A Course in Heat Transfer

Reference Data
Module

by

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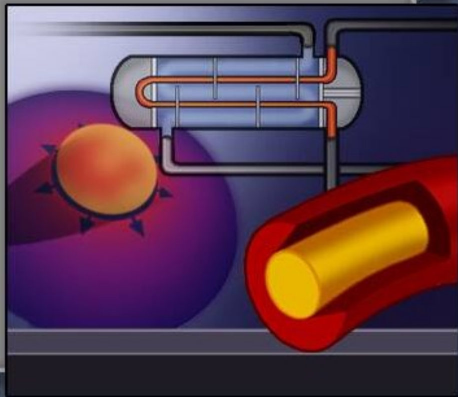

NAVIGATION

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Physical Properties of Water (SI Units)

Temperature (ºC)	Density ρ ((kg/m^3)	Dynamic Viscosity μ (N·s/m^2)	Kinematic Viscosity ν (m^2/s)	Surface Tension σ (N/m)	Vapor Pressure p_v [N/m^2(abs)]	Speed of Sound c (m/s)
0	999.9	1.787 E–3	1.787 E–6	7.56 E–2	6.105 E+2	1403
5	1000.0	1.519 E–3	1.519 E–6	7.49 E–2	8.722 E+2	1427
10	999.7	1.307 E–3	1.307 E–6	7.42 E–2	1.228 E+3	1447
20	998.2	1.002 E–3	1.004 E–6	7.28 E–2	2.338 E+3	1481
30	995.7	7.975 E–4	8.009 E–7	7.12 E–2	4.243 E+3	1507
40	992.2	6.529 E–4	6.580 E–7	6.96 E–2	7.376 E+3	1526
50	988.1	5.468 E–4	5.534 E–7	6.79 E–2	1.233 E+4	1541
60	983.2	4.665 E–4	4.745 E–7	6.62 E–2	1.992 E+4	1552
70	977.8	1.042 E–4	4.134 E–7	6.44 E–2	3.116 E+4	1555
80	971.8	3.547 E–4	3.650 E–7	6.26 E–2	4.734 E+4	1555
90	965.3	3.147 E–4	3.260 E–7	6.08 E–2	7.010 E+4	1550
100	958.4	2.818 E–4	2.940 E–7	5.89 E–2	1.013 E+5	1543

Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed. New York: John Wiley & Sons.

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Physical Properties of Water (BG Units)

Temperature (ºC)	Density ρ ((kg/m^3)	Dynamic Viscosity μ (lb·s/ft^2)	Kinematic Viscosity ν (ft^2/s)	Surface Tension σ (lb/ft)	Vapor Pressure p_v [lb/in.^{2}(abs)]	Speed of Sound c (ft/s)
32	1.940	3.732 E–5	1.924 E–5	5.18 E–3	8.854 E–2	4603
40	1.940	3.228 E–5	1.664 E–5	5.13 E–3	1.217 E–1	4672
50	1.940	2.730 E–5	1.407 E–5	5.09 E–3	1.781 E–1	4748
60	1.938	2.344 E–5	1.210 E–5	5.03 E–3	2.563 E–1	4814
70	1.936	2.037 E–5	1.052 E–5	4.97 E–3	3.631 E–1	4871
80	1.934	1.791 E–5	9.262 E–6	4.91 E–3	5.069 E–1	4819
90	1.931	1.500 E–5	8.233 E–6	4.86 E–3	6.979 E–1	4960
100	1.927	1.423 E–5	7.383 E–6	4.79 E–3	9.493 E–1	4995
120	1.918	1.164 E–5	6.067 E–6	4.67 E–3	1.692 E+0	5049
140	1.908	9.743 E–6	5.106 E–6	4.53 E–3	2.888 E+0	5091
160	1.896	8.315 E–6	4.385 E–6	4.40 E–3	4.736 E+0	5101
180	1.883	7.207 E–6	3.827 E–6	4.26 E–3	7.507 E+0	5195
200	1.869	6.342 E–6	3.393 E–6	4.12 E–3	1.152 E+1	5089
212	1.860	5.886 E–6	3.165 E–6	4.04 E–3	1.469 E+1	5062

Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed. New York: John Wiley & Sons.

