PROPERTIES OF LIQUIDS

Function values at 100 kPa and 288 K for room-temperature liquids, or at 100 kPa and the normal boiling point for room-temperature gases, or the normal melting point for room-temperature solids, or the triple point for sublimating substances (C_2H_2, CO_2, SF_8 and UF_8).

Substance	Formula	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 $\alpha\cdot 10^6$ K^{-1}	Compres-sibility[a] $\kappa\cdot 10^9$ Pa^{-1}	Surface tension[b] σ N/m	Thermal capacity c_p J/(kg·K)	Thermal conductivity k W/(m·K)	Dynamic viscosity $\mu\cdot 10^6$ Pa·s
Acetylene	C_2H_2	193[c]	193[c]	115[c]	700[c]	615[c]	2500		0.001	3000	0.50	160
Acetone	C_3H_6O	178	329	98	532	749	1400	1.2	0.024	2150	0.18	330
Ammonia	NH_3	195	240	332	1357	697	1800	0.7	0.022	4600	0.50	266
Aniline	C_6H_7N	276	457	114	434	1021	840	0.36	0.042	2140	0.17	4467
Argon	Ar	84	87	30	163	1395	4500	2.1	0.014	625	0.13	240
1,3-Butadiene	C_4H_6	164	269	148		621	1800	1.9	0.013	2260	0.13	
Benzene	C_6H_6	279	353	126	394	884	1400	1.6	0.029	1720	0.15	653
n-Butane	C_4H_{10}	135	273	80	365	602[d]	1800	2.2	0.012	2400	0.12	282
iso-Butane	C_4H_{10}	114	261	78	366	594[e]	1900	2.3	0.012	2300	0.12	150
Carbon dioxide	CO_2	217[f]	217[f]	185[f]	350[f]	1180[f]	3200[f]	1.9[f]	0.017[f]	1950[f]	0.18[f]	260[f]
Carbon tetrachloride	CCl_4	250	350	30	195	1590	1240	1.0	0.027	840	0.11	967
Cyclohexane	C_6H_{12}	280	354	31	360	778	1400	1.9	0.025	1860	0.13	411
Chloroform	$CHCl_3$	210	335	74	247	1489	1200	0.69	0.027	980	0.13	562
n_Decane	$C_{10}H_{22}$	243	447	202	276	730	1010	0.84	0.024	2000	0.15	920
Diesel	($C_{12}H_{26}$)	235[g]	470[g]		250	840	830		0.028	1900	0.15	2400
1-Dodecene	$C_{12}H_{24}$	238	586	122	373	761	980			2150	0.14	1360
n-Dodecane	$C_{12}H_{26}$	263	489	216	257	780	920	0.77	0.025	2220	0.14	1340
DME (dimethyl ether)	C_2H_6O	132	250	107	460	736	1900	1.6	0.011	2540	0.14	100

ETBE (ethyl tert-butyl ether)	$C_6H_{14}O$	179	340			770						400
Ethane	C_2H_6	90	185	95	520	544[h]	2300[h]	1.8[h]	0.016[h]	2440[h]	0.17[h]	169[h]
Ethanol	C_2H_6O	156	351	108	860	790	1100	1.1	0.023	2440	0.18	1194
Ether (diethyl ether)	$C_4H_{10}O$	157	308	99	351	715	1630		0.016	2260	0.14	230
Ethylene glycol	$C_2H_6O_2$	262	471	181	800	1110	650	0.33	0.048	2400	0.26	$16\cdot10^3$
Ethylene	C_2H_4	104	169	120	483	568[i]	2500	1.8	0.016	2420	0.19	176
Gasoline	(C_8H_{18})	217[g]	360[g]		340	750	900		0.025	2100	0.15	380
Glycerol (glycerine)	$C_3H_8O_3$	291	560	199	663	1260	500	0.21	0.064	2430	0.30	$1400\cdot10^3$
Helium (^4He)	He	0.95	4.2	3.5	20.7	125	205 000	520	0.0001	5000	0.02	3.2
Helium-3 (^3He)	He	NA	3.2	NA	8.7	59	50 000	300		1500		
n-Heptane	C_7H_{16}	182	372	140	321	684	1600	2.9	0.020	2220	0.13	409
n-Hexane	C_6H_{14}	178	342	150	337	658	1600	2.7	0.019	2260	0.12	320
n-Hexadecane (cetane)	$C_{16}H_{34}$	291	550	230	358	773			0.028	2210	0.15	3030
Hydrazine	N_2H_4	275	387	395	1400	1010	2090	0.22	0.067	3080	0.57	900
Hydrogen[i]	H_2	14	20	59	448	71	16 600	19	0.002	8700	0.12	10
(Hydrogen) Deuterium	D_2	19	23	49	304	163	16 700	13		8000	0.14	
Hydrogen peroxide	H_2O_2	273	423	368	1519	1450	790	0.21	0.080	2620	0.55	1200
Kerosene, Jet A-1, RP1	$(C_{12}H_{24})$	230[g]	450[g]		250	820	830	0.70	0.028	2000	0.13	2400
Mercury	Hg	234	630	12	301	13546	180	0.038	0.490	139	9.3	1550
Methane	CH_4	91	112	58	511	423	3500	2.2	0.012	3420	0.18	110
Methanol	CH_4O	175	338	99	1100	791	1490	1.05	0.023	2510	0.21	593
MMH (monomethyl hydrazine)	CH_6N_2	221	364			875				2950	0.25	
MTBE (methyl tert-butyl ether)	$C_5H_{12}O$	164	328	88		740				2090	0.12	350
Nitric acid	HNO_3	231	394	167	615	1510		0.32	0.042	2000	0.29	800
Nitrogen	N_2	63	77	26	199	807	5700	3.2	0.012	2040	0.145	161
di-Nitrogen oxide	N_2O	182	185	149	376	1230	2400	1.1	0.024	1720	0.20	325
di-Nitrogen tetroxide[k]	N_2O_4	262	294	160	330	1440				1550	0.29	

