CHAPTER 38

PHYSICAL PROPERTIES OF MATERIALS

VALUES in the following tables are in consistent units to assist the engineer looking for approximate values. For data on refrigerants, see Chapter 19; for secondary coolants, see Chapter 21. Chapter 25 gives more information on the values for materials used in building construction and insulation. Many properties vary with temperature, material density, and composition. The references document the source of the values and provide more detail or values for materials not listed here.

Table 1 Properties of Vapor

Material	Relative Molecular Mass	Normal Boiling Point, °C	Critical Temperature, °C	Critical Pressure, kPa	Density, kg/m³	Specific Heat, J/(kg·K)	Thermal Conductivity, W/(m·K)	Viscosity, μPa·s
Alcohol, Ethyl	46.07[a]	78.6[a]	243.2[b]	6 394[b]		1520[j]	0.013[a]	14.2[j] (289)
Alcohol, Methyl	32.04[a]	65.0[a]	240.1[b]	7 977[b]		1350[j]	0.0301[r]	14.8[j] (272)
Ammonia	17.03[a]	–33.2[a]	132.6[b]	11 300[b]	7.72[b]	2200[aa]	0.0221[b]	9.30[aa]
Argon	39.948[a]	–185.9*	–122.5*	4 860[b]	1.785[b]	523[c]	0.016[a]	21.0[a]
Acetylene	26.04[a]	–83.7[a]	36.1[b]	6 280[b]	1.17[b]	1580[a]	0.0187[b]	9.34[a]
Benzene	78.11[a]	80.2[a]	289.6[d]	4 924[d]	2.68[e] (80)	1300[e] (80)	0.0071[e]	7.0[a]
Bromine	159.82[a]	58.8[a]	58.8[d]	10 340[d]	6.1[f] (59)	230[f] (100)	0.0061[a]	17[a]
Butane	58.12[a]	–0.5[a]	152.1[d]	3 797[d]	2.69[g]	1580[aa]	0.014[a]	7.0[a]
Carbon dioxide	44.01[a]	–78.5[a]	31.1[d]	7 384[d]	1.97[g]	840[g]	0.015[a]	14[h]
Carbon disulfide	76.13[h]	46.3[h]	278.9[h]	7 212[h]		599.0[p] (27)		
Carbon monoxide	28.01[a]	–191.5[a]	–140.3[d]	3 500[d]	1.25[d]	1100[f]	0.0230[a]	17[a]
Carbon tetrachloride	153.84[g]	76.6[h]	283.3[h]	4 560[h]		862[q] (27)		16.0[j]
Chlorine	70.91[a]	–34.7[a]	144.1[d]	7 710[d]	3.22[d]	490[a]	0.0080[a]	12[a]
Chloroform	119.39[h]	61.8[h]	263.4[h]	5 470[h]		528[j]	0.014[r]	16[j]
Ethyl chloride	64.52[h]	12.4[h]	187.3[h]	5 270[h]	2.872[b]	1780[r]	0.00872[j]	16.0[q]
