2. THERMOPHYSICAL PROPERTIES

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When organizing a chapter of thermophysical properties with limited space, some difficult decisions have to be made. Since this is a handbook for heat transfer practitioners, emphasis has been placed on transport rather than thermodynamic properties. The primary exception has been the inclusion of densities and isobaric specific heats, which are needed for the calculation of Prandtl numbers and thermal diffusivities.

In the spirit of today's computer usage, a number of gas properties are given in equation rather than tabular form. However, they are accompanied by skeleton tables to allow for program checks.

Because new refrigerants are being considered and used in technical applications, a number of transport and thermodynamic property tables are included for these substances.

Whenever possible, the properties in this chapter are divided into those for gases, liquids, and solids. There are unavoidable overlaps to this arrangement when the tables account for phase changes such as in the case of water.

2.1. CONVERSION FACTORS

Table 2.1 Conversion Factors for Units of Density

	kg/m^3	lb_m/ft^3	$lb_m/(U.K.\ gal)$	$lb_m/(U.S.\ gal)$	$slug/ft^3$	g/cm^3	t/m^3	U.K. ton/yd^3	U.S. ton/yd^3
kg/m^3	1	0.06243	0.01002	8.3454.−3	1.9403.−3	0.001	0.001	7.5248.−4	8.4278.−4
lb_m/ft^3	16.0185	1	0.16054	0.13368	0.03108	0.01602	0.01602	1.2054.−2	1.3500.−2
$lb_m/(U.K.\ gal)$	99.7763	6.22884	1	0.83268	0.19360	0.09976	0.09976	7.5080.−2	8.4090.−2
$lb_m/(U.S.\ gal)$	119.826	7.48052	1.20094	1	0.2325	0.11983	0.11983	9.0167.−2	1.0099.−1
$slug/ft^3$	515.38	32.1740	5.1653	4.3011	1	0.51538	0.51538	0.43435	0.43435
g/cm^3	1000	62.428	10.0224	8.34540	1.9403	1	1	0.75250	0.84280
t/m^3	1000	62.428	10.0224	8.34540	1.9403	1	1	0.75250	0.84280
U.K. ton/yd^3	1328.94	82.963	13.319	11.0905	2.5785	1.3289	1.3289	1	1.120
U.S. ton/yd^3	1186.5	74.075	11.892	9.9022	2.3023	1.1865	1.1865	0.89286	1

The notation 8.3454.−3 signifies 8.3454×10^{-3}.

Table 2.2 Conversion Factors for Units of Energy

	joule (J)	ft·lb$_f$	cal$_{th}$	cal$_{IT}$	liter·atm	kJ	Btu	hp·h	kWh
joule (J)	1	0.73756	0.23901	0.23885	9.8690.−3	10^{-3}	9.4783.−4	3.7251.−7	2.7773.−7
ft·lb$_f$	1.35582	1	0.32405	0.32384	1.33205.−2	1.3558.−3	1.2851.−3	5.0505.−7	3.7655.−7
cal$_{th}$	4.184	3.08596	1	0.99934	0.04129	4.184.−3	3.9657.−3	1.5586.−6	1.1620.−6
cal$_{IT}$	4.1868	3.08798	1.00066	1	0.04132	4.1868.−3	3.9683.−3	1.5596.−6	1.1628.−6
liter·atm	101.328	74.735	24.218	24.202	1	0.10325	9.6041.−2	3.7745.−5	2.8142.−5
kJ	1000	737.56	239.01	238.85	9.86896	1	0.94783	3.7251.−4	2.7773.−4
Btu	1055.05	778.16	252.16	252.00	10.4122	1.05505	1	3.9301.−4	2.9302.−4
hp·h	2.6845.+6	1.98.+6	641,617	641,197	26,494	2684.52	2544.5	1	0.74558
kWh	3.600.+6	2.6557.+6	860,564	8.6.+5	35,534	3600	3412.8	1.34125	1
thermie	4.184.+6	3.087.+6	10^6	9.9934.+5	4.129.+3	4.184.+3	3.9657.+3	1.5586	1.1620

The notation 9.8690.−3, 4.184.+6 signifies 9.8690×10^{-3}, 4.184×10^6.

Table 2.3 Conversion Factors for Units of Mass

	g	lb$_m$	kg	slug	U.S. ton (short ton)	t (metric ton)	U.K. ton (long ton)
g	1	2.2046.−3	0.001	6.8522.−5	1.1023.−6	10^{-6}	9.8421.−7
lb$_m$	453.592	1	0.45359	0.031081	0.0005	4.5359.−4	4.4643.−4
kg	1000	2.20462	1	0.06852	1.1023.−3	0.001	9.8421.−4
slug	14,593.9	32.1740	14.5939	1	0.01609	0.01459	0.01436
U.S. ton (short ton)	907,185	2000	907.185	62.162	1	0.90719	0.89286
t (metric ton)	10^6	2204.62	1000	68.5218	1.10231	1	0.98421
U.K. ton (long ton)	1,016,047	2240	1016.05	69.621	1.12	1.01604	1

The notation 2.2046.−3 signifies 2.2046×10^{-3}.

Source: National Bureau of Standards Letter Circular 1071, 7 pp., 1976.

Table 2.4 Conversion Factors for Units of Pressure

	dyn/cm^2 *	N/m^2 = Pa	lb_f/ft^2	mmHg	in (H_2O)	in (Hg)	lb_f/in^2	kg/cm^2	bar	atm
dyn/cm^2	1	0.1	2.0886.−3	7.5006.−4	4.0148.−4	2.9530.−5	1.4504.−5	1.0197.−6	10^{-6}	9.8692.−7
N/m^2	10	1	2.0886.−2	7.5006.−3	4.0148.−3	2.9530.−4	1.4504.−4	1.0197.−5	10^{-5}	9.8692.−6
lb_f/ft^2	478.79	47.879	1	0.35913	0.19221	1.4138.−2	6.9444.−3	4.8824.−4	4.7880.−4	4.7254.−4
mmHg	1333.22	133.32	2.7845	1	0.53526	0.03937	0.01934	1.3595.−3	1.3332.−3	1.3158.−3
in (H_2O)	2490.8	249.08	5.2023	1.8683	1	0.07355	0.03613	2.5399.−3	2.4908.−3	2.4585.−3
in (Hg)	33864	3386.4	70.727	25.400	13.596	1	0.49116	0.03453	0.03386	0.03342
lb_f/in^2	68,947	6894.7	144	51.715	27.680	2.03601	1	0.07031	0.06895	0.06805
kg/cm^2	980,665	98,067	2048.2	735.57	393.71	28.959	14.223	1	0.98067	0.96784
bar	10^6	10^5	2088.5	750.06	401.47	29.530	14.504	1.01972	1	0.98692
atm	1,013,250	101,325	2116.2	760	406.79	29.921	14.696	1.03323	1.01325	1

* 1 dyn/cm^2 = 1 microbar.

The notation 2.0886.−3 signifies 2.0886×10^{-3}.

Table 2.5 Conversion Factors for Units of Specific Energy

	$ft \cdot lb_f/lb_m$	J/g	Btu/lb_m	cal/g
$ft \cdot lb_f/lb_m$	1	2.989.−3	1.285.−3	7.143.−4
J/g	334.54	1	0.4299	0.2388
Btu/lb_m	778.16	2.326	1	0.5556
cal/g	1400	4.184	1.8	1

Table 2.6 Conversion Factors for Units of Specific Energy per Degree

	J/(g·K)	$Btu_{th}/(lb·°F)$	$cal_{th}/(g·°C)$	$Btu_{IT}/(lb_m·°F)$	$cal_{IT}/(g·°C)$
J/(g·K)	1	0.23901	0.23901	0.23885	0.23885
$Btu_{th}/(lb_m·°F)$	4.184	1	1	0.99933	0.99933
$cal_{th}/(g·°C)$	4.184	1	1	0.99933	0.99933
$Btu_{IT}/(lb_m·°F)$	4.1868	1.00067	1.00067	1	1
$cal_{IT}/(g·°C)$	4.1868	1.00067	1.00067	1	1

Table 2.7 Conversion Factors for Units of Thermal Conductivity

	Btu·in/(h·ft^{2}·°F)	W/(m·K)	kcal/(h·m·°C)	Btu/(h·ft·°F)	W/(cm·K)	cal/(s·cm·°C)	Btu·in/(s·ft^{2}·°F)
Btu·in/(h·ft^{2}·°F)	1	0.1441	0.1240	0.08333	1.441.−3	3.445.−4	2.777.−4
W/(m·K)	6.938	1	0.8604	0.5782	0.01	2.390.−3	1.926.−3
kcal/(h·m·°C)	8.064	1.162	1	0.6720	0.01162	2.778.−3	2.240.−3
Btu/(h·ft·°F)	12	1.730	1.488	1	0.01730	4.134.−3	3.333.−3
W/(cm·K)	694	100	86.04	57.82	1	0.2390	0.1926
cal/(s·cm·°C)	2903	418.4	360	241.9	4.184	1	0.8063
Btu·in/(s·ft^{2}·°F)	3600	519.2	446.7	300	5.192	1.2402	1

The notation 1.441.−3 signifies 1.441×10^{-3}.

Table 2.8 Conversion Factors for Units of Dynamic Viscosity

	micropoise	$lb_m/(ft·h)$	centipoise	slug/(ft·h)	poise (P)	$N·s/m^2$	Pa·s	$lb_m/(s·ft)$	$lb_f·s/ft^2$
micropoise	1	2.4191.−4	10^{-4}	7.5188.−6	10^{-6}	10^{-7}	10^{-7}	6.7197.−8	2.0885.−9
$lb_m/(ft·h)$	4134	1	0.4134	3.1081.−2	4.1338.−3	4.1338.−4	4.1338.−4	2.7778.−4	8.6336.−6
centipoise	10^4	2.4191	1	7.5188.−2	0.01	0.001	0.001	6.7197.−4	2.0885.−5
slug/(ft·h)	1.3300.+5	32.174	13.300	1	0.1330	1.3300.−2	1.3300.−2	8.9372.−3	2.7778.−4
poise (P)	10^6	241.91	100	7.5188	1	0.1	0.1	6.7197.−2	2.0835.−3
$N·s/m^2$	10^7	2419.1	1000	75.188	10	1	1	0.6720	2.0885.−2
Pa·s	10^7	2419.1	1000	75.188	10	1	1	0.6720	2.0885.−2
$lb_m/(ft·s)$	1.4882.+7	3600	1488.2	111.89	14.882	1.4882	1.4882	1	0.03108
$lb_f·s/ft^2$	4.7880.+8	1.1583.+5	4.7880.+4	3600	478.80	47.880	47.880	32.174	1
1 $lb_m/(ft·h)$ = 1 poundal·h/ft^2; 1 P = 1 g/(cm·s).									
The notation 2.4191.−4, 1.4882.+7 signifies 2.4191×10^{-4}, 1.4882×10^7.									

Table 2.9 Conversion Factors for Units of Kinematic Viscosity

	ft^2/h	stokes (St)	m^2/h	ft^2/s	m^2/s
ft^2/h	1	0.2581	0.0929	2.778.−4	2.581.−5
stokes (St)	3.8750	1	0.36	1.076.−3	10^{-4}
m^2/h	10.7639	2.7778	1	2.990.−3	2.778.−4
ft^2/s	3.600	929.03	334.45	1	0.09290
m^2/s	38,750	10,000	3600	10.7639	1
The notation 2.581.−5 signifies 2.581×10^{-5}.					
1 stoke = 1 cm^2/s.					

2.2. THERMOPHYSICAL PROPERTIES OF GASES

Table 2.10 treats the specific heats, dynamic viscosities, and thermal conductivities as functions of temperature only. To obtain the density of a gas, the perfect gas law may be used, i.e.,

$$P = \rho RT$$

Table 2.10 Thermophysical Properties of Thirteen Common Gases Using Computer Equations

Air

At/mol wt (kg/mol): 28.966
Gas constant (kJ/kg K): .287040
At/mol formula: (mixture)

Critical temperature (K): 132.6
Critical pressure (MPa): 3.77

$c_p = \sum [A(N)T^N]$

A(0) = 0.103409E+1
A(1) = −0.2848870E-3
A(2) = 0.7816818E-6
A(3) = −0.4970786E-9
A(4) = 0.1077024E-12

$k = \sum [C(N)T^N]$

Temperature range: 250 ≤ T ≤ 1050 K

Coefficients:
C(0) = −2.276501E-3
C(1) = 1.2598485E-4
C(2) = −1.4815235E-7
C(3) = 1.73550646E-10
C(4) = −1.066657E-13
C(5) = 2.47663035E-17
C(6) = 0.0

$\mu = \sum [B(N)T^N]$

Temperature range: 250 ≤ T < 600 K

Coefficients:
B(0) = −9.8601E-1
B(1) = 9.080125E-2
B(2) = −1.17635575E-4
B(3) = 1.2349703E-7
B(4) = −5.7971299E-11
B(5) = 0.0
B(6) = 0.0

Temperature range: 600 ≤ T ≤ 1050 K

Coefficients:
B(0) = 4.8856745
B(1) = 5.43232E-2
B(2) = −2.4261775E-5
B(3) = 7.9306E-9
B(4) = −1.10398E-12
B(5) = 0.0
B(6) = 0.0

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	1.0064	18.53	26.07
500	1.0317	26.82	39.48
1000	1.1415	41.77	67.21

Argon

At/mol wt (kg/mol): 39.948
Gas constant (kJ/kg K): .208129
At/mol formula: Ar

Critical temperature (K): 150.8
Critical pressure (MPa): 4.87
Sat temp at one atmosphere (K): 87.5

$c_p = \sum [A(N)T^N]$

Temperature range: 200 ≤ T ≤ 1600 K

Coefficients:
A(0) = 0.52034
A(1) = 0.0
A(2) = 0.0
A(3) = 0.0
A(4) = 0.0
A(5) = 0.0
A(6) = 0.0

$k = \sum [C(N)T^N]$

Temperature range: 200 ≤ T ≤ 1000 K

Coefficients:
C(0) = −5.2839462E-4
C(1) = 7.60706705E-5
C(2) = −6.4749393E-8
C(3) = 5.41874502E-11
C(4) = −3.22024235E-14
C(5) = 1.17962552E-17
C(6) = −1.86231745E-21

$\mu = \sum [B(N)T^N]$

Temperature range: 200 ≤ T < 540 K

Coefficients:
B(0) = 1.22573
B(1) = 5.9456964E-2
B(2) = 1.897011E-4
B(3) = −8.171242E-7
B(4) = 1.2939183E-9
B(5) = −7.5027442E-13
B(6) = 0.0

Temperature range: 540 ≤ T ≤ 1000 K

Coefficients:
B(0) = 4.03764
B(1) = 7.3665688E-2
B(2) = −3.3867E-5
B(3) = 1.127158E-8
B(4) = −1.585569E-12
B(5) = 0.0
B(6) = 0.0

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	0.5203	22.73	17.69
500	0.5203	33.66	26.42
1000	0.5203	53.52	42.71

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

n-Butane

At/mol wt (kg/mol): 58.124
Gas constant (kJ/kg K): .143044
At/mol formula: C_4H_{10}

Critical temperature (K): 408.1
Critical pressure (MPa): 3.65
Sat temp at one atmosphere (K): 261.5

$c_p = \sum [A(N)T^N]$

Temperature range: $280 \le T < 755$ K

Coefficients:
A(0) = 2.3665134E-1
A(1) = 5.10573E-3
A(2) = −4.16089E-7
A(3) = −1.1450804E-9
A(4) = 0.0
A(5) = 0.0
A(6) = 0.0

Temperature range: $755 \le T \le 1080$ K

Coefficients:
A(0) = 4.40126486
A(1) = −1.390866545E-2
A(2) = 3.471109E-5
A(3) = −3.45278E-8
A(4) = 1.619382E-11
A(5) = −2.966666E-15
A(6) = 0.0

$\mu = \sum [B(N)T^N]$

Temperature range: $270 \le T \le 520$ K

Coefficients:
B(0) = −1.099487E-2
B(1) = 2.634504E-2
B(2) = −3.54700854E-6
B(3) = 0.0
B(4) = 0.0
B(5) = 0.0
B(6) = 0.0

$k = \sum [C(N)T^N]$

Temperature range: $280 \le T \le 500$ K

Coefficients:
C(0) = 3.79912E-3
C(1) = −3.38011396E-5
C(2) = 3.15886537E-7
C(3) = −2.25600514E-10
C(4) = 0.0
C(5) = 0.0
C(6) = 0.0

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	1.700	7.573	16.00
500	2.542	12.27	37.67
1000	3.903	—	—

Carbon dioxide

At/mol wt (kg/mol): 44.01
Gas constant (kJ/kg K): .188919
At/mol formula: CO_2

Critical temperature (K): 304.1
Critical pressure (MPa): 7.38
Sat temp at one atmosphere (K): 194.7

$c_p = \sum [A(N)T^N]$

Temperature range: $200 \le T \le 1000$ K

Coefficients:
A(0) = 4.5386462E-1
A(1) = 1.5334795E-3
A(2) = −4.195556E-7
A(3) = −1.871946E-9
A(4) = 2.862388E-12
A(5) = −1.6962E-15
A(6) = 3.717285E-19

$\mu = \sum [B(N)T^N]$

Temperature range: $200 \le T \le 1000$ K

Coefficients:
B(0) = −8.095191E-1
B(1) = 6.0395329E-2
B(2) = −2.824853E-5
B(3) = 9.843776E-9
B(4) = −1.47315277E-12
B(5) = 0.0
B(6) = 0.0

$k = \sum [C(N)T^N]$

Temperature range: $200 \le T < 600$ K

Coefficients:
C(0) = 2.971488E-3
C(1) = −1.33471677E-5
C(2) = 3.14443715E-7
C(3) = −4.75106178E-10
C(4) = 2.68500151E-13
C(5) = 0.0
C(6) = 0.0

Temperature range: $600 \le T \le 1000$ K

Coefficients:
C(0) = 6.085375E-2
C(1) = −3.63680275E-4
C(2) = 1.0134366E-6
C(3) = −9.7042356E-10
C(4) = 3.27864115E-13
C(5) = 0.0
C(6) = 0.0

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	0.845	15.02	16.61
500	1.013	23.46	32.30
1000	1.234	39.71	68.05

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

Carbon monoxide

At/mol wt (kg/mol): 28.011
Gas constant (kJ/kg K): .296828
At/mol formula: CO

Critical temperature (K): 132.9
Critical pressure (MPa): 3.5
Sat temp at one atmosphere (K): 81.6

$c_p = \sum [A(N)T^N]$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

A(0) = 1.020802	A(4) = −7.93722E-12
A(1) = 3.82075E-4	A(5) = 4.291972E-15
A(2) = −2.4945E-6	A(6) = −8.903274E-19
A(3) = 6.81145E-9	

$\mu = \sum [B(N)T^N]$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

B(0) = −5.24575E-1	B(4) = −2.83747E-11
B(1) = 7.9606E-2	B(5) = 5.317831E-15
B(2) = −7.82295E-5	B(6) = 0.0
B(3) = 6.2821488E-8	

$k = \sum [C(N)T^N]$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

C(0) = −7.41704398E-4	C(4) = 3.65528473E-14
C(1) = 9.87435265E-5	C(5) = −1.2427179E-17
C(2) = −3.77511167E-8	C(6) = 0.0
C(3) = −1.99334224E-11	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	1.040	17.80	25.21
500	1.064	25.97	38.60
1000	1.184	40.62	64.44

Ethane

At/mol wt (kg/mol): 30.07
Gas constant (kJ/kg K): .276498
At/mol formula: C_2H_6

Critical temperature (K): 305.4
Critical pressure (MPa): 4.88
Sat temp at one atmosphere (K): 184.6

$c_p = \sum [A(N)T^N]$

Temperature range: $280 \le T < 755$ K

Coefficients:

A(0) = 5.319795E-1	A(4) = 0.0
A(1) = 3.755877E-3	A(5) = 0.0
A(2) = 1.789289E-6	A(6) = 0.0
A(3) = −2.13225E-9	

Temperature range: $755 \le T \le 1080$ K

Coefficients:

A(0) = 3.7183729	A(4) = 1.382794E-11
A(1) = −1.0891558E-2	A(5) = −2.52553E-15
A(2) = 2.95115E-5	A(6) = 0.0
A(3) = −2.95597E-8	

$\mu = \sum [B(N)T^N]$

Temperature range: $200 \le T \le 1000$ K

Coefficients:

B(0) = −5.107728E-1	B(4) = 0.0
B(1) = 3.76582E-2	B(5) = 0.0
B(2) = −1.59412113E-5	B(6) = 0.0
B(3) = 3.906E-9	

$k = \sum [C(N)T^N]$

Temperature range: $200 \le T \le 1000$ K

Coefficients:

C(0) = −3.83815197E-2	C(4) = −1.369896E-11
C(1) = 5.47282126E-4	C(5) = 1.05765043E-14
C(2) = −2.80760648E-6	C(6) = −3.16347435E-18
C(3) = 8.74854603E-9	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	1.762	9.457	21.76
500	2.591	14.82	51.83
1000	4.081	25.11	163.9

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

Helium

At/mol wt (kg/mol): 4.003
Gas constant (kJ/kg K): 2.077022
At/mol formula: He
Critical temperature (K): 5.189
Critical pressure (MPa): .23
Sat temp at one atmosphere (K): 4.3

$c_p = \sum [A(N)T^N]$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

A(0) = 5.1931	A(2) = 0.0	A(4) = 0.0	A(6) = 0.0
A(1) = 0.0	A(3) = 0.0	A(5) = 0.0	

$\mu = \sum [B(N)T^N]$

Temperature range: $250 \le T < 500$ K

Coefficients:

B(0) = 3.9414E-1	B(4) = −2.4278655E-8	
B(1) = 1.7213335E-1	B(5) = 3.641644E-11	
B(2) = −1.38733E-3	B(6) = −2.14117E-14	
B(3) = 8.020045E-6		

Temperature range: $500 \le T \le 1050$ K

Coefficients:

B(0) = 7.442412	B(4) = 0.0	
B(1) = 4.6649873E-2	B(5) = 0.0	
B(2) = −1.0385665E-5	B(6) = 0.0	
B(3) = 1.35269E-9		

$k = \sum [C(N)T^N]$

Temperature range: $250 \le T < 300$ K

Coefficients:

C(0) = 1.028793E-2	C(4) = −1.3477236E-11
C(1) = 8.51625139E-4	C(5) = 0.0
C(2) = −3.14258034E-6	C(6) = 0.0
C(3) = 1.02188556E-8	

Temperature range: $300 \le T < 500$ K

Coefficients:

C(0) = −7.761491E-3	C(4) = 0.0
C(1) = 8.66192033E-4	C(5) = 0.0
C(2) = −1.5559338E-6	C(6) = 0.0
C(3) = 1.40150565E-9	

Temperature range: $500 \le T \le 1050$ K

Coefficients:

C(0) = −9.0656E-2	C(4) = −1.26457196E-13
C(1) = 9.37593087E-4	C(5) = 0.0
C(2) = −9.13347535E-7	C(6) = 0.0
C(3) = 5.55037072E-10	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	5.193	19.94	149.7
500	5.193	28.17	211.5
1000	5.193	45.06	362.2

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

Hydrogen

At/mol wt (kg/mol): 2.016
Gas constant (kJ/kg K): 4.124289
At/mol formula: H_2

Critical temperature (K): 33.3
Critical pressure (MPa): 1.3
Sat temp at one atmosphere (K): 20.4

$$c_p = \sum [A(N)T^N]$$

Temperature range: $250 \le T < 425$ K

Coefficients:

A(0) = 5.0066253	A(4) = −8.4758275E-9
A(1) = 1.01569422E-1	A(5) = 1.43800374E-11
A(2) = −6.02891517E-4	A(6) = −9.8072403E-15
A(3) = 2.7375894E-6	

Temperature range: $425 \le T < 490$ K

Coefficients:

A(0) = 1.44947E+1	A(4) = 0.0
A(1) = 0.0	A(5) = 0.0
A(2) = 0.0	A(6) = 0.0
A(3) = 0.0	

Temperature range: $490 \le T \le 1050$ K

Coefficients:

A(0) = 1.4920082E+1	A(4) = 0.0
A(1) = −1.996917584E-3	A(5) = 0.0
A(2) = 2.540615E-6	A(6) = 0.0
A(3) = −4.7588954E-10	

$$\mu = \sum [B(N)T^N]$$

Temperature range: $250 \le T < 500$ K

Coefficients:

B(0) = −1.35666E-1	B(4) = −5.23104E-9
B(1) = 6.84115878E-2	B(5) = 7.4490972E-12
B(2) = −3.928747E-4	B(6) = −4.250937E-15
B(3) = 1.8996E-6	

Temperature range: $500 \le T \le 1050$ K

Coefficients:

B(0) = 2.72941	B(4) = −5.2889938E-13
B(1) = 2.3224377E-2	B(5) = 0.0
B(2) = −7.6287854E-6	B(6) = 0.0
B(3) = 2.92585E-9	

$$k = \sum [C(N)T^N]$$

Temperature range: $250 \le T < 500$ K

Coefficients:

C(0) = 2.009705E-2	C(4) = 5.52407932E-12
C(1) = 3.234622E-4	C(5) = 0.0
C(2) = 2.1637249E-6	C(6) = 0.0
C(3) = −6.49151204E-9	

Temperature range: $500 \le T \le 1050$ K

Coefficients:

C(0) = 1.083105E-1	C(4) = 4.6468625E-14
C(1) = 2.21163789E-4	C(5) = 0.0
C(2) = 2.26380948E-7	C(6) = 0.0
C(3) = −1.74258636E-10	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	14.27	8.949	181.3
500	14.50	12.72	256.6
1000	14.99	20.72	428.1

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

Methane

At/mol wt (kg/mol): 16.043
Gas constant (kJ/kg K): .518251
At/mol formula: CH_4

Critical temperature (K): 190.5
Critical pressure (MPa): 4.6
Sat temp at one atmosphere (K): 111.5

$c_p = \sum [A(N)T^N]$

Temperature range: $280 \le T < 755$ K

Coefficients:

A(0) = 1.9165258	A(4) = 0.0
A(1) = −1.09269E-3	A(5) = 0.0
A(2) = 8.696605E-6	A(6) = 0.0
A(3) = −5.2291144E-9	

Temperature range: $755 \le T \le 1080$ K

Coefficients:

A(0) = 1.04356E+1	A(4) = 3.9030203E-11
A(1) = −4.2025284E-2	A(5) = −7.1345169E-15
A(2) = 8.849006E-5	A(6) = 0.0
A(3) = −8.4304566E-8	

$\mu = \sum [B(N)T^N]$

Temperature range: $200 \le T \le 1000$ K

Coefficients:

B(0) = 2.968267E-1	B(4) = 7.543269E-11
B(1) = 3.711201E-2	B(5) = −2.7237166E-14
B(2) = 1.218298E-5	B(6) = 0.0
B(3) = −7.02426E-8	

$k = \sum [C(N)T^N]$

Temperature range: $200 \le T \le 1000$ K

Coefficients:

C(0) = −1.3401499E-2	C(4) = −9.1405505E-12
C(1) = 3.6630706E-4	C(5) = 6.7896889E-15
C(2) = −1.82248608E-6	C(6) = −1.95048736E-18
C(3) = 5.93987998E-9	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	2.230	11.18	33.88
500	2.891	16.98	67.03
1000	4.491	27.54	169.0

Nitrogen

At/mol wt (kg/mol): 28.013
Gas constant (kJ/kg K): .296798
At/mol formula: N_2

Critical temperature (K): 126.2
Critical pressure (MPa): 3.4
Sat temp at one atmosphere (K): 77.3

$c_p = \sum [A(N)T^N]$

Temperature range: $280 \le T < 590$ K

Coefficients:

A(0) = 1.088047	A(4) = 0.0
A(1) = −3.55968E-4	A(5) = 0.0
A(2) = 7.2907605E-7	A(6) = 0.0
A(3) = −2.8861556E-10	

Temperature range: $590 \le T \le 1080$ K

Coefficients:

A(0) = 1.4055077	A(4) = 2.08491259E-12
A(1) = −2.1894566E-3	A(5) = −3.7903033E-16
A(2) = 4.7852898E-6	A(6) = 0.0
A(3) = −4.540166E-9	

$\mu = \sum [B(N)T^N]$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

B(0) = 2.5465E-2	B(4) = −1.5622457E-11
B(1) = 7.5336535E-2	B(5) = 2.249666E-15
B(2) = −6.51566245E-5	B(6) = 0.0
B(3) = 4.34945E-8	

$k = \sum [C(N)T^N]$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

C(0) = −1.5231785E-3	C(4) = −6.36537349E-14
C(1) = 1.18879965E-4	C(5) = 1.47167023E-17
C(2) = −1.2092845E-7	C(6) = 0.0
C(3) = 1.15567802E-10	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	1.039	17.82	25.90
500	1.056	25.94	38.61
1000	1.167	40.33	63.06

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

Oxygen

At/mol wt (kg/mol): 31.999	Critical temperature (K): 154.6
Gas constant (kJ/kg K): .259832	Critical pressure (MPa): 5.04
At/mol formula: O_2	Sat temp at one atmosphere (K): 90

$$c_p = \sum [A(N)T^N]$$

Temperature range: $250 \le T < 590$ K

Coefficients:

A(0) = 9.29247E-1	A(4) = 0.0
A(1) = −3.220603E-4	A(5) = 0.0
A(2) = 1.166523E-6	A(6) = 0.0
A(3) = −7.1157865E-10	

Temperature range: $590 \le T \le 1050$ K

Coefficients:

A(0) = 5.977293E-1	A(4) = −1.1772692E-13
A(1) = 1.183704E-3	A(5) = 0.0
A(2) = −1.156226E-6	A(6) = 0.0
A(3) = 5.82171E-10	

$$\mu = \sum [B(N)T^N]$$

Temperature range: $250 \le T \le 1050$ K

Coefficients:

B(0) = −3.97863E-1	B(4) = −1.690435E-11
B(1) = 8.7605894E-2	B(5) = 2.534147E-15
B(2) = −7.064124E-5	B(6) = 0.0
B(3) = 4.6287E-8	

$$k = \sum [C(N)T^N]$$

Temperature range: $250 \le T < 1000$ K

Coefficients:

C(0) = −7.6727798E-4	C(4) = 0.0
C(1) = 1.03560076E-4	C(5) = 0.0
C(2) = −4.62034365E-8	C(6) = 0.0
C(3) = 1.51980292E-11	

Temperature range: $1000 \le T \le 1050$ K

Coefficients:

C(0) = −1.8654526E-1	C(4) = −7.84907953E-14
C(1) = 7.05649428E-4	C(5) = 0.0
C(2) = −7.71025034E-7	C(6) = 0.0
C(3) = 4.02143777E-10	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	0.918	20.65	26.55
500	0.970	30.55	41.36
1000	1.090	48.48	71.79

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

Propane

At/mol wt (kg/mol): 44.097
Gas constant (kJ/kg K): 0.207519
At/mol formula: C_3H_8

Critical temperature (K): 369.8
Critical pressure (MPa): 4.26
Sat temp at one atmosphere (K): 231.1

$c_p = \sum [A(N)T^N]$

Temperature range: $280 \le T < 755$ K

Coefficients:

A(0) = 8.41607E-2	A(4) = 0.0
A(1) = 5.7701407E-3	A(5) = 0.0
A(2) = −1.292127E-6	A(6) = 0.0
A(3) = −6.9945925E-10	

Temperature range: $755 \le T \le 1080$ K

Coefficients:

A(0) = 3.47456	A(4) = 1.2466175E-11
A(1) = −9.4956207E-3	A(5) = −2.271073E-15
A(2) = 2.643558E-5	A(6) = 0.0
A(3) = −2.6640384E-8	

$\mu = \sum [B(N)T^N]$

Temperature range: $270 \le T \le 600$ K

Coefficients:

B(0) = −3.543711E-1	B(4) = 0.0
B(1) = 3.080096E-2	B(5) = 0.0
B(2) = −6.99723E-6	B(6) = 0.0
B(3) = 0.0	

$k = \sum [C(N)T^N]$

Temperature range: $270 \le T \le 500$ K

Coefficients:

C(0) = −1.07682209E-2	C(4) = 0.0
C(1) = 8.38590352E-5	C(5) = 0.0
C(2) = 4.22059864E-8	C(6) = 0.0
C(3) = 0.0	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	1.680	8.256	18.19
500	2.559	13.30	41.71
1000	3.969	—	—

Sulfur dioxide

At/mol wt (kg/mol): 64.063
Gas constant (kJ/kg K): .129784
At/mol formula: SO_2

Critical temperature (K): 430.7
Critical pressure (MPa): 7.88
Sat temp at one atmosphere (K): 268.4

$c_p = \sum [A(N)T^N]$

Temperature range: $300 \le T \le 1100$ K

Coefficients:

A(0) = 4.32805E-1	A(4) = 1.0409341E-12
A(1) = 5.9994156E-4	A(5) = −2.5313735E-16
A(2) = 4.593367E-7	A(6) = 0.0
A(3) = −1.433024E-9	

$\mu = \sum [B(N)T^N]$

Temperature range: $300 \le T \le 1100$ K

Coefficients:

B(0) = −1.141748	B(4) = 0.0
B(1) = 5.1281456E-2	B(5) = 0.0
B(2) = −1.3886282E-5	B(6) = 0.0
B(3) = 2.15266E-9	

$k = \sum [C(N)T^N]$

Temperature range: $300 \le T \le 900$ K

Coefficients:

C(0) = −1.86270694E-2	C(4) = −7.53585825E-12
C(1) = 3.19110134E-4	C(5) = 5.48078289E-15
C(2) = −1.73644245E-6	C(6) = −1.56355469E-18
C(3) = 5.09847985E-9	

Skeleton table

T (K)	c_p (kJ/kg K)	μ (Ns/m²) E6	k (W/m K) E3
300	0.623	13.05	9.623
500	0.726	21.30	19.98
900	0.834	35.33	39.98

Extracted from Ref. 4 with permission.
E-2 signifies $\times 10^{-2}$, etc.