n-Octane	C_8H_{18}	217	399	181	306	703	2000	4	0.022	2100	0.15	562
iso-Octane	C_8H_{18}	166	372	180	308	692			0.018	2100	0.10	350
Oil (mineral, vegetable...)[l]	$C_{18}H_{36}O_2$					900	900	0.5		2000	0.15	$10^3..10^7$
Oxygen	O_2	54	90	14	213	1142	4 400	2.0	0.020	1700	0.15	
n-Pentane	C_5H_{12}	143	309	116	356	626	1700	2.4	0.016	2180	0.14	229
Propane[m]	C_3H_8	85	231	95	430	581	2000	2.0	0.016	2140	0.13	198[j]
Propylene (propene)	C_3H_6	88	225	71	437	612	2000	2.0	0.008	2200	0.11	190
Propylene glycol	$C_3H_8O_2$	214	461	99	800	1036	730		0.040	2790	0.20	$42\cdot10^3$
R12 [n]	CCl_2F_2	115	243		165	1488	2000	2.0	0.016	966	0.07	200
R134a (tetrafluoroethane)[o]	CF_3CH_2F	170	247	1300	215	1380	2200	2.0	0.015	1280	0.10	380
R410A[p]	n.a.	120	222		190	1350	2300	1.7	0.018	1368	0.17	
Silicone oil DMS-10	$-[Si(CH_3)_2O]-$			1050		950	900	0.6	0.021	1800	0.11	9500
Sodium[q]	Na	371	1160	115	1020	780[q]	70	0.2	0.200	1250	60	200
Sulfur dioxide	SO_2	198	263	135	389	1455	1700	1.0			0.20	550
Sulfur hexafluoride[r]	SF_6	223	223	40	162	1845	2800	3.2	0.011	837		
Sulfuric acid	H_2SO_4	283	561		745	1840		0.3		1400		23000
Tetradecafluorohexane[s] (FC-72)	C_6F_{14}	183	329		88	1680	1560		0.010	1100	0.057	640
UDMH (unsym.dim.hydrazine)	$C_2H_8N_2$	216	337			790				2650	0.16	
Uranium hexafluoride[t]	UF_6	337	337	54	82	3670	6000		0.018	620	1.9	900
Water[u]	H_2O	273	373	334	2257	999	150	0.45	0.073[t]	4180	0.60	1000[t]
Water, Heavy[v]	D_2O	277	374	319	2090	1105	100	0.47	0.073	4210	0.60	
Xenon	Xe	161	165	17	96	2990	2300	1.7	0.018	350	0.07	450

a) The compressibility coefficient, κ, is related to the speed of sound, c, and the density by $c=(\rho\kappa)^{-1/2}$ (e.g. for pure water $c=(\rho\kappa)^{-1/2}=(998\cdot0.46\cdot10^{-9})^{-1/2}=1480$ m/s; and roughly the same for sea water). For liquid-vapour equilibrium, κ and α increase a lot with T and p diverging at the critical point.

b) Surface tension for liquid in air. For liquid in water (if immiscible, of course), values may differ (e.g. for benzene in air σ=0.029 N/m but σ=0.035 N/m for benzene in water).