Ethylene	28.03[h]	–103.7[h]	10.0[h]	5 120[h]	1.25[b]	1470[aa]	0.0176[aa]	9.60[aa]
Ethyl ether	74.12[h]	34.7[h]	192.7[h]	3 610[h]		2470[h] (35)		11.3[q]
Fluorine	38.00[h]	–187.0[h]	–129.2[h]	5 580[h]	1.637[b]	812[j]	0.0254[j]	37[j]
Helium	4.0026[a]	–269.0[i]	–267.9[h]	229[i]	0.178[i]	5192[aa]	0.142[aa]	19.0[aa]
Hydrogen	2.0159[a]	–253.1[i]	–240.0[i]	1 316[i]	0.0900[i]	14 200[j]	0.168[aa]	8.40[aa]
Hydrogen chloride	36.461[a]	–84.9[a]	51.4[d]	8 260[d]	1.640[b]	800[j]	0.0131[j]	13.3[j]
Hydrogen sulfide	34.080[a]	–60.8[a]	100.4[d]	9 012[d]	1.54[b]	996[j]	0.0130[j]	11.6[j]
Heptane (m)	100.21[a]	98.5[a]	266.8[b]	2 720[b]	3.4[k]	1990[j]	0.0185[j]	7.00[j]
Hexane (m)	86.18[a]	66.9[a]	234.8[d]	3 030[d]	3.4[k]	1880[j]	0.0168[j]	7.52[j]
Isobutane	58.12[f]	–11.6*	135.1[j]	3 648[j]	2.47[s] (21)	1570[aa]	0.014[aa]	6.94[aa]
Methane	16.04[a]	–164.0[a]	–81.8[j]	4 641[b]	0.718[b]	2180[aa]	0.0310[aa]	10.3[aa]
Methyl chloride	50.49[a]	–24.3[a]	143.2[j]	6 678[b]	2.307[b]	770[aa]	0.0093[aa]	10.1[aa]
Naphthalene	128.19[a]	218.0*	469.1[j]	3 972[j]		1310[q] (25)		
Neon	20.183[a]	–247.0[a]	–228.8[j]	2 698[j]		1030[aa]	0.0464[aa]	30.0[aa]
Nitric oxide	30.01[a]	–152.0[a]	–92.9[j]	6 546[j]		996[j]		29.4[j]
Nitrogen	28.01[a]	–195.8[a]	–146.9[j]	3 394[b]		1040[j]	0.0240[aa]	16.6[aa]
Nitrous oxide	44.01[a]	–88.5[a]	36.4[j]	7 235[j]		850[j]	0.01731[j] (26.8)	22.4[j]
Nitrogen tetroxide	92.02[a]		158.3[j]	10 133[j]		842[p] (27)	0.0401[r] (55)	
Oxygen	31.9977*	–183.0[a]	–118.6*	5 043*		913[j]	0.0244[aa]	19.1[aa]
n-Pentane	72.53[a]	36.1*	196.7[j]	3 375[j]		1680[a] (27)	0.0152[j] (26.8)	11.7[j]
Phenol	74.11[b]	181.4[b]	418.9[b]	6 130[b]	2.6[k]	1400[k]	0.017[k]	12[k]
Propane	44.09[g]	–42.1[g]	96.7*	4 248*	2.02[g]	1571[j] (4.5)	0.015[j]	7.40[j]
Propylene	42.08[b]	–47.7[l]	91.8[l]	4 622[l]	1.92[l]	1460[aa]	0.014[aa]	8.06[aa]
Sulfur dioxide	64.06[b]	–10.0[b]	156.9[b]	7 874[b]	2.93[b]	607[l]	0.0085[j]	11.6[j]
Water vapor	18.02[b]	100.0[m]	374.0*	22 064*	0.598[m]	2050[aa]	0.0247[m]	12.1[aa]

