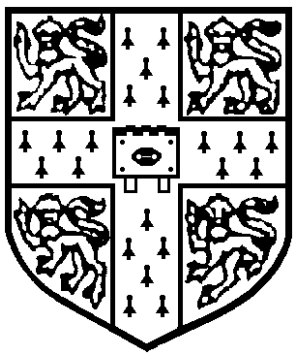
Thermofluids Data Book

for Part I of the
Engineering Tripos

2017 Edition



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Latest revisions

Current release THERMOFLUIDS_DATA_v_20 (12/01/21)
Previous release THERMOFLUIDS_DATA_v_19 (19/7/19)

Updates since previous release
Correction to the value of $\overline{R}$ (page 13).
The pressure-enthalpy chart of R-134a has been replaced (page 39)

CONTENTS

THERMODYNAMIC DEFINITIONS & RELATIONSHIPS

Specific enthalpy	$h \equiv u + pv$
Specific heat capacity at constant volume	$c_v \equiv \left(\frac{\partial u}{\partial T} \right)_v$
Specific heat capacity at constant pressure	$c_p \equiv \left(\frac{\partial h}{\partial T} \right)_p$
Ratio of specific heat capacities	$\gamma \equiv \frac{c_p}{c_v}$
Coefficient of volume expansion	$\beta \equiv \frac{1}{v}\left(\frac{\partial v}{\partial T} \right)_p$
Coefficient of compressibility	$\kappa \equiv -\frac{1}{v}\left(\frac{\partial v}{\partial p} \right)_T$
For a simple compressible substance, in the absence of capillarity, electric and magnetic fields	$Tds = du + pdv = dh - vdp$

IDEAL GAS RELATIONSHIPS

Equation of state

$$\begin{cases} pV = n\bar{R}T \\ pV = mRT \\ pv = RT \\ p = \rho RT \end{cases}$$

Relationship between c_p, c_v and R

$$c_p - c_v = R$$

Speed of sound

$$a = \sqrt{\gamma RT}$$

PERFECT GAS RELATIONSHIPS

Change in specific internal energy

$$u_2 - u_1 = c_v(T_2 - T_1)$$

Change in specific enthalpy

$$h_2 - h_1 = c_p(T_2 - T_1)$$

Change in specific entropy

$$s_2 - s_1 = \begin{cases} c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{v_2}{v_1}\right) \\ c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{p_2}{p_1}\right) \\ c_v \ln\left(\frac{p_2}{p_1}\right) + c_p \ln\left(\frac{v_2}{v_1}\right) \end{cases}$$

For *Isentropic* changes

$$pv^{\gamma} = const.$$
$$Tv^{\gamma-1} = const.$$
$$T / p^{(\gamma-1)/\gamma} = const.$$

MIXTURES OF PERFECT GASES

For a mixture of N perfect gases where, for component -*i*, m_i = mass, p_i = partial pressure, $h_i = h_i(T)$ = partial specific enthalpy, $s_i = s_i(T, p_i)$ = partial specific entropy, n_i = number of mols and the overbar signifies a partial molar quantity:

Pressure of the mixture

$$p_{mixture} = \sum_{i=1}^{i=N} p_i$$

Enthalpy of the mixture

$$H_{mixture} = \sum_{i=1}^{i=N} m_i h_i = \sum_{i=1}^{i=N} n_i \bar{h}_i$$

Entropy of the mixture

$$S_{mixture} = \sum_{i=1}^{i=N} m_i s_i = \sum_{i=1}^{i=N} n_i \bar{s}_i$$

NON-DIMENSIONAL GROUPS

Reynolds Number	$Re = \frac{\rho V d}{\mu} = \frac{V d}{\nu}$
Mach Number	$M = \frac{V}{a}$
Froude Number	$Fr = \frac{V}{\sqrt{gz}}$
Prandtl Number	$Pr = \frac{\mu c_p}{\lambda} = \frac{\nu}{\alpha}$
Biot Number	$Bi = \frac{hs}{\lambda}$
Fourier Number	$Fo = \frac{\alpha \tau}{s^2}$
Drag Coefficient	$C_D = \frac{D}{\frac{1}{2}\rho V^2 A}$
Lift Coefficient	$C_L = \frac{L}{\frac{1}{2}\rho V^2 A}$
Skin Friction Coefficient	$c_f = \frac{\tau_w}{\frac{1}{2}\rho V^2}$
Friction Factor	$f = 4c_f$
Discharge Coefficient	$C_d = \frac{\dot{m}_{actual}}{\dot{m}_{ideal}}$
Nusselt Number	$Nu = \frac{hd}{\lambda}$
Grashof Number	$Gr = \frac{g d^3 \beta \Delta T}{\nu^2}$
Stanton Number	$St = \frac{Nu}{RePr} = \frac{h}{\rho V c_p}$

HEAT TRANSFER

Conduction, Convection and Radiation

Rate of heat transfer $\dot{Q}$ by *convection* from a body of surface area A

$$\dot{Q} = hA\left(T_{body} - T_{surroundings}\right)$$

Rate of heat transfer $\dot{Q}$ by *conduction* along a straight bar of cross-sectional area A

$$\dot{Q} = -\lambda A\frac{dT}{dx}$$

Rate of heat transfer $\dot{Q}$ by *conduction* radially in a straight circular bar of length L

$$\dot{Q} = -\lambda 2\pi rL\frac{dT}{dr}$$

Rate of heat transfer $\dot{Q}$ by *radiation*[1] from a grey body of surface area A and emissivity ε

$$\dot{Q} = \varepsilon\dot{Q}_{black} = \varepsilon\sigma AT^4$$

where σ = 5.67x10^{-8} Wm^{-2}K^{-4} is the Stefan-Boltzmann constant.

Logarithmic-Mean Temperature Difference (LMTD)

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\Delta T_1/\Delta T_2\right)}$$

Convective heat transfer for fully developed flow in circular pipes of diameter d

Overall heat transfer for laminar flow with constant wall temperature

$$Nu_d = 3.66 \qquad Re_d < 2300 \qquad 0.1 < Pr$$

Overall heat transfer for turbulent flow with constant wall temperature

$$Nu_d = 0.023Re_d^{0.8}Pr^{0.4} \qquad 2300 < Re_d < 10^7 \qquad 0.5 < Pr < 120$$

Heat transfer due to natural convection from a vertical isothermal plate of height *L*

Overall heat transfer

$$Nu_L = 0.52\left(GrPr\right)^{0.25} \qquad Pr \approx 1$$

Reynolds Analogy

$$St = \frac{c_f}{2}$$

[1] Note that the net rate of heat transfer will be less due to incident radiation

EQUATIONS FOR SYSTEMS

Definition of a system
A system is a fixed quantity of matter.

Conservation of mass applied to a system
The mass of a system is constant, i.e.

$$m = const.$$

1st Law of Thermodynamics applied to a system
When heat transfer to, and work done by, a system are defined as positive and the system is undergoing a cyclic process

$$\oint dQ = \oint dW$$

When heat transfer to, and work done by, a system of mass m undergoing a process between state 1 and state 2 are defined as positive and in the absence of capillarity, electric and magnetic fields

$$Q - W = E_2 - E_1 = (U_2 + \tfrac{1}{2}mV_2^2 + mgz_2) - (U_1 + \tfrac{1}{2}mV_1^2 + mgz_1)$$

2nd Law of Thermodynamics applied to a system
When heat transfer to a system undergoing a cyclic process is defined as positive, the Clausius inequality is

$$\oint \frac{dQ}{T} \leq 0$$

When heat transfer to a system of mass m undergoing a process is defined as positive

$$mds = \frac{dQ}{T} + mds_{irrev} \qquad \text{where} \qquad ds_{irrev} \geq 0$$

where ds_{irrev} is the entropy created per unit mass by irreversibilities.

***pdv* work for a system**
When the surface of a system undergoes displacement between state 1 and state 2 and the pressure causing the displacement is known over the entire surface that is displaced, the displacement work done by the system during this process is

$$W = \int_1^2 pdV$$

EQUATIONS FOR CONTROL VOLUMES

Definition of a control volume
A control volume is that region of space that is enclosed by a rigid control surface.

The requirements for steady flow within a control volume
For steady-flow, conditions within the control volume are not, on average, changing so that the mass, momentum, energy and entropy within the control volume remain constant.

Conservation of mass applied to a control volume - the *Continuity Equation*
In general, this may be written in vector form as

$$\frac{d}{dt}\iiint_{cv}\rho dV+\oiint_{cs}\rho\underline{V}\bullet\underline{dA}=0$$

where $\underline{dA}$ is positive *out* of the control volume. It may also be written as

$$\frac{dm_{cv}}{dt}+\sum\dot{m}_{out}-\sum\dot{m}_{in}=0$$

For *steady flow*, the above becomes

$$\sum\dot{m}_{out}=\sum\dot{m}_{in}$$

Momentum equations applied to a control volume, including the *Steady Flow Momentum Equation* (SFME)
In general, this may be written in vector form as

$$\frac{d}{dt}\iiint_{cv}\rho\underline{V}dV+\oiint_{cs}\rho\underline{V}\underline{V}\bullet\underline{dA}=\underline{F}-\oiint_{cs}p\underline{dA}$$

where $\underline{dA}$ is positive *out* of the control volume and $\underline{F}$ is the sum of all the non-pressure forces on the flow.

For *steady flow*, the above becomes the *Steady Flow Momentum Equation (SFME)*

$$\oiint_{cs}\rho\underline{V}\underline{V}\bullet\underline{dA}=\underline{F}-\oiint_{cs}p\underline{dA}$$

and in *x* and y coordinates, the *SFME* is

$$\sum\dot{m}_{out}V_{x,out}-\sum\dot{m}_{in}V_{x,in}=\sum F_x+\left(\sum pA\right)_x$$

$$\sum\dot{m}_{out}V_{y,out}-\sum\dot{m}_{in}V_{y,in}=\sum F_y+\left(\sum pA\right)_y$$

where care is needed with respect to the sign of the V_x, V_y and A terms.

1st Law of Thermodynamics applied to a control volume, including the *Steady Flow Energy Equation (SFEE)*

In the absence of capillarity, electric and magnetic fields, the 1st Law becomes

$$\frac{dE_{cv}}{dt} + \sum \dot{m}_{out}\left(h_{out} + \tfrac{1}{2}V_{out}^2 + gz_{out}\right) - \sum \dot{m}_{in}\left(h_{in} + \tfrac{1}{2}V_{in}^2 + gz_{in}\right) = \dot{Q} - \dot{W}_x$$

where E_{cv} is the total energy within the control volume, $\dot{Q}$ is the rate of heat transfer to the control volume and $\dot{W}_x$ is the rate of shaft work transferred from the control volume.

For *steady flow*, the above becomes the *Steady Flow Energy Equation (SFEE)*

$$\sum \dot{m}_{out}\left(h_{out} + \tfrac{1}{2}V_{out}^2 + gz_{out}\right) - \sum \dot{m}_{in}\left(h_{in} + \tfrac{1}{2}V_{in}^2 + gz_{in}\right) = \dot{Q} - \dot{W}_x$$

2nd Law of Thermodynamics applied to a control volume

When heat transfer to a control volume is defined as positive

$$\frac{dS_{cv}}{dt} + \sum \dot{m}_{out} s_{out} - \sum \dot{m}_{in} s_{in} = \int_A \frac{d\dot{Q}}{T} + \dot{S}_{irrev} \qquad \text{where} \qquad \dot{S}_{irrev} \geq 0$$

where $d\dot{Q}$ is the rate of heat transfer to an area dA of the control surface at temperature T and the integration is over the whole area A of the control surface, S_{cv} is the total entropy within the control volume and $\dot{S}_{irrev}$ is the rate of entropy creation within the control volume due to irreversibilities.

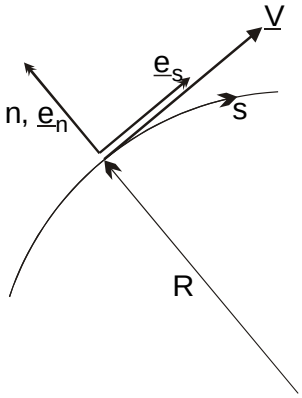
EQUATIONS FOR STREAMLINES

Bernoulli's Equation for incompressible inviscid steady flow along a streamline

$$p + \tfrac{1}{2}\rho V^2 + \rho g z = const.$$

The pressure gradient normal to a streamline with a radius of curvature R

$$\frac{dp}{dn} = \frac{\rho V^2}{R}$$



INCOMPRESSIBLE VISCOUS PIPE FLOW

The pressure drop along a pipe of constant diameter d and length L, with viscous flow

$$\Delta p = 4c_f \frac{L}{d}\frac{1}{2}\rho V^2 = f\frac{L}{d}\frac{1}{2}\rho V^2$$

EQUATIONS OF MOTION IN DIFFERENTIAL FORM

VISCOUS STEADY FLOW OF A FLUID

Mass conservation (continuity)

Intrinsic coordinates $\left(\underline{e}_s\frac{\partial}{\partial s} + \underline{e}_n\frac{\partial}{\partial n}\right).\left(\rho V \underline{e}_s\right) = 0$

Vector Notation $\nabla.\left(\rho\underline{V}\right) = 0$

Momentum

Intrinsic coordinates $\rho\left(V\frac{\partial V}{\partial s}\underline{e}_s - \frac{V^2}{R}\underline{e}_n\right) = -\frac{\partial p}{\partial s}\underline{e}_s - \frac{\partial p}{\partial n}\underline{e}_n + \rho\underline{g} + \underline{viscous}$

Vector Notation $\rho\underline{V}\cdot\nabla\underline{V} = -\nabla p + \rho\underline{g} + \underline{viscous}$

VISCOUS UNSTEADY FLOW OF AN INCOMPRESSIBLE FLUID

$\nabla.\underline{V} = 0$ $\qquad$ $\rho\left(\frac{\partial\underline{V}}{\partial t} + \underline{V}\cdot\nabla\underline{V}\right) = -\nabla p + \rho\underline{g} + \mu\nabla^2\underline{V}$

THERMODYNAMIC EFFICIENCIES

Efficiency of a cycle

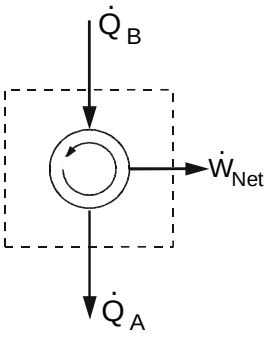
$$\eta_{cycle} \equiv \frac{\dot{W}_{net}}{\dot{Q}_B}$$

but

$$\dot{W}_{net} = \dot{Q}_B - \dot{Q}_A$$

so

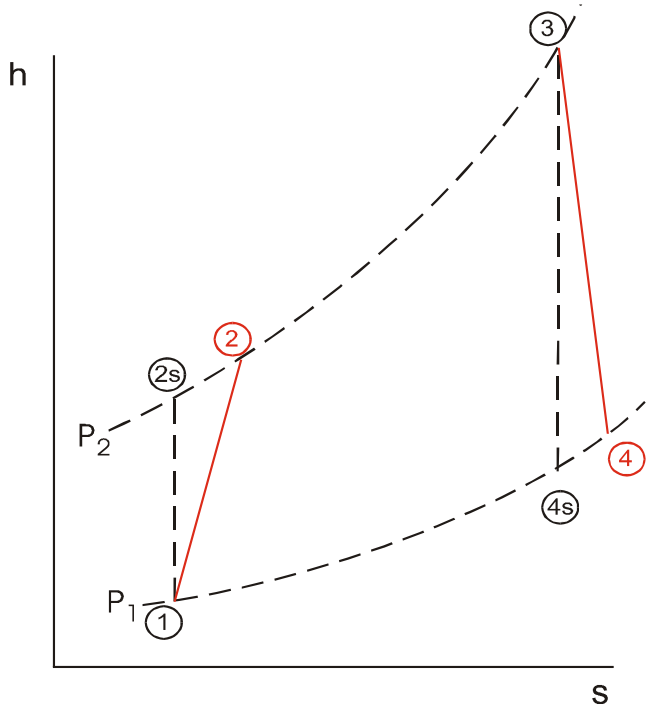
$$\eta_{cycle} = 1 - \frac{\dot{Q}_A}{\dot{Q}_B}$$



Isentropic efficiencies of compressors and turbines

$$\eta_c \equiv \frac{\text{Ideal Work Input}}{\text{Actual Work Input}} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$\eta_t \equiv \frac{\text{Actual Work Output}}{\text{Ideal Work Output}} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$



COMBUSTION

The SFEE applied to stoichiometric combustion at constant T and p

When heat transfer to a control volume is defined as positive and in the absence of shaft work, changes in KE and PE, capillarity, electric and magnetic fields, the rate of heat transfer and the calorific value (CV) are related by

$$\dot{Q} = \dot{m}_{fuel}\left(-CV\right) = \dot{n}_{fuel}\Delta\bar{h}$$

where

$$\dot{m}_{fuel} = M\dot{n}_{fuel}$$

Calorific values of common fuels (Enthalpies of Reaction)

In the following table, the calorific value is equal and opposite to the enthalpy of reaction when the reactants and products are at 25°C and 1.01324 bar. In the evaluation of the lower calorific value and lower enthalpy of reaction, the steam is assumed to be dry saturated.