From the specific heat and density and using other given properties, the thermal diffusivity and Prandtl number may be calculated.

For each gas, skeleton tables of the properties are given at several temperatures so that computer program checks can be made.

Table 2.11 Compressibility Factors

Compressibility factor Z of air*

	Pressure, bar													
T (K)	1	5	10	20	40	60	80	100	150	200	250	300	400	500
75	0.0052	0.0260	0.0519	0.1036	0.2063	0.3082	0.4094	0.5099	0.7581	1.0025	—	—	—	—
80	—	0.0250	0.0499	0.0995	0.1981	0.2958	0.3927	0.4887	0.7258	0.9588	1.1931	1.4139	—	—
90	0.9764	0.0236	0.0471	0.0940	0.1866	0.2781	0.3686	0.4581	0.6779	0.8929	1.1098	1.3110	1.7161	2.1105
100	0.9797	0.8872	0.0453	0.0900	0.1782	0.2635	0.3498	0.4337	0.6386	0.8377	1.0395	1.2227	1.5937	1.9536
120	0.9880	0.9373	0.8660	0.6730	0.1778	0.2557	0.3371	0.4132	0.5964	0.7720	0.9530	1.1076	1.5091	1.7366
140	0.9927	0.9614	0.9205	0.8297	0.5856	0.3313	0.3737	0.4340	0.5909	0.7699	0.9114	1.0393	1.3202	1.5903
160	0.9951	0.9748	0.9489	0.8954	0.7803	0.6603	0.5696	0.5489	0.6340	0.7564	0.8840	1.0105	1.2585	1.4970
180	0.9967	0.9832	0.9660	0.9314	0.8625	0.7977	0.7432	0.7084	0.7180	0.7986	0.9000	1.0068	1.2232	1.4361
200	0.9978	0.9886	0.9767	0.9539	0.9100	0.8701	0.8374	0.8142	0.8061	0.8549	0.9311	1.0185	1.2054	1.3944
250	0.9992	0.9957	0.9911	0.9822	0.9671	0.9549	0.9463	0.9411	0.9450	0.9713	1.0152	1.0702	1.1990	1.3392
300	0.9999	0.9987	0.9974	0.9950	0.9917	0.9901	0.9903	0.9930	1.0074	1.0326	1.0669	1.1089	1.2073	1.3163
350	1.0000	1.0002	1.0004	1.0014	1.0038	1.0075	1.0121	1.0183	1.0377	1.0635	1.0947	1.1303	1.2116	1.3015
400	1.0002	1.0012	1.0025	1.0046	1.0100	1.0159	1.0229	1.0312	1.0533	1.0795	1.1087	1.1411	1.2117	1.2890
450	1.0003	1.0016	1.0034	1.0063	1.0133	1.0210	1.0287	1.0374	1.0614	1.0913	1.1183	1.1463	1.2090	1.2778
500	1.0003	1.0020	1.0034	1.0074	1.0151	1.0234	1.0323	1.0410	1.0650	1.0913	1.1183	1.1463	1.2051	1.2667
600	1.0004	1.0022	1.0039	1.0081	1.0164	1.0253	1.0340	1.0434	1.0678	1.0920	1.1172	1.1427	1.1947	1.2475
800	1.0004	1.0020	1.0038	1.0077	1.0157	1.0240	1.0321	1.0408	1.0621	1.0844	1.1061	1.1283	1.1720	1.2150
1000	1.0004	1.0018	1.0037	1.0068	1.0142	1.0215	1.0290	1.0365	1.0556	1.0744	1.0948	1.1131	1.1515	1.1889

Compressibility factor Z of argon†

			Pressure, bar								
T (K)	Sat. liquid	Sat. vapor	1	50	100	150	200	250	300	400	500
85	0.0031	0.9706	0.0040	—	—	—	—	—	—	—	—
90	0.0052	0.9579	0.9684	0.1919	0.3801	0.5648	0.7467	0.9260	—	—	—
95	0.0080	0.9415	0.9731	0.1859	0.3675	0.5456	0.7205	0.8928	1.0625	1.3959	—
100	0.0119	0.9220	0.9773	0.1807	0.3567	0.5288	0.6975	0.8634	1.0267	1.3470	1.6932
120	0.0418	0.8112	0.9866	0.1683	0.3280	0.4818	0.6311	0.7770	0.9197	1.1981	1.4978
140	0.1153	0.6144	0.9915	0.1737	0.3230	0.4636	0.5985	0.7294	0.8568	1.1040	1.3699
160	—	—	0.9943	0.6161	0.3610	0.4766	0.5954	0.7122	0.8265	1.0478	1.2866
180	—	—	0.9962	0.7754	0.5432	0.5405	0.6246	0.7014	0.8200	1.0165	1.2321
200	—	—	0.9972	0.8509	0.7121	0.6540	0.6870	0.7555	0.8360	1.0051	1.1982
250	—	—	0.9988	0.9374	0.8877	0.8602	0.8591	0.8812	0.9208	1.0263	1.1713
300	—	—	0.9995	0.9730	0.9552	0.9482	0.9533	0.9694	0.9950	1.0673	1.1786
350	—	—	0.9998	0.9911	0.9880	0.9915	0.9987	1.0179	1.0399	1.0971	1.1902
400	—	—	1.0001	1.0006	1.0056	1.0148	1.0280	1.0450	1.0656	1.1157	1.1976
450	—	—	1.0001	1.0063	1.0154	1.0276	1.0427	1.0602	1.0804	1.1258	1.2002
500	—	—	1.0002	1.0090	1.0205	1.0342	1.0501	1.0678	1.0874	1.1301	1.1997
600	—	—	1.0003	1.0118	1.0250	1.0394	1.0553	1.0723	1.0904	1.1291	1.1933
700	—	—	1.0003	1.0128	1.0261	1.0399	1.0551	1.0709	1.0874	1.1224	1.1821
800	—	—	1.0003	1.0126	1.0258	1.0396	1.0532	1.0678	1.0830	1.1147	1.1707
900	—	—	1.0003	1.0122	1.0250	1.0378	1.0506	1.0643	1.0782	1.1068	1.1596
1000	—	—	1.0002	1.0119	1.0239	1.0364	1.0484	1.0608	1.0736	1.0999	1.1497

Note: See page 2.15 for footnotes.

Compressibility factor Z of carbon dioxide[‡]

	Pressure, bar											
T (°C)	1	5	10	20	40	60	80	100	200	300	400	500
0	0.9933	0.9658	0.9294	0.8496	—	—	—	—	—	—	—	—
50	0.9964	0.9805	0.9607	0.9195	0.8300	0.7264	0.5981	0.4239	—	—	—	—
100	0.9977	0.9883	0.9764	0.9524	0.9034	0.8533	0.8022	0.7514	0.5891	0.6420	—	—
150	0.9985	0.9927	0.9853	0.9705	0.9416	0.9131	0.8854	0.8590	0.7651	0.7623	0.8235	0.9098
200	0.9991	0.9953	0.9908	0.9818	0.9640	0.9473	0.9313	0.9170	0.8649	0.8619	0.8995	0.9621
250	0.9994	0.9971	0.9943	0.9886	0.9783	0.9684	0.9593	0.9511	0.9253	0.9294	0.9508	1.0096
300	0.9996	0.9982	0.9967	0.9936	0.9875	0.9822	0.9773	0.9733	0.9640	0.9746	1.0030	1.0464
350	0.9998	0.9991	0.9983	0.9964	0.9938	0.9914	0.9896	0.9882	0.9895	1.0053	1.0340	1.0734
400	0.9999	0.9997	0.9994	0.9989	0.9982	0.9979	0.9979	0.9984	1.0073	1.0266	1.0559	1.0928
450	1.0000	1.0000	1.0003	1.0005	1.0013	1.0023	1.0038	1.0056	1.0170	1.0412	1.0709	1.1067
500	1.0000	1.0004	1.0008	1.0015	1.0035	1.0056	1.0079	1.0107	1.0282	1.0522	1.0820	1.1165
600	1.0000	1.0007	1.0013	1.0030	1.0062	1.0093	1.0129	1.0168	1.0386	1.0648	1.0948	1.1277
700	1.0003	1.0010	1.0017	1.0036	1.0073	1.0161	1.0155	1.0198	1.0436	1.0707	1.1000	1.1318
800	1.0002	1.0009	1.0019	1.0040	1.0082	1.0122	1.0168	1.0212	1.0458	1.0731	1.1016	1.1324
900	1.0002	1.0009	1.0020	1.0041	1.0083	1.0128	1.0171	1.0221	1.0463	1.0726	1.1012	1.1303
1000	1.0002	1.0009	1.0021	1.0042	1.0084	1.0128	1.0172	1.0218	1.0460	1.0725	1.0725	1.1274

Compressibility factor Z of methane[§]

	Pressure, bar											
T (K)	1	5	10	20	40	60	80	100	200	300	400	500
100	0.0044	0.0219	0.0437	0.0874	0.1741	0.2604	0.3459	0.4313	0.8498	1.2585	1.6579	2.0492
150	0.9856	0.9243	0.8333	0.0708	0.1401	0.2078	0.2748	0.3405	0.6573	0.9602	1.2519	1.5359
200	0.9937	0.9682	0.9350	0.8629	0.6858	0.3755	0.3218	0.3657	0.6148	0.8564	1.0894	1.3145
250	0.9972	0.9841	0.9678	0.9356	0.8694	0.8035	0.7403	0.6889	0.6953	0.8593	1.0383	1.2172
300	0.9982	0.9915	0.9828	0.9663	0.9342	0.9042	0.8773	0.8548	0.8280	0.9140	1.0417	1.1812
350	0.9988	0.9954	0.9905	0.9821	0.9657	0.9513	0.9390	0.9293	0.9226	0.9775	1.0678	1.1751
400	0.9995	0.9976	0.9957	0.9908	0.9833	0.9771	0.9721	0.9691	0.9783	1.0258	1.0968	1.1821
450	0.9999	0.9996	0.9991	0.9965	0.9941	0.9923	0.9917	0.9922	1.0128	1.0577	1.1195	1.1916
500	1.0000	1.0000	1.0000	1.0003	1.0009	1.0021	1.0043	1.0068	1.0335	1.0780	1.1347	1.1990
600	1.0002	1.0010	1.0021	1.0040	1.0083	1.0128	1.0175	1.0227	1.0555	1.0989	1.1495	1.2049
700	1.0003	1.0014	1.0028	1.0061	1.0116	1.0177	1.0237	1.0298	1.0646	1.1056	1.1522	1.2023
800	1.0003	1.0017	1.0034	1.0068	1.0130	1.0198	1.0264	1.0331	1.0680	1.1071	1.1500	1.1956
900	1.0004	1.0018	1.0036	1.0071	1.0137	1.0206	1.0274	1.0340	1.0680	1.1056	1.1457	1.1878
1000	1.0004	1.0014	1.0036	1.0072	1.0142	1.0208	1.0275	1.0342	1.0678	1.1033	1.1400	1.1790

Compressibility factor Z of nitrogen[¶]												
	Pressure, bar											
T (K)	1	5	10	20	40	60	80	100	200	300	400	500
70	0.0057	0.0287	0.0573	0.1143	0.2277	0.3400	0.4516	0.5623	1.1044	1.6308	Solid	Solid
80	0.9593	0.0264	0.0528	0.1053	0.2093	0.3122	0.4140	0.5148	1.0061	1.4797	1.9396	2.3879
90	0.9722	0.0251	0.0500	0.0996	0.1975	0.2938	0.3888	0.4826	0.9362	1.3700	1.7890	2.1962
100	0.9798	0.8910	0.0487	0.0966	0.1905	0.2823	0.3720	0.4605	0.8840	1.2852	1.6707	2.0441
120	0.9883	0.9397	0.8732	0.7059	0.1975	0.2822	0.3641	0.4438	0.8188	1.1684	1.5015	1.8223
140	0.9927	0.9635	0.9253	0.8433	0.6376	0.4251	0.4278	0.4799	0.7942	1.0996	1.3920	1.6726
160	0.9952	0.9766	0.9529	0.9042	0.8031	0.7017	0.6304	0.6134	0.8107	1.0708	1.3275	1.5762
180	0.9967	0.9846	0.9690	0.9381	0.8782	0.8125	0.7784	0.7530	0.8550	1.0669	1.2893	1.5105
200	0.9978	0.9897	0.9791	0.9592	0.9212	0.8882	0.8621	0.8455	0.9067	1.0760	1.2683	1.4631
250	0.9992	0.9960	0.9924	0.9857	0.9741	0.9655	0.9604	0.9589	1.0048	1.1143	1.2501	1.3962
300	0.9998	0.9990	0.9983	0.9971	0.9964	0.9973	1.0000	1.0052	1.0559	1.1422	1.2480	1.3629
350	1.0001	1.0007	1.0011	1.0029	1.0069	1.0125	1.0189	1.0271	1.0810	1.1560	1.2445	1.3405
400	1.0002	1.0011	1.0024	1.0057	1.0125	1.0199	1.0283	1.0377	1.0926	1.1609	1.2382	1.3216
450	1.0003	1.0018	1.0033	1.0073	1.0153	1.0238	1.0332	1.0430	1.0973	1.1606	1.2303	1.3043
500	1.0004	1.0020	1.0040	1.0081	1.0167	1.0257	1.0350	1.0451	1.0984	1.1575	1.2213	1.2881
600	1.0004	1.0021	1.0040	1.0084	1.0173	1.0263	1.0355	1.0450	1.0951	1.1540	1.2028	1.2657
800	1.0004	1.0017	1.0036	1.0074	1.0157	1.0237	1.0320	1.0402	1.0832	1.1264	1.1701	1.2140
1000	1.0003	1.0015	1.0034	1.0067	1.0136	1.0205	1.0275	1.0347	1.0714	1.1078	1.1449	1.1814

Compressibility factor Z of oxygen**												
	Pressure, bar											
T (K)	1	5	10	20	40	60	80	100	200	300	400	500
75	0.0043	0.0213	0.0425	0.0849	0.1693	0.2533	0.3368	0.4200	0.8301	1.2322	1.6278	2.0175
80	0.0041	0.0203	0.0406	0.0811	0.1616	0.2418	0.3214	0.4007	0.7912	1.1738	1.5495	1.9196
90	0.0038	0.0188	0.0376	0.0750	0.1494	0.2233	0.2966	0.3696	0.7281	1.0780	1.4211	1.7580
100	0.9757	0.0177	0.0354	0.0705	0.1404	0.2096	0.2783	0.3464	0.6798	1.0040	1.3206	1.6309
120	0.9855	0.9246	0.8367	0.0660	0.1302	0.1935	0.2558	0.3173	0.6148	0.8999	1.1762	1.4456
140	0.9911	0.9535	0.9034	0.7852	0.1334	0.1940	0.2527	0.3099	0.5815	0.8374	1.0832	1.3214
160	0.9939	0.9697	0.9379	0.8689	0.6991	0.3725	0.2969	0.3378	0.5766	0.8058	1.0249	1.2364
180	0.9960	0.9793	0.9579	0.9134	0.8167	0.7696	0.5954	0.5106	0.6043	0.8025	0.9990	1.1888
200	0.9970	0.9853	0.9705	0.9399	0.8768	0.8140	0.7534	0.6997	0.6720	0.8204	0.9907	1.1623
250	0.9987	0.9938	0.9870	0.9736	0.9477	0.9237	0.9030	0.8858	0.8563	0.9172	1.0222	1.1431
300	0.9994	0.9968	0.9941	0.9884	0.9771	0.9676	0.9597	0.9542	0.9560	0.9972	1.0689	1.1572
350	0.9998	0.9990	0.9979	0.9961	0.9919	0.9890	0.9870	0.9870	1.0049	1.0451	1.1023	1.1722
400	1.0000	1.0000	1.0000	1.0000	1.0003	1.0011	1.0022	1.0045	1.0305	1.0718	1.1227	1.1816
450	1.0002	1.0007	1.0015	1.0024	1.0048	1.0074	1.0106	1.0152	1.0445	1.0859	1.1334	1.1859
500	1.0002	1.0011	1.0022	1.0038	1.0075	1.0115	1.0161	1.0207	1.0523	1.0927	1.1380	1.1866
600	1.0003	1.0014	1.0024	1.0052	1.0102	1.0153	1.0207	1.0266	1.0582	1.0961	1.1374	1.1803
800	1.0003	1.0014	1.0026	1.0055	1.0109	1.0164	1.0219	1.0271	1.0565	1.0888	1.1231	1.1582
1000	1.0003	1.0013	1.0026	1.0053	1.0101	1.0149	1.0198	1.0253	1.0507	1.0783	1.1072	1.1369

Compressibility factor Z of propylene††													
	Pressure, bar												
T (K)	1	5	10	20	40	60	80	100	200	400	600	800	1000
200	0.004	0.008	0.039	0.079	0.157	0.236	—	—	—	—	—	—	—
250	0.975	0.018	0.035	0.070	0.139	0.207	—	—	—	—	—	—	—
300	0.986	0.927	0.840	0.067	0.132	0.195	—	—	—	—	—	—	—
350	0.992	0.957	0.909	0.623	0.148	0.207	—	—	—	—	—	—	—
400	0.995	0.972	0.943	0.881	0.715	0.563	0.405	0.399	0.611	1.058	1.478	1.878	2.265
450	0.996	0.979	0.962	0.922	0.829	0.759	0.678	0.616	0.667	1.044	1.420	1.781	2.129

Compressibility factor Z of water substance											
	Pressure, bar										
T (K)	1	5	10	15	20	25	30	40	50	60	80
400	0.990	0.003	0.006	0.009	0.012	0.014	0.017	0.023	0.029	0.035	0.046
450	0.993	0.003	0.006	0.009	0.012	0.014	0.016	0.022	0.027	0.033	0.043
500	0.996	0.980	0.958	0.930	0.901	0.878	0.016	0.021	0.026	0.031	0.042
550	0.997	0.985	0.969	0.956	0.939	0.922	0.904	0.865	0.822	0.773	0.042
600	0.998	0.990	0.979	0.970	0.961	0.948	0.935	0.910	0.885	0.858	0.798
650	0.999	0.992	0.984	0.977	0.968	0.959	0.958	0.937	0.919	0.902	0.864
700	1.000	0.994	0.988	0.984	0.976	0.967	0.966	0.952	0.941	0.929	0.900
750	1.000	0.996	0.991	0.988	0.981	0.975	0.971	0.961	0.955	0.945	0.927
800	1.000	0.997	0.993	0.991	0.985	0.982	0.976	0.970	0.966	0.957	0.945
850	1.000	0.997	0.995	0.992	0.989	0.984	0.981	0.977	0.973	0.967	0.957
900	1.000	0.998	0.997	0.993	0.992	0.989	0.986	0.982	0.979	0.974	0.965
950	1.000	0.998	0.997	0.994	0.994	0.993	0.991	0.985	0.983	0.980	0.973
1000	1.000	0.999	0.998	0.995	0.995	0.994	0.993	0.990	0.987	0.985	0.978
1200	1.000	1.000	0.999	0.998	0.998	0.997	0.997	0.995	0.994	0.994	0.992
1400	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.998	0.998	0.998
1600	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1800	1.001	1.001	1.001	1.000	1.000	1.000	1.000	1.000	1.000	1.001	1.002
2000	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.003	1.003

* Calculated from values of pressure, volume (or density), and temperature in A. A. Vasserman, Y. Z. Kazavchinskii, and V. A. Rabinovich, *Thermophysical Properties of Air and Air Components,* Nauka, Moscow, 1966, and NBS-NSF Trans. TT 70-50095, 1971; and A. A. Vasserman and V. A. Rabinovich, *Thermophysical Properties of Liquid Air and Its Components,* Moscow, 1968, and NBS-NSF Trans. 69-55092, 1970.

† Calculated from *P-v-T* values tabulated in A. A. Vasserman and V. A. Rabinovich, *Thermophysical Properties of Liquid Air and Its Components,* Israeli Program for Scientific Translations TT 69-55092, 235 pp., 1970; A. A. Vasserman, Y. Z. Kazavchinskii, and V. A. Rabinovich, *Thermophysical Properties of Air and Air Components,* IPST TT 70-50095, 383 pp., 1971.

‡ Calculated from density-pressure-temperature data in Vukalovitch and Altunin, *Thermophysical Properties of Carbon Dioxide,* Atomizdat, Moscow, 1965, and Collet's, London, 1968, trans.

§ Computed from pressure-volume-temperature tables in Zagoruchenko and Zhuravlev, *Thermophysical Properties of Gaseous and Liquid Methane,* Moscow, 1969, and NBS-NSF TT 70-50097, 1970 translation.

¶ Computed from tables in A. A. Vasserman, Y. Z. Kazavchinskii, and V. A. Rabinovich, *Thermophysical Properties of Air and Air Components,* Nauka, Moscow, 1966, and NBS-NSF Trans. TT 70-50095, 1971.

** Computed from tables in A. A. Vasserman, Y. Z. Kazavchinskii, and V. A. Rabinovich, *Thermophysical Properties of Air and Air Components,* Nauka, Moscow, 1966, and NBS-NSF Trans. TT 70-50095, 1971.

†† Calculated from *P-v-T* tables of D. M. Vashchenko, Y. F. Voinov, et al., Standartov, Moscow, Monograph 8, 1971; NBS IR 75-763, NTIS COM-75-11276, 203 pp., 1972; republished 1975.

Table 2.12 Isobaric Specific Heats to High Temperatures

T (K)	Ar	CCl_2F_2	CH_4	CH_3OH	CO	CO_2	H_2	H_2O	He	N_2	NH_3	NO	N_2O	O_2	SO_2	Air*	T (K)
100	2.500	4.780	4.000	4.323	3.501	3.512	—	4.006	2.500	3.500	4.003	3.886	3.530	3.501	4.032	3.5824	100

T (K)	Ar	CCl F	CH	CH OH	CO	CO	H	H O	He	N	NH	NO	N O	O	SO	Air*	T (K)
200	2.5 00	7.0 21	4.0 26	4.8 30	3.5 01	3.8 81	—	4.0 10	2.5 00	3.5 01	4.0 58	3.6 59	4.0 43	3.5 03	4.3 75	3.5 062	200
300	2.5 00	8.7 21	4.2 95	5.5 31	3.5 05	4.4 60	—	4.0 40	2.5 00	3.5 03	4.2 81	3.5 90	4.6 55	3.5 34	4.8 03	3.5 059	300
400	2.5 00	9.9 00	4.8 71	6.5 30	3.5 29	4.9 52	—	4.1 20	2.5 00	3.5 18	4.6 22	3.6 02	5.1 34	3.6 21	5.2 29	3.5 333	400
500	2.5 00	10. 706	5.5 74	7.5 63	3.5 83	5.3 46	3.5 20	4.2 36	2.5 00	3.5 58	5.0 00	3.6 67	5.5 15	3.7 39	5.6 00	3.5 882	500
600	2.5 00	11. 258	6.2 82	8.5 02	3.6 61	5.6 69	3.5 27	4.3 68	2.5 00	3.6 21	5.3 76	3.7 58	5.8 28	3.8 60	5.8 97	3.6 626	600
700	2.5 00	11. 644	6.9 51	9.3 27	3.7 49	5.9 38	3.5 40	4.5 08	2.5 00	3.6 99	5.7 38	3.8 53	6.0 88	3.9 67	6.1 27	3.7 455	700
800	2.5 00	11. 920	7.5 69	10. 051	3.8 37	6.1 63	3.5 62	4.6 56	2.5 00	3.7 81	6.0 84	3.9 42	6.3 05	4.0 57	6.3 04	3.8 28	800
900	2.5 00	12. 122	8.1 31	10. 686	3.9 18	6.3 51	3.5 93	4.8 08	2.5 00	3.8 60	6.4 13	4.0 21	6.4 86	4.1 32	6.4 41	3.9 06	900
100 0	2.5 00	12. 274	8.6 35	11. 245	3.9 91	6.5 09	3.6 32	4.9 62	2.5 00	3.9 32	6.7 22	4.0 89	6.6 38	4.1 94	6.5 50	3.9 79	100 0
110 0	2.5 00	12. 391	9.0 84	11. 735	4.0 54	6.6 43	3.6 77	5.1 14	2.5 00	3.9 98	7.0 10	4.1 47	6.7 65	4.2 46	6.6 36	4.0 46	110 0
120 0	2.5 00	12. 482	9.4 82	12. 165	4.1 10	6.7 56	3.7 26	5.2 62	2.5 00	4.0 56	7.2 75	4.1 97	6.8 72	4.2 90	6.7 07	4.1 09	120 0
130 0	2.5 00	12. 555	9.8 32	12. 543	4.1 58	6.8 52	3.7 77	5.4 04	2.5 00	4.1 07	7.5 17	4.2 39	6.9 62	4.3 28	6.7 65	4.1 71	130 0
140 0	2.5 00	12. 613	10. 140	12. 875	4.1 99	6.9 34	3.8 29	5.5 38	2.5 00	4.1 51	7.7 37	4.2 75	7.0 40	4.3 63	6.8 14	4.2 30	140 0
150 0	2.5 00	12. 661	10. 410	13. 167	4.2 35	7.0 04	3.8 80	5.6 63	2.5 00	4.1 90	7.9 35	4.3 06	7.1 07	4.3 95	6.8 55	4.2 89	150 0
160 0	2.5 00	12. 700	10. 649	13. 424	4.2 66	7.0 65	3.9 31	5.7 80	2.5 00	4.2 24	8.1 13	4.3 33	7.1 64	4.4 26	6.8 91	4.3 52	160 0
170 0	2.5 00	12. 734	10. 859	13. 650	4.2 94	7.1 18	3.9 79	5.8 87	2.5 00	4.2 54	8.2 74	4.3 56	7.2 15	4.4 55	6.9 22	4.4 18	170 0
180 0	2.5 00	12. 762	11. 044	13. 851	4.3 18	7.1 64	4.0 26	5.9 87	2.5 00	4.2 81	8.4 19	4.3 77	7.2 60	4.4 83	6.9 50	4.4 87	180 0
190 0	2.5 00	12. 785	11. 208	14. 029	4.3 39	7.2 05	4.0 70	6.0 79	2.5 00	4.3 04	8.5 49	4.3 95	7.2 99	4.5 11	6.9 75	4.5 66	190 0
200 0	2.5 00	12. 806	11. 354	14. 187	4.3 58	7.2 42	4.1 12	6.1 64	2.5 00	4.3 25	8.6 67	4.4 11	7.3 35	4.5 39	6.9 97	4.6 62	200 0

T (K)	Ar	CCl F	CH	CH OH	CO	CO	H	H O	He	N	NH	NO	N O	O	SO	Air*	T (K)
2100	2.500	12.823	11.483	14.328	4.375	7.274	4.152	6.242	2.500	4.344	8.773	4.425	7.367	4.567	7.017	4.781	2100
2200	2.500	12.839	11.599	14.454	4.390	7.303	4.189	6.314	2.500	4.360	8.869	4.438	7.395	4.594	7.036	4.947	2200
2300	2.500	12.852	11.703	14.567	4.404	7.329	4.224	6.381	2.500	4.375	8.956	4.450	7.422	4.621	7.053	5.179	2300
2400	2.500	12.864	11.796	14.668	4.416	7.353	4.257	6.443	2.500	4.389	9.035	4.461	7.446	4.647	7.069	5.484	2400
2500	2.500	12.875	11.880	14.760	4.427	7.375	4.288	6.500	2.500	4.401	9.107	4.471	7.468	4.673	7.084	5.882	2500
2600	2.500	12.884	11.955	14.843	4.437	7.395	4.318	6.553	2.500	4.413	9.172	4.480	7.488	4.699	7.099	6.400	2600
2700	2.500	12.892	12.024	14.918	4.447	7.413	4.346	6.603	2.500	4.423	9.232	4.489	7.508	4.724	7.112	7.056	2700
2800	2.500	12.900	12.086	14.987	4.456	7.430	4.372	6.649	2.500	4.433	9.287	4.497	7.526	4.748	7.125	7.887	2800
2900	2.500	12.906	12.143	15.049	4.464	7.445	4.397	6.692	2.500	4.442	9.338	4.504	7.542	4.771	7.137	8.866	2900
3000	2.500	12.913	12.194	15.106	4.471	7.460	4.421	6.733	2.500	4.450	9.384	4.511	7.558	4.794	7.149	9.966	3000
3100	2.500	12.918	12.242	15.158	4.478	7.474	4.444	6.771	2.500	4.457	9.427	4.518	7.573	4.816	7.160	—	3100
3200	2.500	12.923	12.285	15.206	4.485	7.486	4.465	6.807	2.500	4.464	9.467	4.524	7.588	4.837	7.171	—	3200
3300	2.500	12.928	12.325	15.250	4.491	7.499	4.486	6.841	2.500	4.471	9.504	4.530	7.601	4.858	7.182	—	3300
3400	2.500	12.932	12.361	15.290	4.497	7.510	4.505	6.873	2.500	4.477	9.538	4.535	7.614	4.877	7.192	—	3400
3500	2.500	12.936	12.395	15.327	4.502	7.521	4.524	6.903	2.500	4.483	9.570	4.541	7.627	4.896	7.202	—	3500
3600	2.500	12.939	12.427	15.362	4.508	7.531	4.542	6.932	2.500	4.489	9.600	4.546	7.639	4.913	7.212	—	3600
3700	2.500	12.942	12.455	15.394	4.513	7.541	4.559	6.960	2.500	4.494	9.628	4.551	7.651	4.930	7.222	—	3700
3800	2.500	12.945	12.482	15.424	4.517	7.550	4.576	6.986	2.500	4.499	9.654	4.556	7.662	4.946	7.231	—	3800
3900	2.500	12.948	12.507	15.451	4.522	7.559	4.592	7.011	2.500	4.504	9.678	4.560	7.673	4.961	7.240	—	3900

T (K)	Ar	CClF	CH	CHOH	CO	CO	H	H O	He	N	NH	NO	N O	O	SO	Air*	T (K)
4000	2.500	12.951	12.530	15.477	4.526	7.568	4.608	7.035	2.500	4.508	9.701	4.565	7.683	4.976	7.250	—	4000
4100	2.500	12.953	12.552	15.501	4.531	7.576	4.623	7.058	2.500	4.513	9.723	4.569	7.694	4.989	7.259	—	4100
4200	2.500	12.955	12.572	15.523	4.535	7.584	4.637	7.080	2.500	4.517	9.743	4.573	7.704	5.002	7.267	—	4200
4300	2.500	12.957	12.591	15.544	4.538	7.592	4.651	7.102	2.500	4.521	9.763	4.577	7.714	5.015	7.276	—	4300
4400	2.500	12.959	12.609	15.564	4.542	7.599	4.665	7.122	2.500	4.525	9.781	4.581	7.723	5.026	7.285	—	4400
4500	2.500	12.961	12.625	15.582	4.546	7.606	4.678	7.142	2.500	4.528	9.798	4.585	7.733	5.037	7.293	—	4500
4600	2.500	12.963	12.641	15.599	4.549	7.614	4.691	7.161	2.500	4.532	9.815	4.589	7.742	5.048	7.302	—	4600
4700	2.500	12.964	12.655	15.616	4.553	7.620	4.704	7.180	2.500	4.535	9.831	4.593	7.751	5.058	7.310	—	4700
4800	2.500	12.966	12.669	15.631	4.556	7.627	4.717	7.198	2.500	4.539	9.845	4.596	7.760	5.068	7.319	—	4800
4900	2.500	12.967	12.682	15.645	4.559	7.634	4.729	7.216	2.500	4.542	9.860	4.600	7.769	5.078	7.327	—	4900
5000	2.500	12.968	12.694	15.659	4.563	7.640	4.740	7.233	2.500	4.545	9.873	4.604	7.778	5.087	7.335	—	5000

All table values are for the dimensionless ratio c_p/R, where R is the gas constant. To obtain values of c_p, multiply the tabular values by the appropriate gas constant. Thus, for specific heats in units of kJ(kg mol)(K), multiply by 8.31434; for specific heats in Btu/(lb mol)(°R), multiply by 1.986, etc.