*Data source unknown.

Notes: 1. Properties at 101.325 kPa and 0°C, or the saturation temperature if higher than 0°C, unless otherwise noted in parentheses.

2. Superscript letters indicate data source from the section on References.

Table 2 Properties of Liquids

Name or Description	Normal Boiling Point, °C at 101.325 kPa	Enthalpy of Vaporization, kJ/kg	Specific Heat, c_p J/(kg·K)	Temp., °C	Viscosity μPa·s	Temp., °C	Enthalpy of Fusion, kJ/kg	Density kg/m³	Temp., °C	Thermal Conductivity W/(m·K)	Temp., °C	Vapor Pressure kPa	Temp., °C	Freezing Point, °C
Acetic acid	118.6[a]	405.0[b]	2180[b]	26 to 95	1 222[f]	20	195[b]	1049[a]	20	0.17[b]	20	53.3[a]	99	16.7[a]
Acetone	56.3[a]	532.4[b]	2150[b]	3 to 23	331[f]	20	98.0[b]	791[a]	20	0.1761[b]	30	53.3[a]	40	–95.4[a]
Allyl alcohol	97.1[a]	684.1[b]	2740[b]	21 to 96	1 363[f]	20		853.9[a]	20	0.180[b]	25 to 30	53.3[a]	80	–129.0[a]
n-Amyl alcohol	138.2[i]	503.1[b]			4 004[f]	23	112[b]	817.9[f]	15	0.16[b]	30	13.3[a]	86	–79.0[a]
Ammonia	–33.2[a]	1357[b]	4601[b]	0	266[f]	–33	322.40[b]	696.8[b]	–45	0.50[b]	–15 to 30	53.3[a]	–45	–77.8[a]
Alcohol-ethyl	78.6[a]	854.8[b]	2840[b]	0 to 98	1 194[f]	20	108[b]	789.2[a]	20	0.182[b]	20	13.3[a]	35	117.3[a]
Alcohol-methyl	65.0[a]	1100[b]	2510[b]	15 to 20	592.8[f]	20	99.3[a]	791.3[a]	20	0.215[b]	20	13.3[a]	21	–97.8[a]
Aniline	184.4[a]	434.0[b]	2140[b]	8 to 82	4 467.0[f]	20	114[b]	1021[a]	20	0.173[b]	–2 to 20	1.3[a]	69	–6.2[a]
Benzene	80.2[a]	394.0[h]	1720[h]	20	653[a]	20	126[h]	879[d]	20	0.147[h]	20	10[d]	20	5.9[a]
Bromine	58.8[a]	185[d]	448[f]	20	988[a]	20	66.30[d]	3119[f]	20	0.122[a]	25	22.0[d]	20	–7.2[a]
n-Butyl alcohol	117.6[a]	591.5[h]	2350[f]	20	2950[f]	20	125[b]	811[a]	20	0.15[h]	20	0.7[d]	20	–90.2[a]
n-Butyric acid	163.6[a]	504.7[h]	2150[f]	20	1 540[a]	20	126[a]	964[a]	20	0.16[h]	12	0.09[d]	20	–6.2[a]
Calcium chloride brine (20% by mass)			3110[i]	20	2 000[i]	20		1180[i]	20	0.574[i]	20			–16.2[i]
Carbon disulfide	46.3[a]	346.1[h]	1000[i]	20	360[a]	20	57.70[d]	1260[d]	20	0.16[b]	30	39.3[d]	20	–111.2[a]
Carbon tetrachloride	76.7[a]	195[h]	842[f]	20	967[a]	20	29.80[d]	1590[d]	20	0.11[j]	20	12[d]	20	–22.8[a]
Chloroform	61.3[v]	247[v]	980[v]	20	562[v]	20		1489[v]	20	0.13[v]	20	21.3[v]	20	–63.3[v]
n-Decane	174.1[b]		2000[b]	20			202[b]	730[b]	20	0.15[b]	20	0.17[b]	20	–29.8[b]
Ethyl ether	34.5[v]	351[v]	2260[v]	20	230[v]	20	98.60[v]	714.6[v]	20	0.14[b]	20	58.7[v]	20	–116.3[v]
Ethyl acetate	77.2[v]	427.5[v]	1950[v]	20	451[v]	20	119[b]	838[v]	20	0.175[b]	20	9.6[b]	20	–82.4[v]
Ethyl chloride	12.4[j]	385.9[f] (20)	1540[f]	0			69.04[a]	897.8[a]	20	0.310[f]	1	53.3[y]	12	–136.4[a]
Ethyl iodide	72.3[a]	191[f] (71)	1540[f]	0	9.90[f]	20		1935.8[a]	20	0.370[f]	30	13.3[y]	18	–108.0*
Ethylene bromide	131.6[a]	231[f] (99)	729[f]	20	28.7[f]	20	57.73[a]	2179.3[a]	20			1.3[y]	19	9.6[a]
Ethylene chloride	83.6[a]	365.8[f] (153)	1260[f]	20	14.0[f]	20	88.43[a]	1235[a]	20			8.0[y]	18	–35.4[a]
