PROPERTIES OF SOLIDS

(Function values at 288 K. Note: there is little variation in the thermal capacity of metals, even when molten)

Substance	Note	Melting temp. T_f K	Boiling temp. T_b K	Melting enthalpy h_{sl} kJ/kg	Boiling enthalpy h_{lv} kJ/kg	Density (mass) ρ kg/m^3	Thermal expansion (linear*) $\alpha\cdot10^6$ K^{-1}	Sound speed(**) c m/s	Thermal capacity c J/(kg K)	Thermal conductivity k W/(m K)	Solar absorptance (normal) α -	Emissivity (hemispherical, bolometric) ε -
Alumina	1	2300	3200	1070		3980	7	5600	840	33[1]	0.1..0.25	0.3..0.5
Aluminium	2	933	2790	395	10 700	2710	24	5500	896	220	0.1..0.15	0.05[2]
Aluminium alloy A7075	3	750[3]				2810	23.4	6300	960	134	0.1..0.15	0.05[2]
Asbestos	4	1420				2400			1050	0.15		0.95
Asphalt	5	400[5]				2000	200		920	0.7	0.9	0.9
Ash	6					640			800	0.07		
Bakelite	7	430[7]				1400	40		1000	1	0.9	0.94
Beryllium	8	1580	2740	900	33 000	1850	11	12800	1850	190	0.5..0.7	0.18
Brass	9	1200				8780	20	4600	400	150		0.03..0.25
Brick	10					1970	10	3600	800	0.7	0.6	0.9
Bronze	11	1300				8800	18		400	50..80		
Carbon fibre composite	12	400[12]				1500	2		1100	20[12]	0.85	0.85
Cement mortar	13					3000	20		670	0.3	0.6	0.9
Charcoal	14					240			840	0.05	0.95	0.95
Clay & pottery	15					1000			920	1.3	0.4	0.95
Coal	16	3910				1400			1000	0.17	0.95	0.80..0.95
Concrete	17					2100..3000	8..14	4300	653	1.5	0.6	0.8
Copper	18	1358	2830	205	4800	8910	17	3800	390	395	0.2..0.5	0.05
Cork	19					100			2000	0.05		0.7
Diamond	20	4760[20]	4100[20]			3510	0.8	12000	500[20]	2000[20]		0.02
Elastomer (rubber)	21	400[21]				1100	200..300	1600	2000	0.1	0.9	0.9

Glass (optical)	22					4000	6		500	1.4		
Glass (pyrex)	23					2230	3	5600	840	1.1		0.9
Glass (quartz)	24	1970	2230			2650	0.55	5700	780	1.5		0.93
Glass (window)	25	1400				2500	9	5600	820	0.8..1.1	0.1	0.9
Glass (wool)	26					52			657	0.038		
Granite	27	1510				2600..2800	6..10	6000	830	2.5..3		0.45
Graphite	28	4760[28)]	4100	9000	30000	2260	5..10	1200	750	120[28)]	0.95	0.80
Ice	29	273	373	333	2260	920	50	3500	2040	2.3	0.3..0.5	0.92
Invar	30	1770				8100	1.2	4700	460	11	0.4	
Iron (cast-)	31	1800	3000	290	6300	7200	9..12	5000	420	40	0.3	0.2..0.6
Leather	32					1000			1500	0.16	0.7	0.95
Magnesium	33	923	1360	350		1730	26	5800	1000	160		0.2..0.5
Marble	34	1170[34)]				2700	12	3800	880	2.6	0.4	0.90
Methacrylate (PMMA)	35	400[35)]				1180	60..70	2700	1600	0.19		0.9
Nickel	36	1720	3100	298	6400	8900	13	6000	440	90	0.2	0.05
Paper	37	550[37)]				900			1500	0.07..0.13	0.3	0.95
Plaster	38					2290			900	0.83		0.9
Platinum	39	2040	4100	114	2600	21470	9	3300	130	70		0.09
Polyethylene	40	320[40)]				920	180..400	2000	2300	0.35		0.9
Polystyrene foam	41	360[41)]				40[41)]	70..130	2300	1300	0.035		0.9
Polyurethane	42	360[42)]				25..150	150		1120	0.025		0.9
Polyvinylchloride (PVC)	43	360[43)]				1400	90..180	2300	960	0.10		0.9
Salt	44	1075	1690	515	2900	2170	44		850	6.5		
Sand & soil	45	1970	2230			1600	0.5		900	0.3..0.6	0.4..0.8	0.6..0.9
Sapphire	46	2310	3250	1050		3980	5..6		700	35[46)]	0.2	0.02
Silicon	47	1687	3530	1650	10600	2330	2.3	8400	710	150	0.7	0.70
Silver	48	1235	2430	110	2350	10500	20	3700	235	425		0.02
Snow	49	273				100..500			2000	0.05..0.2	0.2	0.85
Sodium	50	371	1160	113	4250	970	71	3200	1200	140		
Steel (carbon-)	51	1810	3100	290	6300	7800	12	5100	500	52[51)]	0.2	0.2..0.6

