Appendix I: IAPWS Releases and Guidelines

Edited by
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INTRODUCTION

The International Association for the Properties of Water and Steam[1] (IAPWS) prepares and promulgates two primary series of documents: Releases and Guidelines. The purpose and definition of these documents are contained in the Statues and By-Laws of the IAPWS which were revised and issued in Orlando in September 1994.

Section 2.2 of the Statutes states:

> "The Association shall prepare and cause to be published and promulgated in various ways in printed or electronic format internationally agreed-upon, critically evaluated representations of thermophysical property data for use by scientists and engineers the world over." It further states:
>
> "These formats may include, but not necessarily be limited to, Releases, Supplementary Releases, Guidelines, and the Proceedings of International Conferences."

The Statutes define the above formats as follows:

> "Releases provide carefully evaluated, internationally agreed-upon data and formulations of properties for which measurements of high quality exist over a wide range of states. The quality of formulations shall represent the best available at the time of adoption. The releases are intended to provide a basis for technical and scientific calculations over an extended period of time."
>
> "Guidelines are carefully evaluated internationally agreed-upon data and formulations of properties for which measurements of high quality over a wide range of states do not exist or cannot be made. The quality of these data and formulations shall be as high as the quality of the database will allow; however, it is accepted that these documents can be expected to need revision as new measurements are made or new equations become available."

These documents are known and used by the electric power industry throughout the world, and are increasingly being found useful by scientists and engineers in other fields. All of these

[1] The International Association for the Properties of Water and Steam, IAPWS, formerly was known as the International Association for the Properties of Steam, IAPS.

documents are available free of charge from the Executive Secretary and unrestricted publication is allowed in all countries, however, this supposes that the requestor knows what is available.

To make the list of these documents and the documents themselves more readily available, it was considered appropriate to publish all current documents in these proceedings of this conference. Accordingly, this Appendix contains the text of all Releases and Guidelines which have been issued by the IAPWS up to its 12th International Conference held in Orlando in September of 1994. One exception is the 1967 IFC Formulation for Industrial Use. It is the oldest Release and is rather large and readily available from other sources. It can be found for example in "ASME Steam Tables. Thermodynamic and Transport Properties of Steam", Sixth Edition, (1993) published by The American Society of Mechanical Engineers, 345 East 47th St., New York, NY. 10017. That volume contains both 'The 1967 IFC Formulation for Industrial Use' and 'The 1963 International Skeleton Tables'. The latter is superseded by the 'IAPS skeleton tables 1985 for the thermodynamic properties of ordinary water substance' released in 1985 and revised in 1994. The above volume is accompanied by floppy disks containing an operating properties calculation program. An additional source of the 1967 Formulation is: "Properties of Water and Steam in SI-Units." - "Zustandsgrößen von Wasser und Wasserdampf in SI-Einheiten", prepared by Ernst Schmidt and edited by Ulrich Grigull (1989) and published by Springer-Verlag, Berlin, BRD. A similar version is available in Japanese entitled "1980 SI JSME Steam Tables." This is available from the Japan Society of Mechanical Engineers.

The preparation of releases and guidelines is an on-going process. An updated listing of releases and guidelines will be provided in the proceedings of future International Conferences on the Properties of Water and Steam. Copies of the Releases and Guidelines and further information on the status of the documents is available from the current Executive Secretary of IAPWS:

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CONTENTS

The contents of this appendix, namely, Releases and Guidelines issued up to September 1994 are listed below. The releases are given in inverse order of the date released, i.e date of issue, most-recent first.

IAPWS Releases

IAPWS Supplementary Releases

IAPWS Guidelines

Release on the Refractive Index of Ordinary Water and Steam as a Function of Wavelength, Temperature and Pressure

Issued by the International Association for the Properties of Water and Steam

President: Dr. Johanna M.H. Levelt Sengers
Thermophysics Division
National Institute of Standards and Technology
Gaithersburg, MD 20899, U.S.A.

Tokyo, Japan
September 1991

This release has been authorized by the International Association for the Properties of Water and Steam (IAPWS) at its meeting in Tokyo, Japan, Sept. 15 - 20, 1991, for issue by its Secretariat. The members of IAPWS are Canada, the Czechoslovak Socialist Republic, the Federal Republic of Germany, France, Japan, the Union of Soviet Socialist Republics, the United Kingdom, and the United States of America.

