

PROPERTY TABLES AND CHARTS (ENGLISH UNITS)

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TABLE A-1E

Molar mass, gas constant, and ideal-gas specific heats of some substances

Substance	Molar Mass, <i>M</i> , lbm/lbmol	Gas Constant <i>R</i> *		Specific Heat Data at 77°F		
		Btu/ lbm · R	psia · ft ³ / lbm · R	<i>c_p</i> , Btu/lbm · R	<i>c_v</i> , Btu/lbm · R	<i>k</i> = <i>c_p</i> / <i>c_v</i>
Air	28.97	0.06855	0.3704	0.2400	0.1715	1.400
Ammonia, NH ₃	17.03	0.1166	0.6301	0.4999	0.3834	1.304
Argon, Ar	39.95	0.04970	0.2686	0.1243	0.07457	1.667
Bromine, Br ₂	159.81	0.01242	0.06714	0.0538	0.04137	1.300
Isobutane, C ₄ H ₁₀	58.12	0.03415	0.1846	0.3972	0.3631	1.094
<i>n</i> -Butane, C ₄ H ₁₀	58.12	0.03415	0.1846	0.4046	0.3705	1.092
Carbon dioxide, CO ₂	44.01	0.04512	0.2438	0.2016	0.1564	1.288
Carbon monoxide, CO	28.01	0.07089	0.3831	0.2482	0.1772	1.400
Chlorine, Cl ₂	70.905	0.02802	0.1514	0.1142	0.08618	1.325
Chlorodifluoromethane (R-22), CHClF ₂	86.47	0.02297	0.1241	0.1552	0.1322	1.174
Ethane, C ₂ H ₆	30.070	0.06604	0.3569	0.4166	0.3506	1.188
Ethylene, C ₂ H ₄	28.054	0.07079	0.3826	0.3647	0.2940	1.241
Fluorine, F ₂	38.00	0.05224	0.2823	0.1967	0.1445	1.362
Helium, He	4.003	0.4961	2.681	1.2403	0.7442	1.667
<i>n</i> -Heptane, C ₇ H ₁₆	100.20	0.01982	0.1071	0.3939	0.3740	1.053
<i>n</i> -Hexane, C ₆ H ₁₄	86.18	0.02304	0.1245	0.3951	0.3721	1.062
Hydrogen, H ₂	2.016	0.9850	5.323	3.416	2.431	1.405
Krypton, Kr	83.80	0.02370	0.1281	0.05923	0.03554	1.667
Methane, CH ₄	16.04	0.1238	0.6688	0.5317	0.4080	1.303
Neon, Ne	20.183	0.09838	0.5316	0.2460	0.1476	1.667
Nitrogen, N ₂	28.01	0.07089	0.3831	0.2484	0.1774	1.400
Nitric oxide, NO	30.006	0.06618	0.3577	0.2387	0.1725	1.384
Nitrogen dioxide, NO ₂	46.006	0.04512	0.2438	0.1925	0.1474	1.306
Oxygen, O ₂	32.00	0.06205	0.3353	0.2193	0.1572	1.395
<i>n</i> -Pentane, C ₅ H ₁₂	72.15	0.02752	0.1487	0.3974	0.3700	1.074
Propane, C ₃ H ₈	44.097	0.04502	0.2433	0.3986	0.3535	1.127
Propylene, C ₃ H ₆	42.08	0.04720	0.2550	0.3657	0.3184	1.148
Steam, H ₂ O	18.015	0.1102	0.5957	0.4455	0.3351	1.329
Sulfur dioxide, SO ₂	64.06	0.03100	0.1675	0.1488	0.1178	1.263
Tetrachloromethane, CCl ₄	153.82	0.01291	0.06976	0.1293	0.1164	1.111
Tetrafluoroethane (R-134a), C ₂ H ₂ F ₄	102.03	0.01946	0.1052	0.1991	0.1796	1.108
Trifluoroethane (R-143a), C ₂ H ₃ F ₃	84.04	0.02363	0.1277	0.2219	0.1983	1.119
Xenon, Xe	131.30	0.01512	0.08173	0.03781	0.02269	1.667

*The gas constant is calculated from $R = R_u/M$, where $R_u = 1.9859$ Btu/lbmol · R = 10.732 psia · ft³/lbmol · R is the universal gas constant and M is the molar mass.

Source: Specific heat values are mostly obtained from the property routines prepared by The National Institute of Standards and Technology (NIST), Gaithersburg, MD.

TABLE A-2E

Boiling and freezing point properties

Substance	Boiling Data at 1 atm		Freezing Data		Liquid Properties		
	Normal Boiling Point, °F	Latent Heat of Vaporization h_{fg} , Btu/lbm	Freezing Point, °F	Latent Heat of Fusion h_{if} , Btu/lbm	Temperature, °F	Density ρ , lbm/ft ³	Specific Heat c_p , Btu/lbm · R
Ammonia	-27.9	24.54	-107.9	138.6	-27.9	42.6	1.06
					0	41.3	1.083
					40	39.5	1.103
					80	37.5	1.135
Argon	-302.6	69.5	-308.7	12.0	-302.6	87.0	0.272
Benzene	176.4	169.4	41.9	54.2	68	54.9	0.411
Brine (20% sodium chloride by mass)	219.0	—	0.7	—	68	71.8	0.743
<i>n</i> -Butane	31.1	165.6	-217.3	34.5	31.1	37.5	0.552
Carbon dioxide	-109.2*	99.6 (at 32°F)	-69.8	—	32	57.8	0.583
Ethanol	172.8	360.5	-173.6	46.9	77	48.9	0.588
Ethyl alcohol	173.5	368	-248.8	46.4	68	49.3	0.678
Ethylene glycol	388.6	344.0	12.6	77.9	68	69.2	0.678
Glycerine	355.8	419	66.0	86.3	68	78.7	0.554
Helium	-452.1	9.80	—	—	-452.1	9.13	5.45
Hydrogen	-423.0	191.7	-434.5	25.6	-423.0	4.41	2.39
Isobutane	10.9	157.8	-255.5	45.5	10.9	37.1	0.545
Kerosene	399–559	108	-12.8	—	68	51.2	0.478
Mercury	674.1	126.7	-38.0	4.90	77	847	0.033
Methane	-258.7	219.6	296.0	25.1	-258.7	26.4	0.834
					-160	20.0	1.074
Methanol	148.1	473	-143.9	42.7	77	49.1	0.609
Nitrogen	-320.4	85.4	-346.0	10.9	-320.4	50.5	0.492
					-260	38.2	0.643
					68	43.9	0.502
Octane	256.6	131.7	-71.5	77.9	77	56.8	0.430
Oil (light)	—	—	—	—	77	71.2	0.408
Oxygen	-297.3	91.5	-361.8	5.9	-297.3	40.0	0.478
Petroleum	—	99–165	—	—	68	36.3	0.538
Propane	-43.7	184.0	-305.8	34.4	-43.7	33.0	0.604
					32	33.0	0.604
					100	29.4	0.673
					32	80.9	0.318
Refrigerant-134a	-15.0	93.2	-141.9	—	-40	88.5	0.283
					-15	86.0	0.294
					32	80.9	0.318
					90	73.6	0.348
Water	212	970.5	32	143.5	32	62.4	1.01
					90	62.1	1.00
					150	61.2	1.00
					212	59.8	1.01
					—	—	—

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

TABLE A-3E

Properties of solid metals

Composition	Melting Point, R	ρ lbm/ft ³	Properties at 540 R			Properties at Various Temperatures (R), k (Btu/h · ft · R)/ c_p (Btu/lbm · R)					
			c_p (Btu/lbm · R)	k (Btu/h · ft · R)	$\alpha \times 10^6$ ft ² /s	180	360	720	1080	1440	1800
Aluminum	1679	168	0.216	137	1045	174.5	137	138.6	133.4	126	
Pure						0.115	0.191	0.226	0.246	0.273	
Alloy 2024-T6 (4.5% Cu, 1.5% Mg, 0.6% Mn)	1395	173	0.209	102.3	785.8	37.6	94.2	107.5	107.5		
Alloy 195, cast (4.5% Cu)		174.2	0.211	97	734	0.113	0.188	0.22	0.249		
Beryllium	2790	115.5	0.436	115.6	637.2	572	174	93	72.8	61.3	52.5
Bismuth	981	610.5	0.029	4.6	71	0.048	0.266	0.523	0.621	0.624	0.72
Boron	4631	156	0.264	15.6	105	9.5	5.6	4.06			
Cadmium	1069	540	0.055	55.6	521	0.026	0.028	0.03			
Chromium	3812	447	0.107	54.1	313.2	109.7	32.06	9.7	6.1	5.5	5.7
Cobalt	3184	553.2	0.101	57.3	286.3	0.03	0.143	0.349	0.451	0.515	0.558
Copper	2445	559	0.092	231.7	1259.3	117.3	57.4	54.7			
Pure						0.047	0.053	0.057			
Commercial bronze (90% Cu, 10% Al)	2328	550	0.1	30	150.7	91.9	64.1	52.5	46.6	41.2	37.8
Phosphor gear bronze (89% Cu, 11% Sn)	1987	548.1	0.084	31.2	183	0.045	0.091	0.115	0.129	0.138	0.147
Cartridge brass (70% Cu, 30% Zn)	2139	532.5	0.09	63.6	364.9	96.5	70.5	49.3	39	33.6	80.1
Constantan (55% Cu, 45% Ni)	2687	557	0.092	13.3	72.3	0.056	0.09	0.107	0.12	0.131	0.145
Germanium	2180	334.6	0.08	34.6	373.5	278.5	238.6	227.07	219	212	203.4
Gold	2405	1205	0.03	183.2	1367	0.06	0.085	0.094	0.01	0.103	0.107
Iridium	4896	1404.6	0.031	85	541.4	24.3	30	34			
Iron:	3258	491.3	0.106	46.4	248.6	23.7	37.6	42.8			
Pure						43.3	54.9	79.2	86.0		
Armco (99.75% pure)		491.3	0.106	42	222.8	9.8	1.1	0.09	0.09	0.101	
Carbon steels		490.3	0.103	35	190.6	0.06	0.09				
Plain carbon (Mn \leq 1%, Si \leq 0.1%)						134	56	25	15.7	11.4	10.05
AISI 1010		489	0.103	37	202.4	0.045	0.069	0.08	0.083	0.085	0.089
Carbon-silicon (Mn \leq 1%, 0.1% < Si \leq 0.6%)		488	0.106	30	160.4	0.026	0.029	0.031	0.032	0.033	0.034
Carbon-manganese-silicon (1% < Mn \leq 1.65%, 0.1% < Si \leq 0.6%)		508	0.104	23.7	125	99.4	88.4	83.2	79.7	76.3	72.8
Chromium (low) steels:		488.3	0.106	21.8	117.4	0.021	0.029	0.031	0.032	0.034	0.036
$\frac{1}{2}$ Cr- $\frac{1}{4}$ Mo-Si (0.18% C, 0.65% Cr, 0.23% Mo, 0.6% Si)1						77.4	54.3	40.2	31.6	25.01	19
1 Cr- $\frac{1}{2}$ Mo (0.16% C, 1% Cr, 0.54% Mo, 0.39% Si)		490.6	0.106	24.5	131.3	0.051	0.091	0.117	0.137	0.162	0.232
1 Cr-V (0.2% C, 1.02% Cr, 0.15% V)		489.2	0.106	28.3	151.8	0.051	0.091	0.117	0.137	0.162	0.233
								32.8	27.7	22.7	17.4
								0.116	0.113	0.163	0.279
								33.9	28.2	22.7	18
								0.116	0.133	0.163	0.278
								28.8	25.4	21.6	17
								0.119	0.139	0.166	0.231
								24.4	23	20.2	16
								0.116	0.133	0.163	0.260
								22	21.2	19.3	15.6
								0.117	0.137	0.164	0.23
								24.3	22.6	20	15.8
								0.117	0.137	0.164	0.231
								27.0	24.3	21	16.3
								0.117	0.137	0.164	0.231