Steel (stainless-)	52	1700	3000	280	6300	7850	15..17	5100	500	17	0.4[52)]	0.2..0.3
Teflon (PTFE)	53	650				2150	100..200	1400	1030	0.25	0.12	0.85
Tin	54	505	2870	60	2500	7300	23	3800	230	70		0.05
Titanium	55	1940	3600	295	8900	4530	9	6100	610	22[55)]	0.4..0.7	0.2..0.5
Uranium	56	1410	4400	38	1800	19050	14	3400	120	28		
Uranium oxide	57	3140	4100			10970	24		240	7.9		0.85
Wolfram	58	3695	5800	285	4200	19400	4.5	5200	130	180	0.45	0.09[58)]
Wool, hair	59					50..150			1360	0.05		
Wood (oak)	60	550[60)]				750	50[60)]	3800	2390	0.17[60)]	0.35	0.9
Wood (pine)	61					450	35[61)]	3400	2700	0.15[61)]	0.6	0.9
Wood-dust	62					190				0.05		0.75

*Linear thermal dilatation. Volumetric expansion coefficients, as used for liquids and gases, are three times the value of linear expansion coefficients.

**The speed of sound in solids depends on propagation mode and solid shape. Values here compiled apply to longitudinal-wave (i.e. pressure wave, or P-wave) along thin solids (rods, bars, pipes); values for bulk solids are some 20% higher. Sound propagation as transversal waves (i.e. shear waves, or S-waves) are some 40% lower (e.g. for a mild steel rod c=5100±100 m/s, but for a steel block c=6000±100 m/s, and c=3100±100 m/s for shear waves.

1) Alumina (Al_2O_3, M=0.102 kg/mol) is a typical refractory material (i.e. resistant to very high temperatures). Conductivity decreases a lot with temperature (k=120 W/(m·K) at 100 K, k=50 W/(m·K) at 200 K, k=12 W/(m·K) at 500 K, k=5 W/(m·K) at 1500 K).. See also sapphire properties.

2) Aluminium (Al, M=0.027 kg/mol, a face-centred-cubic crystal, is seldom used pure. The liquid at the melting point has ρ_L=2360 kg/m^3 (notice a rather large 6% volume increase on melting), α_L=125·10^{-6} 1/K, c_L=1130 J/(kg·K), k_L=90 W/(m·K), σ=0.86 N/m, μ=1200 μPa·s. Thermal conductivity of pure aluminium may reach k=237 W/(m·K) at 288 K, and decreases to k=220 W/(m·K) at 800 K; at cryogenic temperatures, k=50 W/(m·K) at 100 K, increasing to a maximum of k=25·10^3 W/(m·K) at 10 K and then decreasing towards zero proportionally to T, with k=4·10^3 W/(m·K) at 1 K). Aluminium alloys may have k=100..200 W/(m·K); e.g. see A7075 below. Emissivity may vary a lot, from 0.05 if polished, to 0.8 if hard anodised or dew-covered, or even ε=0.85 if black anodised. Solar absorptance also may vary from 0.09 if polished to 0.4 if hard anodised; aluminium foil gets hot under sunshine because α/ε=0.15/0.05>1). Aluminium paint may have ε=0.3 when bright and ε=0.6 when dull.

