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PROPERTIES OF GASES

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

Substance	Formula	Molar	Boiling	Critical	Critical	Critical	Pitzer's	Thermal	Thermal	Dynamic
		mass	temp.	temp	pressure	compressibility	acentric	capacity ^b	conductivity ^c	viscosity ^d
		M	T_b	T_{cr}	p_{cr}	factor ^a	factor	c_p	k	$\mu \cdot 10^6$
		kg/mol	K	K	MPa	Z_{cr}	ω	J/(kg·K)	W/(m·K)	Pa·s
Acetone	C ₃ H ₆ O	0.058	329.2	508	4.70	0.233	0.309	1300		
Acetylene	C ₂ H 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 ₆ H ₆	0.078	353.3	563	4.92	0.271	0.212	1300	0.007	7.0
1,3-Butadiene	C ₄ H ₆	0.054	268.5	425	4.33	0.270	0.193	1510		
n-Butane	C ₄ H ₁₀	0.058	272.6	425	3.80	0.274	0.193	1580	0.015	7.0
iso-Butane	C ₄ H 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 ₆ H ₁₂	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 ₂ H ₆ O	0.046	250.6	400	5.37	0.271	0.274	1430		
Ethane	C ₂ H ₆	0.030	184.6	305	4.88	0.285	0.100	1700	0.020	11.0
Ethanol	C ₂ H ₆ O	0.046	351.5	516	6.39	0.248	0.635	1520	0.013	14.2
Ether (diethyl ether)	C ₄ H ₁₀ O	0.074	307.6	467	3.61	0.260	0.281	1600	0.015	7.5
ETBE (ethyl tert-butyl ether)	C ₆ H ₁₄ O	0.102	345	517	3.11	0.274	0.298	1550		
Ethylene	C ₂ H ₄	0.028	169.5	283	5.12	0.276	0.085	1470	0.018	9.6
Ethylene glycol	C ₂ H ₆ O ₂	0.062	471	645	7.53	0.268	1.137	1410		
Helium (⁴ He)	He	0.004	4.2	5.3	0.23	0.301	-0.387	5190	0.142	19.0
Helium 3 (³ He)	He	0.003	3.2	3.3	0.11	0.301	-0.460			
n-Heptane	C ₇ H ₁₆	0.100	371	540	2.77	0.263	0.350	1650	0.013	6.5
n-Hexane	C ₆ H ₁₄	0.086	342	508	3.03	0.263	0.296	1700	0.014	6.5
Hydrazine	N ₂ H 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
Hydrogen peroxide ⁱ	H ₂ O ₂	0.034	272.7	728 ⁱ	22			1270		
Mercury ^j	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 ₄ O	0.032	338.1	513	8.08	0.224	0.559	1350	0.015	9.8
MTBE (methyl tert-butyl ether)	C ₅ H 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 ^k	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 ^l	N ₂ O	0.044	184.7	310	7.25	0.272	0.160	864	0.015	13.6
n-Octane	C ₈ H ₁₈	0.114	399	569	2.49	0.259	0.394	1700	0.020	7.5
iso-Octane	C ₈ H 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 ₅ H ₁₂	0.072	301.3	461	3.33	0.268	0.227	1680	0.015	11.7
n-Pentane	C ₅ H ₁₂	0.072	309.2	470	3.38	0.262	0.251	1680	0.015	11.7
Phenol	C ₆ H ₆ O	0.094	455	694	6.13	0.243	0.426			
Propane	C ₃ H ₈	0.044	231.1	370	4.26	0.281	0.152	1570	0.015	7.4
iso-Propanol	C ₃ H ₈ O	0.060	355.4	508	4.76	0.248	0.669	1540		
Propylene (propene)	C ₃ H ₆	0.042	225.4	365	4.62	0.275	0.148	1460	0.014	8.1
Propylene glycol	C ₃ H ₈ O ₂	0.076	461.3	626	6.10	0.280	1.107			
R12 (CFC-12) (dichlorodifluoromethane)	CCl ₂ F ₂	0.121	243.0	385	4.14	0.280	0.179	573	0.008	12.5
R134a (HFC-134a) (tetrafluoroethane)	CF ₃ CH ₂ F	0.102	246.6	374	4.07	0.258	0.330	840	0.014	12.2
R410A ^m	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 ⁿ	SF ₆	0.146	204.9 ^f	319	3.76	0.360	0.210	598	0.12	16.0
Toluene	C ₇ H ₈	0.092	383.7	592	4.13	0.284	0.266			
Tetradecafluorohexane	C ₆ F ₁₄	0.338	329	449	1.83					
Uranium hexafluoride ^o	UF ₆	0.352	329 ^f	503	4.60	0.282	0.092	370	0.009	20
Water (steam) ^p	H ₂ O	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

^aCritical 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 $v_{cr}=209 \cdot 10^{-6} \text{ m}^3/\text{mol}$ and $\rho_{cr}=351 \text{ kg/m}^3$).