TABLE A-3E

Properties of solid metals

Composition	Melting Point, R	Properties at 540 R				Properties at Various Temperatures (R), k (Btu/h · ft · R)/ c_p (Btu/lbm · R)					
		ρ lbm/ft ³	c_p (Btu/lbm · R)	k (Btu/h · ft · R)	$\alpha \times 10^6$ ft ² /s	180	360	720	1080	1440	1800
Stainless steels:		503	0.114	8.7	42			10	11.6	13.2	14.7
AISI 302								0.122	0.133	0.140	0.144
AISI 304	3006	493.2	0.114	8.6	42.5	5.31	7.3	9.6	11.5	13	14.7
						0.064	0.096	0.123	0.133	0.139	0.145
AISI 316		514.3	0.111	7.8	37.5			8.8	10.6	12.3	14
						0.12	0.131	0.137	0.143		
AISI 347		498	0.114	8.2	40			9.1	1.1	12.7	14.3
								0.122	0.133	0.14	0.144
Lead	1082	708	0.03	20.4	259.4	23	21.2	19.7	18.1		
						0.028	0.029	0.031	0.034		
Magnesium	1661	109	0.245	90.2	943	87.9	91.9	88.4	86.0	84.4	
						0.155	0.223	0.256	0.279	0.302	
Molybdenum	5209	639.3	0.06	79.7	578	1034	82.6	77.4	72.8	68.2	64.7
						0.038	0.053	0.062	0.065	0.068	0.070
Nickel:	3110	555.6	0.106	52.4	247.6	94.8	61.8	46.3	37.9	39	41.4
Pure						0.055	0.091	0.115	0.141	0.126	0.134
Nichrome (80% Ni, 20% Cr)	3010	524.4	0.1	6.9	36.6			8.0	9.3	12.2	
Inconel X-750 (73% Ni, 15% Cr, 6.7% Fe)	2997	531.3	0.104	6.8	33.4	5	5.9	7.8	9.8	11.8	13.9
						—	0.088	0.112	0.121	0.13	0.149
Niobium	4934	535	0.063	31	254	31.9	30.4	32	33.6	35.4	32.2
						0.044	0.059	0.065	0.067	0.069	0.071
Palladium	3289	750.4	0.058	41.5	263.7	44.2	41.4	42.5	46	50	54.4
						0.04	0.054	0.059	0.062	0.064	0.067
Platinum:	3681	1339	0.031	41.4	270	44.7	42	41.5	42.3	43.7	45.5
Pure						0.024	0.03	0.032	0.034	0.035	0.036
Alloy 60Pt-40Rh (60% Pt, 40% Rh)	3240	1038.2	0.038	27.2	187.3			30	34	37.5	40
								—	—	—	—
Rhenium	6215	1317.2	0.032	27.7	180	34	30	26.6	25.5	25.4	25.8
						0.023	0.03	0.033	0.034	0.036	0.037
Rhodium	4025	777.2	0.058	86.7	534	107.5	89	84.3	78.5	73.4	70
						0.035	0.052	0.06	0.065	0.069	0.074
Silicon	3033	145.5	0.17	85.5	960.2	510.8	152.5	57.2	35.8	24.4	18.0
						0.061	0.132	0.189	0.207	0.218	0.226
Silver	2223	656	0.056	248	1873	257	248.4	245.5	238	228.8	219
						0.044	0.053	0.057	0.059	0.062	0.066
Tantalum	5884	1036.3	0.033	33.2	266	34.2	33.2	33.4	34	34.3	34.8
						0.026	0.031	0.034	0.035	0.036	0.036
Thorium	3641	730.4	0.028	31.2	420.9	34.6	31.5	31.4	32.2	32.9	32.9
						0.024	0.027	0.029	0.032	0.035	0.037
Tin	909	456.3	0.054	38.5	431.6	49.2	42.4	35.9			
						0.044	0.051	0.058			
Titanium	3515	281	0.013	12.7	100.3	17.6	14.2	11.8	11.2	11.4	12
						0.071	0.111	0.131	0.141	0.151	0.161
Tungsten	6588	1204.9	0.031	100.5	735.2	120.2	107.5	92	79.2	72.2	68.2
						0.020	0.029	0.032	0.033	0.034	0.035
Uranium	2531	1190.5	0.027	16	134.5	12.5	14.5	17.1	19.6	22.4	25.4
						0.022	0.026	0.029	0.035	0.042	0.043
Vanadium	3946	381	0.117	17.7	110.9	20.7	18	18	19.3	20.6	22.0
						0.061	0.102	0.123	0.128	0.134	0.142
Zinc	1247	445.7	0.093	67	450	67.6	68.2	64.1	59.5		
						0.07	0.087	0.096	0.104		
Zirconium	3825	410.2	0.067	13.1	133.5	19.2	14.6	12.5	12	12.5	13.7
						0.049	0.063	0.072	0.77	0.082	0.087

Source: Tables A-3E and A-4E are obtained from the respective tables in SI units in Appendix 1 using proper conversion factors.

TABLE A-4E

Properties of solid nonmentals

Composition	Melting Point, R	Properties at 540 R				Properties at Various Temperatures (R), k (Btu/h · ft · R)/ c_p (Btu/lbm · R)					
		ρ lbm/ft ³	c_p (Btu/ lbm · R)	k (Btu/ h · ft · R)	$\alpha \times 10^6$ ft ² /s	180	360	720	1080	1440	1800
Aluminum oxide, sapphire	4181	247.8	0.182	26.6	162.5	260	47.4	18.7	11	7.5	6
Aluminum oxide polycrystalline	4181	247.8	0.182	20.8	128	76.8	31.7	15.3	9.3	6	4.5
Beryllium oxide	4905	187.3	0.246	157.2	947.3			0.224	0.265	0.281	0.293
								0.244	0.265	0.281	0.293
Boron	4631	156	0.264	16	107.5	109.8	30.3	113.2	64.2	40.4	27.2
								0.322	0.40	0.44	0.459
Boron fiber epoxy (30% vol.) composite	1062	130						0.355	0.445	0.509	0.561
k , to fibers				1.3		1.2	1.3	1.31			
k , \perp to fibers				0.34		0.21	0.28	0.34			
c_p			0.268			0.086	0.18	0.34			
Carbon	2700	121.7	—	0.92	—	0.38	0.68	1.09	1.26	1.36	1.46
Amorphous Diamond, type IIa insulator	—	219	0.121	1329	—	5778	2311.2	889.8			
Graphite, pyrolytic	4091	138					0.005	0.046	0.203		
k , to layers				1126.7		2871.6	1866.3	803.2	515.4	385.4	308.5
k , \perp to layers				3.3		9.7	5.3	2.4	1.5	1.16	0.92
c_p			0.169			0.32	0.098	0.236	0.335	0.394	0.428
Graphite fiber epoxy (25% vol.) composite	810	87.4									
k , heat flow to fibers				6.4		3.3	5.0	7.5			
k , heat flow \perp to fibers				0.5	5	0.4	0.63				
c_p			0.223			0.08	0.153	0.29			
Pyroceram, Corning 9606	2921	162.3	0.193	2.3	20.3	3.0	2.3	2.1	1.9	1.7	1.7
Silicon carbide,	5580	197.3	0.161	283.1	2475.7						50.3
								0.210	0.25	0.27	0.285
Silicon dioxide, crystalline (quartz)	3389	165.4									
k , to c -axis				6		22.5	9.5	4.4	2.9	2.4	
k , \perp to c -axis				3.6		12.0	5.9	2.7	2	1.8	
c_p			0.177					0.211	0.256	0.298	
Silicon dioxide, polycrystalline (fused silica)	3389	138.6	0.177	0.79	9	0.4	0.65	0.87	1.01	1.25	1.65
Silicon nitride	3911	150	0.165	9.2	104	—	—	0.216	0.248	0.264	0.276
						—	0.138	8.0	6.5	5.7	5.0
						—	0.185	0.185	0.223	0.253	0.275
Sulfur	706	130	0.169	0.1	1.51	0.095	0.1				
						0.962	0.144				
Thorium dioxide	6431	568.7	0.561	7.5	65.7			5.9	3.8	2.7	2.12
								0.609	0.654	0.680	0.704
Titanium dioxide, polycrystalline	3840	259.5	0.170	4.9	30.1			4.0	2.9	2.3	2
								0.192	0.210	0.217	0.222

TABLE A-5E

Properties of building materials
(at a mean temperature of 75°F)

Material	Thickness, <i>L</i> in	Density, ρ lbm/ft ³	Thermal Conductivity, <i>k</i> Btu-in/h · ft ² · °F	Specific Heat, c_p Btu/lbm · R	<i>R</i> -value (for listed thickness, <i>L/k</i>), °F · h · ft ² /Btu
Building Boards					
Asbestos-cement board	¼ in.	120	—	0.24	0.06
Gypsum of plaster board	⅜ in.	50	—	0.26	0.32
	½ in.	50	—	—	0.45
Plywood (Douglas fir)	—	34	0.80	0.29	—
	¼ in.	34	—	0.29	0.31
	⅜ in.	34	—	0.29	0.47
	½ in.	34	—	0.29	0.62
	¾ in.	34	—	0.29	0.93
Insulated board and sheathing (regular density)	½ in.	18	—	0.31	1.32
	²⁵ / ₃₂ in.	18	—	0.31	2.06
Hardboard (high density, standard tempered)	—	63	1.00	0.32	—
Particle board					
Medium density	—	50	0.94	0.31	—
Underlayment	⅝ in.	40	—	0.29	0.82
Wood subfloor	¾ in.	—	—	0.33	0.94
Building Membranes					
Vapor-permeable felt	—	—	—	—	0.06
Vapor-seal (2 layers of mopped 17.3 lbm/ft ² felt)	—	—	—	—	0.12
Flooring Materials					
Carpet and fibrous pad	—	—	—	0.34	2.08
Carpet and rubber pad	—	—	—	0.33	1.23
Tile (asphalt, linoleum, vinyl)	—	—	—	0.30	0.05
Masonry Materials					
<i>Masonry units:</i>					
Brick, common		120	5.0	—	—
Brick, face		130	9.0	—	—
Brick, fire clay		150	9.3	—	—
		120	6.2	0.19	—
		70	2.8	—	—
Concrete blocks (3 oval cores, sand and gravel aggregate)	4 in.	—	5.34	—	0.71
	8 in.	—	6.94	—	1.11
	12 in.	—	9.02	—	1.28
<i>Concretes</i>					
Lightweight aggregates		120	5.2	—	—
(including expanded shale, clay, or slate, expanded slags, cinders; pumice; and scoria)		100	3.6	0.2	—
		80	2.5	0.2	—
		60	1.7	—	—
		40	1.15	—	—
Cement/lime, mortar, and stucco		120	9.7	—	—
		80	4.5	—	—
Stucco		116	5.0	—	—

TABLE A-5E

Properties of building materials (*Concluded*)
(at a mean temperature of 75°F)

Material	Thickness, <i>L</i> in	Density, ρ lbm/ft ³	Thermal Conductivity, <i>k</i> Btu-in/h · ft ² · °F	Specific Heat, c_p Btu/lbm · R	<i>R</i> -value (for listed thickness, <i>L/k</i>), °F · h · ft ² /Btu
Roofing					
Asbestos-cement shingles		120	—	0.24	0.21
Asphalt roll roofing		70	—	0.36	0.15
Asphalt shingles		70	—	0.30	0.44
Built-in roofing	3/8 in.	70	—	0.35	0.33
Slate	1/2 in.	—	—	0.30	0.05
Wood shingles (plain and plastic film faced)		—	—	0.31	0.94
Plastering Materials					
Cement plaster, sand aggregate	3/4 in.	1.16	5.0	0.20	0.15
Gypsum plaster					
Lightweight aggregate	1/2 in.	45	—	—	0.32
Sand aggregate	1/2 in.	105	5.6	0.20	0.09
Perlite aggregate	—	45	1.5	0.32	—
Siding Material (on flat surfaces)					
Asbestos-cement shingles	—	120	—	—	0.21
Hardboard siding	7/16 in.	—	—	0.28	0.67
Wood (drop) siding	1 in.	—	—	0.31	0.79
Wood (plywood) siding, lapped	3/8 in.	—	—	0.29	0.59
Aluminum or steel siding (over sheeting):					
Hollow backed	3/8 in.	—	—	0.29	0.61
Insulating-board backed	3/8 in.	—	—	0.32	1.82
Architectural glass	—	158	6.9	0.21	0.10
Woods					
Hardwoods (maple, oak etc.)	—	45	1.10	0.30	—
Softwoods (fir, pine, etc.)	—	32	0.80	0.33	—
Metals					
Aluminum (1100)	—	171	1536	0.214	—
Steel, mild	—	489	314	0.120	—
Steel Stainless,	—	494	108	0.109	—

Source: Tables A-5E and A-6E are adapted from *ASHRAE, Handbook of Fundamentals* (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1993), Chap. 22, Table 4. Used with permission.