Thermal properties of saturated liquid water (H_2O)

T (K)	ρ (kg/m^3)	c_p (J/kg•K)	$\mu \times 10^7$ (kg/m•s)	$\nu \times 10^7$ (m^2/s)	$k \times 10^7$ (W/m•K)	$\alpha \times 10^6$ (m^2/s)	Pr	$\beta \times 10^6$ (K^{-1})
273	999.8	4,217	17,525	175.3	569	13.50	12.99	−68.05
283	999.7	4,193	12,993	129.9	586	13.98	9.30	199.6
293	998.3	4,182	10,015	100.3	602	14.42	6.96	241.5
303	995.7	4,179	7,970	80.04	617	14.83	5.40	292.6
313	992.3	4,179	6,513	65.64	630	15.19	4.32	350.7
323	988.0	4,181	5,440	55.06	643	15.57	3.54	413.9
333	983.2	4,185	4,630	47.09	653	15.87	2.97	480.3
343	977.7	4,190	4,005	40.96	662	16.16	2.54	548.6
353	971.6	4,197	3,510	36.13	669	16.41	2.20	617.3
363	965.2	4,205	3,113	32.25	675	16.63	1.94	685.2
373	958.1	4,216	2,790	29.12	680	16.83	1.73	751.8
383	950.7	4,229	2,522	26.53	683	16.99	1.56	816.1
393	942.9	4,245	2,300	24.39	685	17.11	1.43	877.9
403	934.6	4,263	2,110	22.58	687	17.24	1.31	937.1
413	925.8	4,285	1,950	21.06	687	17.32	1.22	993.7
423	916.8	4,310	1,810	19.74	686	17.36	1.14	1,048
433	907.3	4,339	1,690	18.63	684	17.37	1.07	1,101
443	897.3	4,371	1,585	17.66	681	17.36	1.02	1,153
453	886.9	4,408	1,493	16.83	676	17.29	0.974	1,206
463	876.0	4,449	1,412	16.12	671	17.22	0.936	1.261

Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases,* 2nd ed. New York: John Wiley & Sons.

Thermal properties of selected liquids at 300 K

Liquid	ρ (kg/m^3)	c_p (J/kg•K)	$\mu \times 10^5$ (kg/m•s)	$\nu \times 10^8$ (m^2/s)	$k \times 10^3$ (W/m•K)	$\alpha \times 10^8$ (m^2/s)	Pr
Acetone	782	2180	33.1	42.3	169	9.91	4.27
Ammonia	600	4825	13.1	21.8	465	16.1	1.36
Benzene	881	1730	58.0	65.8	144	9.45	6.97
Carbon tetrachloride	1581	864	88.0	55.7	103	7.54	7.38
Ethyl alcohol	802	2457	105	131	168	8.53	15.4
Ethylether	715	2260	23.0	32.2	140	8.66	3.71
Methyl alcohol	785	2480	53.0	67.5	200	10.3	6.57
Octane	703	2100	56.2	79.9	150	10.2	7.87
n-pentane	626	2330	22.6	36.1	110	7.54	4.79
Toluene	860	1700	54.1	62.9	133	9.10	6.92

1. Lide, D. R., ed. 1997. *CRC Handbook of Chemistry and Physics.* Boca Raton, La.: CRC Press.
2. *1997 ASHRAE Handbook Fundamentals SI Edition.* 1997. Atlanta Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
3. Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases,* 2nd ed. New York: John Wiley & Sons.

Physical properties of metals in the liquid state

T (K)	ρ (kg/m^3)	c_p (J/kg•K)	$\mu \times 10^7$ (kg/m•s)	$\nu \times 10^7$ (m^2/s)	$k \times 10^7$ (W/m•K)	$\alpha \times 10^6$ (m^2/s)	Pr	$\beta \times 10^6$ (K^{-1})
Potassium (K) (T_{mp} = 337 K)								
422	807	795	0.372	4.610	45.0	70.1	0.0066	0.295
533	780	795	0.238	3.051	42.7	689	0.0044	0.305
700	742	754	0.179	2.412	39.4	70.4	0.0034	0.321
866	702	754	0.149	2.123	35.6	67.3	0.0032	0.339
978	675	754	0.134	1.988	33.0	64.9	0.0031	0.353
Sodium (Na) (T_{mp} = 371 K)								
366	929	1,381	0.699	7.52	86.2	67.2	0.0112	0.264
478	902	1,340	0.432	4.79	80.3	66.4	0.0072	0.272
644	860	1,298	0.283	3.29	72.3	64.8	0.0051	0.285
811	820	1,256	0.208	2.54	65.4	63.5	0.0040	0.299
978	779	1,256	0.179	2.30	59.7	61.0	0.0038	0.315

Lyon, R. N., ed. 1952. *Liquid Metals Handbook*, 2nd ed. Washington, D.C.: Atomic Energy Commission and Department of the Navy.