Stoichiometric Equation	**Molar Mass *M* of Fuel** $\frac{\text{kg}}{\text{kmol}}$	**Phase**	**Calorific Value** MJ/kg	
$C+\frac{1}{2}O_2 \rightarrow CO$	12	solid	9.190	
$C+O_2 \rightarrow CO_2$	12	solid	32.760	
$CO+\frac{1}{2}O_2 \rightarrow CO_2$	28	gas	10.100	
			Higher: H_2O to water	Lower: H_2O to steam
$H_2+\frac{1}{2}O_2 \rightarrow H_2O$	2[†]	gas	142.000	120.000
$CH_4+2O_2 \rightarrow CO_2+2H_2O$	16	gas	55.500	50.010
$C_2H_6+3.5O_2 \rightarrow 2CO_2+3H_2O$	30	gas	51.870	47.470
$C_3H_8+5O_2 \rightarrow 3CO_2+4H_2O$	44	gas	50.360	46.360
$C_4H_{10}+6.5O_2 \rightarrow 4CO_2+5H_2O$	58	gas	49.520	45.730
$C_8H_{18}+12.5O_2 \rightarrow 8CO_2+9H_2O$	114	gas	48.270	44.800
$C_8H_{18}+12.5O_2 \rightarrow 8CO_2+9H_2O$	114	liquid	47.900	44.430

[†] A more exact value is 2.016

PROPERTIES OF PERFECT GASES

Values of M, R, c_p, c_v and γ

At normal atmospheric conditions, and over a limited range of temperature and pressure, the gases listed below may be assumed to behave as perfect gases. That is, they may be assumed to have the equation of state $p\bar{v} = \bar{R}T$, and to have constant specific heat capacities.

Gas	Molar mass M kg/kmol	Gas constant R kJ/kg K	c_p kJ/kg K	c_v kJ/kg K	$\gamma \equiv \frac{c_p}{c_v}$
Air[#]	29.0	0.287	1.005	0.718	1.40
Atmospheric nitrogen[†]	28.15	0.295	1.033	0.738	1.40
N_2	28	0.297	1.04	0.74	1.40
O_2	32	0.260	0.92	0.66	1.40
Ar	40	0.208	0.52	0.31	1.67
H_2	2[*]	4.120	14.20	10.08	1.41
He	4	2.080	5.19	3.11	1.67
CO	28	0.297	1.04	0.74	1.40
CO_2	44	0.189	0.83	0.63	1.31
SO_2	64	0.130	0.61	0.48	1.26
CH_4	16	0.520	2.23	1.71	1.31
C_2H_6	30	0.277	1.75	1.47	1.19
C_3H_6	42	0.198	1.52	1.32	1.15

Real gases are not perfect gases, and the rounded values for R, c_p c_v and c_p/c_v listed above do not exactly satisfy the relationships between these quantities that would be obtained for perfect gases.

Molar (universal) gas constant

$$\bar{R} = MR = 8.3145 \text{ kJ/kmol K}$$

Molar volume of a perfect gas

1 kmol of any perfect gas occupies a volume of approximately 22.7 m^3 at s.t.p. (0 °C and 1 bar) and contains 6.022×10^{26} particles.

[#] Air contains 21.0% O_2 and 79.0% atmospheric nitrogen by volume (*Volumetric* and *Molar Analyses*); 23.2% O_2 and 76.8% atmospheric nitrogen by weight (*Gravimetric Analysis*).

[†] Air contains 0.93 % of argon (Ar) and traces of other gases; these and the nitrogen together are called *atmospheric nitrogen.*

[*] A more exact value is 2.016.

MOLAR ENTHALPIES OF COMMON GASES AT LOW PRESSURES

At low pressures, and over the temperature range quoted, the gases listed in this Table behave as semi-perfect gases. That is, while having the molar equation of state $p\bar{v} = \bar{R}T$, their specific heat capacities c_p and c_v are not constant but are functions only of temperature.

Gas	Air	N_2	O_2	H_2	CO	CO_2	H_2O	Gas
Molar Mass kg/kmol	29	28	32	2†	28	44	18	Molar Mass kg/kmol
Temperature K	Molar enthalpy MJ/kmol							Temperature K
200	5.79	5.81	5.79	5.69	5.81	5.96	6.62	200
298.15=25°C	8.64	8.67	8.66	8.46	8.67	9.37	9.90	25°C=298.15
300	8.70	8.72	8.71	8.52	8.72	9.44	9.96	300
400	11.62	11.64	11.68	11.42	11.64	13.37	13.35	400
500	14.57	14.58	14.74	14.34	14.60	17.67	16.82	500
600	17.59	17.56	17.90	17.27	17.61	22.27	20.39	600
700	20.66	20.61	21.16	20.21	20.69	27.12	24.09	700
800	23.81	23.72	24.50	23.16	23.85	32.18	27.90	800
900	27.03	26.89	27.90	26.13	27.07	37.41	31.83	900
1000	30.30	30.14	31.37	29.14	30.36	42.78	35.90	1000
1100	33.64	33.44	34.88	32.18	33.71	48.27	40.09	1100
1200	37.02	36.79	38.43	35.26	37.11	53.87	44.41	1200
1300	40.44	40.19	42.01	38.38	40.54	59.55	48.84	1300
1400	43.90	43.62	45.63	41.54	44.02	65.31	53.39	1400
1500	47.39	47.09	49.27	44.75	47.53	71.13	58.05	1500
1600	50.92	50.59	52.94	48.00	51.07	77.01	62.81	1600
1700	54.47	54.12	56.63	51.29	54.63	82.94	67.65	1700
1800	58.04	57.67	60.35	54.62	58.21	88.92	72.58	1800
1900	61.63	61.25	64.09	58.00	61.81	94.93	77.59	1900
2000	65.24	64.84	67.86	61.40	65.42	100.97	82.67	2000
2100	68.87	68.44	71.65	64.84	69.06	107.05	87.81	2100
2200	72.52	72.06	75.46	68.31	72.70	113.15	93.01	2200
2300	76.18	75.70	79.29	71.82	76.36	119.28	98.27	2300
2400	79.86	79.35	83.14	75.35	80.03	125.43	103.58	2400
2500	83.55	83.01	87.02	78.90	83.71	131.61	108.94	2500
2600	87.25	86.68	90.92	82.48	87.40	137.80	114.34	2600
2700	90.96	90.36	94.83	86.09	91.10	144.02	119.78	2700
2800	94.69	94.05	98.77	89.72	94.80	150.25	125.26	2800
2900	98.42	97.74	102.72	93.37	98.51	156.50	130.77	2900
3000	102.16	101.44	106.70	97.04	102.23	162.76	136.31	3000

Notes:
(1) The molar enthalpies listed are those in the ideal gas state at zero pressure, but the values given are also valid at and around atmospheric pressure.
(2) In this table, the arbitrary datum state for zero enthalpy is that of the substance in the ideal gas state at zero pressure and zero absolute temperature.
(3) The values for atmospheric nitrogen, N_2^*, may be taken to be the same as those for N_2.

† A more exact value is 2.016

THERMOCHEMICAL DATA FOR EQUILIBRIUM REACTIONS

The tables of equilibrium constants and standard enthalpy change on the next page relate to the reactions listed below

Stoichiometric equations

$$\sum_i \nu_i A_i = 0$$

where ν_i is the stoichiometric coefficient of the substance whose chemical symbol is A_i.

(1) **$-2H + H_2 = 0$**
(2) **$-2N + N_2 = 0$**
(3) **$-2O + O_2 = 0$**
(4) **$-2NO + N_2 + O_2 = 0$**
(5) **$-H_2 - \frac{1}{2} O_2 + H_2O = 0$**
(6) **$-\frac{1}{2} H_2 - OH + H_2O = 0$**
(7) **$-CO - \frac{1}{2} O_2 + CO_2 = 0$**
(8) **$-CO - H_2O + CO_2 + H_2 = 0$**
(9) **$-\frac{1}{2} N_2 - \frac{3}{2} H_2 + NH_3 = 0$**

Equilibrium constants

The equilibrium constant K_p is given by

$$\ln(K_p) = \sum_i \nu_i \ln p_i^*$$

where $p_i^* \equiv p_i' / p_0$

$p_i' \equiv$ partial pressure of species A_i in **bars**

$p_0 \equiv$ standard pressure $\equiv$ **1 bar**

Thus p_i^* is numerically equal to p_i' but is dimensionless.

Standard free enthalpy of reaction

At a given temperature, the standard free enthalpy of reaction (or the *standard Gibbs function change*) ΔG_T^0 may be calculated from the listed value of $\ln(K_p)$ by the following equation:

$$\begin{aligned} \Delta G_T^0 &= -\bar{R} T \ln K_p \\ &= -8.3145\, T \ln(K_p) \quad \text{kJ kmol}^{-1} \end{aligned}$$

Standard enthalpy of reaction

The Standard enthalpy of reaction is given by

$$\Delta H_T^0 = \sum_i \nu_i \left[\tilde{h}_i\right]_T^0 = \sum_i \nu_i \left(\left[\Delta H_f\right]_T^0\right)_i$$

where

$$\left[\tilde{h}_i\right]_T^0 = \left(\left[\Delta H_f\right]_{298}^0\right)_i + \left(\left[\bar{h}\right]_T^0 - \left[\bar{h}\right]_{298}^0\right)_i$$

where $\left(\left[\Delta H_f\right]_T^0\right)_i$ is the *standard enthalpy of formation* of species *i* at temperature *T* and a pressure p_0 = 1 bar.

Equilibrium constants & standard enthalpies of reaction

Reaction Number	1	2	3	4	5	6	7	8	9
$\sum_i \nu_i =$	–1	–1	–1	0	– ½	– ½	– ½	0	–1
Temperature K	Equilibrium Constant $\ln(K_p)$								
200	250.149	554.472	285.471	105.592	139.972	161.789	159.692	19.719	15.433
298.15	163.986	367.479	186.975	69.865	92.207	106.228	103.762	11.554	6.593
400	119.150	270.329	135.715	51.311	67.321	77.284	74.669	7.348	1.778
600	75.217	175.356	85.523	33.203	42.897	48.905	46.245	3.348	–3.191
800	53.126	127.753	60.319	24.145	30.592	34.634	32.036	1.444	–5.822
1000	39.803	99.127	45.150	18.706	23.162	26.033	23.528	0.366	–7.457
1200	30.874	80.011	35.005	15.082	18.182	20.281	17.871	–0.311	–8.570
1400	24.463	66.329	27.742	12.489	14.608	16.160	13.841	–0.767	–9.371
1600	19.632	56.055	22.285	10.546	11.921	13.065	10.829	–1.091	–9.972
1800	15.865	48.051	18.030	9.035	9.825	10.657	8.497	–1.329	–10.439
2000	12.835	41.645	14.622	7.824	8.145	8.727	6.634	–1.510	–10.810
2200	10.353	36.391	11.827	6.834	6.768	7.148	5.119	–1.649	–11.109
2400	8.276	32.011	9.497	6.010	5.619	5.831	3.859	–1.759	–11.358
2600	6.512	28.304	7.521	5.314	4.647	4.718	2.800	–1.847	–11.563
2800	5.002	25.117	5.286	4.720	3.811	3.763	1.893	–1.918	–11.738
3000	3.685	22.359	4.357	4.205	3.086	2.936	1.110	–1.976	–11.885
Temperature K	Standard Enthalpy of Reaction ΔH_T^0 MJ kmol^{-1}								
200	–434.7	–944.1	–496.9	–180.4	–240.9	–280.2	–282.1	–41.21	–43.71
298.15	–436.0	–945.3	–498.4	–180.6	–241.8	–281.3	–283.0	–41.17	–45.90
400	–437.3	–946.6	–499.8	–180.7	–242.8	–282.4	–283.5	–40.63	–48.04
600	–439.7	–948.9	–502.1	–180.7	–244.8	–284.1	–283.6	–38.88	–51.39
800	–442.1	–951.1	–503.9	–180.8	–246.5	–285.5	–283.3	–36.82	–53.66
1000	–444.5	–953.0	–505.4	–180.9	–247.9	–286.6	–282.6	–34.74	–55.07
1200	–446.7	–954.7	–506.7	–180.9	–249.0	–287.4	–281.8	–32.79	–55.83
1400	–448.7	–956.1	–507.8	–181.0	–249.9	–287.9	–280.9	–30.98	–56.07
1600	–450.6	–957.5	–508.9	–181.0	–250.6	–288.4	–279.9	–29.29	–55.99
1800	–452.3	–958.7	–509.8	–181.0	–251.2	–288.6	–278.9	–27.71	–55.66
2000	–453.8	–959.9	–510.6	–181.0	–251.7	–288.8	–277.9	–26.22	–55.19
2200	–455.2	–961.0	–511.4	–180.8	–252.1	–288.9	–276.8	–24.79	–54.61
2400	–456.4	–962.1	–512.0	–180.7	–252.4	–289.0	–275.8	–23.41	–53.92
2600	–457.6	–963.1	–512.5	–180.4	–252.7	–289.0	–274.8	–22.07	–53.12
2800	–458.6	–964.1	–513.0	–180.1	–253.0	–288.9	–273.7	–20.77	–52.22
3000	–459.6	–965.0	–513.4	–179.7	–253.3	–288.9	–272.7	–19.49	–51.20

Warning: These tables list *absolute* temperatures

DATA FOR STEAM

Source of data

The following tables have been produced using equations from the *IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use* and the *Supplementary Release: Saturation Properties of Ordinary Water Substance*. These documents can be found on the International Association for the Properties of Water and Steam website http://www.iapws.org.

