alloy steel, Q & T	

sources: "Helpful Hints," by Russell, Burdall & Waard Corp., Mentor, Ohio 44060; see also Chapter 23 and SAE standard J1199, and ASTM standard F568.

From: The CRC Press Handbook of Mechanical Engineering, CRC Press, Boca Raton, FL, 1998.

Appendix C

Material Properties

TABLE C.1
Alphabetical List of Atomic Weights for Common Elements¹

Name	Symbol	At. No.	Atomic Weight	Footnotes
Actinium	Ac	89	[227]	
Aluminum	Al	13	26.981538(2)	
Americium	Am	95	[243]	
Antimony	Sb	51	121.760(1)	g
Argon	Ar	18	39.948(1)	g r
Arsenic	As	33	74.92160(2)	
Astatine	At	85	[210]	
Barium	Ba	56	137.32(7)	
Berkelium	Bk	97	[247]	
Beryllium	Be	4	9.012182(3)	
Bismuth	Bi	83	208.98038(2)	
Bohrium	Bh	107	[264]	
Boron	B	5	10.811(7)	g m r
Bromine	Br	35	79.904(1)	
Cadmium	Cd	48	112.411(8)	g
Calcium	Ca	20	40.078(4)	g
Californium	Cf	98	[251]	
Carbon	C	6	12.0107(8)	g r
Cerium	Ce	58	140.116(1)	g
Cesium	Cs	55	132.90545(2)	
Chlorine	Cl	17	35.4527(9)	m
Chromium	Cr	24	51.9961(6)	
Cobalt	Co	27	58.933200(9)	
Copper	Cu	29	63.546(3)	r
Curium	Cm	96	[247]	
Dubnium	Db	105	[262]	
Dysprosium	Dy	66	162.59(3)	g
Einsteinium	Es	99	[252]	
Erbium	Er	68	167.26(3)	g
Europium	Eu	63	151.964(1)	g
Fermium	Fm	100	[257]	
Fluorine	F	9	18.9984032(5)	
Francium	Fr	87	[223]	
Gadolinium	Gd	64	157.25(3)	g
Gallium	Ga	31	69.723(1)	
Germanium	Ge	32	72.61(2)	
Gold	Au	79	196.96655(2)	
Hafnium	Hf	72	178.49(2)	
Hassium	Hs	108	[269]	
Helium	He	2	4.002602(2)	g r

TABLE C.1 (Continued)
Alphabetical List of Atomic Weights for Common Elements¹

Name	Symbol	At. No.	Atomic Weight	Footnotes
Holmium	Ho	67	164.93032(2)	
Hydrogen	H	1	1.00794(7)	g m r
Indium	In	49	114.818(3)	
Iodine	I	53	126.90447(3)	
Iridium	Ir	77	192.217(3)	
Iron	Fe	26	55.845(2)	
Krypton	Kr	36	83.80(1)	g m
Lanthanum	La	57	138.9055(2)	g
Lawrencium	Lr	103	[262]	
Lead	Pb	82	207.2(1)	g r
Lithium	Li	3	6.941(2)	g m r
Lutetium	Lu	71	174.967(1)	g
Magnesium	Mg	12	24.3050(6)	
Manganese	Mn	25	54.938049(9)	
Meitnerium	Mt	109	[268]	
Mendelevium	Md	101	[258]	
Mercury	Hg	80	200.59(2)	
Molybdenum	Mo	42	95.94(1)	g
Neodymium	Nd	60	144.24(3)	g
Neon	Ne	10	20.1797(6)	g m
Neptunium	Np	93	[237]	
Nickel	Ni	28	58.6934(2)	
Niobium	Nb	41	92.90638(2)	
Nitrogen	N	7	14.00674(7)	g r
Nobelium	No	102	[259]	
Osmium	Os	76	190.23(3)	g
Oxygen	O	8	15.9994(3)	g r
Palladium	Pd	46	106.42(1)	g
Phosphorus	P	15	30.973761(2)	
Platinum	Pt	78	195.078(2)	
Plutonium	Pu	94	[244]	
Polonium	Po	84	[209]	
Potassium	K	19	39.0983(1)	g
Praseodymium	Pr	59	140.90765(2)	
Promethium	Pm	61	[145]	
Protactinium	Pa	91	231.03588(2)	
Radium	Ra	88	[226]	
Radon	Rn	86	[222]	
Rhenium	Re	75	186.207(1)	
Rhodium	Rh	45	102.90550(2)	
Rubidium	Rb	37	85.4678(3)	g
Ruthenium	Ru	44	101.07(2)	g
Rutherfordium	Rf	104	[261]	
Samarium	Sm	62	150.36(3)	g
Scandium	Sc	21	44.955910(8)	
Seaborgium	Sg	106	[266]	
Selenium	Se	34	78.96(3)	
Silicon	Si	14	28.0855(3)	r

TABLE C.1 (Continued)
Alphabetical List of Atomic Weights for Common Elements¹

Name	Symbol	At. No.	Atomic Weight	Footnotes
Silver	Ag	47	107.8682(2)	g
Sodium	Na	11	22.989770(2)	
Strontium	Sr	38	87.62(1)	g r
Sulfur	S	16	32.066(6)	g r
Tantalum	Ta	73	180.9479(1)	
Technetium	Tc	43	[98]	
Tellurium	Te	52	127.60(3)	g
Terbium	Tb	65	158.92534(2)	
Thallium	Tl	81	204.3833(2)	
Thorium	Th	90	232.0381(1)	g
Thulium	Tm	69	168.93421(2)	
Tin	Sn	50	118.710(7)	g
Titanium	Ti	22	47.867(1)	
Tungsten	W	74	183.84(1)	
Uranium	U	92	238.0289(1)	g m
Vanadium	V	23	50.9415(1)	
Xenon	Xe	54	131.29(2)	g m
Ytterbium	Yb	70	173.04(3)	g
Yttrium	Y	39	88.90585(2)	
Zinc	Zn	30	65.39(2)	
Zirconium	Zr	40	92.224(2)	g

g – geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the table may exceed the stated uncertainty.

m – modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. Substantial deviations in atomic weight of the element from that given the table can occur.

r – range in isotopic composition of normal terrestrial material prevents a more precise atomic weight being given; the tabulated atomic weight value should be applicable to any normal material.

This table of atomic weights is reprinted from the 1995 report of the IUPAC Commission on Atomic Weights and Isotopic Abundances. The Standard Atomic Weights apply to the elements as they exist naturally on Earth, and the uncertainties take into account the isotopic variation found in most laboratory samples. Further comments on the variability are given in the footnotes.

The number in parentheses following the atomic weight value gives the uncertainty in the last digit. An entry in brackets indicates that mass number of the longest-lived isotope of an element that has no stable isotopes and for which a Standard Atomic Weight cannot be defined because of wide variability in isotopic composition (or complete absence) in nature.

REFERENCE

IUPAC Commission on Atomic Weights and Isotopic Abundances, Atomic Weights of the Elements, 1995, *Pure Appl. Chem.*, 68, 2339, 1996.

Source: Courtesy of CRC Press.¹

TABLE C.2
Volumetric Analysis of Typical Gaseous Fuel Mixtures

Fuel Gas Component	Natural Gas				LPG		Refinery Gases (Dry)						Waste Gases	
	Tulsa	Alaska	Netherlands	Algeria	Propane	Butane	Cracked Gas	Coking Gas	Reforming Gas	FCC Gas	Refinery Gas Sample 1	Refinery Gas Sample 2	PSA Gas	Flexicoking Gas
CH ₄	93.4%	99%	81%	87%	—	—	65%	40%	28%	32%	36%	53%	17%	1%
C ₂ H ₄	—	—	—	—	—	—	3%	3%	7%	7%	5%	2%	—	—
C ₂ H ₆	2.7%	—	3%	9%	—	—	16%	21%	28%	9%	18%	19%	—	—
C ₃ H ₆	—	—	—	—	—	—	2%	1%	3%	15%	8%	6%	—	—
C ₃ H ₈	0.6%	—	0.4%	2.7%	100%	—	7%	24%	22%	25%	20%	14%	—	—
C ₄ H ₈	—	—	—	—	—	100%	1%	—	—	—	—	—	—	—
C ₄ H ₁₀	0.2%	—	0.1%	1.1%	—	—	3%	7%	7%	0%	2%	1%	—	—
C ₅ & Higher	—	—	—	—	—	—	1%	—	—	—	—	—	—	—
H ₂	—	—	—	—	—	—	3%	4%	5%	6%	3%	3%	28%	21%
CO	—	—	—	—	—	—	—	—	—	—	—	—	10%	20%
CO ₂	0.7%	—	0.9%	—	—	—	—	—	—	—	—	—	44%	10%
N ₂	2.4%	1%	14%	0%	—	—	—	—	—	7%	8%	3%	<1%	45%
H ₂ O	—	—	—	—	—	—	—	—	—	—	—	—	<1%	3%
O ₂	—	—	—	—	—	—	—	—	—	—	—	—	—	—
H ₂ S	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Data compiled from a variety of sources.