Ethylene glycol

$$\rho = 1082.22 + 1.34031T - (5.63785 \times 10^{-3})T^2 + (4.97135 \times 10^{-6})T^3$$

$$c_p = 889.59 + 5.27817T - (9.16533 \times 10^{-4})T^2 + (8.80859 \times 10^{-7})T^3$$

$$\log(\mu \times 10^2) = 21..5824 - 0.14900T + (3.40615 \times 10^{-4})T^2 - (2.71336 \times 10^{-7})T^3$$

$$k \times 10^3 = 526.92 - 0.88347T + (3.15190 \times 10^{-4})T^2 - (2.42873 \times 10^{-7})T^3$$

$$\beta \times 10^3 = \left(\frac{1}{\rho}\right)\left[-1.34031 + 0.01128T - (1.49141 \times 10^{-5})T^2\right]$$

1. Union Carbide
2. Hagen, K. D. 1999. *Heat Transfer with Applications.* Upper Saddle River, New Jersey: Prentice Hall.

Ethylene glycol + water (50/50 vol)

$$\rho = 984.39 + 1.06485T - (2.67192 \times 10^{-3})T^2 + (2.53477 \times 10^{-7})T^3$$

$$c_p = 2177.05 + 3.60500T + (7.77104 \times 10^{-4})T^2 - (7.75096 \times 10^{-7})T^3$$

$$\log(\mu \times 10^3) = 65.677 - 0.73037T + (3.09175 \times 10^{-3})T^2$$

$$-(5.93326 \times 10^{-6})T^3 + (4.30591 \times 10^{-9})T^4$$

$$\beta \times 10^3 = \left(\frac{1}{\rho}\right)\left[-1.06485 + (5.34384 \times 10^{-3})T - (7.60431 \times 10^{-7})T^2\right]$$

1. *1997 ASHRAE Handbook Fundamentals SI Edition.* 1997. Atlanta Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
2. Hagen, K. D. 1999. *Heat Transfer with Applications.* Upper Saddle River, New Jersey: Prentice Hall.

Glycerin

$$\rho = 1124.6 + 1.33754T - (2.99136 \times 10^{-3})T^2$$

$$c_p = 896.95 + 4.52584T + (1.43224 \times 10^{-3})T^2$$

$$\log(\mu \times 10^2) = 32.1741 - 0.20448T + (4.60137 \times 10^{-4})T^2 - (3.81826 \times 10^{-7})T^3$$

$$k \times 10^3 = 229.67 + 0.18820T - (7.71975 \times 10^{-5})T^2$$

$$\beta \times 10^3 = \left(\frac{1}{\rho}\right)[-1.33754 + (5.98272 \times 10^{-3})T]$$

1. Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed. New York: John Wiley & Sons.
2. Hagen, K. D. 1999. *Heat Transfer with Applications*. Upper Saddle River, New Jersey: Prentice Hall.

Refrigerant-134a (CH_2FCF_3) (liquid)

$$\rho = 1728.1 + 0.86760T - (7.62887 \times 10^{-3})T^2$$

$$c_p = 1727.2 - 7.91930T + 0.01825T^2$$

$$\mu \times 10^6 = 2389.4 - 12.67181T + 0.01782T^2$$

$$k \times 10^3 = 190.29 - 0.46193T + (1.73576 \times 10^{-4})T^2$$

$$\beta \times 10^3 = \left(\frac{1}{\rho}\right)[-0.86760 + (1.52577 \times 10^{-2})T]$$

1. *1997 ASHRAE Handbook Fundamentals SI Edition*. 1997. Atlanta Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
2. Hagen, K. D. 1999. *Heat Transfer with Applications*. Upper Saddle River, New Jersey: Prentice Hall.

SAE 5W-30 engine oil

$$\rho = 1052.3 - 0.6420T$$

$$c_p = 753.7 + 3.650T$$

$$\log(\mu \times 10^2) = 58.2987 - 0.53817T + (1.92827 \times 10^{-3})T^2 - (3.16448 \times 10^{-6})T^3 + (1.97922 \times 10^{-9})T^4$$

$$k \times 10^3 = 0.1447 - (2.3073 \times 10^{-5})T$$

$$\beta \times 10^3 = \frac{0.6420}{\rho}$$

1. Tseregounis, S. I. 1996. *Private Communication.* Warren, Mich.: General Motors Research and Development Center.
2. Stachowiak, G. W., and A. W. Batchelor. 1993. *Engineering Tribology.* Amsterdam: Elsevier Publishing.
3. Hagen, K. D. 1999. *Heat Transfer with Applications.* Upper Saddle River, New Jersey: Prentice Hall.

