PROPERTIES OF GASES

(Function values at 100 kPa and 288 K or the normal boiling temperature if greater.)

Substance	Formula	Molar mass M kg/mol	Boiling temp. T_b K	Critical temp T_{cr} K	Critical pressure p_{cr} MPa	Critical compressibility factor[a] Z_{cr}	Pitzer's acentric factor ω	Thermal capacity[b] c_p J/(kg·K)	Thermal conductivity[c] k W/(m·K)	Dynamic viscosity[d] $\mu\cdot10^6$ Pa·s
Acetone	C_3H_6O	0.058	329.2	508	4.70	0.233	0.309	1300		
Acetylene	C_2H_2	0.026	189.5[f]	309	6.20	0.271	0.184	1580	0.019	9.3
Air	79%N_2+ 21%O_2	0.029	82[e]	132[g]	3.75[g]	0.28[g]	0.035	1004	0.024	18.1
Ammonia	NH_3	0.017	239.8	406	11.30	0.242	0.250	2200	0.022	9.3
Argon	Ar	0.040	87.4	151	4.86	0.291	0	523	0.018	21.0
Benzene	C_6H_6	0.078	353.3	563	4.92	0.271	0.212	1300	0.007	7.0
1,3-Butadiene	C_4H_6	0.054	268.5	425	4.33	0.270	0.193	1510		
n-Butane	C_4H_{10}	0.058	272.6	425	3.80	0.274	0.193	1580	0.015	7.0
iso-Butane	C_4H_{10}	0.058	261.5	408	3.64	0.280	0.176	1580	0.015	9.0
Carbon dioxide	CO_2	0.044	194.7[f]	304	7.38	0.274	0.225	840[h]	0.016	14,4
Carbon monoxide	CO	0.028	81.7	133	3.50	0.295	0.049	1100	0.023	17.0
Carbon tetrachloride	CCl_4	0.154	349.7	556	4.56	0.272	0.194	862	0.017	16.0
Cyclohexane	C_6H_6	0.084	353.9	554	4.07	0.273	0.212			
n-Decane	$C_{10}H_{22}$	0.142	447.3	619	2.12	0.247	0.490	1680		
n-Dodecane	$C_{12}H_{26}$	0.170	489.4	659	1.80	0.240	0.562	1690		
DME (dimethyl ether)	C_2H_6O	0.046	250.6	400	5.37	0.271	0.274	1430		
Ethane	C_2H_6	0.030	184.6	305	4.88	0.285	0.100	1700	0.020	11.0
Ethanol	C_2H_6O	0.046	351.5	516	6.39	0.248	0.635	1520	0.013	14.2
Ether (diethyl ether)	$C_4H_{10}O$	0.074	307.6	467	3.61	0.260	0.281	1600	0.015	7.5
ETBE (ethyl tert-butyl ether)	$C_6H_{14}O$	0.102	345	517	3.11	0.274	0.298	1550		
Ethylene	C_2H_4	0.028	169.5	283	5.12	0.276	0.085	1470	0.018	9.6
Ethylene glycol	$C_2H_6O_2$	0.062	471	645	7.53	0.268	1.137	1410		
Helium (^4He)	He	0.004	4.2	5.3	0.23	0.301	-0.387	5190	0.142	19.0
Helium 3 (^3He)	He	0.003	3.2	3.3	0.11	0.301	-0.460			
n-Heptane	C_7H_{16}	0.100	371	540	2.77	0.263	0.350	1650	0.013	6.5
n-Hexane	C_6H_{14}	0.086	342	508	3.03	0.263	0.296	1700	0.014	6.5
Hydrazine	N_2H_4	0.032	387	653	14.7	0.376	0.325			
Hydrogen	H_2	0.002	20.1	33	1.32	0.305	-0.22	14200	0.168	8.4
(Hydrogen) Deuterium	D_2	0.004	23.6	38	1.66	0.249	-0.16	14200	0.131	12
Mercury[i]	Hg	0.201	630	736	104					
Methane	CH_4	0.016	112	191	4.60	0.288	0.010	2180	0.031	10.3
Methanol	CH_4O	0.032	338.1	513	8.08	0.224	0.559	1350	0.015	9.8
MTBE (methyl tert-butyl ether)	$C_5H_{12}O$	0.088	328	497	3.43	0.273	0.267	1500		
Neon	Ne	0.020	26.2	44	2.70	0.301	0	1030	0.046	30.0