TABLE A-6E

Properties of insulating materials
(at a mean temperature of 75°F)

Material	Thickness, <i>L</i> in	Density, ρ lbm/ft ³	Thermal Conductivity, <i>k</i> Btu-in/h · ft ² · °F	Specific Heat, c_p Btu/lbm · R	<i>R</i> -value (for listed thickness, <i>L/k</i>) °F · h · ft ² /Btu
Blanket and Batt					
Mineral fiber (fibrous form)	~2 to 2¾ in	0.3–2.0	—	0.17–0.23	7
processed from rock, slag, or glass)	~3 to 3½ in	0.3–2.0	—	0.17–0.23	11
	~5¼ to 6½ in	0.3–2.0	—	0.17–0.23	19
Board and Slab					
Cellular glass		8.5	0.38	0.24	—
Glass fiber (organic bonded)		4–9	0.25	0.23	—
Expanded polystyrene (molded beads)		1.0	0.28	0.29	—
Expanded polyurethane (<i>R</i> -11 expanded)		1.5	0.16	0.38	—
Expanded perlite (organic bonded)		1.0	0.36	0.30	—
Expanded rubber (rigid)		4.5	0.22	0.40	—
Mineral fiber with resin binder		15	0.29	0.17	—
Cork		7.5	0.27	0.43	—
Sprayed or Formed in Place					
Polyurethane foam		1.5–2.5	0.16–0.18	—	—
Glass fiber		3.5–4.5	0.26–0.27	—	—
Urethane, two-part mixture (rigid foam)		4.4	0.18	0.25	—
Mineral wool granules with asbestos/inorganic binders (sprayed)		12	0.32	—	—
Loose Fill					
Mineral fiber (rock, slag, or glass)	~3.75 to 5 in	0.6–0.20	—	0.17	11
	~6.5 to 8.75 in	0.6–0.20	—	0.17	19
	~7.5 to 10 in	—	—	0.17	22
	~7.25 in	—	—	0.17	30
Silica aerogel		7.6	0.17	—	—
Vermiculite (expanded)		7–8	0.47	—	—
Perlite, expanded		2–4.1	0.27–0.31	—	—
Sawdust or shavings		8–15	0.45	—	—
Cellulosic insulation (milled paper or wood pulp)		0.3–3.2	0.27–0.32	—	—
Cork, granulated		10	0.31	—	—
Roof Insulation					
Cellular glass	—	9	0.4	0.24	—
Preformed, for use above deck	½ in	—	—	0.24	1.39
	1 in	—	—	0.50	2.78
	2 in	—	—	0.94	5.56
Reflective Insulation					
Silica powder (evacuated)		10	0.0118	—	—
Aluminum foil separating fluffy glass mats; 10–12 layers (evacuated); for cryogenic applications (270 R)		2.5	0.0011	—	—
Aluminum foil and glass paper laminate; 75–150 layers (evacuated); for cryogenic applications (270 R)		7.5	0.00012	—	—

TABLE A-7E

Properties of common foods

(a) Specific heats and freezing-point properties

Food	Water Content, ^a % (mass)	Freezing Point, ^a °F	Specific Heat, ^b Btu/lbm·°F		Latent Heat of Fusion ^c Btu/lbm	Food	Water Content, ^a % (mass)	Freezing Point, ^a °F	Specific Heat, ^b Btu/lbm·°F		Latent Heat of Fusion ^c Btu/lbm
			Above Freezing	Below Freezing					Above Freezing	Below Freezing	
Vegetables											
Artichokes	84	30	0.873	0.453	121	Pears	83	29	0.865	0.450	119
Asparagus	93	31	0.945	0.481	134	Pineapples	85	30	0.881	0.456	122
Beans, snap	89	31	0.913	0.468	128	Plums	86	31	0.889	0.459	124
Broccoli	90	31	0.921	0.471	129	Quinces	85	28	0.881	0.456	122
Cabbage	92	30	0.937	0.478	132	Raisins	18	—	—	0.255	26
Carrots	88	29	0.905	0.465	126	Strawberries	90	31	0.921	0.471	129
Cauliflower	92	31	0.937	0.478	132	Tangerines	87	30	0.897	0.462	125
Celery	94	31	0.953	0.484	135	Watermelon	93	31	0.945	0.481	134
Corn, sweet	74	31	0.793	0.423	106	Fish/Seafood					
Cucumbers	96	31	0.969	0.490	138	Cod, whole	78	28	0.825	0.435	112
Eggplant	93	31	0.945	0.481	134	Hallbut, whole	75	28	0.801	0.426	108
Horseradish	75	29	0.801	0.426	108	Lobster	79	28	0.833	0.438	113
Leeks	85	31	0.881	0.456	122	Mackerel	57	28	0.657	0.372	82
Lettuce	95	32	0.961	0.487	136	Salmon, whole	64	28	0.713	0.393	92
Mushrooms	91	30	0.929	0.474	131	Shrimp	83	28	0.865	0.450	119
Okra	90	29	0.921	0.471	129	Meats					
Onions, green	89	30	0.913	0.468	128	Beef carcass	49	29	0.593	0.348	70
Onions, dry	88	31	0.905	0.465	126	Liver	70	29	0.761	0.411	101
Parsley	85	30	0.881	0.456	122	Round, beef	67	—	0.737	0.402	96
Peas, green	74	31	0.793	0.423	106	Sirloin, beef	56	—	0.649	0.369	80
Peppers, sweet	92	31	0.937	0.478	132	Chicken	74	27	0.793	0.423	106
Potatoes	78	31	0.825	0.435	112	Lamb leg	65	—	0.721	0.396	93
Pumpkins	91	31	0.929	0.474	131	Pork carcass	37	—	0.497	0.312	53
Spinach	93	31	0.945	0.481	134	Ham	56	29	0.649	0.369	80
Tomatoes, ripe	94	31	0.953	0.484	135	Pork sausage	38	—	0.505	0.315	55
Turnips	92	30	0.937	0.478	132	Turkey	64	—	0.713	0.393	92
Fruits						Other					
Apples	84	30	0.873	0.453	121	Almonds	5	—	—	0.216	7
Apricots	85	30	0.881	0.456	122	Butter	16	—	—	0.249	23
Avocados	65	31	0.721	0.396	93	Cheese, cheddar	37	9	0.497	0.312	53
Bananas	75	31	0.801	0.426	108	Cheese, Swiss	39	14	0.513	0.318	56
Blueberries	82	29	0.857	0.447	118	Chocolate, milk	1	—	—	0.204	1
Cantaloupes	92	30	0.937	0.478	132	Eggs, whole	74	31	0.793	0.423	106
Cherries, sour	84	29	0.873	0.453	121	Honey	17	—	—	0.252	24
Cherries, sweet	80	29	0.841	0.441	115	Ice cream	63	22	0.705	0.390	90
Figs, dried	23	—	—	0.270	33	Milk, whole	88	31	0.905	0.465	126
Figs, fresh	78	28	0.825	0.435	112	Peanuts	6	—	—	0.219	9
Grapefruit	89	30	0.913	0.468	128	Peanuts, roasted	2	—	—	0.207	3
Grapes	82	29	0.857	0.447	118	Pecans	3	—	—	0.210	4
Lemons	89	29	0.913	0.468	128	Walnuts	4	—	—	0.213	6
Olives	75	29	0.801	0.426	108						
Oranges	87	31	0.897	0.462	125						
Peaches	89	30	0.913	0.468	128						

Source: ^aWater content and freezing point data are from ASHRAE, *Handbook of Fundamentals*, 1-P version (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1993), Chap. 30, Table 1. Used with permission. Freezing point is the temperature at which freezing starts for fruits and vegetables, and the average freezing temperature for other foods.

^bSpecific heat data are based on the specific heat values of water and ice at 32°F and are determined from Siebel's formulas: $C_{p, fresh} = 0.800 \times (\text{Water content}) + 0.200$, above freezing, and $C_{p, frozen} = 0.300 \times (\text{Water content}) + 0.200$, below freezing.

^cThe latent heat of fusion is determined by multiplying the heat of fusion of water (143 Btu/lbm) by the water content of the food.

TABLE A-7E

Properties of common foods (Concluded)
(b) Other properties

Food	Water Content, % (mass)	Temperature, T °F	Density, ρ lbm/ft ³	Thermal Conductivity, k Btu/h · ft · °F	Thermal Diffusivity, α ft ² /S	Specific Heat, c_p Btu/lbm · R
Fruits/Vegetables						
Apple juice	87	68	62.4	0.323	1.51×10^{-6}	0.922
Apples	85	32–86	52.4	0.242	1.47×10^{-6}	0.910
Apples, dried	41.6	73	53.4	0.127	1.03×10^{-6}	0.650
Apricots, dried	43.6	73	82.4	0.217	1.22×10^{-6}	0.662
Bananas, fresh	76	41	61.2	0.278	1.51×10^{-6}	0.856
Broccoli	—	21	35.0	0.223	—	—
Cherries, fresh	92	32–86	65.5	0.315	1.42×10^{-6}	0.952
Figs	40.4	73	77.5	0.179	1.03×10^{-6}	0.642
Grape juice	89	68	62.4	0.328	1.51×10^{-6}	0.934
Peaches	36–90	2–32	59.9	0.304	1.51×10^{-6}	0.934
Plums	—	3	38.1	0.143	—	—
Potatoes	32–158	0–70	65.7	0.288	1.40×10^{-6}	0.868
Raisins	32	73	86.2	0.217	1.18×10^{-6}	0.592
Meats						
Beef, ground	67	43	59.3	0.235	1.40×10^{-6}	0.802
Beef, lean	74	37	68.0	0.272	1.40×10^{-6}	0.844
Beef fat	0	95	50.5	0.110	—	—
Beef liver	72	95	—	0.259	—	0.832
Cat food	39.7	73	71.2	0.188	1.18×10^{-6}	0.638
Chicken breast	75	32	65.5	0.275	1.40×10^{-6}	0.850
Dog food	30.6	73	77.4	0.184	1.18×10^{-6}	0.584
Fish, cod	81	37	73.7	0.309	1.29×10^{-6}	0.886
Fish, salmon	67	37	—	0.307	—	0.802
Ham	71.8	72	64.3	0.277	1.51×10^{-6}	0.831
Lamb	72	72	64.3	0.263	1.40×10^{-6}	0.832
Pork, lean	72	39	64.3	0.263	1.40×10^{-6}	0.832
Turkey breast	74	37	65.5	0.287	1.40×10^{-6}	0.844
Veal	75	72	66.2	0.272	1.40×10^{-6}	0.850
Other						
Butter	16	39	—	0.114	—	0.496
Chocolate cake	31.9	73	21.2	0.061	1.29×10^{-6}	0.591
Margarine	16	40	62.4	0.135	1.18×10^{-6}	0.496
Milk, skimmed	91	72	—	0.327	—	0.946
Milk, whole	88	82	—	0.335	—	0.928
Olive oil	0	90	56.8	0.097	—	—
Peanut oil	0	39	57.4	0.097	—	—
Water	100	0	62.4	0.329	1.51×10^{-6}	1.000
	100	30	59.6	0.357	1.61×10^{-6}	1.000
White cake	32.3	73	28.1	0.047	1.08×10^{-6}	0.594

Source: Data obtained primarily from ASHRAE, *Handbook of Fundamentals*, I-P version (Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1993), Chap. 30, Tables 7 and 9. Used with permission.

Most specific heats are calculated from $c_p = 0.4 + 0.6 \times (\text{Water content})$, which is a good approximation in the temperature range of 40 to 90°F. Most thermal diffusivities are calculated from $\alpha = k/\rho c_p$. Property values given above are valid for the specified water content.