Water

$$\rho = 2446 - 20.6741T + 0.11576T^2 - (3.12895 \times 10^{-4})T^3 + (4.05050 \times 10^{-7})T^4 - (2.05460 \times 10^{-10})T^5$$

$$c_p = \exp\left[\frac{8.29041 - 0.012557T}{1 - (1.52373 \times 10^{-3})T}\right]$$

$$\mu \times 10^7 = \exp\left[\frac{1.12646 - 0.039638T}{1 - (7.29769 \times 10^{-3})T}\right]$$

$$k \times 10^3 = 62.282 - 1.76841T + 0.03499T^3 - (1.15706 \times 10^{-4})T^3 + (1.53599 \times 10^{-7})T^4 - 7.74770 \times 10^{-11})T^5$$

$$\beta \times 10^6 = \left(\frac{1}{\rho}\right)[20.6741 - 0.23152T + (9.38685 \times 10^{-4})T^2 - (1.62020 \times 10^{-6})T^3 + 1.02730 \times 10^{-9})T^4]$$

1. Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases,* 2nd ed. New York: John Wiley & Sons.
2. Hagen, K. D. 1999. *Heat Transfer with Applications.* Upper Saddle River, New Jersey: Prentice Hall.

Thermal properties of air 100 - 1100 K

T (K) Air	ρ (kg/m^3)	c_p (J/kg•K)	$\mu \times 10^7$ (kg/m•s)	$\nu \times 10^7$ (m^2/s)	$k \times 10^7$ (W/m•K)	$\alpha \times 10^6$ (m^2/s)	Pr
100	3.5562	1,032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1,012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1,007	132.5	7.590	181	10.3	0.737
250	1.3947	1,006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1,007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1,009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1,014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1,021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1,030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1,040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1,051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1,063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1,075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1,087	354.6	76.37	54.9	109	0.702
800	0.4354	1,099	369.8	84.93	57.3	120	0.709
850	0.4097	1,110	384.3	9380	59.6	131	0.716
900	0.3868	1,121	398.1	102.9	62.0	143	0.720
950	0.3666	1,131	411.3	112.2	64.3	155	0.723
1,000	0.3482	1,141	424.4	121.9	66.7	168	0.726
1,100	0.3166	1,159	449.0	141.8	71.5	195	0.728

Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed. New York: John Wiley & Sons.

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Air (1 atm)

$$\log \rho = 2.55182 - 1.003311 \log T$$

$$c_p = 1083.21 - 0.71465T + (2.08832 \times 10^{-3})T^2 - (2.31029 \times 10^{-6})T^3$$
$$+ (1.35272 \times 10^{-9})T^4 - (4.12726 \times 10^{-13})T^5 + (5.27547 \times 10^{-17})T^6$$

$$\mu \times 10^7 = 4.12235 + 0.72111T - (4.28173 \times 10^{-4})T^2 + (5.86408 \times 10^{-8})T^3$$
$$+ (1.25726 \times 10^{-10})T^4 - (6.68760 \times 10^{-14})T^5 + (1.05134 \times 10^{-17})T^6$$

$$k \times 10^3 = 0.81363 + 0.08083T + (6.13727 \times 10^{-5})T^2 - (2.10686 \times 10^{-7})T^3$$
$$+ (2.0609 \times 10^{-10}T^4 - (8.42775 \times 10^{-14})T^5 + (1.27292 \times 10^{-17})T^6$$

Ammonia

$$\log \rho = 2.33138 - 1.00695 \log T$$

$$c_p = 2666.4 - 5.17638T + 0.01455T^2 - (9.98984 \times 10^{-6})T^3$$

$$\mu \times 10^7 = 96.51 - 0.31668T + (1.49445 \times 10^{-3})T^2 - (1.11027 \times 10^{-6})T^3$$

$$k \times 10^3 = 44.80 - 0.28639T + (9.27401 \times 10^{-4})T^2 - (6.47476 \times 10^{-7})T^3$$

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Argon

$$\log \rho = 1.70029 - 1.006801 \log T$$

$$\log c_p = 4.39149 - 1.89717 \log T + 0.71455(\log T)^2 - 0.08948(\log T)^3$$

$$\mu \times 10^7 = -4.28101 + 0.92898T - (5.76258 \times 10^{-4})T^2 + (2.03286 \times 10^{-7})T^3$$

$$k \times 10^3 = 0.30374 + 0.06705T - (3.38561 \times 10^{-5})T^2 + (1.01005 \times 10^{-8})T^3$$

