2.3.5 Thermal Expansion

Coefficients of expansion

Coefficients of thermal expansion are normally described either as the increase in length (or volume, esp. for liquids) per unit length at a given temperature, known as the *expansivity*, α. = $(l/L)(dL/dT)$, or as the mean expansion coefficient over a temperature range, $\bar{\alpha} = (1/L_0)(\Delta L/\Delta T)$, where L is the instantaneous length, L_0 is an initial length, T is temperature, and ΔL and ΔT are changes in length referenced to a temperature at which L_0 was measured. The latter form is more common than the former in engineering texts. Significant differences in numerical data can arise between the two methods. In this section, expansivity data only are given. The latter form can be determined from the former by integration over ΔT. To a first approximation, *cubical* or *volume* expansivities of solids are three times the linear expansivity.

Coefficients of cubical expansion of liquids

The following table gives values for the cubical (volume) expansivity $(l/V)(dV/dT)$ at T = 293 K (20 °C). Generally, the expansivity increases with increasing temperature.

Liquid	$\alpha/10^{-5}K^{-1}$	*Liquid*	$\alpha/10^{-5}K^{-1}$
Acetic acid	107	Ethyl bromide	141
Acetone	143	Ethylene glycol	57

Alcohol, methyl	118	Glycerol (glycerine)	49
Alcohol, ethyl	109	Mercury*	18.2
Aniline	85	Methyl iodide	120
Benzene	121	n-Pentane	158
Bromine	112	Sulphuric acid (100%)	56
Carbon disulphide	119	Toluene	107
Carbon tetrachloride	122	Turpentine	96
Chloroform	127	m-Xylene	99
Ether	163	Water**	21

* See also section 2.2.1 (Density of mercury).
** See also section 2.2.1 (Density of water).

Coefficients of linear expansion of solids

The expansivities of the majority of solid materials increase with increasing temperature, and can be represented by an equation of the form $\alpha = a + bT + cT^2$ over limited temperature ranges. The tables in this section cover elements, metal alloys, ceramics and miscellaneous materials.

Many materials exhibit anisotropic thermal expansion behaviour. When single crystals are in common use, data in the respective principal directions are given. Otherwise a homogeneous isotropic polycrystal-line solid is assumed. High levels of anisotropy and/or phase changes can lead to microcracking and thermal expansion hysteresis. Complex multiphase materials possess thermal expansion characteristics which are related to the expansion coefficients and elastic moduli of the individual components. Only approximate ranges can be cited. Further, more detailed data can be obtained from Touloukian *et al*., (1971).

Elements	$\alpha/(10^{-6}\ K^{-1}$						
	100 K	200 K	293 K	500 K	800 K	1100 K	1500 K
Aluminium	12.2	20.3	23.1	26.4	34.0	–	–
Antimony*	9.1	10.5	11.0	11.7	11.7	–	–
Beryllium*	1.3	7.1	11.3	15.1	19.1	21.6	23.7
Bismuth*	12.3	13.1	13.4	12.7	–	–	–
Boron	–	–	4.7	5.4	6.2	6.8	–
Cadmium	26.9	29.8	30.8	36.0	–	–	–
Carbon, vitreous	–	–	3.1	3.3	3.6	4.0	4.6
Carbon, diamond	0.05	0.4	1.0	2.3	3.7	4.7	5.6
Carbon, graphite, polycrystalline**	–	–	7.1	7.5	8.1	8.6	9.3
Carbon, pyrolytic, para. deposition	–	–	23.1	24.4	25.9	27.2	28.6
perp. deposition	–	–	−0.6	0.6	0.8	1.7	2.5
Chromium	2.3	5.3	4.9[a]	8.8	10.8	12.3	14.9
Cobalt*	6.8	11.5	13.0	15.0[b]	15.2	17.0	–
Copper	10.3	15.2	16.5	18.3	20.3	23.7	–
Germanium	2.4	4.9	5.7	6.5	7.2	7.8	–
Gold	11.8	13.7	14.2	15.4	17.0	19.7	–
Indium*	25.4	28.1	32.1	–	–	–	–
Iridium	4.4	5.9	6.4	7.2	8.1	8.5	9.4
Iron	5.6	10.1	11.8	13.9	16.2	16.7[c]	23.3[c]
Lead	25.6	27.5	28.9	33.3	–	–	–
Magnesium*	−0.2	0	8.2	11.3	13.2	14.4	–
Molybdenum	2.8	4.6	4.8	5.1	5.7	6.5	7.5