TRIPLE POINT DATA FOR STEAM

Temperature = 273.16 K (0.01°C)

Pressure = 0.00611 bar

Phase	Specific volume m^3/kg	Specific enthalpy kJ/kg	Specific entropy kJ/kg K
Ice	0.0010905	-333.5	-1.221
Water	0.0010002	0.000612	0.0
Steam	206	2500.9	9.156

CRITICAL POINT DATA FOR STEAM

Temperature = 647.096 K (373.946°C)

Pressure = 220.64 bar

Density = 322 kg/m^3

PROPERTIES OF SATURATED WATER & STEAM:

Temperatures from the triple point to the critical point

Temp.	Pressure	Specific volume		Spec. int. energy		Specific enthalpy			Specific entropy		Temp.
°C	bar	m^3/kg		kJ/kg		kJ/kg			kJ/kg K		°C
T	p	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	T
0.01	**0.00611**	**0.001000**	**206.005**	**0.0**	**2375.0**	**0.0**	**2500.9**	**2500.9**	**0.000**	**9.156**	**0.01**
2	0.00706	0.001000	179.776	8.4	2377.6	8.4	2496.2	2504.6	0.031	9.103	**2**
4	0.00814	0.001000	157.135	16.8	2380.4	16.8	2491.4	2508.2	0.061	9.051	**4**
6	0.00935	0.001000	137.652	25.2	2383.1	25.2	2486.7	2511.9	0.091	8.999	**6**
8	0.01073	0.001000	120.846	33.6	2385.9	33.6	2481.9	2515.6	0.121	8.949	**8**
10	0.01228	0.001000	106.319	42.0	2388.6	42.0	2477.2	2519.2	0.151	8.900	**10**
12	0.01403	0.001001	93.732	50.4	2391.4	50.4	2472.5	2522.9	0.181	8.851	**12**
14	0.01599	0.001001	82.804	58.8	2394.1	58.8	2467.7	2526.5	0.210	8.804	**14**
16	0.01819	0.001001	73.295	67.2	2396.9	67.2	2463.0	2530.2	0.239	8.757	**16**
18	0.02065	0.001001	65.005	75.5	2399.6	75.5	2458.3	2533.8	0.268	8.711	**18**
20	0.02339	0.001002	57.762	83.9	2402.3	83.9	2453.5	2537.4	0.296	8.666	**20**
22	0.02645	0.001002	51.422	92.3	2405.0	92.3	2448.8	2541.1	0.325	8.622	**22**
24	0.02986	0.001003	45.861	100.6	2407.8	100.6	2444.1	2544.7	0.353	8.578	**24**
25	**0.03170**	**0.001003**	**43.340**	**104.8**	**2409.1**	**104.8**	**2441.7**	**2546.5**	**0.367**	**8.557**	**25**
26	0.03364	0.001003	40.975	109.0	2410.5	109.0	2439.3	2548.3	0.381	8.535	**26**
28	0.03783	0.001004	36.673	117.4	2413.2	117.4	2434.6	2551.9	0.409	8.493	**28**
30	0.04247	0.001004	32.879	125.7	2415.9	125.7	2429.8	2555.5	0.437	8.452	**30**
32	0.04760	0.001005	29.527	134.1	2418.6	134.1	2425.1	2559.2	0.464	8.411	**32**
34	0.05325	0.001006	26.560	142.4	2421.3	142.4	2420.3	2562.8	0.492	8.371	**34**
36	0.05948	0.001006	23.929	150.8	2424.0	150.8	2415.5	2566.3	0.519	8.332	**36**
38	0.06633	0.001007	21.593	159.2	2426.7	159.2	2410.8	2569.9	0.546	8.294	**38**
40	0.07385	0.001008	19.515	167.5	2429.4	167.5	2406.0	2573.5	0.572	8.256	**40**
42	0.08210	0.001009	17.663	175.9	2432.1	175.9	2401.2	2577.1	0.599	8.218	**42**
44	0.09113	0.001010	16.010	184.2	2434.7	184.2	2396.4	2580.6	0.625	8.181	**44**
46	0.10100	0.001010	14.534	192.6	2437.4	192.6	2391.6	2584.2	0.652	8.145	**46**
48	0.11178	0.001011	13.212	201.0	2440.1	201.0	2386.8	2587.8	0.678	8.110	**48**
50	0.12352	0.001012	12.026	209.3	2442.7	209.3	2382.0	2591.3	0.704	8.075	**50**
52	0.13632	0.001013	10.962	217.7	2445.4	217.7	2377.1	2594.8	0.730	8.040	**52**
54	0.15023	0.001014	10.006	226.0	2448.0	226.1	2372.3	2598.3	0.755	8.007	**54**
56	0.16534	0.001015	9.145	234.4	2450.7	234.4	2367.4	2601.8	0.781	7.973	**56**
58	0.18172	0.001016	8.368	242.8	2453.3	242.8	2362.5	2605.3	0.806	7.940	**58**
60	0.19947	0.001017	7.667	251.1	2455.9	251.2	2357.7	2608.8	0.831	7.908	**60**
62	0.21868	0.001018	7.033	259.5	2458.5	259.5	2352.8	2612.3	0.856	7.876	**62**
64	0.23944	0.001019	6.460	267.9	2461.1	267.9	2347.9	2615.8	0.881	7.845	**64**
66	0.26184	0.001020	5.940	276.3	2463.7	276.3	2342.9	2619.2	0.906	7.814	**66**
68	0.28600	0.001022	5.468	284.6	2466.3	284.7	2338.0	2622.7	0.931	7.784	**68**
70	0.31202	0.001023	5.040	293.0	2468.8	293.1	2333.0	2626.1	0.955	7.754	**70**
72	0.34002	0.001024	4.650	301.4	2471.4	301.4	2328.1	2629.5	0.979	7.725	**72**
74	0.37010	0.001025	4.295	309.8	2474.0	309.8	2323.1	2632.9	1.004	7.696	**74**
76	0.40240	0.001026	3.971	318.2	2476.5	318.2	2318.1	2636.3	1.028	7.667	**76**
78	0.43704	0.001028	3.675	326.6	2479.0	326.6	2313.1	2639.7	1.052	7.639	**78**
80	0.47416	0.001029	3.405	335.0	2481.5	335.0	2308.0	2643.0	1.076	7.611	**80**
82	0.51388	0.001030	3.158	343.3	2484.1	343.4	2303.0	2646.4	1.099	7.584	**82**
84	0.55636	0.001032	2.932	351.7	2486.5	351.8	2297.9	2649.7	1.123	7.557	**84**
86	0.60174	0.001033	2.725	360.1	2489.0	360.2	2292.8	2653.0	1.146	7.530	**86**
88	0.65018	0.001035	2.534	368.6	2491.5	368.6	2287.6	2656.3	1.170	7.504	**88**
90	0.70183	0.001036	2.359	377.0	2494.0	377.0	2282.5	2659.5	1.193	7.478	**90**
92	0.75685	0.001037	2.198	385.4	2496.4	385.4	2277.3	2662.8	1.216	7.453	**92**
94	0.81542	0.001039	2.050	393.8	2498.8	393.9	2272.1	2666.0	1.239	7.428	**94**
96	0.87771	0.001040	1.914	402.2	2501.2	402.3	2266.9	2669.2	1.262	7.403	**96**
98	0.94390	0.001042	1.788	410.6	2503.6	410.7	2261.7	2672.4	1.285	7.378	**98**
100	1.01418	0.001043	1.672	419.1	2506.0	419.2	2256.4	2675.6	1.307	7.354	**100**
T	p	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	T

Properties of Saturated Water & Steam continued:
Temperatures from the triple point to the critical point

Temp.	Pressure	Specific volume		Spec. int. energy		Specific enthalpy			Specific entropy		Temp.
°C	bar	m^3/kg		kJ/kg		kJ/kg			kJ/kg K		°C
T	p	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	T
100	1.014	0.001043	1.67196	419.1	2506.0	419.2	2256.4	2675.6	1.307	7.354	**100**
105	1.209	0.001047	1.41856	440.1	2511.9	440.3	2243.1	2683.4	1.363	7.295	**105**
110	1.434	0.001052	1.20945	461.3	2517.7	461.4	2229.6	2691.1	1.419	7.238	**110**
115	1.692	0.001056	1.03598	482.4	2523.3	482.6	2216.0	2698.6	1.474	7.183	**115**
120	1.987	0.001060	0.89133	503.6	2528.8	503.8	2202.1	2705.9	1.528	7.129	**120**
125	2.322	0.001065	0.77012	524.8	2534.3	525.1	2188.0	2713.1	1.582	7.077	**125**
130	2.703	0.001070	0.66808	546.1	2539.5	546.4	2173.7	2720.1	1.635	7.026	**130**
135	3.132	0.001075	0.58179	567.4	2544.6	567.7	2159.1	2726.9	1.687	6.977	**135**
140	3.615	0.001080	0.50850	588.8	2549.6	589.2	2144.3	2733.4	1.739	6.929	**140**
145	4.157	0.001085	0.44600	610.2	2554.4	610.6	2129.2	2739.8	1.791	6.883	**145**
150	4.762	0.001091	0.39248	631.7	2559.0	632.2	2113.7	2745.9	1.842	6.837	**150**
155	5.435	0.001096	0.34648	653.2	2563.5	653.8	2098.0	2751.8	1.892	6.793	**155**
160	6.182	0.001102	0.30680	674.8	2567.8	675.5	2082.0	2757.4	1.943	6.749	**160**
165	7.009	0.001108	0.27244	696.5	2571.8	697.2	2065.6	2762.8	1.992	6.707	**165**
170	7.922	0.001114	0.24260	718.2	2575.7	719.1	2048.8	2767.9	2.042	6.665	**170**
175	8.926	0.001121	0.21659	740.0	2579.4	741.0	2031.7	2772.7	2.091	6.624	**175**
180	10.028	0.001127	0.19384	761.9	2582.8	763.1	2014.2	2777.2	2.139	6.584	**180**
185	11.235	0.001134	0.17390	783.9	2586.0	785.2	1996.2	2781.4	2.188	6.545	**185**
190	12.552	0.001141	0.15636	806.0	2589.0	807.4	1977.8	2785.3	2.235	6.506	**190**
195	13.988	0.001149	0.14089	828.2	2591.7	829.8	1959.0	2788.8	2.283	6.468	**195**
200	15.549	0.001157	0.12721	850.5	2594.2	852.3	1939.7	2792.0	2.331	6.430	**200**
205	17.243	0.001164	0.11508	872.9	2596.4	874.9	1919.9	2794.8	2.378	6.393	**205**
210	19.077	0.001173	0.10429	895.4	2598.3	897.6	1899.6	2797.3	2.424	6.356	**210**
215	21.059	0.001181	0.09468	918.0	2599.9	920.5	1878.8	2799.3	2.471	6.320	**215**
220	23.196	0.001190	0.08609	940.8	2601.2	943.6	1857.4	2800.9	2.518	6.284	**220**
225	25.497	0.001199	0.07841	963.7	2602.2	966.8	1835.3	2802.2	2.564	6.248	**225**
230	27.971	0.001209	0.07151	986.8	2602.9	990.2	1812.7	2802.9	2.610	6.213	**230**
235	30.626	0.001219	0.06530	1010.0	2603.2	1013.8	1789.4	2803.2	2.656	6.178	**235**
240	33.470	0.001229	0.05971	1033.4	2603.1	1037.6	1765.4	2803.0	2.702	6.142	**240**
245	36.512	0.001240	0.05466	1057.0	2602.7	1061.5	1740.7	2802.2	2.748	6.107	**245**
250	39.762	0.001252	0.05009	1080.8	2601.8	1085.8	1715.2	2800.9	2.793	6.072	**250**
255	43.229	0.001263	0.04594	1104.8	2600.5	1110.2	1688.9	2799.1	2.839	6.037	**255**
260	46.923	0.001276	0.04218	1129.0	2598.7	1134.9	1661.7	2796.6	2.885	6.002	**260**
265	50.853	0.001289	0.03875	1153.4	2596.5	1159.9	1633.6	2793.5	2.930	5.966	**265**
270	55.030	0.001303	0.03562	1178.1	2593.7	1185.2	1604.5	2789.7	2.976	5.930	**270**
275	59.464	0.001317	0.03277	1203.0	2590.3	1210.9	1574.3	2785.2	3.022	5.894	**275**
280	64.166	0.001333	0.03015	1228.3	2586.4	1236.8	1543.0	2779.9	3.068	5.858	**280**
285	69.146	0.001349	0.02776	1253.9	2581.8	1263.2	1510.5	2773.7	3.114	5.821	**285**
290	74.418	0.001366	0.02555	1279.8	2576.5	1290.0	1476.7	2766.7	3.161	5.783	**290**
295	79.991	0.001384	0.02353	1306.1	2570.5	1317.2	1441.5	2758.7	3.208	5.745	**295**
300	85.879	0.001404	0.02166	1332.8	2563.6	1344.9	1404.7	2749.6	3.255	5.706	**300**
305	92.094	0.001425	0.01993	1360.1	2555.8	1373.2	1366.2	2739.4	3.302	5.666	**305**
310	98.650	0.001447	0.01833	1387.8	2547.1	1402.1	1325.8	2727.9	3.351	5.624	**310**
315	105.561	0.001472	0.01685	1416.2	2537.2	1431.7	1283.3	2715.0	3.399	5.582	**315**
320	112.843	0.001499	0.01547	1445.2	2526.0	1462.1	1238.5	2700.6	3.449	5.537	**320**
325	120.510	0.001528	0.01418	1475.0	2513.4	1493.4	1190.9	2684.3	3.500	5.491	**325**
330	128.581	0.001560	0.01298	1505.7	2499.2	1525.8	1140.2	2666.0	3.552	5.442	**330**
335	137.073	0.001597	0.01185	1537.5	2483.0	1559.4	1086.0	2645.4	3.605	5.391	**335**
340	146.007	0.001638	0.01078	1570.7	2464.5	1594.6	1027.4	2621.9	3.660	5.336	**340**
345	155.406	0.001685	0.00977	1605.4	2443.2	1631.6	963.4	2595.1	3.718	5.276	**345**
350	165.293	0.001741	0.00881	1642.3	2418.3	1671.1	892.7	2563.8	3.779	5.211	**350**
355	175.700	0.001808	0.00787	1682.1	2388.6	1713.9	812.9	2526.9	3.844	5.138	**355**
360	186.660	0.001895	0.00695	1726.2	2351.8	1761.5	720.0	2481.6	3.916	5.054	**360**
365	198.218	0.002015	0.00601	1777.2	2303.6	1817.2	605.5	2422.7	4.000	4.949	**365**
370	210.438	0.002217	0.00495	1844.5	2230.1	1891.2	443.1	2334.3	4.112	4.801	**370**
373.95	**220.640**	**0.003106**	**0.00311**	**2018.1**	**2018.1**	**2086.6**	**0.0**	**2086.6**	**4.410**	**4.410**	**373.95**
T	p	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	T