Details about the formulation, the data sources and their evaluation are given in the paper "Refractive Index of Water and Steam as function of Wavelength, Temperature and Density", by P. Schiebener, J. Straub, J.M.H. Levelt Sengers and J.S. Gallagher, *J. Phys. Chem. Ref. Data*, 19, 677-715, 1990.

This release supersedes any previous release on this topic.

The Refractive Index of Ordinary Water and Steam

as a Function of Wavelength, Temperature and Pressure

Nomenclature

T denotes absolute temperature on the International Practical Temperature Scale of 1968;

t denotes Celsius temperature

ρ denotes density. If the density is to be calculated from pressure and temperature, the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General use should to be employed.

n denotes refractive index with respect to vacuum.

λ denotes wavelength.

Reference Constants

Reference temperature:

$T^* = 273.15$ K

Reference density:

$\rho^* = 1000$ kg·m^{-3}

Reference wavelength

$\lambda^* = 0.589$ μm

Dimensionless variables

Temperature: $\overline{T} = T/T^*$

Density: $\overline{\rho} = \rho/\rho^*$

Wavelength $\overline{\lambda} = \lambda/\lambda^*$

Range of validity of the formulation

IAPWS endorses the validity of Eq.(1) for the refractive index in the following range:

Temperature $0 < t < 500^{\circ}$C

density $0 < \rho < 1060$ kg·m^{-3}

wavelength $0.2 < \lambda < 1.1$ μm

Formulation

The refractive index n is represented by the following equation:

$$\left[\frac{n^2 - 1}{n^2 + 2}\right]\frac{1}{\bar{\rho}} = a_0 + a_1\,\bar{\rho} + a_2\,\bar{T} + a_3\,\bar{\lambda}^2\,\bar{T} + a_4 / \bar{\lambda}^2 + \frac{a_5}{\bar{\lambda}^2 - \bar{\lambda}_{UV}^2} + \frac{a_6}{\bar{\lambda}^2 - \bar{\lambda}_{IR}^2} + a_7\,\bar{\rho}^2 \qquad (1)$$

The coefficients a_0 to a_7, and the constants $\bar{\lambda}_{UV}$ and $\bar{\lambda}_{IR}$ are given in Table 1.

Table 1. Coefficients of the formulation, Eq. (1)

$a_0 = +\ 0.243905091$	$\bar{\lambda}_{UV} = 0.2292020$
$a_1 = +\ 9.53518094 \cdot 10^{-3}$	$\bar{\lambda}_{IR} = 5.432937$
$a_2 = -\ 3.64358110 \cdot 10^{-3}$	
$a_3 = +\ 2.65666426 \cdot 10^{-4}$	
$a_4 = +\ 1.59189325 \cdot 10^{-3}$	
$a_5 = +\ 2.45733798 \cdot 10^{-3}$	
$a_6 = +\ 0.897478251$	
$a_7 = -\ 1.63066183 \cdot 10^{-2}$	

Remark

The data sources and their evaluation are given in the supporting document, by P.Schiebener, J. Straub, J.M.H. Levelt Sengers and J.S.Gallagher, J. Phys. Chem. Ref. Data, 19, 677–715, (1990); see also Erratum, J. Phys. Chem. Ref. Data 19, 1617, (1990).

Uncertainty

The estimated uncertainty of the representation of the refractive index, in the absence of error in the independent variables, is given in Table 2. Note that above 225°C, there are no data supporting the estimate.

Table 2. Estimated Uncertainty of the Formulation

Wavelength μm	Temperature range, °C	Pressure range, MPa	Phase	Est. uncert. in n absolute
visible	–12 to 5	ambient	liquid	$12 \cdot 10^{-5}$
visible	5 to 60	ambient	liquid	$15 \cdot 10^{-6}$
visible	60 to 100	ambient	liquid	$(1 \text{ to } 3) \cdot 10^{-4}$
visible	0 to 60	up to 150	liquid	$2 \cdot 10^{-4}$
visible	100 to 225	0 to 2	vapor	$5 \cdot 10^{-6}$
IR to 1.1	ambient	ambient	liquid	$1 \cdot 10^{-3}$
UV to 0.21	0 to 100	ambient	liquid	$5 \cdot 10^{-4}$
In the following ranges there are no supporting data				
visible	0 to 374	0 to 0.1 P_{sat}	vapor	$5 \cdot 10^{-6}$
visible	225 to 374	0.1 P_{sat} to P_{sat}	vapor	$1 \cdot 10^{-4}$
visible	60 to 374	P_{sat} to 200	liquid	$1 \cdot 10^{-3}$
visible	>374	up to pressure at $1/3\ \rho_c$	low–density	$1 \cdot 10^{-5}$
visible	>374	beyond pressure at ρ_c	high–density	$2 \cdot 10^{-3}$