c) Acetylene has no normal points for melting and boiling because at the normal pressure of 100 kPa the only phase change is the solid-gas transition at 189 K (normal sublimation point). Data in this table refers to the triple point: p_{tr}=128 kPa, T_{tr}=193 K=–80 ºC; i.e., $\rho_{l,tr}$=615 kg/m^3, $h_{sv}=h_{sl}+h_{lv}$=115+700=815 kJ/kg. Sublimation point data: T=189 K=–84 ºC, ρ_s=729 kg/m^3, h_{sv}=820 kJ/kg. See additional comments in f).

d) n-Butane liquid density at 288 K and its equilibrium pressure (175 kPa): ρ_l=584 kg/m^3.
e) iso-Butane liquid density at 288 K and its equilibrium pressure (258 kPa): ρ_l=563 kg/m^3.
f) Carbon dioxide has no normal points for melting and boiling because at the normal pressure of 100 kPa the only phase change is the solid-gas transition at 195 K (normal sublimation point). Data in this table refers to the triple point: p_{tr}=518 kPa, T_{tr}=217 K=−56.3 ºC; i.e., $\rho_{l,tr}$=615 kg/m^3, h_{sv}=h_{sl}+h_{lv}=185+350=535 kJ/kg. Sublimation point data: T=195 K=−78.5 ºC, ρ_s=1560 kg/m^3 (if well compacted), h_{sv}=575 kJ/kg. Notice that most liquid properties vary a lot near the critical point, which is the case at room temperature for CO_2, C_2H_2, C_2H_4, C_2H_6, N_2O, SF_6, and UF_6. For liquid CO_2 at 288 K and its equilibrium pressure (5.1 MPa): ρ=823 kg/m^3, α=3200·10^{-6} K^{-1}, κ=7.8·10^{-9} Pa^{-1}, σ=0.002 N/m, k=0.09 W/(m·K), and μ=70·10^{-6} Pa·s, and c_p=3420 J/(kg·K), growing from c_p=1950 J/(kg·K) at the triple point, to infinity at the critical point (the difference between c_p and c_v of the saturated liquid is important in this case: the thermal capacity at constant volume at 288 K and 5.1 MPa is c_v=990 J/(kg·K)).
g) Diesel, gasoline and kerosene are mixtures of various compositions and have not precise boiling or melting points (e.g. at 300 K 10%wt of gasoline is in the vapour state, and at 440 K 90%). Surface tension may vary in the range σ=0.022..0.035 N/m. Jet A-1 is a kerosene fuel with additives to freeze at −50 ºC and ρ=800..820 kg/m^3, c=2000..2100 J/(kg·K), k=0.10..0.14 W/(m·K)). Rocket propellant RP1 is similar to Jet A-1. Surrogate pure components are often used for theoretical studies, but only a few properties can be properly matched: octane (normal or iso) is used as surrogate of gasoline, and dodecane or dodecene for diesel, kerosene, Jet A-1 and RP1.
h) Liquid ethane at 288 K and its equilibrium pressure (3.36 MPa) has ρ_l=358 kg/m^3, α=0.013 K^{-1}, c=430 m/s, c_p=4750 J/(kg·K),.k=0.079 W/(m·K), and μ=45·10^{-6} Pa·s.
i) There are two spin-isomers of H_2: ortho and para. Gas at room temperature is mostly orthohydrogen, but, when liquefied, it is important to convert it to almost pure parahydrogen because otherwise there is a slow natural conversion of ortho to para with a release of 516 kJ/kg that contributes to boil-off.
j) Data for H_2O_2 pure. H_2O_2 is most used in aqueous solutions, with >80 % mass fraction in propulsion (named HTP, high test peroxide), with around 30 % as a chemical in industry for bleaching (its main application), and with around 3 % in medicine as antiseptic. The peroxide bond (a single bond HO−OH) is unstable and slowly decomposes, so that storage tanks should be vented, and kept cool and in the dark. It decomposes violently at high temperature (its boiling point is extrapolated, but solutions may be safely distilled under reduced pressure), or at room temperature in contact with catalysts like silver. Density of solid at melting point is 1700 kg/m^3, and that of pure liquid at 100 ºC is 1350 kg/m^3. H_2O_2/H_2O solutions are eutectic, i.e. although both pure substances melt at around 0 ºC, a 50 %wt mix melts at −52 ºC.
k) At equilibrium, there is always a mixture of dinitrogen tetroxide (N_2O_4) and nitrogen dioxide (NO_2).The NO_2/N_2O_4 equilibrium depends on temperature, NO_2 being favoured in the gas phase at high temperatures, whereas N_2O_4 is preponderant in the gas phase at low temperature, and in condensed phases. When condensing, at 21.3 ºC at 100 kPa, most of the liquid is N_2O_4 which is colourless or pale brownish; when solidified (at −11.2 ºC) a white solid appears. N_2O_4 is a hypergolic propellant that spontaneously reacts upon contact with various forms of hydrazine, all of them liquid at normal pressure; this fact, and the ease of liquefying the N_2O_4 (liquid at 100 kPa for T<21 ºC), makes them popular bipropellants for spacecraft rockets.
l) Formula of oleic acid (CH_3-$(CH_2)_7$-CH=CH-$(CH_2)_7$-COOH, T_m=268 K, h_{sl}=75 kJ/kg,), the major component in olive oil. Oils are thick liquids (non-volatile and viscous) made directly (natural oils) or indirectly (synthetic oils) from fossil matter, living matter, or minerals. Mineral oils are high hydrocarbons obtained from petroleum distillation and used either as fuels (diesel oil and heavy fuel oil) or as lubricants (lube oils). Fat oils are triglycerides-esters from plants or animals (olive, soybean, peanut sunflower, coconut, corn linseed, palm, essential oils, whale, castor). They are organic (carbon) or inorganic (silicon) polymers with a range of molar mass values, and do not show sharp phase transitions. Density: they are usually less dense than water (but sulphuric oleum nearly reaches a density double than water): e.g. olive and vegetable oils have some ρ=915..925 kg/m^3, whereas lubricant, combustible and hydraulic oils may have ρ=800..1000 kg/m^3. Thermal capacity: values are near c_p=2000 J/kg·K) in most cases; lube oils have about 1800 J/kg·K) at 250 K, linearly increasing to about 3000 J/kg·K) at 600 K; oils use for heat transfer may have values some 200 J/kg·K) lower. Thermal conductivity: all of them are poor conductors, with k=0.10..0.15 W/m·K), slightly decreasing with temperature, even for thermal oils, which are just more resistant to high temperatures (up to 600 K). Viscosity: oil viscosity may vary orders of magnitude from one oil to the other, and decreases exponentially with temperature; e.g. at 15 ºC, μ=3·10^{-3} Pa·s for light silicone oils, gas oil and diesel oil, μ=80·10^{-3} Pa·s for olive oil and light mineral oils, μ>1000·10^{-3} Pa·s for fuel oil and thick silicone oils).
m) Liquid propane at 288 K and its equilibrium pressure (729 kPa) has ρ_l=508 kg/m^3, α=2990·10^{-6} K^{-1}, c=780 m/s, c_p=2620 J/(kg·K),.k=0.099 W/(m·K), and μ=108·10^{-6} Pa·s.