PROPERTIES OF SATURATED WATER & STEAM:

Pressures from the triple point to the critical point

Pressure	Temp.	Specific volume		Spec. int. energy		Specific enthalpy			Specific entropy		Pressure
bar	°C	m^3/kg		kJ/kg		kJ/kg			kJ/kg K		bar
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p
0.00611	**0.01**	**0.001000**	**206.0005**	**0.0**	**2375.0**	**0.0**	**2500.9**	**2500.9**	**0.000**	**9.156**	**0.00611**
0.02	17.50	0.001001	66.990	73.4	2398.9	73.4	2459.5	2532.9	0.261	8.723	**0.02**
0.04	28.96	0.001004	34.791	121.4	2414.5	121.4	2432.3	2553.7	0.422	8.473	**0.04**
0.06	36.16	0.001006	23.733	151.5	2424.2	151.5	2415.2	2566.6	0.521	8.329	**0.06**
0.08	41.51	0.001008	18.099	173.8	2431.4	173.8	2402.4	2576.2	0.592	8.227	**0.08**
0.10	45.81	0.001010	14.670	191.8	2437.2	191.8	2392.1	2583.9	0.649	8.149	**0.10**
0.12	49.42	0.001012	12.358	206.9	2442.0	206.9	2383.4	2590.3	0.696	8.085	**0.12**
0.14	52.55	0.001013	10.691	220.0	2446.1	220.0	2375.8	2595.8	0.737	8.031	**0.14**
0.16	55.31	0.001015	9.431	231.5	2449.8	231.6	2369.1	2600.6	0.772	7.985	**0.16**
0.18	57.80	0.001016	8.443	241.9	2453.0	241.9	2363.0	2605.0	0.804	7.944	**0.18**
0.20	60.06	0.001017	7.648	251.4	2456.0	251.4	2357.5	2608.9	0.832	7.907	**0.20**
0.22	62.13	0.001018	6.994	260.1	2458.7	260.1	2352.4	2612.5	0.858	7.874	**0.22**
0.24	64.05	0.001019	6.446	268.1	2461.2	268.1	2347.7	2615.9	0.882	7.844	**0.24**
0.26	65.84	0.001020	5.979	275.6	2463.5	275.6	2343.3	2619.0	0.904	7.817	**0.26**
0.28	67.52	0.001021	5.578	282.6	2465.7	282.6	2339.2	2621.8	0.925	7.791	**0.28**
0.30	69.09	0.001022	5.229	289.2	2467.7	289.3	2335.3	2624.5	0.944	7.767	**0.30**
0.32	70.58	0.001023	4.922	295.5	2469.6	295.5	2331.6	2627.1	0.962	7.745	**0.32**
0.34	72.00	0.001024	4.650	301.4	2471.4	301.4	2328.1	2629.5	0.979	7.725	**0.34**
0.36	73.34	0.001025	4.407	307.0	2473.1	307.1	2324.7	2631.8	0.996	7.705	**0.36**
0.38	74.63	0.001026	4.190	312.4	2474.8	312.5	2321.5	2634.0	1.011	7.687	**0.38**
0.40	75.86	0.001026	3.993	317.6	2476.3	317.6	2318.4	2636.1	1.026	7.669	**0.40**
0.42	77.03	0.001027	3.815	322.5	2477.8	322.6	2315.5	2638.0	1.040	7.652	**0.42**
0.44	78.16	0.001028	3.652	327.3	2479.2	327.3	2312.6	2639.9	1.054	7.637	**0.44**
0.46	79.25	0.001029	3.503	331.8	2480.6	331.9	2309.9	2641.8	1.067	7.621	**0.46**
0.48	80.30	0.001029	3.367	336.2	2481.9	336.3	2307.2	2643.5	1.079	7.607	**0.48**
0.50	81.32	0.001030	3.240	340.5	2483.2	340.5	2304.7	2645.2	1.091	7.593	**0.50**
0.52	82.30	0.001031	3.123	344.6	2484.4	344.6	2302.2	2646.8	1.103	7.580	**0.52**
0.54	83.25	0.001031	3.015	348.6	2485.6	348.6	2299.8	2648.4	1.114	7.567	**0.54**
0.56	84.17	0.001032	2.914	352.4	2486.8	352.5	2297.4	2649.9	1.125	7.555	**0.56**
0.58	85.06	0.001032	2.820	356.2	2487.9	356.3	2295.2	2651.4	1.135	7.543	**0.58**
0.60	85.93	0.001033	2.732	359.8	2488.9	359.9	2293.0	2652.9	1.145	7.531	**0.60**
0.62	86.77	0.001034	2.649	363.4	2490.0	363.4	2290.8	2654.2	1.155	7.520	**0.62**
0.64	87.59	0.001034	2.572	366.8	2491.0	366.9	2288.7	2655.6	1.165	7.509	**0.64**
0.66	88.39	0.001035	2.499	370.2	2492.0	370.3	2286.6	2656.9	1.174	7.499	**0.66**
0.68	89.17	0.001035	2.430	373.5	2492.9	373.5	2284.6	2658.2	1.183	7.489	**0.68**
0.70	89.93	0.001036	2.365	376.7	2493.9	376.7	2282.7	2659.4	1.192	7.479	**0.70**
0.72	90.67	0.001036	2.304	379.8	2494.8	379.9	2280.8	2660.6	1.201	7.470	**0.72**
0.74	91.40	0.001037	2.245	382.9	2495.7	382.9	2278.9	2661.8	1.209	7.460	**0.74**
0.76	92.11	0.001037	2.190	385.8	2496.5	385.9	2277.0	2663.0	1.217	7.451	**0.76**
0.78	92.81	0.001038	2.137	388.8	2497.4	388.8	2275.2	2664.1	1.225	7.443	**0.78**
0.80	93.49	0.001039	2.087	391.6	2498.2	391.7	2273.5	2665.2	1.233	7.434	**0.80**
0.82	94.15	0.001039	2.040	394.4	2499.0	394.5	2271.7	2666.3	1.241	7.426	**0.82**
0.84	94.80	0.001039	1.994	397.2	2499.8	397.3	2270.0	2667.3	1.248	7.418	**0.84**
0.86	95.44	0.001040	1.951	399.9	2500.6	400.0	2268.4	2668.3	1.255	7.410	**0.86**
0.88	96.07	0.001040	1.909	402.5	2501.3	402.6	2266.7	2669.3	1.263	7.402	**0.88**
0.90	96.69	0.001041	1.870	405.1	2502.1	405.2	2265.1	2670.3	1.270	7.394	**0.90**
0.92	97.29	0.001041	1.832	407.6	2502.8	407.7	2263.5	2671.3	1.277	7.387	**0.92**
0.94	97.89	0.001042	1.795	410.1	2503.5	410.2	2262.0	2672.2	1.283	7.380	**0.94**
0.96	98.47	0.001042	1.760	412.6	2504.2	412.7	2260.4	2673.1	1.290	7.373	**0.96**
0.98	99.04	0.001043	1.726	415.0	2504.9	415.1	2258.9	2674.1	1.296	7.366	**0.98**
1.00	99.61	0.001043	1.694	417.4	2505.5	417.5	2257.4	2674.9	1.303	7.359	**1.00**
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p

Properties of Saturated Water & Steam continued:
Pressures from the triple point to the critical point

Pressure	Temp.	Specific volume		Spec. int. energy		Specific enthalpy			Specific entropy		Pressure
bar	°C	m³/kg		kJ/kg		kJ/kg			kJ/kg K		bar
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p
1.0	99.61	0.001043	1.6941	417.4	2505.5	417.5	2257.4	2674.9	1.303	7.359	**1.0**
1.5	111.35	0.001053	1.1594	467.0	2519.2	467.1	2226.0	2693.1	1.434	7.223	**1.5**
2.0	120.21	0.001061	0.8858	504.5	2529.1	504.7	2201.5	2706.2	1.530	7.127	**2.0**
2.5	127.41	0.001067	0.7187	535.1	2536.8	535.3	2181.1	2716.5	1.607	7.053	**2.5**
3.0	133.52	0.001073	0.6058	561.1	2543.1	561.4	2163.5	2724.9	1.672	6.992	**3.0**
3.5	138.86	0.001079	0.5242	583.9	2548.5	584.3	2147.7	2732.0	1.727	6.940	**3.5**
4.0	143.61	0.001084	0.4624	604.2	2553.1	604.7	2133.4	2738.1	1.776	6.896	**4.0**
4.5	147.90	0.001088	0.4139	622.7	2557.1	623.1	2120.2	2743.4	1.820	6.856	**4.5**
5.0	151.83	0.001093	0.3748	639.5	2560.7	640.1	2108.0	2748.1	1.860	6.821	**5.0**
5.5	155.46	0.001097	0.3426	655.2	2563.9	655.8	2096.6	2752.3	1.897	6.789	**5.5**
6.0	158.83	0.001101	0.3156	669.7	2566.8	670.4	2085.8	2756.1	1.931	6.759	**6.0**
6.5	161.98	0.001104	0.2926	683.4	2569.4	684.1	2075.5	2759.6	1.962	6.732	**6.5**
7.0	164.95	0.001108	0.2728	696.2	2571.8	697.0	2065.8	2762.8	1.992	6.707	**7.0**
7.5	167.75	0.001111	0.2555	708.4	2574.0	709.2	2056.4	2765.6	2.019	6.684	**7.5**
8.0	170.41	0.001115	0.2403	720.0	2576.0	720.9	2047.4	2768.3	2.046	6.662	**8.0**
8.5	172.94	0.001118	0.2269	731.0	2577.9	732.0	2038.8	2770.8	2.070	6.641	**8.5**
9.0	175.35	0.001121	0.2149	741.6	2579.6	742.6	2030.5	2773.0	2.094	6.621	**9.0**
9.5	177.66	0.001124	0.2041	751.7	2581.2	752.7	2022.4	2775.1	2.117	6.603	**9.5**
10.0	179.88	0.001127	0.1944	761.4	2582.7	762.5	2014.6	2777.1	2.138	6.585	**10.0**
10.5	182.01	0.001130	0.1855	770.8	2584.1	771.9	2007.0	2778.9	2.159	6.568	**10.5**
11.0	184.06	0.001133	0.1775	779.8	2585.5	781.0	1999.6	2780.6	2.178	6.552	**11.0**
11.5	186.04	0.001136	0.1701	788.5	2586.7	789.8	1992.4	2782.2	2.198	6.537	**11.5**
12.0	187.96	0.001138	0.1633	797.0	2587.8	798.3	1985.4	2783.7	2.216	6.522	**12.0**
12.5	189.81	0.001141	0.1570	805.2	2588.9	806.6	1978.6	2785.1	2.234	6.507	**12.5**
13.0	191.60	0.001144	0.1512	813.1	2589.9	814.6	1971.9	2786.5	2.251	6.494	**13.0**
13.5	193.35	0.001146	0.1458	820.8	2590.9	822.4	1965.3	2787.7	2.267	6.480	**13.5**
14.0	195.04	0.001149	0.1408	828.4	2591.8	830.0	1958.9	2788.8	2.284	6.467	**14.0**
14.5	196.68	0.001151	0.1361	835.7	2592.6	837.4	1952.6	2789.9	2.299	6.455	**14.5**
15.0	198.29	0.001154	0.1317	842.8	2593.4	844.6	1946.4	2791.0	2.314	6.443	**15.0**
15.5	199.85	0.001156	0.1276	849.8	2594.1	851.6	1940.3	2791.9	2.329	6.431	**15.5**
16.0	201.37	0.001159	0.1237	856.6	2594.8	858.5	1934.4	2792.8	2.343	6.420	**16.0**
16.5	202.86	0.001161	0.1201	863.3	2595.5	865.2	1928.5	2793.7	2.357	6.409	**16.5**
17.0	204.31	0.001163	0.1167	869.8	2596.1	871.7	1922.7	2794.5	2.371	6.398	**17.0**
17.5	205.72	0.001166	0.1134	876.1	2596.7	878.2	1917.0	2795.2	2.384	6.388	**17.5**
18.0	207.11	0.001168	0.1104	882.4	2597.2	884.5	1911.4	2795.9	2.397	6.377	**18.0**
18.5	208.47	0.001170	0.1075	888.5	2597.8	890.7	1905.9	2796.6	2.410	6.368	**18.5**
19.0	209.80	0.001172	0.1047	894.5	2598.2	896.7	1900.5	2797.2	2.423	6.358	**19.0**
19.5	211.10	0.001175	0.1021	900.4	2598.7	902.7	1895.1	2797.8	2.435	6.348	**19.5**
20.0	212.38	0.001177	0.0996	906.2	2599.1	908.5	1889.8	2798.3	2.447	6.339	**20.0**
20.5	213.63	0.001179	0.0972	911.8	2599.5	914.2	1884.6	2798.8	2.458	6.330	**20.5**
21.0	214.86	0.001181	0.0949	917.4	2599.9	919.9	1879.4	2799.3	2.470	6.321	**21.0**
21.5	216.06	0.001183	0.0928	922.9	2600.2	925.4	1874.3	2799.7	2.481	6.312	**21.5**
22.0	217.25	0.001185	0.0907	928.3	2600.6	930.9	1869.2	2800.1	2.492	6.304	**22.0**
22.5	218.41	0.001187	0.0887	933.6	2600.9	936.3	1864.2	2800.5	2.503	6.295	**22.5**
23.0	219.56	0.001189	0.0868	938.8	2601.1	941.5	1859.3	2800.8	2.513	6.287	**23.0**
23.5	220.68	0.001191	0.0850	943.9	2601.4	946.7	1854.4	2801.1	2.524	6.279	**23.5**
24.0	221.79	0.001193	0.0832	949.0	2601.6	951.9	1849.6	2801.4	2.534	6.271	**24.0**
24.5	222.88	0.001195	0.0816	954.0	2601.9	956.9	1844.8	2801.7	2.544	6.263	**24.5**
25.0	223.95	0.001197	0.0800	958.9	2602.1	961.9	1840.0	2801.9	2.554	6.256	**25.0**
25.5	225.01	0.001199	0.0784	963.8	2602.2	966.8	1835.3	2802.2	2.564	6.248	**25.5**
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p

Properties of Saturated Water & Steam continued:
Pressures from the triple point to the critical point