TABLE A-8E

Properties of miscellaneous materials
(values are at 540 R unless indicated otherwise)

Material	Density, ρ lbm/ft ³	Thermal Conductivity, k Btu/h · ft · R	Specific Heat, c_p Btu/lbm · R	Material	Density, ρ lbm/ft ³	Thermal Conductivity, k Btu/h · ft · R	Specific Heat, c_p Btu/lbm · R
Asphalt	132.0	0.036	0.220	Ice			
Bakelite	81.2	0.81	0.350	492 R	57.4	1.09	0.487
Brick, refractory				455 R	57.6	1.17	0.465
Chrome brick				311 R	57.9	2.02	0.349
851 R	187.9	1.33	0.199	Leather, sole	62.3	0.092	—
1481 R	—	1.44	—	Linoleum	33.4	0.047	—
2111 R	—	1.16	—		73.7	0.11	—
Fire clay, burnt				Mica	181.0	0.30	—
2880 R				Paper	58.1	0.10	0.320
1391 R	128.0	0.58	0.229	Plastics			
1931 R	—	0.64	—	Plexiglass	74.3	0.11	0.350
2471 R	—	0.64	—	Teflon			
Fire clay, burnt				540 R	137.3	0.20	0.251
3105 R				720 R	—	0.26	—
1391 R	145.1	0.75	0.229	Lexan	74.9	0.11	0.301
1931 R	—	0.81	—	Nylon	71.5	0.17	—
2471 R	—	0.81	—	Polypropylene	56.8	0.069	0.388
Fire clay brick				Polyester	87.1	0.087	0.279
860 R	165.1	0.58	0.229	PVC, vinyl	91.8	0.058	0.201
1660 R	—	0.87	—	Porcelain	143.6	0.87	—
2660 R	—	1.04	—	Rubber, natural	71.8	0.16	—
Magnesite				Rubber,			
860 R	—	2.20	0.270	vulcanized			
1660 R	—	1.62	—	Soft	68.7	0.075	0.480
2660 R	—	1.10	—	Hard	74.3	0.092	—
Chicken meat,				Sand	94.6	0.1–0.6	0.191
white (74.4% water content)				Snow, fresh	6.24	0.35	—
356 R	—	0.92	—	Snow 492 R	31.2	1.27	—
419 R	—	0.86	—	Soil, dry	93.6	0.58	0.454
455 R	—	0.78	—	Soil, wet	118.6	1.16	0.525
492 R	—	0.28	—	Sugar	99.9	0.34	—
527 R	—	0.28	—	Tissue, human			
Clay, dry	96.8	0.54	—	Skin	—	0.21	—
Clay, wet	93.3	0.97	—	Fat layer	—	0.12	—
Coal, anthracite	84.3	0.15	0.301	Muscle	—	0.24	—
Concrete (stone mix)	143.6	0.81	0.210	Vaseline	—	0.098	—
Cork	5.37	0.028	0.485	Wood, cross-grain			
Cotton	5.0	0.035	0.311	Balsa	8.74	0.032	—
Fat	—	0.10	—	Fir	25.9	0.064	0.650
Glass				Oak	34.0	0.098	0.570
Window	174.8	0.40	0.179	White pine	27.2	0.064	—
Pyrex	138.9	0.6–0.8	0.199	Yellow pine	40.0	0.087	0.670
Crown	156.1	0.61	—	Wood, radial			
Lead	212.2	0.49	—	Oak	34.0	0.11	0.570
				Fir	26.2	0.081	0.650
				Wool, ship	9.05	0.029	—

TABLE A-9E

Properties of saturated water

Temp. <i>T</i> , °F	Saturation Pressure <i>P</i> _{sat} , psia	Density ρ , lbm/ft ³		Enthalpy of Vaporization <i>h</i> _{fg} , Btu/lbm	Specific Heat <i>c</i> _p , Btu/lbm · R		Thermal Conductivity <i>k</i> , Btu/h · ft · R		Dynamic Viscosity μ , lbm/ft · s		Prandtl Number Pr		Volume Expansion Coefficient β , 1/R
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	
32.02	0.0887	62.41	0.00030	1075	1.010	0.446	0.324	0.0099	1.204×10^{-3}	6.194×10^{-6}	13.5	1.00	-0.038×10^{-3}
40	0.1217	62.42	0.00034	1071	1.004	0.447	0.329	0.0100	1.308×10^{-3}	6.278×10^{-6}	11.4	1.01	$A0.003 \times 10^{-3}$
50	0.1780	62.41	0.00059	1065	1.000	0.448	0.335	0.0102	8.781×10^{-4}	6.361×10^{-6}	9.44	1.01	0.047×10^{-3}
60	0.2563	62.36	0.00083	1060	0.999	0.449	0.341	0.0104	7.536×10^{-4}	6.444×10^{-6}	7.95	1.00	0.080×10^{-3}
70	0.3632	62.30	0.00115	1054	0.999	0.450	0.347	0.0106	6.556×10^{-4}	6.556×10^{-6}	6.79	1.00	0.115×10^{-3}
80	0.5073	62.22	0.00158	1048	0.999	0.451	0.352	0.0108	5.764×10^{-4}	6.667×10^{-6}	5.89	1.00	0.145×10^{-3}
90	0.6988	62.12	0.00214	1043	0.999	0.453	0.358	0.0110	5.117×10^{-4}	6.778×10^{-6}	5.14	1.00	0.174×10^{-3}
100	0.9503	62.00	0.00286	1037	0.999	0.454	0.363	0.0112	4.578×10^{-4}	6.889×10^{-6}	4.54	1.01	0.200×10^{-3}
110	1.2763	61.86	0.00377	1031	0.999	0.456	0.367	0.0115	4.128×10^{-4}	7.000×10^{-6}	4.05	1.00	0.224×10^{-3}
120	1.6945	61.71	0.00493	1026	0.999	0.458	0.371	0.0117	3.744×10^{-4}	7.111×10^{-6}	3.63	1.00	0.246×10^{-3}
130	2.225	61.55	0.00636	1020	0.999	0.460	0.375	0.0120	3.417×10^{-4}	7.222×10^{-6}	3.28	1.00	0.267×10^{-3}
140	2.892	61.38	0.00814	1014	0.999	0.463	0.378	0.0122	3.136×10^{-4}	7.333×10^{-6}	2.98	1.00	0.287×10^{-3}
150	3.722	61.19	0.0103	1008	1.000	0.465	0.381	0.0125	2.889×10^{-4}	7.472×10^{-6}	2.73	1.00	0.306×10^{-3}
160	4.745	60.99	0.0129	1002	1.000	0.468	0.384	0.0128	2.675×10^{-4}	7.583×10^{-6}	2.51	1.00	0.325×10^{-3}
170	5.996	60.79	0.0161	996	1.001	0.472	0.386	0.0131	2.483×10^{-4}	7.722×10^{-6}	2.90	1.00	0.346×10^{-3}
180	7.515	60.57	0.0199	990	1.002	0.475	0.388	0.0134	2.317×10^{-4}	7.833×10^{-6}	2.15	1.00	0.367×10^{-3}
190	9.343	60.35	0.0244	984	1.004	0.479	0.390	0.0137	2.169×10^{-4}	7.972×10^{-6}	2.01	1.00	0.382×10^{-3}
200	11.53	60.12	0.0297	978	1.005	0.483	0.391	0.0141	2.036×10^{-4}	8.083×10^{-6}	1.88	1.00	0.395×10^{-3}
210	14.125	59.87	0.0359	972	1.007	0.487	0.392	0.0144	1.917×10^{-4}	8.222×10^{-6}	1.77	1.00	0.412×10^{-3}
212	14.698	59.82	0.0373	970	1.007	0.488	0.392	0.0145	1.894×10^{-4}	8.250×10^{-6}	1.75	1.00	0.417×10^{-3}
220	17.19	59.62	0.0432	965	1.009	0.492	0.393	0.0148	1.808×10^{-4}	8.333×10^{-6}	1.67	1.00	0.429×10^{-3}
230	20.78	59.36	0.0516	959	1.011	0.497	0.394	0.0152	1.711×10^{-4}	8.472×10^{-6}	1.58	1.00	0.443×10^{-3}
240	24.97	59.09	0.0612	952	1.013	0.503	0.394	0.0156	1.625×10^{-4}	8.611×10^{-6}	1.50	1.00	0.462×10^{-3}
250	29.82	58.82	0.0723	946	1.015	0.509	0.395	0.0160	1.544×10^{-4}	8.611×10^{-6}	1.43	1.00	0.480×10^{-3}
260	35.42	58.53	0.0850	939	1.018	0.516	0.395	0.0164	1.472×10^{-4}	8.661×10^{-6}	1.37	1.00	0.497×10^{-3}
270	41.85	58.24	0.0993	932	1.020	0.523	0.395	0.0168	1.406×10^{-4}	9.000×10^{-6}	1.31	1.01	0.514×10^{-3}
280	49.18	57.94	0.1156	926	1.023	0.530	0.395	0.0172	1.344×10^{-4}	9.111×10^{-6}	1.25	1.01	0.532×10^{-3}
290	57-53	57.63	0.1330	918	1.026	0.538	0.395	0.0177	1.289×10^{-4}	9.250×10^{-6}	1.21	1.01	0.549×10^{-3}
300	66.98	57.31	0.1545	910	1.029	0.547	0.394	0.0182	1.236×10^{-4}	9.389×10^{-6}	1.16	1.02	0.566×10^{-3}
320	89.60	56.65	0.2033	895	1.036	0.567	0.393	0.0191	1.144×10^{-4}	9.639×10^{-6}	1.09	1.03	0.636×10^{-3}
340	117.93	55.95	0.2637	880	1.044	0.590	0.391	0.0202	1.063×10^{-4}	9.889×10^{-6}	1.02	1.04	0.656×10^{-3}
360	152.92	56.22	0.3377	863	1.054	0.617	0.389	0.0213	9.972×10^{-5}	1.013×10^{-5}	0.973	1.06	0.681×10^{-3}
380	195.60	54.46	0.4275	845	1.065	0.647	0.385	0.0224	9.361×10^{-5}	1.041×10^{-5}	0.932	1.08	0.720×10^{-3}
400	241.1	53.65	0.5359	827	1.078	0.683	0.382	0.0237	8.833×10^{-5}	1.066×10^{-5}	0.893	1.11	0.771×10^{-3}
450	422.1	51.46	0.9082	775	1.121	0.799	0.370	0.0271	7.722×10^{-5}	1.130×10^{-5}	0.842	1.20	0.912×10^{-3}
500	680.0	48.95	1.479	715	1.188	0.972	0.352	0.0312	6.833×10^{-5}	1.200×10^{-5}	0.830	1.35	1.111×10^{-3}
550	1046.7	45.96	4.268	641	1.298	1.247	0.329	0.0368	6.083×10^{-5}	1.280×10^{-5}	0.864	1.56	1.445×10^{-3}
600	1541	42.32	3.736	550	1.509	1.759	0.299	0.0461	5.389×10^{-5}	1.380×10^{-5}	0.979	1.90	1.883×10^{-3}
650	2210	37.31	6.152	422	2.086	3.103	0.267	0.0677	4.639×10^{-5}	1.542×10^{-5}	1.30	2.54	
700	3090	27.28	13.44	168	13.80	25.90	0.254	0.1964	3.417×10^{-5}	2.044×10^{-5}	6.68	9.71	
705.44	3204	19.79	19.79	0	∞	∞	∞	∞	2.897×10^{-5}	2.897×10^{-5}			

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/Pr$. The temperatures 32.02°F, 212°F, and 705.44°F are the triple-, boiling-, and critical-point temperatures of water, respectively. All properties listed above (except the vapor density) can be used at any pressures with negligible error except at temperatures near the critical-point value.

Note 2: The unit Btu/lbm · °F for specific heat is equivalent to Btu/lbm · R, and the unit Btu/h · ft · °F for thermal conductivity is equivalent to Btu/h · ft · R.

Source: Viscosity and thermal conductivity data are from J. V. Sengers and J. T. T. Watson, *Journal of Physical and Chemical Reference Data* 15 (1986), pp. 1291–1322. Other data are obtained from various sources or calculated.