* Data for air from "Tables of Thermal Properties of Gases," U.S. Department of Commerce, National Bureau of Standards, Circular 564, 1955.

Source: R. A. Svehla, "Estimated Viscosities and Thermal Conductivities at High Temperatures," *NASA Tech. Rep.* R-132, 1962.

Table 2.13 Thermophysical Properties of Selected Gases

Substance	Data	Property (at low pressure)	T (°C) –150	–100	–50	0	25	100	200	300	400	600	800	1 000	1 200
			T (K) 123.15	173.15	223.15	273.15	298.15	373.15	473.15	573.15	673.15	873.15	1 073.15	1 273.15	1 473.15
Acetone	Chemical formula: C_3H_6O Molecular weight: 58.08 Normal density (at 0°C, 101.3 kPa): 2.59 kg/m³ Boiling point: 56.1°C Critical temperature: 235.0°C Critical pressure: 4.761 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	L	L	L	1.557	1.838	2.093	2.311	2.659	2.906	3.098	3.006
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	L	L	L	0.018	(0.027)	(0.038)	(0.051)	(0.076)	—	—	—
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	L	L	L	0.931	1.21	1.46	1.72	2.20	2.64	3.05	3.42
Acetylene	Chemical formula: C_2H_2 Molecular weight: 26.04 Normal density (at 0°C, 101.3 kPa): 1.17 kg/m³ Boiling point: –83.95°C Critical temperature: 35.55°C Critical pressure: 6.24 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	1.503	1.616	1.687	1.871	2.047	2.177	2.286	2.462	2.613	2.734	2.834
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	0.013	0.018	0.021	0.030	0.042	0.053	0.066	0.087	0.107	0.125	0.143
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	0.785	0.960	1.04	1.28	1.55	1.83	2.08	2.53	2.93	3.30	3.65
Ammonia	Chemical formula: NH_3 Molecular weight: 17.03 Normal density (at 0°C, 101.3 kPa): 0.76 kg/m³ Boiling point: –33.4°C Critical temperature: 132.4°C Critical pressure: 11.29 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	L	2.056	2.093	2.219	2.366	2.516	2.663	2.805	3.538	4.099	4.509
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	L	0.022	0.024	0.033	0.047	0.067	0.088	0.109	0.209	0.304	0.388
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	L	0.930	1.00	1.28	1.65	1.99	2.34	2.67	4.16	5.40	6.49
Benzene	Chemical formula: C_6H_6 Molecular weight: 78.11 Normal density (at 0°C, 101.3 kPa): 3.49 kg/m³ Boiling point: 80.1°C Critical temperature: 289.45°C Critical pressure: 4.924 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	S	L	L	1.336	1.679	1.959	2.186	2.525	2.767	2.943	3.077
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	S	L	L	0.020	0.030	(0.036)	(0.047)	(0.070)	(0.092)	(0.112)	(0.130)
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	S	L	L	0.951	1.20	1.45	(1.65)	(2.10)	(2.53)	(2.95)	(3.35)

S, solid; L, liquid; values in parentheses are estimated values.

Substance	Data	Property (at low pressure)	T (°C) –150	–100	–50	0	25	100	200	300	400	600	800	1 000	1 200
			T (K) 123.15	173.15	223.15	273.15	298.15	373.15	473.15	573.15	673.15	873.15	1 073.15	1 273.15	1 473.15
Bromine	Chemical formula: Br_2	Specific heat capacity	S	S	S	L	L	0.227	0.229	0.230	0.231	0.232	0.234	0.235	0.237
	Molecular weight: 159.81	$c_{p,g}$ (kJ/kg K)													
	Normal density (at 0°C,														
	101.3 kPa): 7.13 kg/m³	Thermal conductivity	S	S	S	L	L	0.006	0.007	0.009	0.011	0.013	0.021	0.026	0.032
	Boiling point: 58.75°C	λ_g [(W/m²)/(K/m)]													
	Critical temperature:														
	310.85°C	Dynamic viscosity	S	S	S	L	L	1.88	2.37	2.92	3.40	3.87	5.98	7.73	9.25
	Critical pressure: 10.34 MPa	η_g (10^{-5} Ns/m²)													
Carbon Tetra-chloride	Chemical formula: CCL_4	Specific heat capacity	S	S	S	L	L	0.586	0.624	0.645	0.657	0.670	0.691	0.696	0.699
	Molecular weight: 153.82	$c_{p,g}$ (kJ/kg K)													
	Normal density (at 0°C,														
	101.3 kPa): 6.87 kg/m³	Thermal conductivity	S	S	S	L	L	0.009	0.012	0.015	0.019	0.021	0.032	0.041	0.049
	Boiling point: 76.7°C	λ_g [(W/m²)/(K/m)]													
	Critical temperature:														
	283.2°C	Dynamic viscosity	S	S	S	L	L	1.23	1.53	1.83	2.12	2.38	3.45	4.35	5.15
	Critical pressure: 4.56 MPa	η_g (10^{-5} Ns/m²)													
Chlorine	Chemical formula: Cl_2	Specific heat capacity	S	L	L	0.473	0.477	0.494	0.507	0.515	0.523	0.528	0.536	0.544	0.548
	Molecular weight: 70.91	$c_{p,g}$ (kJ/kg K)													
	Normal density (at 0°C,														
	101.3 kPa): 3.16 kg/m³	Thermal conductivity	S	L	L	0.008	0.009	0.012	0.015	0.018	0.021	0.024	0.035	0.045	0.054
	Boiling point: –34.04°C	λ_g [(W/m²)/(K/m)]													
	Critical temperature:														
	144.0°C	Dynamic viscosity	S	L	L	1.23	1.34	1.68	2.10	2.50	2.86	3.22	4.68	5.90	6.99
	Critical pressure: 7.710 MPa	η_g (10^{-5} Ns/m²)													
Ethanol	Chemical formula: C_2H_6O	Specific heat capacity	S	L	L	L	L	1.825	2.114	2.370	2.596	2.964	3.245	3.458	3.622
	Molecular weight: 46.07	$c_{p,g}$ (kJ/kg K)													
	Normal density (at 0°C,														
	101.3 kPa): 2.06 kg/m³	Thermal conductivity	S	L	L	L	L	0.023	0.039	0.047	(0.059)	(0.079)	—	—	—
	Boiling point: 78.31°C	λ_g [(W/m²)/(K/m)]													
	Critical temperature:														
	243.1°C	Dynamic viscosity	S	L	L	L	L	1.09	1.38	1.65	1.88	2.36	2.78	3.17	3.52
	Critical pressure: 6.39 MPa	η_g (10^{-5} Ns/m²)													

Ethylene	Chemical formula: C_2H_4 Molecular weight: 28.05 Normal density (at 0°C, 101.3 kPa): 1.26 kg/m³ Boiling point: −103.72°C Critical temperature: 9.50°C Critical pressure: 5.06 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	L	1.654	1.319	1.461	1.553	1.830	2.177	2.479	2.738	3.157	3.475	3.722	3.910
		Thermal conductivity λ_g [(W/m²)/(K/m)]	L	0.009	0.013	0.017	0.021	0.031	0.044	0.060	0.075	0.106	0.136	0.162	0.188
		Dynamic viscosity η_g (10^{-5} Ns/m²)	L	0.592	0.770	0.939	1.02	1.27	1.55	1.78	2.01	2.44	2.79	3.07	3.45
Ethylene Glycol	Chemical formula: $C_2H_6O_2$ Molecular weight: 62.07 Normal density (at 0°C, 101.3 kPa): 2.77 kg/m³ Boiling point: 197.25°C Critical temperature: 371.85°C Critical pressure: 7.7 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	S	L	L	L	(1.826)	(2.057)	(2.260)	(2.590)	—	—	—
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	S	L	L	L	(0.029)	(0.040)	(0.052)	(0.076)	—	—	—
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	S	L	L	L	(1.31)	(1.59)	(1.86)	(2.35)	—	—	—

			T (°C)												
			−150	−100	−50	0	25	100	200	300	400	500	1 000	1 500	2 000
Substance	Data	Property (at low pressure)	T (K) 123.15	173.15	223.15	273.15	298.15	373.15	473.15	573.15	673.15	773.15	1 273.15	1 773.15	2 273.15
Fluorine	Chemical formula: F_2 Molecular weight: 38.00 Normal density (at 0°C, 101.3 kPa): 1.70 kg/m³ Boiling point: −187.95°C Critical temperature: −129.15°C Critical pressure: 5.32 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	0.766	0.755	0.795	0.816	0.825	0.862	0.904	0.921	0.938	0.950	0.988	1.001	1.009
		Thermal conductivity λ_g [(W/m²)/(K/m)]	0.010	0.015	0.020	0.024	0.027	0.033	0.040	0.047	0.053	0.060	0.091	0.115	0.137
		Dynamic viscosity η_g (10^{-5} Ns/m²)	0.890	1.25	1.56	2.09	2.42	2.79	3.30	3.90	4.37	4.81	7.67	10.3	12.5
Glycerol	Chemical formula: $C_3H_8O_3$ Molecular weight: 92.09 Normal density (at 0°C, 101.3 kPa): 4.11 kg/m³ Boiling point: 289.85°C Critical temperature: 452.85°C Critical pressure: 6.69 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	S	S	L	L	L	(2.15)	(2.29)	(2.53)	—	—	—
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	S	S	L	L	L	(0.030)	(0.040)	(0.062)	—	—	—
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	S	S	L	L	L	(1.42)	(1.66)	(2.16)	—	—	—

S, solid; L, liquid; values in parentheses are estimated values.

Substance	Data	Property (at low pressure)	T (°C) −150	−100	−50	0	25	100	200	300	400	500	1 000	1 500	2 000
			T (K) 123.15	173.15	223.15	273.15	298.15	373.15	473.15	573.15	673.15	773.15	1 273.15	1 773.15	2 273.15
Heptane	Chemical formula: C_7H_{16} Molecular weight: 100.20 Normal density (at 0°C, 101.3 kPa): 4.47 kg/m³ Boiling point: 98.45°C Critical temperature: 267.46°C Critical pressure: 2.736 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	L	L	L	2.026	2.437	2.793	3.070	3.571	3.936	4.212	4.417
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	L	L	L	0.017	0.029	0.041	0.054	0.080	0.104	0.124	(0.142)
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	L	L	L	0.76	0.95	1.14	1.32	1.65	1.97	2.26	(2.55)
Hexane	Chemical formula: C_6H_{14} Molecular weight: 86.18 Normal density (at 0°C, 101.3 kPa): 3.85 kg/m³ Boiling point: 68.73°C Critical temperature: 234.29°C Critical pressure: 3.031 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	L	L	L	2.026	2.441	2.801	3.120	3.583	3.957	4.237	4.446
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	L	L	L	0.019	0.030	0.043	0.056	0.084	0.109	0.132	(0.152)
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	L	L	L	0.822	1.04	1.23	1.48	1.90	2.12	2.40	2.66
Methanol	Chemical formula: CH_4O Molecular weight: 32.04 Normal density (at 0°C, 101.3 kPa): 1.43 kg/m³ Boiling point: 64.7°C Critical temperature: 240°C Critical pressure: 7.95 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	L	L	L	1.595	1.823	2.064	2.273	2.629	3.01	3.23	3.40
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	L	L	L	0.026	0.045	0.055	0.071	0.104	0.136	0.167	0.197
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	L	L	L	1.22	1.56	1.89	2.20	2.79	3.33	3.82	4.28

Substance	Data	Property (at low pressure)	T (°C) −150	−100	−50	0	25	100	200	300	400	600	800	1 000	1 200
			T (K) 123.15	173.15	223.15	273.15	298.15	373.15	473.15	573.15	673.15	873.15	1 073.15	1 273.15	1 473.15
Ketene	Chemical formula: C_2H_2O Molecular weight: 42.04 Normal density (at 0°C, 101.3 kPa): 1.88 kg/m³ Boiling point: −41.15°C Critical temperature: 106.85°C Critical pressure: 6.48 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	L	L	1.093	1.143	1.290	1.461	1.599	1.717	1.905	2.043	2.148	2.227
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	L	L	(0.015)	(0.017)	(0.024)	(0.034)	(0.045)	(0.055)	(0.070)	—	—	—
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	L	L	(1.05)	(1.15)	(1.43)	(1.78)	(2.10)	(2.40)	(2.94)	—	—	—

Krypton	Chemical formula: Kr Molecular weight: 83.80 Normal density (at 0°C, 101.3 kPa): 3.74 kg/m³ Boiling point: −153.35°C Critical temperature: −63.755°C Critical pressure: 5.502 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.247
		Thermal conductivity λ_g [(W/m²)/(K/m)]	0.004	0.006	0.007	0.009	0.010	0.012	0.014	0.016	0.018	0.021	0.030	0.035	0.041
		Dynamic viscosity η_g (10^{-5} Ns/m²)	1.05	1.49	1.91	2.33	2.52	3.06	3.74	4.38	4.91	5.39	7.55	9.39	11.02
Nitric Oxide	Chemical formula: NO Molecular weight: 30.01 Normal density (at 0°C, 101.3 kPa): 1.34 kg/m³ Boiling point: −151.75°C Critical temperature: −93.15°C Critical pressure: 6.48 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	0.971	0.971	0.971	0.971	0.971	0.980	1.005	1.030	1.059	1.089	1.176	1.218	1.239
		Thermal conductivity λ_g [(W/m²)/(K/m)]	0.013	0.018	0.021	0.024	0.026	0.031	0.038	0.046	0.053	0.059	0.088	0.113	0.135
		Dynamic viscosity η_g (10^{-5} Ns/m²)	0.85	1.21	1.49	1.79	1.92	2.27	2.68	3.12	3.47	3.85	5.29	6.55	7.72
Nitrogen Dioxide	Chemical formula: NO_2 Molecular weight: 46.01 Normal density (at 0°C, 101.3 kPa): 2.05 kg/m³ Boiling point: 21.1°C Critical temperature: 158.2°C Critical pressure: 10.13 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	S	L	0.808	0.858	0.929	0.984	1.034	1.080	1.193	1.256	1.281
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	S	L	1.18	0.065	0.033	0.040	0.047	0.055	0.085	—	—
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	S	L	(1.49)	1.84	2.26	2.65	2.99	3.32	4.55	—	—
Neon	Chemical formula: Ne Molecular weight: 20.18 Normal density (at 0°C, 101.3 kPa): 0.90 kg/m³ Boiling point: −246.06°C Critical temperature: −228.75°C Critical pressure: 2.654 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
		Thermal conductivity λ_g [(W/m²)/(K/m)]	0.027	0.034	0.041	0.046	0.049	0.057	0.067	0.077	0.087	0.097	0.132	0.154	0.180
		Dynamic viscosity η_g (10^{-5} Ns/m²)	1.67	2.14	2.58	2.99	3.12	3.65	4.26	4.89	5.32	5.81	7.81	9.95	11.68
Pentane	Chemical formula: C_5H_{12} Molecular weight: 72.15 Normal density (at 0°C, 101.3 kPa): 3.22 kg/m³ Boiling point: 36.05°C Critical temperature: 196.45°C Critical pressure: 3.369 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	L	L	L	L	2.026	2.445	2.809	3.115	3.613	3.990	4.275	4.488
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	L	L	L	L	0.021	0.034	0.047	0.061	0.090	0.117	0.142	(0.162)
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	L	L	L	L	0.860	1.09	1.29	1.49	1.85	2.17	2.46	2.74

S, solid; L, liquid; values in parentheses are estimated values.

Substance	Data	Property (at low pressure)	T (°C) –150	–100	–50	0	25	100	200	300	400	600	800	1 000	1 200
			T (K) 123.15	173.15	223.15	273.15	298.15	373.15	473.15	573.15	673.15	873.15	1 073.15	1 273.15	1 473.15
Propylene	Chemical formula: C_3H_6 Molecular weight: 42.08 Normal density (at 0°C, 101.3 kPa): 1.90 kg/m³ Boiling point: –47.7°C Critical temperature: 91.65°C Critical pressure: 4.61 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	L	L	L	1.424	1.520	1.800	2.160	2.479	2.755	3.203	3.542	3.802	3.998
		Thermal conductivity λ_g [(W/m²)/(K/m)]	L	L	L	0.014	0.017	0.026	0.039	0.054	0.069	0.099	0.127	0.155	0.180
		Dynamic viscosity η_g (10^{-5} Ns/m²)	L	L	L	0.780	0.860	1.07	1.34	1.59	1.82	2.23	2.62	2.97	3.29
Toluene	Chemical formula: C_7H_8 Molecular weight: 92.14 Normal density (at 0°C, 101.3 kPa): 4.11 kg/m³ Boiling point: 110.63°C Critical temperature: 320.85°C Critical pressure: 4.05 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	S	L	L	L	L	1.758	2.047	2.286	2.650	2.914	3.102	3.245
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	S	L	L	L	L	0.032	0.042	(0.052)	(0.072)	(0.092)	(0.112)	(0.130)
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	S	L	L	L	L	1.12	1.33	1.545	1.95	(2.33)	(2.68)	(3.01)
Xenon	Chemical formula: Xe Molecular weight: 131.30 Normal density (at 0°C, 101.3 kPa): 5.86 kg/m³ Boiling point: –108.15°C Critical temperature: 16.55°C Critical pressure: 5.822 MPa	Specific heat capacity $c_{p,g}$ (kJ/kg K)	S	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159	0.159
		Thermal conductivity λ_g [(W/m²)/(K/m)]	S	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.013	0.018	0.022	0.026
		Dynamic viscosity η_g (10^{-5} Ns/m²)	S	1.39	1.78	2.11	2.29	2.83	3.50	4.15	4.73	5.24	7.38	9.22	1.084

S, solid; L, liquid; values in parentheses are estimated values.
Source: Ref. 5 with permission.

Table 2.14 Fickian Diffusion Coefficients [(m^2/s) × 10^{-4}] at Atmospheric Pressure

T (K)	D_{ij}
Air–carbon dioxide [20]	
276.2	0.1420
317.2	0.1772
Ammonia-helium [23]	
274.2	0.668
308.2	0.783
331.1	0.881
Ammonia-neon [23]	
274.2	0.298
308.4	0.378
333.1	0.419
Ammonia-xenon [23]	
274.2	0.114
308.4	0.145
333.1	0.173
Argon-argon [7]	
77.5	0.0134
90	0.0180
194.5	0.0830
273	0.156
295	0.178
353	0.249
Argon-argon [12]	
273	0.156
293	0.175
303	0.186
318	0.204
Argon-helium [11]	
287.9	0.697
354.0	0.979
418.0	1.398
Argon-helium [12]	
273.0	0.640
288.0	0.701
303.0	0.760
318.0	0.825
Argon-xenon [12]	
273.0	0.0943
288.0	0.102
303.0	0.114
318.0	0.128
Argon-xenon [13]	
194.7	0.0508
273.2	0.0962
329.9	0.1366
378.0	0.1759
Carbon dioxide–argon [25]	
293	0.139

T (K)	D_{ij}
Carbon dioxide–argon [20]	
276.2	0.1326
317.2	0.1652
Nitrogen-nitrogen [7]	
77.5	0.0168
194.5	0.104
273	0.185
298	0.212
353	0.287
Nitrogen-xenon [17]	
242.2	0.0854
274.6	0.1070
303.45	0.1301
334.2	0.1549
Oxygen-argon [24]	
293.2	0.200
Oxygen-argon [16]	
243.2	0.135
274.7	0.168
304.5	0.202
334.0	0.239
Oxygen-helium [16]	
244.2	0.536
274.0	0.640
304.4	0.761
334.0	0.912
Oxygen-oxygen [7]	
77.5	0.0153
194.5	0.104
273	0.187
298	0.232
353	0.301
Oxygen-water [4]	
307.9	0.282
328.8	0.318
352.2	0.352
Oxygen-xenon [16]	
242.2	0.084
274.75	0.100
303.55	0.126
333.6	0.149
Water-air [3]	
289.9	0.244
365.6	0.357
372.5	0.377
Water–carbon dioxide [3]	
296.1	0.164
365.6	0.249
372.6	0.259

T (K)	D_{ij}
Water–carbon dioxide [4]	
307.5	0.202
328.6	0.211
352.4	0.245
Water-helium [4]	
307.2	0.902
328.5	1.011
352.5	1.121
Water-hydrogen [3]	
293.1	0.850
322.7	1.012
365.6	1.24
365.6	1.26
372.5	1.28
Hydrogen (trace)-oxygen [2]	
300	0.820
400	1.40
500	2.10
600	2.89
700	3.81
800	4.74
900	5.74
Hydrogen-neon [10]	
242.2	0.792
274.2	0.974
303.2	1.150
341.2	1.405
Hydrogen-xenon [10]	
242.2	0.410
274.2	0.508
303.9	0.612
341.2	0.751
Methane-methane [7]	
90	0.0266
194.5	0.0992
273	0.206
298	0.240
353	0.318
Methane-methane [21]	
298.2	0.235
353.6	0.315
382.6	0.360
Methane-water [4]	
307.5	0.292
328.6	0.331
352.1	0.356

T (K)	D_{ij}
Neon-argon [15]	
273.0	0.276
288.0	0.300
303.0	0.327
318.0	0.357
Neon-neon [7]	
77.5	0.0492
194.5	0.255
273	0.452
298	0.516
353	0.703
Neon-xenon [14]	
273.0	0.186
288.0	0.202
303.0	0.221
318.0	0.244
Nitrogen-argon [17]	
244.2	0.1348
274.6	0.1689
303.55	0.1999
334.7	0.2433
Nitrogen-helium [17]	
243.2	0.477
275.0	0.596
303.55	0.719
332.5	0.811
Helium-nitrogen (20% N_2) [27]	
190	0.305
298	0.712
300	0.738
305	0.747
310	0.740
320	0.812
330	0.857
340	0.881
350	0.946
360	0.967
370	1.035
380	1.051
390	1.107
400	1.157
Helium-nitrogen (50% N_2) [27]	
190	0.310
298	0.725
300	0.751
305	0.758

Note: See page 2.25 for footnotes and references.

T (K)	D_{ij}
Helium-nitrogen (50% N_2) [27] (Continued)	
310	0.759
320	0.827
330	0.879
340	0.899
350	0.966
360	0.985
370	1.058
380	1.068
390	1.144
400	1.180
Helium-nitrogen (100% N_2 extrapolated) [27]	
190	0.317
298	0.740
300	0.766
305	0.774
310	0.775
320	0.845
330	0.902
340	0.921
350	0.989
360	1.013
370	1.086
380	1.094
390	1.168
400	1.210
Helium-oxygen (trace) [18]	
298	0.729
323	0.809
353	0.987
383	1.120
413	1.245
443	1.420
473	1.595
498	1.683
Helium-xenon [12]	
273.0	0.501
288.0	0.550
303.0	0.604
318.0	0.655
Hydrogen-argon [10]	
242.2	0.562
274.2	0.698
303.9	0.830
341.2	1.010
Hydrogen-argon [11]	
287.9	0.828
354.2	1.111
418.0	1.714

T (K)	D_{ij}
Hydrogen (trace)-argon [9]	
295	0.83
448	1.76
628	3.21
806	4.86
958	6.81
1069	8.10
Helium-argon (trace) [18]	
413	1.237
443	1.401
473	1.612
498	1.728
Helium (trace)-argon [8]	
300	0.76
400	1.26
500	1.86
600	2.56
700	3.35
800	4.23
900	5.20
1000	6.25
1100	7.38
Helium–carbon dioxide [20]	
276.2	0.5312
317.2	0.6607
346.2	0.7646
Helium–carbon dioxide (trace) [18]	
298	0.612
323	0.678
353	0.800
583	0.884
413	1.040
443	1.133
473	1.279
498	1.414
Helium–methyl alcohol (trace) [18]	
423	1.032
443	1.135
463	1.218
483	1.335
503	1.389
523	1.475
Helium-neon [14]	
273.0	0.906
288.0	0.986
303.0	1.065
318.0	1.158

T (K)	D_{ij}
Helium-nitrogen (trace) [18]	
298	0.687
323	0.766
353	0.893
383	1.077
413	1.200
443	1.289
473	1.569
498	1.650
Helium (trace)-nitrogen [1]	
300	0.743
400	1.21
500	1.76
600	2.40
700	3.11
800	3.90
900	4.76
1000	5.69
1200	7.74
Carbon dioxide–nitrogen (trace) [1]	
300	0.177
400	0.300
500	0.445
600	0.610
700	0.798
800	0.998
900	1.22
1000	1.47
1100	1.70
Carbon dioxide–nitrogen [26]	
295	0.159
1156	1.78
1158	1.92
1286	2.34
1333	2.26
1426	2.55
1430	2.72
1469	2.85
1490	2.92
1653	3.32
Carbon dioxide–nitrous oxide [19]	
194.8	0.0531
273.2	0.0996
312.8	0.1280
362.6	0.1683

T (K)	D_{ij}
Carbon dioxide–oxygen (trace) [2]	
300	0.160
400	0.270
500	0.400
600	0.565
700	0.740
800	0.928
900	1.14
1000	1.39
Carbon monoxide–carbon monoxide [22]	
194.7	0.109
273.2	0.190
319.6	0.247
373.0	0.323
Carbon monoxide–nitrogen [22]	
194.7	0.105
273.2	0.186
319.6	0.242
373.0	0.318
Carbon monoxide (trace)–oxygen [2]	
300	0.212
400	0.376
500	0.552
600	0.746
700	0.961
800	1.22
Helium-air [20]	
276.2	0.6242
317.2	0.7652
346.2	0.9019
Helium-argon [20]	
276.2	0.6460
317.2	0.7968
346.2	0.9244
Helium-argon (trace) [18]	
298	0.729
323	0.809
353	0.978
383	1.122
Carbon dioxide–argon [26]	
295	0.139
1181	1.88
1207	1.88
1315	2.38

T (K)	D_{ij}
Carbon dioxide–argon [26] (Continued)	
1368	2.59
1383	2.13
1427	2.53
1445	2.66
1495	2.65
1503	2.84
1538	3.08
1676	3.21
Carbon dioxide–carbon dioxide [7]	
194.7	0.0500
273	0.0907
298	0.113
353	0.153

T (K)	D_{ij}
Carbon dioxide–carbon dioxide [19]	
194.8	0.0516
273.2	0.0970
312.8	0.1248
362.6	0.1644
Carbon dioxide–carbon dioxide [5]	
233	0.0662
253	0.0794
274	0.0925
293	0.1087
313	0.1239
333	0.1395
363	0.1613
393	0.1876
423	0.2164
453	0.2477
483	0.2892

T (K)	D_{ij}
Carbon dioxide–carbon dioxide [6]	
296	0.109
298	0.109
1180	1.73
	1.84
1218	2.04
1330	2.38
1445	2.80
	2.86
1450	2.56
1487	2.88
1490	2.98
1520	2.78
1576	3.12
1580	3.33
1665	3.29
1680	3.50

T (K)	D_{ij}
Carbon dioxide–nitrogen [24]	
289	0.158
Water-hydrogen [4]	
307.3	1.020
328.6	1.121
352.7	1.200
Water-nitrogen [4]	
307.6	0.256
328.6	0.303
352.2	0.359
Xenon-xenon [13]	
194.7	0.0257
273.2	0.0480
293.0	0.0443
300.5	0.0576
329.9	0.0684
378.0	0.0900

All the D_{ij} values are in $(m^2/s) \times 10^{-4}$. For example, at 276.2 K the interdiffusion coefficient for the air–carbon dioxide mixture is 1.420×10^{-5} m^2/s.

For an extensive review with formula fits but no data tables, see Marrero and Mason, *J. Phys. Chem. Ref. Data,* **1**:3–118 (1972). Interpolation from a graph of log D_{ij} versus log T is often simple.

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2.3. THERMOPHYSICAL PROPERTIES OF LIQUIDS

Table 2.15 Thermophysical Properties of Saturated Water and Steam

	Liquid				Steam			
T (°C)	$\eta \cdot 10^7$	$\lambda \cdot 10^3$	c_p	Pr	$\eta \cdot 10^7$	$\lambda \cdot 10^3$	c_p	Pr
0	17 525	569	4.217	12.99	80.4	17.6	1.864	0.85
10	12 992	586	4.193	9.30	84.5	18.2	1.868	0.87
20	10 015	602	4.182	6.96	88.5	18.8	1.874	0.88
30	7 970	617	4.179	5.40	92.6	19.4	1.883	0.90
40	6 513	630	4.179	4.32	96.6	20.1	1.894	0.91
50	5 440	643	4.181	3.54	100	20.9	1.907	0.92
60	4 630	653	4.185	2.97	105	21.6	1.924	0.94
70	4 005	662	4.190	2.54	109	22.3	1.944	0.95
80	3 510	669	4.197	2.20	113	23.1	1.969	0.96
90	3 113	675	4.205	1.94	117	23.9	1.999	0.98
100	2 790	680	4.216	1.73	121	24.8	2.034	0.99
110	2 522	683	4.229	1.56	124	25.8	2.075	1.00
120	2 300	685	4.245	1.43	128	26.7	2.124	1.02
130	2 110	687	4.263	1.31	132	27.8	2.180	1.04
140	1 950	687	4.285	1.22	135	28.8	2.245	1.05
150	1 810	686	4.310	1.14	139	30.0	2.320	1.08
160	1 690	684	4.339	1.07	142	31.3	2.406	1.09
170	1 585	681	4.371	1.02	146	32.6	2.504	1.12
180	1 493	676	4.408	0.97	149	34.1	2.615	1.14
190	1 412	671	4.449	0.94	153	35.7	2.741	1.17
200	1 338	664	4.497	0.91	156	37.5	2.883	1.20
210	1 273	657	4.551	0.88	160	39.4	3.043	1.24
220	1 215	648	4.614	0.86	163	41.5	3.223	1.27
230	1 162	639	4.686	0.85	167	43.9	3.426	1.30
240	1 114	629	4.770	0.85	171	46.5	3.656	1.34

	Liquid				Steam			
T (°C)	η · 10	λ · 10	c	Pr	η · 10	λ · 10	c	Pr
250	1 070	617	4.869	0.84	174	49.5	3.918	1.38
260	1 030	604	4.985	0.85	178	52.8	4.221	1.42
270	994	589	5.13	0.86	182	56.6	4.574	1.47
280	961	573	5.30	0.89	187	60.9	4.996	1.53
290	930	557	5.51	0.92	193	66.0	5.51	1.61
300	901	540	5.77	0.96	198	71.9	6.14	1.69
310	865	522	6.12	1.01	205	79.1	6.96	1.80
320	830	503	6.59	1.09	214	87.8	8.05	1.96
330	790	482	7.25	1.19	225	98.9	9.59	2.18
340	748	460	8.27	1.34	238	113	11.92	2.51
350	700	435	10.08	1.62	256	130	15.95	3.14
360	644	401	14.99	2.41	282	150	26.79	5.04
370	564	338	53.9	8.99	335	183	112.9	20.66

Viscosity η (N·s/m^2), thermal conductivity λ (W/m·deg), heat capacity c_p (kJ/kg·deg), Prandtl number Pr.