Pressure	Temp.	Specific volume		Spec. int. energy		Specific enthalpy			Specific entropy		Pressure
bar	°C	m^3/kg		kJ/kg		kJ/kg			kJ/kg K		bar
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p
26.0	226.05	0.001201	0.0769	968.6	2602.4	971.7	1830.7	2802.3	2.574	6.241	**26.0**
26.5	227.07	0.001203	0.0755	973.3	2602.5	976.5	1826.1	2802.5	2.583	6.234	**26.5**
27.0	228.08	0.001205	0.0741	977.9	2602.7	981.2	1821.5	2802.7	2.592	6.226	**27.0**
27.5	229.07	0.001207	0.0727	982.5	2602.8	985.9	1816.9	2802.8	2.601	6.219	**27.5**
28.0	230.06	0.001209	0.0714	987.1	2602.9	990.5	1812.4	2802.9	2.611	6.212	**28.0**
28.5	231.02	0.001211	0.0702	991.6	2603.0	995.0	1808.0	2803.0	2.619	6.206	**28.5**
29.0	231.98	0.001213	0.0690	996.0	2603.1	999.5	1803.6	2803.1	2.628	6.199	**29.0**
29.5	232.92	0.001215	0.0678	1000.4	2603.1	1004.0	1799.2	2803.1	2.637	6.192	**29.5**
30	233.85	0.001217	0.06667	1004.7	2603.2	1008.4	1794.8	2803.2	2.645	6.186	**30**
32	237.46	0.001224	0.06248	1021.5	2603.2	1025.4	1777.7	2803.1	2.679	6.160	**32**
34	240.90	0.001231	0.05876	1037.7	2603.1	1041.8	1761.0	2802.9	2.710	6.136	**34**
36	244.18	0.001238	0.05545	1053.1	2602.8	1057.6	1744.8	2802.4	2.740	6.113	**36**
38	247.33	0.001245	0.05247	1068.1	2602.3	1072.8	1728.9	2801.7	2.769	6.091	**38**
40	250.35	0.001252	0.04978	1082.5	2601.7	1087.5	1713.3	2800.8	2.797	6.070	**40**
42	253.26	0.001259	0.04733	1096.4	2601.0	1101.7	1698.1	2799.8	2.823	6.049	**42**
44	256.07	0.001266	0.04510	1109.9	2600.1	1115.5	1683.1	2798.6	2.849	6.029	**44**
46	258.78	0.001273	0.04306	1123.0	2599.2	1128.9	1668.4	2797.3	2.874	6.010	**46**
48	261.40	0.001280	0.04118	1135.8	2598.1	1141.9	1653.9	2795.8	2.898	5.992	**48**
50	263.94	0.001286	0.03945	1148.2	2597.0	1154.6	1639.6	2794.2	2.921	5.974	**50**
52	266.40	0.001293	0.03784	1160.3	2595.7	1167.0	1625.5	2792.5	2.943	5.956	**52**
54	268.79	0.001299	0.03635	1172.1	2594.4	1179.1	1611.6	2790.7	2.965	5.939	**54**
56	271.12	0.001306	0.03496	1183.6	2593.0	1190.9	1597.8	2788.8	2.986	5.922	**56**
58	273.38	0.001312	0.03366	1194.9	2591.5	1202.5	1584.2	2786.7	3.007	5.906	**58**
60	275.58	0.001319	0.03245	1206.0	2589.9	1213.9	1570.7	2784.6	3.027	5.890	**60**
62	277.73	0.001326	0.03131	1216.8	2588.3	1225.0	1557.4	2782.4	3.047	5.875	**62**
64	279.83	0.001332	0.03024	1227.4	2586.5	1235.9	1544.1	2780.1	3.067	5.859	**64**
66	281.87	0.001339	0.02923	1237.8	2584.8	1246.7	1531.0	2777.7	3.085	5.844	**66**
68	283.87	0.001345	0.02828	1248.1	2582.9	1257.2	1518.0	2775.2	3.104	5.829	**68**
70	285.83	0.001352	0.02738	1258.1	2581.0	1267.6	1505.0	2772.6	3.122	5.815	**70**
72	287.74	0.001358	0.02653	1268.0	2579.0	1277.8	1492.2	2770.0	3.140	5.800	**72**
74	289.61	0.001365	0.02572	1277.8	2577.0	1287.9	1479.4	2767.3	3.157	5.786	**74**
76	291.45	0.001371	0.02495	1287.4	2574.9	1297.8	1466.7	2764.5	3.174	5.772	**76**
78	293.25	0.001378	0.02422	1296.8	2572.7	1307.6	1454.0	2761.6	3.191	5.759	**78**
80	295.01	0.001384	0.02352	1306.1	2570.5	1317.2	1441.4	2758.7	3.208	5.745	**80**
82	296.74	0.001391	0.02286	1315.3	2568.2	1326.7	1428.9	2755.7	3.224	5.732	**82**
84	298.43	0.001398	0.02223	1324.4	2565.9	1336.2	1416.4	2752.6	3.240	5.718	**84**
86	300.10	0.001404	0.02162	1333.4	2563.5	1345.5	1404.0	2749.4	3.256	5.705	**86**
88	301.74	0.001411	0.02104	1342.2	2561.0	1354.7	1391.5	2746.2	3.271	5.692	**88**
90	303.35	0.001418	0.02049	1351.0	2558.5	1363.8	1379.2	2742.9	3.287	5.679	**90**
92	304.93	0.001425	0.01996	1359.7	2556.0	1372.8	1366.8	2739.6	3.302	5.666	**92**
94	306.48	0.001431	0.01945	1368.2	2553.3	1381.7	1354.5	2736.1	3.317	5.654	**94**
96	308.01	0.001438	0.01895	1376.7	2550.7	1390.5	1342.1	2732.6	3.331	5.641	**96**
98	309.52	0.001445	0.01848	1385.1	2548.0	1399.3	1329.8	2729.1	3.346	5.628	**98**
100	311.00	0.001452	0.01803	1393.4	2545.2	1407.9	1317.5	2725.5	3.360	5.616	**100**
105	314.60	0.001470	0.01696	1413.9	2538.0	1429.3	1286.8	2716.1	3.396	5.585	**105**
110	318.08	0.001488	0.01599	1433.9	2530.4	1450.3	1256.0	2706.3	3.430	5.554	**110**
115	321.43	0.001507	0.01509	1453.6	2522.5	1471.0	1225.1	2696.1	3.464	5.524	**115**
120	324.68	0.001526	0.01426	1473.0	2514.3	1491.3	1194.1	2685.4	3.496	5.494	**120**
125	327.81	0.001546	0.01350	1492.2	2505.6	1511.5	1162.8	2674.3	3.529	5.464	**125**
130	330.85	0.001566	0.01278	1511.1	2496.5	1531.4	1131.3	2662.7	3.561	5.434	**130**
135	333.80	0.001588	0.01211	1529.8	2487.0	1551.2	1099.3	2650.6	3.592	5.403	**135**
140	336.67	0.001610	0.01149	1548.4	2477.1	1571.0	1067.0	2637.9	3.623	5.373	**140**
145	339.45	0.001633	0.01090	1566.9	2466.7	1590.6	1034.1	2624.7	3.654	5.342	**145**
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p

Properties of Saturated Water & Steam continued:
Pressures from the triple point to the critical point

Pressure	Temp.	Specific volume		Spec. int. energy		Specific enthalpy			Specific entropy		Pressure
bar	°C	m^3/kg		kJ/kg		kJ/kg			kJ/kg K		bar
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p
150	342.16	0.001657	0.01034	1585.4	2455.7	1610.3	1000.5	2610.8	3.685	5.311	**150**
155	344.79	0.001683	0.00981	1603.9	2444.2	1630.0	966.2	2596.3	3.715	5.279	**155**
160	347.35	0.001710	0.00931	1622.5	2432.0	1649.9	931.1	2581.0	3.746	5.247	**160**
165	349.86	0.001739	0.00883	1641.2	2419.1	1669.9	894.9	2564.8	3.777	5.213	**165**
170	352.29	0.001770	0.00837	1660.2	2405.4	1690.3	857.4	2547.7	3.808	5.179	**170**
175	354.67	0.001804	0.00793	1679.4	2390.7	1711.0	818.5	2529.5	3.840	5.143	**175**
180	356.99	0.001840	0.00750	1699.1	2374.9	1732.2	777.8	2510.0	3.872	5.106	**180**
185	359.26	0.001881	0.00709	1719.3	2357.9	1754.1	734.9	2489.0	3.905	5.067	**185**
190	361.47	0.001926	0.00668	1740.3	2339.1	1776.9	689.2	2466.0	3.940	5.026	**190**
195	363.63	0.001977	0.00627	1762.3	2318.4	1800.9	639.8	2440.7	3.976	4.981	**195**
200	365.75	0.002038	0.00586	1785.9	2294.8	1826.6	585.4	2412.1	4.015	4.931	**200**
205	367.81	0.002111	0.00544	1811.7	2267.3	1855.0	523.8	2378.9	4.057	4.875	**205**
210	369.83	0.002207	0.00499	1841.6	2233.5	1888.0	450.4	2338.4	4.107	4.808	**210**
215	371.79	0.002349	0.00448	1879.5	2187.4	1930.0	353.6	2283.6	4.171	4.719	**215**
220	373.71	0.002703	0.00364	1951.6	2092.4	2011.1	161.5	2172.6	4.294	4.544	**220**
220.64	**373.95**	**0.003106**	**0.00311**	**2018.1**	**2018.1**	**2086.6**	**0.0**	**2086.6**	**4.410**	**4.410**	**220.64**
p	T	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p

SPECIFIC ENTHALPY OF WATER AND STEAM

kJ/kg

Pressure (bar)	0.1	0.5	1	5	10	20	40	60	80	100	150	200	220.64	250	300	400	500	1000
Temp (^{o}C)													Critical Isobar					
0.01	0	0.1	0.1	0.5	1	2	4.1	6.1	8.1	10.1	15.1	20.1	22.1	25	29.9	39.6	49.2	95.4
25	104.8	104.9	104.9	105.3	105.8	106.7	108.5	110.4	112.2	114.1	118.6	123.2	125.1	127.8	132.3	141.3	150.2	194.1
50	2592.0	209.4	209.4	209.8	210.2	211.1	212.8	214.5	216.2	217.9	222.2	226.5	228.3	230.8	235.1	243.6	252.0	293.9
75	2639.8	314.0	314.1	314.4	314.8	315.6	317.2	318.8	320.5	322.1	326.1	330.1	331.8	334.2	338.2	346.2	354.3	394.3
100	2687.5	2682.4	2675.8	419.5	419.8	420.6	422.1	423.6	425.1	426.6	430.4	434.2	435.7	438.0	441.7	449.3	456.9	495.1
125	2735.2	2731.5	2726.7	525.3	525.6	526.3	527.7	529.1	530.5	531.8	535.3	538.8	540.3	542.4	545.9	553.0	560.1	596.3
150	2783.0	2780.2	2776.6	632.2	632.5	633.1	634.4	635.6	636.9	638.1	641.3	644.4	645.8	647.7	650.9	657.4	664.0	697.9
175	2831.2	2828.9	2826.1	2801.4	741.1	741.6	742.7	743.7	744.8	745.9	748.6	751.4	752.6	754.2	757.1	763.0	768.9	800.2
200	2879.6	2877.8	2875.5	2855.8	2828.3	852.5	853.3	854.1	854.9	855.8	858.0	860.3	861.2	862.6	865.0	870.0	875.2	903.4
225	2928.4	2926.8	2924.9	2908.8	2887.0	2836.1	967.1	967.6	968.1	968.7	970.1	971.7	972.4	973.4	975.2	979.0	983.2	1007.6
250	2977.4	2976.1	2974.5	2961.0	2943.1	2903.2	1085.8	1085.7	1085.7	1085.8	1086.1	1086.7	1087.0	1087.4	1088.4	1090.7	1093.5	1113.1
275	3026.9	3025.8	3024.4	3012.9	2997.8	2965.2	2887.3	1210.9	1210.0	1209.3	1207.8	1206.7	1206.4	1206.0	1205.7	1205.8	1206.8	1220.2
300	3076.7	3075.8	3074.5	3064.6	3051.6	3024.2	2961.7	2885.5	2786.5	1343.3	1338.3	1334.4	1333.0	1331.3	1328.9	1325.6	1324.0	1329.1
325	3126.9	3126.1	3125.0	3116.3	3105.0	3081.5	3029.5	2969.5	2898.4	2810.3	1485.6	1475.2	1471.7	1467.3	1461.1	1452.2	1446.4	1440.3
350	3177.5	3176.8	3175.8	3168.1	3158.2	3137.7	3093.3	3043.9	2988.1	2924.0	2693.1	1646.0	1635.6	1623.9	1608.8	1588.8	1576.1	1554.0
375	3228.5	3227.9	3227.0	3220.1	3211.3	3193.2	3154.7	3112.8	3066.9	3016.3	2858.9	2602.6	2337.7	1849.4	1791.8	1742.6	1716.6	1670.8
400	3279.9	3279.3	3278.6	3272.3	3264.5	3248.3	3214.5	3178.2	3139.4	3097.4	2975.7	2816.9	2732.9	2578.6	2152.8	1931.4	1874.4	1791.1
425	3331.8	3331.2	3330.5	3324.9	3317.8	3303.3	3273.2	3241.4	3207.7	3172.0	3072.3	2953.0	2896.1	2805.0	2611.8	2199.0	2060.7	1915.7
450	3384.0	3383.5	3382.8	3377.7	3371.3	3358.2	3331.2	3302.9	3273.3	3242.3	3157.9	3061.7	3017.8	2950.6	2821.0	2511.8	2284.7	2044.7
475	3436.6	3436.2	3435.6	3430.9	3425.1	3413.2	3388.7	3363.4	3337.1	3309.7	3236.6	3155.8	3120.0	3066.2	2966.8	2740.2	2520.0	2178.5
500	3489.7	3489.3	3488.7	3484.5	3479.1	3468.2	3446.0	3423.1	3399.5	3375.1	3310.8	3241.2	3210.8	3165.9	3084.7	2906.5	2722.6	2316.2
550	3597.1	3596.8	3596.3	3592.7	3588.1	3579.0	3560.3	3541.3	3521.8	3502.0	3450.4	3396.1	3373.0	3339.2	3279.7	3154.4	3025.3	2595.9
600	3706.3	3706.0	3705.6	3702.5	3698.6	3690.7	3674.9	3658.7	3642.4	3625.8	3583.1	3539.0	3520.4	3493.5	3446.7	3350.4	3252.5	2865.1
650	3817.2	3816.9	3816.6	3813.9	3810.5	3803.8	3790.1	3776.2	3762.3	3748.1	3712.1	3675.3	3659.8	3637.7	3599.4	3521.6	3443.4	3110.5
700	3929.9	3929.7	3929.4	3927.0	3924.1	3918.2	3906.3	3894.3	3882.2	3870.0	3839.1	3807.8	3794.7	3776.0	3743.9	3679.1	3614.6	3330.7
750	4044.4	4044.2	4043.9	4041.8	4039.3	4034.1	4023.6	4013.2	4002.6	3992.0	3965.2	3938.1	3926.9	3910.9	3883.4	3828.4	3773.9	3530.5
800	4160.6	4160.4	4160.2	4158.4	4156.1	4151.5	4142.3	4133.1	4123.8	4114.5	4091.1	4067.5	4057.7	4043.8	4020.0	3972.6	3925.8	3715.3