3) A7075 is an aluminium alloy with 6%Zn, 2.5%Mg, 1.5%Cu,), with $T_{melting}$=750 K but $T_{freezing}$=900 K; α=23.4·10^{-6} 1/K at 25 ºC (α=25.2·10^{-6} 1/K at 200 ºC). Aluminium alloys are designated by 4 figures related to composition: 1xxx if Al>99%, 2xxx with Cu, 4xxx with Si, 5xxx with Mg, 7xxx with Zn). Duralumin (Al-2024: 4.4%Cu, 1%Mg, 0.75%Mn, 0.4%Si) has T_f=775 K, ρ=2770 kg/m^3, c_p=875 J/(kg·K) and k=174 W/(m·K), increasing to k=188 W/(m·K) at 500 K; it was the most common aerospace alloys, but were susceptible to stress corrosion cracking and are increasingly replaced by 7000 series (mainly Al-7075).

4) Asbestos is a plait of $Mg_3Si_2O_5$ fibres. It is rarely use nowadays after its dust was found to be carcinogenic.

5) Asphalt here refers to the solid residue of crude-oil distillation, a polycyclic aromatic hydrocarbon mix (e.g. 85%C10%H5%S) also known as bitumen, and used as a water-prof layer in buildings. Notice, however, that the main use of asphalt is as a binder in road paving, asphalt concrete (often shorted to asphalt), a composite material with asphalt (the binder) and gravel (ceramic aggregates) with higher density (2300..2500 kg/m^3, higher thermal conductivity (1..3 W/(m·K))), and higher heat capacity (1000..1300 J/(kg·K)). Asphalt (the binder) gets soft and may creep when warm (but it may oxidise and get stiffer under strong sunshine), and gets brittle at freezing temperatures; it is handled as a viscous liquid at about 150 ºC.

6) Ash, the fine particulate residue from wood burning, is sometimes used as a thermal insulator.

7) Bakelite is a thermosetting polymer resin (decompose before softening) of phenol and formaldehyde (PF, $(C_6H_6O{\cdot}CH_2O)_n$), used since its inception (1907) as a heat-resistant electrical insulator. Bakelite is produced in many different grades to meet different mechanical, electrical, and thermal properties; e.g. density may be in the range ρ=1300..1700 kg/m^3, thermal expansion α=(20..120)·10^{-6} 1/K, thermal capacity c=900..1600 J/(kg·K), thermal conductivity k=0.2..1.4 W/(m·K); in fact, when graphite particles are added, thermal conductivity is enhanced from k=5 W/(m·K) for 30 %vol graphite to k=12.3 for 55 %.

8) Beryllium metal (M=0.009 kg/mol, ρ_L=1690 kg/m^3) is used in the aerospace industry (e.g. Saturn V nozzles), due to its stiffness (Young modulus 30% larger than steel), light weight, high melting point, high thermal and electrical conductivities, and dimensional stability over a wide temperature range. Sound speed is one of the largest. It is transparent to X-rays.

9) Brass is typically a 60%Cu, 40%Zn yellowish alloy. Thermal conductivity decreases with Cu content (for 70%Cu-30%Zn k=115 W/(m·K)). Brass emissivity may range from 0.05 (polished) to 0.25 (dull).

10) Bricks are made by baking clay at high temperature. Fireclay bricks have k=0.9 W/(m·K) at 288 K and k=1.8 W/(m·K) at 1500 K; at these high temperatures, emissivity is ε=0.6 for the common red brick, but may be down to 0.3 for white refractory bricks.

11) Bronze is a seawater resistant copper alloy, typically 84%Cu, 9%Zn, 6%Sn; aluminium bronze typically has 90%Cu, 10%Al.

12) Carbon fibre reinforced polymer (CFRP) is a structural composite much used in aerospace and other advanced technologies). Properties depend a lot on fibre volume-fraction and type of polymer (epoxy resins are most used, but polyester and vinyl ester are also used). The carbon-fibre alone may have ρ=1800 kg/m^3, c=750 J/(kg·K), k=300..500 W/(m•K), and epoxy alone may have ρ=1200 kg/m^3, c=1200 J/(kg·K), k=0.25 W/(m·K), and very low electrical conductivity. Notice the low thermal expansion coefficient. Some epoxy resins may work up to 450 K.

13) Cement mortar, as used to glue tiles, is a cured mixture (after 1 day) of water with fine grey powders from calcinated clays and limestones (the composition of the powder is $3CaO{\cdot}SiO_2+2CaO{\cdot}SiO_2+3CaO{\cdot}Al_2O_3$.