Nickel	6.6	11.3	13.4	15.3	16.8	17.8	20.3
Niobium	5.2	6.8	7.3	7.8	8.2	8.7	9.3
Palladium	8.0	10.7	11.8	13.2	14.5	16.3	–
Platinum	6.6	8.5	8.8	9.6	10.3	11.1	12.8
Rhodium	5.0	7.3	8.2	9.3	10.8	12.5	14.8
Silicon	−0.4	1.5	2.6	3.5	4.1	4.5	4.7
Silver	14.2	17.8	18.9	20.6	23.7	27.1	–
Tantalum	4.8	6.0	6.3	6.8	7.2	7.4	7.8
Thallium*	25.2	28.0	29.9	34.7	–	–	–
Tin*	16.5	19.6	22.0	27.2	–	–	–
Titanium*	4.5	7.4	8.6	9.9	11.1	11.7[d]	12.9
Tungsten	2.6	4.1	4.5	4.6	5.0	5.3	5.5
Uranium*	10.0	13.4	13.9	16.9	24.3[e]	22.9[e]	–
Vanadium	5.1	7.1	8.4	9.9	10.9	12.0	14.1
Zinc*	24.5	28.6	30.2	32.8	–	–	–

* Crystallographically anisotropic. Data are for isotropic polycrystalline bodies. For anisotropic bodies, data vary.

** Data for isotropic POCO Grade AXM-5Q isotropic graphite. Most polycrystalline graphites are anisotropic.

[a] Phase change at 311 K.

[b] Phase change at 690 K.

[c] Phase changes at 1 185 K and 1 667 K.

[d] Phase change at 1 156 K.

[e] Phase change at 941 K and 1 048 K.

Metal alloys	$\alpha/(10^{-6}\ K^{-1})$

(Approximate compositions in mass %)	100 K	200 K	293 K	500 K	800 K	1 100 k
Aluminium bronze (90 Cu + 5 Al + 4.5 Ni)	12–14	–	15.9	18.1	20.3	–
Brass (67 Cu + 33 Zn)	–	–	17.5	20.0	22.5	–
Bronze (85 Cu + 15 Sn)	–	–	17.3	19.3	21.9	–
Cast iron (Fe + 3 C + 2 Si)	–	–	11.9	13.1	14.5	–
Constantan (65 Cu + 35 Ni)	11.2	–	15.0	17.4	19.2	–
Cupro-nickel (65 Ni + 30 Cu + 1.5 Fe + 1 Mn)	9.8	–	12.7	15.4	18.2	–
Dural (94 Al + 4 to 5 Cu)	13.1	–	21.6	27.5	30.1	–
Inconel	8.7	–	11.6	14.4	17.6	–
Nickel–iron alloys*						
(64 Fe + 36 Ni, Invar)	1.4	0.53	0.13	5.1	17.1	–
(63 Fe + 32 Ni + 4 Co, Super Invar)	–	–	0.0	–	–	–
(50 Fe + 50 Ni)	–	–	9.9	10.2	13.7	17.3
Phosphor bronze	–	–	17.0	20.0	–	–
Stainless steel						
(ferritic types, 16–19 Cr + 6–14 Ni)	7.0	9.2	11.1	15.0	19.7	23.2
(austenitic types e.g. 13–17 Cr + 10 Ni)	6.0	7.9	9.5	12.1	13.8	13.9
Steel, carbon (0.7–1.4 C)	6.9	–	10.7	13.7	16.2	–
Stellite (65 Co + 20–30 Cr + 6–15 W)	6.9	9.3	11.2	14.6	17.2	17.4
Tungsten carbide cermets (4–11 Co)	–	–	3.7	4.3	4.8	5.5

* Note that Ni–Fe–Co alloys have low expansivities below the gamma to alpha phase transformation and high expansions above this temperature. Expansivities and the transition temperature depend critically on the proportions of the major as well as minor elements; see for example. Partridge (1949) or ASM Metals Handbook (1981).