SPECIFIC ENTROPY OF WATER AND STEAM

kJ/kg K

Pressure (bar)	0.1	0.5	1	5	10	20	40	60	80	100	150	200	220.64	250	300	400	500	1000
Temp (^{o}C)													Critical Isobar					
0.01	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0003	0.0004	0.0005	0.0006	0.0006	0.0006	0.0006	0.0004	-0.0001	-0.0009	-0.0084
25	0.3672	0.3672	0.3672	0.3671	0.3670	0.3667	0.3662	0.3657	0.3651	0.3646	0.3632	0.3619	0.3613	0.3605	0.3591	0.3561	0.3532	0.3371
50	8.1741	0.7038	0.7038	0.7036	0.7034	0.7029	0.7020	0.7010	0.7001	0.6992	0.6969	0.6946	0.6937	0.6923	0.6901	0.6855	0.6810	0.6587
75	8.3167	1.0158	1.0157	1.0155	1.0152	1.0145	1.0133	1.0120	1.0108	1.0096	1.0065	1.0035	1.0022	1.0004	0.9975	0.9916	0.9858	0.9579
100	8.4489	7.6953	7.3610	1.3069	1.3065	1.3057	1.3042	1.3026	1.3011	1.2996	1.2958	1.2920	1.2905	1.2883	1.2847	1.2775	1.2705	1.2375
125	8.5726	7.8225	7.4932	1.5813	1.5808	1.5799	1.5780	1.5762	1.5743	1.5725	1.5680	1.5635	1.5617	1.5591	1.5548	1.5464	1.5381	1.4999
150	8.6892	7.9413	7.6148	1.8418	1.8412	1.8401	1.8379	1.8357	1.8335	1.8313	1.8260	1.8208	1.8186	1.8156	1.8106	1.8008	1.7912	1.7475
175	8.7997	8.0531	7.7284	6.9427	2.0905	2.0892	2.0865	2.0839	2.0813	2.0788	2.0725	2.0664	2.0639	2.0604	2.0545	2.0431	2.0321	1.9824
200	8.9049	8.1592	7.8356	7.0610	6.6955	2.3298	2.3267	2.3235	2.3205	2.3174	2.3100	2.3027	2.2998	2.2956	2.2888	2.2755	2.2628	2.2064
225	9.0053	8.2602	7.9374	7.1702	6.8165	6.4160	2.5612	2.5573	2.5536	2.5499	2.5409	2.5322	2.5287	2.5237	2.5156	2.5000	2.4853	2.4210
250	9.1015	8.3568	8.0346	7.2724	6.9265	6.5475	2.7935	2.7886	2.7839	2.7792	2.7680	2.7573	2.7530	2.7471	2.7373	2.7187	2.7013	2.6277
275	9.1938	8.4495	8.1277	7.3692	7.0286	6.6631	6.2312	3.0222	3.0159	3.0097	2.9951	2.9814	2.9760	2.9685	2.9563	2.9336	2.9128	2.8276
300	9.2827	8.5386	8.2172	7.4614	7.1246	6.7684	6.3639	6.0703	5.7937	3.2488	3.2279	3.2091	3.2018	3.1919	3.1760	3.1473	3.1218	3.0219
325	9.3684	8.6246	8.3034	7.5497	7.2158	6.8662	6.4797	6.2137	5.9851	5.7596	3.4793	3.4495	3.4385	3.4241	3.4017	3.3634	3.3308	3.2117
350	9.4513	8.7076	8.3866	7.6346	7.3029	6.9583	6.5843	6.3357	6.1321	5.9459	5.4437	3.7290	3.7069	3.6804	3.6436	3.5871	3.5431	3.3979
375	9.5315	8.7880	8.4671	7.7164	7.3864	7.0457	6.6809	6.4441	6.2561	6.0911	5.7050	5.2275	4.7985	4.0344	3.9313	3.8290	3.7642	3.5816
400	9.6094	8.8659	8.5452	7.7955	7.4669	7.1292	6.7714	6.5432	6.3658	6.2141	5.8819	5.5525	5.4001	5.1400	4.4757	4.1145	4.0029	3.7639
425	9.6849	8.9416	8.6209	7.8722	7.5447	7.2093	6.8570	6.6352	6.4655	6.3229	6.0229	5.7514	5.6384	5.4707	5.1473	4.5044	4.2746	3.9455
450	9.7584	9.0151	8.6946	7.9465	7.6200	7.2866	6.9386	6.7219	6.5579	6.4219	6.1434	5.9043	5.8098	5.6759	5.4421	4.9448	4.5896	4.1271
475	9.8300	9.0867	8.7663	8.0188	7.6931	7.3613	7.0169	6.8041	6.6445	6.5135	6.2505	6.0324	5.9487	5.8331	5.6404	5.2556	4.9097	4.3089
500	9.8998	9.1566	8.8361	8.0892	7.7641	7.4337	7.0922	6.8826	6.7266	6.5995	6.3480	6.1446	6.0682	5.9642	5.7956	5.4744	5.1762	4.4900
550	10.0344	9.2913	8.9709	8.2249	7.9008	7.5725	7.2355	7.0307	6.8799	6.7585	6.5230	6.3389	6.2715	6.1816	6.0402	5.7857	5.5563	4.8405
600	10.1631	9.4201	9.0998	8.3543	8.0310	7.7043	7.3705	7.1693	7.0221	6.9045	6.6796	6.5075	6.4455	6.3637	6.2373	6.0170	5.8245	5.1581
650	10.2866	9.5436	9.2234	8.4784	8.1557	7.8302	7.4988	7.3001	7.1556	7.0408	6.8233	6.6593	6.6008	6.5242	6.4074	6.2078	6.0373	5.4315
700	10.4055	9.6625	9.3424	8.5977	8.2755	7.9509	7.6214	7.4246	7.2821	7.1693	6.9572	6.7990	6.7431	6.6702	6.5598	6.3740	6.2178	5.6639
750	10.5202	9.7773	9.4572	8.7128	8.3909	8.0670	7.7390	7.5438	7.4028	7.2916	7.0836	6.9297	6.8756	6.8054	6.6997	6.5236	6.3775	5.8642
800	10.6311	9.8882	9.5681	8.8240	8.5024	8.1790	7.8523	7.6582	7.5184	7.4085	7.2037	7.0531	7.0004	6.9322	6.8300	6.6612	6.5225	6.0406

DENSITY OF WATER AND STEAM

kg/m^3

Pressure (bar)	0.1	0.5	1	5	10	20	40	60	80	100	150	200	220.64	250	300	400	500	1000
Temp (^{o}C)													Critical Isobar					
0.01	999.8	999.8	999.8	1000.0	1000.3	1000.8	1001.8	1002.8	1003.8	1004.8	1007.3	1009.7	1010.7	1012.2	1014.5	1019.2	1023.8	1045.3
25	997.0	997.0	997.0	997.2	997.5	997.9	998.8	999.7	1000.6	1001.5	1003.7	1005.8	1006.7	1008.0	1010.1	1014.3	1018.4	1037.9
50	0.0673	988.0	988.0	988.2	988.4	988.9	989.7	990.6	991.5	992.3	994.4	996.5	997.4	998.6	1000.7	1004.7	1008.7	1027.4
75	0.0624	974.8	974.8	975.0	975.2	975.7	976.6	977.5	978.3	979.2	981.3	983.5	984.4	985.6	987.7	991.8	995.8	1014.6
100	0.0582	0.293	0.590	958.5	958.8	959.2	960.2	961.1	962.0	962.9	965.2	967.4	968.4	969.6	971.8	976.1	980.3	999.8
125	0.0545	0.274	0.550	939.2	939.4	939.9	940.9	941.9	942.9	943.9	946.4	948.8	949.8	951.2	953.5	958.1	962.5	983.1
150	0.0512	0.257	0.516	917.0	917.3	917.9	919.0	920.1	921.2	922.3	925.0	927.7	928.8	930.3	932.9	937.9	942.7	964.8
175	0.0484	0.243	0.487	2.503	892.4	893.0	894.3	895.6	896.8	898.1	901.1	904.1	905.4	907.1	909.9	915.5	920.9	945.0
200	0.0458	0.230	0.460	2.353	4.850	865.0	866.5	868.0	869.5	870.9	874.5	878.0	879.4	881.3	884.6	890.9	897.0	923.7
225	0.0435	0.218	0.437	2.223	4.550	9.63	835.1	836.9	838.7	840.4	844.7	848.8	850.5	852.8	856.6	864.0	870.9	901.0
250	0.0414	0.207	0.416	2.108	4.300	8.97	798.9	801.2	803.5	805.7	811.0	816.1	818.1	820.9	825.6	834.3	842.4	876.7
275	0.0395	0.198	0.396	2.006	4.070	8.43	18.31	759.1	762.2	765.1	772.2	778.7	781.3	784.8	790.6	801.4	811.1	850.8
300	0.0378	0.189	0.379	1.913	3.880	7.97	16.99	27.63	41.2	715.3	725.6	734.7	738.2	743.0	750.7	764.4	776.5	823.2
325	0.0362	0.181	0.363	1.830	3.700	7.57	15.93	25.39	36.5	50.3	664.9	679.8	685.3	692.4	703.4	722.0	737.6	793.7
350	0.0348	0.174	0.348	1.754	3.540	7.21	15.04	23.67	33.4	44.6	87.1	600.6	612.0	625.5	643.9	671.9	693.2	762.3
375	0.0334	0.167	0.335	1.684	3.390	6.90	14.28	22.27	31.0	40.7	71.9	130.3	210.0	505.5	558.2	609.3	641.2	728.8
400	0.0322	0.161	0.322	1.620	3.260	6.61	13.62	21.09	29.1	37.8	63.8	100.5	121.9	166.5	357.4	523.3	577.8	692.9
425	0.0310	0.155	0.311	1.561	3.140	6.35	13.03	20.07	27.5	35.5	58.3	87.1	101.8	126.8	188.7	394.1	497.7	654.7
450	0.0300	0.150	0.300	1.506	3.030	6.11	12.49	19.17	26.2	33.6	54.1	78.6	90.3	109.0	148.4	270.9	402.0	614.2
475	0.0290	0.145	0.290	1.454	2.920	5.90	12.01	18.37	25.0	31.9	50.8	72.4	82.4	97.8	128.1	210.0	315.2	571.7
500	0.0280	0.140	0.280	1.407	2.820	5.69	11.57	17.65	23.9	30.5	48.0	67.6	76.4	89.7	115.1	177.8	257.1	528.3
550	0.0263	0.132	0.263	1.320	2.650	5.33	10.79	16.39	22.1	28.0	43.6	60.3	67.7	78.5	98.3	143.2	195.4	444.6
600	0.0248	0.124	0.248	1.244	2.490	5.01	10.12	15.32	20.6	26.1	40.1	55.0	61.4	70.7	87.4	123.6	163.7	374.2
650	0.0235	0.117	0.235	1.176	2.360	4.73	9.53	14.40	19.4	24.4	37.3	50.8	56.5	64.8	79.4	110.5	143.7	321.0
700	0.0223	0.111	0.223	1.115	2.230	4.48	9.01	13.60	18.2	22.9	34.9	47.3	52.5	60.1	73.2	100.7	129.6	282.0
750	0.0212	0.106	0.212	1.060	2.120	4.25	8.55	12.88	17.3	21.7	32.9	44.4	49.2	56.2	68.2	93.1	118.8	253.0
800	0.020	0.101	0.202	1.010	2.020	4.05	8.14	12.25	16.4	20.6	31.1	41.9	46.4	52.8	64.0	86.8	110.2	230.6

SPECIFIC INTERNAL ENERGY OF WATER AND STEAM

kJ/kg

Pressure (bar)	0.1	0.5	1	5	10	20	40	60	80	100	150	200	220.64	250	300	400	500	1000
Temp (^{o}C)													Critical Isobar					
0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	-0.2
25	104.8	104.8	104.8	104.8	104.7	104.7	104.5	104.4	104.2	104.1	103.7	103.3	103.2	102.9	102.6	101.9	101.1	97.7
50	2443.3	209.3	209.3	209.3	209.2	209.0	208.7	208.4	208.2	207.9	207.1	206.4	206.2	205.8	205.1	203.7	202.5	196.6
75	2479.5	314.0	314.0	313.9	313.8	313.6	313.1	312.7	312.3	311.9	310.8	309.8	309.4	308.8	307.8	305.9	304.1	295.8
100	2515.5	2511.5	2506.2	418.9	418.8	418.5	417.9	417.4	416.8	416.2	414.8	413.5	412.9	412.2	410.9	408.4	405.9	395.1
125	2551.6	2548.7	2545.0	524.7	524.5	524.2	523.4	522.7	522.0	521.2	519.5	517.8	517.1	516.1	514.4	511.2	508.2	494.6
150	2587.9	2585.7	2582.9	631.6	631.4	630.9	630.0	629.1	628.2	627.3	625.1	622.9	622.0	620.8	618.7	614.8	611.0	594.3
175	2624.5	2622.8	2620.6	2601.6	740.0	739.4	738.2	737.0	735.9	734.8	732.0	729.3	728.2	726.7	724.1	719.3	714.6	694.4
200	2661.3	2660.0	2658.2	2643.3	2622.2	850.1	848.6	847.2	845.7	844.3	840.8	837.5	836.1	834.2	831.1	825.1	819.4	795.1
225	2698.5	2697.4	2695.9	2683.9	2667.3	2628.5	962.3	960.5	958.6	956.8	952.4	948.1	946.4	944.1	940.2	932.7	925.8	896.6
250	2736.1	2735.1	2733.9	2723.8	2710.4	2680.2	1080.8	1078.2	1075.8	1073.4	1067.6	1062.2	1060.0	1057.0	1052.0	1042.7	1034.2	999.1
275	2774.0	2773.2	2772.1	2763.6	2752.3	2727.8	2668.9	1203.0	1199.5	1196.2	1188.3	1181.0	1178.1	1174.2	1167.7	1155.9	1145.2	1102.7
300	2812.3	2811.6	2810.6	2803.2	2793.6	2773.2	2726.2	2668.4	2592.3	1329.4	1317.6	1307.1	1303.1	1297.6	1288.9	1273.3	1259.6	1207.6
325	2850.9	2850.3	2849.5	2843.0	2834.7	2817.2	2778.3	2733.1	2679.2	2611.6	1463.0	1445.8	1439.5	1431.2	1418.4	1396.7	1378.6	1314.3
350	2890.0	2889.4	2888.7	2883.0	2875.7	2860.5	2827.4	2790.4	2748.3	2699.6	2520.9	1612.7	1599.6	1583.9	1562.2	1529.3	1503.9	1422.8
375	2929.5	2929.0	2928.3	2923.2	2916.7	2903.3	2874.7	2843.4	2808.9	2770.7	2650.4	2449.1	2232.6	1799.9	1738.1	1677.0	1638.6	1533.6
400	2969.3	2968.9	2968.3	2963.7	2957.9	2945.9	2920.7	2893.7	2864.6	2833.1	2740.6	2617.9	2551.9	2428.5	2068.9	1854.9	1787.8	1646.8
425	3009.6	3009.2	3008.7	3004.5	2999.2	2988.5	2966.1	2942.4	2917.2	2890.4	2815.0	2723.5	2679.3	2607.8	2452.8	2097.5	1960.2	1762.9
450	3050.3	3049.9	3049.4	3045.6	3040.9	3031.1	3011.0	2989.9	2967.8	2944.5	2880.7	2807.2	2773.4	2721.2	2618.9	2364.2	2160.3	1881.9
475	3091.4	3091.0	3090.6	3087.1	3082.8	3073.9	3055.7	3036.7	3017.0	2996.5	2941.3	2879.7	2852.1	2810.5	2732.7	2549.7	2361.4	2003.6
500	3132.9	3132.6	3132.2	3129.0	3125.0	3116.9	3100.3	3083.1	3065.4	3047.0	2998.4	2945.3	2922.0	2887.3	2824.0	2681.6	2528.1	2126.9
550	3217.2	3217.0	3216.6	3213.9	3210.5	3203.6	3189.5	3175.2	3160.5	3145.4	3106.2	3064.7	3046.9	3020.8	2974.5	2875.0	2769.5	2371.0
600	3303.3	3303.1	3302.8	3300.4	3297.5	3291.5	3279.4	3267.2	3254.7	3242.0	3209.3	3175.3	3160.9	3140.0	3103.4	3026.8	2947.1	2597.9
650	3391.2	3391.0	3390.7	3388.6	3386.0	3380.8	3370.3	3359.6	3348.9	3337.9	3310.1	3281.4	3269.3	3251.9	3221.7	3159.5	3095.6	2798.9
700	3480.8	3480.6	3480.4	3478.5	3476.2	3471.6	3462.4	3453.0	3443.6	3434.0	3409.8	3385.1	3374.7	3359.9	3334.3	3282.0	3228.7	2976.1
750	3572.2	3572.0	3571.8	3570.2	3568.1	3564.0	3555.8	3547.5	3539.1	3530.7	3509.4	3487.7	3478.7	3465.8	3443.6	3398.6	3353.1	3135.2
800	3665.3	3665.2	3665.0	3663.6	3661.7	3658.0	3650.6	3643.2	3635.7	3628.2	3609.2	3590.1	3582.1	3570.7	3551.2	3511.8	3472.2	3281.7