Nitrogen	N_2	0.028	77.4	126	3.39	0.290	0.038	1040	0.024	16.6
Nitrogen dioxide[j]	NO_2	0.046	294.4	431	10.1	0.233		800	0.017	130
Nitrogen monoxide	NO	0.030	121.2	180	6.55	0.250	0.607	996	0.024	29.4
di-Nitrogen oxide[k]	N_2O	0.044	184.7	310	7.26	0.272	0.141	864	0.015	13.6
n-Octane	C_8H_{18}	0.114	399	569	2.49	0.259	0.394	1700	0.020	7.5
iso-Octane	C_8H_{18}	0.114	372	544	2.59	0.267		1650		
Ozone	O_3	0.048	161.4	268	6.78	0.272				
Oxygen	O_2	0.032	90.2	155	5.08	0.288	0.021	913	0.024	19.1
iso-Pentane	C_5H_{12}	0.072	301.3	461	3.33	0.268	0.227	1680	0.015	11.7
n-Pentane	C_5H_{12}	0.072	309.2	470	3.38	0.262	0.251	1680	0.015	11.7
Phenol	C_6H_6O	0.094	455	694	6.13	0.243	0.426			
Propane	C_3H_8	0.044	231.1	370	4.26	0.281	0.152	1570	0.015	7.4
iso-Propanol	C_3H_8O	0.060	355.4	508	4.76	0.248	0.669	1540		
Propylene (propene)	C_3H_6	0.042	225.4	365	4.62	0.275	0.148	1460	0.014	8.1
Propylene glycol	$C_3H_8O_2$	0.076	461.3	626	6.10	0.280	1.107			
R12 (CFC-12) (dichlorodifluoromethane)	CCl_2F_2	0.121	243.0	385	4.14	0.280	0.179	573	0.008	12.5
R134a (HFC-134a) (tetrafluoroethane)	CF_3CH_2F	0.102	246.6	374	4.07	0.258	0.330	840	0.014	12.2
R410A[l]	n.a.	0.073	221.8	345	4.90	0.271	0.296	820		
Sulfur dioxide	SO_2	0.064	263.2	430	7.87	0.264	0.251	607	0.009	11.6
Sulfur hexafluoride[m]	SF_6	0.146	204.9[f]	319	3.76	0.360	0.210	598	0.12	16.0
Toluene	C_7H_8	0.092	383.7	592	4.13	0.284	0.266			
Tetradecafluorohexane	C_6F_{14}	0.338	329	449	1.83					
Uranium hexafluoride[n]	UF_6	0.352	329[f]	503	4.60	0.282	0.092	370	0.009	20
Water (steam)[p]	H_2O	0.018	372.8	647.3	22.12	0.229	0.344	2050[p]	0.025	12.1
Xenon	Xe	0.131	165.0	289.8	5.84	0.291	0	158	0.006	22.5

[a]Critical molar volumes can be obtained from $v_{cr}=Z_{cr}RT_{cr}/p_{cr}$, and critical densities from $\rho_{cr}=M/v_{cr}$ (e.g. for acetone $v_{cr}=209\cdot10^{-6}$ m^3/mol and $\rho_{cr}=351$ kg/m^3.

[b]Thermal capacities of monoatomic gases do not change with temperature, but for polyatomic gases it increases more the more atoms has the molecule.

[c] Thermal conductivity of gases increases with the square root of temperature, decreases with the square root of molar mass, and do not change with pressure. Thermal diffusivity $a\equiv k/(\rho c_p)$. According to simple generalised transport theory in gases, thermal diffusivity, mass diffusivity and kinematic viscosity of gases have the same values.

[d] Dynamic viscosity of gases increases with the square root of temperature, and do not change with pressure. Kinematic viscosity $\nu\equiv\mu/\rho$.

[e] Bubble point.

[f] Sublimation point.

[g] Pseudo-critical point (Kay's model).