Carbon dioxide

$$\log \rho = 2.73878 - 1.00535 \log T$$

$$c_p = 438.38 + 1.78238T - (1.51821 \times 10^{-3})T^2 + (5.42004 \times 10^{-7})T^3$$

$$\mu \times 10^7 = -11.88865 + 0.611933T - (2.68668 \times 10^{-4})T^2 + (6.44312 \times 10^{-8})T^3$$

$$k \times 10^3 = -0.14761 + 0.03134T + (1.02456 \times 10^{-4})T^3 - (6.92754 \times 10^{-8})T^3$$

Helium

$$\log \rho = 1.67499 - 0.997711 \log T$$

$$\mu \times 10^7 = 53.934 + 0.51628T - (1.53395 \times 10^{-4})T^2 + (3.09242 \times 10^{-8})T^3$$

$$k \times 10^3 = 37.147 + 0.40379T - (1.00516 \times 10^{-4})T^2 + (1.76137 \times 10^{-8})T^3$$

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Hydrogen

$$\log \rho = 1.38415 - 1.00025 \log T$$

$$c_p = 7359 + 52.768T - 0.14776T^2 + (2.01558 \times 10^{-4})T^3$$
$$-(1.41616 \times 10^{-7})T^4 + (4.94995 \times 10^{-11})T^5 - (6.78504 \times 10^{-15})T^6$$

$$\mu \times 10^7 = 21.297 + 0.24580T - (8.31987 \times 10^{-5})T^2 + (1.74024 \times 10^{-8})T^3$$

$$k \times 10^3 = 27.535 + 0.54203T - (1.73110 \times 10^{-4}T^2 + (5.85159 \times 10^{-8})T^3$$

Methane

$$\log \rho = 2.31365 - 1.01076 \log T$$

$$c_p = 2632 - 6.29939T + 0.02128T^2 - (1.53535 \times 10^{-5})T^3$$

$$\mu \times 10^7 = -4.26905 + 0.46482T - (2.95931 \times 10^{-4})T^2 + (1.03030 \times 10^{-7})T^3$$

$$k \times 10^3 = 5.34048 + 0.04799T + (1.77229 \times 10^{-4})T^2 - (5.45455 \times 10^{-8})T^3$$

Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed. New York: John Wiley & Sons.

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Nitrogen

$$\log \rho = 2.54117 - 1.004721 \log T$$

$$c_p = 1093.84 - 0.37167T + (7.41563 \times 10^{-4})T^2 - (2.94906 \times 10^{-7})T^3$$

$$\mu \times 10^7 = 8.82353 + 0.66875T - (3.99709 \times 10^{-4})T^2 + (1.20754 \times 10^{-7})T^3$$

$$k \times 10^3 = -0.02104 + 0.10218T - (6.02143 \times 10^{-5})T^2 + (2.28582 \times 10^{-8})T^3$$

Oxygen

$$\log \rho = 2.60148 - 1.005701 \log T$$

$$c_p = 1068.85 - 1.59151T + (5.38758 \times 10^{-3})T^2 - (7.08515 \times 10^{-6})T^3 ß$$

$$\mu \times 10^7 = 4.70598 + 0.79510T - (4.61161 \times 10^{-4})T^2 + (1.37102 \times 10^{-7})T^3$$

$$k \times 10^3 = 0.19674 + 0.09693T - (3.85719 \times 10^{-5})T^2 + (1.19573 \times 10^{-8})T^3$$

Vargaftik, N. B. 1975. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed. New York: John Wiley & Sons.

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Refrigerant-12 (CCl_2F_2) (gas)

$$\rho = 992.07 - 15.84475T + 0.09623T^2 - (2.66144 \times 10^{-4})T^3 + (2.87072 \times 10^{-7})T^4$$

$$c_p = -3057.96 + 40.79543T - 0.15865T^2 + (2.15100 \times 10^{-4})T^3$$

$$\mu \times 10^6 = -44.055 + 0.54351T - (1.91416 \times 10^{-3})T^2 + (2.47345 \times 10^{-6})T^3$$

$$k \times 10^3 = -21.428 + 0.25441T - (8.54618 \times 10^{-4})T^2 + (1.19140 \times 10^{-6})T^3$$