TABLE C.3
Physical Constants of Typical Gaseous Fuel Mixtures

Fuel Gas Component	Natural Gas				LPG		Refinery Gases (Dry)						Waste Gases	
	Tulsa	Alaska	Netherlands	Algeria	Propane	Butane	Cracked Gas	Coking Gas	Reforming Gas	FCC Gas	Refinery Gas Sample 1	Refinery Gas Sample 2	PSA Gas	Flexicoking Gas
Molecular weight	17.16	16.1	18.51	18.49	44.1	58.12	22.76	28.62	30.21	29.18	28.02	24.61	25.68	23.73
Lower heating value (LHV), Btu/SCF	913	905	799	1025	2316	3010	1247	1542	1622	1459	1389	1297	263	131
Higher heating value (HHV), Btu/SCF	1012	1005	886	1133	2517	3262	1369	1686	1769	1587	1515	1421	294	142
Specific gravity (14.696 psia/60°F, Air = 1.0)	0.59	0.56	0.64	0.64	1.53	1.1	0.79	0.99	1.05	1.01	0.97	0.85	0.89	0.82
Wobbe number, HHV/(SG ^{1/2})	1318	1343	1108	1416	2035	3110	1540	1694	1726	1579	1538	1541	312	157
Isentropic coefficient (Cp/Cv)	1.30	1.31	1.31	1.28	1.13	1.10	1.24	1.19	1.19	1.20	1.21	1.23	1.33	1.38
Stoichiometric air required, SCF/MMBtu	10554	10567	10554	10525	10369	10371	10402	10379	10322	10234	10311	10375	9667	8265
Stoichiometric air required, lb _m /MMBtu	805	806	805	803	791	791	794	792	787	781	787	792	738	630
Air required for 15% excess air, SCF/MMBtu	12138	12152	12138	12104	11925	11926	11962	11936	11870	11769	11858	11931	11117	9505
Air required for 15% excess air, lb _m /MMBtu	923	924	923	920	907	907	910	908	903	895	902	907	845	723
Volume of dry combustion products, SCF/MMBtu	10983	10956	11141	10953	10962	10996	10890	10909	10871	10847	10911	10904	11722	13517
Weight of dry combustion products, lb _m /MMBtu	865	862	876	863	870	874	861	864	862	860	864	862	985	1103
Volume of wet combustion products, SCF/MMBtu	13257	13258	13415	13163	12788	12757	12935	12862	12771	12689	12821	12902	14198	15585
Weight of wet combustion products, lb _m /MMBtu	973	971	984	968	957	958	958	957	952	948	864	957	1102	1201
Adiabatic flame temperature, °F	3306	3308	3284	3317	3351	3351	3342	3348	3359	3371	3353	3345	3001	2856

Note: All values calculated using 60°F fuel gas and 60°F, 50% relative humidity combustion air.

TABLE C.4
Physical Constants of Typical Gaseous Fuel Mixture Components

No.	Fuel Gas Component	Chemical Formula	Molecular Weight	Boiling Point 14,696 psia (°F)	Vapor Pressure 100°F (psia)	Specific Heat Capacity, C _p 60°F & 14,696 psia (Btu/lb _m /°F)	Latent Heat of Vaporization 14,696 psia & Boiling Point (Btu/lb _m)	Gas Density Ideal Gas, 14,696 psia, 60°F										Heating Value								Theoretical Air Required (lb _m /10,000 Btu)										Flammability Limits (vol% in air mixture)		
								Specific Gravity (Air = 1)	Gas Density (lb _m /ft ³)	Specific Volume (ft ³ /lb _m)	LHV (Net)	HHV (Gross)	LHV (Net)	HHV (Gross)	Unit Volume per Unit Volume of Combustible				Unit Mass per Unit Mass of Combustible				O ₂	N ₂	Air	CO ₂	H ₂ O	N ₂	SO ₂	Lower	Upper	No.						
															Required for Combustion		Flue Gas Products		Required for Combustion		Flue Gas Products																	
															Paraffin (alkane) Series (C _n H _{2n+2})																							
1	Methane	CH ₄	16.04	-258.69	—	0.5266	219.22	0.554	0.042	23.651	912	1,013	21,495	23,845	2.0	7.547	9.547	1.0	2.0	7.547	—	3.989	13.246	17.235	2.743	2.246	13.246	—	7.219	5.0	15.0	1						
2	Ethane	C ₂ H ₆	30.07	-127.48	—	0.4097	210.41	1.038	0.079	12.618	1,639	1,792	20,418	22,323	3.5	13.206	16.706	2.0	3.0	13.206	—	3.724	12.367	16.092	2.927	1.797	12.367	—	7.209	2.9	13.0	2						
3	Propane	C ₃ H ₈	44.10	-43.67	190	0.3881	183.05	1.522	0.116	8.604	2,385	2,592	19,937	21,669	5.0	18.866	23.866	3.0	4.0	18.866	—	3.628	12.047	15.676	2.994	1.624	12.047	—	7.234	2.1	9.5	3						
4	<i>n</i> -Butane	C ₄ H ₁₀	58.12	31.10	51.6	0.3867	165.65	2.007	0.153	6.528	3,113	3,373	19,679	21,321	6.5	24.526	31.026	4.0	5.0	24.526	—	3.578	11.882	15.460	3.029	1.550	11.882	—	7.251	1.8	8.4	4						
5	Isobutane	C ₄ H ₁₀	58.12	10.90	72.2	0.3872	157.53	2.007	0.153	6.528	3,105	3,365	19,629	21,271	6.5	24.526	31.026	4.0	5.0	24.526	—	3.578	11.882	15.460	3.029	1.550	11.882	—	7.268	1.8	8.4	5						
6	<i>n</i> -Pentane	C ₅ H ₁₂	72.15	96.92	15.57	0.3883	153.59	2.491	0.190	5.259	3,714	4,017	19,507	21,095	8.0	30.186	38.186	5.0	6.0	30.186	—	3.548	11.781	15.329	3.050	1.498	11.781	—	7.267	1.4	8.3	6						
7	isopentane	C ₅ H ₁₂	72.15	82.12	20.44	0.3827	147.13	2.491	0.190	5.259	3,705	4,017	19,459	21,047	8.0	30.186	38.186	5.0	6.0	30.186	—	3.548	11.781	15.329	3.050	1.498	11.781	—	7.283	1.4	8.3	7						
8	Neopentane	C ₅ H ₁₂	72.15	49.10	35.9	0.3666	135.58	2.491	0.190	5.259	3,692	3,994	19,390	20,978	8.0	30.186	38.183	5.0	6.0	30.186	—	3.548	11.781	15.329	3.050	1.498	11.781	—	7.307	1.4	8.3	8						
9	<i>n</i> -Hexane	C ₆ H ₁₄	86.18	155.72	4.956	0.3664	143.95	2.975	0.227	4.403	4,415	4,767	19,415	20,966	9.5	35.846	45.346	6.0	7.0	35.846	—	3.527	11.713	15.240	3.064	1.463	11.713	—	7.269	1.2	7.7	9						
Naphthene (cycloalkane) Series (C _n H _{2n})																																						
10	Cyclopentane	C ₅ H ₁₀	70.13	120.60	9.917	0.2712	137.35	2.420	0.180	5.556	3,512	3,764	19,005	20,368	7.5	27.939	35.180	5.0	5.0	28.939	—	3.850	11.155	14.793	3.146	1.283	11.155	—	7.262	—	—	10						
11	Cyclohexane	C ₆ H ₁₂	84.16	177.40	3.267	0.2901	153.25	2.910	0.220	5.545	4,180	4,482	18,849	20,211	9.0	33.528	42.970	6.0	6.0	33.528	—	4.620	13.386	17.750	3.146	1.283	11.155	—	7.848	1.3	8.4	11						
Olefin Series (C _n H _{2n})																																						
12	Ethene (Ethylene)	C ₂ H ₄	28.05	-154.62	—	0.3622	207.57	0.969	0.074	13.525	1,512	1,613	20,275	21,636	3.0	11.320	14.320	2.0	2.0	11.320	—	3.422	11.362	14.784	3.138	1.284	11.362	—	6.833	2.7	34.0	12						
13	Propene (Propylene)	C ₃ H ₆	42.08	-53.90	226.4	0.3541	188.18	1.453	0.111	9.017	2,185	2,336	19,687	21,048	4.5	16.980	21.480	3.0	3.0	16.980	—	3.422	11.362	14.784	3.138	1.284	11.362	—	7.024	2.0	10.0	13						
14	1-Butene (Butylene)	C ₄ H ₈	56.11	20.75	63.05	0.3548	167.94	1.937	0.148	6.762	2,885	3,086	19,493	20,854	6.0	22.640	28.640	4.0	4.0	22.640	—	3.422	11.362	14.784	3.138	1.284	11.362	—	7.089	1.6	9.3	14						
15	Isobutene	C ₄ H ₈	56.11	19.59	63.4	0.3701	169.48	1.937	0.148	6.762	2,868	3,069	19,376	20,737	6.0	22.640	28.640	4.0	4.0	22.640	—	3.422	11.362	14.784	3.138	1.284	11.362	—	7.129	1.6	—	15						
16	1-Pentene	C ₅ H ₁₀	70.13	85.93	19.115	0.3635	154.46	2.421	0.185	5.410	3,585	3,837	19,359	20,720	7.5	28.300	35.800	5.0	5.0	28.300	—	3.422	11.362	14.784	3.138	1.284	11.362	—	7.135	1.4	8.7	16						
Aromatic Series (C _n H _{2n-6})																																						
17	Benzene	C ₆ H ₆	78.11	176.17	3.224	0.2429	169.31	2.697	0.206	4.857	3,595	3,746	17,421	18,184	7.5	28.300	35.800	6.0	3.0	28.300	—	3.072	10.201	13.274	3.380	0.692	10.201	—	7.300	1.38	7.98	17						
18	Toluene	C ₇ H ₈	92.14	231.13	1.032	0.2598	154.84	3.181	0.243	4.118	4,296	4,497	17,672	18,501	9.0	33.959	42.959	7.0	4.0	33.959	—	3.125	10.378	13.504	3.343	0.782	10.378	—	7.299	1.28	7.18	18						
19	<i>o</i> -Xylene	C ₈ H ₁₀	106.17	291.97	0.264	0.2914	149.1	3.665	0.280	3.574	4,970	5,222	17,734	18,633	10.5	39.619	50.119	8.0	5.0	39.619	—	3.164	10.508	13.673	3.316	0.848	10.508	—	7.338	1.18	6.48	19						
20	<i>m</i> -Xylene	C ₈ H ₁₀	106.17	282.41	0.326	0.2782	147.2	3.665	0.280	3.574	4,970	5,222	17,734	18,633	10.5	39.619	50.119	8.0	5.0	39.619	—	3.164	10.508	13.673	3.316	0.848	10.508	—	7.338	1.18	6.48	20						
21	<i>p</i> -Xylene	C ₈ H ₁₀	106.17	281.05	0.342	0.2769	144.52	3.665	0.280	3.574	4,970	5,222	17,734	18,633	10.5	39.619	50.119	8.0	5.0	39.619	—	3.164	10.508	13.673	3.316	0.848	10.508	—	7.338	1.18	6.48	21						