^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 $a=k/(\rho c_p)$. 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 $\nu=\mu/\rho$.

^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 CO₂ gas at 288 K and 100 kPa, thermal capacity at constant pressure is $c_p=840 \text{ J}/(\text{kg} \cdot \text{K})$, growing at constant $T=288 \text{ K}$ from $c_p=833 \text{ J}/(\text{kg} \cdot \text{K})$ at very low pressure, to $c_p=3010 \text{ J}/(\text{kg} \cdot \text{K})$ at the saturation pressure (5063 kPa). Thermal capacity in the ideal gas limit ($p \rightarrow 0$) varies almost linearly (e.g. $c_p=753 \text{ J}/(\text{kg} \cdot \text{K})$ at the triple-point temperature, $c_p=850 \text{ J}/(\text{kg} \cdot \text{K})$ at the critical-point temperature).

ⁱ Data for [H₂O₂](#) pure (H₂O₂ is most used in aqueous solutions). Critical temperature extrapolated from corresponding states theory, because H₂O₂ decomposes violently at such high temperatures).

^j Mercury is obtained by oxidation of cinnabar at some 600 °C and vapour condensation. Mercury vapour should not exceed 0.1 mg/m³ in breathing air (notice that saturated air at 20 °C already contains more than that limit).

^k Nitrogen dioxide, NO₂, is a very toxic brown gas at normal conditions (but readily condensable, $T_b=21.3 \text{ °C}$). All nitrogen oxides slowly decomposing to nitrogen and oxygen, making it difficult to keep them in pure state; besides, NO₂ is paramagnetic, but readily dimerises to dinitrogen tetroxide, N₂O₄, 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 ($2\text{NO}_2(\text{g})=\text{N}_2\text{O}_4(\text{g})+57 \text{ kJ/mol}$), which can be seen sinking to the bottom because of buoyancy). The $\text{NO}_2/\text{N}_2\text{O}_4$ equilibrium depends on temperature, NO_2 being favoured at high temperatures and N_2O_4 at low temperatures; when condensing (at $21.3 \text{ }^\circ\text{C}$ at 100 kPa), most of the liquid is N_2O_4 which is colourless or pale brownish, and if solidified (at $-11.2 \text{ }^\circ\text{C}$) 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.

- ^l 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. Priestley 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 .
- ^m 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.
- ⁿ 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 absorbance (it is the most potent greenhouse gas, $\text{GWP}=22\ 000$), what has been used as a trace gas for gas-leakage detection.
- ^o 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 ($p_v=11 \text{ kPa}$ at $20 \text{ }^\circ\text{C}$).
- ^p The boiling point of water at 100 kPa is $T_b=372.75\pm 0.02 \text{ K}$ ($99.60\pm 0.02 \text{ }^\circ\text{C}$), whereas at 101.325 kPa (1 atm) it is $373.12\pm 0.02 \text{ K}$ ($99.97\pm 0.02 \text{ }^\circ\text{C}$). Steam thermal capacity varies appreciably with T and p : at $p\rightarrow 0$, $c_p(T)$ grows almost linearly from $1890 \text{ J/(kg}\cdot\text{K)}$ at $100 \text{ }^\circ\text{C}$ to $2130 \text{ J/(kg}\cdot\text{K)}$ at $500 \text{ }^\circ\text{C}$, but a high- p it has a minimum (e.g. at 200 kPa , $c_p=2180 \text{ J/(kg}\cdot\text{K)}$ as saturated vapour at $120 \text{ }^\circ\text{C}$, drops to a minimum $c_p=2010 \text{ J/(kg}\cdot\text{K)}$ at $230 \text{ }^\circ\text{C}$, and grows to match $c_p(T,p\rightarrow 0)$ at high- T , say $c_p=2130 \text{ J/(kg}\cdot\text{K)}$ at $500 \text{ }^\circ\text{C}$). For the perfect gas model in adiabatic expansion of steam, a value of $\gamma=c_p/c_v=1.33$ is recommended.