Refrigerant-134a (CH_2FCF_3) (gas)

$$\rho = \left(\frac{-3.87325 + 0.020213T}{1 - 22.08494 \times 10^{-3}T} \right)^2$$

$$c_p = 44886.3 - 676.907T + 3.85902T^2 - (9.73043 \times 10^{-3})T^3 + (9.21174 \times 10^{-6})T^4$$

$$\mu \times 10^6 = 134.455 - 2.03995T + 0.01204T^2 - (3.09866 \times 10^{-5})T^3 + (2.99859 \times 10^{-8})T^4$$

$$k \times 10^3 = -97.45182 + 1.04946T - (3.60580 \times 10^{-3})T^2 + (4.49592 \times 10^{-6})T^3$$

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Thermal properties of metallic solids at 300 K

Metal	T_{mp}† (K)	ρ (kg/m^3)	c_p (J/kg•K)	k (W/m•K)	$\alpha \times 10^5$ (m^2/s)
Aluminum, Pure	933	2,702	903	237	9.71
Copper, Pure	1,356	8,933	385	401	11.7
Gold	1,336	19,300	129	317	12.7
Iron, Pure	1,810	7,870	447	80.3	2.28
Nickel, Pure	1,728	8,900	444	90.7	2.30
Platinum	2,045	21,450	133	71.6	2.51
Silicon	1,683	2,330	712	148	8.92
Silver	1,235	10,500	235	429	17.4
Titanium	1,953	4,500	522	21.9	0.932

Thermal properties of structural building materials at 300 K

Building Material	ρ (kg/m^3)	c_p (J/kg•K)	k (W/m•K)	$\alpha \times 10^7$ (m^2/s)
Asbestos-cement board	290	590	0.058	3.39
Asphalt roofing shingles	1100	1260	0.13	0.94
Brick, common	1920	835	0.72	4.49
Concrete blocks				
Sand and gravel aggregate, 200 mm thick, 2 or 3 cores	2100	920	1.1	5.69
Concretes				
Aggregate, low density	960		0.33	
Gypsum or plaster board	800	1090	0.16	1.83
Oak wood	704		0.17	
Pine wood	615		0.153	
Plywood	540	1210	0.12	1.84

1. Touloukian, Y. S., and C. Y. Ho, eds. 1972. *Thermophysical Properties of Matter.* Vol. 1, *Thermal Conductivity of Metallic Solids.* Vol. 2, *Thermal Conductivity of Nonmetallic Solids.* Vol. 4, *Specific heat of Metallic Solids.* Vol. 5, *Specific heat of Metallic Solids.* New York: Plenum Press.
2. Lide, D. R., ed. 1997. *CRC Handbook of Chemistry and Physics.* Boca Raton, La.: CRC Press.
3. Boyer, H. E. and T. L. Gall, eds. 1985. *Metals Handbook Desk Edition.* Metals Park, Ohio: American Society for Metals.
4. Taylor, L., ed. 1961. *Metals Handbook* 8th ed. *Properties and Selection of Metals,* Vol. 1. Metals Park, Ohio: American Society for Metals.
5. *1997 ASHRAE Handbook Fundamentals SI Edition.* 1997. Atlanta Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
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Thermal properties of ceramics and glasses at 300 K

Material	ρ (kg/m^3)	c_p ($J/kg \cdot K$)	k ($W/m \cdot K$)	$\alpha \times 10^7$ (m^2/s)
Alumina (Al_2O_3)				
Single crystal (sapphire)	3,970	765	46	15.2
Polycrystalline	3,970	765	36	11.9
Porcelain	2,300	750	2.2	1.28
Pyrex	2,170	716	1.06	0.682
Window glass	2,800		0.700	

Thermal properties of miscellaneous solids at 300 K

Material	ρ (kg/m^3)	c_p ($J/kg \cdot K$)	k ($W/m \cdot K$)	$\alpha \times 10^7$ (m^2/s)
Asphalt	2,110	920	0.740	3.81
Earth				
Soil, dry		754	0.130	
Soil, wet, loosely packed	1,730		1.067	
Soil, wet, tightly packed	1,860		1.44	
Clay	2,080	921	1.73	9.02
Sand	1,520	921	0.317	2.26

1. Touloukian, Y. S., and C. Y. Ho, eds. 1972. *Thermophysical Properties of Matter.* Vol. 1, *Thermal Conductivity of Metallic Solids.* Vol. 2, *Thermal Conductivity of Nonmetallic Solids. Vol. 4, Specific heat of Metallic Solids.* Vol. 5, *Specific heat of Metallic Solids.* New York: Plenum Press.
2. Lide, D. R., ed. 1997. *CRC Handbook of Chemistry and Physics.* Boca Raton, La.: CRC Press.
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Thermal conductivity k(W/m•K), of metallic solids as a function of temperature