		Additional Fuel Gas Components																													
22 Acetylene	C ₂ H ₂	26.04	-119	—	0.3966	—	0.899	0.069	14.572	1,448	1,499	20,769	21,502	2.5	9.433	11.933	2.0	1.0	9.433	—	3.072	10.201	13.274	3.380	0.692	10.201	—	7.300	2.5	80	22
23 Methyl alcohol	CH ₃ OH	32.04	148.1	4.63	0.3231	473	1.106	0.084	11.841	767	868	9,066	10,258	1.5	5.660	7.160	1.0	2.0	5.660	—	4.498	4.974	6.482	1.373	1.124	4.974	—	6.309	6.72	36.5	23
24 Ethyl alcohol	C ₂ H ₅ OH	46.07	172.92	2.3	0.3323	367	1.590	0.121	8.236	1,449	1,600	11,918	13,161	3.0	11.320	14.320	2.0	3.0	11.320	—	2.084	6.919	9.003	1.911	1.173	6.919	—	6.841	3.28	18.95	24
25 Ammonia	NH ₃	17.03	-28.2	212	0.5002	587.2	0.588	0.045	22.279	364	441	7,966	9,567	0.75	2.830	3.582	—	1.5	3.330	—	1.409	4.679	6.008	—	1.587	5.502	—	6.298	15.50	27.00	25
26 Hydrogen	H ₂	2.02	-423.0	—	3.4080	193.9	0.070	0.005	188.217	274.6	325.0	51,625	61,095	0.5	1.887	2.387	—	1.0	1.887	—	7.936	26.323	34.290	—	8.937	26.353	—	5.613	4.00	74.20	26
27 Oxygen	O ₂	32.00	-297.4	—	0.2186	91.6	1.105	0.084	11.858	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27
28 Nitrogen	N ₂	29.16	-320.4	—	0.2482	87.8	0.972	0.074	13.472	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28
29 Carbon monoxide	CO	28.01	-313.6	—	0.2484	92.7	0.967	0.074	13.546	321.9	321.9	4,347	4,347	0.5	1.877	2.387	1.0	—	1.887	—	—	1.897	2.468	1.571	—	1.870	—	5.677	12.50	74.20	29
30 Carbon dioxide	CO ₂	44.01	-109.3	—	0.1991	238.2	1.519	0.116	8.621	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30
31 Hydrogen sulfide	H ₂ S	34.08	-76.6	394.0	0.2380	235.6	1.177	0.090	11.133	595	646	6,537	7,097	1.5	5.660	7.160	—	1.0	5.660	1.0	1.410	4.682	6.093	—	0.529	4.682	1.880	8.585	4.30	45.50	31
32 Sulfur dioxide	SO ₂	64.06	14.0	88	0.1450	166.7	2.212	0.169	5.923	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	32
33 Water vapor	H ₂ O	18.02	212.0	0.9492	0.4446	970.3	0.622	0.047	21.061	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	33
34 Air	—	29.97	-317.6	—	0.2400	92	1.000	0.076	13.099	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	34

TABLE C.5
Combustion Data for Hydrocarbons*

Hydrocarbon	Formula	Higher heating value (vapor), Btu/lb _m	Theor. air/fuel ratio, by mass	Max flame speed, ft/sec	Adiabatic flame temp (in air), °F	Ignition temp (in air), °F	Flash point, °F	Flammability limits (in air), % by volume	
PARAFFINS OR ALKANES									
Methane	CH ₄	23875	17.195	1.1	3484	1301	gas	5.0	15.0
Ethane	C ₂ H ₆	22323	15.899	1.3	3540	968–1166	gas	3.0	12.5
Propane	C ₃ H ₈	21669	15.246	1.3	3573	871	gas	2.1	10.1
<i>n</i> -Butane	C ₄ H ₁₀	21321	14.984	1.2	3583	761	– 76	1.86	8.41
<i>iso</i> -Butane	C ₄ H ₁₀	21271	14.984	1.2	3583	864	– 117	1.80	8.44
<i>n</i> -Pentane	C ₅ H ₁₂	21095	15.323	1.3	4050	588	< – 40	1.40	7.80
<i>iso</i> -Pentane	C ₅ H ₁₂	21047	15.323	1.2	4055	788	< – 60	1.32	9.16
Neopentane	C ₅ H ₁₂	20978	15.323	1.1	4060	842	gas	1.38	7.22
<i>n</i> -Hexane	C ₆ H ₁₄	20966	15.238	1.3	4030	478	– 7	1.25	7.0
Neohexane	C ₆ H ₁₄	20931	15.238	1.2	4055	797	– 54	1.19	7.58
<i>n</i> -Heptane	C ₇ H ₁₆	20854	15.141	1.3	3985	433	25	1.00	6.00
Triptane	C ₇ H ₁₆	20824	15.141	1.2	4035	849	—	1.08	6.69
<i>n</i> -Octane	C ₈ H ₁₈	20796	15.093	—	—	428	56	0.95	3.20
<i>iso</i> -Octane	C ₈ H ₁₈	20770	15.093	1.1	—	837	10	0.79	5.94
OLEFINS OR ALKENES									
Ethylene	C ₂ H ₄	21636	14.807	2.2	4250	914	gas	2.75	28.6
Propylene	C ₃ H ₆	21048	14.807	1.4	4090	856	gas	2.00	11.1
Butylene	C ₄ H ₈	20854	14.807	1.4	4030	829	gas	1.98	9.65
<i>iso</i> -Butene	C ₄ H ₈	20737	14.807	1.2	—	869	gas	1.8	9.0
<i>n</i> -Pentene	C ₅ H ₁₀	20720	14.807	1.4	4165	569	—	1.65	7.70
AROMATICS									
Benzene	C ₆ H ₆	18184	13.297	1.3	4110	1044	12	1.35	6.65
Toluene	C ₇ H ₈	18501	13.503	1.2	4050	997	40	1.27	6.75
<i>p</i> -Xylene	C ₈ H ₁₀	18663	13.663	—	4010	867	63	1.00	6.00
OTHER HYDROCARBONS									
Acetylene	C ₂ H ₂	21502	13.297	4.6	4770	763–824	gas	2.50	81.0
Naphthalene	C ₁₀ H ₈	17303	12.932	—	4100	959	174	0.90	5.9

* Based largely on: *Gas Engineers' Handbook*, American Gas Association, Inc., Industrial Park, 1967.