P_{sat} is the saturation pressure, and ρ_c the critical density

Tabulation

Table 3 contains refractive index values calculated from the formulation Eq. (1). If the densities are calculated from the IAPS 1984 formulation to one part in 10^6, and the coefficients in Table 2 are carried to the number of significant digits stated, the formulation should reproduce the figures listed in Table 3 to within one unit of the least significant digit.

Table 3. Refractive index values from the formulation

Wavelength	T	Pressure MPa			
μm	°C	0.1	1.0	10.0	100.0
0.22650	0.0	1.394498	1.394682	1.396504	1.412766
	100.0	1.0002167	1.375639	1.377308	1.391997
	200.0	1.0001683	1.0017758	1.338327	1.359343
	500.0	1.0001008	1.0010156	1.0109996	1.198280
0.58900	0.0	1.334325	1.334475	1.335956	1.349139
	100.0	1.0001875	1.318744	1.320107	1.332079
	200.0	1.0001456	1.0015362	1.287917	1.305209
	500.0	1.0000871	1.0008774	1.0095017	1.170203
1.01398	0.0	1.326119	1.326264	1.327700	1.340476
	100.0	1.0001836	1.311276	1.312600	1.324225
	200.0	1.0001426	1.0015053	1.281550	1.298384
	500.0	1.0000856	1.0008619	1.0093339	1.167084

Temperature Scale

This formulation was completed before the publication of the temperature scale ITS90 and also employs densities taken from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General use. The values of refractive index obtained from this formulation are for temperatures on the scale IPTS68.

Release on the Pressure along the Melting and the Sublimation Curves of Ordinary Water Substance

Issued by the International Association for the Properties of Water and Steam

President: J. R. Cooper
Queen Mary and Westfield College
London E1 4NS England

Milan, Italy, September 1993

Revision of the 1989 Release

This release has been authorized by the International Association for the Properties of Water and Steam (IAPWS) at its meeting in Milan, Italy, 12 - 18 September 1993, for issue by its Secretariat. The members of IAPWS are: Canada, Czech Republic, Denmark, the Federal Republic of Germany, France, Japan, Russia, the United Kingdom, and the United States of America, and the associate members are: Argentina and Italy.

IAPWS issued in 1989 a Release on the Pressure along the Melting and Sublimation Curves of Ordinary Water Substance based on the IPTS-68 temperature scale. This revised release has been prepared with the temperatures of the triple points and the coefficients in the correlation equations changed to correspond to the ITS-90. To obtain the values for the new coefficients, the equations have been refitted using the same input data but with temperatures converted to ITS-90.

Compared with the IPTS-68 temperatures in the original release, one more decimal place is given here to the converted ITS-90 temperatures. This ensures that any recalculation to the original IPTS-68 temperature values produces the same figures as given in the original source after rounding to the same number of decimal places. This increase by one decimal in the converted ITS-90 temperatures does not imply that these values have been redetermined or are more accurate than previously stated on IPTS-68. In the second revision, Equation (6) has been replaced by a simpler equation which better represents the derivatives of the sublimation pressure. Moreover, the parameter in Equation (4) has been adjusted for a better representation of the ice VI - ice VII - liquid triple point.

Further details about the equations presented in this release can be found in an article "International Equations for the Pressure along the Melting and the Sublimation Curves of Ordinary Water Substance" by W. Wagner, A. Saul, and A. Pruß, published in the Journal of Physical and Chemical Reference Data.

Equations for the Pressure along the Melting and the Sublimation Curves of Ordinary Water Substance

1 Nomenclature

Thermodynamic quantities:

p = Pressure
T = Temperature
θ = T/T_n
π = p_m/p_n

Subscripts:

m	Denotes a value on the melting curve
n	Denotes a quantity used to obtain a dimensionless variable
subl	Denotes a value on the sublimation curve
t	Denotes a value at a triple point

Note: T denotes absolute Temperature on the International Temperature Scale of 1990.