[h] Most gas properties vary a lot near the critical point, what may be here the case; e.g., for CO_2 gas at 288 K and 100 kPa, thermal capacity at constant pressure is c_p=840 J/(kg·K), growing at constant T=288 K from c_p=833 J/(kg·K) at very low pressure, to c_p=3010 J/(kg·K) at the saturation pressure (5063 kPa). Thermal capacity in the ideal gas limit (p$\to$0) varies almost linearly (e.g. c_p=753 J/(kg·K) at the triple-point temperature, c_p=850 J/(kg·K) at the critical-point temperature).

[i] Mercury is obtained by oxidation of cinnabar at some 600 ºC and vapour condensation. Mercury vapour should not exceed 0.1 mg/m^3 in breathing air (notice that saturated air at 20 ºC already contains more than that limit.

[j] Nitrogen dioxide, NO_2, is a very toxic brown gas at normal conditions (but readily condensable, T_b=21.3 ºC). All nitrogen oxides slowly decomposing to nitrogen and oxygen, making it difficult to keep them in pure state; besides, NO_2 is paramagnetic, but readily dimerises to dinitrogen tetroxide, N_2O_4, a diamagnetic pale-yellow or colourless gas with double density than NO_2 (e.g. when heating from above an ampoule containing NO_2, some N_2O_4 is formed at the top ($2NO_2(g)=N_2O_4(g)$+57 kJ/mol), which can be seen sinking to the bottom because of buoyancy). The NO_2/N_2O_4 equilibrium depends on temperature, NO_2 being favoured at

high temperatures and N_2O_4 at low temperatures; when condensing (at 21.3 ºC at 100 kPa), most of the liquid is N_2O_4 which is colourless or pale brownish, and if solidified (at −11.2 ºC) a white solid appears. The liquid N_2O_4 is a hypergolic propellant that spontaneously reacts upon contact with various forms of hydrazine, which makes the pair a popular bipropellant for spacecraft rockets.

[k] Di-nitrogen oxide, N_2O, also known as nitrous oxide (NO is nitric oxide), or nitrogen hemi-oxide, or nitrogen protoxide, or laughing gas, is used in respiratory anaesthesia since the pioneering trials of Sir Humphrey Davy in 1789 shortly after its discovery by J. Prietsley in 1772, as a non-flammable non-ozone-depleting propellant in aerosol cans, and as a fuel additive to enhance combustion (it liberates oxygen; if added as compressed liquid in the intake manifold, it greatly increases fuel load). It has a global warming potential (GWP) of 300 times that of CO_2, being the third contributor to anthropogenic GWP, after CO_2 and CH_4.

[l] 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. The critical point of a binary mixture is defined as the point where $\partial^2 g/\partial x^2$ and $\partial^3 g/\partial x^3$ are simultaneously zero, where g is the Gibbs energy and x is the mole fraction of a component.

[m] Sulfur hexafluoride is a synthetic gas used as insulator for electrical equipment (breakdown potential three times larger than air, and as a fluorine source for edging in the electronics industry. It is a non-flammable, non-toxic gas, which decomposes at 750 K; it has low water solubility, and a very large IR absortance (it is the most potent greenhouse gas, GWP=22 000), what has been used as a trace gas for gas-leakage detection.

[n] Uranium hexafluoride, perhaps the heaviest simple molecule, is the only uranium compound presently used in industrially enrichment of U-235, both on gas diffusion and on gas centrifugation processes. At room conditions, it is a white crystalline solid with a high vapour pressure (p_v=11 kPa at 20 ºC).

[p] 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). Steam thermal capacity varies appreciably with T and p: at $p\to 0$, $c_p(T)$ grows almost linearly from 1890 J/(kg·K) at 100 ºC to 2130 J/(kg·K) at 500 ºC, but a high-p it has a minimum (e.g. at 200 kPa, c_p=2180 J/(kg·K) as saturated vapour at 120 ºC, drops to a minimum c_p=2010 J/(kg·K) at 230 ºC, and grows to match $c_p(T,p\to 0)$ at high-T, say c_p=2130 J/(kg·K) at 500 ºC). For the perfect gas model in adiabatic expansion of steam, a value of $\gamma=c_p/c_v$=1.33 is recommended.