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Physical Measurements in Gas Dynamics and Combustion, Princeton University Press, 1954.

Note: For heating value in J/kg, multiply the value in Btu/lb_m by 2324. For flame speed in m/s, multiply the value in ft/s by 0.3048.

From: The CRC Press Handbook of Mechanical Engineering, CRC Press, Boca Raton, FL, 1998.

TABLE C.6
Thermodynamic Data for Common Substances

$\bar{h}_f^\circ$ and $\bar{g}_f^\circ$ (kJ/kmol), $\bar{s}^\circ$ (kJ/kmol•K)

Substance	Formula	$\bar{h}_f^\circ$	$\bar{g}_f^\circ$	$\bar{s}^\circ$
Carbon	C(s)	0	0	5.74
Hydrogen	H ₂ (g)	0	0	130.57
Nitrogen	N ₂ (g)	0	0	191.50
Oxygen	O ₂ (g)	0	0	205.03
Carbon monoxide	CO(g)	-110,530	-137,150	197.54
Carbon dioxide	CO ₂ (g)	-393,520	-394,380	213.69
Water	H ₂ O(g)	-241,820	-228,590	188.72
	H ₂ O(l)	-285,830	-237,180	69.95
Hydrogen peroxide	H ₂ O ₂ (g)	-136,310	-105,600	232.63
Ammonia	NH ₃ (g)	-46,190	-16,590	192.33
Oxygen	O(g)	249,170	231,770	160.95
Hydrogen	H(g)	218,000	203,290	114.61
Nitrogen	N(g)	472,680	455,510	153.19
Hydroxyl	OH(g)	39,460	34,280	183.75
Methane	CH ₄ (g)	-74,850	-50,790	186.16
Acetylene	C ₂ H ₂ (g)	226,730	209,170	200.85
Ethylene	C ₂ H ₄ (g)	52,280	68,120	219.83
Ethane	C ₂ H ₆ (g)	-84,680	-32,890	229.49
Propylene	C ₃ H ₆ (g)	20,410	62,720	266.94
Propane	C ₃ H ₈ (g)	-103,850	-23,490	269.91
Butane	C ₄ H ₁₀ (g)	-126,150	-15,710	310.03
Pentane	C ₅ H ₁₂ (g)	-146,440	-8200	348.40
Octane	C ₈ H ₁₈ (g)	-208,450	17,320	463.67
	C ₈ H ₁₈ (l)	-249,910	6610	360.79
Benzene	C ₆ H ₆ (g)	82,930	129,660	269.20
Methyl alcohol	CH ₃ OH(g)	-200,890	-162,140	239.70
	CH ₃ OH(l)	-238,810	-166,290	126.80
Ethyl alcohol	C ₂ H ₅ OH(g)	-235,310	-168,570	282.59
	C ₂ H ₅ OH(l)	-277,690	174,890	160.70

Source: Adapted from Wark, K. 1983. *Thermodynamics*, 4th ed. McGraw-Hill, New York, as 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.

From: *The CRC Handbook of Thermal Engineering* CRC Press, Boca Raton, FL, 2000.

TABLE C.7
Properties of Dry Air at Atmospheric Pressure

Symbols and Units:

K = absolute temperature, degrees Kelvin
deg C = temperature, degrees Celsius
deg F = temperature, degrees Fahrenheit
 ρ = density, kg/m³
 c_p = specific heat capacity, kJ/kg-K
 c_p/c_v = specific heat capacity ratio, dimensionless
 μ = viscosity, N·s/m² × 10⁶ (For N·s/m² (= kg/m·s) multiply tabulated values by 10⁻⁶)
 k = thermal conductivity, W/m·k × 10³ (For W/m·K multiply tabulated values by 10⁻³)
 Pr = Prandtl number, dimensionless
 h = enthalpy, kJ/kg
 V_s = sound velocity, m/s

Temperature			Properties							
K	deg C	deg F	ρ	c_p	c_p/c_v	μ	k	Pr	h	V_s
100	-173.15	-280	3.598	1.028		6.929	9.248	.770	98.42	198.4
110	-163.15	-262	3.256	1.022	1.420 2	7.633	10.15	.768	108.7	208.7
120	-153.15	-244	2.975	1.017	1.416 6	8.319	11.05	.766	118.8	218.4
130	-143.15	-226	2.740	1.014	1.413 9	8.990	11.94	.763	129.0	227.6
140	-133.15	-208	2.540	1.012	1.411 9	9.646	12.84	.761	139.1	236.4
150	-123.15	-190	2.367	1.010	1.410 2	10.28	13.73	.758	149.2	245.0
160	-113.15	-172	2.217	1.009	1.408 9	10.91	14.61	.754	159.4	253.2
170	-103.15	-154	2.085	1.008	1.407 9	11.52	15.49	.750	169.4	261.0
180	-93.15	-136	1.968	1.007	1.407 1	12.12	16.37	.746	179.5	268.7
190	-83.15	-118	1.863	1.007	1.406 4	12.71	17.23	.743	189.6	276.2
200	-73.15	-100	1.769	1.006	1.405 7	13.28	18.09	.739	199.7	283.4
205	-68.15	-91	1.726	1.006	1.405 5	13.56	18.52	.738	204.7	286.9
210	-63.15	-82	1.684	1.006	1.405 3	13.85	18.94	.736	209.7	290.5
215	-58.15	-73	1.646	1.006	1.405 0	14.12	19.36	.734	214.8	293.9
220	-53.15	-64	1.607	1.006	1.404 8	14.40	19.78	.732	219.8	297.4
225	-48.15	-55	1.572	1.006	1.404 6	14.67	20.20	.731	224.8	300.8
230	-43.15	-46	1.537	1.006	1.404 4	14.94	20.62	.729	229.8	304.1
235	-38.15	-37	1.505	1.006	1.404 2	15.20	21.04	.727	234.9	307.4
240	-33.15	-28	1.473	1.005	1.404 0	15.47	21.45	.725	239.9	310.6
245	-28.15	-19	1.443	1.005	1.403 8	15.73	21.86	.724	244.9	313.8
250	-23.15	-10	1.413	1.005	1.403 6	15.99	22.27	.722	250.0	317.1
255	-18.15	-1	1.386	1.005	1.403 4	16.25	22.68	.721	255.0	320.2
260	-13.15	8	1.359	1.005	1.403 2	16.50	23.08	.719	260.0	323.4
265	-8.15	17	1.333	1.005	1.403 0	16.75	23.48	.717	265.0	326.5
270	-3.15	26	1.308	1.006	1.402 9	17.00	23.88	.716	270.1	329.6
275	+1.85	35	1.285	1.006	1.402 6	17.26	24.28	.715	275.1	332.6
280	6.85	44	1.261	1.006	1.402 4	17.50	24.67	.713	280.1	335.6
285	11.85	53	1.240	1.006	1.402 2	17.74	25.06	.711	285.1	338.5
290	16.85	62	1.218	1.006	1.402 0	17.98	25.47	.710	290.2	341.5
295	21.85	71	1.197	1.006	1.401 8	18.22	25.85	.709	295.2	344.4
300	26.85	80	1.177	1.006	1.401 7	18.46	26.24	.708	300.2	347.3
305	31.85	89	1.158	1.006	1.401 5	18.70	26.63	.707	305.3	350.2
310	36.85	98	1.139	1.007	1.401 3	18.93	27.01	.705	310.3	353.1
315	41.85	107	1.121	1.007	1.401 0	19.15	27.40	.704	315.3	355.8
320	46.85	116	1.103	1.007	1.400 8	19.39	27.78	.703	320.4	358.7

* Condensed and computed from: Tables of Thermal Properties of Gases, National Bureau of Standards Circular 564, U.S. Government Printing Office, November 1955.

From: *The CRC Press Handbook of Thermal Engineering*, CRC Press, Boca Raton, FL, 2000.