Source: Ref. 2 with permission.

Table 2.16 Thermophysical Properties of Water and Steam at Various Temperatures and Pressures

		T (K)											
Pressure, bar		300	350	400	450	500	550	600	650	700	800	900	1000
	μ	8.57.−4	3.70.−4	1.32.−5	1.52.−5	1.73.−5	1.94.−5	2.15.−5	2.36.−5	2.57.−5	2.98.−5	3.39.−5	3.78.−5
	c_p	4.18	4.19	1.99	1.97	1.98	2.00	2.02	2.06	2.09	2.15	2.22	2.29
1	k	0.614	0.668	0.0268	0.0311	0.0358	0.0410	0.0464	0.0521	0.0581	0.0710	0.0843	0.0981
	Pr	5.81	2.32	0.980	0.967	0.955	0.945	0.936	0.928	0.920	0.906	0.891	0.881
	μ	8.57.−4	3.70.−4	2.17.−4	1.49.−5	1.72.−5	1.93.−5	2.15.−5	2.36.−5	2.57.−5	2.98.−5	3.39.−5	3.78.−5
	c_p	4.18	4.19	4.26	2.21	2.10	2.07	2.07	2.08	2.11	2.16	2.23	2.29

Pressure, bar		T (K) 300	350	400	450	500	550	600	650	700	800	900	1000
5	k	0.614	0.668	0.689	0.0335	0.0369	0.0416	0.0469	0.0526	0.0585	0.0713	0.0846	0.0984
	Pr	5.82	2.32	1.34	0.983	0.973	0.959	0.947	0.937	0.925	0.907	0.892	0.881
	μ	8.57.−4	3.70.−4	2.17.−4	1.51.−4	1.71.−5	1.93.−5	2.15.−5	2.37.−5	2.58.−5	2.99.−5	3.39.−5	3.78.−5
	c_p	4.18	4.19	4.25	4.39	2.29	2.17	2.13	2.13	2.13	2.18	2.24	2.30
10	k	0.615	0.668	0.689	0.677	0.0380	0.0423	0.0474	0.0530	0.0590	0.0717	0.0851	0.0988
	Pr	5.82	2.32	1.34	0.981	1.028	0.988	0.963	0.949	0.931	0.908	0.892	0.881
	μ	8.56.−4	3.71.−4	2.18.−4	1.51.−4	1.68.−5	1.92.−5	2.15.−5	2.38.−5	2.59.−5	3.00.−5	3.40.−5	3.79.−5
	c_p	4.17	4.19	4.25	4.39	2.84	2.41	2.26	2.22	2.19	2.21	2.26	2.32
20	k	0.616	0.669	0.689	0.679	0.0402	0.0435	0.0485	0.0539	0.0599	0.0726	0.0859	0.0996
	Pr	5.80	2.32	1.34	0.979	1.19	1.063	0.999	0.977	0.946	0.912	0.893	0.881
	μ	8.55.−4	3.71.−4	2.18.−4	1.52.−4	1.19.−4	1.89.−5	2.15.−5	2.40.−5	2.61.−5	3.02.−5	3.42.−5	3.80.−5
	c_p	4.17	4.19	4.25	4.38	4.65	3.18	2.60	2.42	2.32	2.28	2.30	2.34
40	k	0.617	0.671	0.690	0.680	0.644	0.0488	0.0516	0.0564	0.0620	0.0744	0.0877	0.101
	Pr	5.78	2.31	1.34	0.977	0.862	1.23	1.08	1.031	0.975	0.924	0.895	0.881
	μ	8.54.−4	3.72.−4	2.19.−4	1.53.−4	1.20.−4	9.84.−5	2.14.−5	2.43.−5	2.63.−5	3.04.−5	3.43.−5	3.82.−5
	c_p	4.16	4.18	4.24	4.37	4.63	5.26	3.11	2.68	2.47	2.35	2.34	2.37
60	k	0.619	0.672	0.692	0.682	0.646	0.579	0.0561	0.0594	0.0645	0.0764	0.0895	0.103
	Pr	5.74	2.31	1.34	0.976	0.859	0.893	1.19	1.095	1.008	0.934	0.899	0.879
	μ	8.53.−4	3.72.−4	2.19.−4	1.53.−4	1.20.−4	9.92.−5	2.14.−5	2.46.−5	2.66.−5	3.06.−5	3.45.−5	3.83.−5
	c_p	4.16	4.18	4.24	4.36	4.62	5.21	3.88	3.00	2.65	2.43	2.39	2.40
80	k	0.620	0.674	0.693	0.684	0.648	0.583	0.0628	0.0631	0.0672	0.0785	0.0914	0.105

Pressure, bar		T (K) 300	350	400	450	500	550	600	650	700	800	900	1000
	Pr	5.72	2.31	1.34	0.975	0.856	0.886	1.33	1.17	1.046	0.946	0.902	0.877
	μ	8.52.−4	3.73.−4	2.20.−4	1.53.−4	1.21.−4	9.98.−5	2.14.−5	2.49.−5	2.69.−5	3.08.−5	3.47.−5	3.85.−5
	c_p	4.15	4.17	4.23	4.35	4.60	5.17	5.22	3.42	2.85	2.52	2.44	2.44
100	k	0.622	0.675	0.694	0.685	0.651	0.588	0.0730	0.0679	0.0704	0.0807	0.0934	0.107
	Pr	5.69	2.31	1.34	0.975	0.853	0.879	1.74	1.25	1.088	0.960	0.905	0.876

The notation 8.57.−4 signifies 8.57×10^{-4}.

Table 2.17 Isobaric Specific Heat for Water and Steam at Various Temperatures and Pressures

T (°C)	Pressure, bar 0.1	1	10	20	40	60	80	100
0	4.218	4.217	4.212	4.207	4.196	4.186	4.176	4.165
50	1.929	4.181	4.179	4.176	4.172	4.167	4.163	4.158
100	1.910	2.038	4.214	4.211	4.207	4.202	4.198	4.194
120	1.913	2.007	4.243	4.240	4.235	4.230	4.226	4.221
140	1.918	1.984	4.283	4.280	4.275	4.269	4.263	4.258
160	1.926	1.977	4.337	4.334	4.327	4.320	4.313	4.307
180	1.933	1.974	2.613	4.403	4.395	4.386	4.378	4.370
200	1.944	1.975	2.433	4.494	4.483	4.472	4.461	4.450
220	1.954	1.979	2.316	2.939	4.601	4.586	4.571	4.557
240	1.964	1.985	2.242	2.674	4.763	4.741	4.720	4.700
260	1.976	1.993	2.194	2.505	3.582	4.964	4.932	4.902
280	1.987	2.001	2.163	2.395	3.116	4.514	5.25	5.20
300	1.999	2.010	2.141	2.321	2.834	3.679	5.31	5.70
320	2.011	2.021	2.126	2.268	2.649	3.217	4.118	5.79
340	2.024	2.032	2.122	2.239	2.536	2.943	3.526	4.412
350	2.030	2.038	2.125	2.235	2.504	2.861	3.350	4.043

	Pressure, bar							
T (°C)	0.1	1	10	20	40	60	80	100
360	2.037	2.044	2.127	2.231	2.478	2.793	3.216	3.769
365	2.040	2.048	2.128	2.227	2.462	2.759	3.134	3.655
370	2.043	2.050	2.128	2.222	2.446	2.725	3.072	3.546
375	2.046	2.053	2.127	2.218	2.428	2.690	3.018	3.446
380	2.049	2.056	2.127	2.212	2.412	2.657	2.964	3.356
385	2.052	2.059	2.126	2.207	2.396	2.627	2.913	3.274
390	2.056	2.061	2.125	2.202	2.381	2.600	2.867	3.201
395	2.059	2.065	2.125	2.200	2.369	2.575	2.826	3.137
400	2.062	2.068	2.126	2.197	2.358	2.553	2.789	3.078
405	2.066	2.071	2.127	2.195	2.349	2.534	2.756	3.025
410	2.069	2.074	2.128	2.193	2.340	2.517	2.727	2.979
415	2.072	2.077	2.129	2.192	2.334	2.501	2.700	2.936
420	2.076	2.080	2.131	2.192	2.327	2.487	2.675	2.898
425	2.079	2.083	2.132	2.190	2.321	2.474	2.653	2.863
430	2.082	2.086	2.134	2.190	2.316	2.462	2.632	2.830
440	2.089	2.093	2.138	2.190	2.307	2.441	2.596	2.773
450	2.095	2.099	2.141	2.191	2.300	2.424	2.565	2.726
460	2.102	2.106	2.146	2.192	2.294	2.409	2.538	2.684
480	2.116	2.119	2.154	2.196	2.286	2.385	2.496	2.618
500	2.129	2.132	2.164	2.201	2.281	2.368	2.464	2.569
520	2.142	2.146	2.175	2.208	2.280	2.357	3.441	2.531
540	2.156	2.159	2.185	2.216	2.280	2.349	2.423	2.502
560	2.170	2.173	2.197	2.226	2.285	2.349	2.416	2.487
580	2.184	2.187	2.208	2.233	2.285	2.342	2.401	2.465
600	2.198	2.200	2.219	2.240	2.287	2.336	2.389	2.445
620	2.212	2.213	2.230	2.250	2.291	2.334	2.381	2.431

	Pressure, bar							
T (°C)	0.1	1	10	20	40	60	80	100
640	2.226	2.227	2.243	2.260	2.298	2.337	2.379	2.423
660	2.240	2.241	2.256	2.272	2.307	2.343	2.381	2.421
680	2.254	2.255	2.270	2.286	2.317	2.352	2.388	2.424
700	2.268	2.270	2.283	2.299	2.330	2.362	2.398	2.429
800	2.339	2.341	2.352	2.364	2.389	2.414	2.440	2.465

	Pressure, bar							
T (°C)	150	175	200	210	220	225	230	240
0	4.141	4.129	4.117	4.113	4.108	4.106	4.103	4.099
50	4.148	4.142	4.137	4.135	4.133	4.132	4.131	4.129
100	4.183	4.178	4.173	4.171	4.169	4.168	4.167	4.165
120	4.209	4.204	4.198	4.196	4.194	4.193	4.192	4.189
140	4.245	4.238	4.232	4.229	4.227	4.226	4.224	4.222
160	4.291	4.283	4.276	4.273	4.270	4.268	4.267	4.264
180	4.350	4.340	4.331	4.328	4.324	4.322	4.320	4.317
200	4.425	4.413	4.402	4.397	4.393	4.390	4.388	4.384
220	4.523	4.508	4.492	4.486	4.481	4.478	4.475	4.469
240	4.653	4.632	4.611	4.603	4.595	4.591	4.588	4.580
260	4.832	4.801	4.772	4.760	4.749	4.744	4.738	4.728
280	5.09	5.04	4.997	4.979	4.963	4.955	4.947	4.931
300	5.50	5.41	5.33	5.31	5.28	5.26	5.25	5.23
320	6.23	6.05	5.89	5.84	5.79	5.76	5.74	5.69
340	8.14	7.45	7.01	6.87	6.74	6.68	6.63	6.53
350	8.68	9.27	9.10	7.81	7.56	7.45	7.35	7.17
360	6.86	12.57	11.37	10.18	9.40	9.10	8.84	8.41
365	6.15	9.84	19.72	13.77	11.62	10.94	10.40	9.58
370	5.69	8.36	18.38	75.67	18.38	15.56	13.84	11.79

	Pressure, bar							
T (°C)	0.1	1	10	20	40	60	80	100
375	5.33	7.40	12.71	19.03	52.7	81.49	29.52	17.44
380	5.02	6.68	10.19	13.14	19.19	25.71	40.95	68.4
385	4.750	6.13	8.68	10.49	13.38	15.62	18.88	33.4
390	4.520	5.68	7.65	8.90	10.68	11.88	13.42	18.21
395	4.325	5.32	6.90	7.83	9.06	9.84	10.77	13.29
400	4.155	5.02	6.33	7.06	7.97	8.53	9.16	10.76
405	4.007	4.770	5.87	6.46	7.18	7.60	8.06	9.20
410	3.879	4.556	5.50	5.99	6.57	6.90	7.26	8.12
415	3.764	4.371	5.19	5.61	6.09	6.36	6.65	7.32
420	3.664	4.211	4.933	5.29	5.70	5.92	6.16	6.71
425	3.573	4.069	4.711	5.02	5.37	5.56	5.77	6.22
430	3.491	4.945	4.520	4.795	5.10	5.26	5.44	5.83
440	3.350	3.734	4.205	4.424	4.664	4.791	4.927	5.22
450	3.235	3.564	3.959	4.139	4.333	4.435	4.544	4.77
460	3.138	3.424	3.761	3.912	4.074	4.159	4.247	4.43
480	2.986	3.210	3.465	3.576	3.695	3.756	3.819	3.95
500	2.875	3.056	3.257	3.343	3.434	3.481	3.529	3.63
520	2.791	2.940	3.104	3.174	3.247	3.284	3.322	3.40
540	2.726	2.852	2.989	3.046	3.106	3.136	3.167	3.23
560	2.683	2.791	2.906	2.954	3.003	3.028	3.054	3.10
580	2.638	2.733	2.833	2.875	2.918	2.939	2.961	3.01
600	2.598	2.682	2.770	2.807	2.844	2.863	2.882	2.92
620	2.566	2.640	2.717	2.709	2.781	2.798	2.814	2.85
640	2.542	2.607	2.675	2.703	2.731	2.746	2.760	2.79
660	2.528	2.585	2.644	2.669	2.694	2.707	2.719	2.75
680	2.520	2.572	2.625	2.646	2.669	2.680	2.691	2.71

	Pressure, bar							
T (°C)	0.1	1	10	20	40	60	80	100
700	2.518	2.565	2.613	2.632	2.652	2.662	2.672	2.69
800	2.531	2.564	2.598	2.611	2.625	2.632	2.639	2.65

	Pressure, bar							
T (°C)	250	270	300	400	500	600	800	1000
0	4.095	4.086	4.073	4.032	3.993	3.956	3.882	3.800
50	4.127	4.123	4.117	4.098	4.080	4.064	4.035	4.010
100	4.163	4.159	1.153	4.135	4.117	4.100	4.068	4.039
120	4.187	4.183	4.177	4.156	4.137	4.119	4.085	4.054
140	4.220	4.215	4.208	4.185	4.163	4.143	4.105	4.071
160	4.261	4.255	4.247	4.220	4.196	4.172	4.130	4.092
180	4.313	4.306	4.296	4.265	4.235	4.208	4.159	4.116
200	4.379	4.371	4.358	4.319	4.284	4.252	4.195	4.145
220	4.464	4.452	4.437	4.388	4.344	4.305	4.237	4.180
240	4.572	4.558	4.537	4.474	4.419	4.371	4.290	4.223
260	4.717	4.697	4.669	4.584	4.514	4.453	4.354	4.276
280	4.916	4.886	4.845	4.728	4.633	4.555	4.432	4.340
300	5.20	5.16	5.09	4.920	4.788	4.683	4.524	4.411
320	5.65	5.57	5.46	5.19	4.996	4.848	4.633	4.485
340	6.43	6.27	6.07	5.60	5.30	5.08	4.766	4.552
350	7.02	6.76	6.45	5.81	5.45	5.20	4.871	4.663
360	8.07	7.56	7.03	6.10	5.64	5.34	4.954	4.719
365	8.99	8.18	7.43	6.27	5.73	5.40	4.987	4.737
370	10.56	9.12	7.98	6.48	5.84	5.47	5.03	4.764
375	13.76	10.67	8.76	6.70	5.96	5.56	5.08	4.802
380	23.37	13.51	9.90	6.97	6.10	5.65	5.14	4.843
385	73.1	20.07	11.68	7.30	6.26	5.75	5.20	4.884

	Pressure, bar							
T (°C)	0.1	1	10	20	40	60	80	100
390	28.04	38.02	14.60	7.71	6.43	5.84	5.25	4.919
395	17.31	33.71	19.68	8.19	6.61	5.94	5.30	4.949
400	13.02	21.11	25.71	8.78	6.81	6.05	5.34	4.974
405	10.67	15.32	24.85	9.47	7.04	6.16	5.38	4.996
410	9.17	12.22	19.59	10.25	7.29	6.27	5.42	5.02
415	8.12	10.30	15.45	11.12	7.57	6.40	5.46	5.04
420	7.35	8.99	12.70	12.00	7.87	6.54	5.51	5.06
425	6.74	8.04	10.83	12.73	8.18	6.69	5.56	5.08
430	6.26	7.32	9.49	13.13	8.50	6.84	5.61	5.10
440	5.54	6.28	7.73	12.54	9.08	7.17	5.72	5.15
450	5.02	5.58	6.62	10.89	9.48	7.47	5.84	5.20
460	4.631	5.08	5.87	9.28	9.52	7.71	5.97	5.26
480	4.089	4.389	4.902	7.08	8.55	7.87	6.19	5.40
500	3.731	3.951	4.316	5.81	7.20	7.48	6.31	5.51
520	3.481	3.650	3.926	5.02	6.13	6.76	6.28	5.58
540	3.295	3.431	3.650	4.487	5.37	6.03	6.10	5.56
560	3.158	3.268	3.442	4.095	4.796	5.38	5.75	5.43
580	3.051	3.144	3.290	3.823	4.387	5.890	5.39	5.28
600	2.960	3.040	3.165	3.614	4.082	4.510	5.03	5.08
620	2.882	2.952	3.060	3.446	3.845	4.216	4.724	4.871
640	2.819	2.880	2.974	3.308	3.654	3.981	4.465	4.669
660	2.771	2.824	2.906	3.197	3.500	3.791	4.249	4.485
680	2.736	2.783	2.855	3.110	3.376	3.637	4.068	4.322
700	2.713	2.755	2.819	3.044	3.279	3.513	3.916	4.178
800	2.666	2.694	2.736	2.879	3.024	3.168	3.441	3.669

Source: Ref. 2 with permission.

Table 2.18 Dynamic Viscosity [$\eta \cdot 10^7$ (N·s/m^2)] of Water and Steam at Various Temperatures and Pressures

	Pressure, bar								
T (°C)	1	20	40	60	80	100	150	200	210
0	17,525	17,514	17,502	17,491	17,480	17,468	17,439	17,411	17,405
10	12,992	12,986	12,980	12,975	12,969	12,963	12,948	12,934	12,931
20	10,015	10,013	10,010	10,008	10,005	10,003	9,997	9,991	9,990
30	7,971	7,970	7,970	7,970	7,970	7,969	7,968	7,968	7,968
40	6,513	6,514	6,515	6,516	6,517	6,519	6,521	6,524	6,525
50	5,441	5,443	5,445	5,447	5,449	5,451	5,456	5,461	5,462
60	4,630	4,633	4,636	6,638	4,641	4,644	4,650	4,657	4,658
70	4,004	4,007	4,010	4,013	4,016	4,019	4,027	4,036	4,038
80	3,509	3,513	3,516	3,520	3,523	3,527	3,535	3,544	3,546
90	3,113	3,116	3,120	3,124	3,128	3,131	3,141	3,150	3,152
100	121	2,793	2,797	2,801	2,805	2,809	2,819	2,828	2,830
110	125	2,526	2,530	2,534	2,538	2,542	2,552	2,563	2,565
120	129	2,303	2,307	2,311	2,315	2,319	2,330	2,340	2,342
130	133	2,114	2,118	2,123	2,127	2,131	2,142	2,152	2,154
140	137	1,953	1,957	1,962	1,966	1,970	1,981	1,992	1,994
150	141	1,814	1,818	1,823	1,827	1,832	1,843	1,854	1,856
160	146	1,693	1,698	1,702	1,707	1,711	1,722	1,734	1,736
170	150	1,588	1,592	1,597	1,601	1,606	1,617	1,628	1,631
180	154	1,495	1,500	1,504	1,509	1,513	1,525	1,536	1,538
190	158	1,413	1,417	1,422	1,426	1,431	1,442	1,454	1,456
200	162	1,339	1,343	1,348	1,353	1,358	1,369	1,381	1,383
210	166	1,275	1,278	1,282	1,287	1,292	1,303	1,315	1,317
220	170	164	1,218	1,223	1,228	1,232	1,244	1,256	1,258
230	174	169	1,164	1,169	1,174	1,179	1,190	1,202	1,204
240	178	174	1,115	1,120	1,125	1,129	1,141	1,153	1,156

	Pressure, bar								
T (°C)	1	20	40	60	80	100	150	200	210
250	182	179	1,070	1,075	1,080	1,084	1,096	1,108	1,111
260	186	183	180	1,033	1,039	1,043	1,055	1,067	1,069
270	190	188	185	995	1,000	1,005	1,017	1,029	1,031
280	194	193	191	189	964	969	981	993	996
290	198	197	196	194	931	936	948	960	963
300	202	202	201	200	199	904	917	929	932
310	207	206	206	206	206	866	881	895	898
320	211	211	211	212	212	213	843	859	862
330	215	216	216	218	219	221	800	820	824
340	219	220	222	224	226	229	749	777	782
350	223	225	227	229	232	236	248	727	734
360	227	229	231	234	237	241	255	661	673
370	231	233	236	239	243	246	259	298	335
380	235	238	240	243	246	250	263	288	297
390	239	242	244	247	250	254	266	286	292
400	243	246	248	251	254	258	268	286	290
410	247	250	252	255	258	261	272	287	291
420	251	254	256	259	262	265	275	288	292
430	255	258	260	263	266	269	278	290	294
440	260	262	264	267	269	272	281	293	296
450	264	266	268	270	273	276	285	296	298
460	268	270	272	274	277	280	288	298	301
470	272	274	276	278	281	284	292	301	304
480	276	278	280	282	285	288	295	304	307
490	280	282	284	286	289	291	299	308	310
500	284	286	288	290	293	295	302	311	313

	Pressure, bar								
T (°C)	1	20	40	60	80	100	150	200	210
520	292	294	296	298	301	303	310	318	320
540	300	302	304	306	308	311	317	324	326
560	308	310	312	314	316	319	325	332	333
580	316	318	320	322	324	326	332	339	340
600	325	326	328	330	332	334	340	346	347
620	333	334	336	338	340	342	348	353	355
640	341	342	344	346	348	350	355	361	362
660	349	351	352	354	356	358	363	368	370
680	357	359	360	362	364	366	371	376	377
700	365	367	368	370	372	374	378	384	385
T (°C)	**220**	**230**	**240**	**250**	**300**	**400**	**500**	**600**	**800**
0	17,399	17,394	17,388	17,382	17,353	17,296	17,239	17,182	17,067
10	12,928	12,925	12,922	12,919	12,905	12,875	12,846	12,817	12,759
20	9,988	9,987	9,986	9,985	9,979	9,967	9,954	9,942	9,918
30	7,967	7,967	7,967	7,967	7,966	7,965	7,963	7,962	7,959
40	6,225	6,526	6,526	6,527	6,529	6,535	6,540	6,546	6,557
50	5,463	5,464	5,465	5,466	5,471	5,481	5,491	5,502	5,522
60	4,660	4,661	4,662	4,664	4,670	4,684	4,697	4,711	4,737
70	4,038	4,040	4,041	4,043	4,051	4,066	4,082	4,098	4,129
80	3,548	3,549	3,551	3,553	3,561	3,579	3,596	3,614	3,648
90	3,154	3,155	3,157	3,159	3,168	3,187	3,206	3,224	3,261
100	2,832	2,834	2,836	2,838	2,848	2,867	2,887	2,906	2,945
110	2,567	2,569	2,571	2,573	2,583	2,603	2,623	2,644	2,684
120	2,344	2,347	2,349	2,351	2,361	2,382	2,403	2,424	2,465
130	2,157	2,159	2,161	2,163	2,174	2,195	2,216	2,237	2,280
140	1,996	1,998	2,000	2,003	2,013	2,035	2,057	2,078	2,122

	Pressure, bar								
T (°C)	1	20	40	60	80	100	150	200	210
150	1,858	1,860	1,862	1,865	1,876	1,898	1,920	1,941	1,985
160	1,738	1,740	1,742	1,745	1,756	1,778	1,800	1,822	1,867
170	1,633	1,635	1,637	1,640	1,651	1,674	1,696	1,718	1,763
180	1,540	1,543	1,545	1,547	1,559	1,581	1,604	1,627	1,672
190	1,458	1,461	1,463	1,465	1,477	1,500	1,523	1,546	1,591
200	1,385	1,388	1,390	1,392	1,404	1,427	1,450	1,473	1,519
210	1,320	1,322	1,324	1,327	1,338	1,362	1,385	1,408	1,455
220	1,261	1,263	1,265	1,268	1,279	1,303	1,326	1,350	1,397
230	1,207	1,209	1,212	1,214	1,226	1,249	1,273	1,297	1,344
240	1,158	1,160	1,163	1,165	1,177	1,201	1,225	1,248	1,296
250	1,113	1,116	1,118	1,120	1,132	1,156	1,180	1,204	1,252
260	1,072	1,074	1,077	1,079	1,091	1,115	1,140	1,164	1,212
270	1,034	1,036	1,038	1,041	1,053	1,077	1,102	1,126	1,175
280	998	1,001	1,003	1,006	1,018	1,042	1,067	1,091	1,140
290	965	968	970	972	985	1,009	1,034	1,059	1,108
300	934	937	939	941	954	978	1,004	1,028	1,078
310	901	904	906	909	922	948	972	997	1,045
320	865	868	871	874	888	915	940	964	1,012
330	827	831	834	837	853	881	908	932	980
340	786	790	794	798	817	848	876	901	949
350	740	745	751	756	779	815	845	871	920
360	683	692	700	707	738	781	814	842	891
370	596	617	633	646	692	746	784	813	864
380	311	340	468	537	630	703	748	783	840
390	300	310	324	348	561	667	721	759	817
400	296	303	311	321	458	627	692	735	797

	Pressure, bar								
T (°C)	1	20	40	60	80	100	150	200	210
410	295	300	306	313	380	580	660	710	777
420	296	300	304	310	352	529	626	683	758
430	297	300	304	309	340	479	591	656	737
440	299	302	305	309	334	438	555	628	716
450	301	304	307	310	331	411	521	599	695
460	303	306	309	312	330	394	495	572	674
470	306	308	311	314	330	383	466	546	654
480	309	311	313	316	331	376	446	522	633
490	312	314	316	318	332	371	432	502	614
500	315	317	319	321	334	369	421	485	596
520	321	323	325	327	338	367	408	460	563
540	328	330	331	333	343	368	402	444	537
560	335	336	338	340	348	370	399	435	516
580	342	343	345	346	354	374	399	430	502
600	349	350	352	353	361	379	401	428	491
620	356	357	359	360	367	384	404	428	484
640	363	365	366	367	374	389	408	429	480
660	371	372	373	374	381	395	412	432	477
680	378	379	380	382	388	401	418	435	477
700	386	387	388	389	395	408	422	439	478

Source: Ref. 2 with permission.

Table 2.19 Thermal Conductivity [$\lambda \cdot 10^3$ (W/m·deg)] of Water and Steam at Various Temperatures and Pressures

	Pressure, bar							
T (°C)	1	20	40	60	80	100	150	200
0	569	570	572	574	575	577	581	585
10	588	589	590	592	594	595	599	603

	Pressure, bar							
T (°C)	1	20	40	60	80	100	150	200
20	603	605	607	608	610	612	616	620
30	617	620	622	623	625	627	631	634
40	630	633	635	637	638	640	644	648
50	643	645	647	648	650	651	655	659
60	653	655	657	658	660	661	665	669
70	662	664	665	667	668	670	674	677
80	669	671	673	674	676	677	681	684
90	675	677	679	680	682	683	687	690
100	24.5	682	684	685	686	688	691	694
110	25.2	686	687	688	690	691	694	698
120	26.0	688	689	691	692	693	697	700
130	26.9	689	690	692	693	694	698	701
140	27.7	689	690	692	693	694	698	701
150	28.6	688	689	690	692	693	696	700
160	29.5	685	687	688	690	691	694	698
170	30.4	682	683	685	686	688	691	695
180	31.3	677	679	680	682	683	687	691
190	32.2	672	673	675	677	678	682	686
200	33.1	665	667	668	670	672	676	681
210	34.1	657	659	661	663	665	670	674
220	35.1	40.0	650	652	654	656	662	667
230	36.1	40.3	640	643	645	647	653	658
240	37.1	40.8	629	632	634	637	643	649
250	38.1	41.4	616	619	622	625	632	639
260	39.1	42.1	48.9	606	609	612	620	628
270	40.1	42.9	48.7	590	594	598	607	616

	Pressure, bar							
T (°C)	1	20	40	60	80	100	150	200
280	41.2	43.8	48.8	58.1	578	582	593	602
290	42.3	44.7	49.1	56.8	560	565	577	587
300	43.3	45.7	49.6	56.1	66.9	545	559	571
310	44.4	46.7	50.3	55.8	64.7	523	539	553
320	45.5	47.7	51.0	55.9	63.3	75.2	516	532
330	46.7	48.8	51.8	56.2	62.5	72.0	491	509
340	47.8	49.9	52.7	56.7	62.1	69.9	462	483
350	49.0	51.0	53.7	57.3	62.1	68.8	104	454
360	50.1	52.1	54.7	58.0	62.3	68.1	94.8	420
370	51.3	53.2	55.7	58.8	62.7	67.8	89.3	163
380	52.5	54.4	56.7	59.7	63.3	67.8	85.9	129
390	53.6	55.5	57.8	60.6	64.0	68.1	83.6	115
400	54.8	56.7	58.9	61.6	64.7	68.6	82.2	107
410	56.0	57.9	60.1	62.6	65.6	69.1	81.2	102
420	57.3	59.1	61.2	63.7	66.5	69.8	80.8	98.3
430	58.5	60.3	62.4	64.8	67.5	70.6	80.6	95.7
440	59.7	61.5	63.6	65.9	68.5	71.4	80.6	94.1
450	61.0	62.8	64.8	67.0	69.5	72.4	81.0	93.3
460	62.2	64.0	66.0	68.2	70.6	73.3	81.5	92.4
470	63.5	65.3	67.2	69.4	71.7	74.3	82.0	92.1
480	64.8	66.5	68.5	70.6	72.9	75.4	82.7	92.1
490	66.0	67.8	69.7	71.8	74.0	76.5	83.5	92.2
500	67.3	69.1	71.0	73.0	75.2	77.6	84.3	92.6
520	69.9	71.7	73.5	75.5	77.6	79.9	86.2	93.7
540	72.5	74.3	76.1	78.1	80.1	82.3	88.2	95.2
560	75.2	76.9	78.7	80.6	82.7	84.7	90.4	96.9

	Pressure, bar							
T (°C)	1	20	40	60	80	100	150	200
580	77.8	79.6	81.4	83.3	85.2	87.3	92.7	98.8
600	80.5	82.3	84.1	85.9	87.8	89.8	95.1	101
620	83.2	85.0	86.7	88.6	90.5	92.4	97.6	103
640	85.9	87.7	89.5	91.3	93.2	95.1	100	105
660	88.7	90.4	92.2	94.0	95.8	97.7	103	108
680	91.4	93.1	94.9	96.7	98.5	100	105	110
700	94.2	95.9	97.7	99.5	101	103	108	113
***T* (°C)**	**210**	**220**	**230**	**240**	**250**	**300**	**400**	**500**
0	586	586	587	588	589	592	599	606
10	604	605	606	606	607	611	617	624
20	620	621	622	623	623	627	634	640
30	635	636	637	637	638	642	648	654
40	648	649	650	650	651	654	661	666
50	660	660	661	662	662	666	672	678
60	670	670	671	672	672	676	682	687
70	678	679	679	680	681	684	690	695
80	685	686	686	687	688	691	697	702
90	691	691	692	693	693	696	702	708
100	695	696	696	697	698	701	707	713
110	698	699	700	700	701	704	710	716
120	700	701	702	702	703	706	712	718
130	702	702	703	703	704	707	714	720
140	701	702	703	703	704	707	714	720
150	700	701	702	702	703	706	713	720
160	698	699	700	700	701	705	711	718
170	696	696	697	698	698	702	709	716

	Pressure, bar							
T (°C)	1	20	40	60	80	100	150	200
180	692	692	693	694	695	698	706	713
190	687	688	688	689	690	694	702	709
200	681	682	683	684	685	689	697	704
210	675	676	677	678	678	683	691	699
220	668	669	670	671	672	676	685	693
230	660	661	662	663	664	669	678	686
240	650	652	653	654	655	660	670	679
250	640	642	643	644	646	651	662	671
260	630	631	632	634	635	642	653	663
270	617	619	621	622	624	631	643	653
280	604	606	608	609	611	619	633	643
290	590	592	594	595	597	606	622	633
300	573	576	578	580	582	592	609	622
310	555	558	561	563	566	577	596	610
320	535	538	541	544	547	560	582	597
330	513	516	520	523	526	541	566	583
340	488	491	495	499	503	520	548	568
350	458	463	467	472	476	496	529	552
360	425	430	435	440	445	468	504	537
370	206	392	385	396	406	437	479	514
380	147	170	185	269	322	398	453	490
390	126	140	150	165	188	338	423	465
400	115	124	134	144	156	262	388	439
410	108	114	124	132	141	206	348	411
420	103	108	116	123	130	177	307	382
430	99.8	104	109	116	122	160	271	352

	Pressure, bar							
T (°C)	1	20	40	60	80	100	150	200
440	97.6	101	105	110	116	148	241	323
450	96.0	99.2	103	106	111	139	217	297
460	95.0	97.9	101	104	108	131	198	274
470	94.5	97.0	99.7	103	106	125	184	253
480	94.2	96.5	99.0	102	104	120	172	236
490	94.2	96.4	98.7	101	103	118	163	220
500	94.4	96.4	98.5	101	103	116	155	207
520	95.3	97.1	98.9	101	103	113	142	186
540	96.6	98.2	99.8	102	103	112	136	170
560	98.3	99.7	101	103	104	112	133	159
580	100	101	103	104	106	113	131	153
600	102	103	105	106	107	114	130	149
620	104	105	107	108	109	116	130	147
640	106	108	109	110	111	117	131	147
660	109	110	111	112	113	119	132	146
680	111	112	113	115	116	121	133	147
700	114	115	116	117	118	124	135	148

Source: Ref. 2 with permission.