14) Charcoal is the solid residue of the anaerobic pyrolysis of wood, used for fuel.

15) Clay is a very fine grained material that consists of hydrated aluminium silicate, silica, and organic fragments, as found in the land; it gets plastic when moist, and gets hard, brittle and more dense on baking over 900 K (pottery vitrification; earthenware is produced at 1000..1400 K and porcelain at 1400..1700 K, with a larger proportion of kaolin). Porcelain has ρ=2500 kg/m^3, α=5·10^{-6} 1/K, c_p=900 J/(kg·K) and k=1.5..2.5 W/(m·K).

16) Coal (dried) is not a pure substance; its averaged composition is 85%C5%H5%O5%inert. When heated, trapped volatile organic compounds are first released (400 K), and afterwards (500 K) vapours from thermal decomposition: benzene and toluene. See graphite and diamond for pure-carbon properties.

17) Concrete is a composite material obtained by curing (for 1 month) a mixture of water with cement, sand and gravel.

18) Copper (Cu, M=0.0635 kg/mol, a face-centred-cubic crystal) is one of the best thermal and electrical conductors, with ρ_L=7970 kg/m^3, α_L=100·10^{-6} K^{-1}, c_{pL}=502 J/(kg·K) and k_L=350 W/(m·K). Constantan (45%Ni) only has k=23 W/(m·K). German silver (alpaca, 50%Cu, 30%Zn, 20%Ni, although the latter may vary a lot) only has k=25 W/(m·K), being a very good electrical conductor. Copper emissivity may range from 0.05 (polished) to 0.85 (oxidised).

19) Cork, the thick light porous outer bark of the cork oak, is widely used as a thermal (and acoustic) insulator.

20) Diamond is a metastable crystalline phase (fcc) of pure carbon. If heated under vacuum, diamond transforms to graphite before melting, and graphite sublimes. If heated in air, diamond burns at about 1000 K. Its thermal capacity varies a lot with temperature up to T_{Debye}=2000 K (100 J/(mol·K) at 150 K, 1000 J/(mol·K) at 350 K, 2500 J/(mol·K) at 800 K). Its thermal conductivity varies a lot with temperature, impurities and isotopic composition (typically 100 W/(m·K) at 10 K, from 100 W/(m·K) to 10000 W/(m·K) at 100 K, and then decreasing with temperature). Its thermal expansion coefficient grows from 0.8 at 300 K to 5 at 1300 K. Diamond is transparent in the UV (from 225 nm), the visible and IR bands, with a high refractive index. 2.42, slowly decreasing with wavelength (2.39 at 10 μm), and slowly increasing with temperature in the whole range. It has a very low emissivity, 0.02..0.03 at 10 μm.

21) Elastomer, as silicone rubber with k=0.2 W/(m·K), neoprene rubber with k=0.2 W/(m·K), etc.

22) Optical or Flint glass (SiO_2 50%, PbO 50%) is a high-refractive-index glass, n=1.6..1.7 (against n=1.5..1.6 for common glasses), mainly used for lenses.

23) Pyrex is a thermal and chemical resistant glass, used for laboratory and oven work (SiO_2 80%, B_2O_3 13%, also known as borosilicate glass).

24) Quartz glass, also known as fused quartz or fused silica, is pure silica (>99.5% SiO_2) in amorphous form, obtained by melting pure silica sand at about 2000 K, and used as a thermal and chemical resistant glass, and for its optical properties (fibre optics, UV windows, near-IR windows); quartz windows (a few mm to a few cm thick) have some 90% radiation transmittance in the range $0.2<\lambda<2.5$ μm. Quartz glass has one of the lowest thermal expansion values, α_L=0.55·10^{-6} K^{-1} from 300 K to 700 K (important for thermal shock and optical stability of mirrors and lenses). Quartz glass has k=1.5 W/(m·K), but mono-crystalline quartz has k=11 W/(m·K) along the c-axis and k=6.5 W/(m·K) across.