TRANSPORT PROPERTIES OF SATURATED WATER & STEAM

Temp. °C	**Specific volume** m^3/kg		**Isobaric specific heat capacity** kJ/kg K		**Thermal conductivity** W/m K		**Dynamic viscosity** kg/s m		**Prandtl number** $= \mu c_p / \lambda$		**Temp**. °C
	v_f	v_g	c_{p_f}	c_{p_g}	λ_f	λ_g	$\mu_f / 10^{-3}$	$\mu_g / 10^{-6}$	Pr_f	Pr_g	
0.01	**0.00100**	**206.2**	**4.217**	**1.854**	**0.569**	**0.0173**	**1.755**	**8.8**	**13.02**	**0.942**	**0.01**
10	0.00100	106.4	4.193	1.860	0.587	0.0185	1.301	9.1	9.29	0.915	10
20	0.00100	57.8	4.182	1.866	0.603	0.0191	1.002	9.4	6.95	0.918	20
30	0.00100	32.9	4.179	1.885	0.618	0.0198	0.797	9.7	5.39	0.923	30
40	0.00101	19.5	4.179	1.885	0.632	0.0204	0.651	10.1	4.31	0.930	40
50	0.00101	12.05	4.181	1.899	0.643	0.0210	0.544	10.4	3.53	0.939	50
60	0.00102	7.68	4.185	1.915	0.653	0.0217	0.462	10.7	2.96	0.947	60
70	0.00102	5.05	4.190	1.936	0.662	0.0224	0.400	11.1	2.53	0.956	70
80	0.00103	3.41	4.197	1.962	0.670	0.0231	0.350	11.4	2.19	0.966	80
90	0.00104	2.36	4.205	1.992	0.676	0.0240	0.311	11.7	1.93	0.976	90
100	0.00104	1.673	4.216	2.028	0.681	0.0249	0.278	12.1	1.723	0.986	100
125	0.00107	0.770	4.254	2.147	0.687	0.0272	0.219	13.3	1.358	1.047	125
150	0.00109	0.392	4.310	2.314	0.687	0.0300	0.180	14.4	1.133	1.110	150
175	0.00112	0.217	4.389	2.542	0.679	0.0334	0.153	15.6	0.990	1.185	175
200	0.00116	0.127	4.497	2.843	0.665	0.0375	0.133	16.7	0.902	1.270	200
225	0.00120	0.0783	4.648	3.238	0.644	0.0427	0.1182	17.9	0.853	1.36	225
250	0.00125	0.0500	4.867	3.772	0.616	0.0495	0.1065	19.1	0.841	1.45	250
275	0.00132	0.0327	5.202	4.561	0.582	0.0587	0.0972	20.2	0.869	1.56	275
300	0.00140	0.0216	5.762	5.863	0.541	0.0719	0.0897	21.4	0.955	1.74	300
325	0.00153	0.0142	6.861	8.440	0.493	0.0929	0.0790	23.0	1.100	2.09	325
350	0.00174	0.00880	10.10	17.15	0.437	0.1343	0.0648	25.8	1.50	3.29	350
360	0.00190	0.00694	14.6	25.1	0.400	0.168	0.0582	27.5	2.11	3.89	360
374.15	**0.00317**	**0.00317**	**∞**	**∞**	**0.24**	**0.24**	**0.045**	**45.0**	**∞**	**∞**	**374.15**

TRANSPORT PROPERTIES OF STEAM

Temp. °C	Isobaric sp. heat capacity kJ/kg K c_p	Thermal conductivity W/m K λ	Dynamic viscosity kg/s m $\mu/10^{-6}$	Prandtl number $Pr = \mu c_p / \lambda$
100	2.028	0.0245	12.1	0.986
200	1.979	0.0331	16.2	0.968
300	2.010	0.0434	20.4	0.946
400	2.067	0.0548	24.6	0.928
500	2.132	0.0673	28.8	0.912
600	2.201	0.0805	32.9	0.898
700	2.268	0.0942	36.8	0.887
800	2.332	0.1080	40.6	0.876

Values for water at atmospheric pressure between 0°C and 100°C are given with sufficient accuracy by the saturated values in the previous table.

The above values are correct for a pressure of 1 atm = 1.01325 bar but may be used with sufficient accuracy at other pressures.

TRANSPORT PROPERTIES OF AIR

Temp. °C	Isobaric sp. heat capacity kJ/kg K c_p	Thermal conductivity W/m K λ	Dynamic viscosity kg/s m $\mu/10^{-6}$	Prandtl number $Pr = \mu c_p / \lambda$
-100	1.01	0.016	12	0.75
0	1.01	0.024	17	0.72
100	1.02	0.032	22	0.70
200	1.03	0.039	26	0.69
300	1.05	0.045	30	0.69
400	1.07	0.051	33	0.70
500	1.10	0.056	36	0.70
600	1.12	0.061	39	0.71
700	1.14	0.066	42	0.72
800	1.16	0.071	44	0.73

This table may be used with reasonable accuracy for values of c_p, γ, μ and Pr of N_2, O_2 and CO.

The above values are correct for a pressure of 1 atm = 1.01325 bar but may be used with sufficient accuracy at other pressures.

TRANSPORT PROPERTIES OF CARBON DIOXIDE

Temp. °C	Isobaric sp. heat capacity kJ/kg K c_p	Thermal conductivity W/m K λ	Dynamic viscosity kg/s m $\mu/10^{-6}$	Prandtl number $Pr = \mu c_p / \lambda$
-50	0.79	0.011	11	0.79
0	0.83	0.015	14	0.78
100	0.92	0.022	18	0.75
200	1.00	0.030	22	0.73
300	1.06	0.038	26	0.72
400	1.11	0.046	29	0.71
500	1.16	0.053	32	0.70
600	1.20	0.061	35	0.69
700	1.23	0.069	38	0.68
800	1.25	0.078	41	0.67

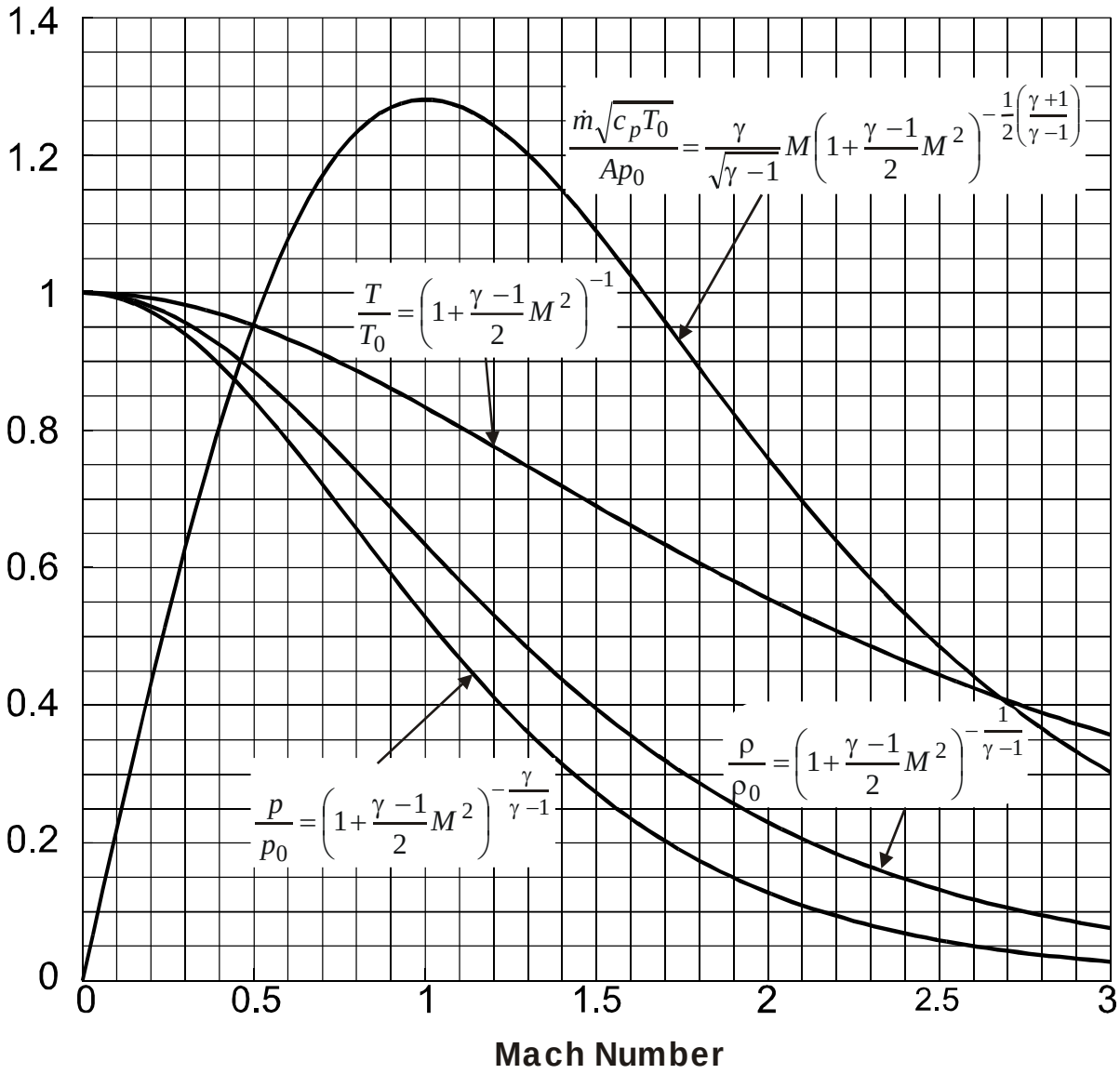
The above values are correct for a pressure of 1 atm = 1.01325 bar but may be used with sufficient accuracy at other pressures.

TRANSPORT PROPERTIES OF HYDROGEN

Temp. °C	Isobaric sp. heat capacity kJ/kg K c_p	Thermal conductivity W/m K λ	Dynamic viscosity kg/s m $\mu/10^{-6}$	Prandtl number $Pr = \mu c_p / \lambda$
-200	10.6	0.050	3.3	0.71
-100	13.1	0.112	6.2	0.72
0	14.2	0.172	8.4	0.69
100	14.5	0.220	10.3	0.68
200	14.5	0.307	12.1	0.67
300	14.5	0.307	13.8	0.66
400	14.6	0.348	15.4	0.65
500	14.7	0.387	16.9	0.64
600	14.8	0.427	18.3	0.63
700	14.9	0.476	19.9	0.62
800	15.1	0.528	21.1	0.61

The above values are correct for a pressure of 1 atm = 1.01325 bar but may be used with sufficient accuracy at other pressures.

PERFECT GAS RELATIONS FOR COMPRESSIBLE FLOW FOR γ=1.4



Notes:

(1) $T_0 = const.$ in adiabatic flow with no shaft work

(2) If flow is isentropic, $p_0 = const.$ and $\rho_0 = const.$ when $T_0 = const.$

(3) At Mach 1 and when γ=1.4, $\frac{\dot{m}\sqrt{c_p T_0}}{A p_0} = 1.281$

PROPERTIES OF GASES AT SEA LEVEL CONDITIONS

The following data are at $p_{sl} = 1.01325\,\text{bar}$ and $T_{sl} = 15\,°\text{C}$.

	Air	CO_2	H_2	*He*
Density ρ kg/m^3	1.225	1.860	0.0852	0.1693
Viscosity μ kg/m s	17.9×10^{-6}	14.4×10^{-6}	8.9×10^{-6}	19.7×10^{-6}
Kinematic viscosity υ m^2/s	14.64×10^{-6}	7.7×10^{-6}	104×10^{-6}	116×10^{-6}
Speed of sound m/s	340	264	1292	988
Thermal conductivity λ W/m K	0.0252	0.0153	0.180	0.150

PROPERTIES OF LIQUIDS AT SEA LEVEL CONDITIONS

The following data are at $p_{sl} = 1.01325\,\text{bar}$ and $T_{sl} = 15\,°\text{C}$.