TABLE A-10E

Properties of saturated refrigerant-134a

Temp. T_s , °F	Saturation Pressure P_{sat} , psia	Density ρ , lbm/ft ³		Enthalpy of Vaporization h_{fg} , Btu/lbm	Specific Heat c_p , Btu/lbm-R		Thermal Conductivity k , Btu/h-ft-R		Dynamic Viscosity μ , lbm/ft-s		Prandtl Number Pr		Volume Expansion Coefficient β , 1/R	Surface Tension lbf/ft
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
-40	7.4	88.51	0.1731	97.1	0.2996	0.1788	0.0636	0.00466	3.278×10^{-4}	1.714×10^{-6}	5.558	0.237	0.00114	0.001206
-30	9.9	87.5	0.2258	95.6	0.3021	0.1829	0.0626	0.00497	3.004×10^{-4}	2.053×10^{-6}	5.226	0.272	0.00117	0.001146
-20	12.9	86.48	0.2905	94.1	0.3046	0.1872	0.0613	0.00529	2.762×10^{-4}	2.433×10^{-6}	4.937	0.310	0.00120	0.001087
-10	16.6	85.44	0.3691	92.5	0.3074	0.1918	0.0602	0.00559	2.546×10^{-4}	2.856×10^{-6}	4.684	0.352	0.00124	0.001029
0	21.2	84.38	0.4635	90.9	0.3103	0.1966	0.0589	0.00589	2.345×10^{-4}	3.314×10^{-6}	4.463	0.398	0.00128	0.000972
10	26.6	83.31	0.5761	89.3	0.3134	0.2017	0.0576	0.00619	2.181×10^{-4}	3.811×10^{-6}	4.269	0.447	0.00132	0.000915
20	33.1	82.2	0.7094	87.5	0.3167	0.2070	0.0563	0.00648	2.024×10^{-4}	4.342×10^{-6}	4.098	0.500	0.00132	0.000859
30	40.8	81.08	0.866	85.8	0.3203	0.2127	0.0550	0.00676	1.883×10^{-4}	4.906×10^{-6}	3.947	0.555	0.00142	0.000803
40	49.8	79.92	1.049	83.9	0.3240	0.2188	0.0536	0.00704	1.752×10^{-4}	5.494×10^{-6}	3.814	0.614	0.00149	0.000749
50	60.2	78.73	1.262	82.0	0.3281	0.2253	0.0522	0.00732	1.633×10^{-4}	6.103×10^{-6}	3.697	0.677	0.00156	0.000695
60	72.2	77.51	1.509	80.0	0.3325	0.2323	0.0507	0.00758	1.522×10^{-4}	6.725×10^{-6}	3.594	0.742	0.00163	0.000642
70	85.9	76.25	1.794	78.0	0.3372	0.2398	0.0492	0.00785	1.420×10^{-4}	7.356×10^{-6}	3.504	0.810	0.00173	0.000590
80	101.4	74.94	2.122	75.8	0.3424	0.2481	0.0476	0.00810	1.324×10^{-4}	7.986×10^{-6}	3.425	0.880	0.00183	0.000538
90	119.1	73.59	2.5	73.5	0.3481	0.2572	0.0460	0.00835	1.234×10^{-4}	8.611×10^{-6}	3.357	0.955	0.00195	0.000488
100	138.9	72.17	2.935	71.1	0.3548	0.2674	0.0444	0.00860	1.149×10^{-4}	9.222×10^{-6}	3.303	1.032	0.00210	0.000439
110	161.2	70.69	3.435	68.5	0.3627	0.2790	0.0427	0.00884	1.068×10^{-4}	9.814×10^{-6}	3.262	1.115	0.00227	0.000391
120	186.0	69.13	4.012	65.8	0.3719	0.2925	0.0410	0.00908	9.911×10^{-5}	1.038×10^{-5}	3.235	1.204	0.00248	0.000344
130	213.5	67.48	4.679	62.9	0.3829	0.3083	0.0392	0.00931	9.175×10^{-5}	1.092×10^{-5}	3.223	1.303	0.00275	0.000299
140	244.1	65.72	5.455	59.8	0.3963	0.3276	0.0374	0.00954	8.464×10^{-5}	1.144×10^{-5}	3.229	1.416	0.00308	0.000255
150	277.8	63.83	6.367	56.4	0.4131	0.3520	0.0355	0.00976	7.778×10^{-5}	1.195×10^{-5}	3.259	1.551	0.00351	0.000212
160	314.9	61.76	7.45	52.7	0.4352	0.3839	0.0335	0.00998	7.108×10^{-5}	1.245×10^{-5}	3.324	1.725	0.00411	0.000171
170	355.8	59.47	8.762	48.5	0.4659	0.4286	0.0314	0.01020	6.450×10^{-5}	1.298×10^{-5}	3.443	1.963	0.00498	0.000132
180	400.7	56.85	10.4	43.7	0.5123	0.4960	0.0292	0.01041	5.792×10^{-5}	1.366×10^{-5}	3.661	2.327	0.00637	0.000095
190	449.9	53.75	12.53	38.0	0.5929	0.6112	0.0267	0.01063	5.119×10^{-5}	1.431×10^{-5}	4.090	2.964	0.00891	0.000061
200	504.0	49.75	15.57	30.7	0.7717	0.8544	0.0239	0.01085	4.397×10^{-5}	1.544×10^{-5}	5.119	4.376	0.01490	0.000031
210	563.8	43.19	21.18	18.9	1.4786	1.6683	0.0199	0.01110	3.483×10^{-5}	1.787×10^{-5}	9.311	9.669	0.04021	0.000006

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/Pr$. The properties listed here (except the vapor density) can be used at any pressures with negligible error except at temperatures near the critical-point value.

Note 2: The unit Btu/lbm · °F for specific heat is equivalent to Btu/lbm-R, and the unit Btu/h-ft-°F for thermal conductivity is equivalent to Btu/h-ft-R.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: R. Tilner-Roth and H. D. Baehr, "An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for Temperatures from 170 K to 455 K and Pressures up to 70 Mpa," *J. Phys. Chem. Ref. Data*, Vol. 23, No.5, 1994; M. J. Assael, N. K. Dalouti, A. A. Griva, and J. H. Dymond, "Viscosity and Thermal Conductivity of Halogenated Methane and Ethane Refrigerants," *IJR*, Vol. 22, pp. 525-535, 1999; NIST REPROP 6 program (M. O. McLinden, S. A. Klein, E. W. Lemmon, and A. P. Peskin, Physical and Chemical Properties Division, National Institute of Standards and Technology, Boulder, CO 80303, 1995).

TABLE A-11E

Properties of saturated ammonia

Temp. <i>T</i> , °F	Saturation Pressure <i>P</i> _{sat} , psia	Density ρ , lbm/ft ³		Enthalpy of Vaporization <i>h</i> _{fg} , Btu/lbm	Specific Heat <i>c</i> _p , Btu/lbm-R		Thermal Conductivity <i>k</i> , Btu/h-ft-R		Dynamic Viscosity μ , lbm/ft-s		Prandtl Number Pr		Volume Expansion Coefficient β , 1/R	Surface Tension lb/ft
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
-40	10.4	43.08	0.0402	597.0	1.0542	0.5354	-	0.01026	1.966 × 10 ⁻⁴	5.342 × 10 ⁻⁶	-	1.003	0.00098	0.002443
-30	13.9	42.66	0.0527	590.2	1.0610	0.5457	-	0.01057	1.853 × 10 ⁻⁴	5.472 × 10 ⁻⁶	-	1.017	0.00101	0.002357
-20	18.3	42.33	0.0681	583.2	1.0677	0.5571	0.3501	0.01089	1.746 × 10 ⁻⁴	5.600 × 10 ⁻⁶	1.917	1.031	0.00103	0.002272
-10	23.7	41.79	0.0869	575.9	1.0742	0.5698	0.3426	0.01121	1.645 × 10 ⁻⁴	5.731 × 10 ⁻⁶	1.856	1.048	0.00106	0.002187
0	30-4	41.34	0.1097	568.4	1.0807	0.5838	0.3352	0.01154	1.549 × 10 ⁻⁴	5.861 × 10 ⁻⁶	1.797	1.068	0.00109	0.002103
10	38.5	40.89	0.1370	560.7	1.0873	0.5992	0.3278	0.01187	1.458 × 10 ⁻⁴	5.994 × 10 ⁻⁶	1.740	1.089	0.00112	0.002018
20	48.2	40.43	0.1694	552.6	1.0941	0.6160	0.3203	0.01220	1.371 × 10 ⁻⁴	6.125 × 10 ⁻⁶	1.686	1.113	0.00116	0.001934
30	59.8	39.96	0.2075	544.4	1.1012	0.6344	0.3129	0.01254	1.290 × 10 ⁻⁴	6.256 × 10 ⁻⁶	1.634	1.140	0.00119	0.001850
40	73.4	39.48	0.2521	535.8	1.1087	0.6544	0.3055	0.01288	1.213 × 10 ⁻⁴	6.389 × 10 ⁻⁶	1.585	1.168	0.00123	0.001767
50	89.2	38.99	0.3040	526.9	1.1168	0.6762	0.2980	0.01323	1.140 × 10 ⁻⁴	6.522 × 10 ⁻⁶	1.539	1.200	0.00128	0.001684
60	107.7	38.50	0.3641	517.7	1.1256	0.6999	0.2906	0.01358	1.072 × 10 ⁻⁴	6.656 × 10 ⁻⁶	1.495	1.234	0.00132	0.001601
70	128.9	37.99	0.4332	508.1	1.1353	0.7257	0.2832	0.01394	1.008 × 10 ⁻⁴	6.786 × 10 ⁻⁶	1.456	1.272	0.00137	0.001518
80	153.2	37.47	0.5124	498.2	1.1461	0.7539	0.2757	0.01431	9.486 × 10 ⁻⁵	6.922 × 10 ⁻⁶	1.419	1.313	0.00143	0.001436
90	180.8	36.94	0.6029	487.8	1.1582	0.7846	0.2683	0.01468	8.922 × 10 ⁻⁵	7.056 × 10 ⁻⁶	1.387	1.358	0.00149	0.001354
100	212.0	36.40	0.7060	477.0	1.1719	0.8183	0.2609	0.01505	8.397 × 10 ⁻⁵	7.189 × 10 ⁻⁶	1.358	1.407	0.00156	0.001273
110	247.2	35.83	0.8233	465.8	1.1875	0.8554	0.2535	0.01543	7.903 × 10 ⁻⁵	7.325 × 10 ⁻⁶	1.333	1.461	0.00164	0.001192
120	286.5	35.26	0.9564	454.1	1.2054	0.8965	0.2460	0.01582	7.444 × 10 ⁻⁵	7.458 × 10 ⁻⁶	1.313	1.522	0.00174	0.001111
130	330.4	34.66	1.1074	441.7	1.2261	0.9425	0.2386	0.01621	7.017 × 10 ⁻⁵	7.594 × 10 ⁻⁶	1.298	1.589	0.00184	0.001031
140	379.4	34.04	1.2786	428.8	1.2502	0.9943	0.2312	0.01661	6.617 × 10 ⁻⁵	7.731 × 10 ⁻⁶	1.288	1.666	0.00196	0.000951
150	433.2	33.39	1.4730	415.2	1.2785	1.0533	0.2237	0.01702	6.244 × 10 ⁻⁵	7.867 × 10 ⁻⁶	1.285	1.753	0.00211	0.000872
160	492.7	32.72	1.6940	400.8	1.3120	1.1214	0.2163	0.01744	5.900 × 10 ⁻⁵	8.006 × 10 ⁻⁶	1.288	1.853	0.00228	0.000794
170	558.2	32.01	1.9460	385.4	1.3523	1.2012	0.2089	0.01786	5.578 × 10 ⁻⁵	8.142 × 10 ⁻⁶	1.300	1.971	0.00249	0.000716
180	630.1	31.26	2.2346	369.1	1.4015	1.2965	0.2014	0.01829	5.278 × 10 ⁻⁵	8.281 × 10 ⁻⁶	1.322	2.113	0.00274	0.000638
190	708.5	30.47	2.5670	351.6	1.4624	1.4128	0.1940	0.01874	5.000 × 10 ⁻⁵	8.419 × 10 ⁻⁶	1.357	2.286	0.00306	0.000562
200	794.4	29.62	2.9527	332.7	1.5397	1.5586	0.1866	0.01919	4.742 × 10 ⁻⁵	8.561 × 10 ⁻⁶	1.409	2.503	0.00348	0.000486
210	887.9	28.70	3.4053	312.0	1.6411	1.7473	0.1791	0.01966	4500 × 10 ⁻⁵	8.703 × 10 ⁻⁶	1.484	2.784	0.00403	0.000411
220	989.5	27.69	3.9440	289.2	1.7798	2.0022	0.1717	0.02015	4.275 × 10 ⁻⁵	8.844 × 10 ⁻⁶	1.595	3.164	0.00480	0.000338
230	1099.0	25.57	4.5987	263.5	1.9824	2.3659	0.1643	0.02065	4.064 × 10 ⁻⁵	8.989 × 10 ⁻⁶	1.765	3.707	0.00594	0.000265
240	1219.4	25.28	5.4197	234.0	2.3100	2.9264	0.1568	0.02119	3.864 × 10 ⁻⁵	9.136 × 10 ⁻⁶	2.049	4.542	0.00784	0.000194

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/Pr$. The properties listed here (except the vapor density) can be used at any pressures with negligible error except at temperatures near the critical-point value.

Note 2: The unit Btu/lbm-°F for specific heat is equivalent to Btu/lbm-R, and the unit Btu/h-ft-°F for thermal conductivity is equivalent to Btu/h-ft-R.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Tillner-Roth, Harms-Watzenterg, and Baehr, "Eine neue Fundamentalgleichung für Ammoniak," *DKV-Tagungsbericht* 20: 167-181, 1993; Liley and Desai, "Thermophysical Properties of Refrigerants," *ASHRAE*, 1993, ISBN 1-1883413-10-9.