25) Window glass (common glass, comprising >90% of all glass production), also known as soda-lime or crown glass (SiO_2 75%, Na_2O 15%, CaO 10%), is a low-melting-temperature glass used for windows and containers. Common glass loses its fragility at some 700 K (glassware can then be worked), and creeps at 1000 K under its own weight. Light transmission in common glass has nearly the same cut-off window as quartz glass, $0.3<\lambda<2.5$ μm in this case, but transmittance is smaller and non-constant (e.g. drops to 0.6 at 1 μm for a 10 mm thick glass). An ordinary second-surface mirror has a solar absorptance of α=0.14 (if aluminized; α=0.07 if silvered). Notice that a glass window do not let ultraviolet and infrared radiation pass, what explains the green-house effect, and why filament-emission heats up bulbs of incandescent lamps (average absorptance from a 3000 K source is around 0.7).

26) Wool glass, glass fibre or fibreglass (SiO_2 55%, CaO 16%, Al_2O_3 15%, MgO 4%), is easily drawn into fibres, and used in composites, insulation and fire protection.

27) Granite is the commonest igneous rock in the Earth crust (SiO_2 70%, Al_2O_3 20%), its thermal conductivity decreases from k=3 W/(m·K) at 300 K to k=1 W/(m·K) at 1000 K increasing a little with the high pressures in the Earth crust.

28) Graphite is pure carbon as found in nature in the hexagonal crystal lattice, or as made by sintering carbon powder (amorphous), used as a thermal and electrical conductor, as a nuclear-reactor moderator, and as a self-lubricant. It does not melt but sublimates at 100 kPa (T_{subl}=4100 K), its triple point being at 4760 K and 10.3 MPa. Its thermal conductivity varies a lot: from 80 W/(m·K) perpendicular to the hexagonal-crystal layers, to up to 250 W/(m·K) along the layer direction (but it may reach more than 2000 W/(m·K) along single layers and nanotubes); for amorphous graphite, typical values are around 120 W/(m·K). Emissivity at room temperature of bulk graphite may be in the range 0.60..0.95, depending on preparation (the largest in powder form), but very thin graphite films and graphene may have apparent infrared emissivity in the range 0.2..0.4, depending on substrate, with larger values at shorter wavelengths.

29) Ice (from water) may have air and solids trapped, modifying its properties. Ice at –100 ºC has ρ=929 kg/m^3, α=28·10^{-6} 1/K, c_p=1360 J/(kg·K) and k=3.6 W/(m·K). For frosty ice and snow, thermal conductivity dependence a lot on density, $k=0.024+(\rho/\rho_w)+1.7(\rho/\rho_w)^3$ W/(m·K), where ρ_w=1000 kg/m^3 (e.g. k=0.16 W/(m·K) for ρ=130 kg/m^3, a typical density value for frost grown on finned-tubes heat exchangers)

. Bulk water may have α=0.95..0.99 and ε=0.95..0.98 (recall it is normal solar absorptance; at grazing angles a water surface reflects all, both in the visible and the infrared bands), with very pronounced spectral changes; ice and snow may have α=0.1..0.4 and ε=0.90, but clouds of droplets or ice crystals may have α=0.1..0.5 and ε=0.8..0.9. The sound speed in water is 1500 m/s; 1450 m/s in mercury, 1120 m/s in methyl alcohol). Mind that the volumetric thermal-expansion coefficient is three times the linear values here quoted. Emissivity of non-metal liquids is ε=0.8..0.9, but for liquid mercury ε=0.10.

30) Invar is a 64%Fe and 36%Ni single-phase alloy (i.e. a solid solution). Its thermal expansion coefficient is very small (α<1.5·10^{-6} K^{-1}) in the –20..100 ºC range, growing to about α=8·10^{-6} K^{-1} at 400 ºC.

31) Cast iron (96%Fe, 4%C) is the raw product of iron making in the blast furnace (ρ_L=7010 kg/m^3). Pure iron (Fe, M=0.056 kg/mol), changes from Fe-α-bcc to Fe-γ-fcc at 1180 K, from Fe-γ-fcc to Fe-δ-bcc at 1167 K, melts at T_m=1810 K, and vaporises at T_b=3100 K. At room temperatures, ρ=7870 kg/m^3, k=80 W/(m·K), it is ferromagnetic (with T_{Curie}=1040 K), and it is called ferrite (but some ferromagnetic ceramics are also called ferrite). Emissivity may vary from ε=0.2 when new, to ε=0.6 when old; galvanised sheet may change from ε=0.2 when new, to ε=0.8 when old; wrought iron may reach ε=0.95.