	Hg	H_2O
Density ρ kg/m^3	13595.1	1000
Viscosity μ kg/m s	1.59×10^{-3}	1.14×10^{-3}
Kinematic viscosity υ m^2/s	0.117×10^{-6}	1.14×10^{-6}
Thermal conductivity λ W/m K	8.36	0.620

THE INTERNATIONAL STANDARD ATMOSPHERE

The sea-level condition for the international standard atmosphere is given by

$$p_{sl} = 1.01325\,\text{bar} = 760\,\text{mm Hg}$$

$$T_{sl} = 15\,°\text{C} = 288.15\,\text{K}$$

for which

$$\rho_{sl} = 1.225\,\text{kg/m}^3$$

$$\upsilon_{sl} = \frac{\mu_{sl}}{\rho_{sl}} = 14.64\times10^{-6}\ \text{m}^2/\text{s}$$

$$a_{sl} = \sqrt{\gamma R T_{sl}} = 340\,\text{m/s}$$

PROPERTIES OF THE INTERNATIONAL STANDARD ATMOSPHERE AT ALTITUDE

Height m	$\frac{T}{T_{sl}}$	$\frac{p}{p_{sl}}$	$\frac{\rho}{\rho_{sl}}$	$\frac{\nu}{\nu_{sl}}$
0	1.0000	1.0000	1.0000	1.0000
1000	0.9774	0.8870	0.9075	1.0826
2000	0.9549	0.7846	0.8217	1.1739
3000	0.9324	0.6920	0.7422	1.2753
4000	0.9098	0.6085	0.6689	1.3881
5000	0.8873	0.5334	0.6012	1.5138
6000	0.8648	0.4660	0.5389	1.6543
7000	0.8423	0.4057	0.4816	1.8117
8000	0.8198	0.3519	0.4292	1.9887
9000	0.7973	0.3040	0.3813	2.1881
10000	0.7748	0.2615	0.3376	2.4137
11000	0.7523	0.2240	0.2978	2.6697
12000	0.7519	0.1915	0.2546	3.1206
13000	0.7519	0.1636	0.2176	3.6514
14000	0.7519	0.1398	0.1860	4.2722
15000	0.7519	0.1195	0.1590	4.9983
16000	0.7519	0.1022	0.1359	5.8476
17000	0.7519	0.0873	0.1162	6.8408
18000	0.7519	0.0747	0.0993	8.0023
19000	0.7519	0.0638	0.0849	9.3606
20000	0.7519	0.0546	0.0726	10.9488
21000	0.7551	0.0467	0.0618	12.9031
22000	0.7585	0.0399	0.0527	15.2021
23000	0.7620	0.0342	0.0449	17.8964
24000	0.7654	0.0293	0.0383	21.0515
25000	0.7689	0.0252	0.0327	24.7434
26000	0.7723	0.0216	0.0280	29.0603
27000	0.7758	0.0186	0.0239	34.1039
28000	0.7792	0.0160	0.0205	39.9926
29000	0.7826	0.0137	0.0175	46.8626
30000	0.7861	0.0118	0.0150	54.8714

The speed of sound at altitude is given by

$$\frac{a}{a_{sl}} = \sqrt{\frac{T}{T_{sl}}}$$

The viscosity at altitude is given approximately by

$$\mu = \frac{1.458 \times 10^{-6} T^{3/2}}{T + 110.4} \text{ kg/m.s}$$

PHYSICAL CONSTANTS

Absolute zero of temperature	-273.15°C
Acceleration due to gravity, g	9. 80665 m/s^2
Avogadro's number, N_A	6.022×10^{26} $kmol^{-1}$
Base of natural logarithms, e	2.7182818
Boltzmann's constant, k	1.381×10^{-23} J/K
Electronic charge, e	-1.602×10^{-19} C
Faraday's constant, F	9.648×10^{7} C/kmol
Universal Gas constant, $\overline{R}$	8.3143 kJ/kmol K
Permeability of vacuum, μ_o	1.257×10^{-6} H/m
Permittivity of vacuum, ε_o	8.854×10^{-12} F/m
Pi, π	3.14159265
Planck's constant, h	6.626×10^{-34} Js
Stefan-Boltzmann's constant, σ	5.67×10^{-8} W/m^2K^4
Velocity of light in vacuum, c	2.998×10^{8} m/s
Volume of perfect gas at STP	22.41 $m^3/kmol$

CONVERSION OF NON-SI TO SI UNITS

Non SI Unit		Conversion			SI Unit
Length					
1 yard (yd)			=	0.9144	m
1 foot (ft)	=	0.9144/3.0	≈	0.3048	m
1 inch (in)	=	0.9144/36.0	≈	0.0254	m
1 mile (mile)	=	0.9144×1760	≈	1609	m
Mass					
1 pound (lb)			=	0.45359237	kg
1 ounce (oz)	=	$0.45359237/16$	≈	0.02835	kg
1 hundredweight (cwt)	=	0.45359237×112	≈	50.8	kg
1 tonne (t)	=		=	1000	kg
1 ton (ton)	=	0.45359237×2240	≈	1016	kg
Force					
1 dyne (dyn)			=	10^{-5}	N
1 ounce (ozf)	=	$0.45359237 \times 9.80665/16$	≈	0.278	N
1 pound force (lbf)	=	$0.45359237 \times 9.80665$	≈	4.45	N
1 ton force (tonf)	=	$0.45359237 \times 9.80665 \times 2240$	≈	9960	N
Volume					
1 Imperial gallon (gal)			=	0.0045460916	m^3
1 pint (pt)	=	0.0045460916/8	≈	0.0005683	m^3
1 litre (l)			=	0.001	m^3
Dynamic Viscosity					
1 poise (P)			=	0.1	Ns/m^2

CONVERSION OF NON-SI TO SI UNITS cont.

Non SI Unit		Conversion			SI Unit
Kinematic Viscosity					
1 stokes (St)			=	10^{-4}	m^2/s
Energy					
1 erg			=	10^{-7}	J
1 calorie (cal)			=	4.1868	J
1 Cal (kcal)			=	4186.8	J
1 Btu	=	$4.1868 \times 0.45359237 / 1.8$	≈	1055	J
Power					
1 horsepower (hp)	=	$550 \times \left(\frac{0.9144}{3}\right) \times 0.45359237 \times 9.80665$	≈	746	W
Pressure					
1 dyn/cm^2			=	0.1	Pa
1 N/m^2			=	1	Pa
1 mm H_2O	=	$1000 \times 0.001 \times 9.80665$	=	9.80665	Pa
1 mm Hg	=	$13595.1 \times 0.001 \times 9.80665$	=	133.32	Pa
1 torr	=	$101325/760$	=	133.32	Pa
1 in Hg	=	$13595.1 \times 9.80665 \times \frac{0.9144}{36}$	=	3386	Pa
1 lb/in^2	=	$0.45359237 \times 9.80665 \times \left(\frac{36}{0.9144}\right)^2$	=	6895	Pa
1 bar			=	100000	Pa
1 atm			=	101325	Pa
1 kgf/mm^2	=	$1 \times 9.80665 \times 1000000$	=	9806650	Pa

SOURCES OF INFORMATION

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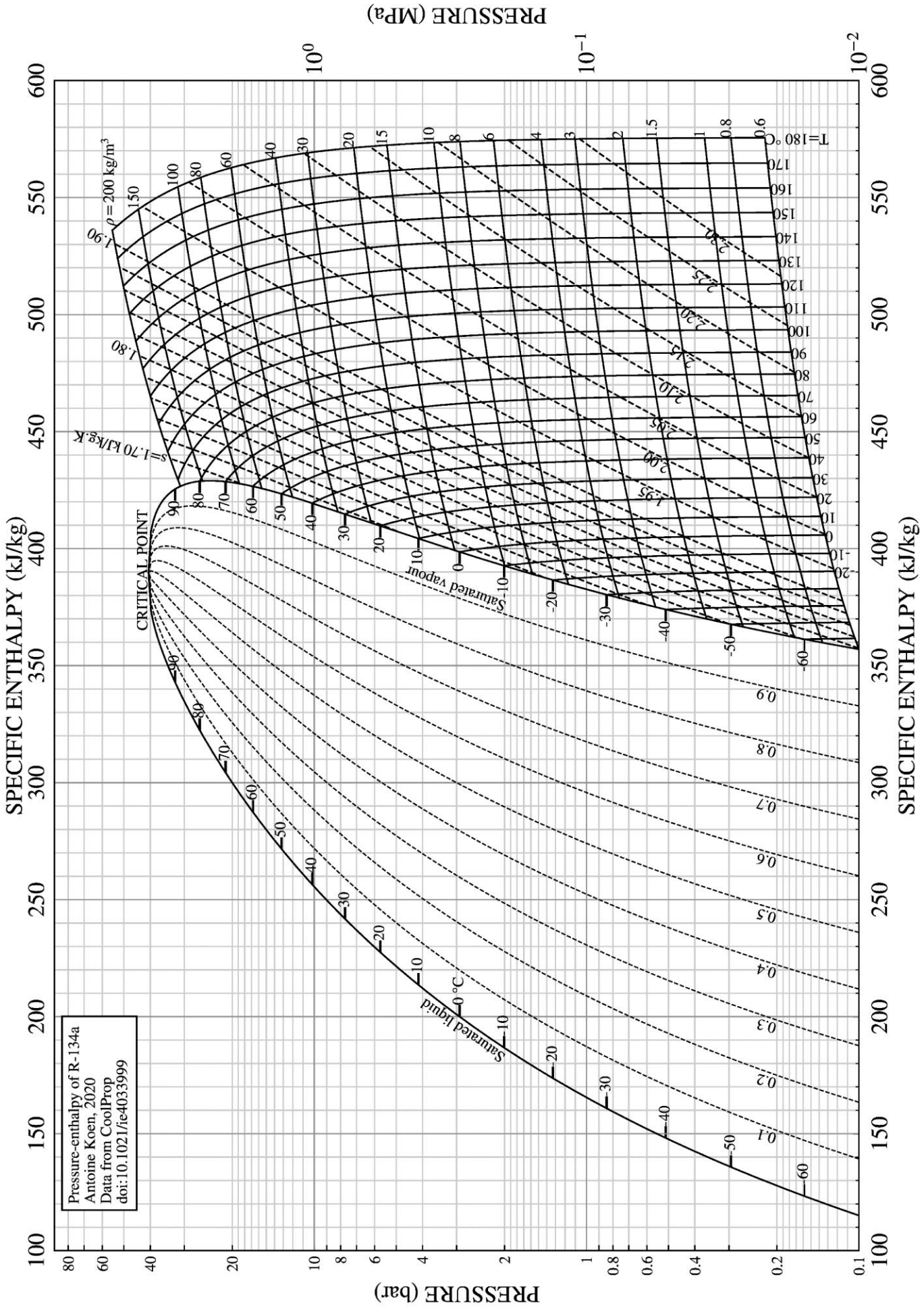
The Pressure-Enthalpy chart for the refrigerant R-134a produced by Antoine Koen, 2020. Data from CoolProp. doi:10.1021/ie4033999

CRITICAL POINT DATA FOR REFRIGERANT R-134a (CH_2FCF_3)

Critical Temperature =	101.08 ^oC
Critical Pressure =	40.603 bar
Critical Volume =	0.0019 m^3/kg
Molecular Weight =	102.03 kg/kMol

PROPERTIES TABLE FOR REFRIGERANT R-134a (CH_2FCF_3)

Saturation Temp. ^oC	Saturation Pressure bar	Saturated						Superheated by				Saturation Temp.
		Specific volume m^3/kg		Specific enthalpy kJ/kg		Specific entropy kJ/kg K		20K		40K		
								kJ/kg	kJ/kg K	kJ/kg	kJ/kg K	^oC
T_{sat}	P_{sat}	v_f	v_g	h_f	h_g	s_f	s_g	h	s	h	s	T_{sat}
-45	0.39	0.00070	0.46458	141.9	370.8	0.7687	1.7722	385.8	1.8348	401.3	1.8949	**-45**
-40	0.51	0.00071	0.36094	148.1	374.0	0.7956	1.7643	389.2	1.8270	405.0	1.8869	**-40**
-35	0.66	0.00071	0.28390	154.4	377.2	0.8221	1.7574	392.7	1.8201	408.6	1.8797	**-35**
-30	0.84	0.00072	0.22585	160.8	380.3	0.8483	1.7512	396.1	1.8139	412.3	1.8734	**-30**
-25	1.06	0.00073	0.18155	167.2	383.4	0.8743	1.7458	399.5	1.8085	416.0	1.8678	**-25**
-20	1.33	0.00074	0.14735	173.6	386.5	0.8999	1.7410	402.9	1.8037	419.7	1.8629	**-20**
-15	1.64	0.00074	0.12065	180.1	389.6	0.9253	1.7368	406.3	1.7995	423.4	1.8587	**-15**
-10	2.01	0.00075	0.09959	186.7	392.7	0.9505	1.7331	409.7	1.7959	427.0	1.8550	**-10**
-5	2.43	0.00076	0.08281	193.3	395.6	0.9753	1.7299	413.1	1.7927	430.7	1.8518	**-5**
0	2.93	0.00077	0.06933	**200.0**	398.6	**1.0000**	1.7270	416.4	1.7900	434.3	1.8491	**0**
5	3.50	0.00078	0.05840	206.8	401.5	1.0244	1.7245	419.7	1.7877	437.9	1.8469	**5**
10	4.15	0.00079	0.04947	213.6	404.3	1.0486	1.7222	422.9	1.7857	441.5	1.8450	**10**
15	4.88	0.00080	0.04212	220.5	407.1	1.0726	1.7202	426.1	1.7840	445.0	1.8434	**15**
20	5.72	0.00082	0.03602	227.5	409.8	1.0965	1.7183	429.3	1.7825	448.5	1.8422	**20**
25	6.65	0.00083	0.03093	234.6	412.3	1.1202	1.7165	432.3	1.7813	452.0	1.8412	**25**
30	7.70	0.00084	0.02666	241.7	414.8	1.1438	1.7148	435.4	1.7803	455.4	1.8405	**30**
35	8.87	0.00086	0.02305	249.0	417.2	1.1672	1.7130	438.3	1.7794	458.8	1.8399	**35**
40	10.17	0.00087	0.01999	256.4	419.4	1.1906	1.7112	441.2	1.7786	462.1	1.8395	**40**
45	11.60	0.00089	0.01736	263.9	421.5	1.2140	1.7093	444.0	1.7779	465.4	1.8393	**45**
50	13.18	0.00091	0.01511	271.6	423.4	1.2374	1.7073	446.7	1.7772	468.6	1.8392	**50**
60	16.82	0.00095	0.01148	287.5	426.6	1.2846	1.7022	451.8	1.7759	474.8	1.8392	**60**
70	21.16	0.00101	0.00871	304.3	428.6	1.3329	1.6953	456.4	1.7743	480.7	1.8394	**70**
80	26.33	0.00108	0.00654	322.4	428.8	1.3834	1.6848	460.4	1.7722	486.2	1.8395	**80**
90	32.45	0.00119	0.00481	342.9	425.4	1.4393	1.6665	463.8	1.7692	491.3	1.8392	**90**
100	39.73	0.00148	0.00345	373.3	407.7	1.5183	1.6105	466.4	1.7650	495.9	1.8384	**100**


SPECIFIC ENTHALPY (kJ/kg)
PRESSURE (bar)
PRESSURE (MPa)
CRITICAL POINT
Saturated liquid
Saturated vapour
Pressure-enthalpy of R-134a
Antoine Koen, 2020
Data from CoolProp
doi:10.1021/ie4033999

Enthalpy-Entropy Diagram for Steam

Plotted from the IAPWS equations http://www.iapws.org (Duncan A. Simpson (2002))