Table 2.20 Surface Tension [σ (dynes/cm)] of Water in Air

T (°C)	σ	T (°C)	σ	T (°C)	σ	T (°C)	σ
0	75.50	130	52.90	260	23.73	362	1.53
10	74.40	140	50.79	270	21.33	363	1.37
20	72.88	150	48.68	280	18.94	364	1.22
30	71.20	160	46.51	290	16.60	365	1.07
40	69.48	170	44.38	300	14.29	366	0.93
50	67.77	180	42.19	310	12.04	367	0.79
60	66.07	190	40.00	320	9.84	368	0.66
70	64.36	200	37.77	330	7.69	369	0.54
80	62.69	210	35.51	340	5.61	370	0.42
90	60.79	220	33.21	350	3.64	371	0.31
100	58.91	230	30.88	355	2.71	372	0.20
110	56.97	240	28.52	360	1.85	373	0.10
120	54.96	250	26.13	361	1.68	374.15	0

Source: Ref. 2 with permission.

Table 2.21 Surface Tension (N/m) of Various Liquids

	T (K)										
Substance	250	260	270	280	290	300	320	340	360	380	400
Acetone	0.0292	0.0280	0.0267	0.0254	0.0241	0.0229	0.0203	0.0178	0.016	0.014	0.012
Benzene	—	—	0.0321	0.0307	0.0293	0.0279	0.0253	0.0228	0.0204	0.0180	0.0156
Bromine	0.047	0.046	0.045	0.044	0.0425	0.041	0.038	0.035	0.032	0.030	0.027
Butane	0.0176	0.0164	0.0152	0.0140	0.0128	0.0116	0.0092	0.0069	0.0049	0.0031	0.0016
Chlorine	0.0243	0.0227	0.0212	0.0197	0.0182	0.0167	0.0137	0.0107	0.0079	0.0051	0.0037
Decane	0.0278	0.0269	0.0260	0.0251	0.0241	0.0233	0.0215	0.0196	0.0178	0.0161	0.0145

Substance	T (K) 250	260	270	280	290	300	320	340	360	380	400
Diphenyl	—	—	—	—	—	0.0416	0.0388	0.0362	0.0338	0.0316	0.0295
Ethane	0.0061	0.0049	0.0037	0.0026	0.0015	0.0007	—	—	—	—	—
Ethanol	—	—	0.0247	0.0239	0.0231	0.0222	0.0204	0.0186	0.0167	0.0148	0.0126
Ethylene	0.0033	0.0020	0.0009	0.0002	—	—	—	—	—	—	—
Heptane	0.0242	0.0233	0.0224	0.0214	0.0204	0.0194	0.0175	0.0156	0.0137	0.0118	0.0100
Hexane	0.0230	0.0219	0.0207	0.0198	0.0187	0.0176	0.0154	0.0134	0.0116	0.0096	0.0077
Methanol	0.0266	0.0257	0.0248	0.0238	0.0229	0.0221	0.0204	0.0187	0.0169	0.0150	0.0129
Nonane	0.0270	0.0261	0.0251	0.0242	0.0232	0.0223	0.0204	0.0186	0.0167	0.0148	0.0129
Octane	0.0256	0.0247	0.0237	0.0228	0.0219	0.0210	0.0191	0.0173	0.0155	0.0138	0.0123
Pentane	0.0210	0.0198	0.0186	0.0175	0.0164	0.0153	0.0131	0.0108	0.0088	0.0069	0.0053
Propane	0.0128	0.0114	0.0101	0.0088	0.0076	0.0064	0.0043	0.0025	0.0007	—	—
Propanol	0.0274	0.0266	0.0258	0.0249	0.0241	0.0232	0.0214	0.0198	0.0182	0.0168	0.0155
Propylene	0.0132	0.0119	0.0105	0.0090	0.0077	0.0064	0.0041	0.0022	0.0005	—	—
R 12	0.0147	0.0134	0.0121	0.0108	0.0095	0.0082	0.0057	0.0034	—	—	—
Toluene	0.0345	0.0330	0.0315	0.0301	0.0288	0.0275	0.0251	0.0227	0.0205	0.0185	0.0165
Water	—	—	—	0.0747	0.0733	0.0717	0.0685	0.0651	0.0615	0.0576	0.0536

Table 2.22 Isobaric Expansion Coefficient of Water (β) at one bar

T (°C)	$\beta \times 10^4$ (1/K)	T (°C)	$\beta \times 10^4$ (1/K)	T (°C)	$\beta \times 10^4$ (1/K)	T (°C)	$\beta \times 10^4$ (1/K)
10	0.883	35	3.47	60	5.22	85	6.69
15	1.51	40	3.86	65	5.53	90	6.96
20	2.08	45	4.23	70	5.82	95	7.22
25	2.59	50	4.57	75	6.12	99.63	7.46
30	3.05	55	4.90	80	6.40		

Calculated from data in Ref. 7.

Table 2.23 Heat Capacity of Seawater (kJ/kg K) at Various Temperatures and Salinities

	Salinity, g/kg															
T (°C)	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
0	4.209	4.143	4.081	4.021	3.964	3.910	3.858	3.809	3.763	3.720	3.679	3.641	3.606	3.573	3.543	3.516
10	4.198	4.136	4.077	4.020	3.965	3.913	3.863	3.815	3.770	3.727	3.686	3.648	3.612	3.579	3.547	3.518
20	4.189	4.131	4.074	4.020	3.967	3.917	3.868	3.822	3.777	3.735	3.694	3.656	3.619	3.584	3.552	3.521
30	4.184	4.128	4.074	4.021	3.971	3.922	3.874	3.829	3.785	3.743	3.702	3.663	3.626	3.591	3.557	3.525
40	4.180	4.127	4.075	4.024	3.975	3.927	3.881	3.836	3.793	3.751	3.710	3.671	3.633	3.597	3.562	3.529
50	4.180	4.128	4.078	4.029	3.981	3.934	3.888	3.844	3.801	3.759	3.719	3.679	3.641	3.604	3.568	3.533
60	4.181	4.131	4.082	4.034	3.987	3.941	3.896	3.853	3.810	3.768	3.727	3.687	3.649	3.611	3.574	3.538
70	4.186	4.137	4.088	4.041	3.995	3.950	3.905	3.861	3.819	3.777	3.736	3.696	3.657	3.618	3.581	3.544
80	4.192	4.144	4.096	4.050	4.004	3.959	3.914	3.871	3.828	3.786	3.745	3.704	3.665	3.626	3.588	3.551
90	4.202	4.154	4.106	4.059	4.014	3.968	3.924	3.880	3.837	3.795	3.754	3.713	3.673	3.634	3.595	3.558
100	4.213	4.165	4.118	4.071	4.025	3.979	3.934	3.891	3.847	3.805	3.763	3.722	3.682	3.642	3.603	3.565
110	4.228	4.179	4.131	4.083	4.037	3.991	3.946	3.901	3.857	3.815	3.772	3.731	3.690	3.651	3.612	3.573
120	4.245	4.195	4.146	4.097	4.050	4.003	3.957	3.912	3.868	3.825	3.782	3.740	3.700	3.659	3.620	3.582
130	4.264	4.213	4.162	4.113	4.064	4.016	3.970	3.924	3.879	3.835	3.792	3.750	3.709	3.669	3.629	3.591
140	4.286	4.233	4.181	4.129	4.079	4.030	3.982	3.936	3.890	3.845	3.802	3.760	3.718	3.678	3.639	3.601
150	4.311	4.255	4.201	4.148	4.096	4.045	3.996	3.948	3.902	3.856	3.812	3.769	3.728	3.688	3.649	3.611
160	4.338	4.279	4.222	4.167	4.113	4.061	4.010	3.961	3.913	3.867	3.823	3.780	3.738	3.698	3.659	3.622
170	4.367	4.306	4.246	4.188	4.132	4.078	4.025	3.974	3.926	3.878	3.833	3.790	3.748	3.708	3.670	3.634
180	4.399	4.334	4.271	4.210	4.152	4.095	4.041	3.988	3.938	3.890	3.844	3.800	3.758	3.719	3.681	3.646

	30	31	32	33	34	35	36	37	38	39	40
0	4.021	4.015	4.010	4.004	3.998	3.992	3.987	3.981	3.975	3.970	3.964
10	4.020	4.014	4.009	4.003	3.998	3.992	3.987	3.981	3.976	3.971	3.965
20	4.020	4.015	4.009	4.004	3.999	3.993	3.988	3.983	3.978	3.973	3.967
30	4.021	4.016	4.011	4.006	4.001	3.996	3.991	3.986	3.981	3.976	3.971
40	4.024	4.019	4.014	4.009	4.004	4.000	3.995	3.990	3.985	3.980	3.975
50	4.029	4.024	4.019	4.014	4.009	4.004	4.000	3.995	3.990	3.985	3.981
60	4.034	4.029	4.025	4.020	4.015	4.011	4.006	4.001	3.997	3.992	3.987
70	4.041	4.037	4.032	4.027	4.023	4.018	4.013	4.009	4.004	4.000	3.995
80	4.050	4.045	4.040	4.036	4.031	4.027	4.022	4.017	4.013	4.008	4.004
90	4.059	4.055	4.050	4.046	4.041	4.036	4.032	4.027	4.023	4.018	4.014
100	4.071	4.066	4.061	4.057	4.052	4.048	4.043	4.038	4.034	4.029	4.025
110	4.083	4.079	4.074	4.069	4.065	4.060	4.055	4.051	4.046	4.041	4.037
120	4.097	4.092	4.088	4.083	4.078	4.073	4.069	4.064	4.059	4.054	4.050
130	4.113	4.108	4.103	4.098	4.093	4.088	4.083	4.078	4.074	4.069	4.064
140	4.129	4.124	4.119	4.114	4.109	4.104	4.099	4.094	4.089	4.084	4.079
150	4.148	4.142	4.137	4.132	4.127	4.121	4.116	4.111	4.106	4.101	4.096
160	4.167	4.162	4.156	4.151	4.145	4.140	4.135	4.129	4.124	4.119	4.113
170	4.188	4.182	4.177	4.171	4.165	4.160	4.154	4.149	4.143	4.137	4.132
180	4.120	4.204	4.198	4.192	4.187	4.181	4.175	4.169	4.163	4.157	4.152

Source: Ref. 3 with permission.

Table 2.24 Dynamic Viscosity of Seawater (10^{-3} Ns/m^2) at Various Temperatures and Salinities

	Salinity, g/kg															
T (°C)	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
0	1.775	1.802	1.831	1.861	1.893	1.928	1.965	2.005	2.049	2.096	2.147	2.202	2.261	2.326	2.395	2.470
10	1.304	1.327	1.350	1.375	1.401	1.429	1.459	1.491	1.526	1.563	1.603	1.646	1.693	1.743	1.797	1.855
20	1.002	1.021	1.041	1.061	1.083	1.106	1.131	1.157	1.185	1.216	1.248	1.283	1.321	1.361	1.404	1.451
30	0.797	0.814	0.830	0.848	0.866	0.886	0.906	0.929	0.952	0.977	1.004	1.033	1.064	1.098	1.133	1.171
40	0.653	0.667	0.681	0.696	0.712	0.729	0.747	0.765	0.786	0.807	0.830	0.854	0.880	0.908	0.938	0.970
50	0.546	0.559	0.571	0.585	0.599	0.613	0.629	0.645	0.662	0.681	0.700	0.721	0.744	0.768	0.793	0.821
60	0.466	0.477	0.488	0.500	0.512	0.525	0.539	0.553	0.568	0.584	0.602	0.620	0.639	0.660	0.682	0.706
70	0.404	0.414	0.424	0.434	0.445	0.457	0.469	0.481	0.495	0.509	0.524	0.540	0.558	0.576	0.595	0.616
80	0.355	0.364	0.373	0.382	0.392	0.402	0.413	0.424	0.436	0.449	0.463	0.477	0.492	0.508	0.525	0.544
90	0.315	0.323	0.331	0.340	0.349	0.358	0.368	0.378	0.389	0.400	0.412	0.425	0.439	0.453	0.469	0.485
100	0.282	0.290	0.297	0.305	0.313	0.322	0.331	0.340	0.350	0.360	0.371	0.383	0.395	0.408	0.422	0.436
110	0.255	0.262	0.269	0.276	0.284	0.291	0.300	0.308	0.317	0.326	0.336	0.347	0.358	0.370	0.382	0.395
120	0.232	0.239	0.245	0.252	0.259	0.266	0.273	0.281	0.289	0.298	0.307	0.317	0.327	0.337	0.349	0.361
130	0.213	0.219	0.225	0.231	0.237	0.244	0.251	0.258	0.266	0.273	0.282	0.291	0.300	0.310	0.320	0.331
140	0.196	0.201	0.207	0.213	0.219	0.225	0.231	0.238	0.245	0.252	0.260	0.268	0.277	0.286	0.295	0.305
150	0.181	0.187	0.192	0.197	0.203	0.208	0.214	0.221	0.227	0.234	0.241	0.249	0.256	0.265	0.273	0.283
160	0.169	0.173	0.178	0.183	0.189	0.194	0.200	0.205	0.211	0.218	0.224	0.231	0.239	0.246	0.254	0.263
170	0.157	0.162	0.167	0.171	0.176	0.181	0.186	0.192	0.198	0.203	0.210	0.216	0.223	0.230	0.237	0.245
180	0.147	0.152	0.156	0.161	0.165	0.170	0.175	0.180	0.185	0.191	0.196	0.202	0.209	0.215	0.222	0.230

	30	31	32	33	34	35	36	37	38	39	40
0	1.861	1.864	1.867	1.871	1.874	1.877	1.880	1.883	1.887	1.890	1.893
10	1.375	1.377	1.380	1.382	1.365	1.388	1.390	1.393	1.396	1.398	1.401
20	1.061	1.063	1.065	1.068	1.070	1.072	1.074	1.076	1.078	1.081	1.083
30	0.848	0.850	0.851	0.853	0.855	0.857	0.859	0.861	0.862	0.864	0.866
40	0.696	0.698	0.699	0.701	0.702	0.704	0.706	0.707	0.709	0.710	0.712
50	0.585	0.586	0.587	0.589	0.590	0.592	0.593	0.594	0.596	0.597	0.599
60	0.500	0.501	0.503	0.504	0.505	0.506	0.507	0.509	0.510	0.511	0.512
70	0.434	0.435	0.437	0.438	0.439	0.440	0.441	0.442	0.443	0.444	0.445
80	0.382	0.383	0.384	0.385	0.386	0.387	0.388	0.389	0.390	0.391	0.392
90	0.340	0.341	0.342	0.343	0.343	0.344	0.345	0.346	0.347	0.348	0.349
100	0.305	0.306	0.307	0.308	0.308	0.309	0.310	0.311	0.312	0.312	0.313
110	0.276	0.277	0.278	0.278	0.279	0.280	0.281	0.281	0.282	0.283	0.284
120	0.252	0.252	0.253	0.254	0.254	0.255	0.256	0.257	0.257	0.258	0.259
130	0.231	0.231	0.232	0.233	0.233	0.234	0.235	0.235	0.236	0.237	0.237
140	0.213	0.213	0.214	0.215	0.215	0.216	0.216	0.217	0.218	0.218	0.219
150	0.197	0.198	0.198	0.199	0.199	0.200	0.200	0.201	0.202	0.202	0.203
160	0.183	0.184	0.184	0.185	0.186	0.186	0.187	0.187	0.188	0.188	0.189
170	0.171	0.172	0.172	0.173	0.173	0.174	0.174	0.175	0.175	0.176	0.176
180	0.161	0.161	0.161	0.162	0.162	0.163	0.163	0.164	0.164	0.165	0.165

Source: Ref. 3 with permission.

Table 2.25 Thermal Conductivity of Seawater (mW/m K) at Various Temperatures and Salinities

	Salinity, g/kg																
T (°C)	0	10	20	30	35*	40	50	60	70	80	90	100	110	120	130	140	150
0	572	570	569	567	566	565	563	562	560	558	556	554	552	550	548	546	544
10	589	587	586	584	584	583	581	580	578	577	575	573	571	570	568	566	564
20	604	603	602	600	600	599	598	597	595	594	592	591	589	588	586	585	583
30	618	617	616	615	614	614	613	612	611	609	608	607	606	604	603	602	600
40	630	629	629	628	628	627	626	626	625	624	623	622	621	620	618	617	616
50	641	641	640	640	639	639	639	638	637	637	636	635	634	633	632	631	630
60	651	651	650	650	650	650	649	649	649	648	648	647	646	646	645	644	644
70	659	659	659	659	659	659	659	659	658	658	658	658	657	657	656	656	655
80	666	666	667	667	667	667	667	667	667	667	667	667	667	666	666	666	666
90	672	672	673	673	673	674	674	674	674	675	675	675	675	675	675	675	675
100	676	677	678	678	679	679	680	680	681	681	681	682	682	682	682	682	683
110	680	681	682	683	683	683	684	685	685	686	687	687	688	688	688	689	689
120	682	683	684	685	686	686	687	688	689	690	691	691	692	693	693	694	694
130	683	685	686	687	688	688	690	691	692	693	694	695	695	696	697	698	699
140	684	685	687	688	689	689	691	692	693	694	696	697	698	699	700	701	702
150	683	684	686	688	688	689	691	692	694	695	696	698	699	700	701	702	703
160	681	683	684	686	687	688	690	691	693	694	696	697	699	700	701	703	704
170	678	680	682	684	685	686	687	689	691	693	694	696	698	699	701	702	704
180	674	676	678	680	681	682	684	686	686	690	692	694	695	697	699	700	702

* "Normal" seawater.

Source: Ref. 3 with permission.

Table 2.26 Prandtl Number of Seawater at Various Temperatures and Salinities

	Salinity, g/kg																
T (°C)	0	10	20	30	35*	40	50	60	70	80	90	100	110	120	130	140	150
0	13.1	13.1	13.1	13.2	13.2	13.3	13.4	13.5	13.6	13.8	14.0	14.3	14.5	14.8	15.2	15.5	16.0
10	9.29	9.35	9.39	9.46	9.49	9.53	9.62	9.72	9.84	9.97	10.1	10.3	10.5	10.7	11.0	11.2	11.6
20	6.95	6.99	7.04	7.11	7.13	7.17	7.24	7.33	7.43	7.53	7.67	7.80	7.96	8.13	8.32	8.52	8.76
30	5.40	5.45	5.49	5.54	5.58	5.60	5.67	5.74	5.82	5.92	6.01	6.12	6.24	6.39	6.54	6.69	6.88
40	4.33	4.38	4.41	4.46	4.48	4.51	4.57	4.63	4.70	4.78	4.86	4.95	5.05	5.16	5.28	5.42	5.56
50	3.56	3.60	3.64	3.68	3.71	3.73	3.77	3.83	3.89	3.95	4.02	4.10	4.18	4.28	4.38	4.48	4.60
60	2.99	3.03	3.06	3.10	3.12	3.14	3.19	3.24	3.28	3.34	3.40	3.47	3.54	3.61	3.69	3.78	3.88
70	2.57	2.60	2.63	2.66	2.68	2.70	2.74	2.78	2.82	2.87	2.92	2.98	3.04	3.11	3.18	3.25	3.33
80	2.23	2.26	2.29	2.32	2.34	2.35	2.39	2.42	2.46	2.50	2.55	2.60	2.65	2.71	2.77	2.83	2.90
90	1.97	2.00	2.02	2.05	2.06	2.08	2.11	2.14	2.18	2.21	2.25	2.29	2.34	2.39	2.44	2.50	2.56
100	1.75	1.78	1.80	1.83	1.84	1.86	1.88	1.92	1.94	1.98	2.01	2.05	2.09	2.13	2.18	2.23	2.28
110	1.59	1.61	1.63	1.65	1.66	1.68	1.70	1.73	1.75	1.78	1.81	1.84	1.88	1.92	1.96	2.00	2.05
120	1.44	1.47	1.49	1.51	1.51	1.53	1.55	1.57	1.60	1.62	1.65	1.68	1.71	1.75	1.78	1.82	1.86
130	1.33	1.35	1.37	1.38	1.39	1.40	1.42	1.44	1.46	1.49	1.51	1.54	1.57	1.60	1.63	1.66	1.70
140	1.23	1.24	1.26	1.28	1.29	1.30	1.31	1.33	1.35	1.37	1.39	1.42	1.44	1.47	1.50	1.53	1.56
150	1.14	1.16	1.18	1.19	1.20	1.21	1.22	1.24	1.26	1.27	1.30	1.32	1.34	1.36	1.39	1.42	1.45
160	1.08	1.08	1.10	1.11	1.12	1.13	1.14	1.16	1.17	1.19	1.21	1.23	1.25	1.28	1.30	1.32	1.35
170	1.01	1.03	1.04	1.05	1.06	1.06	1.07	1.09	1.10	1.12	1.13	1.16	1.17	1.20	1.22	1.24	1.26

T (°C)	Salinity, g/kg																
	0	10	20	30	35*	40	50	60	70	80	90	100	110	120	130	140	150
180	0.959	0.975	0.983	0.997	1.000	1.000	1.002	1.003	1.004	1.006	1.007	1.009	1.010	1.013	1.014	1.017	1.019

* "Normal" seawater.

Source: Ref. 3 with permission.

Table 2.27 Density of Seawater (kg/m^3) at Various Temperatures and Salinities

T (°C)	Salinity, g/kg										
	30	31	32	33	34	35*	36	37	38	39	40
0	1,024.2	1,024.9	1,025.7	1,026.5	1,027.3	1,028.1	1,028.9	1,029.6	1,030.4	1,031.2	1,032.0
10	1,023.2	1,023.9	1,024.7	1,025.4	1,026.2	1,027.0	1,027.7	1,028.5	1,029.3	1,030.0	1,030.8
20	1,020.8	1,021.5	1,022.3	1,023.0	1,023.8	1,024.5	1,025.3	1,026.0	1,026.8	1,027.5	1,028.3
30	1,017.6	1,018.4	1,019.1	1,019.9	1,020.6	1,021.4	1,022.1	1,022.9	1,023.6	1,024.4	1,025.1
40	1,013.9	1,014.7	1,015.4	1,016.2	1,016.9	1,017.7	1,018.4	1,019.1	1,019.9	1,020.6	1,021.4
50	1,009.7	1,010.4	1,011.2	1,011.9	1,012.6	1,013.4	1,014.1	1,014.8	1,015.6	1,016.3	1,017.1
60	1,004.9	1,005.6	1,006.3	1,007.1	1,007.8	1,008.6	1,009.3	1,010.0	1,010.8	1,011.5	1,012.2
70	999.5	1,000.3	1,001.0	1,001.7	1,002.5	1,003.2	1,003.9	1,004.7	1,005.4	1,006.2	1,006.9
80	993.7	994.4	995.2	995.9	996.6	997.4	998.1	998.8	999.6	1,000.3	1,001.1
90	987.4	988.1	988.8	989.6	990.3	991.1	991.8	992.5	993.3	994.0	994.7
100	980.6	981.3	982.1	982.8	983.5	984.3	985.0	985.8	986.5	987.2	988.0
110	973.3	974.1	974.8	975.6	976.3	977.1	977.8	978.6	979.3	980.0	980.8
120	965.7	966.4	967.2	967.9	968.7	969.4	970.2	970.9	971.7	972.4	973.2
130	957.6	958.4	959.1	959.9	960.6	961.4	962.1	962.9	963.7	964.4	965.2
140	949.1	949.9	950.7	951.4	952.2	953.0	953.7	954.5	955.3	956.0	956.8
150	940.3	941.1	941.8	942.6	943.4	944.2	945.0	945.7	946.5	947.3	948.1
160	931.1	931.9	932.7	933.5	934.3	935.1	935.8	936.6	937.4	938.2	939.0
170	921.6	922.4	923.2	924.0	924.8	925.6	926.4	927.2	928.0	928.8	929.6
180	911.7	912.6	913.4	914.2	915.0	915.8	916.7	917.5	918.3	919.1	919.9

T (°C)	Salinity, g/kg														
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
0	1,008.1	1,016.2	1,024.2	1,032.0	1,039.8	1,047.6	1,055.5	1,063.5	1,071.6	1,079.7	1,088.0	1,096.2	1,104.4	1,112.5	1,120.4
10	1,007.7	1,015.5	1,023.2	1,030.2	1,038.4	1,046.0	1,053.8	1,061.6	1,669.6	1,077.6	1,085.7	1,093.9	1,102.0	1,110.1	1,118.0
20	1,005.8	1,013.3	1,020.8	1,028.3	1,035.9	1,043.5	1,051.2	1,058.9	1,066.7	1,074.5	1,082.4	1,090.3	1,098.2	1,106.2	1,114.2
30	1,002.8	1,010.2	1,017.6	1,025.1	1,032.6	1,040.2	1,047.8	1,055.4	1,063.1	1,070.8	1,078.5	1,086.3	1,094.1	1,102.0	1,109.9
40	999.2	1,006.6	1,013.9	1,021.4	1,028.8	1,036.3	1,043.8	1,051.4	1,059.0	1,066.6	1,074.2	1,081.9	1,089.6	1,097.4	1,105.2
50	995.0	1,002.3	1,009.7	1,017.1	1,024.5	1,031.9	1,039.4	1,046.9	1,054.4	1,062.0	1,069.5	1,077.1	1,084.8	1,092.4	1,100.1
60	990.2	997.5	1,004.9	1,012.2	1,019.6	1,027.0	1,034.5	1,041.9	1,049.4	1,056.9	1,064.4	1,072.0	1,079.5	1,087.1	1,094.8
70	984.9	992.2	999.5	1,006.9	1,014.3	1,021.7	1,029.1	1,036.5	1,043.9	1,051.4	1,058.9	1,066.4	1,074.0	1,081.5	1,089.1
80	979.0	986.4	993.7	1,001.1	1,008.4	1,015.8	1,023.2	1,030.6	1,038.1	1,045.5	1,053.0	1,060.5	1,068.0	1,075.6	1,083.1
90	972.7	980.0	987.4	994.7	1,002.1	1,009.5	1,017.0	1,024.4	1,031.8	1,039.3	1,046.8	1,054.3	1,061.8	1,069.3	1,076.8
100	965.8	973.2	980.6	988.0	995.4	1,002.8	1,010.3	1,017.7	1,025.2	1,032.7	1,040.2	1,047.7	1,055.2	1,062.7	1,070.3
110	958.5	965.9	973.3	980.8	988.3	995.7	1,003.2	1,010.7	1,018.2	1,025.7	1,033.2	1,040.8	1,048.3	1,055.9	1,063.4
120	950.7	958.2	965.7	973.2	980.7	988.2	995.8	1,003.3	1,010.9	1,018.4	1,026.0	1,033.6	1,041.2	1,048.7	1,056.3
130	942.4	950.0	957.6	965.2	972.8	980.4	988.0	995.6	1,003.2	1,010.8	1,018.5	1,026.1	1,033.7	1,041.3	1,049.0
140	933.8	941.4	949.1	956.8	964.5	972.2	979.9	987.6	995.2	1,002.9	1,010.6	1,018.3	1,026.0	1,033.7	1,041.4
150	924.7	932.5	940.3	948.1	955.9	963.7	971.4	979.2	987.0	994.8	1,002.5	1,010.3	1,018.0	1,025.8	1,033.6
160	915.2	923.2	931.1	939.0	946.9	954.8	962.7	970.6	978.5	986.3	994.2	1,002.0	1,009.9	1,017.7	1,025.5
170	905.4	913.5	921.6	929.6	937.7	945.7	953.7	961.7	969.7	977.6	985.6	993.5	1,001.4	1,009.3	1,017.2
180	895.3	903.5	911.7	919.9	928.1	936.3	944.4	952.6	960.7	968.7	976.8	984.8	992.8	1,000.8	1,008.7

* "Normal" seawater.
Source: Ref. 3 with permission.