32) Leather, i.e. tanned skin. Thermal conductivity in living skin varies with depth (epidermis, dermis), moisture, and blood-capillary irrigation, with a typical value of 0.4W/(m·K). Human skin solar absorptance range from 0.6 (white skin) to 0.8 (black skin), whereas IR-emissivity is 0.97..0.99 independent of skin colour or the presence of sweat.

33) Magnesium (Mg, M=0.0243 kg/mol, hexagonal compact crystal), with ρ_L=1570 kg/m^3, α_L=17·10^{-6} K^{-1}, c_{pL}=1330 J/(kg·K) and k_L=167 W/(m·K).

34) Marble is $CaCO_3$; this temperature-value corresponds to carbonate decomposition ($CaCO_3=CaO+CO_2$).

35) Polymethyl-methacrylate (PMMA) is a thermoplastic polymer; the melting-temperature must be understood as glass-transition temperature (softening point); PMMA is a rigid transparent plastic (also known as plexiglas, lucite...) that starts to decompose at 500 K. Transmittance in the visible is τ=0.92, with refractive index 1.49; transmittance in the is near infrared (1..3 μm) is also about 0.9 for thickness <0.5 mm, but for much thicker sheets it decreases to almost zero at several wavelengths. It is opaque in the far infrared (λ>3 μm).

36) Nickel (Ni, M=0.0587 kg/mol, fcc), with ρ_L=7710 kg/m^3. The same values may be used for many Ni-alloys, (i.e. those for coins and for high-temperature work) except for conductivity, that for very pure nickel may reach k=94 W/(m·K), for inconel-600 (76%Ni, 16%Cr, 8%Fe, used in furnaces) is k=15 W/(m·K), for nimonic-90 (60%Ni, 20%Cr, 16%Co, 2.5%Ti, 1.5%Al, used in turbine blades) is k=12 W/(m·K), for nichrome-C (60%Ni, 25%Fe, 15%Cr, used in furnace heaters) is k=13 W/(m·K), for monel (68%Ni, 29%Cu, 1%Mn, used in silvery coins) is k=21 W/(m·K), for cupronickel-25 (25%Ni, 75%Cu, used in marine components and silvery coins) is k=29 W/(m·K), for chromel (90%Ni, 10%Cr, used in thermocouples) is k=17 W/(m·K), for alumel (95%Ni, 2%Al, 2%Mn, used in thermocouples) is k=30 W/(m·K), etc. Bright inconel has α=0.90 and ε=0.20.

37) Paper is basically cellulose and decomposes at 550 K giving volatile organic compounds. Quoted optical properties only for white paper. Cardboard conductivity may range from an equivalent k=0.05 W/(m·K) for corrugated types to k=0.20 W/(m·K) for bulk types. Straw has k=0.05 W/(m·K).

38) Plaster, applied as a finishing layer in masonry work and let setting, is mainly hydrated calcium sulphate, $CaSO_4·2H_2O$.

39) Platinum (Pt, M=0.195 kg/mol, fcc) is only used in laboratories, in precious metal alloys and finely dispersed as a catalyst, with ρ_L=18820 kg/m^3.

40) Polyethylene (PE) is a thermoplastic polymer; the melting-temperature must be understood as glass-transition temperature (softening point); it has the largest polymer production, and is used for films, bags, toys and pipes. Emissivity of thin plastic films is much lower than the quoted bulk value (e.g. ε=0.15 for a 0.1 mm film).

41) Expanded polystyrene (styrofoam) is the white rigid plastic used for thermal insulation and in flotation devices. It was the first foamed polymer (with R12). The melting-temperature must be understood as softening point. Compact polystyrene (e.g. CD jewel box) has ρ_L=1040 kg/m^3, c_p=1200 J/(kg·K) and k=0.15 W/(m·K).

42) Expanded polyurethane is the most common thermoplastic used in upholstery and insulation (thermal and acoustical); the melting-temperature must be understood as softening point. Notice that compact polyurethane (e.g. sport shoe soles) is a thermoset that looks like teflon or polycarbonate and has ρ_L=1100 kg/m^3, c_p=1400 J/(kg·K), and k=0.20 W/(m·K).

43) PVC is a thermoplastic polymer; the melting-temperature must be understood as glass-transition temperature (softening point); it is used for chemical-resistant pipes. Emissivity of thin plastic films is much lower than the quoted bulk value (e.g. ε=0.6 for a 0.1 mm film).