TABLE A-12E

Properties of saturated propane

Temp. T_s , °F	Saturation Pressure P_{sat} , psia	Density ρ , lbm/ft ³		Enthalpy of Vaporization h_{fg} , Btu/lbm	Specific Heat c_p , Btu/lbm-R		Thermal Conductivity k , Btu/h-ft-R		Dynamic Viscosity μ , lbm/ft-s		Prandtl Number Pr		Volume Expansion Coefficient β , 1/R	Surface Tension lb/ft
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
-200	0.0201	42.06	0.0003	217.7	0.4750	0.2595	0.1073	0.00313	5.012×10^{-4}	2.789×10^{-6}	7.991	0.833	0.00083	0.001890
-180	0.0752	41.36	0.0011	213.4	0.4793	0.2680	0.1033	0.00347	3.941×10^{-4}	2.975×10^{-6}	6.582	0.826	0.00086	0.001780
-160	0.2307	40.65	0.0032	209.1	0.4845	0.2769	0.0992	0.00384	3.199×10^{-4}	3.164×10^{-6}	5.626	0.821	0.00088	0.001671
-140	0.6037	39.93	0.0078	204.8	0.4907	0.2866	0.0949	0.00423	2.660×10^{-4}	3.358×10^{-6}	4.951	0.818	0.00091	0.001563
-120	1.389	39.20	0.0170	200.5	0.4982	0.2971	0.0906	0.00465	2.252×10^{-4}	3.556×10^{-6}	4.457	0.817	0.00094	0.001455
-100	2.878	38.46	0.0334	196.1	0.5069	0.3087	0.0863	0.00511	1.934×10^{-4}	3.756×10^{-6}	4.087	0.817	0.00097	0.001349
-90	4.006	38.08	0.0453	193.9	0.5117	0.3150	0.0842	0.00534	1.799×10^{-4}	3.858×10^{-6}	3.936	0.819	0.00099	0.001297
-80	5.467	37.70	0.0605	191.6	0.5169	0.3215	0.0821	0.00559	1.678×10^{-4}	3.961×10^{-6}	3.803	0.820	0.00101	0.001244
-70	7.327	37.32	0.0793	189.3	0.5224	0.3284	0.0800	0.00585	1.569×10^{-4}	4.067×10^{-6}	3.686	0.822	0.00104	0.001192
-60	9.657	36.93	0.1024	186.9	0.5283	0.3357	0.0780	0.00611	1.469×10^{-4}	4.172×10^{-6}	3.582	0.825	0.00106	0.001140
-50	12.54	36.54	0.1305	184.4	0.5345	0.3433	0.0760	0.00639	1.378×10^{-4}	4.278×10^{-6}	3.490	0.828	0.00109	0.001089
-40	16.05	36.13	0.1641	181.9	0.5392	0.3513	0.0740	0.00668	1.294×10^{-4}	4.386×10^{-6}	3.395	0.831	0.00112	0.001038
-30	20.29	35.73	0.2041	179.3	0.5460	0.3596	0.0721	0.00697	1.217×10^{-4}	4.497×10^{-6}	3.320	0.835	0.00115	0.000987
-20	25.34	35.31	0.2512	176.6	0.5531	0.3684	0.0702	0.00728	1.146×10^{-4}	4.611×10^{-6}	3.253	0.840	0.00119	0.000937
-10	31.3	34.89	0.3063	173.8	0.5607	0.3776	0.0683	0.00761	1.079×10^{-4}	4.725×10^{-6}	3.192	0.845	0.00123	0.000887
0	38.28	34.46	0.3703	170.9	0.5689	0.3874	0.0665	0.00794	1.018×10^{-4}	4.842×10^{-6}	3.137	0.850	0.00127	0.000838
10	46.38	34.02	0.4441	167.9	0.5775	0.3976	0.0647	0.00829	9.606×10^{-5}	4.961×10^{-6}	3.088	0.857	0.00132	0.000789
20	55.7	33.56	0.5289	164.8	0.5867	0.4084	0.0629	0.00865	9.067×10^{-5}	5.086×10^{-6}	3.043	0.864	0.00138	0.000740
30	66.35	33.10	0.6259	161.6	0.5966	0.4199	0.0512	0.00903	8.561×10^{-5}	5.211×10^{-6}	3.003	0.873	0.00144	0.000692
40	78.45	32.62	0.7365	158.1	0.6072	0.4321	0.0595	0.00942	8.081×10^{-5}	5.342×10^{-6}	2.967	0.882	0.00151	0.000644
50	92.12	32.13	0.8621	154.6	0.6187	0.4452	0.0579	0.00983	7.631×10^{-5}	5.478×10^{-6}	2.935	0.893	0.00159	0.000597
60	107.5	31.63	1.0046	150.8	0.6311	0.4593	0.0563	0.01025	7.200×10^{-5}	5.617×10^{-6}	2.906	0.906	0.00168	0.000551
70	124.6	31.11	1.1659	146.8	0.6447	0.4746	0.0547	0.01070	6.794×10^{-5}	5.764×10^{-6}	2.881	0.921	0.00179	0.000505
80	143.7	30.56	1.3484	142.7	0.6596	0.4915	0.0532	0.01116	6.406×10^{-5}	5.919×10^{-6}	2.860	0.938	0.00191	0.000460
90	164.8	30.00	1.5549	138.2	0.6762	0.5103	0.0517	0.01165	6.033×10^{-5}	6.081×10^{-6}	2.843	0.959	0.00205	0.000416
100	188.1	29.41	1.7887	133.6	0.6947	0.5315	0.0501	0.01217	5.675×10^{-5}	6.256×10^{-6}	2.831	0.984	0.00222	0.000372
120	241.8	28.13	2.3562	123.2	0.7403	0.5844	0.0472	0.01328	5.000×10^{-5}	6.644×10^{-6}	2.825	1.052	0.00267	0.000288
140	306.1	26.69	3.1003	111.1	0.7841	0.6613	0.0442	0.01454	4.358×10^{-5}	7.111×10^{-6}	2.784	1.164	0.00338	0.000208
160	382.4	24.98	4.1145	96.4	0.8696	0.7911	0.0411	0.01603	3.733×10^{-5}	7.719×10^{-6}	2.845	1.371	0.00459	0.000133
180	472.9	22.79	5.6265	77.1	1.1436	1.0813	0.0376	0.01793	3.083×10^{-5}	8.617×10^{-6}	3.380	1.870	0.00791	0.000065

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/Pr$. The properties listed here (except the vapor density) can be used at any pressures with negligible error at temperatures near the critical-point value.

Note 2: The unit Btu/lbm-°F for specific heat is equivalent to Btu/lbm-R, and the unit Btu/h-ft-°F for thermal conductivity is equivalent to Btu/h-ft-R.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Reiner Tillner-Roth, "Fundamental Equations of State," Shaker, Verlag, Aachen, 1998; B. A. Younglove and J. F. Ely, "Thermophysical Properties of Fluids. II Methane, Ethane, Propane, Isobutane, and Normal Butane," *J. Phys. Chem. Ref. Data*, Vol. 16, No. 4, 1987; G. R. Somayajulu, "A Generalized Equation for Surface Tension from the Triple-Point to the Critical-Point," *International Journal of Thermophysics*, Vol. 9, No. 4, 1988.

TABLE A-13E

Properties of liquids

Temp. $T, ^\circ\text{F}$	Density $\rho, \text{lbm/ft}^3$	Specific Heat $c_p, \text{Btu/lbm}\cdot\text{R}$	Thermal Conductivity $k, \text{Btu/h}\cdot\text{ft}\cdot\text{R}$	Thermal Diffusivity $\alpha, \text{ft}^2/\text{s}$	Dynamic Viscosity $\mu, \text{lbm/ft}\cdot\text{s}$	Kinematic Viscosity $\nu, \text{ft}^2/\text{s}$	Prandtl Number Pr	Volume Expansion Coeff. $\beta,$ 1/R
<i>Methane (CH₄)</i>								
-280	27.41	0.8152	0.1205	1.497×10^{-6}	1.057×10^{-4}	3.857×10^{-6}	2.575	0.00175
-260	26.43	0.8301	0.1097	1.389×10^{-6}	8.014×10^{-5}	3.032×10^{-6}	2.183	0.00192
-240	25.39	0.8523	0.0994	1.276×10^{-6}	6.303×10^{-5}	2.482×10^{-6}	1.945	0.00215
-220	24.27	0.8838	0.0896	1.159×10^{-6}	5.075×10^{-5}	2.091×10^{-6}	1.803	0.00247
-200	23.04	0.9314	0.0801	1.036×10^{-6}	4.142×10^{-5}	1.798×10^{-6}	1.734	0.00295
-180	21.64	1.010	0.0709	9.008×10^{-7}	3.394×10^{-5}	1.568×10^{-6}	1.741	0.00374
-160	19.99	1.158	0.0616	7.397×10^{-7}	2.758×10^{-5}	1.379×10^{-6}	1.865	0.00526
-140	17.84	1.542	0.0518	5.234×10^{-7}	2.168×10^{-5}	1.215×10^{-6}	2.322	0.00943
<i>Methanol [CH₃(OH)]</i>								
70	49.15	0.6024	0.1148	1.076×10^{-6}	3.872×10^{-4}	7.879×10^{-6}	7.317	0.000656
90	48.50	0.6189	0.1143	1.057×10^{-6}	3.317×10^{-4}	6.840×10^{-6}	6.468	0.000671
110	47.85	0.6373	0.1138	1.036×10^{-6}	2.872×10^{-4}	6.005×10^{-6}	5.793	0.000691
130	47.18	0.6576	0.1133	1.014×10^{-6}	2.513×10^{-4}	5.326×10^{-6}	5.250	0.000716
150	46.50	0.6796	0.1128	9.918×10^{-7}	2.218×10^{-4}	4.769×10^{-6}	4.808	0.000749
170	45.80	0.7035	0.1124	9.687×10^{-7}	1.973×10^{-4}	4.308×10^{-6}	4.447	0.000789
<i>Isobutane (R600a)</i>								
-150	42.75	0.4483	0.0799	1.157×10^{-6}	6.417×10^{-4}	1.500×10^{-5}	12.96	0.000785
-100	41.06	0.4721	0.0782	1.120×10^{-6}	3.669×10^{-4}	8.939×10^{-6}	7.977	0.000836
-50	39.31	0.4986	0.0731	1.036×10^{-6}	2.376×10^{-4}	6.043×10^{-6}	5.830	0.000908
0	37.48	0.5289	0.0664	9.299×10^{-7}	1.651×10^{-4}	4.406×10^{-6}	4.738	0.001012
50	35.52	0.5643	0.0591	8.187×10^{-7}	1.196×10^{-4}	3.368×10^{-6}	4.114	0.001169
100	33.35	0.6075	0.0521	7.139×10^{-7}	8.847×10^{-5}	2.653×10^{-6}	3.716	0.001421
150	30.84	0.6656	0.0457	6.188×10^{-7}	6.558×10^{-5}	2.127×10^{-6}	3.437	0.001883
200	27.73	0.7635	0.0400	5.249×10^{-7}	4.750×10^{-5}	1.713×10^{-6}	3.264	0.002970
<i>Glycerin</i>								
32	79.65	0.5402	0.163	1.052×10^{-6}	7.047	0.08847	84101	
40	79.49	0.5458	0.1637	1.048×10^{-6}	4.803	0.06042	57655	
50	79.28	0.5541	0.1645	1.040×10^{-6}	2.850	0.03594	34561	
60	79.07	0.5632	0.1651	1.029×10^{-6}	1.547	0.01956	18995	
70	78.86	0.5715	0.1652	1.018×10^{-6}	0.9422	0.01195	11730	
80	78.66	0.5794	0.1652	1.007×10^{-6}	0.5497	0.00699	6941	
90	78.45	0.5878	0.1652	9.955×10^{-7}	0.3756	0.004787	4809	
100	78.24	0.5964	0.1653	9.841×10^{-7}	0.2277	0.00291	2957	
<i>Engine Oil (unused)</i>								
32	56.12	0.4291	0.0849	9.792×10^{-7}	2.563	4.566×10^{-2}	46636	0.000389
50	55.79	0.4395	0.08338	9.448×10^{-7}	1.210	2.169×10^{-2}	22963	0.000389
75	55.3	0.4531	0.08378	9.288×10^{-7}	0.4286	7.751×10^{-3}	8345	0.000389
100	54.77	0.4669	0.08367	9.089×10^{-7}	0.1630	2.977×10^{-3}	3275	0.000389
125	54.24	0.4809	0.08207	8.740×10^{-7}	7.617×10^{-2}	1.404×10^{-3}	1607	0.000389
150	53.73	0.4946	0.08046	8.411×10^{-7}	3.833×10^{-2}	7.135×10^{-4}	848.3	0.000389
200	52.68	0.5231	0.07936	7.999×10^{-7}	1.405×10^{-2}	2.668×10^{-4}	333.6	0.000389
250	51.71	0.5523	0.07776	7.563×10^{-7}	6.744×10^{-3}	1.304×10^{-4}	172.5	0.000389
300	50.63	0.5818	0.07673	7.236×10^{-7}	3.661×10^{-3}	7.232×10^{-5}	99.94	0.000389

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Originally based on various sources.