2 Melting Pressure

2.1 Melting pressure of ice I (temperature range from 273.16 to 251.165 K)

$$\pi = 1 - 0.626000 \times 10^6 (1 - \theta^{-3}) + 0.197135 \times 10^6 (1 - \theta^{21.2}) \quad (1)$$

with $T_n = 273.16$ K and $p_n = 0.000611657$ MPa.

2.2 Melting pressure of ice III (temperature range from 251.165 to 256.164 K)

$$\pi = 1 - 0.295252 (1 - \theta^{60}) \quad (2)$$

with $T_n = 251.165$ K and $p_n = 209.9$ MPa.

2.3 Melting pressure of ice V (temperature range from 256.164 to 273.31 K)

$$\pi = 1 - 1.18721 (1 - \theta^{8}) \quad (3)$$

with $T_n = 256.164$ K and $p_n = 350.1$ MPa.

2.4 Melting pressure of ice VI (temperature range from 273.31 to 355 K)

$$\pi = 1 - 1.07476 (1 - \theta^{4.6}) \quad (4)$$

with $T_n = 273.31$ K and $p_n = 632.4$ MPa.

2.5 Melting pressure of ice VII (temperature range from 355 to 715 K)

$$\ln(\pi) = 0.173683 \times 10^{1} (1 - \theta^{-1}) - 0.544606 \times 10^{-1} (1 - \theta^{5}) + 0.806106 \times 10^{-7} (1 - \theta^{22}) \quad (5)$$

with $T_n = 355$ K and $p_n = 2216$ MPa.

Note: The upper temperature of the range of Eq. (5) corresponds to the highest temperature for which measurements exist and not the end of the melting curve of ice VII.

Eqs. (1) to (5) are constrained to fit the experimental values T_t and p_t of the relevant triple points given in Table 1.

Table 1: Values for the triple points of the solid phases which coexist with the liquid.

Coexisting phases	T_t / K	p_t / MPa
ice I - ice III – liquid	251.165	209.9
ice III - ice V – liquid	256.164	350.1
ice V - ice VI – liquid	273.31	632.4
ice VI - ice VII – liquid	355	2216

3 Sublimation pressure

$$\ln\left[\frac{p_{subl}}{p_n}\right] = a_1\left(1 - \theta^{-1.5}\right) + a_2\left(1 - \theta^{-1.25}\right) \quad (6)$$

with $a_1 = -13.9281690$ $\quad T_n = 273.16$ K $= T_t$

$a_2 = 34.7078238$ $\quad p_n = 611.657$ Pa $= p_t$

Note: Eq. (6) is valid from 190 to 273.16 K.

4 Range of validity of the equations

IAPWS endorses the validity of the equations presented in this release for each of the saturation lines. Eqs. (1) to (4) are valid for the entire range of the solid-liquid equilibrium. Eqs. (5) to (6) only cover the ranges of the solid-liquid or solid-vapor equilibrium, respectively, as indicated.

5 Estimates of uncertainty

The estimated uncertainties of the melting and sublimation pressures calculated from Eqs. (1) to (6) are listed in Table 2. Based on the relatively high uncertainties of the experimental melting pressures, the derivatives of Eqs. (1) to (5) could be subjected to larger errors.

Table 2: Estimated uncertainties of the calculated pressures.

Equation	Equilibrium	Percentage uncertainty
(1)	ice I – liquid	$\leq \pm 3$
(2)	ice III – liquid	$\leq \pm 3$
(3)	ice V – liquid	$\leq \pm 3$
(4)	ice VI – liquid	$\leq \pm 3$
(5)	ice VII – liquid	$\leq \pm 7$
(6)	ice I – gas	$T < 250$ K: $\leq \pm 0.5$ $T \geq 250$ K: $\leq \pm 0.1$

6 Computer-program verification

To assist the user in computer-program verification, Table 3 lists values for the pressures calculated from each of the six equations at one temperature within the range of validity.

Table 3. Pressures calculated from Eqs. (1) to (6) at the selected temperatures.