44) Common salt (NaCl, M=0.056 kg/mol, fcc), with ρ_L=1490 kg/m^3, α_L=36·10^{-6} K^{-1}, c_{pL}=1440 J/(kg·K) and k_L=0.30 W/(m·K). Density refers to single-crystal sample; granular material show lower densities according to the void fraction (typical values for table salt may be around 1300 kg/m^3; and around 890 kg/m^3 for table sugar). Single crystal salt, halite, is nearly transparent from visible wavelengths far into the infrared (to around 60 μm).

45) Sand (SiO_2), loose rounded grains of silica (0.2 and 2 mm in size), is sometimes used as a thermal insulator. Soil, the top layer of the land surface of the earth that is composed of disintegrated rock particles, humus, water, and air, may be ascribed the following average properties: ρ=(1400±200) kg/m^3, c=(1300±300) J/(kg·K), k=(0.5±0.2) W/(m·K), a=(0.3±0.2)·10^{-6} m^2/s; e.g. thermal conductivity depends on soil composition and texture; it increases with density and water content, and decreases with organic-mater content. Solar absorptance increases with moisture content.

46) Sapphire (Al_2O_3) is a synthetic crystal used in special optical window (scratch resistant, thermal resistant, and very wide transmission band). Synthetic sapphire was first produced in 1902 by melting a finely powdered aluminium oxide using an oxyhydrogen flame, and crystallising the melted droplets into a boule. k=45 W/(m·K) at 0 ºC, decreasing towards k=10 W/(m·K) above 200 ºC. Its refractive index is n=1.77, being transparent in the 150..5500 nm wavelength range. Natural sapphire is a blue gemstone, a variety of the mineral corundum.

47) Silicon (Si, M=0.028 kg/mol, bcc) is the second most abundant crust element (26%wt; after 47%wt oxygen); it looks like a metal but behaves more like a glass, It is the basic component of most electronic chips. In its liquid state it has ρ_L=2510 kg/m^3, α_L=15·10^{-6} K^{-1}, c_{pL}=1050 J/(kg·K), σ=0.72 N/m and k_L=22 W/(m·K). Silicon, as well as water, bismuth, gallium and some others, present the anomaly of increasing density on melting (silicon and germanium shrink some 12% on melting, more than the 8.3% of water-ice). It is nearly transparent to infrared radiation, like germanium; emissivity grows almost linearly from ε=0.4 at 100 K to ε=0.7 at 300 K. It also has a maximum in density, at about 123 K (thermal expansion coefficient goes from -0.34·10^{-6} K^{-1} at 100 K, to 2.62·10^{-6} K^{-1} at 300 K). Thermal conductivity drops with temperature (k=110 W/(m·K) at 100 ºC). Gallium arsenide (GaAs), with k=44 W/(m·K), and thermal expansion α=6.5·10^{-6} K^{-1}, is taking over silicon in most efficient solar cells.

48) Silver (Ag, M=0.108 kg/mol, fcc) is used in precious metals alloys, with ρ_L=9200 kg/m^3, α_L=10·10^{-6} K^{-1}, c_{pL}=290 J/(kg·K) and k_L=375 W/(m·K). German silver (see Copper) is not a silver alloy.

49) Snow from water (see comments on Ice).

50) Sodium (Na, M=0.023 kg/mol, bcc) is a silvery white soft metal, obtained by electrolysis of common salt (really from a mixture of some 40% NaCl and 60% $CaCl_2$ to lower the melting point). Molten sodium, or a melt alloy of sodium and potassium, is used as an efficient heat-transfer fluid. Sodium vapour is used in lamps for street lighting. T_{cr}=2570 K.

51) Carbon steels. k=52 W/(m·K) for mild-carbon steel with <0.4%C, but k=42 W/(m·K) for carbon steel with 1%C, k=32 W/(m·K) for carbon steel with 1.5%C, etc. Conductivity decreases with temperature (k=30 W/(m·K) at 1000 K). Thermal capacity increases a lot: , c_p=700 J/(kg·K) at 800 K , c_p=1200 J/(kg·K) at 1000 K. Steel emissivity may range from 0.05 (polished) to 0.8 (oxidised).