n) R12, dichlorodifluoromethane (also named freon), was the most used refrigerant in the 20th c. since its first synthesis in 1929 to its production banning in 1995. Liquid R12 at 288 K and its equilibrium pressure (488 kPa) has ρ_l=1350 kg/m^3, α=2600·10^{-6} K^{-1}, c=553 m/s, σ=0.010 N/m, c_p=964 J/(kg·K),.k=0.087 W/(m·K), and μ=343·10^{-6} Pa·s.

o) Liquid R134a at 288 K and its equilibrium pressure (486 kPa) has ρ_l=1244 kg/m^3, α=2920·10^{-6} K^{-1}, c=553 m/s, σ=0.010 N/m, c_p=1390 J/(kg·K),.k=0.085 W/(m·K), and μ=221·10^{-6} Pa·s.

p) R410A is a near-azeotropic mixture of R32 (difluoromethane, CH_2F_2) and R125 (pentafluoroethane, CHF_2CF_3), 50/50 by weight (70/30 molar), which can be approximated as a pure substance. Liquid R410A at 288 K and its equilibrium pressure (1253 kPa) has ρ_l=1107 kg/m^3, α=4220·10^{-6} K^{-1}, c=485 m/s, σ=0.007 N/m, c_p=1610 J/(kg·K).

q) Sodium, M=0.023 kg/mol, ρ_L=780 kg/m^3, ρ_S=970 kg/m^3. The Na-K eutectic alloy, with 22% Na by mass, is a room-temperature liquid, T_m=–12.6 ºC, T_b=785 ºC, used in high-temperature high-heat-transfer applications; at 100 ºC, ρ=855 kg/m^3, α=340·10^{-6} 1/K, c=936 J/(kg·K), k=23 W/(m·K), μ=505·10^{-6} Pa·s, σ=115·10^{-3} N/m and σ_{elec}=2.5·10^6 S/m, i.e. 4% that of Cu.