TABLE C.7 (Continued)
Properties of Dry Air at Atmospheric Pressure

Temperature			Properties							
<i>K</i>	<i>deg C</i>	<i>deg F</i>	ρ	c_p	c_p/c_v	μ	k	Pr	h	V_a
325	51.85	125	1.086	1.008	1.400 6	19.63	28.15	.702	325.4	361.4
330	56.85	134	1.070	1.008	1.400 4	19.85	28.53	.701	330.4	364.2
335	61.85	143	1.054	1.008	1.400 1	20.08	28.90	.700	335.5	366.9
340	66.85	152	1.038	1.008	1.399 9	20.30	29.28	.699	340.5	369.6
345	71.85	161	1.023	1.009	1.399 6	20.52	29.64	.698	345.6	372.3
350	76.85	170	1.008	1.009	1.399 3	20.75	30.03	.697	350.6	375.0
355	81.85	179	0.994 5	1.010	1.399 0	20.97	30.39	.696	355.7	377.6
360	86.85	188	0.980 5	1.010	1.398 7	21.18	30.78	.695	360.7	380.2
365	91.85	197	0.967 2	1.010	1.398 4	21.38	31.14	.694	365.8	382.8
370	96.85	206	0.953 9	1.011	1.398 1	21.60	31.50	.693	370.8	385.4
375	101.85	215	0.941 3	1.011	1.397 8	21.81	31.86	.692	375.9	388.0
380	106.85	224	0.928 8	1.012	1.397 5	22.02	32.23	.691	380.9	390.5
385	111.85	233	0.916 9	1.012	1.397 1	22.24	32.59	.690	386.0	393.0
390	116.85	242	0.905 0	1.013	1.396 8	22.44	32.95	.690	391.0	395.5
395	121.85	251	0.893 6	1.014	1.396 4	22.65	33.31	.689	396.1	398.0
400	126.85	260	0.882 2	1.014	1.396 1	22.86	33.65	.689	401.2	400.4
410	136.85	278	0.860 8	1.015	1.395 3	23.27	34.35	.688	411.3	405.3
420	146.85	296	0.840 2	1.017	1.394 6	23.66	35.05	.687	421.5	410.2
430	156.85	314	0.820 7	1.018	1.393 8	24.06	35.75	.686	431.7	414.9
440	166.85	332	0.802 1	1.020	1.392 9	24.45	36.43	.684	441.9	419.6
450	176.85	350	0.784 2	1.021	1.392 0	24.85	37.10	.684	452.1	424.2
460	186.85	368	0.767 7	1.023	1.391 1	25.22	37.78	.683	462.3	428.7
470	196.85	386	0.750 9	1.024	1.390 1	25.58	38.46	.682	472.5	433.2
480	206.85	404	0.735 1	1.026	1.389 2	25.96	39.11	.681	482.8	437.6
490	216.85	422	0.720 1	1.028	1.388 1	26.32	39.76	.680	493.0	442.0
500	226.85	440	0.705 7	1.030	1.387 1	26.70	40.41	.680	503.3	446.4
510	236.85	458	0.691 9	1.032	1.386 1	27.06	41.06	.680	513.6	450.6
520	246.85	476	0.678 6	1.034	1.385 1	27.42	41.69	.680	524.0	454.9
530	256.85	494	0.665 8	1.036	1.384 0	27.78	42.32	.680	534.3	459.0
540	266.85	512	0.653 5	1.038	1.382 9	28.14	42.94	.680	544.7	463.2
550	276.85	530	0.641 6	1.040	1.381 8	28.48	43.57	.680	555.1	467.3
560	286.85	548	0.630 1	1.042	1.380 6	28.83	44.20	.680	565.5	471.3
570	296.85	566	0.619 0	1.044	1.379 5	29.17	44.80	.680	575.9	475.3
580	306.85	584	0.608 4	1.047	1.378 3	29.52	45.41	.680	586.4	479.2
590	316.85	602	0.598 0	1.049	1.377 2	29.84	46.01	.680	596.9	483.2
600	326.85	620	0.588 1	1.051	1.376 0	30.17	46.61	.680	607.4	486.9
620	346.85	656	0.569 1	1.056	1.373 7	30.82	47.80	.681	628.4	494.5
640	366.85	692	0.551 4	1.061	1.371 4	31.47	48.96	.682	649.6	502.1
660	386.85	728	0.534 7	1.065	1.369 1	32.09	50.12	.682	670.9	509.4
680	406.85	764	0.518 9	1.070	1.366 8	32.71	51.25	.683	692.2	516.7
700	426.85	800	0.504 0	1.075	1.364 6	33.32	52.36	.684	713.7	523.7
720	446.85	836	0.490 1	1.080	1.362 3	33.92	53.45	.685	735.2	531.0
740	466.85	872	0.476 9	1.085	1.360 1	34.52	54.53	.686	756.9	537.6
760	486.85	908	0.464 3	1.089	1.358 0	35.11	55.62	.687	778.6	544.6
780	506.85	944	0.452 4	1.094	1.355 9	35.69	56.68	.688	800.5	551.2
800	526.85	980	0.441 0	1.099	1.354	36.24	57.74	.689	822.4	557.8
850	576.85	1 070	0.415 2	1.110	1.349	37.63	60.30	.693	877.5	574.1
900	626.85	1 160	0.392 0	1.121	1.345	38.97	62.76	.696	933.4	589.6
950	676.85	1 250	0.371 4	1.132	1.340	40.26	65.20	.699	989.7	604.9
1 000	726.85	1 340	0.352 9	1.142	1.336	41.53	67.54	.702	1 046	619.5
1 100	826.85	1 520	0.320 8	1.161	1.329	43.96			1 162	648.0
1 200	926.85	1 700	0.294 1	1.179	1.322	46.26			1 279	675.2
1 300	1 026.85	1 880	0.271 4	1.197	1.316	48.46			1 398	701.0
1 400	1 126.85	2 060	0.252 1	1.214	1.310	50.57			1 518	725.9
1 500	1 220.85	2 240	0.235 3	1.231	1.304	52.61			1 640	749.4
1 600	1 326.85	2 420	0.220 6	1.249	1.299	54.57			1 764	772.6
1 800	1 526.85	2 780	0.196 0	1.288	1.288	58.29			2 018	815.7
2 000	1 726.85	3 140	0.176 4	1.338	1.274				2 280	855.5
2 400	2 126.85	3 860	0.146 7	1.574	1.238				2 853	924.4
2 800	2 526.85	4 580	0.124 5	2.259	1.196				3 599	983.1

TABLE C.8
Properties of Gases and Vapors in English and Metric Units

<i>Common name(s)</i>	<i>Acetylene (Ethyne)</i>	<i>Butadiene</i>	<i>n-Butane</i>	<i>Isobutane (2-Methyl propane)</i>
<i>Chemical formula</i>	C_2H_2	C_4H_6	C_4H_{10}	C_4H_{10}
<i>Refrigerant number</i>	—	—	600	600a
CHEMICAL AND PHYSICAL PROPERTIES				
Molecular weight	26.04	54.09	58.12	58.12
Specific gravity, air = 1	0.90	1.87	2.07	2.07
Specific volume, ft ³ /lb	14.9	7.1	6.5	6.5
Specific volume, m ³ /kg	0.93	0.44	0.405	0.418
Density of liquid (at atm bp), lb/ft ³	43.0		37.5	37.2
Density of liquid (at atm bp), kg/m ³	693.		604.	599.
Vapor pressure at 25 deg C, psia			35.4	50.4
Vapor pressure at 25 deg C, MN/m ²			0.024 4	0.347
Viscosity (abs), lbm/ft-sec	6.72×10^{-6}		4.8×10^{-6}	
Viscosity (abs), centipoises ^a	0.01		0.007	
Sound velocity in gas, m/sec	343	226	216	216
THERMAL AND THERMODYNAMIC PROPERTIES				
Specific heat, c_p , Btu/lb-deg F or cal/g-deg C	0.40	0.341	0.39	0.39
Specific heat, c_p , J/kg-K	1 674.	1 427.	1 675.	1 630.
Specific heat ratio, c_p/c_v	1.25	1.12	1.096	1.10
Gas constant R , ft-lb/lb-deg R	59.3	28.55	26.56	26.56
Gas constant R , J/kg-deg C	319	154.	143.	143.
Thermal conductivity, Btu/hr-ft-deg F	0.014		0.01	0.01
Thermal conductivity, W/m-deg C	0.024		0.017	0.017
Boiling point (sat 14.7 psia), deg F	-103	24.1	31.2	10.8
Boiling point (sat 760 mm), deg C	-75	-4.5	-0.4	-11.8
Latent heat of evap (at bp), Btu/lb	264		165.6	157.5
Latent heat of evap (at bp), J/kg	614 000		386 000	366 000
Freezing (melting) point, deg F (1 atm)	-116	-164.	-217.	-229
Freezing (melting) point, deg C (1 atm)	-82.2	-109.	-138	-145
Latent heat of fusion, Btu/lb	23.		19.2	
Latent heat of fusion, J/kg	53 500		44 700	
Critical temperature, deg F	97.1		306	273.
Critical temperature, deg C	36.2	171.	152.	134.
Critical pressure, psia	907.	652.	550.	537.
Critical pressure, MN/m ²	6.25		3.8	3.7
Critical volume, ft ³ /lb			0.070	
Critical volume, m ³ /kg			0.004 3	
Flammable (yes or no)	Yes	Yes	Yes	Yes
Heat of combustion, Btu/ft ³	1 450	2 950	3 300	3 300
Heat of combustion, Btu/lb	21 600	20 900	21 400	21 400
Heat of combustion, kJ/kg	50 200	48 600	49 700	49 700

^aFor N·sec/m² divide by 1 000.