Ethylene glycol	198.1[a]	800.1[f] (344)					181.10[a]	1109[a]	20	0.173[f]	20	0.1[y]	53	–10.8[a]
Formic acid	99.8[a]	502.0[f] (216)	2200[f]	20	29.7[f]	20	276.54[a]	1219[a]	20	0.180[a]	–2	5.3[y]	23	7.4[a]
Glycerin (glycerol)	179.9*				17 800[f]	20		1261[a]	20	0.195[a]	20	0.1[a]	51	18.9[a]
Heptane	97.5[a]	321[f]	2220[j]	20	409[a]	20	140[b]	684[a]	20	0.128[j]	20	4.73[y]	20	–92.2[a]
Hexane	65.9[a]	337[f]	2250[j]	20	320[d]	20	150[b]	658[a]	20	0.125[j]	20	16.00[y]	20	–96.2[a]
Hydrogen chloride	–85.9[a]	444[f]					54.9[f]	1190[d]	b.p.					–115.8[a]
Isobutyl alcohol	107.1[a]	579[f]	486[f]	20	3 910[f]	20		801[f]	20	0.14[f]	20	1.3[y]	20	–109.0[a]
Kerosene	204 to 293[b]		2000[n]	20	2 480[b]	20		820[a]	20	0.15[n]	20			
Linseed oil					42 900[b]	20		920[d]	20					–24.9[a]
Methyl acetate	56.1[a]	412[f]	1950[f]	20	389[f]	20		971[a]	20	0.16[f]	20	22.64[y]	20	–99.2†[a]
Methyl iodide	41.6[a]	192[f]			500[f]	20		2270[a]	20			42.7[y]	20	–67.5[a]
Naphthalene	209.8[a]	316[f]	1680[f]	m.p.	901[b]	m.p.	151[b]	976[y]	m.p.			0.291[b]	20	79.3[a]
Nitric acid	85.1[v]	628[v]	1700[v]	20	910[k]	20	166[v]	1512[v]	20	0.28[v]	20	0.236[v]	20	–42.7[v]
Nitrobenzene	209.9[b]	330[b]	1450[b]	20	2 150[b]	20	93.69[v]	1200[b]	20	1.7[b]	20	0.001[b]	20	4.8[b]
Octane	124.8[b]	306.3[b]	2100[b]	20	562[b]	20	180.70[b]	703[b]	20	0.15[b]	20	0.056[b]	20	–57.5[b]
Petroleum		230 to 384[w]	2000 to 3000[w]	20	7900 to 1.2×10^{6}[w]	20		640 to 1000[w]	20					
n-Pentane	35.1[a]	357.3[h]	2330[h]	20	226[d]	20	117[h]	626[a]	20	0.11[h]	20	56.7[d]	20	–130.8[a]
Propionic acid	140.2[a]	413.6[f]	1980[h]	20	1 102[a]	20		992[a]	20	0.173*	12	0.4[d]	20	–21.8[a]
Sodium chloride brine														
20% by mass	103.9[a]		3110[x]	20	1 570[x]	20		1150[x]	20	0.583[x]	20	0.076[x]	20	–17.4[x]
10% by mass	100.9[a]		3620[x]	20	1 180[x]	20		1070[x]	20	0.593[x]	20	0.087[x]	20	–7.4[x]
Sodium hydroxide and water (15% by mass)	100.7[v]		3610[b]	20				1150[b]	20					–22.0[b]
Sulfuric acid and water														
100% by mass	286.8[v]		1400[b]	20	22 000[b]	20		1833[v]	20			0.001[b]	20	9.6[b]
95% by mass	300.9[v]		1460[v]	20	21 000[v]	20		1836[v]	20			0.001[v]	20	–29.2[v]
90% by mass	259.1[v]		1600[v]	20	25 000[v]	20		1816[v]	20	0.38[b]	20	0.001[v]	20	–10.5[v]
Toluene ($C_6H_5CH_3$)	108.9[b]	363[b]	1690[v]	20	587[v]	20	71.90[b]	867[b]	20	0.16[b]	20	0.12[b]	20	–96.0[b]
Turpentine	148.9[a]	286[v]	1700[b]	20	546[b]	20		863[b]	20	0.13[b]	20			
Water	100.0*	2257[m]	4180[m]	20	988[m]	20	333.8[b]	998.20[m]	20	0.602[m]	20	2.34*	20	–1.0[m]
Xylene [$C_6H_4(CH_3)_2$]														
Ortho	142.9[b]	347[b]	1720[b]	20	831[b]	20	128[b]	881[b]	20	1.6[b]	20	0.0260[b]	20	–26.2[b]
Meta	137.9[b]	342[b]	1670[b]	20	628[b]	20	109[b]	867[b]	0	1.6[b]	20	0.0290[b]	20	–48.2[b]
Para	136.9[b]	340[b]	1640[b]	20	670[b]	20	161[b]	862[b]	20			0.0300[b]	20	11.9[b]
Zinc sulfate and water														
10% by mass			3700[b]	20	1 570[a]	20		1110[r]	20	0.583[a]	20			–2.3[a]
1% by mass			3300[b]	20	1 100[a]	20		1010[r]	20	0.598[a]	20			–1.2[a]