Table 2.28 Thermophysical Properties of Selected Liquids at Temperatures Below Their Boiling Points

			T (°C)												
			−150	−100	−75	−50	−25	0	20	50	100	150	200	250	300
			T (K)												
Substance	Data	Property	123.15	173.15	198.15	223.15	248.15	273.15	293.15	323.15	373.15	423.15	473.15	523.15	573.15
Acetone	Chemical formula: C_3H_6O	Density ρ_l (kg/m³)	S	S	893	868	840	812	791	756	V	V	V	V	V
	Molecular weight: 58.08	Specific heat capacity													
	Melting point: −93.2°C	$c_{p,l}$ (kJ/kg K)	S	S	2.010	2.039	2.072	2.102	2.156	2.252	V	V	V	V	V
	Boiling point: 56.1°C	Thermal conductivity													
	Critical temperature: 235°C	λ_l [(W/m²)/(K/m)]	S	S	0.179	0.175	0.170	0.165	0.160	0.154	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 4.761 MPa	η_l (10^{-5} Ns/m²)	S	S	134.1	82.0	56.0	39.8	32.5	24.9	V	V	V	V	V
Acetylene	Chemical formula: C_2H_2	Density ρ_l (kg/m³)	S	S	612	V	V	V	V	V	V	V	V	V	V
	Molecular weight: 26.04	Specific heat capacity													
	Melting point: −80.75°C	$c_{p,l}$ (kJ/kg K)	S	S	(3.1)	V	V	V	V	V	V	V	V	V	V
	Boiling point: −83.95°C	Thermal conductivity													
	Critical temperature: 35.55°C	λ_l [(W/m²)/(K/m)]	S	S	(0.54)	V	V	V	V	V	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 6.24 MPa	η_l (10^{-5} Ns/m²)	S	S	(16)	V	V	V	V	V	V	V	V	V	V
Benzene	Chemical formula: C_6H_6	Density ρ_l (kg/m³)	S	S	S	S	S	S	879	847	V	V	V	V	V
	Molecular weight: 78.11	Specific heat capacity													
	Melting point: 5.55°C	$c_{p,l}$ (kJ/kg K)	S	S	S	S	S	S	1.729	1.821	V	V	V	V	V
	Boiling point: 80.11°C	Thermal conductivity													
	Critical temperature: 289.45°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	S	0.144	0.134	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 4.924 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	S	64.9	43.6	V	V	V	V	V
Dowtherm A	Chemical formula: Mixture $(C_6H_5)_2O$ (73.5%); $(C_6H_5)_2$ (26.5%)	Density ρ_l (kg/m³)	S	S	S	S	S	S	1,060	1,036	995	951	906	858	V
		Specific heat capacity													
		$c_{p,l}$ (kJ/kg K)	S	S	S	S	S	S	1.574	1.660	1.800	1.947	2.087	2.219	V
	Molecular weight: 166	Thermal conductivity													
	Melting point: 12°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	S	0.141	0.137	0.132	0.125	0.119	0.113	V
	Boiling point: 257.1°C	Dynamic viscosity													
	Critical temperature: 497°C	η_l (10^{-5} Ns/m²)	S	S	S	S	S	S	380	215	100	58	39	28	—
	Critical pressure: 3.134 MPa														
Dowtherm J	Chemical formula: $C_{10}H_{14}$	Density ρ_l (kg/m³)	S	S	S	917	897	888	872	842	801	754	V	V	V
	Molecular weight: 134	Specific heat capacity													
	Melting point: —	$c_{p,l}$ (kJ/kg K)	S	S	S	1.650	1.713	1.772	1.830	1.924	2.093	2.278	V	V	V
	Boiling point: 181°C	Thermal conductivity													
	Critical temperature: 383°C	λ_l [(W/m²)/(K/m)]	S	S	S	0.137	0.135	0.134	0.133	0.130	0.126	0.122	V	V	V
		Dynamic viscosity													
	Critical pressure: 2.837 MPa	η_l (10^{-5} Ns/m²)	S	S	S	410	225	140	90	62	36	22	V	V	V

S, solid; V, vapor; values in parentheses are estimated values.

			T (°C)											
			−150	−100	−75	−50	−25	0	20	50	100	150	200	250	300
			T (K)												
Substance	Data	Property	123.15	173.15	198.15	223.15	248.15	273.15	293.15	323.15	373.15	423.15	473.15	523.15	573.15
Ethanol	Chemical formula: C_2H_6O	Density ρ_l (kg/m³)	S	892	870	850	825	806	789	763	V	V	V	V	V
	Molecular weight: 46.07	Specific heat capacity													
	Melting point: −114.5°C	c_{pl} (kJ/kg K)	S	1.901	1.947	2.014	2.093	2.232	2.395	2.801	V	V	V	V	V
	Boiling point: 78.3°C	Thermal conductivity													
	Critical temperature: 243.10°C	λ_l [(W/m²)/(K/m)]	S	0.197	0.193	0.188	0.183	0.177	0.173	0.165	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 6.39 MPa	η_l (10^{-5} Ns/m²)	S	4,701	1,526	640	324.1	1768.6	120.1	70.1	V	V	V	V	V
Ethylene	Chemical formula: C_2H_4	Density ρ_l (kg/m³)	630	V	V	V	V	V	V	V	V	V	V	V	V
	Molecular weight: 28.05	Specific heat capacity													
	Melting point: −169.15°C	c_{pl} (kJ/kg K)	2.433	V	V	V	V	V	V	V	V	V	V	V	V
	Boiling point: −103.72°C	Thermal conductivity													
	Critical temperature: 9.5°C	λ_l [(W/m²)/(K/m)]	0.242	V	V	V	V	V	V	V	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 5.06 MPa	η_l (10^{-5} Ns/m²)	41.0	V	V	V	V	V	V	V	V	V	V	V	V
Ethylene Glycol	Chemical formula: C_2H_6O	Density ρ_l (kg/m³)	S	S	S	S	S	1,128	1,115	1091	1,055	1,016	V	V	V
	Molecular weight: 62.07	Specific heat capacity													
	Melting point: −12.95°C	c_{pl} (kJ/kg K)	S	S	S	S	S	2.261	2.357	2.500	2.847	(2.94)	V	V	V
	Boiling point: 197.25°C	Thermal conductivity													
	Critical temperature: 371.85C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	0.254	0.256	0.260	0.265	(0.252)	V	V	V
		Dynamic viscosity													
	Critical pressure: 7.7 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	5,701	2,041	707	202	85.9	V	V	V
Glycerol	Chemical formula: $C_3H_8O_3$	Density ρ_l (kg/m³)	S	S	S	S	S	S	1,260	1,242	1,209	1,154	1,090	(1007)	V
	Molecular weight: 92.09	Specific heat capacity													
	Melting point: 17.85°C	c_{pl} (kJ/kg K)	S	S	S	S	S	S	2.366	2.512	2.805	3.06	3.34	(3.74)	V
	Boiling point: 290°C	Thermal conductivity													
	Critical temperature: 452.85°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	S	0.286	0.290	0.297	0.300	0.295	0.282	V
		Dynamic viscosity													
	Critical pressure: 6.69 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	S	149900	(18000)	1300	170	22.0	(3.0)	V
Heptane	Chemical formula: C_7H_{16}	Density ρ_l (kg/m³)	S	S	761	741	721	701	684	658	V	V	V	V	V
	Molecular weight: 100.20	Specific heat capacity													
	Melting point: −90.55°C	c_{pl} (kJ/kg K)	S	S	2.104	2.035	2.081	2.144	2.198	2.307	V	V	V	V	V
	Boiling point: 98.45°C	Thermal conductivity													
	Critical temperature: 267.46°C	λ_l [(W/m²)/(K/m)]	S	S	0.156	0.148	0.139	0.131	0.124	0.114	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 2.736 MPa	η_l (10^{-5} Ns/m²)	S	S	129.0	96.6	72.5	52.6	41.3	30.2	V	V	V	V	V
Hexane	Chemical formula: C_6H_{14}	Density ρ_l (kg/m³)	S	S	742	721	700	678	659	631	V	V	V	V	V

	Molecular weight: 86.18 Melting point: −95.32°C Boiling point: 68.73°C Critical temperature: 234.29°C Critical pressure: 3.031 MPa	Specific heat capacity c_{pl} (kJ/kg K) Thermal conductivity λ_l [(W/m²)/(K/m)] Dynamic viscosity η_l (10^{-5} Ns/m²)	S S S	S S S	1.993 0.156 92.0	2.035 0.146 68.5	2.093 0.137 51.5	2.165 0.127 38.3	2.227 0.120 30.8	(2.37) 0.110 22.9	V V V	V V V	V V V	V V V	V V V
Ketene	Chemical formula: C_2H_2O Molecular weight: 42.04 Melting point: −135.15°C Boiling point: −41.15°C Critical temperature: 106.85°C Critical pressure: 6.48 MPa	Density ρ_l (kg/m³) Specific heat capacity c_{pl} (kJ/kg K) Thermal conductivity λ_l [(W/m²)/(K/m)] Dynamic viscosity η_l (10^{-5} Ns/m²)	S S S S	(1080) (1.79) (0.267) —	(1030) (1.92) (0.250) —	(979) (2.02) (0.233) (110)	V V V V	V V V V	V V V V	V V V V	V V V V	V V V V	V V V V	V V V V
Naphthalene	Chemical formula: $C_{10}H_8$ Molecular weight: 128.17 Melting point: 80.35°C Boiling point: 217.95°C Critical temperature: 475.25°C Critical pressure: 4.05 MPa	Density ρ_l (kg/m³) Specific heat capacity c_{pl} (kJ/kg K) Thermal conductivity λ_l [(W/m²)/(K/m)] Dynamic viscosity η_l (10^{-5} Ns/m²)	S S S S	S S S S	S S S S	S S S S	S S S S	S S S S	S S S S	S S S S	963 1.805 0.137 77.4	922 1.993 0.130 52.0	(878) 2.139 0.123 37.5	V V V V	V V V V
Nitrogen Dioxide	Chemical formula: NO_2 Molecular weight: 46.01 Melting point: −11.25°C Boiling point: 21.15°C Critical temperature: 158.25°C Critical pressure: 1.013 MPa	Density ρ_l (kg/m³) Specific heat capacity c_{pl} (kJ/kg K) Thermal conductivity λ_l [(W/m²)/(K/m)] Dynamic viscosity η_l (10^{-5} Ns/m²)	S S S S	S S S S	S S S S	S S S S	S S S S	S S S S	S S S S	1,494 1.505 0.140 49.4	1,446 1.535 0.130 4.21	V V V V	V V V V	V V V V	V V V V
Pentane	Chemical formula: C_5H_{12} Molecular weight: 72.15 Melting point: −129.75°C Boiling point: 36.05°C Critical temperature: 196.45°C Critical pressure: 3.369 MPa	Density ρ_l (kg/m³) Specific heat capacity c_{pl} (kJ/kg K) Thermal conductivity λ_l [(W/m²)/(K/m)] Dynamic viscosity η_l (10^{-5} Ns/m²)	S S S S	737 1.972 0.155 125.0	715 2.001 0.151 66.0	693 2.060 0.148 48.4	670 2.123 0.144 36.4	646 2.206 0.140 27.7	626 2.273 0.136 22.7	V V V V	V V V V	V V V V	V V V V	V V V V
Propylene	Chemical formula: C_3H_6 Molecular weight: 42.08 Melting point: −185.25°C Boiling point: −47.7°C Critical temperature: 91.65°C Critical pressure: 4.61 MPa	Density ρ_l (kg/m³) Specific heat capacity c_{pl} (kJ/kg K) Thermal conductivity λ_l [(W/m²)/(K/m)] Dynamic viscosity η_l (10^{-5} Ns/m²)	729 2.098 0.217 129.1	671 2.085 0.179 37.0	641 2.123 0.160 26.5	612 2.177 0.145 19.2	V V V V	V V V V	V V V V	V V V V	V V V V	V V V V	V V V V	V V V V

S, solid; V, vapor; values in parentheses are estimated values.

Substance	Data	Property	T (°C) −150	−100	−75	−50	−25	0	20	50	100	150	200	250	300
			T (K) 123.15	173.15	198.15	223.15	248.15	273.15	293.15	323.15	373.15	423.15	473.15	523.15	573.15
Toluene	Chemical formula: C_7H_8	Density ρ_l (kg/m³)	S	S	955	932	908	885	867	839	793	V	V	V	V
	Molecular weight: 92.14	Specific heat capacity													
	Melting point: −94.99°C	c_{pl} (kJ/kg K)	S	S	1.465	1.507	1.553	1.612	1.717	1.800	1.968	V	V	V	V
	Boiling point: 110.63°C	Thermal conductivity													
	Critical temperature: 320.85°C	λ_l [(W/m²)/(K/m)]	S	S	0.156	0.152	0.148	0.144	0.141	0.136	0.128	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 4.05 MPa	η_l (10^{-5} Ns/m²)	S	S	500	212	117.0	77.3	58.6	41.9	26.9	V	V	V	V

Substance	Data	Property	T (°C) −200	−180	−160	−140	−120	−100	−50	0	20	50	100	150	200
			T (K) 73.15	93.15	113.15	133.15	153.15	173.15	223.15	273.15	293.15	323.15	373.15	423.15	473.15
Ammonia	Chemical formula: NH_3	Density ρ_l (kg/m³)	S	S	S	S	S	S	695	V	V	V	V	V	V
	Molecular weight: 17.03	Specific heat capacity													
	Melting point: −77.7°C	c_{pl} (kJ/kg K)	S	S	S	S	S	S	4.45	V	V	V	V	V	V
	Boiling point: −33.41°C	Thermal conductivity													
	Critical temperature: 132.4°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	S	0.547	V	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 11.29 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	S	31.7	V	V	V	V	V	V
Bromine	Chemical formula: Br_2	Density ρ_l (kg/m³)	S	S	S	S	S	S	S	3,208	3,140	(3040)	V	V	V
	Molecular weight: 159.81	Specific heat capacity													
	Melting point: −8.25°C	c_{pl} (kJ/kg K)	S	S	S	S	S	S	S	0.448	0.452	0.456	V	V	V
	Boiling point: 58.75°C	Thermal conductivity													
	Critical temperature: 310.85°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	S	S	(0.129)	0.124	0.117	V	V	V
		Dynamic viscosity													
	Critical pressure: 10.3 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	S	S	124	99.6	76.2	V	V	V
Carbon Tetrachloride	Chemical formula: CCl_4	Density ρ_l (kg/m³)	S	S	S	S	S	S	S	1,633	1,594	1,534	V	V	V
	Molecular weight: 153.82	Specific heat capacity													
	Melting point: −22.9°C	c_{pl} (kJ/kg K)	S	S	S	S	S	S	S	0.842	0.850	0.862	V	V	V
	Boiling point: 76.7°C	Thermal conductivity													
	Critical temperature: 283.21°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	S	S	0.107	0.106	0.105	V	V	V
		Dynamic viscosity													
	Critical pressure: 4.56 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	S	S	134.9	96.1	65.4	V	V	V
Chlorine	Chemical formula: Cl_2	Density ρ_l (kg/m³)	S	S	S	S	S	1,717	1,598	V	V	V	V	V	V
	Molecular weight: 70.91	Specific heat capacity													
	Melting point: −100.50°C	c_{pl} (kJ/kg K)	S	S	S	S	S	0.883	0.892	V	V	V	V	V	V
	Boiling point: −34.04°C	Thermal conductivity													
	Critical temperature: 144.0°C	λ_l [(W/m²)/(K/m)]	S	S	S	S	S	0.198	0.186	V	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 7.71 MPa	η_l (10^{-5} Ns/m²)	S	S	S	S	S	104.0	55.4	V	V	V	V	V	V
Fluorine	Chemical formula: F_2	Density ρ_l (kg/m³)	1,140	V	V	V	V	V	V	V	V	V	V	V	V
	Molecular weight: 38.00	Specific heat capacity													
	Melting point: −220.15°C	c_{pl} (kJ/kg K)	1.51	V	V	V	V	V	V	V	V	V	V	V	V
	Boiling point: −187.95°C	Thermal conductivity													
	Critical temperature: −129.15°C	λ_l [(W/m²)/(K/m)]	(0.155)	V	V	V	V	V	V	V	V	V	V	V	V
		Dynamic viscosity													
	Critical pressure: 5.32 MPa	η_l (10^{-5} Ns/m²)	34.9	V	V	V	V	V	V	V	V	V	V	V	V

S, solid; V, vapor; values in parentheses are estimated values.
Source: Ref. 5 with permission.

Table 2.29 Thermophysical Properties of Liquid Metals

Composition	Melting point (K)	T (K)	ρ (kg/m^3)	c_p (kJ/kg·K)	ν · 10^7 (m^2/s)	k (W/m·K)	α · 10^5 (m^2/s)	Pr
Bismuth	544	589	10,011	0.1444	1.617	16.4	0.138	0.0142
		811	9,739	0.1545	1.133	15.6	1.035	0.0110
		1033	9,467	0.1645	0.8343	15.6	1.001	0.0083
Lead	600	644	10,540	0.159	2.276	16.1	1.084	0.024
		755	10,412	0.155	1.849	15.6	1.223	0.017
		977	10,140	—	1.347	14.9	—	—
Potassium	337	422	807.3	0.80	4.608	45.0	6.99	0.0066
		700	741.7	0.75	2.397	39.5	7.07	0.0034
		977	674.4	0.75	1.905	33.1	6.55	0.0029
Sodium	371	366	929.1	1.38	7.516	86.2	6.71	0.011
		644	860.2	1.30	3.270	72.3	6.48	0.0051
		977	778.5	1.26	2.285	59.7	6.12	0.0037
NaK (45%/55%)	292	366	887.4	1.130	6.522	25.6	2.552	0.026
		644	821.7	1.055	2.871	27.5	3.17	0.0091
		977	740.1	1.043	2.174	28.9	3.74	0.0058
NaK (22%/78%)	262	366	849.0	0.946	5.797	24.4	3.05	0.019
		672	775.3	0.879	2.666	26.7	3.92	0.0068
		1033	690.4	0.883	2.118	—	—	—
PbBi (44.5%/55.5%)	398	422	10,524	0.147	—	9.05	0.586	—
		644	10,236	0.147	1.496	11.86	0.790	0.189
		922	9,835	—	1.171	—	—	—

Adapted from *Liquid Materials Handbook,* 23rd ed., the Atomic Energy Commission, Department of the Navy, Washington, DC, 1952.

2.4. THERMOPHYSICAL PROPERTIES OF SOLIDS

Table 2.30 Density of Selected Elements (kg/m^3)

	Symbol								
T (K)	Al	Sb*	Ba	Be*	Bi*	Cd*	Ca	Ce	Cs
50	2736	6734	3650	1863	9880	8830	1572		1962
100	2732	6726	3640	1862	9870	8800	1568		1944
150	2726	6716	3630	1861	9850	8760	1563		1926
200	2719	6706	3620	1860	9830	8720	1559		1907
250	2710	6695	3610	1858	9810	8680	1554		1887
300	2701	6685	3600	1855	9790	8640	1550	6860	1866
400	2681	6662	3580	1848	9750	8560	1539	6850	1781
500	2661	6638	3555	1840	9710	8470	1528	6840	1723
600	2639	6615	3530	1831		8010	1517	6820	1666
800	2591	6569		1812		7805		6790	1552
1000	2365	6431	___	1790		7590	___	6760	1438
1200	2305	6307		1768					1311
1400	2255	6170		1744					1182
1600									
1800									
2000									

* Polycrystalline form tabulated. Above the horizontal line the condensed phase is solid; below, it is liquid.
† Hysteresis effect present.

	Symbol										
T (K)	Cr	Cu	Co	Dy*	Er	Eu*	Gd*	Ga	Ge	Au	Hf
50	7160	9019	8925	8578	9120		7966		5363	19,490	13,350
100	7155	9009	8919	8579	9105		7960		5358	19,460	13,340
150	7150	8992	8905	8581	9090		7954		5353	19,420	13,330
200	7145	8973	8892	8580	9080		7949		5348	19,380	13,320
250	7140	8951	8876	8567	9070		†		5344	19,340	13,310
300	7135	8930	8860	8554	9060	5240	†	5910	5340	19,300	13,300
400	7120	8884	8823	8530	9030	5190	†	6010	5330	19,210	13,275
500	7110	8837	8784	8507	9000	5155	7926	5946	5320	19,130	13,250
600	7080	8787	8744	8484	8970	5127	7907	5880	5310	19,040	13,220
800	7040	8686	8642	8431	8910		7866	5770	5290	18,860	13,170
1000	7000	8568	8561	8377	8840	___	7818	5650	5265	18,660	13,110
1200	6945	8458	8475		8740		7754	5540	5240	18,440	13,050
1400	6890	7920					___	5420		17,230	
1600	6830	7750	___	___	___					16,950	
1800	6760	7600	7630								
2000	6700	7460	7410								___

	Ho	In*	Ir	Fe	La*	Pb	Li	Lu*	Mg	Mo
50	8820	7460	22,600	7910	6203	11,570	547	9830	1765	10,260
100	8815	7430	22,580	7900	6200	11,520	546	9840	1762	10,260
150	8810	7400	22,560	7890	6196	11,470	543	9840	1757	10,250
200	8800	7370	22,540	7880	6193	11,430	541	9850	1752	10,250
250	8790	7340	22,520	7870	6190	11,380	537	9840	1746	10,250
300	8780	7310	22,500	7860	6187	11,330	533	9830	1740	10,240
400	8755	7230	22,450	7830	6180	11,230	526	9800	1736	10,220
500	8730	6980	22,410	7800	6160	11,130	492	9770	1731	10,210
600	8700	6810	22,360	7760	6170	11,010	482	9740	1726	10,190
800	8650		22,250	7690	6140	10,430	462	9660	1715	10,160
1000	8600		22,140	7650	6160	10,190	442	9580	1517	10,120
1200			22,030	7620		9,940	442	9500	1409	10,080
1400			21,920	7520			402			10,040
1600	___		21,790	7420			381			10,000
1800			21,660	7320			361	___		9,950
2000			21,510	7030			341			9,900

	Ni	Nb	Os	Pd	Pt	Pu	K	Pa*
50	8960	8610	22,550	12,110	21,570	20,270	905	
100	8960	8600	22,540	12,100	21,550	20,170	898	
150	8940	8590	22,520	12,090	21,530	20,080	890	
200	8930	8580	22,510	12,070	21,500	19,990	882	
250	8910	8570	22,490	12,050	21,470	19,860	873	
300	8900	8570	22,480	12,030	21,450	19,730	863	15,370
400	8860	8550	22,450	11,980	21,380	17,720	814	15,320
500	8820	8530	22,420	11,940	21,330	17,920	790	15,280
600	8780	8510	22,390	11,890	21,270	15,300	767	15,230
800	8690	8470	22,320	11,790	21,140	16,370	720	15,150

* Polycrystalline form tabulated. Above the horizontal line the condensed phase is solid; below, it is liquid.
† Hysteresis effect present.

	Symbol							
T (K)	Ni	Nb	Os	Pd	Pt	Pu	K	Pa*
1000	8610	8430	22,250	11,680	21,010		672	15,050
1200	8510	8380		11,570	20,870		623	14,910
1400	8410	8340			20,720		574	
1600	8320	8290			20,570		527	
1800	7690	8250			20,400			
2000	7450	8200			20,220			

	Re*	Rh	Rb	Sc*	Ag	Na	Sr	Ta
50	21,100	12,490			10,620	1014	2655	16,500
100	21,070	12,480			10,600	1007	2638	16,490
150	21,040	12,470			10,575	999	2632	16,480
200	21,020	12,460			10,550	990	2621	16,460
250	21,010	12,445			10,520	980	2618	16,450
300	21,000	12,430		3000	10,490	970	2615	16,440
400	20,960	12,400	14,320	2990	10,430	921		16,410
500	20,920	12,360	13,860	2980	10,360	897		16,370
600	20,880	12,330	13,400	2970	10,300	874		16,340
800	20,800	12,250	12,340	2950	10,160	826		16,270
1000	20,710	12,170	11,560	2930	10,010	779		16,200
1200	20,630	12,080	10,640	2910	9,850	731		16,130
1400	20,540	11,980	9,720		9,170	683		16,060
1600	20,450	11,880			8,980	638		15,980
1800	20,350							15,910
2000	20,250							15,820

	Tl	Th	Tm*	Sn	Ti	W	U*	V	Yb	Y*	Zn*	Zr*
50	12,080	11,745	9370		4530	19,320	19,240	6080		4500	7280	6540
100	12,040	11,740	9360		4510	19,310	19,210	6074		4490	7260	6535
150	12,000	11,745	9350		4515	19,300	19,170	6068		4485	7230	6530
200	11,950	11,750	9340		4520	19,290	19,140	6062		4480	7200	6525
250	11,900	11,735	9330		4515	19,280	19,100	6056		4475	7170	6520
300	11,850	11,720	9320	7280	4510	19,270	19,070	6050	7020	4470	7135	6515
400	11,730	11,680	9280		4490	19,240	18,980	6030	6960	4450	7070	6510
500	11,500	11,630	9250	6900	4480	19,220	18,890	6010	6900	4440	7000	6490
600	11,250	11,590	9210	6900	4470	19,190	18,790	6000	6850	4420	6935	6480
800	10,960	11,500	9150	6760	4440	19,130	18,550	5960	6720	4390	6430	6450
1000		11,400	9080	6620	4410	19,080	18,110	5920	6590	4360	6260	6420
1200		11,300		6480	4380	19,020	17,760	5880		4320		6410
1400				6340	4350	18,950	17,530	5830				6380
1600					4320	18,890		5780				6340
1800						18,830		5730				6300
2000					4110	18,760						6260

* Polycrystalline form tabulated. Above the horizontal line the condensed phase is solid; below, it is liquid.
† Hysteresis effect present.

Table 2.31 Heat Capacity of Selected Elements (kJ/kg K)

	T (K)																		
Symbol	10	15	20	25	30	40	50	60	80	100	150	200	250	300	400	500	600	800	1000	1200
Al	0.00014	0.00040	0.00089	0.01175	0.03315	0.07775	0.1422	0.2142	0.3567	0.4811	0.6833	0.7977	0.8599	0.9029	0.9499	0.9977	1.0422	1.1344	0.9211	0.9211
Sb	0.00021	0.00069	0.02600	0.04002	0.05546	0.08332	0.1033	0.1355	0.1600	0.1691	0.1911	0.2000	0.2055	0.2099	0.2133	0.2199	0.2255	0.2377	0.2588	0.2588
Ba	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1922	0.2022	0.2133	0.2222	0.2477	0.2099	0.2299
Be	0.00003	0.00009	0.00014	0.00028	0.00042	—	0.01186	—	—	0.1955	0.6100	1.1099	1.5377	1.8400	2.1911	2.4422	2.6055	2.8233	3.0188	3.2177
Bi	0.01004	0.02440	0.03440	0.04887	0.05779	0.07229	0.08555	0.0922	0.1022	0.1099	0.1177	0.1200	0.1211	0.1222	0.1233	—	0.1422	0.1366	0.1311	—
Cd	0.00082	0.02333	0.04662	0.06366	0.08660	0.1188	0.1455	0.1599	0.1833	0.1988	0.2133	0.2221	0.2277	0.2311	0.2422	0.2522	—	—	—	—
Ca	0.00042	0.01157	0.03996	0.06647	0.09330	0.1944	0.2711	0.3400	0.4277	0.4866	0.5733	0.6177	0.6400	0.6656	0.6855	0.7299	0.7633	0.8433	0.9911	0.7722
Ce	0.03314	0.03440	0.05526	0.07335	0.09220	—	0.09926	—	—	0.1933	0.2000	0.2066	0.2099	0.2122	0.2188	0.2300	0.2422	0.2666	0.2900	—
Cs	0.08331	0.12331	0.14770	0.15999	0.16887	—	0.18226	—	—	0.19339	0.2022	0.2088	0.2188	—	0.2400	0.2322	0.2244	0.2177	0.2311	0.2488
Cr	0.00008	0.00012	0.00021	0.00045	0.00077	0.01107	0.0388	0.0599	0.1277	0.1900	0.3177	0.3822	0.4244	0.4500	0.5001	0.5377	0.5655	0.6111	0.6533	0.6922
Co	0.00012	0.00026	0.00048	0.01106	0.01171	0.04404	0.0700	0.1100	0.1844	0.2344	0.3299	0.3766	0.4066	0.4266	0.4551	0.4844	0.5099	0.5433	0.6311	0.6511
Cu	0.00009	0.00027	0.00076	0.01158	0.02270	0.0599	0.0999	0.1377	0.2033	0.2544	0.3233	0.3577	0.3777	0.3866	0.3966	0.4066	0.4311	0.4488	0.4466	0.4800
Dy	0.00046	0.01154	0.03445	0.05566	0.07883	—	0.1422	—	—	0.2144	0.2800	0.1799	0.1733	0.1688	0.1700	0.1766	0.1811	0.1900	0.1988	0.2055
Er	0.01118	0.04000	0.12556	0.09333	0.11551	—	0.1700	—	—	0.1477	0.1555	0.1622	0.1655	0.1688	0.1722	0.1766	0.1799	0.1877	0.1944	0.2000

Symbol	T (K) 10	15	20	25	30	40	50	60	80	100	150	200	250	300	400	500	600	800	1000	1200
Eu	0.02256	0.05573	0.06655	0.09111	—	—	—	—	—	—	—	—	—	0.176	0.182	0.187	0.193	0.204	0.215	—
Gd	0.00048	0.01122	0.02282	0.04071	0.06649	—	0.1235	—	—	0.184	0.208	0.230	0.265	0.231	0.186	0.191	0.195	0.204	0.213	—
Ga	0.00035	0.01150	0.03222	0.05504	0.07714	0.110	0.154	0.177	0.216	0.266	0.316	0.341	0.359	0.377	—	—	—	—	—	—
Ge	0.00008	0.00044	0.01129	0.02236	0.03663	0.06619	0.08660	0.108	0.153	0.192	0.257	0.286	0.305	0.323	0.343	0.355	0.364	0.377	0.390	0.396
Au	0.00026	0.00074	0.01163	0.02263	0.03670	0.05569	0.072	0.084	0.100	0.109	0.119	0.124	0.127	0.129	0.131	0.133	0.136	0.141	0.147	0.153
Hf	0.00009	0.00038	0.00096	0.01180	0.02281	—	0.068	—	—	0.115	0.131	0.137	0.141	0.143	0.146	0.149	0.151	0.157	0.163	0.169
Ho	0.01162	0.03398	0.05580	0.07556	0.09331	—	0.149	—	—	—	0.161	0.161	0.163	0.165	0.170	0.174	0.178	0.187	0.195	—
In	0.01155	0.03367	0.06008	0.08557	0.108	0.140	0.159	0.176	0.193	0.214	0.220	0.224	0.227	0.233	0.252	—	—	—	—	—
Ir	0.00003	0.00008	0.00021	0.00048	0.00094	—	0.03381	—	—	0.09003	0.113	0.122	0.128	0.131	0.133	0.137	0.140	0.146	0.152	—
Fe	0.00013	0.00026	0.00039	0.00075	0.01124	0.02776	0.054	0.086	0.154	0.216	0.324	0.384	0.422	0.450	0.491	0.524	0.555	0.692	1.034	—
La	0.00078	0.02241	0.04446	0.06663	0.07750	0.113	0.133	0.145	0.161	0.170	0.182	—	—	0.200	0.205	0.210	0.215	0.224	0.234	—
Pb	0.01135	0.03351	0.05531	0.06678	0.07796	0.09944	0.103	0.108	0.114	0.118	0.122	0.125	0.127	0.129	0.132	0.137	0.142	—	—	—