Note: The properties of pure gases are given at 25°C (77°F, 298 K) and atmospheric pressure (except as stated).
From: The CRC Press Handbook of Thermal Engineering, CRC Press, Boca Raton, FL, 2000.

TABLE C.8 (Continued)
Properties of Gases and Vapors in English and Metric Units

<i>Common name(s)</i>	<i>1-Butene (Butylene)</i>	<i>cis-2-Butene</i>	<i>trans-2-Butene</i>	<i>Isobutene</i>
<i>Chemical formula</i>	<i>C₄H₈</i>	<i>C₄H₈</i>	<i>C₄H₈</i>	<i>C₄H₈</i>
<i>Refrigerant number</i>	—	—	—	—
CHEMICAL AND PHYSICAL PROPERTIES				
Molecular weight	56.108	56.108	56.108	56.108
Specific gravity, air = 1	1.94	1.94	1.94	1.94
Specific volume, ft ³ /lb	6.7	6.7	6.7	6.7
Specific volume, m ³ /kg	0.42	0.42	0.42	0.42
Density of liquid (at atm bp), lb/ft ³				
Density of liquid (at atm bp), kg/m ³				
Vapor pressure at 25 deg C, psia				
Vapor pressure at 25 deg C, MN/m ²				
Viscosity (abs), lbm/ft-sec				
Viscosity (abs), centipoises*				
Sound velocity in gas, m/sec	222	223.	221.	221.
THERMAL AND THERMODYNAMIC PROPERTIES				
Specific heat, <i>c_p</i> , Btu/lb-deg F or cal/g-deg C	0.36	0.327	0.365	0.37
Specific heat, <i>c_p</i> , J/kg-K	1 505.	1 368.	1 527.	1 548.
Specific heat ratio, <i>c_p/c_v</i>	1.112	1.121	1.107	1.10
Gas constant <i>R</i> , ft-lb/lb-deg F	27.52			
Gas constant <i>R</i> , J/kg-deg C	148.			
Thermal conductivity, Btu/hr-ft-deg F				
Thermal conductivity, W/m-deg C				
Boiling point (sat 14.7 psia), deg F	20.6	38.6	33.6	19.2
Boiling point (sat 760 mm), deg C	-6.3	3.7	0.9	-7.1
Latent heat of evap (at bp), Btu/lb	167.9	178.9	174.4	169.
Latent heat of evap (at bp), J/kg	391 000	416 000.	406 000.	393 000.
Freezing (melting) point, deg F (1 atm)	-301.6	-218.	-158.	
Freezing (melting) point, deg C (1 atm)	-185.3	-138.9	-105.5	
Latent heat of fusion, Btu/lb	16.4	31.2	41.6	25.3
Latent heat of fusion, J/kg	38 100	72 600.	96 800.	58 800.
Critical temperature, deg F	291.			
Critical temperature, deg C	144.	160.	155.	
Critical pressure, psia	621.	595.	610.	
Critical pressure, MN/m ²	4.28	4.10	4.20	
Critical volume, ft ³ /lb	0.068			
Critical volume, m ³ /kg	0.004 2			
Flammable (yes or no)	Yes	Yes	Yes	Yes
Heat of combustion, Btu/ft ³	3 150	3 150.	3 150.	3 150.
Heat of combustion, Btu/lb	21 000	21 000.	21 000.	21 000.
Heat of combustion, kJ/kg	48 800	48 800.	48 800.	48 800.

*For N·sec/m² divide by 1 000.

TABLE C.8 (Continued)
Properties of Gases and Vapors in English and Metric Units

<i>Common name(s)</i>	<i>Carbon dioxide</i>	<i>Carbon monoxide</i>	<i>Ethane</i>	<i>Ethylene (Ethene)</i>
<i>Chemical formula</i>	<i>CO₂</i>	<i>CO</i>	<i>C₂H₆</i>	<i>C₂H₄</i>
<i>Refrigerant number</i>	<i>744</i>	<i>—</i>	<i>170</i>	<i>1150</i>
CHEMICAL AND PHYSICAL PROPERTIES				
Molecular weight	44.01	28.011	30.070	28.054
Specific gravity, air = 1	1.52	0.967	1.04	0.969
Specific volume, ft ³ /lb	8.8	14.0	13.025	13.9
Specific volume, m ³ /kg	0.55	0.874	0.815	0.87
Density of liquid (at atm bp), lb/ft ³	—	—	28.	35.5
Density of liquid (at atm bp), kg/m ³	—	—	449.	569.
Vapor pressure at 25 deg C, psia	931.	—	—	—
Vapor pressure at 25 deg C, MN/m ²	6.42	—	—	—
Viscosity (abs), lbm/ft-sec	9.4 × 10 ⁻⁶	12.1 × 10 ⁻⁶	64. × 10 ⁻⁶	6.72 × 10 ⁻⁶
Viscosity (abs), centipoises ^a	0.014	0.018	0.095	0.010
Sound velocity in gas, m/sec	270.	352.	316.	331.
THERMAL AND THERMODYNAMIC PROPERTIES				
Specific heat, <i>c_p</i> , Btu/lb-deg F or cal/g-deg C	0.205	0.25	0.41	0.37
Specific heat, <i>c_p</i> , J/kg-K	876.	1 046.	1 715.	1 548.
Specific heat ratio, <i>c_p/c_v</i>	1.30	1.40	1.20	1.24
Gas constant <i>R</i> , ft-lb/lb-deg F	35.1	55.2	51.4	55.1
Gas constant <i>R</i> , J/kg-deg C	189.	297.	276.	296.
Thermal conductivity, Btu/hr-ft-deg F	0.01	0.014	0.010	0.010
Thermal conductivity, W/m-deg C	0.017	0.024	0.017	0.017
Boiling point (sat 14.7 psia), deg F	-109.4 ^b	-312.7	-127.	-155.
Boiling point (sat 760 mm), deg C	-78.5	-191.5	-88.3	-103.8
Latent heat of evap (at bp), Btu/lb	246.	92.8	210.	208.
Latent heat of evap (at bp), J/kg	572 000.	216 000.	488 000.	484 000.
Freezing (melting) point, deg F (1 atm)	—	-337.	-278.	-272.
Freezing (melting) point, deg C (1 atm)	—	-205.	-172.2	-169.
Latent heat of fusion, Btu/lb	—	12.8	41.	51.5
Latent heat of fusion, J/kg	—	—	95 300.	120 000.
Critical temperature, deg F	88.	-220.	90.1	49.
Critical temperature, deg C	31.	-140.	32.2	9.5
Critical pressure, psia	1 072.	507.	709.	741.
Critical pressure, MN/m ²	7.4	3.49	4.89	5.11
Critical volume, ft ³ /lb	—	0.053	0.076	0.073
Critical volume, m ³ /kg	—	0.003 3	0.004 7	0.004 6
Flammable (yes or no)	No	Yes	Yes	Yes
Heat of combustion, Btu/ft ³	—	310.	—	1 480.
Heat of combustion, Btu/lb	—	4 340.	22 300.	20 600.
Heat of combustion, kJ/kg	—	10 100.	51 800.	47 800.

^aFor N-sec/m² divide by 1 000.