*Data source unknown.
†Approximate solidification temperature.

Notes: Superscript letters indicate data source from the section on References.
m.p. = melting point b.p. = boiling point

Table 3 Properties of Solids

Material Description	Specific Heat, J/(kg·K)	Density, kg/m^3	Thermal Conductivity, W/(m·K)	Emissivity Ratio	Emissivity Surface Condition
Aluminum (alloy 1100)	896[b]	2 740[u]	221[u]	0.09[n]	Commercial sheet
				0.20[n]	Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	400[n]	8 280[u]	100[u]		
Asbestos: Fiber	1050[b]	2 400[u]	0.170[u]		
Insulation	800[t]	580[b]	0.16[b]	0.93[b]	"Paper"
Ashes, wood	800[t]	640[b]	0.071[b] (50)		
Asphalt	920[b]	2 110[b]	0.74[b]		
Bakelite	1500[b]	1 300[u]	17[u]		
Bell metal	360[t] (50)				
Bismuth tin	170*		65.0*		
Brick, building	800[b]	1 970[u]	0.7[b]	0.93*	
Brass: Red (85% Cu, 15% Zn)	400[u]	8 780[u]	150[u]	0.030[b]	Highly polished
Yellow (65% Cu, 35% Zn)	400[u]	8 310[u]	120[u]	0.033[b]	Highly polished
Bronze	435[t]	8 490[t]	29[d] (0)		
Cadmium	230[a]	8 650[f]	92.9[b]	0.02[d]	
Carbon (gas retort)	710[a]		0.35[b] (–17)	0.81[a]	
Cardboard			0.07[b]		
Cellulose	1300[b]	54[t]	0.057[t]		
Cement (Portland clinker)	670[b]	1 920[i]	0.029[i]		
Chalk	900[t]	2 290[t]	0.83*	0.34*	About 120°C
Charcoal (wood)	840[t]	240[a]	0.05[a] (200)		
Chrome brick	710[b]	3 200[b]	1.2[b]		
Clay	920[b]	1 000[t]			
Coal	1000[b]	1 400[t]	0.17[f] (0)		
Coal tars	1500[b] (40)	1 200[b]	0.1[b]		
Coke (petroleum, powdered)	1500[b] (400)	990[b]	0.95[b] (400)		
Concrete (stone)	653[b] (200)	2 300[b]	0.93[b]		
Copper (electrolytic)	390[u]	8 910[u]	393[u]	0.072[n]	commercial, shiny
Cork (granulated)	2030[t]	86[t]	0.048[t] (–5)		
Cotton (fiber)	1340[u]	1 500[u]	0.042[u]		
Cryolite ($AlF_3 \cdot 3NaF$)	1060[b]	2 900[b]			
Diamond	616[b]	2 420[t]	47[t]		
Earth (dry and packed)		1 500[t]	0.064*	0.41*	
Felt		330[b]	0.05[b]		
Fireclay brick	829[b] (100)	1 790[t]	1[b] (200)	0.75[n]	At 1000°C
Fluorspar (CaF_2)	880[b]	3 190[v]	1.1[v]		
German silver (nickel silver)	400[u]	8 730[u]	33[u]	0.135[n]	Polished
Glass: Crown (soda-lime)	750[b]	2 470[u]	1.0[t] (93)	0.94[n]	Smooth
Flint (lead)	490[b]	4 280[u]	1.4[r]		
Heat-resistant	840[b]	2 230[t]	1.0[t] (93)		
"Wool"	657[b]	52.0[t]	0.038[t]		
Gold	131[u]	19 350[u]	297[t]	0.02[n]	Highly polished
Graphite: Powder	691*		0.183*		
Impervious	670[u]	1 870[u]	130[u]	0.75[n]	
Gypsum	1080[b]	1 200[b]	0.43[b]	0.903[b]	On a smooth plate
Hemp (fiber)	1352.3[u]	1 500[u]			
Ice: 0°C	2040[t]	921[b]	2.24[b]	0.95*	
–20°C	1950[t]		2.44*		
Iron: Cast	500[v] (100)	7 210[t]	47.7[b] (54)	0.435[b]	Freshly turned
Wrought		7 700[b]	60.4[b]	0.94[b]	Dull, oxidized
Lead	129[u]	11 300[u]	34.8[u]	0.28[n]	Gray, oxidized
Leather (sole)		1 000[b]	0.16[b]		
Limestone	909[b]	1 650[b]	0.93[b]	0.36* to 0.90	At 63 to 193°C
Linen			0.09[b]		
Litharge (lead monoxide)	230[b]	7 850[b]			
Magnesia: Powdered	980[b] (100)	796[b]	0.61[b] (47)		
Light carbonate		210[b]	0.059[b]		
Magnesite brick	930[b] (100)	2 530[b]	3.8[b] (204)		
Magnesium	1000[b]	1 730[u]	160[u]	0.55[n]	Oxidized
Marble	880[b]	2 600[b]	2.6[b]	0.931[b]	Light gray, polished
Nickel, polished	440[u]	8 890[u]	59.5[u]	0.045[n]	Electroplated
Paints: White lacquer				0.80[n]	
White enamel				0.91[n]	On rough plate
Black lacquer				0.80[n]	
Black shellac		1 000[u]	0.26[u]	0.91[n]	"Matte" finish
Flat black lacquer				0.96[n]	
Aluminum lacquer				0.39[n]	On rough plate