r) Sulfur hexafluoride has no normal points for melting and boiling because at the normal pressure of 100 kPa the only phase change is the solid-gas transition at 209 K (normal sublimation point). Data in this table refers to the triple point: p_{tr}=226 kPa, T_{tr}=224 K=–49.4 ºC; i.e., $\rho_{l,tr}$=1845 kg/m^3, $h_{sv}=h_{sl}+h_{lv}$=40+162=202 kJ/kg. Sublimation point data: T=209 K=–63.9 ºC, ρ_s=2770 kg/m^3, h_{sv}=202 kJ/kg. Liquid at 288 K and its equilibrium pressure (1.85 MPa) has ρ_l=1440 kg/m^3, α=7070·10^{-6} K^{-1}, c=252 m/s, σ=0.003 N/m, and c_p=1165 J/(kg·K). See further data under Gas properties. See additional comments in f).

s) Tetradecafluorohexane or perfluorohexane (traded as Fluorinert FC-72, or as Flutec PP1), is a liquid coolant commonly used in electronics cooling because of its electrical insulation properties and stability (thermal, chemical, and biological). Its vapour pressure at 25 ºC is 30 kPa. Its refractive index is n=1.251. It has zero ozone depletion potential (ODP=0), but a high global warming potential (GWP>5000).

t) Uranium hexafluoride has no normal points for melting and boiling because at the normal pressure of 100 kPa the only phase change is the solid-gas transition at 329 K (normal sublimation point). Data in this table refers to the triple point: p_{tr}=152 kPa, T_{tr}=337 K=–64 ºC; i.e., $\rho_{l,tr}$=3700 kg/m^3, $h_{sv}=h_{sl}+h_{lv}$=54+82=136 kJ/kg. Sublimation point data: T=329 K=56.4 ºC, ρ_s=4850 kg/m^3, h_{sv}=136 kJ/kg. See further data under Gas properties. See additional comments in f).

u) Water properties may be used as a first approximation for many natural aqueous solutions (milk, wine, beer, vinegar, seawater, urine, fruit juices, etc.). Their densities are typically ρ=1020..1030 kg/m^3, their melting points 1..2 K below that of water, their boiling points 0.5..1.5 K above that of water, their thermal capacities some 80% of water. Pure water has anomalous dilatation in the 0..4 ºC range, with maximum density ρ=1000 kg/m^3 at T_4=3.98 ºC=277.13 K decreasing with temperature to 958 kg/m^3 at 100 ºC (with a minimum of 322 kg/m^3 at the critical point); a good approximation in the 0..200 ºC range may be $\rho=1000-0.1\cdot(T-T_4)-0.0033\cdot(T-T_4)^2$ kg/m^3, with T_4 as above. Interface tension of water/air or water/vapour is 0.073 N/m, but for water/mercury 0.390 N/m, water/octane 0.052 N/m, water/benzene 0.035 N/m. Contact angle water/glass in air 0º if pure, some 30º typical; mercury/glass in air 140º if pure, some 120º typical. Liquid viscosity varies a lot with temperature; e.g. for water, μ=1.8·10^{-3} Pa·s at 0 ºC, 0.5·10^{-3} Pa·s at 50 ºC and 0.35·10^{-3} Pa·s at 100 ºC. The boiling point of water at 100 kPa is T_b=372.75±0.02 K (99.60±0.02 ºC), whereas at 101.325 kPa (1 atm) it is 373.12±0.02 K (99.97±0.02 ºC).

v) Heavy water usually means water that has been enriched in the deuterium isotope, D, which is not radioactive (without changing oxygen isotope composition), in the form HDO or D_2O; data here only apply to D_2O. Heavy water, contrary to normal (or light) water, does not quench thirst; seeds do not germinate. Additional data: for H_2O (i.e. hydrogen oxide), ρ_{max}=1000 kg/m^3 at 3.98 ºC (ρ_{sol}=917 kg/m^3 at T_f=0 ºC); for D_2O (i.e. deuterium oxide): ρ_{max}=1106 kg/m^3 at 11.2 ºC, ρ_{sol}=1018 kg/m^3 at T_f=3.82 ºC (thus, a heavy-water ice-cube sinks in normal water); for T_2O (i.e. tritium oxide): ρ_{max}=1215 kg/m^3 at 13.4 ºC, ρ_{sol}=?? kg/m^3 at T_f=4.49 ºC.