Symbol	T (K)																		
	10	15	20	25	30	40	50	60	80	100	150	200	250	300	400	500	600	800	1000	1200
Li	0.00090	0.02559	0.05573	0.10125	0.16888	—	0.549	—	—	1.923	2.701	3.105	3.377	3.54	3.76	4.34	4.26	4.17	4.15	4.14
Lu	0.00029	0.00096	0.02010	0.03349	0.04883	—	0.091	—	—	0.129	0.141	0.147	0.151	0.154	0.158	0.161	0.165	0.172	0.179	—
Mg	0.00017	0.00066	0.01448	0.03110	0.05668	0.138	0.243	0.336	0.513	0.648	0.842	0.929	0.985	1.005	1.082	1.131	1.177	1.263	—	—
Mn (α)	0.00031	0.00052	0.00091	0.01145	0.02251	0.046	0.088	0.127	0.213	0.268	0.365	0.420	0.454	0.481	0.510	0.551	0.581	0.635	0.688	—
Hg	0.02225	0.03559	0.05515	0.06333	0.07737	0.08895	0.09993	0.107	0.116	0.121	0.129	0.136	0.141	0.139	0.136	0.135	0.135	0.104	—	—
Mo	0.00005	0.00013	0.00029	0.00058	0.00096	0.00236	0.00410	0.00610	0.0105	0.0140	0.0196	0.0223	0.0241	0.0248	0.0261	0.0268	0.0274	0.0280	0.0292	—
Nd	0.03565	0.05519	0.07711	0.08827	0.09883	0.1200	0.1500	0.1600	0.1778	0.1855	0.1966	—	—	—	0.2255	0.2400	0.2555	0.2877	0.3188	—
Ni	0.00018	0.00031	0.00058	0.01000	0.01166	0.03380	0.0688	0.1033	0.1733	0.2322	0.3299	0.3833	0.4166	0.4444	0.4900	0.5400	0.5900	0.5300	0.5566	0.5822
Nb	0.00022	0.00054	0.01773	0.02210	0.03350	0.06680	0.099	0.127	0.173	0.202	0.238	0.254	0.263	0.268	0.272	0.277	0.281	0.290	0.298	0.307
Os	—	—	—	—	—	—	—	—	—	—	—	—	—	0.131	0.133	0.135	0.137	0.141	0.145	0.148
Pd	0.00021	0.00047	0.00091	0.01161	0.02259	0.05009	0.077	0.101	0.141	0.168	0.208	0.228	0.238	0.245	0.250	0.255	0.261	0.271	0.282	0.293
Pt	0.00011	0.00034	0.00077	0.01139	0.02211	0.03382	0.054	0.069	0.088	0.101	0.118	0.127	0.132	0.134	0.136	0.138	0.140	0.146	0.152	0.158
Pu	—	—	—	—	—	—	—	—	—	—	0.096	0.111	0.124	0.132	—	—	—	—	—	—

Symbol	T (K)																		
	10	15	20	25	30	40	50	60	80	100	150	200	250	300	400	500	600	800	1000	1200
K	—	—	—	—	—	—	—	—	—	—	0.672	0.694	0.718	0.768	0.805	0.785	0.771	0.761	0.792	0.846
Pr	0.02994	0.06000	0.09444	0.12990	0.15505	—	0.184	—	—	0.186	0.191	0.193	0.195	0.197	0.201	0.211	0.220	0.240	0.258	—
Pa	—	—	—	—	—	—	—	—	—	—	—	—	—	0.126	0.131	0.137	0.143	0.153	0.165	—
Re	—	—	0.00034	0.00072	0.00121	—	0.043	—	—	0.097	0.120	0.130	0.137	0.138	0.139	0.142	0.145	0.151	0.156	—
Rh	0.00007	0.00014	0.00027	0.00056	0.00106	0.00266	0.00489	0.0072	0.0114	0.0147	0.0195	0.0220	0.0234	0.0246	0.0257	0.0265	0.0274	0.0290	0.0307	—
Rb	0.08447	0.14444	0.18775	0.21998	0.23999	—	0.27241	—	—	0.299	0.310	0.321	0.335	0.365	0.367	—	—	—	—	—
Ru	0.00004	0.00009	0.00017	0.00035	0.00070	—	0.00368	—	—	0.0134	0.0187	0.0215	0.0229	0.0238	0.0242	0.0248	0.0255	0.0267	0.0279	—
Sc	0.00035	0.00081	0.00158	0.00270	0.00437	—	0.01433	—	—	0.0365	0.0470	0.0520	0.0548	0.0564	0.0570	0.0580	0.0589	0.0610	0.0630	—
Ag	0.00019	0.00066	0.00159	0.00291	0.00443	0.00778	0.0108	0.0133	0.0166	0.0187	0.0213	0.0225	0.0232	0.0236	0.0240	0.0245	0.0251	0.0264	0.0276	0.0291
Na	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.37	1.33	1.30	1.26	1.26	1.29
Sr	—	—	—	—	—	—	—	—	—	—	—	—	—	0.301	0.318	0.334	0.349	0.382	0.454	0.353
Ta	0.00012	0.00036	0.00082	0.00152	0.00237	0.00421	0.00590	0.0075	0.0095	0.0108	0.0125	0.0132	0.0137	0.0141	0.0145	0.0148	0.0149	0.0152	0.0160	—
Te	0.00069	0.00203	0.00354	0.00508	0.00737	0.00922	0.0116	0.0132	0.0155	0.0169	0.0186	0.0193	0.0197	0.0201	0.0206	0.0211	0.0216	0.0225	—	—

Symbol	*T* (K) 10	15	20	25	30	40	50	60	80	100	150	200	250	300	400	500	600	800	1000	1200
Tl	0.01166	0.03326	0.04491	0.06651	0.07778	0.09920	0.1033	0.1088	0.1116	0.1120	0.1124	0.1126	0.1128	0.1130	0.1136	0.1143	—	—	—	—
Th	0.00029	0.00094	0.00200	0.00325	0.00433	—	0.0073	—	—	0.0099	0.0108	0.0112	0.0115	0.0118	0.0124	0.0129	0.0134	0.0145	0.0156	0.0167
Tm	0.01116	0.03327	0.06629	0.09973	0.13005	—	0.2266	—	—	0.1500	0.1544	0.1577	0.1588	0.1600	0.1633	0.1667	0.1711	0.1778	0.1866	—
Sn	0.00078	0.00226	0.00400	0.00582	0.00760	0.0108	0.0130	0.0149	0.0173	0.0189	0.0206	0.0214	0.0220	0.0222	0.0245	0.0267	0.0257	0.0257	0.0257	—
Ti	0.00013	0.00033	0.00069	0.00140	0.00248	0.00516	0.0094	0.0144	0.0227	0.0295	0.0406	0.0464	0.0501	0.0525	0.0555	0.0578	0.0597	0.0627	0.0652	—
W	0.00002	0.00007	0.00019	0.00042	0.00078	0.00184	0.00332	0.0048	0.0072	0.0089	0.0113	0.0125	0.0131	0.0135	0.0137	0.0139	0.0140	0.0144	0.0148	—
U	0.00015	0.00055	0.00128	0.00230	0.00339	—	0.0659	—	—	0.0094	0.0103	0.0109	0.0114	0.0117	0.0124	0.0134	0.0145	0.0174	0.0178	—
V	0.00023	0.00043	0.00072	0.00107	0.00189	0.00420	0.00730	0.0115	0.0190	0.0257	0.0379	0.0434	0.0462	0.0483	0.0512	0.0528	0.0540	0.0563	0.0598	—
Yb	0.00085	0.00254	0.00457	0.00653	0.00808	—	0.0116	—	—	0.0139	0.0145	0.0149	0.0151	0.0155	0.0160	0.0171	0.0172	0.0178	0.0185	0.0213
Y	0.00026	0.00089	0.00212	0.00329	0.00593	—	0.0137	—	—	0.0233	0.0265	0.0282	0.0292	0.0298	0.0305	0.0313	0.0321	0.0338	0.0354	0.0372
Zn	0.00025	0.00109	0.00269	0.00493	0.00760	0.0123	0.0170	0.0205	0.0258	0.0295	0.0345	0.0366	0.0380	0.0389	0.0404	0.0419	0.0435	0.0479	0.0479	—
Zr	0.00014	0.00046	0.00119	0.00220	0.00344	0.00941	0.0101	0.0108	0.0116	0.0120	0.0124	0.0126	0.0128	0.0130	0.0136	0.0143	0.0153	0.0153	0.0153	—

Table 2.32 Thermal Conductivity and Density of Selected Elements

Substance	Chemical formula	T (°C)	T (°K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Aluminum, 99.75%	Al	–190	83.15		255.860
		0	273.15	2,700	229.111
		200	473.15		229.111
		300	573.15		222.133
		800	1073.15		125.604
99%		–100	173.15	—	209.340
		0	273.15		209.340
		100	373.15		207.014
		300	573.15		222.133
Antimony, very pure	Sb	–190	83.15		20.934
		–100	173.15		19.190
		0	273.15		17.678
		100	373.15	6,690	16.282
		300	573.15		15.817
		500	773.15		18.608
Beryllium, 99.5%	Be	–250	23.15		94.203
		–100	173.15		125.604
		0	273.15	1,850	160.494
		100	373.15		190.732
		200	473.15		215.155
Bismuth	Bi	–190	83.15		25.586
		–100	173.15		12.095
		0	273.15	9,800	8.374
		100	373.15		7.211
		200	473.15		7.211
Cadmium, pure	Cd	–190	83.15		104.670
		–100	173.15		96.529
		0	273.15	8,620	93.040
		100	373.15		91.877
		200	473.15		91.296
		300	573.15		87.807
Cobalt, 97.1%	Co	20	293.15	≈8,900	69.780
Copper, pure	Cu	–180	93.15		464.037
99.9–98%		–100	173.15		407.050
		0	273.15	8,930	386.116
		100	373.15		379.138
		200	473.15		373.323
		400	673.15		364.019
		600	873.15		353.552
Commercial		20	293.15	8,300	372.160
Electrolytic, pure		–180	93.15		488.460
		0	273.15	8,900	395.420
		100	373.15		391.931
		300	573.15		381.464
		800	1073.15		367.508
Gold 99.999%	Au	–190	83.15		327.966
		0	273.15	19,290	310.521
		100	373.15		310.521
		300	573.15		304.706
99.98%		0	273.15		294.239
		100	373.15		294.239

Substance	Chemical formula	T (°C)	T (°K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Iridium, pure	Ir	0	273.15	22,420	59.313
		100	373.15		56.987
Iron (Armc)	Fe	20	293.15	7,850	73.169
99.92%		100	373.15		67.454
		200	473.15		61.639
		400	673.15		48.846
		600	873.15		38.379
		800	1073.15		29.075
Cast, 1% Ni		20	293.15	7,280	50.009
		100	373.15		49.428
		300	573.15		46.520
		500	773.15		37.216
Cast, 3% C		20	293.15	7,280	55.824 . . . 63.965
Steel, 99.2%		0	273.15	7,800	45.357
Fe, 0.2% C		100	373.15		45.357
		300	573.15		43.031
		500	773.15		37.216
		800	1073.15		30.238
Wrought, pure		0	273.15	7,800	59.313
		100	373.15		56.987
		200	473.15		52.335
		400	673.15		44.194
		600	873.15		37.216
		800	1073.15		29.075
Lead, pure	Pb	−250	23.15		48.846
		−200	73.15		40.705
		−100	173.15		36.867
		0	273.15		35.123
		20	293.15	11,340	34.774
		100	373.15		33.378
		300	573.15		29.773
		500	773.15		16.747
Lithium, pure	Li	0	273.15	530	70.943
		100	373.15		70.943
Magnesium, pure	Mg	−190	83.15		186.080
		0	273.15	1,740	172.124
		200	473.15		162.820
99.6%		0	273.15	≈1,740	144.212
		100	373.15		139.560
		300	573.15		131.419
		500	773.15		131.419
Manganese	Mn	0	273.15	7,300	50.242
Mercury	Hg	−190	83.15		48.846
		−100	173.15		36.053
		−50	223.15		27.912
	(Liquid)	0	273.15	13,595	8.141

Substance	Chemical formula	T (°C)	T (°K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Molybdenum 99.84%	Mo	−180	93.15		174.450
		−100	173.15		138.397
		0	273.15	10,200	137.234
		100	373.15		137.234
		1000	1273.15		98.855
Nickel 99.94%	Ni	−180	93.15		110.485
		0	273.15	8,800	93.040
		100	373.15		82.573
		200	473.15		73.269
		300	573.15		63.965
		400	673.15		59.313
		500	773.15		61.639
99.2%		0	273.15		67.454
		100	373.15		62.802
		200	473.15	—	58.150
		400	673.15		52.335
		600	873.15		56.987
		800	1073.15		62.802
97 to 99%		−100	173.15		55.824
		0	273.15		58.150
		100	373.15		56.987
		200	473.15	—	54.661
		400	673.15		48.846
		600	873.15		53.498
		800	1073.15		58.150
Palladium, pure	Pd	−190	83.15		76.758
		0	273.15	—	68.617
		100	373.15		73.269
Platinum, pure	Pt	−190	83.15		77.921
		0	273.15	21,400	70.013
		100	373.15		71.408
		300	573.15		75.595
		500	773.15		79.084
		800	1073.15		86.062
		1000	1273.15		89.551
Potassium, pure	K	0	273.15	860	136.071
		100	373.15		118.626
Rhodium, pure	Rh	−190	83.15		212.829
		0	273.15	12,500	88.388
		100	373.15		80.247
Silver > 99.98%	Ag	−190	83.15		425.658
		0	273.15	10,500	418.680
		100	373.15		416.354
		300	573.15		407.050
99.9%		−100	173.15		419.843
		0	273.15	10,500	410.539
		100	373.15		391.931
		300	573.15		361.693
		500	773.15		362.856

Substance	Chemical formula	T (°C)	T (°K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Sodium, pure	Na	–100	173.15		154.679
		0	273.15	970	100.018
		50	323.15		93.040
		100	373.15		83.736
Tantalum	Ta	0	273.15	16,650	54.661
		100	373.15		54.080
		1000	1273.15		63.965
		1400	1673.15		72.106
		1800	2073.15		82.573
Thallium, pure	Tl	–190	83.15		62.802
		0	273.15	11,840	51.172
		100	373.15		41.868
Tin, pure	Sn	–150	123.15		79.084
		–100	173.15		74.432
		0	273.15	7,300	66.058
		100	373.15		59.313
		200	473.15		56.987
Wolfram	W	–190	83.15		217.481
		0	273.15	19,300	166.309
		100	373.15		151.190
		500	773.15		119.789
		1000	1273.15		98.855
		1500	1773.15		113.974
		2000	2273.15		136.071
		2400	2673.15		146.538
Zinc, pure	Zn	–100	173.15		115.137
		0	273.15	7,130	112.811
		100	373.15		109.904
		200	473.15		105.833
		300	573.15		101.181

Source: Ref. 2 with permission.

Table 2.33 Thermal Diffusivity of Selected Elements (m^2/s)

	Element											
T (K)	Al	Sb	Be	Cd	Ca	Ce	Cs	Cr	Co	Cu	Dy	Er
10	9.90	0.0339		0.0148			4.2.–4	0.072	0.025	2.30	2.5.–4	6.6.–5
15	2.40	0.00735		0.0020			2.5.–4	0.061	0.016	0.70	1.0.–4	2.3.–5
20	0.50	0.00177		6.1.–4			1.9.–4	0.038	0.011	0.16	4.7.–5	6.8.–6
25	0.15	6.8.–4		3.5.–4			1.7.–4	0.018	0.005	0.047	3.1.–5	1.0.–5
30	0.06	4.1.–4		2.2.–4			1.5.–4	0.010	0.003	0.018	2.4.–5	8.4.–6
40	0.012	2.0.–4		1.5.–5			1.3.–4	3.7.–3	1.1.–3	4.0.–3	1.5.–5	6.8.–6
50	3.3.–3	1.2.–4		1.1.–4			1.26.–4	7.5.–4	4.8.–4	1.4.–3	1.1.–5	6.0.–6
60	1.4.–3	8.8.–5		8.6.–5			1.20.–4	5.9.–4	2.6.–4	6.9.–4	9.0.–6	5.9.–6
80	4.4.–4	5.6.–5		6.8.–5			1.12.–4	2.0.–4	1.2.–4	3.1.–4	6.5.–6	7.4.–6
100	2.3.–4	4.2.–5	3.58.–3	6.3.–5			1.06.–4	1.2.–4	7.7.–5	2.2.–4	5.5.–6	9.1.–6
150	1.3.–4	2.8.–5	4.0.–4	5.6.–5			9.7.–5	5.7.–5	4.7.–5	1.9.–4	3.8.–6	9.7.–6
200	1.1.–4	2.3.–5	1.5.–4	5.2.–5			9.3.–5	4.1.–5	3.7.–5	1.3.–4	6.3.–6	9.9.–6
250	1.1.–4	2.0.–5	8.3.–5	5.0.–5	2.1.–4		8.8.–5	3.3.–5	3.1.–5	1.2.–4	7.0.–6	9.9.–6
300	9.7.–5	1.7.–5	5.9.–5	4.9.–5	2.0.–4	8.0.–6	8.0.–5	2.9.–5	2.7.–5	1.2.–4	7.4.–6	9.4.–6
400	9.4.–5	1.5.–5	4.0.–5	4.6.–5	1.8.–4	9.0.–6	4.8.–5	2.6.–5	2.2.–5	1.1.–4	7.5.–6	9.0.–6
500	8.9.–5	1.3.–5	3.1.–5	4.3.–5	1.6.–4	1.0.–5	5.1.–5	2.3.–5	1.8.–5	1.1.–4	7.7.–6	8.9.–6
600	8.4.–5	1.2.–5	2.6.–5	1.8.–5	1.5.–4	1.0.–5	5.5.–5	2.0.–5	1.5.–5	1.0.–4	7.9.–6	8.9.–6
800	7.4.–5	1.1.–5	2.1.–5	2.0.–5		1.1.–5	5.8.–5	1.7.–5	1.2.–5	9.0.–5	8.6.–6	9.0.–6
1000	6.6.–5		1.7.–5	2.4.–5		1.1.–5	5.3.–5	1.4.–5	1.0.–5	9.0.–5	9.2.–6	9.1.–6
1200	6.1.–5		1.4.–5				4.6.–5	1.3.–5	9.0.–6	8.0.–5		
1400			1.2.–5				3.9.–5	1.2.–5				
1600								1.1.–5				
1800												
2000												

	Gd	Ge	Au	Hf	Ho	In	Ir	Fe	La	Pb	Li	Lu
10	8.2.–3	0.46	0.060	8.0.–4	9.8.–5	4.3.–3	0.183	0.133		1.1.–3	0.124	7.1.–4
15	3.5.–3	0.072	0.015	3.0.–4	4.0.–5	9.1.–4	0.091	0.075		2.0.–4	0.052	2.5.–4
20	1.4.–3	0.021	0.005	1.4.–4	2.9.–5	4.0.–4	0.046	0.043		9.3.–5	0.023	1.2.–4
25	7.5.–4	0.010	0.002	9.0.–5	2.2.–5	2.3.–4	0.016	0.025	3.4.–5	6.4.–5	0.011	0.7.–4
30	4.8.–4	0.006	0.001	6.0.–5	1.9.–5	1.6.–4	0.007	0.013	2.6.–5	5.1.–5	0.006	0.5.–4
40	2.7.–4	2.4.–3	4.5.–4	3.8.–5	1.5.–5	1.1.–4		3.2.–3	1.4.–5	3.9.–5	2.3.–3	3.0.–5
50	1.6.–4	1.3.–3	3.0.–4	2.8.–5	1.2.–5	8.9.–5	5.6.–4	1.2.–3	1.1.–5	3.5.–5	0.8.–3	2.4.–5
60	1.4.–4	8.2.–4	2.3.–4	2.3.–5	1.1.–5	7.8.–5		4.9.–4	1.0.–5	3.3.–5	0.5.–3	2.0.–5
80	1.0.–4	4.0.–4	1.8.–4	2.1.–5	0.9.–5	7.0.–5		1.6.–4	0.9.–5	3.1.–5	0.2.–3	1.7.–5

Above the solid line a substance is solid; below it, it is liquid.
The notation 5.4.–3 signifies 5.4×10^{-3}.

	Element											
T (K)	Gd	Ge	Au	Hf	Ho	In	Ir	Fe	La	Pb	Li	Lu
100	9.0–5	2.2–4	1.5–4	1.7–5	0.7–5	6.2–5	8.4–5	8.2–5	1.0–5	2.9–5	0.1–3	1.5–5
150	7.0–5	1.0–4	1.40–4	1.4–5	0.9–5	5.8–5	6.3–5	4.1–5	1.0–5	2.7–5	6.5–5	1.3–5
200	6.0–5	6.3–5	1.34–4	1.3–5	1.0–5	5.4–5	5.6–5	3.1–5	1.0–5	2.6–5	5.4–5	1.2–5
250		4.6–5	1.31–4	1.3–5	1.1–5	5.1–5	5.2–5	2.6–5	1.1–5	2.5–5	4.8–5	1.1–5
300		3.5–5	1.27–4	1.2–5	1.1–5	4.8–5	5.0–5	2.2–5	1.1–5	2.4–5	4.5–5	1.1–5
400		2.4–5	1.23–4	1.2–5	1.2–5	4.1–5	4.8–5	1.8–5	1.2–5	2.3–5		1.1–5
500		1.8–5	1.19–4	1.1–5	1.2–5	2.2–5	4.6–5	1.5–5	1.3–5	2.2–5	2.1–5	
600		1.4–5	1.15–4	1.1–5		2.4–5	4.4–5	1.3–5	1.4–5	2.0–5	2.3–5	
800		1.0–5	1.07–4	1.0–5			4.1–5	1.1–5	1.5–5	1.3–5	2.8–5	
1000		0.9–5	9.8–5	1.0–5			3.5–5	1.0–5	1.6–5	1.5–5	3.3–5	
1200		0.8–5	9.0–5	9.0–5			3.3–5			1.7–5	3.7–5	
1400			4.1–5				3.1–5					
1600			4.4–5				3.0–5					
2000												

	Mg	Mo	Ni	Nb	Pd	Pt	K	Pu	Rh	Rb	Ag	Na
10	0.395	0.0292	0.163	1.6–2	0.0428	0.0517			0.357		0.835	
15	0.116	0.0167	0.079	6.7–3	0.0166	0.0114			0.224		0.140	
20	0.050	0.0095	0.033	2.6–3	0.0054	0.0029			0.115		0.031	
25	0.023	0.0057	0.014	1.0–3	0.0021	0.0010			0.044		0.009	
30	0.010	0.0037	0.006	4.6–4	0.0009	0.0005			0.017		0.004	
40	2.6–3	1.4–3	1.7–3	1.6–4	2.8–4	1.6–4			5.1–3		1.3–3	
50	9.2–4	7.1–4	6.2–4	1.3–4	1.3–4	9.2–5	2.3–4		9.3–4		6.6–4	
60	4.9–4	4.0–4	3.1–4	6.0–5	8.2–5	6.3–5	2.1–4		4.1–4		4.5–4	
80	2.1–4	2.0–4	1.3–4	3.9–5	4.8–5	4.3–5	1.9–4		1.8–4		2.8–4	
100	1.5–4	1.3–4	8.0–5	3.2–5	3.8–5	3.6–5	1.8–4	2.1–6	1.0–4		2.3–4	
150	1.1–4	7.4–5	4.2–5	2.6–5	2.9–5	2.9–5		2.1–6	6.5–5		1.9–4	
200	1.0–4	6.3–5	3.1–5	2.4–5	2.6–5	2.7–5		2.2–6	5.6–5		1.8–4	
250	9.1–5	5.7–5	2.6–5	2.4–5	2.5–5	2.5–5		2.3–6	5.2–5		1.8–4	
300	8.9–5	5.4–5	2.3–5	2.3–5	2.4–5	2.5–5		2.6–6	4.9–5		1.7–4	
400	8.2–5	5.1–5	1.9–5	2.4–5	2.5–5	2.5–5	7.3–5		4.6–5	6.1–5	1.7–4	6.9–5
500	7.7–5	4.8–5	1.5–5	2.4–5	2.5–5	2.5–5	7.3–5		4.3–5	5.9–5	1.7–4	6.8–5
600	7.3–5	4.5–5	1.3–5	2.4–5	2.6–5	2.5–5	7.2–5		4.0–5	5.8–5	1.6–4	6.7–5
800	6.7–5	4.2–5	1.4–5	2.5–5	2.8–5	2.5–5	6.7–5		3.6–5	5.5–5	1.5–4	6.4–5

1000	4.3.–5	3.8.–5	1.5.–5	2.6.–5	2.9.–5	2.5.–5	6.0.–5		3.2.–5		1.4.–4	6.0.–5
1200		3.5.–5	1.5.–5	2.6.–5	3.0.–5	2.5.–5	4.7.–5		3.0.–5		1.3.–4	5.3.–5
1400		3.3.–5	1.6.–5	2.7.–5		2.6.–5			2.8.–5			4.7.–5
1600		3.1.–5	1.6.–5	2.7.–5		2.6.–5			2.6.–5			4.1.–5
1800		3.0.–5		2.8.–5	____	2.7.–5						
2000		2.8.–5		2.8.–5		2.8.–5			____			____

	Ta	Te	Th	Sn	Ti	W	U	V	Y	Zn	Zr	
10	5.4.–3	8.0.–4			2.4.–3	1.140	3.4.–4	1.0.–3			1.1.–2	
15	2.4.–3	2.4.–4			1.3.–3	0.350	1.3.–4	7.7.–4		2.5.–2	3.8.–3	
20	1.1.–3	1.4.–4			8.0.–4	0.105	4.5.–5	5.7.–4		4.6.–3	1.4.–3	
25	5.4.–4	9.1.–5			4.7.–4	0.039	3.8.–5	4.6.–4		1.7.–3	6.3.–4	
30	2.9.–4	7.2.–5			3.1.–4	0.013	2.7.–5	3.0.–4		7.0.–4	3.3.–4	
40	1.3.–4	5.8.–5			1.6.–4	2.5.–3	2.0.–5	1.5.–4		3.1.–4	9.6.–5	
50	7.7.–5	5.0.–5			9.6.–5	7.5.–4	1.5.–5	9.2.–5	2.4.–5	1.7.–4	7.4.–5	
60	5.5.–5	4.6.–5			6.3.–5	3.5.–4	1.4.–5	5.9.–5	2.0.–5	1.0.–4	5.9.–5	
80	4.0.–5	4.1.–5			3.8.–5	2.3.–4	1.3.–5	3.4.–5	1.8.–5	7.0.–5	5.0.–5	
100	3.3.–5	3.9.–5	5.2.–5		2.7.–5	1.6.–4	1.2.–5	2.3.–5	1.5.–5	5.5.–5	4.3.–5	
150	2.8.–5	3.5.–5	4.5.–5				1.2.–5	1.4.–5	1.4.–5	5.1.–5		
200	2.6.–5	3.3.–5	4.1.–5				1.2.–5	1.2.–5	1.3.–5	4.7.–5		
250	2.5.–5	3.1.–5	4.0.–5				1.2.–5	1.1.–5	1.3.–5	4.3.–5		
300	2.4.–5	3.0.–5	3.9.–5				1.2.–5	1.1.–5	1.3.–5	4.1.–5		
400	2.4.–5	2.8.–5	3.8.–5				1.3.–5	1.0.–5	1.3.–5	3.9.–5		
500	2.4.–5	2.6.–5	3.7.–5	____			1.3.–5	1.0.–5	1.4.–5	3.7.–5		
600	2.4.–5		3.6.–5	1.8.–4			1.3.–5	1.0.–5	1.4.–5	3.4.–5		
800	2.4.–5		3.4.–5	2.1.–4			1.3.–5	1.1.–5	1.5.–5	1.8.–5		
1000	2.3.–5		3.2.–5	2.4.–4			1.4.–5	1.1.–5	1.5.–5	2.2.–5		
1200	2.3.–5		3.1.–5	2.7.–4				1.1.–5	1.6.–5			
1400	2.3.–5						____					
1600	2.4.–5											
1800					____							
2000	____		____			____		____				

Above the solid line a substance is solid; below it, it is liquid.
The notation 5.4.–3 signifies 5.4×10^{-3}.