52) Stainless Steel (SS) has <0.4%C but >10%Cr. The most used is SS-304, or SS-18/10 (18%Cr-10%Ni) an easily welding non-magnetic steel (austenitic), with a large service temperature range: from 4 K to 1050 K. Conductivity increases with temperature (k=25 W/(m·K) at 1000 K, k=9 W/(m·K) at 100 K, k=0.7 W/(m·K) at 10 K) and decreases with alloying from k=26 W/(m·K) to k=15 W/(m·K). Thermo-optical properties are widely varied with selected coatings (some multilayer vapour depositions methods used for solar collectors achieve α=0.95 and ε=0.05).

53) Teflon (polytetrafluoroethylene) is a thermoplastic polymer used for non-stick coatings and bearings; the melting-temperature must be understood as glass-transition temperature (softening point). Teflon coating has ε=0.4.

54) Tin (Sn, M=0.119 kg/mol, fcc) is used in low-melting-point alloys, with ρ_L=6920 kg/m^3, σ=0.59 N/m.

55) Titanium (Ti, M=0.048 kg/mol, hexagonal compact crystal) is used in temperature-resistant light-alloys, with ρ_L=4100 kg/m^3. Thermal conductivity of Ti-alloys may be much lower; the most used alloy (e.g. in aerospace and biomaterials) has 6% aluminium and 4% vanadium (Ti-6Al-4V or Ti-6-4) has k=6.7 W/(m·K) at 300 K, increasing to k=17 W/(m·K) at 1200 K, and decreasing to k=0.5 W/(m·K) at 5 K. Ti-6-4 has ρ=4430 kg/m^3, α=8.5·10^{-6} 1/K at 300 K, α=9.5·10^{-6} 1/K at 500 K, α=10.5·10^{-6} 1/K at 800 K, starts melting at 1880 K, c=610 J/(kg·K) at 300 K growing to c=1100 J/(kg·K) at 1200 K. Thermo-optical properties vary a lot with treatment, from about $\varepsilon=\alpha$=0.2 for polished alloy, to $\varepsilon=\alpha$=0.6 for oxidised or tiodised (the latter is the typical finishing).

56) Metallic uranium (U, M=0.238 kg/mol, orthorhombic).

57) Uraninite (UO_2, M=0.270 kg/mol, cubic crystal) is greyish-black brittle and heavy mineral (its density may be down to 7000 kg/m^3). Thermal capacity increases with temperature (c_p=360 J/(kg·K) at 1000 K, c_p=410 J/(kg·K) at 2000 K, c_p=700 J/(kg·K) at 3000 K), c_{pL}=550 J/(kg·K). Conductivity decreases with temperature (k=3.5 W/(m·K) at 1000 K, k=2.2 W/(m·K) at 2000 K, k=3.5 W/(m·K) at 3000 K), k_L=11 W/(m·K).

58) Wolfram (W, also known as Tungsten, M=0.184 kg/mol, body-centred-cubic crystal) is a refractory metal, with ρ_L=17600 kg/m^3; its total hemispherical emissivity increases from ε=0.09 at 300 K to ε=0.39 at 3000 K (with a large spectral slope; at 3000 K, ε_λ=0.45 at λ=0.5 μm and ε_λ=0.20 at λ=4 μm). Thermal conductivity drops to k=100 W/(m·K) at 2000 K, and increases to k=250 W/(m·K) at 77 K, to a maximum of k=9700 W/(m·K) at 10 K, and k=1400 W/(m·K) at 1 K.

59) Wool and hair are fibrous proteins (keratin, 50%C7%H15%O15%N3%S10%ash) that decompose when heated.
60) Wood properties depend on moisture content. Wood is a composite fibrous material (of cellulose and lignin fibres, 50%C5%H45%O) that starts to decompose at 550 K. The thermal expansion for oak is $50 \cdot 10^{-6}$ K^{-1} transversal to the fibres but $5 \cdot 10^{-6}$ K^{-1} parallel to the fibres. Linear expansion due to moisture changes is also important, being around $0.0015(\%H_2O)^{-1}$ transversally and much smaller along the fibre. Thermal conductivity increases five times the increase in moisture content. Oak wood is a good example of other hard woods.
61) Pine is a soft wood; see 55 for general comments on wood properties.
62) Wood dust is often used for thermal insulation.