2.2 Mechanical properties of materials

2.2.1 Densities

Density of water (unit 1 kg m^{-3})

Pure air-free water under a pressure of 101 325 Pa.

Temp/ºC	0	2	4	6	8	10	12	14	16	18
0	999.84	999.94	999.97	999.94	999.85	999.70	999.50	999.24	998.94	998.60
20	998.20	997.77	997.30	996.78	996.23	995.64	995.02	994.37	993.68	992.96
40	992.21	991.43	990.62	989.79	988.92	988.03	987.11	986.17	985.20	984.21
60	983.19	982.15	981.09	980.00	978.89	977.76	976.61	975.43	974.24	973.02
80	971.79	970.53	969.25	967.96	966.64	965.30	963.95	962.58	961.18	959.77
100	958.34									

Values based on the following expression (Kell, 1975, 97–105, recalculated for ITS-90 by Bettin and Spieweck, 1990, 195–196):

$$\text{density at } t/°\text{C} = (999.839\,52 + 16.952\,577t - 7.990\,512\,7 \times 10^{-3}t^2 - 46.241\,757 \times 10^{-6}t^3 + 105.846\,01 \times 10^{-9}t^4 - 281.030\,06 \times 10^{-12}t^5)/(1 + 16.887\,236 \times 10^{-3}t)$$

In the range 0 to 25 °C, the correction (/kg m $^{-3}$) for air-saturated water at temperature t (Bignell 1983, 57–59) is

$$-(4.612 - 0.106t) \times 10^{-3}$$

The temperature (t_m/°C) of maximum density at different pressures (p/Pa) is given by

$$t_m = 3.98 - 0.222 \times 10^{-6}(p - 101\ 325)$$

Information on the preparation of water as a reference material, together with the dependence of its density upon isotopic abundance can be found in Marsh (1987, 13–16).

Density of heavy water

Originally calculated by Kell (1967), from measurements by Chang and Tung (1949), Shrader and Wirtz (1951) and Steckel and Szapiro (1963).

t/ºC	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
ρ/kg m^{-3}	1105.62	1105.99	1105.87	1105.34	1104.45	1103.23	1101.73	1099.96	1097.94	1095.69
t/ºC	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
ρ/kg m^{-3}	1093.24	1090.59	1087.76	1084.74	1081.57	1078.23	1074.73	1071.10	1067.34	1063.44

Density of mercury (unit 1 kg m^{-3})

Under a pressure of 101 325 Pa.

Temp/ºC	0	2	4	6	8	10	12	14	16	18
–20	13 644.61	13 639.64	13 634.68	13 629.72	13 624.76	13 619.81	13 614.86	13 609.91	13 604.96	13 600.02
0	13 595.08	13 590.15	13 585.21	13 580.28	13 575.36	13 570.43	13 565.51	13 560.59	13 555.68	13 550.76

20	13 545.85	13 540.95	13 536.04	13 531.14	13 526.24	13 521.34	13 516.45	13 511.56	13 506.67	13 501.78
40	13 496.90	13 492.02	13 487.14	13 482.26	13 477.39	13 472.52	13 467.65	13 462.78	13 457.92	13 453.05
60	13 448.19	13 443.34	13 438.48	13 433.63	13.428.77	13 423.93	13 419.08	13 414.23	13 409.39	13 404.55
80	13 399.71	13 394.87	13 390.04	13 385.20	13 380.37	13 375.54	13 370.72	13 365.89	13 361.07	13 356.24
ºC	0	20	40	60	80	100	120	140	160	180
100	13 351.42	13 303.3	13 255.3	13 207.5	13 159.7	13 112.0	13 064.4	13 016.8	12 969.1	12 921.4
300	12 873.6									

Based on:

Density at 0 °C = 13 595.08 kg m^{-3}

and the expression

$\rho = \rho_0/(1 + \alpha t)$

where ρ is the density at t °C and

$10^8\alpha = 18\ 158.68 + 0.545\ 83t + 3.4980 \times 10^{-3}t^2 + 1.5558 \times 10^{-6}t^3$

The formula for α relates to temperatures expressed in terms of the ITS-90 temperature scale. The formula for α, together with the density at 0°C, was derived by Ambrose (1990, 245–247) from the density at 20 °C determined by Cook (1961) and Cook and Stone (1957) and the expansion formula of Beattie *et al*. (1941), both of which were related to the IPTS-48 scale.