Ceramics, glasses, semiconductors	$\alpha/(10^{-6}\ K^{-1})$						
	100 K	200 K	293 K	500 K	800 K	1 100 K	1 500 K
Alumina (Al_2O_3)	0.6	3.3	5.5	7.8	8.5	9.4	10.2
Beryllia (BeO)	–	–	5.5	8.0	9.5	10.6	12.4
Boron nitride:							
para. hot pressing	–	0–2	0–2.3	0–3	0–4	1–8	4–9
perp, hot pressing	–	~1	0–1	0–1	0–1	1–2	1–2
Cordierites ($Mg_2Al_4Si_5O_{18}$)	–	–	~0	~1.0	1–2	–	–
Forsterites (Mg_2SiO_4)	–	–	9.0	10.3	11.8	13.2	–
Glasses:*							
Borosilicate, Pyrex	1.5	2.7	2.8	3.3	5.0	–	–
Borosilicate, crown	–	–	7–8	–	–	–	–
Dense flint	–	–	8–9	–	–	–	–
Fused silica	−0.53	0.13	0.49	0.63	0.47	0.35	–
Soda-lime (Float)	–	–	7.5	–	–	–	–
Glass–ceramics:*							
Corning 9606	–	–	1.9	3.6	4.1	4.6	–
Corning 9608	–	–	1–2	1–3	1–4	2–5	–
Macor machinable	–	–	~8	~9	~11	~14	–
Zerodur	–	<0.1	<0.1	–	–	–	–
Magnesia (MgO)	2.2	7.6	–	11.0	13	15.2	16.2
Magnesium fluoride:							
para. c-axis	3.9	–	14.5	17.0	19.2	–	–
perp. c-axis	1.4	–	9.5	11.5	15.8	–	–
polycrystalline	2.2	–	11.1	13.3	16.8	–	–
Mullites ($Al_6Si_2O_{13}$)	–	–	3.0	4.4	5.2	6.0	6.5
Porcelains:							
aluminous	–	–	3–6	4–7	5–8	7–10	–
chemical	–	–	2–4	–	–	–	–
quartz	–	–	3–6	4–7	5–8	7–10	–
Pyrophillite, fired 1 250°C**	–	–	2–3	3–4	3–4	–	–
Quartz single crystal:							
para. c-axis	4.0	5.2	6.8	11.4	31.4	–	–

perp. c-axis	9.1	10.3	12.2	19.5	37.6	–	–
Sapphire single crystal:							
para. c-axis	3.6	4.1	4.8	7.9	8.9	9.8	10.9
perp. c-axis	3.3	2.2	6.6	7.4	8.3	9.1	10.0
Semiconductors:							
gallium arsenide	1.9	–	5.7	6.5	7.1	–	–
gallium phosphide	–	–	4.7	5.5	6.0	–	–
indium antimonide	2.8	–	5.0	6.1	–	–	–
Silicon carbides	0.14	–	3.3	4.2	4.9	5.5	6.1
Silicon nitrides	–	–	2.5	2.7	3.2	4.0	4.5
Steatites ($MgSiO_3$)	–	–	6–9	6–9	6–9	–	–
Titania (TiO_2)	6.5	7.1	7.5	8.4	9.3	9.8	–
Zirconia (ZrO_2, stabilised)	–	–	8–9	9–10	11–13	13–15	13–15

* Glasses and glass–ceramics have expansion coefficients tailorable by varying compostion.

** May be anisotropic. Expansivity is a strong function of firing temperature.

Further data on ceramic materials can be found in Morrell (1985).

Miscellaneous materials	$\alpha/(10^{-6}\ K^{-1})$
	293 K
Building materials:	
Brick	3–10
Cement/concrete	7–14
Granite	4–7
Limestone, marble	8–12
Portland stone	~3
Sandstone	~10
Slate	5–12

Plastics and plastic composites:	
(see also section 3.11.1)	
CFRP (cross-ply)	0–3
GRP (cross-ply)	12–20
PTFE	525
Woods:	
along grain	3–6
across grain	35–60

References

R. Morrell (1985) *Handbook of Technical and Engineering Ceramics*, *Part* 1, *An Introduction for the Engineer and Designer*, HMSO.
Metals Handbook (1981) *Ninth Edition*, Vol. 3: *Properties and Selection*, ASM, Metals Park, Ohio.
J. H. Partridge (1949) *Glass-to-metal seals*, Society of Glass Technology, Sheffield.
Y. S. Touloukian *et al.*, (eds.) (1971) *Thermophysical Properties of Matter*, vols 12 and 13, IFI Plenum, NewYork.

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