TABLE C.8 (Continued)
Properties of Gases and Vapors in English and Metric Units

<i>Common name(s)</i>	<i>Hydrogen</i>	<i>Methane</i>	<i>Nitric oxide</i>	<i>Nitrogen</i>
<i>Chemical formula</i>	<i>H₂</i>	<i>CH₄</i>	<i>NO</i>	<i>N₂</i>
<i>Refrigerant number</i>	<i>702</i>	<i>50</i>	<i>—</i>	<i>728</i>
CHEMICAL AND PHYSICAL PROPERTIES				
Molecular weight	2.016	16.044	30.006	28.013 4
Specific gravity, air = 1	0.070	0.554	1.04	0.967
Specific volume, ft ³ /lb	194.	24.2	13.05	13.98
Specific volume, m ³ /kg	12.1	1.51	0.814	0.872
Density of liquid (at atm bp), lb/ft ³	4.43	26.3		50.46
Density of liquid (at atm bp), kg/m ³	71.0	421.		808.4
Vapor pressure at 25 deg C, psia				
Vapor pressure at 25 deg C, MN/m ²				
Viscosity (abs), lbm/ft·sec	6.05 × 10 ⁻⁶	7.39 × 10 ⁻⁶	12.8 × 10 ⁻⁶	12.1 × 10 ⁻⁶
Viscosity (abs), centipoises ^a	0.009	0.011	0.019	0.018
Sound velocity in gas, m/sec	1 315.	446.	341.	353.
THERMAL AND THERMODYNAMIC PROPERTIES				
Specific heat, <i>c_p</i> , Btu/lb·deg F				
or cal/g·deg C	3.42	0.54	0.235	0.249
Specific heat, <i>c_p</i> , J/kg·K	14 310.	2 260.	983.	1 040.
Specific heat ratio, <i>c_p/c_v</i>	1.405	1.31	1.40	1.40
Gas constant <i>R</i> , ft·lb/lb·deg F	767.	96.	51.5	55.2
Gas constant <i>R</i> , J/kg·deg C	4 126.	518.	277.	297.
Thermal conductivity, Btu/hr·ft·deg F	0.105	0.02	0.015	0.015
Thermal conductivity, W/m·deg C	0.018 2	0.035	0.026	0.026
Boiling point (sat 14.7 psia), deg F	−423.	−259.	−240.	−320.4
Boiling point (sat 760 mm), deg C	20.4 K	−434.2	−151.5	−195.8
Latent heat of evap (at bp), Btu/lb	192.	219.2		85.5
Latent heat of evap (at bp), J/kg	447 000.	510 000.		199 000.
Freezing (melting) point, deg F (1 atm)	−434.6	−296.6	−258.	−346.
Freezing (melting) point, deg C (1 atm)	−259.1	−182.6	−161.	−210.
Latent heat of fusion, Btu/lb	25.0	14.	32.9	11.1
Latent heat of fusion, J/kg	58 000.	32 600.	76 500.	25 800.
Critical temperature, deg F	−399.8	−116.	−136.	−232.6
Critical temperature, deg C	−240.0	−82.3	−93.3	−147.
Critical pressure, psia	189.	673.	945.	493.
Critical pressure, MN/m ²	1.30	4.64	6.52	3.40
Critical volume, ft ³ /lb	0.53	0.099	0.033 2	0.051
Critical volume, m ³ /kg	0.033	0.006 2	0.002 07	0.003 18
Flammable (yes or no)	Yes	Yes	No	No
Heat of combustion, Btu/ft ³	320.	985.	—	—
Heat of combustion, Btu/lb	62 050.	2 2900.	—	—
Heat of combustion, kJ/kg	144 000.		—	—

^aFor N·sec/m² divide by 1 000.

TABLE C.8 (Continued)
Properties of Gases and Vapors in English and Metric Units

<i>Common name(s)</i>	<i>Nitrous oxide</i>	<i>Oxygen</i>	<i>Propane</i>	<i>Propylene (Propene)</i>
<i>Chemical formula</i>	<i>N₂O</i>	<i>O₂</i>	<i>C₃H₈</i>	<i>C₃H₆</i>
<i>Refrigerant number</i>	<i>744A</i>	<i>732</i>	<i>290</i>	<i>1 270</i>
CHEMICAL AND PHYSICAL PROPERTIES				
Molecular weight	44.012	31.998 8	44.097	42.08
Specific gravity, air = 1	1.52	1.105	1.52	1.45
Specific volume, ft ³ /lb	8.90	12.24	8.84	9.3
Specific volume, m ³ /kg	0.555	0.764	0.552	0.58
Density of liquid (at atm bp), lb/ft ³	76.6	71.27	36.2	37.5
Density of liquid (at atm bp), kg/m ³	1 227.	1 142.	580.	601.
Vapor pressure at 25 deg C, psia			135.7	166.4
Vapor pressure at 25 deg C, MN/m ²			0.936	1.147
Viscosity (abs), lbm/ft-sec	10.1 × 10 ⁻⁶	13.4 × 10 ⁻⁶	53.8 × 10 ⁻⁶	57.1 × 10 ⁻⁶
Viscosity (abs), centipoises ^a	0.015	0.020	0.080	0.085
Sound velocity in gas, m/sec	268.	329.	253.	261.
THERMAL AND THERMO-DYNAMIC PROPERTIES				
Specific heat, <i>c_p</i> , Btu/lb-deg F or cal/g-deg C	0.21	0.220	0.39	0.36
Specific heat, <i>c_p</i> , J/kg-K	879.	920.	1 630.	1 506.
Specific heat ratio, <i>c_p/c_v</i>	1.31	1.40	1.2	1.16
Gas constant <i>R</i> , ft-lb/lb-deg F	35.1	48.3	35.0	36.7
Gas constant <i>R</i> , J/kg-deg C	189.	260.	188.	197.
Thermal conductivity, Btu/hr-ft-deg F	0.010	0.015	0.010	0.010
Thermal conductivity, W/m-deg C	0.017	0.026	0.017	0.017
Boiling point (sat 14.7 psia), deg F	-127.3	-297.3	-44.	-54.
Boiling point (sat 760 mm), deg C	-88.5	-182.97	-42.2	-48.3
Latent heat of evap (at bp), Btu/lb	161.8	91.7	184.	188.2
Latent heat of evap (at bp), J/kg	376 000.	213 000.	428 000.	438 000.
Freezing (melting) point, deg F (1 atm)	-131.5	-361.1	-309.8	-301.
Freezing (melting) point, deg C (1 atm)	-90.8	-218.4	-189.9	-185.
Latent heat of fusion, Btu/lb	63.9	5.9	19.1	
Latent heat of fusion, J/kg	149 000.	13 700.	44 400.	
Critical temperature, deg F	97.7	-181.5	205.	197.
Critical temperature, deg C	36.5	-118.6	96.	91.7
Critical pressure, psia	1 052.	726.	618.	668.
Critical pressure, MN/m ²	7.25	5.01	4.26	4.61
Critical volume, ft ³ /lb	0.036	0.040	0.073	0.069
Critical volume, m ³ /kg	0.002 2	0.002 5	0.004 5	0.004 3
Flammable (yes or no)	No	No	Yes	Yes
Heat of combustion, Btu/ft ³	—	—	2 450.	2 310.
Heat of combustion, Btu/lb	—	—	21 660.	21 500.
Heat of combustion, kJ/kg	—	—	50 340.	50 000.

^aFor N-sec/m² divide by 1 000.

TABLE C.8 (Continued)
Properties of Gases and Vapors in English and Metric Units

<i>Common name(s)</i>	<i>Sulfur dioxide</i>
<i>Chemical formula</i>	<i>SO₂</i>
<i>Refrigerant number</i>	<i>764</i>
CHEMICAL AND PHYSICAL PROPERTIES	
Molecular weight	64.06
Specific gravity, air = 1	2.21
Specific volume, ft ³ /lb	6.11
Specific volume, m ³ /kg	
Density of liquid (at atm bp), lb/ft ³	42.8
Density of liquid (at atm bp), kg/m ³	585.
Vapor pressure at 25 deg C, psia	56.6
Vapor pressure at 25 deg C, MN/m ²	0.390
Viscosity (abs), lbm/ft-sec	8.74×10^{-6}
Viscosity (abs), centipoises ^a	0.013
Sound velocity in gas, m/sec	220.
THERMAL AND THERMO-DYNAMIC PROPERTIES	
Specific heat, c_p , Btu/lb-deg F or cal/g-deg C	0.11
Specific heat, c_p , J/kg·K	460.
Specific heat ratio, c_p/c_v	1.29
Gas constant R , ft-lb/lb-deg F	24.1
Gas constant R , J/kg-deg C	130.
Thermal conductivity, Btu/hr-ft-deg F	0.006
Thermal conductivity, W/m-deg C	0.010
Boiling point (sat 14.7 psia), deg F	14.0
Boiling point (sat 760 mm), deg C	-10.
Latent heat of evap (at bp), Btu/lb	155.5
Latent heat of evap (at bp), J/kg	362 000.
Freezing (melting) point, deg F (1 atm)	-104.
Freezing (melting) point, deg C (1 atm)	-75.5
Latent heat of fusion, Btu/lb	58.0
Latent heat of fusion, J/kg	135 000.
Critical temperature, deg F	315.5
Critical temperature, deg C	157.6
Critical pressure, psia	1 141.
Critical pressure, MN/m ²	7.87
Critical volume, ft ³ /lb	0.03
Critical volume, m ³ /kg	0.001 9
Flammable (yes or no)	No
Heat of combustion, Btu/ft ³	—
Heat of combustion, Btu/lb	—
Heat of combustion, kJ/kg	—

^aFor N·sec/m² divide by 1 000.