TABLE A-14E

Properties of liquid metals

Temp. $T, ^\circ\text{F}$	Density $\rho, \text{lbm/ft}^3$	Specific Heat $c_p, \text{Btu/lbm}\cdot\text{R}$	Thermal Conductivity $k, \text{Btu/h}\cdot\text{ft}\cdot\text{R}$	Thermal Diffusivity $\alpha, \text{ft}^2/\text{s}$	Dynamic Viscosity $\mu, \text{lbm/ft}\cdot\text{s}$	Kinematic Viscosity $\nu, \text{ft}^2/\text{s}$	Prandtl Number Pr	Volume Expansion Coeff. $\beta,$ 1/R
<i>Mercury (Hg) Melting Point: -38°F</i>								
32	848.7	0.03353	4.727	4.614×10^{-5}	1.133×10^{-3}	1.335×10^{-6}	0.02895	1.005×10^{-4}
50	847.2	0.03344	4.805	4.712×10^{-5}	1.092×10^{-3}	1.289×10^{-6}	0.02737	1.005×10^{-4}
100	842.9	0.03319	5.015	4.980×10^{-5}	9.919×10^{-4}	1.176×10^{-6}	0.02363	1.005×10^{-4}
150	838.7	0.03298	5.221	5.244×10^{-5}	9.122×10^{-4}	1.087×10^{-6}	0.02074	1.005×10^{-4}
200	834.5	0.03279	5.422	5.504×10^{-5}	8.492×10^{-4}	1.017×10^{-6}	0.01849	1.005×10^{-4}
300	826.2	0.03252	5.815	6.013×10^{-5}	7.583×10^{-4}	9.180×10^{-7}	0.01527	1.005×10^{-4}
400	817.9	0.03236	6.184	6.491×10^{-5}	6.972×10^{-4}	8.524×10^{-7}	0.01313	1.008×10^{-4}
500	809.6	0.03230	6.518	6.924×10^{-5}	6.525×10^{-4}	8.061×10^{-7}	0.01164	1.018×10^{-4}
600	801.3	0.03235	6.839	7.329×10^{-5}	6.186×10^{-4}	7.719×10^{-7}	0.01053	1.035×10^{-4}
<i>Bismuth (Bi) Melting Point: 520°F</i>								
700	620.7	0.03509	9.361	1.193×10^{-4}	1.001×10^{-3}	1.614×10^{-6}	0.01352	
800	616.5	0.03569	9.245	1.167×10^{-4}	9.142×10^{-4}	1.482×10^{-6}	0.01271	
900	612.2	0.0363	9.129	1.141×10^{-4}	8.267×10^{-4}	1.350×10^{-6}	0.01183	
1000	608.0	0.0369	9.014	1.116×10^{-4}	7.392×10^{-4}	1.215×10^{-6}	0.0109	
1100	603.7	0.0375	9.014	1.105×10^{-4}	6.872×10^{-4}	1.138×10^{-6}	0.01029	
<i>Lead (Pb) Melting Point: 621°F</i>								
700	658	0.03797	9.302	1.034×10^{-4}	1.612×10^{-3}	2.450×10^{-6}	0.02369	
800	654	0.03750	9.157	1.037×10^{-4}	1.453×10^{-3}	2.223×10^{-6}	0.02143	
900	650	0.03702	9.013	1.040×10^{-4}	1.296×10^{-3}	1.994×10^{-6}	0.01917	
1000	645.7	0.03702	8.912	1.035×10^{-4}	1.202×10^{-3}	1.862×10^{-6}	0.01798	
1100	641.5	0.03702	8.810	1.030×10^{-4}	1.108×10^{-3}	1.727×10^{-6}	0.01676	
1200	637.2	0.03702	8.709	1.025×10^{-4}	1.013×10^{-3}	1.590×10^{-6}	0.01551	
<i>Sodium (Na) Melting Point: 208°F</i>								
300	57.13	0.3258	48.19	7.192×10^{-4}	4.136×10^{-4}	7.239×10^{-6}	0.01007	
400	56.28	0.3219	46.58	7.142×10^{-4}	3.572×10^{-4}	6.350×10^{-6}	0.008891	
500	55.42	0.3181	44.98	7.087×10^{-4}	3.011×10^{-4}	5.433×10^{-6}	0.007667	
600	54.56	0.3143	43.37	7.026×10^{-4}	2.448×10^{-4}	4.488×10^{-6}	0.006387	
800	52.85	0.3089	40.55	6.901×10^{-4}	1.772×10^{-4}	3.354×10^{-6}	0.004860	
1000	51.14	0.3057	38.12	6.773×10^{-4}	1.541×10^{-4}	3.014×10^{-6}	0.004449	
<i>Potassium (K) Melting Point: 147°F</i>								
300	50.40	0.1911	26.00	7.500×10^{-4}	2.486×10^{-4}	4.933×10^{-6}	0.006577	
400	49.58	0.1887	25.37	7.532×10^{-4}	2.231×10^{-4}	4.500×10^{-6}	0.005975	
500	48.76	0.1863	24.73	7.562×10^{-4}	1.976×10^{-4}	4.052×10^{-6}	0.005359	
600	47.94	0.1839	24.09	7.591×10^{-4}	1.721×10^{-4}	3.589×10^{-6}	0.004728	
800	46.31	0.1791	22.82	7.643×10^{-4}	1.210×10^{-4}	2.614×10^{-6}	0.003420	
1000	44.62	0.1791	21.34	7.417×10^{-4}	1.075×10^{-4}	2.409×10^{-6}	0.003248	
<i>Sodium-Potassium (%22Na-%78K) Melting Point: 12°F</i>								
200	52.99	0.2259	14.79	3.432×10^{-4}	3.886×10^{-4}	7.331×10^{-6}	0.02136	
300	52.16	0.2230	14.99	3.580×10^{-4}	3.467×10^{-4}	6.647×10^{-6}	0.01857	
400	51.32	0.2201	15.19	3.735×10^{-4}	3.050×10^{-4}	5.940×10^{-6}	0.0159	
600	49.65	0.2143	15.59	4.070×10^{-4}	2.213×10^{-4}	4.456×10^{-6}	0.01095	
800	47.99	0.2100	15.95	4.396×10^{-4}	1.539×10^{-4}	3.207×10^{-6}	0.007296	
1000	46.36	0.2103	16.20	4.615×10^{-4}	1.353×10^{-4}	2.919×10^{-6}	0.006324	

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Originally based on various sources.

TABLE A-15E

Properties of air at 1 atm pressure

Temp. $T, ^\circ\text{F}$	Density $\rho, \text{lbm/ft}^3$	Specific Heat $c_p, \text{Btu/lbm}\cdot\text{R}$	Thermal Conductivity $k, \text{Btu/h}\cdot\text{ft}\cdot\text{R}$	Thermal Diffusivity $\alpha, \text{ft}^2/\text{s}$	Dynamic Viscosity $\mu, \text{lbm/ft}\cdot\text{s}$	Kinematic Viscosity $\nu, \text{ft}^2/\text{s}$	Prandtl Number Pr
-300	0.24844	0.5072	0.00508	1.119×10^{-5}	4.039×10^{-6}	1.625×10^{-5}	1.4501
-200	0.15276	0.2247	0.00778	6.294×10^{-5}	6.772×10^{-6}	4.433×10^{-5}	0.7042
-100	0.11029	0.2360	0.01037	1.106×10^{-4}	9.042×10^{-6}	8.197×10^{-5}	0.7404
-50	0.09683	0.2389	0.01164	1.397×10^{-4}	1.006×10^{-5}	1.039×10^{-4}	0.7439
0	0.08630	0.2401	0.01288	1.726×10^{-4}	1.102×10^{-5}	1.278×10^{-4}	0.7403
10	0.08446	0.2402	0.01312	1.797×10^{-4}	1.121×10^{-5}	1.328×10^{-4}	0.7391
20	0.08270	0.2403	0.01336	1.868×10^{-4}	1.140×10^{-5}	1.379×10^{-4}	0.7378
30	0.08101	0.2403	0.01361	1.942×10^{-4}	1.158×10^{-5}	1.430×10^{-4}	0.7365
40	0.07939	0.2404	0.01385	2.016×10^{-4}	1.176×10^{-5}	1.482×10^{-4}	0.7350
50	0.07783	0.2404	0.01409	2.092×10^{-4}	1.194×10^{-5}	1.535×10^{-4}	0.7336
60	0.07633	0.2404	0.01433	2.169×10^{-4}	1.212×10^{-5}	1.588×10^{-4}	0.7321
70	0.07489	0.2404	0.01457	2.248×10^{-4}	1.230×10^{-5}	1.643×10^{-4}	0.7306
80	0.07350	0.2404	0.01481	2.328×10^{-4}	1.247×10^{-5}	1.697×10^{-4}	0.7290
90	0.07217	0.2404	0.01505	2.409×10^{-4}	1.265×10^{-5}	1.753×10^{-4}	0.7275
100	0.07088	0.2405	0.01529	2.491×10^{-4}	1.281×10^{-5}	1.809×10^{-4}	0.7260
110	0.06963	0.2405	0.01552	2.575×10^{-4}	1.299×10^{-5}	1.866×10^{-4}	0.7245
120	0.06843	0.2405	0.01576	2.660×10^{-4}	1.316×10^{-5}	1.923×10^{-4}	0.7230
130	0.06727	0.2405	0.01599	2.746×10^{-4}	1.332×10^{-5}	1.981×10^{-4}	0.7216
140	0.06615	0.2406	0.01623	2.833×10^{-4}	1.349×10^{-5}	2.040×10^{-4}	0.7202
150	0.06507	0.2406	0.01646	2.921×10^{-4}	1.365×10^{-5}	2.099×10^{-4}	0.7188
160	0.06402	0.2406	0.01669	3.010×10^{-4}	1.382×10^{-5}	2.159×10^{-4}	0.7174
170	0.06300	0.2407	0.01692	3.100×10^{-4}	1.398×10^{-5}	2.220×10^{-4}	0.7161
180	0.06201	0.2408	0.01715	3.191×10^{-4}	1.414×10^{-5}	2.281×10^{-4}	0.7148
190	0.06106	0.2408	0.01738	3.284×10^{-4}	1.430×10^{-5}	2.343×10^{-4}	0.7136
200	0.06013	0.2409	0.01761	3.377×10^{-4}	1.446×10^{-5}	2.406×10^{-4}	0.7124
250	0.05590	0.2415	0.01874	3.857×10^{-4}	1.524×10^{-5}	2.727×10^{-4}	0.7071
300	0.05222	0.2423	0.01985	4.358×10^{-4}	1.599×10^{-5}	3.063×10^{-4}	0.7028
350	0.04899	0.2433	0.02094	4.879×10^{-4}	1.672×10^{-5}	3.413×10^{-4}	0.6995
400	0.04614	0.2445	0.02200	5.419×10^{-4}	1.743×10^{-5}	3.777×10^{-4}	0.6971
450	0.04361	0.2458	0.02305	5.974×10^{-4}	1.812×10^{-5}	4.154×10^{-4}	0.6953
500	0.04134	0.2472	0.02408	6.546×10^{-4}	1.878×10^{-5}	4.544×10^{-4}	0.6942
600	0.03743	0.2503	0.02608	7.732×10^{-4}	2.007×10^{-5}	5.361×10^{-4}	0.6934
700	0.03421	0.2535	0.02800	8.970×10^{-4}	2.129×10^{-5}	6.225×10^{-4}	0.6940
800	0.03149	0.2568	0.02986	1.025×10^{-3}	2.247×10^{-5}	7.134×10^{-4}	0.6956
900	0.02917	0.2599	0.03164	1.158×10^{-3}	2.359×10^{-5}	8.087×10^{-4}	0.6978
1000	0.02718	0.2630	0.03336	1.296×10^{-3}	2.467×10^{-5}	9.080×10^{-4}	0.7004
1500	0.02024	0.2761	0.04106	2.041×10^{-3}	2.957×10^{-5}	1.460×10^{-3}	0.7158
2000	0.01613	0.2855	0.04752	2.867×10^{-3}	3.379×10^{-5}	2.095×10^{-3}	0.7308
2500	0.01340	0.2922	0.05309	3.765×10^{-3}	3.750×10^{-5}	2.798×10^{-3}	0.7432
3000	0.01147	0.2972	0.05811	4.737×10^{-3}	4.082×10^{-5}	3.560×10^{-3}	0.7516
3500	0.01002	0.3010	0.06293	5.797×10^{-3}	4.381×10^{-5}	4.373×10^{-3}	0.7543
4000	0.00889	0.3040	0.06789	6.975×10^{-3}	4.651×10^{-5}	5.229×10^{-3}	0.7497

Note: For ideal gases, the properties c_p , k , μ , and Pr are independent of pressure. The properties ρ , ν , and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P .