*Data source unknown.

Notes: 1. Values are for room temperature unless otherwise noted in parentheses.

2. Superscript letters indicate data source from the section on References.

Table 3 Properties of Solids (*Continued*)

Material Description	Specific Heat, J/(kg·K)	Density, kg/m^3	Thermal Conductivity, W/(m·K)	Emissivity	
				Ratio	Surface Condition
Paper	1300*	930[b]	0.13[b]	0.92[b]	Pasted on tinned plate
Paraffin	1670[bb]	749[bb]	0.24[b] (0)		
Plaster		2 110[b]	0.74[b] (75)	0.91[b]	Rough
Platinum	130[u]	21 470[u]	69.0[u]	0.054[b]	Polished
Porcelain	750*	260[u]	2.2[u]	0.92[b]	Glazed
Pyrites (copper)	549[b]	4 200[b]			
Pyrites (iron)	569[b] (69)	4 970[v]			
Rock Salt	917[u]	2 180[u]			
Rubber, vulcanized: Soft	2000*	1 100[t]	0.1[t]	0.86[b]	Rough
Hard		1 190[t]	0.16[t]	0.95[b]	Glossy
Sand	800[b]	1 520[b]	0.33[b]		
Sawdust		190[b]	0.05[b]		
Silica	1320[b]	2 240[v]	1.4[t] (93)		
Silver	235[u]	10 500[u]	424[u]	0.02[n]	Polished and at 227 °C
Snow: Freshly fallen		100[y]	0.598[t]		
At 0°C		500[t]	2.2[t]		
Steel (mild)	500[b]	7 830[b]	45.3[b]	0.12[n]	Cleaned
Stone (quarried)	800[b]	1 500[t]			
Tar: Pitch	2500[v]	1 100[u]	0.88[v]		
Bituminous		1 200[t]	0.71[u]		
Tin	233[u]	7 290[u]	64.9[u]	0.06[h]	Bright and at 50°C
Tungsten	130[u]	19 400[u]	201[u]	0.032[n]	Filament at 27°C
Wood: Hardwoods—	1900/2700[b]	370/1100[z]	0.11/0.255[z]		
Ash, white		690[z]	0.172[z]		
Elm, American		580[z]	0.153[z]		
Hickory		800[z]			
Mahogany		550[u]	0.13[u]		
Maple, sugar		720[z]	0.187[z]		
Oak, white	2390[b]	750[z]	0.176[z]	0.90[n]	Planed
Walnut, black		630[z]			
Softwoods—	See Table 4,	350/740[z]	0.11/0.16[z]		
Fir, white	Chapter 24	430[z]	0.12[z]		
Pine, white		430[z]	0.11[z]		
Spruce		420[z]	0.11[z]		
Wool: Fiber	1360[u]	1 300[u]			
Fabric		110/330[u]	0.036/0.063[u]		
Zinc: Cast	390[u]	7 130[u]	110[u]	0.05[n]	Polished
Hot-rolled	390[b]	7 130[b]	110[b]		
Galvanizing				0.23[n]	Fairly bright

*Data source unknown.

Notes: 1. Values are for room temperature unless otherwise noted in parentheses.