Table 2.34 Density and Thermal Conductivity of Alloys

Alloy	Composition (%)	T (°C)	T (K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Aluminum alloys	96 Al, 1.8 Cu, 0.9 Fe, 0.9 Cr, 0.4 Si	20	293.15	—	104.670
Aluminum bronze	95 Cu, 5Al	20	293.15	7800	82.573
Aluminum magnesium	92 Al, 8 Mg	−180	93.15		75.595
		−100	173.15		84.899
		0	273.15		102.344
		20	293.15	≈2600	105.833
		100	373.15		123.278
		200	473.15		147.701
Alusil	80 Al, 20 Si	−180	93.15		122.115
		−100	173.15		141.886
		0	273.15		158.168
		20	293.15	≈2650	160.494
		100	373.15		168.635
		200	473.15		174.450
Bismuth-antimony	80 Bi, 20 Sb	0	273.15	—	6.606
		100	373.15		8.618
	50 Bi, 50 Sb	0	273.15	—	8.327
		100	373.15		9.374
	30 Bi, 70 Sb	0	273.15	—	9.653
		100	373.15		11.660
Brass	90 Cu, 10 Zn	−100	173.15		88.388
		0	273.15	≈8600	102.344
		100	373.15		117.463
		200	473.15		133.745
		300	573.15		148.864
		400	673.15		166.309
		500	773.15		180.265
		600	873.15		195.384
	70 Cu, 30 Zn	0	273.15	≈8600	105.833
		100	373.15		109.322
		200	473.15		110.485
		300	573.15		113.974
		400	673.15		116.300
		500	773.15		119.789
		600	873.15		120.952
	66 Cu, 33 Zn	0	273.15	≈8600	100.018
		100	373.15		106.996
		200	473.15		112.811
		300	573.15		120.952
		400	673.15		127.930
		500	773.15		134.908
		600	873.15		151.190
	60 Cu, 40 Zn	0	273.15	≈8600	105.833
		100	373.15		119.789
		200	473.15		137.234
		300	573.15		152.353
		400	673.15		168.635
		500	773.15		186.080
		600	873.15		200.036

Alloy	Composition (%)	T (°C)	T (K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Brass	61.5 Cu, 38.5 Zn	20	293.15		79.084
		100	373.15		88.388
Bronze	90 Cu, 10 Sn	20	293.15	8766	41.868
	75 Cu, 25 Sn	20	293.15	≈8900	25.586
	88 Cu, 10 Sn, 2 Zn	20	293.15	≈8800	47.683
	84 Cu, 6 Sn, 9 Zn, 1 Pb	20	293.15	—	58.150
	86 Cu, 7 Zn, 6.4 Sn	20	293.15	≈8600	60.476
		100	373.15		70.943
Chrome-nickel steel	0.8 Cr, 3.5 Ni, 0.4 C	20	293.15	8100 . . .	34.890
		100	373.15	8700	36.053
		200	473.15		37.216
		400	673.15		37.216
		600	873.15		31.401
	Cr . . . Ni	20	293.15	7900	13.956
		200	473.15		17.445
		500	773.15		20.934
	17 . . . 19 Cr, 8 Ni, 0.1 . . . 0.2 C	20	293.15	8100 . . .	14.538
		100	373.15	9000	15.701
		200	473.15		16.864
		300	573.15		18.608
		500	773.15		20.934
	10 Cr, 34 Ni	20	293.15		12.212
		100	373.15		13.375
		200	473.15	—	15.119
		300	573.15		16.282
		500	773.15		19.190
	15 Cr, 27 Ni, 3 W, 0.5 C	20	293.15		11.281
		100	373.15		12.793
		200	473.15	—	13.956
		300	573.15		15.119
		500	773.15		18.608
	15 Cr, 13 Ni, 2 W, 0.5 C	20	293.15		11.630
		100	373.15		11.630
		200	473.15	—	11.630
		300	573.15		12.212
		500	773.15		12.793
		800	1073.15		16.282
Chrome steel	0.8 Cr, 0.2 C	100	373.15	≈7850	39.542
		200	473.15		37.216
		400	673.15		31.401
		600	873.15		26.749
	5 Cr, 0.5 Mn, 0.1 C	20	293.15	8100 . . .	37.216
		100	373.15	9000	31.635
		200	473.15		31.053
		500	773.15		33.727
	15 Cr, 0.1 C	20	293.15	8100 . . .	25.586
		500	773.15	9000	25.586

Alloy	Composition (%)	T (°C)	T (K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Chrome steel	14 Cr, 0.3 C	20	293.15	8100 . . .	24.423
		100	373.15	9000	25.005
		200	473.15		25.586
		300	573.15		25.586
		500	773.15		25.586
	16 Cr, 0.9 C	100	373.15	8100 . . .	23.842
		200	473.15	9000	23.260
		300	573.15		23.260
		500	773.15		23.260
		800	1073.15		23.260
	26 Cr, 0.1 C	20	293.15	8100 . . .	19.771
		100	373.15	9000	20.934
		200	473.15		22.097
		300	573.15		22.911
		500	773.15		24.423
Cobalt steel	5 . . . 10 Co	20	293.15	≈7800	40.705
Constantin	60 Cu, 40 Ni	−100	173.15		20.934
		0	273.15		22.213
		20	293.15	8800	22.679
		100	373.15		25.586
Copper alloys	92 Al, 8 Cu	−180	93.15		89.551
		−100	173.15		109.322
		0	273.15		127.930
		20	293.15	≈2800	131.419
		100	373.15		143.049
		200	473.15		152.353
Copper-manganese	70 Cu, 30 Mn	20	293.15	≈7800	12.793
Copper-nickel	90 Cu, 10 Ni	20	293.15	≈8800	58.150
		100	373.15		75.595
	80 Cu, 20 Ni	20	293.15	≈8500	33.727
		100	373.15		40.705
	40 Cu, 60 Ni	20	293.15	≈8400	22.097
		100	373.15		25.586
	18 Cu, 82 Ni	20	293.15		25.586
		100	393.15		25.586
Duralumin	94 . . . 96 Al, 3 . . . 5 Cu, 0.5 Mg	−180	93.15		90.714
		−100	173.15		125.604
		0	273.15		159.331
		20	293.15	≈2800	165.146
		100	373.15		181.428
		200	473.15		194.221
Electron alloy	93 Mg, 4 Zn, 0.5 Cu	20	293.15	1800	116.300
German alloy	88 Al, 10 Zn, 2 Cu	0	273.15	2900	143.049
		20	293.15		145.375
		100	373.15		154.679
Gold-copper alloy	88 Au, 12 Cu	0	273.15	—	55.824
		100	373.15		67.454
	27 Au, 73 Cu	0	273.15	—	90.714
		100	373.15		113.974

Alloy	Composition (%)	T (°C)	T (K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
Invar	35 Ni, 65 Fe	20	293.15	8130	11.049
Lautal	95 Al, 4.5 . . . 5.5 Cu, 0.3 Si	20	293.15	—	139.560
Magnesium-aluminum	92 Mg, 8 Al	−180	93.15		41.868
		−100	173.15		50.009
		0	273.15	≈1800	60.476
		20	293.15		61.639
		100	373.15		69.780
		200	473.15		79.084
	2.5 Al	20	293.15	—	85.597
	4.2 Al	20	293.15	—	69.082
	6.2 Al	20	293.15	—	55.591
	10.3 Al	20	293.15	—	43.496
Magnesium-aluminum-silicone	88 Mg, 10 Al, 2 Si	−180	93.15		30.238
		−100	173.15		40.705
		0	273.15	≈1850	55.824
		20	293.15		58.150
		100	373.15		68.617
		200	473.15		75.595
Magnesium-copper	92 Mg, 8 Cu	−180	93.15		88.388
		−100	173.15		106.996
		0	273.15	≈2400	124.441
		20	293.15		125.604
		100	373.15		130.256
		200	473.15		132.582
	93.7 Mg, 6.3 Cu	20	293.15		131.419
Manganese-nickel steel	12 Mn, 3 Ni, 0.75 C	20	293.15		13.956
		100	373.15		14.770
		200	473.15	—	16.282
		300	573.15		17.445
		500	773.15		19.771
Manganese steel	1.6 Mn, 0.5 C	20	293.15	≈7850	40.705
		100	373.15		40.705
		300	573.15		37.216
		500	773.15		34.890
	2 Mn	20	293.15	≈7850	32.564
	5 Mn	20	293.15	≈7850	18.608
Manganine	84 Cu, 4 Ni, 12 Mn	−100	173.15		16.282
		0	273.15	8400	20.934
		20	293.15		21.864
		100	373.15		26.400
Monel	29 Cu, 67 Ni, 2 Fe	20	293.15	8710	22.097
		100	373.15		24.423
		200	473.15		27.563
		300	573.15		30.238
		400	673.15		33.727

Alloy	Composition (%)	T (°C)	T (K)	Density ρ (kg/m³)	Thermal conductivity λ (W/m K)
New silver	62 Cu, 15 Ni, 22 Zn	−150	123.15	8433	17.678
		−100	173.15		19.170
		+20	293.15		25.005
		100	373.15		31.401
		200	473.15		39.542
		300	573.15		45.357
		400	673.15		48.846
Nickel alloy	70 Ni, 28 Cu, 2 Fe	20	293.15	≈8200	34.890
Nickel-chrome	90 Ni, 10 Cr	0	273.15	≈8220	17.096
		20	293.15		17.445
		100	373.15		18.957
		200	473.15		20.934
		300	573.15		22.795
		400	673.15		24.656
	80 Ni, 20 Cr	0	273.15	≈8200	12.212
		20	293.15		12.560
		100	373.15		13.840
		200	473.15		15.584
		300	573.15		17.212
		400	673.15		18.957
		600	873.15		22.562
Nickel-chrome steel	61 Ni, 15 Cr, 20 Fe, 4 Mn	20	293.15	≈8190	11.630
		100	373.15		11.863
		200	473.15		12.212
		300	573.15		12.444
		400	673.15		12.677
		600	873.15		13.142
		800	1073.15		13.956
	61 Ni, 16 Cr, 23 Fe	0	273.15	≈8190	11.863
		20	293.15		12.095
		100	373.15		13.258
		200	473.15		14.654
		300	573.15		16.049
		400	673.15		17.445
	70 Ni, 18 Cr, 12 Fe	20	293.15	—	11.514
	62 Ni, 12 Cr, 26 Fe	20	293.15	≈8100	13.491
Nickel-silver	—	0	273.15	—	29.308
		100	373.15		37.216
Nickel steel	5 Ni	20	293.15	8130	34.890
	10 Ni	20	293.15		27.912
	15 Ni	20	293.15		22.097
	20 Ni	20	293.15		18.608
	25 Ni	20	293.15		15.119
	30 Ni	20	293.15		12.212
	35 Ni	20	293.15		11.049
	40 Ni	20	293.15		11.049
	50 Ni	20	293.15		14.538
	60 Ni	20	293.15		19.190
	70 Ni	20	293.15		25.586
	80 Ni	20	293.15		32.564

Alloy	Composition (%)	T (°C)	T (K)	Density ρ (kg/m^3)	Thermal conductivity λ (W/m K)
Nickel steel	30 Ni, 1 Mn, 0.25 C	20	293.15	8190	12.095
		100	373.15		13.607
	36 Ni, 0.8 Mn	20	293.15	—	12.095
	1.4 Ni, 0.5 Cr, 0.3 C	20	293.15	≈7850	45.357
		100	373.15		44.194
		300	573.15		40.705
		500	773.15		37.216
Phosphor bronze	92.8 Cu, 5 Sn, 2 Zn, 0.15 P	20	293.15	≈8766	79.084
	91.7 Cu, 8 Sn, 0.3 P	20	293.15	8800	45.357
		100	373.15		52.335
		200	473.15		61.639
	87.8 Cu, 10 Sn, 2 Zn, 0.2 P	20	293.15	—	41.868
	87.2 Cu, 12.4 Sn, 0.4 P	20	293.15	8700	36.053
Piston alloy, cast	91.5 Al, 4.6 Cu, 1.8 Ni, 1.5 Mg	0	273.15	≈2800	143.049
		20	293.15		144.212
		100	373.15		151.190
		200	473.15		158.168
	84 Al, 12 Si, 1.2 Cu, 1 Ni	0	273.15	≈2800	134.908
		20	293.15		134.908
		100	373.15		137.234
		200	473.15		139.560
Platinum-iridium	90 Pt, 10 Ir	0	273.15	—	30.936
		100	373.15		31.401
Platinum-rhodium	90 Pt, 10 Rh	0	273.15	—	30.238
		100	373.15		30.587
Rose's metal	50 Bi, 25 Pb, 25 Sn	20	293.15	—	16.282
Silumin	86 . . . 89 Al, 11 . . . 14 Si	0	273.15	2600	159.331
		20	293.15		161.657
		100	373.15		170.961
Steel	0.1 C	0	273.15	7850	59.313
		100	373.15		52.335
		200	473.15		52.335
		300	573.15		46.520
		400	673.15		44.194
		600	873.15		37.216
		900	1173.15		33.727
	0.2 C	20	293.15	7850	50.009
	0.6 C	20	293.15	7850	46.520
—Bessemer	0.52 C, 0.34 Si	20	293.15	7850	40.240
Tungsten steel	1 W, 0.6 Cr, 0.3 C	20	293.15	7900	39.542
		100	373.15		38.379
		300	573.15		36.053
		500	773.15		33.727
V 1 A steel	—	20	293.15	—	20.934
V 2 A steel	—	20	293.15	7860	15.119
Wood's metal	48 Bi, 26 Pb, 13 Sn, 13 Cd	20	293.15	—	12.793

Source: Ref. 1 with permission.

Table 2.35 Thermophysical Properties of Miscellaneous Materials

Description/composition	Typical properties at 300 K		
	Density ρ (kg/m³)	Thermal conductivity k (W/m·K)	Specific heat c_p (J/kg·K)
Structural building materials			
Building boards			
Asbestos-cement board	1920	0.58	—
Gypsum or plaster board	800	0.17	—
Plywood	545	0.12	1215
Sheathing, regular density	290	0.055	1300
Acoustic tile	290	0.058	1340
Hardboard, siding	640	0.094	1170
Hardboard, high density	1010	0.15	1380
Particle board, low density	590	0.078	1300
Particle board, high density	1000	0.170	1300
Woods			
Hardwoods (oak, maple)	720	0.16	1255
Softwoods (fir, pine)	510	0.12	1380
Masonry materials			
Cement mortar	1860	0.72	780
Brick, common	1920	0.72	835
Brick, face	2083	1.3	—
Clay tile, hollow			
1 cell deep, 10 cm thick	—	0.52	—
3 cells deep, 30 cm thick	—	0.69	—
Concrete block, 3 oval cores			
Sand/gravel, 20 cm thick	—	1.0	—
Cinder aggregate, 20 cm thick	—	0.67	—
Concrete block, rectangular core			
2 core, 20 cm thick, 16 kg	—	1.1	—
Same with filled cores	—	0.60	—
Plastering materials			
Cement plaster, sand aggregate	1860	0.72	—
Gypsum plaster, sand aggregate	1680	0.22	1085
Gypsum plaster, vermiculite aggregate	720	0.25	—

Description/composition	Typical properties at 300 K		
	Density ρ (kg/m³)	Thermal conductivity k (W/m·K)	Specific heat c_p (J/kg·K)
Insulating materials and systems			
Blanket and batt			
Glass fiber, paper faced	16	0.046	—
	28	0.038	—
	40	0.035	—
Glass fiber, coated; duct liner	32	0.038	835
Board and slab			
Cellular glass	145	0.058	1000
Glass fiber, organic bonded	105	0.036	795
Polystyrene, expanded			
Extruded (R-12)	55	0.027	1210
Molded beads	16	0.040	1210
Mineral fiberboard; roofing material	265	0.049	—
Wood, shredded/cemented	350	0.087	1590
Cork	120	0.039	1800
Loose fill			
Cork, granulated	160	0.045	—
Diatomaceous silica, coarse powder	350	0.069	—
	400	0.091	—
Diatomaceous silica, fine powder	200	0.052	—
	275	0.061	—
Glass fiber, poured or blown	16	0.043	835
Vermiculite, flakes	80	0.068	835
	160	0.063	1000
Formed/foamed in place			
Mineral wool granules with asbestos/inorganic binders, sprayed	190	0.046	—
Polyvinyl acetate cork mastic, sprayed or troweled	—	0.100	—
Urethane, two-part mixture; rigid foam	70	0.026	1045
Reflective			
Aluminum foil separating fluffy glass mats; 10–12 layers; evacuated; for cryogenic application (150 K)	40	0.00016	—
Aluminum foil and glass paper laminate; 75–150 layers; evacuated; for cryogenic application (150 K)	120	0.000017	—
Typical silica powder, evacuated	160	0.0017	—

Description/composition	Maximum service T (K)	Typical density (kg/m^3)	Typical thermal conductivity k (W/m·K) at various temperatures												
			200 K	215 K	230 K	240 K	255 K	270 K	285 K	300 K	310 K	365 K	420 K	530 K	645 K	750 K
Industrial insulation																
Blankets																
Blanket, mineral fiber, metal	920	96–192	—	—	—	—	—	—	—	—	0.038	0.046	0.056	0.078	—	—
reinforced	815	40–96	—	—	—	—	—	—	—	—	0.035	0.045	0.058	0.088	—	—
Blanket, mineral fiber, glass;	450	10	—	—	—	0.036	0.038	0.040	0.043	0.048	0.052	0.076	—	—	—	—
fine fiber, organic bonded		12	—	—	—	0.035	0.036	0.039	0.042	0.046	0.049	0.069	—	—	—	—
		16	—	—	—	0.033	0.035	0.036	0.039	0.042	0.046	0.062	—	—	—	—
		24	—	—	—	0.030	0.032	0.033	0.036	0.039	0.040	0.053	—	—	—	—
		32	—	—	—	0.029	0.030	0.032	0.033	0.036	0.038	0.048	—	—	—	—
		48	—	—	—	0.027	0.029	0.030	0.032	0.033	0.035	0.045	—	—	—	—
Blanket, alumina-silica fiber	1530	48	—	—	—	—	—	—	—	—	—	—	—	0.071	0.105	0.150
		64	—	—	—	—	—	—	—	—	—	—	—	0.059	0.087	0.125
		96	—	—	—	—	—	—	—	—	—	—	—	0.052	0.076	0.100
		128	—	—	—	—	—	—	—	—	—	—	—	0.049	0.068	0.091
Felt, semirigid; organic bonded	480	50–125	—	—	—	—	—	0.035	0.036	0.038	0.039	0.051	0.063	—	—	—
	730	50	0.023	0.025	0.026	0.027	0.029	0.030	0.032	0.033	0.035	0.051	0.079	—	—	—
Felt, laminated; no binder	920	120	—	—	—	—	—	—	—	—	—	—	0.051	0.065	0.087	—
Blocks, boards, and pipe insulations																
Asbestos paper, laminated and corrugated																
4-ply	420	190	—	—	—	—	—	—	—	0.078	0.082	0.098	—	—	—	—
6-ply	420	255	—	—	—	—	—	—	—	0.071	0.074	0.085	—	—	—	—
8-ply	420	300	—	—	—	—	—	—	—	0.068	0.071	0.082	—	—	—	—
Magnesia, 85%	590	185	—	—	—	—	—	—	—	—	0.051	0.055	0.061	—	—	—
Calcium silicate	920	190	—	—	—	—	—	—	—	—	0.055	0.059	0.063	0.075	0.089	0.104
Cellular glass	700	145	—	—	0.046	0.048	0.051	0.052	0.055	0.058	0.062	0.069	0.079	—	—	—
Diatomaceous silica	1145	345	—	—	—	—	—	—	—	—	—	—	—	0.092	0.098	0.104
	1310	385	—	—	—	—	—	—	—	—	—	—	—	0.101	0.100	0.115
Polystyrene, rigid																
Extruded (R-12)	350	56	0.023	0.023	0.022	0.023	0.023	0.025	0.026	0.027	0.029	—	—	—	—	—
Extruded (R-12)	350	35	0.023	0.023	0.025	0.023	0.025	0.026	0.027	0.029	—	—	—	—	—	—
Molded beads	350	16	0.026	0.029	0.030	0.033	0.035	0.036	0.038	0.040	—	—	—	—	—	—
Rubber, rigid foamed	340	70	—	—	—	—	—	0.029	0.030	0.032	0.033	—	—	—	—	—
Insulating cement																
Mineral fiber (rock, slag or glass)																
With clay binder	1255	430	—	—	—	—	—	—	—	—	0.071	0.079	0.088	0.105	0.123	—
With hydraulic setting binder	922	560	—	—	—	—	—	—	—	—	0.108	0.115	0.123	0.137	—	—
Loose fill																
Cellulose, wood, or paper pulp	—	45	—	—	—	—	—	—	0.038	0.039	0.042	—	—	—	—	—
Perlite, expanded	—	105	0.036	0.039	0.042	0.043	0.046	0.049	0.051	0.053	0.056	—	—	—	—	—
Vermiculite, expanded	—	122	—	—	0.056	0.058	0.061	0.063	0.065	0.068	0.071	—	—	—	—	—
	—	80	—	—	0.049	0.051	0.055	0.058	0.061	0.063	0.066	—	—	—	—	—

Description/composition	T (K)	Density ρ (kg/m³)	Thermal conductivity k (W/m·K)	Specific heat c_p (J/kg·K)
Other materials				
Asphalt	300	2115	0.062	920
Bakelite	300	1300	1.4	1465
Brick, refractory				
Carborundum	872	—	18.5	—
	1672	—	11.0	—
Chrome brick	473	3010	2.3	835
	823	—	2.5	—
	1173	—	2.0	—
Diatomaceous silica, fired	478	—	0.25	—
	1145	—	0.30	—
Fire clay, burnt 1600 K	773	2050	1.0	960
	1073	—	1.1	—
	1373	—	1.1	—
Fire clay, burnt 1725 K	773	2325	1.3	960
	1073	—	1.4	—
	1373	—	1.4	—
Fire clay brick	478	2645	1.0	960
	922	—	1.5	—
	1478	—	1.8	—
Magnesite	478	—	3.8	1130
	922	—	2.8	—
	1478	—	1.9	—
Clay	300	1460	1.3	880
Coal, anthracite	300	1350	0.26	1260
Concrete (stone mix)	300	2300	1.4	880
Cotton	300	80	0.06	1300
Foodstuffs				
Banana (75.7% water content)	300	980	0.481	3350
Apple, red (75% water content)	300	840	0.513	3600
Cake batter	300	720	0.223	—
Cake, fully done	300	280	0.121	—
Chicken meat, white	198	—	1.60	—
(74.4% water content)	233	—	1.49	—
	253	—	1.35	—
	263	—	1.20	—
	273	—	0.476	—
	283	—	0.480	—
	293	—	0.489	—
Glass				
Plate (soda lime)	300	2500	1.4	750
Pyrex	300	2225	1.4	835
Ice	273	920	0.188	2040
	253	—	0.203	1945
Leather (sole)	300	998	0.013	—
Paper	300	930	0.011	1340
Paraffin	300	900	0.020	2890

Description/composition	T (K)	Density ρ (kg/m³)	Thermal conductivity k (W/m·K)	Specific heat c_p (J/kg·K)
Other materials (continued)				
Rock				
Granite, Barre	300	2630	2.79	775
Limestone, Salem	300	2320	2.15	810
Marble, Halston	300	2680	2.80	830
Quartzite, Sioux	300	2640	5.38	1105
Sandstone, Berea	300	2150	2.90	745
Rubber, vulcanized				
Soft	300	1100	0.012	2010
Hard	300	1190	0.013	—
Sand	300	1515	0.027	800
Soil	300	2050	0.52	1840
Snow	273	110	0.049	—
		500	0.190	—
Teflon	300	2200	0.35	—
	400	—	0.45	—
Tissue, human				
Skin	300	—	0.37	—
Fat layer (adipose)	300	—	0.2	—
Muscle	300	—	0.41	—
Wood, cross grain				
Balsa	300	140	0.055	—
Cypress	300	465	0.097	—
Fir	300	415	0.11	2720
Oak	300	545	0.17	2385
Yellow pine	300	640	0.15	2805
White pine	300	435	0.11	—
Wood, radial				
Oak	300	545	0.19	2385
Fir	300	420	0.14	2720

Source: Ref. 6 with permission.

2.5. THERMOPHYSICAL PROPERTIES OF SATURATED REFRIGERANTS

Table 2.36 Saturation Properties for Refrigerant 22

T_s (°C)	P_s (MPa)	ρ (kg/m³)	C_p (kJ/kg K)	μ (Pas) × 10⁶	κ (mW/m K)	σ (mN/m)
−140	–	1675.3 L	–	–	–	35.70
		– V	0.445	–	–	
−120	0.00023	1624.0 L	–	–	–	32.00
		0.01571 V	0.470	–	–	

T (°C)	P (MPa)	ρ (kg/m)	C (kJ/kg K)	μ (Pas) × 10	κ (mW/m K)	σ (mN/m)
−100	0.00200	1571.7 L	—	—	—	28.37
		0.12051 V	0.497	—	—	
−80	0.01035	1518.3 L	1.070	—	—	24.83
		0.56129 V	0.527	—	—	
−60	0.03747	1463.6 L	1.076	—	123.1	21.39
		1.86102 V	0.563	—	5.61	
−40*	0.10132	1409.1 L	1.092	—	114.1	18.18
		4.7046 V	0.606	—	6.93	
−20	0.24529	1346.8 L	1.125	260.1	104.8	—
		10.797 V	0.667	—	8.27	
0.00	0.49811	1281.8 L	1.171	210.1	96.2	—
		21.263 V	0.744	11.80	9.50	
20	0.91041	1210.0 L	1.238	169.1	87.8	—
		38.565 V	0.849	—	10.71	
40	1.5341	1128.4 L	1.338	136.3	79.8	—
		66.357 V	1.009	—	11.90	
60	2.4274	1030.5 L	1.528	—	—	—
		111.73 V	1.307	—	—	
80	3.6627	894.8 L	2.176	—	—	—
		195.69 V	2.268	—	—	
96.14†	4.9900	523.8 L	—	—	—	0.00
		523.8 V	—	—	—	

* Boiling point.

† Critical point.

L, liquid; V, vapor.

Extracted from Ref. 8 with permission.

Table 2.37 Saturation Properties for Refrigerant 123

T_s (°C)	P_s (MPa)	ρ (kg/m^3)	C_p (kJ/kg K)	μ (Pas) × 10^6	κ (mW/m K)	σ (mN/m)
−107.15*	0.0000	1770.9 L	0.9287	—	—	—
		0.00047 V	0.4737	—	—	—
−100	0.00001	1754.5 L	0.9259	—	—	—
		0.00123 V	0.4863	—	—	—
−80	0.00013	1709.5 L	0.9325	—	—	—
		0.01195 V	0.5202	—	—	—
−60	0.00081	1665.0 L	0.9319	—	—	—
		0.06977 V	0.5529	—	—	—
−40	0.00358	1619.9 L	0.9480	—	—	23.19
		0.28314 V	0.5850	—	—	
−20	0.01200	1573.7 L	0.9681	735.33	89.320	20.65
		0.87999 V	0.6174	9.085	8.051	
0	0.03265	1526.0 L	0.9902	564.55	83.816	18.18
		2.2417 V	0.6508	9.838	9.089	
20	0.07561	1476.5 L	1.0135	442.57	78.512	15.77
		4.9169 V	0.6861	10.562	10.163	
27.46†	0.10000	1457.5 L	1.0226	405.86	76.581	14.88
		6.3917 V	0.6999	10.825	10.576	
40	0.15447	1424.7 L	1.0384	352.37	73.388	13.42
		9.6296 V	0.7242	11.259	11.291	
60	0.28589	1369.9 L	1.0662	233.84	68.417	11.15
		17.310 V	0.7667	11.939	12.496	
80	0.48909	1311.2 L	1.0996	230.53	63.563	8.97
		29.188 V	0.8162	12.625	13.807	
100	0.78554	1246.9 L	1.1432	188.08	58.769	6.88
		46.996 V	0.8779	13.370	15.260	

T (°C)	P (MPa)	ρ (kg/m)	C (kJ/kg K)	μ (Pas) × 10	κ (mW/m K)	σ (mN/m)
120	1.1989	1174.3 L	1.2072	153.35	—	4.91
		73.471 V	0.9643	14.289	—	
140	1.7562	1088.2 L	1.3177	123.81	—	3.08
		113.71 V	1.1106	15.646	—	
160	2.4901	975.66 L	1.5835	—	—	1.44
		180.24 V	1.4728	—	—	
180	3.4505	765.88 L	4.5494	—	—	0.14
		341.95 V	5.6622	—	—	
183.68‡	3.6618	550.00 L	—	—	—	0.00
		550.00 V	—	—	—	
* Triple point.						
† Normal boiling point.						
‡ Critical point.						
L, liquid; V, vapor.						
Extracted from Ref. 9 with permission.						

Table 2.38 Saturation Properties for Refrigerant 134a

T_s (°C)	P_s (MPa)	ρ (kg/m^3)	C_ρ (kJ/kg K)	μ (Pas) × 10^6	κ (mW/m K)	σ (mN/m)
−103.30*	0.00039	1591.1 L	1.1838	2186.6	—	28.15
		0.02817 V	0.5853	6.63	—	
−100	0.0056	1582.3 L	1.1842	1958.2	—	27.56
		0.03969 V	0.5932	6.76	—	
−80	0.00367	1529.0 L	1.1981	1109.9	—	24.11
		0.23429 V	0.6416	7.57	—	
−60	0.01591	1474.3 L	1.2230	715.4	121.1	20.81
		0.92676 V	0.6923	8.38	—	
−40	0.05121	1417.7 L	1.2546	502.2	111.9	17.66

T (°C)	P (MPa)	ρ (kg/m)	C (kJ/kg K)	μ (Pas) × 10	κ (mW/m K)	σ (mN/m)
		2.7695 V	0.7490	9.20	8.19	
−26.08†	0.10133	1376.6 L	1.2805	363.1	105.1	15.54
		5.2566 V	0.7941	9.90	9.55	
−20	0.13273	1358.2 L	1.2930	337.2	102.4	14.51
		6.7845 V	0.8158	10.16	10.11	
0	0.2928	1294.7 L	1.3410	265.3	93.67	11.56
		14.428 V	0.8972	11.02	11.96	
20	0.5717	1225.3 L	1.4048	208.7	84.78	8.76
		27.780 V	1.0006	11.91	13.93	
40	1.0165	1146.7 L	1.4984	162.7	75.69	6.13
		50.085 V	1.1445	12.89	16.19	
60	1.6817	1052.8 L	1.6601	124.1	66.36	3.72
		87.379 V	1.3868	14.15	19.14	
80	2.6332	928.24 L	2.0648	89.69	57.15	1.60
		115.07 V	2.0122	16.31	24.0	
101.06‡	4.0592	511.94 L	—	—	—	0.0
		511.94 V	—	—	—	
* Triple point.						
† Boiling point.						
‡ Critical point.						
Extracted from Ref. 10 with permission.						

Table 2.39 Saturation Properties for Refrigerant 502 (Azeotrope of R22 and R115)

T_s (°C)	P_s (MPa)	ρ (kg/m^3)	C_p (kJ/kg K)	μ (Pas) × 10^6	κ (mW/m K)	σ (mN/m)
−70	0.02757	1557.6 L	1.024	543.6	—	—
		1.8501 V	—	—		
−60	0.04872	1527.2 L	1.042	469.7	97.9	17.41
		3.1417 V	0.574	—	—	
−45.42*	0.10132	1481.5 L	1.071	383.9	92.1	15.16
		6.2181 V	0.600	—	—	
−40	0.12964	1464.0 L	1.082	358.1	90.0	14.35
		7.8315 V	0.609	—	7.11	
−20	0.29101	1396.4 L	1.128	282.6	82.4	11.42
		16.818 V	0.649	—	8.47	
0	0.57313	1322.5 L	1.178	229.2	74.8	8.64
		32.425 V	0.709	11.69	9.80	
20	1.0197	1239.4 L	1.234	—	67.1	—
		58.038 V	0.804	12.84	11.21	
40	1.6770	1140.7 L	1.295	—	—	—
		99.502 V	0.949	13.99	12.81	
60	2.6014	1010.5 L	—	—	—	—
		171.23 V	—	—	—	—
82.2†	4.075	561 L	—	—	—	—
		561 V	—	—	—	

* Boiling point.

† Critical point.

Extracted from Ref. 8 with permission.

Table 2.40 Saturation Properties for Ammonia

T_{sat} (K)	239.75	250	270	290	310	330	350	370	390	400
p_{sat} (kPa)	101.3	165.4	381.9	775.3	1424.9	2422	3870	5891	8606	10,280
ρ_ℓ, kg/m^3	682	669	643	615	584	551	512	466	400	344
ρ_g, kg/m^3	0.86	1.41	3.09	6.08	11.0	18.9	31.5	52.6	93.3	137
h_ℓ, kJ/kg	808.0	854.0	945.7	1039.6	1135.7	1235.7	1341.9	1457.5	1591.4	1675.3
h_g, kJ/kg	2176	2192	2219	2240	2251	2255	2251	2202	2099	1982
$\Delta h_{g,\ell}$, kJ/kg	1368	1338	1273	1200	1115	1019	899	744	508	307
$c_{p,\ell}$, kJ/(kg K)	4.472	4.513	4.585	4.649	4.857	5.066	5.401	5.861	7.74	
$c_{p,g}$, kJ/(kg K)	2.12	2.32	2.69	3.04	3.44	3.90	4.62	6.21	8.07	
$\eta\ell$, μNs/m^2	285	246	190	152	125	105	88.5	70.2	50.7	39.5
η_g, μNs/m^2	9.25	9.59	10.30	11.05	11.86	12.74	13.75	15.06	17.15	19.5
λ_ℓ (mW/m^2)/(K/m)	614	592	569	501	456	411	365	320	275	252
λ_g (mW/m^2)/(K/m)	18.8	19.8	22.7	25.2	28.9	34.3	39.5	50.4	69.2	79.4
Pr_ℓ	2.06	1.88	1.58	1.39	1.36	1.32	1.34	1.41	1.43	
Pr_g	1.04	1.11	1.17	1.25	1.31	1.34	1.49	1.70	1.86	
σ, mN/m	33.9	31.5	26.9	22.4	18.0	13.7	9.60	5.74	2.21	0.68
$\beta_{e,\ell}$, kK^{-1}	1.90	1.98	2.22	2.63	3.18	4.01	5.50	8.75	19.7	29.2

Source: Ref. 3 with permission.

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2.7. NOMENCLATURE

2.7.1. Symbol, Definition, SI Units, English Units

c_p	specific heat at constant pressure: kJ/(kg·K), Btu/(lb $_m$·°F)
c_{pf}	specific heat at constant pressure of saturated liquid: kJ/(kg·K), Btu/(lb $_m$·°F)
c_v	specific heat at constant volume: kJ/(kg·K), Btu/(lb $_m$·°F)
D_{ij}	diffusion coefficient: m ^{2}/s, ft^2/s
g	gravitational acceleration: m/s ^{2}, ft/s^2
k	thermal conductivity: W/(m·K), Btu/(h·ft·°F)
k_f	thermal conductivity of saturated liquid: W/(m·K), Btu/(h·ft·°F)
M	molecular weight: kg/(kilogram-mole), lb $_m$/(pound-mole)
P	pressure: bar, lb$_f$/in^2 (psi)
Pr	Prandtl number, $\mu c_p/k$, dimensionless
R	gas constant: kJ/(kg·K), Btu/(lb$_m$·°R)
T	temperature: K, °R, °C
v	specific volume: m ^{3}/kg, ft ^{3}/lb$_m$
Z	compressibility factor, Pv/RT, dimensionless

Greek Symbols

α	thermal diffusivity: m ^{2}/s, ft^2/s
β	coefficient of volumetric thermal expansion: K $^{-1}$, °R^{-1}
λ or κ	thermal conductivity: W/mK, Btu/h·ft·°F
0 or μ	dynamic viscosity: Pa·s, lb$_m$/(h·ft)
v	kinematic viscosity: m^2/s, ft^2/s
ρ	density: kg/m^3, lb$_m$/ft^3
σ	surface tension: N/m, lb$_f$/ft

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