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and *Thermophysical Properties of Matter*, Vol. 3: *Thermal Conductivity*, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: *Viscosity*, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenum, NY, 1970, ISBN 0-306067020-8.

TABLE A-16E

Properties of gases at 1 atm pressure

Temp. $T, ^\circ\text{F}$	Density $\rho, \text{lbm/ft}^3$	Specific Heat $c_p, \text{Btu/lbm}\cdot\text{R}$	Thermal Conductivity $k, \text{Btu/h}\cdot\text{ft}\cdot\text{R}$	Thermal Diffusivity $\alpha, \text{ft}^2/\text{s}$	Dynamic Viscosity $\mu, \text{lbm/ft}\cdot\text{s}$	Kinematic Viscosity $\nu, \text{ft}^2/\text{s}$	Prandtl Number Pr
Carbon Dioxide, CO_2							
-50	0.14712	0.1797	0.00628	6.600×10^{-5}	7.739×10^{-6}	5.261×10^{-5}	0.7970
0	0.13111	0.1885	0.00758	8.522×10^{-5}	8.661×10^{-6}	6.606×10^{-5}	0.7751
50	0.11825	0.1965	0.00888	1.061×10^{-4}	9.564×10^{-6}	8.086×10^{-5}	0.7621
100	0.10769	0.2039	0.01017	1.286×10^{-4}	1.045×10^{-5}	9.703×10^{-5}	0.7543
200	0.09136	0.2171	0.01273	1.784×10^{-4}	1.217×10^{-5}	1.332×10^{-4}	0.7469
300	0.07934	0.2284	0.01528	2.341×10^{-4}	1.382×10^{-5}	1.743×10^{-4}	0.7445
500	0.06280	0.2473	0.02027	3.626×10^{-4}	1.696×10^{-5}	2.700×10^{-4}	0.7446
1000	0.04129	0.2796	0.03213	7.733×10^{-4}	2.381×10^{-5}	5.767×10^{-4}	0.7458
1500	0.03075	0.2995	0.04281	1.290×10^{-3}	2.956×10^{-5}	9.610×10^{-4}	0.7445
2000	0.02450	0.3124	0.05193	1.885×10^{-3}	3.451×10^{-5}	1.408×10^{-3}	0.7474
Carbon Monoxide, CO							
-50	0.09363	0.2571	0.01118	1.290×10^{-4}	9.419×10^{-6}	1.005×10^{-4}	0.7798
0	0.08345	0.2523	0.01240	1.636×10^{-4}	1.036×10^{-5}	1.242×10^{-4}	0.7593
50	0.07526	0.2496	0.01359	2.009×10^{-4}	1.127×10^{-5}	1.498×10^{-4}	0.7454
100	0.06854	0.2484	0.01476	2.408×10^{-4}	1.214×10^{-5}	1.772×10^{-4}	0.7359
200	0.05815	0.2485	0.01702	3.273×10^{-4}	1.379×10^{-5}	2.372×10^{-4}	0.7247
300	0.05049	0.2505	0.01920	4.217×10^{-4}	1.531×10^{-5}	3.032×10^{-4}	0.7191
500	0.03997	0.2567	0.02331	6.311×10^{-4}	1.802×10^{-5}	4.508×10^{-4}	0.7143
1000	0.02628	0.2732	0.03243	1.254×10^{-3}	2.334×10^{-5}	8.881×10^{-4}	0.7078
1500	0.01957	0.2862	0.04049	2.008×10^{-3}	2.766×10^{-5}	1.413×10^{-3}	0.7038
2000	0.01559	0.2958	0.04822	2.903×10^{-3}	3.231×10^{-5}	2.072×10^{-3}	0.7136
Methane, CH_4							
-50	0.05363	0.5335	0.01401	1.360×10^{-4}	5.861×10^{-6}	1.092×10^{-4}	0.8033
0	0.04779	0.5277	0.01616	1.780×10^{-4}	6.506×10^{-6}	1.361×10^{-4}	0.7649
50	0.04311	0.5320	0.01839	2.228×10^{-4}	7.133×10^{-6}	1.655×10^{-4}	0.7428
100	0.03925	0.5433	0.02071	2.698×10^{-4}	7.742×10^{-6}	1.972×10^{-4}	0.7311
200	0.03330	0.5784	0.02559	3.690×10^{-4}	8.906×10^{-6}	2.674×10^{-4}	0.7245
300	0.02892	0.6226	0.03077	4.748×10^{-4}	1.000×10^{-5}	3.457×10^{-4}	0.7283
500	0.02289	0.7194	0.04195	7.075×10^{-4}	1.200×10^{-5}	5.244×10^{-4}	0.7412
1000	0.01505	0.9438	0.07346	1.436×10^{-3}	1.620×10^{-5}	1.076×10^{-3}	0.7491
1500	0.01121	1.1162	0.10766	2.390×10^{-3}	1.974×10^{-5}	1.760×10^{-3}	0.7366
2000	0.00893	1.2419	0.14151	3.544×10^{-3}	2.327×10^{-5}	2.605×10^{-3}	0.7353
Hydrogen, H_2							
-50	0.00674	3.0603	0.08246	1.110×10^{-3}	4.969×10^{-6}	7.373×10^{-4}	0.6638
0	0.00601	3.2508	0.09049	1.287×10^{-3}	5.381×10^{-6}	8.960×10^{-4}	0.6960
50	0.00542	3.3553	0.09818	1.500×10^{-3}	5.781×10^{-6}	1.067×10^{-3}	0.7112
100	0.00493	3.4118	0.10555	1.742×10^{-3}	6.167×10^{-6}	1.250×10^{-3}	0.7177
200	0.00419	3.4549	0.11946	2.295×10^{-3}	6.911×10^{-6}	1.652×10^{-3}	0.7197
300	0.00363	3.4613	0.13241	2.924×10^{-3}	7.622×10^{-6}	2.098×10^{-3}	0.7174
500	0.00288	3.4572	0.15620	4.363×10^{-3}	8.967×10^{-6}	3.117×10^{-3}	0.7146
1000	0.00189	3.5127	0.20989	8.776×10^{-3}	1.201×10^{-5}	6.354×10^{-3}	0.7241
1500	0.00141	3.6317	0.26381	1.432×10^{-2}	1.477×10^{-5}	1.048×10^{-2}	0.7323
2000	0.00112	3.7656	0.31923	2.098×10^{-2}	1.734×10^{-5}	1.544×10^{-2}	0.7362
Nitrogen, N_2							
-50	0.09364	0.2320	0.01176	1.504×10^{-4}	9.500×10^{-6}	1.014×10^{-4}	0.6746
0	0.08346	0.2441	0.01300	1.773×10^{-4}	1.043×10^{-5}	1.251×10^{-4}	0.7056
50	0.07527	0.2480	0.01420	2.113×10^{-4}	1.134×10^{-5}	1.507×10^{-4}	0.7133

(Continued)

TABLE A-16E

Properties of gases at 1 atm pressure (Continued)

Temp. $T, ^\circ\text{F}$	Density $\rho, \text{lbm/ft}^3$	Specific Heat $c_p, \text{Btu/lbm}\cdot\text{R}$	Thermal Conductivity $k, \text{Btu/h}\cdot\text{ft}\cdot\text{R}$	Thermal Diffusivity $\alpha, \text{ft}^2/\text{s}$	Dynamic Viscosity $\mu, \text{lbm/ft}\cdot\text{s}$	Kinematic Viscosity $\nu, \text{ft}^2/\text{s}$	Prandtl Number Pr
100	0.06854	0.2489	0.01537	2.502×10^{-4}	1.221×10^{-5}	1.783×10^{-4}	0.7126
200	0.05815	0.2487	0.01760	3.379×10^{-4}	1.388×10^{-5}	2.387×10^{-4}	0.7062
300	0.05050	0.2492	0.01970	4.349×10^{-4}	1.543×10^{-5}	3.055×10^{-4}	0.7025
500	0.03997	0.2535	0.02359	6.466×10^{-4}	1.823×10^{-5}	4.559×10^{-4}	0.7051
1000	0.02628	0.2697	0.03204	1.255×10^{-3}	2.387×10^{-5}	9.083×10^{-4}	0.7232
1500	0.01958	0.2831	0.04002	2.006×10^{-3}	2.829×10^{-5}	1.445×10^{-3}	0.7202
2000	0.01560	0.2927	0.04918	2.992×10^{-3}	3.212×10^{-5}	2.059×10^{-3}	0.6882
Oxygen, O_2							
-50	0.10697	0.2331	0.01216	1.355×10^{-4}	1.104×10^{-5}	1.032×10^{-4}	0.7622
0	0.09533	0.2245	0.01346	1.747×10^{-4}	1.218×10^{-5}	1.277×10^{-4}	0.7312
50	0.08598	0.2209	0.01475	2.157×10^{-4}	1.326×10^{-5}	1.543×10^{-4}	0.7152
100	0.07830	0.2200	0.01601	2.582×10^{-4}	1.429×10^{-5}	1.826×10^{-4}	0.7072
200	0.06643	0.2221	0.01851	3.484×10^{-4}	1.625×10^{-5}	2.446×10^{-4}	0.7020
300	0.05768	0.2262	0.02096	4.463×10^{-4}	1.806×10^{-5}	3.132×10^{-4}	0.7018
500	0.04566	0.2352	0.02577	6.665×10^{-4}	2.139×10^{-5}	4.685×10^{-4}	0.7029
1000	0.03002	0.2520	0.03698	1.357×10^{-3}	2.855×10^{-5}	9.509×10^{-4}	0.7005
1500	0.02236	0.2626	0.04701	2.224×10^{-3}	3.474×10^{-5}	1.553×10^{-3}	0.6985
2000	0.01782	0.2701	0.05614	3.241×10^{-3}	4.035×10^{-5}	2.265×10^{-3}	0.6988
Water Vapor, H_2O							
-50	0.06022	0.4512	0.00797	8.153×10^{-5}	4.933×10^{-6}	8.192×10^{-5}	1.0050
0	0.05367	0.4484	0.00898	1.036×10^{-4}	5.592×10^{-6}	1.041×10^{-4}	1.0049
50	0.04841	0.4472	0.01006	1.291×10^{-4}	6.261×10^{-6}	1.293×10^{-4}	1.0018
100	0.04408	0.4473	0.01121	1.579×10^{-4}	6.942×10^{-6}	1.574×10^{-4}	0.9969
200	0.03740	0.4503	0.01372	2.263×10^{-4}	8.333×10^{-6}	2.228×10^{-4}	0.9845
300	0.03248	0.4557	0.01648	3.093×10^{-4}	9.756×10^{-6}	3.004×10^{-4}	0.9713
500	0.02571	0.4707	0.02267	5.204×10^{-4}	1.267×10^{-5}	4.931×10^{-4}	0.9475
1000	0.01690	0.5167	0.04134	1.314×10^{-3}	2.014×10^{-5}	1.191×10^{-3}	0.9063
1500	0.01259	0.5625	0.06315	2.477×10^{-3}	2.742×10^{-5}	2.178×10^{-3}	0.8793
2000	0.01003	0.6034	0.08681	3.984×10^{-3}	3.422×10^{-5}	3.411×10^{-3}	0.8563

Note: For ideal gases, the properties c_p , k , μ , and Pr are independent of pressure. The properties ρ , ν , and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P .

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Originally based on various sources.

TABLE A-17E

Properties of the atmosphere at high altitude

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

Source: U. S. Standard Atmosphere Supplements, U.S. Government Printing Office, 1966. Based on year-round mean conditions at 45° latitude and varies with the time of the year and the weather patterns. The conditions at sea level ($z = D$) are taken to be $P = 14.696$ psia, $T = 59$ °F, $\rho = 0.076474$ lbm/ft³, $g = 32.1741$ ft²/s.