	T(K)								
Metal	100	200	300	400	500	600	800	1000	1200
Aluminum, Pure	302	237	237	240	236	231	218		
Copper, Pure	482	413	401	393	386	379	366	352	339
Gold	327	323	317	311	304	298	285	270	255
Iron, Pure	134	94.0	80.3	69.5	62.1	54.7	43.3	32.8	28.3
Nickel, Pure	164	107	90.7	80.2	72.0	65.6	67.6	71.8	76.2
Platinum	77.5	72.6	71.6	71.8	72.0	73.2	75.6	78.7	82.6
Silicon	884	264	148	98.9	80	61.9	42.2	31.2	25.7
Silver	444	430	429	425	419	412	396	379	361
Titanium	30.5	24.5	21.9	20.4	20.0	19.4	19.7	20.7	22.0

Specific heat, c_p (kJ/kg K), of metallic solids as a function of temperature

	T(K)								
Metal	100	200	300	400	500	600	800	1000	1200
Aluminum, Pure	482	798	903	949	996	1033	1146		
Copper, Pure	252	356	385	397	412	417	433	451	480
Gold	109	124	129	131	133	135	140	145	155
Iron, Pure	216	384	447	490	530	574	680	975	609
Nickel, Pure	232	383	444	485	500	512	530	562	594
Platinum	100	125	133	136	139	141	146	152	157
Silicon	259	556	712	790	829	867	913	946	967
Silver	187	225	235	239	244	250	262	277	292
Titanium	300	465	522	551	572	591	633	675	620

1. Touloukian, Y. S., and C. Y. Ho, eds. 1972. *Thermophysical Properties of Matter.* Vol. 1, *Thermal Conductivity of Metallic Solids.* Vol. 2, *Thermal Conductivity of Nonmetallic Solids.* Vol. 4, *Specific heat of Metallic Solids.* Vol. 5, *Specific heat of Metallic Solids.* New York: Plenum Press.
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ABCDEF GHIJKLM NOPQR STUVWXYZ Alpha-Omega

Symbol	SI units	M,L,t,T	Quantity
A	m^2	L^2	area
A_c	m^2	L^2	cross-sectional area
C	kJ/kg·K	$L^2/t^2 \cdot T$	specific heat
C_h, C_c	W/°C	ML^2/t^3T	heat capacity rate
C_D			drag coefficient
C_f			friction coefficient
C_p	kJ/kg·K	$L^2/t^2 \cdot T$	constant pressure specific heat
C_v	kJ/kg·K	$L^2/t^2 \cdot T$	constant volume specific heat
d, D	m	L	diameter
D_h	m	L	hydraulic diameter
e	kJ/kg	L^2t^{-2}	specific total energy
erfc			complimentary error function
E	kJ	ML^2t^{-2}	total energy
E_b	$kJ/m^2 \cdot s$	Mt^{-3}	blackbody emissive flux
f			friction factor
F	kgm/s^2	MLt^{-2}	force, N
F_D			drag coefficient

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Symbols for Heat Transfer

Symbol	SI units	M,L,t,T	Quantity
g	m/s^2	Lt^{-2}	gravitational acceleration
$\dot{g}$	W/m^3	$ML^{-1}t^{-3}$	heat generation rate, W/m^2
h	$u+Pv$, kJ/kg	L^2t^{-2}	enthalpy
h	$W/m^2\cdot°C$	$Mt^{-3}T^{-1}$	convection heat transfer coefficient
h_{fg}	kJ/kg	L^2t^{-2}	latent heat of vaporization
h_{if}	kJ/kg	L^2t^{-2}	latent heat of fusion
J			Bessel function
k	$Js^{-1}m^{-1}K^{-1}$	$MLt^{-3}T^{-1}$	thermal conductivity
L	m	L	length
L_c	m	L	corrected length
L_h	m	L	hydrodynamic entry length
L_t	m	L	thermal entry length
m	kg	M	mass
$\dot{m}$	kg/s	Mt^{-1}	mass flow rate

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ABCDEF GHIJKLM NOPQR STUVWXYZ Alpha-Omega