2. Superscript letters indicate data source from the section on References.

REFERENCES

[a] *Handbook of chemistry and physics*, 63rd ed. 1982-83. Chemical Rubber Publishing Co., Cleveland, OH.

[b] Perry, R.H. *Chemical engineers' handbook*, 2nd ed., 1941, 5th ed., 1973. McGraw-Hill, New York.

[c] *Tables of thermodynamic and transport properties of air, argon, carbon dioxide, carbon monoxide, hydrogen, nitrogen, oxygen and steam.* 1960. Pergamon Press, Elmsford, NY.

[d] *American Institute of Physics handbook*, 3rd ed. 1972. McGraw-Hill, New York.

[e] Organick and Studhalter. 1948. *Thermodynamic properties of benzene. Chemical Engineering Progress* (November):847.

[f] Lange. 1972. *Handbook of chemistry*, rev. 12th ed. McGraw-Hill, New York.

[g] ASHRAE. 1969. *Thermodynamic properties of refrigerants*.

[h] Reid and Sherwood. 1969. *The properties of gases and liquids*, 2nd ed. McGraw-Hill, New York.

[i] Chapter 19, 1993 *ASHRAE Handbook—Fundamentals*.

[j] *T.P.R.C. data book*. 1966. Thermophysical Properties Research Center, W. Lafayette, IN.

[k] Estimated.

[l] Canjar, L.N., M. Goldman, and H. Marchman. 1951. Thermodynamic properties of propylene. *Industrial and Engineering Chemistry* (May):1183.

[m] *ASME steam tables*. 1967. American Society of Mechanical Engineers, New York.

[n] McAdams, W.H. 1954. *Heat transmission*, 3rd ed. McGraw-Hill, New York.

[o] Stull, D.R. 1947. Vapor pressure of pure substances (organic compounds). *Industrial and Engineering Chemistry* (April):517.

[p] *JANAF thermochemical tables*. 1965. PB 168 370. National Technical Information Service, Springfield, VA.

[q] *Physical properties of chemical compounds*. 1955-61. American Chemical Society, Washington, D.C.

[r] *International critical tables of numerical data*. 1928. National Research Council of USA, McGraw-Hill, New York.

[s] *Matheson gas data book*, 4th ed. 1966. Matheson Company, Inc., East Rutherford, NJ.

[t] Baumeister and Marks. 1967. *Standard handbook for mechanical engineers*. McGraw-Hill, New York.

[u] Miner and Seastone. *Handbook of engineering materials*. John Wiley and Sons, New York.

[v] Kirk and Othmer. 1966. *Encyclopedia of chemical technology.* Interscience Division, John Wiley and Sons, New York.

[w] Gouse and Stevens. 1960. *Chemical technology of petroleum*, 3rd ed. McGraw-Hill, New York.

[x] *Saline water conversion engineering data book*. 1955. M.W. Kellogg Co. for U.S. Department of Interior.

[y] Timmermans, J. *Physicochemical constants of pure organic compounds*, 2nd ed. American Elsevier, New York.

[z] *Wood handbook*. 1955. Handbook No. 72. Forest Products Laboratory, U.S. Department of Agriculture.

[aa] ASHRAE. 1976. *Thermophysical properties of refrigerants*.

[bb] Lane, G. ed. 1986. *Solar heat storage: Latent heat materials, Vol II—Technology.* CRC Press, Chicago.

For the anisotropic material, it requires the mathematics of a second order tensor and up to 21 material property constants. For the special case of orthogonal isotropy, there are three different material property constants for each of Young's Modulus, Shear Modulus and Poisson's ratioâ€”a total of 9 constants to describe the relationship between forces/moments and strains/curvatures. Share this page. 1 PHYSICAL PROPERTIES OF MATERIALS Volumetric and Melting Properties Thermal Properties Mass Diffusion Electrical Properties Electrochemical Processes Â©2010 John Wiley & Sons, Inc. M P Groover, Principles of Modern Manufacturing 4/e SI Version. 2 Physical Properties Defined Properties that define the behavior of materials in response to physical forces other than mechanical Volumetric, thermal, electrical, and electrochemical properties Components in a product must do more than withstand mechanical stresses They must conduct electricity (or prevent conduction), allow heat to transfer (or a