TABLE C.9
Properties of Metals

Composition	Melting Point (K)	Properties at 300 K				Properties at Various Temperatures (K)									
		ρ (kg/m ³)	c_p [J/(kg · K)]	λ [W/(m · K)]	$\kappa \times 10^6$ (m ² /sec)	λ [W/(m · K)]/ c_p [J/(kg · K)]									
						100	200	400	600	800	1000	1200	1500	2000	2500
Aluminum															
Pure	933	2702	903	237	97.1	302	237	240	231	218					
						482	798	949	1033	1146					
Alloy 2024-T6 (4.5% Cu, 1.5% Mg, 0.6% Mn)	775	2770	875	177	73.0	65	163	186	186						
						473	787	925	1042						
Alloy 195, cast (4.5% Cu)		2790	883	168	68.2			174	185						
								—	—						
Beryllium	1550	1850	1825	200	59.2	990	301	161	126	106	90.8	78.7			
						203	111	2191	2604	2823	3018	3227	3519		
							4								
Bismuth	545	9780	122	7.86	6.59	16.5	9.69	7.04							
						112	120	127							
Boron	2573	2500	1107	27.0	9.76	190	55.5	16.8	10.6	9.60	9.85				
						128	600	1463	1892	2160	2338				
Cadmium	594	8650	231	96.8	48.4	203	99.3	94.7							
						198	222	242							
Chromium	2118	7160	449	93.7	29.1	159	111	90.9	80.7	71.3	65.4	61.9	57.2	49.4	
						192	384	484	542	581	616	682	779	937	
Cobalt	1769	8862	421	99.2	26.6	167	122	85.4	67.4	58.2	52.1	49.3	42.5		
						236	379	450	503	550	628	733	674		
Copper															
Pure	1358	8933	385	401	117	482	413	393	379	366	352	339			
						252	356	397	417	433	451	480			
Commercial bronze (90% Cu, 10% Al)	1293	8800	420	52	14		42	52	59						
							785	460	545						
Phosphor gear bronze (89% Cu, 11% Sn)	1104	8780	355	54	17		41	65	74						
							—	—	—						

Cartridge brass (70% Cu, 30% Zn)	1188	8530	380	110	33.9	75	95	137	149				
Constantan (55% Cu, 45% Ni)	1493	8920	384	23	6.71	17	19	360	395	425			
Germanium	1211	5360	322	59.9	34.7	232	96.8	43.2	27.3	19.8	17.4	17.4	
Gold	1336	19,300	129	317	127	190	290	337	348	357	375	395	
Iridium	2720	22,500	130	147	50.3	109	124	131	135	140	145	155	
Iron						172	153	144	138	132	126	120	111
Pure	1810	7870	447	80.2	23.1	90	122	133	138	144	153	161	172
Armco		7870	447	72.7	20.7	134	94.0	69.5	54.7	43.3	32.8	28.3	32.1
Carbon steels						216	384	490	574	680	975	609	654
Plain carbon (Mn ≤ 1%, Si ≤ 0.1%)		7854	434	60.5	17.7	95.6	80.6	65.7	53.1	42.2	32.3	28.7	31.4
AISI 1010		7832	434	63.9	18.8	215	384	490	574	680	975	609	654
Carbon-silicon (Mn ≤ 1%, 0.1% < Si ≤ 0.6%)		7817	446	51.9	14.9			56.7	48.0	39.2	30.0		
Carbon-manganese-silicon (1% < Mn ≤ 1.6%, 0.1% < Si ≤ 0.6%)		8131	434	41.0	11.6			487	559	685	1169		
Chromium (low) steels								58.7	48.8	39.2	31.3		
½Cr-¼Mo-Si (0.18% C, 0.65% Cr, 0.23% Mo, 0.6% Si)		7822	444	37.7	10.9			487	559	685	1168		
1 Cr-½ Mo (0.16% C, 1% Cr, 0.54% Mo, 0.39% Si)		7858	442	42.3	12.2			49.8	44.0	37.4	29.3		
1Cr-V (0.2% C, 1.02% Cr, 0.15% V)		7836	443	48.9	14.1			501	582	699	971		
								42.2	39.7	35.0	27.6		
								487	559	685	1090		
								38.2	36.7	33.3	26.9		
								492	575	688	969		
								42.0	39.1	34.5	27.4		
								492	575	688	969		
								46.8	42.1	36.3	28.2		
								492	575	688	969		

TABLE C.9 (Continued)
Properties of Metals

Composition	Melting Point (K)	Properties at 300 K				Properties at Various Temperatures (K)									
		ρ	c_p	λ	$\kappa \times 10^6$	λ [W/(m · K)]/ c_p [J/(kg · K)]									
		(kg/m ³)	[J/(kg · K)]	[W/(m · K)]	(m ² /sec)	100	200	400	600	800	1000	1200	1500	2000	2500
Stainless steels															
AISI 302		8055	480	15.1	3.91			17.3	20.0	22.8	25.4				
								512	559	585	606				
AISI 304	1670	7900	477	14.9	3.95	9.2	12.6	16.6	19.8	22.6	25.4	28.0	31.7		
						272	402	515	557	582	611	640	682		
AISI 316		8238	468	13.4	3.48			15.2	18.3	21.3	24.2				
								15.2	18.3	21.3	24.2				
AISI 347		7978	480	14.2	3.71			15.8	18.9	21.9	24.7				
								513	559	585	606				
Lead	601	11,340	129	35.3	24.1	39.7	36.7	34.0	31.4						
						118	125	132	142						
Magnesium	923	1740	1024	156	87.6	169	159	153	149	146					
						649	934	1074	1170	1267					
Molybdenum	2894	10,240	251	138	53.7	179	143	134	126	118	112	105	98	90	86
						141	224	261	275	285	295	308	330	380	459
Nickel															
Pure	1728	8900	444	90.7	23.0	164	107	80.2	65.6	67.6	71.8	76.2	82.6		
						232	383	485	592	530	562	594	616		
Nichrome (80% Ni, 20% Cr)	1672	8400	420	12	3.4			14	16	21					
								480	525	545					
Inconel X-750 (73% Ni, 15% Cr, 6.7% Fe)	1665	8510	439	11.7	3.1	8.7	10.3	13.5	17.0	20.5	24.0	27.6	33.0		
							372	473	510	546	626	—	—		
Niobium	2741	8570	265	53.7	23.6	55.2	52.6	55.2	58.2	61.3	64.4	67.5	72.1	79.1	
						188	249	274	283	292	301	310	324	347	
Palladium	1827	12,020	244	71.8	24.5	76.5	71.6	73.6	79.7	86.9	94.2	102	110		
						168	227	251	261	271	281	291	307		

Platinum														
Pure	2045	21,450	133	71.6	25.1	77.5	72.6	71.8	73.2	75.6	78.7	82.6	89.5	99.4
						100	125	136	141	146	152	157	165	179
Alloy 60Pt-40Rh (60% Pt, 40% Rh)	1800	16,630	162	47	17.4			52	59	65	69	73	76	
								—	—	—	—	—	—	
Rhenium	3453	21,100	136	47.9	16.7	58.9	51.0	46.1	44.2	44.1	44.6	45.7	47.8	51.9
						97	127	139	145	151	156	162	171	186
Rhodium	2236	12,450	243	150	49.6	186	154	146	136	127	121	116	110	112
						147	220	253	274	293	311	327	349	376
Silicon	1685	2330	712	148	89.2	884	264	98.9	61.9	42.2	31.2	25.7	22.7	
						259	556	790	867	913	946	967	992	
Silver	1235	10,500	235	429	174	444	430	425	412	396	379	361		
						187	225	239	250	262	277	292		
Tantalum	3269	16,600	140	57.5	24.7	59.2	57.5	57.8	58.6	59.4	60.2	61.0	62.2	64.1
						110	133	144	146	149	152	155	160	172
Thorium	2023	11,700	118	54.0	39.1	59.8	54.6	54.5	55.8	56.9	56.9	58.7		65.6
						99	112	124	134	145	156	167		189
Tin	505	7310	227	66.6	40.1	85.2	73.3	62.2						
						188	215	243						
Titanium	1953	4500	522	21.9	9.32	30.5	24.5	20.4	19.4	19.7	20.7	22.0	24.5	
					300	465	551	591	633	675	620	686		
Tungsten	3660	19,300	132	174	68.3	208	186	159	137	125	118	113	107	100
						87	122	137	142	145	148	152	157	167
Uranium	1406	19,070	116	27.6	12.5	21.7	25.1	29.6	34.0	38.8	43.9	49.0		95
						94	108	125	146	176	180	161		176
Vanadium	2192	6100	489	30.7	10.3	35.8	31.3	31.3	33.3	35.7	38.2	40.8	44.6	50.9
						258	430	515	540	563	597	645	714	867
Zinc	693	7140	389	116	41.8	117	118	111	103					
						297	367	402	436					
Zirconium	2125	6570	278	22.7	12.4	33.2	25.2	21.6	20.7	21.6	23.7	26.0	28.8	33.0
						205	264	300	322	342	362	344	344	344

Source: From G.F. Hewitt, G.L. Shires, and T.R. Bott, Eds., *Process Heat Transfer*, CRC Press, Boca Raton, FL, 1994, 1022-1025.