Symbol	SI units	M,L,t,T	Quantity
NTU			number of transfer units
N_{Bi}			Biot number
N_{Nu}			Nusselt number
N_{Pr}			Prandtl number
N_{Ra}			Rayleigh number
N_{Re}			Reynolds number
p	m	L	perimeter
P	kN/m^2	$ML^{-1}t^{-2}$	pressure
P_v	kN/m^2	$ML^{-1}t^{-2}$	vapor pressure
Q	kJ	ML^2t^{-2}	total amount heat transfer
$\dot{q}$	W/m^2	Mt^{-3}	heat flux
$\dot{Q}$	kW	ML^2t^{-3}	heat transfer rate
r	m	L	radius
r_{cr}	m	L	critical radius of insulation
R	$JK^{-1}mol^{-1}$	$ML^2t^{-2}\ mol^{-1}$	gas constant
R	°C/W	$TM^{-1}L^{-2}t^{+3}$	thermal resistance
R_c	$m^2\cdot°C/W$	$TM^{-1}t^{+3}$	thermal contact resistance
R_f	m^2K/W	$TM^{-1}t^{+3}$	Fouling factor

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ABCDEF GHIJKLM NOPQR STUVWXYZ Alpha-Omega

Symbol	SI units	M,L,t,T	Quantity
S	m	L	conduction shape factor
t	s	t	time
T	°C or K	T	temperature
T_I	°C or K	T	initial temperature
T_f	°C	T	film temperature
T_s	K	T	surface temperature
T_{surr}	K	T	ambient temperature
T_∞	K	T	ambient temperature
u	kJ/kg	L^2t^{-2}	internal energy
U	W/m^2·°C	$Mt^{-3}T^{-1}$	overall heat transfer coefficient
V	m^3	L^3	volume
v	m/s	Lt^{-1}	velocity
v	1/s	t^{-1}	frequency
v_∞	m/s	Lt^{-1}	free stream velocity

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Symbols for Heat Transfer

ABCDEF GHIJKLM NOPQR STUVWXYZ Alpha-Omega

Symbol	SI units	M,L,t,T	Quantity
α	m^2/s	L^2t^{-1}	absorptivity; thermal diffusivity
β	1/K	T^{-1}	volume expansion coefficient
γ	N/m or J/m^2	Mt^{-2}	surface tension
δ	m	L	characteristic length
ΔT_{lm}			log mean temperature difference
ε			emissivity
ε			heat exchanger effectiveness
ε			fin effectiveness
η_{fin}			fin efficiency
μ	kg/m·s	$ML^{-1}t^{-1}$	dynamic viscosity
ν	m^2/s	L^2t^{-1}	kinematic viscosity
ρ	kg/m^3	ML^{-3}	density
σ	$W/m^2 \cdot K^4$	$Mt^{-3}T^{-4}$	Stefan-Boltzmann constant
τ			Fourier number
θ			dimensionless temperature

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Conversion Factors

To convert from BG to SI units, mutiply by

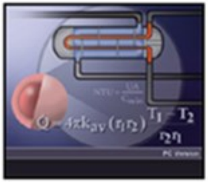
Acceleration	ft/s² → ft/s^2	m/s^2	0.3048
Areas	ft^2	m^2	9.2903 E-2
Density	$slug/ft^3$	kg/m^3	5.1538 E-2
Energy	ft-lbf	J	1.3558
	BTU	J	1.0551 E+3
Force	lbf	N	4.4482
Length	ft	m	0.3048
	in	m	2.5400 E-2
	mi	m	1.6093 E+6
Mass	slug	kg	1.4594 E+1
Mass Flow	slug/s	kg/s	1.4594 E+1
Rate	lbm/s	kg/s	4.5359 E-1
Power	ft-lb/s	W	1.3558
	hp	W	7.4570 E+2

To convert from SI to BG units, divide by

To convert from BG to SI units, mutiply by

Pressure	lbf/ft^2	Pa	4.788 E+1
Pa =N/m^2	lbf/in^2	Pa	6.895 E+3
	atm	Pa	1.013 E+5
(Hg at 60° F)	mmHg	Pa	1.333 E+2
Specific weight	lbf/ft^3	N/m^3	1.571 E+2
Temperature	° F	° C	$T_c = 5/9(t_f - 32°)$
	° R	K	5.556 E-1
Velocity	ft/s	m/s	3.048 E-1
	mi/hr	m/s	4.470 E-1
Viscosity	$lbf \cdot s/ft^2$	$N \cdot s/m^2$	4.788 E+1
	ft^2/s	m^2/s	9.290 E-2
Volume	ft^3	m^3	2.8317 E-2
	gal	m^3	3.7854 E-3
Volume flow	ft^3/s	m^3/s	2.832 E-2
	gal/min	m^3/s	6.309 E-5

To convert from SI to BG units, divide by



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