Other reference materials

A number of other materials (most notably single crystal silicon) are recommended by the International Union of Pure and Applied Chemistry as reference materials for density determination. Details of these, including their preparation, reliability and stability, can be found in Marsh (1987, 30–37).

Approximate densities of commonly used materials*

Substance	Density g cm^{-3}	Substance	Density g cm^{-3}	Substance	Density g cm^{-3}
Acetone	0.8	Gas carbon	1.9	Permalloy C	8.6
Agate	2.6	Gelatine	1.3	Petroleum	0.8
Alcohol	0.8	German silver	8.4	Phosphor-bronze	8.9
Alni	6.9	Glass (soda)	2.5	Pine (white)	0.5
Alnico	7.1	,, (Pyrex)	2.23	Pitch	1.1
Aluminium-bronze		,, (lead)	3–4	Plaster of Paris	1.8
(8% Al)	7.7	Glycerine	1.3	Plastics	see Properties of polymers 3.11.1
Amber	1.1	Gold (22 carat)	17.5	Platinum-iridium	
Asbestos	2.4	,, (9 carat)	11.3	(90/10)	21.5
Ash (timber)	0.75	Granite	2.7	Porcelain	2.3
Asphalt	1.4	Graphite	1.6–2.3	Quartz (crystal)	2.6
Balsa wood	0.2	Gunmetal	8.2	Resin	1.1
Bamboo	0.4	'Heavy alloy'†	16.8–18.0	Sand (dry)	1.6
Bearing metal (80% Sn)	7.3	Ice	0.92	Sealing-wax	1.8
Beech	0.75	Inconel	8.5	Sea water	1.03
Beeswax	0.95	Invar	8.0	Silica (fused)	
Copper-Beryllium	8.2	Ivory	1.8	translucent	2.1
Bone	1.9	Keramot	1.6	transparent	2.2
Borax	1.7	Lard	0.9	Silicon iron	6.9
Boxwood	1.0	Lignum vitae	1.3	Silver sand	2.6
Brass (60/40)	8.4	Linseed oil	0.95	Slate	2.8
,, (70/30)	8.5	Lo Ex	2.7	Soft solder (70% Sn	
Brightray	8.4	Magnalium	2.6	30% Pb)	8.3
Butter	0.9	Mahogany	0.8	Stainless iron	
Carbon steel (< 1 % C)	7.8	Manganin	8.5	(12% Cr)	7.7
Cast iron	7.0–7.4	Marble	2.7	Stainless steel	7.8
Castor oil	0.95	Mazak (No. 2)	6.7	Supermalloy	8.9
Cedarwood	0.55	Methylated spirit	0.8	Tar	1
Charcoal	0.4	Mica	2.8	Teak	0.85
China clay (kaolin)	2.6	Mild steel	7.9	Thiokol	1.4
Coal (anthracite)	1.6	Milk	1.03	Tungsten carbide	
,, (bituminous)	1.4	Monel	8.8	(6% Co)	15.0
Constantan	8.9	Mumetal	8.8	Tungsten carbide	

Cork	0.25	Mycalex	2.4	(12% Co)	14.2
Corundum	4.0	Naphtha	0.8	Turpentine	0.85
Cronite	8.1	Nickel-chromium	8.4	Wax (soft red)	1.0
Diamond	3.5	Nickel-silver	8.8	White spirit	0.85
Duralumin	2.8	Nimonic	8.2	Wrought iron	7.8
Ebonite	1.2	Oak	0.7	Xylol	0.85
Ebony	1.2	Olive oil	0.9	Y-alloy	2.8
Elinvar	8.1	Paraffin oil	0.8		
Emery	4.0	Paraffin wax	0.9		

* For densities of the elements and chemical compounds, see under the Chemistry Section of this book.

† Tungsten with metallic additives.

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