Equation	Equilibrium	T/K	p/MPa
(1)	ice I – liquid	260.0	139.382
(2)	ice III – liquid	254.0	269.456
(3)	ice V – liquid	265.0	479.640
(4)	ice VI – liquid	320.0	1356.76
(5)	ice VII – liquid	550.0	6308.71
(6)	ice I – gas	230.0	0.0000089465

IAPWS Release on the Skeleton Tables 1985 for the Thermodynamic Properties of Ordinary Water Substance

Issued by the International Association for the Properties of Water and Steam

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London E1 4NS, England

(September 1994)

(Revision of the Release of 1985)

IAPWS issued a Release on the IAPS Skeleton Tables 1985 for the Thermodynamic Properties of Ordinary Water Substance based on the International Practical Temperature Scale of 1968 (IPTS-68) in 1985. This revised release has been prepared only to provide the values corresponding to the International Temperature Scale of 1990 (ITS-90).

This release is issued by the International Association for the Properties of Water and Steam (IAPWS) on the authority of the Executive Committee meeting in Orlando, FL, USA, 11-16 September 1994. The members of IAPWS are Argentina, Canada, Czech Republic, Denmark, France, Germany, Japan, Russia, the United Kingdom and the United States of America, and associate member is Italy.

IAPWS issued a *Release on the IAPS Skeleton Tables 1985 for the Thermodynamic Properties of Ordinary Water Substance* based on the International Practical Temperature Scale of 1968 in 1985. The current revised release has been prepared to provide the values corresponding to the International Temperature Scale of 1990 (ITS-90).

The most probable specific volume and specific enthalpy values given in Tables 1 and 2 were simply converted from the previous values based on the equation given in TABLE 1.6 of the report 'Supplementary Information for the ITS-90' prepared by the Comité Consultatif de Thermométrie and published by the Comité International des Poids et Mesures.

The revised values at the saturation conditions given in Table 3 were calculated using the equations given in *IAPWS Supplementary Release on Saturation Properties of Ordinary Water Substance* issued in September 1992.

The critical point temperature has been given as a ITS-90 value. Details of this are given in the following document: *IAPWS Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points*, issued in September 1992.

The tolerances were not changed in this revision.

Part I of this release contains two Skeleton Tables of Thermodynamic Properties of Single-fluid Phase of Ordinary Water Substance. Table 1 gives the most probable specific volume values with their associated tolerances for the range of thermodynamic temperatures 273.15 K - 1073.15 K and pressures up to 1 GPa. Table 2 gives the most probable specific enthalpy values with their associated tolerances for the same range of temperatures and pressures.

Part II of this release contains Skeleton Tables of Thermodynamic Properties along the Saturation Curve of Ordinary Water Substance. Table 3 gives the most probable thermodynamic property values with their associated tolerances for the coexisting vapour-liquid phase between the triple point and the critical point.

Details about the original release can be found in an article "New International Skeleton Tables for the Thermodynamic Properties of Ordinary Water Substance" by H. Sato, M. Uematsu, K. Watanabe, A. Saul, and W. Wagner in the Journal of Physical and Chemical Reference Data, Vol. 17, No. 4, pp. 1439-1540 (1988).

Part I: Skeleton Tables 1985 of Thermodynamic Properties of Single-fluid Phase of Ordinary Water Substance.

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
0.101325	1.00016[a]	1.00296	1.01212	1.02581	1673.5	1793.0	1910.9	2027.9	2143.9	2374.6	2604.4	2833.4
	±0.00001[b]	0.00001	0.00001	0.00002	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.4
				(liquid)	(gas)							
0.5	0.99995	1.00278	1.01194	1.02561	1.04326	1.06477	1.09049	399.32	424.84	474.29	522.53	570.07
	0.00006	0.00006	0.00006	0.00006	0.00006	0.00007	0.00009	0.32	0.32	0.32	0.32	0.34
1.0	0.99969	1.00256	1.01171	1.02537	1.04301	1.06446	1.09014	1.12062	205.87	232.59	257.86	282.40
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00011	0.00014	0.00017	0.21	0.20	0.20	0.20
2.5	0.99893	1.00188	1.01104	1.02467	1.04224	1.06361	1.08914	1.11939	1.15558	86.96	98.85	109.70
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00013	0.00014	0.00018	0.00025	0.09	0.09	0.09
5.0	0.99767	1.00076	1.00993	1.02351	1.04098	1.06218	1.08748	1.11739	1.15302	1.24970	45.30	51.92
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00015	0.00017	0.00020	0.00028	0.00031	0.07	0.08
7.5	0.99642	0.99965	1.00883	1.02237	1.03974	1.06078	1.08584	1.11542	1.15056	1.24530	26.72	32.41
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00029	0.00032	0.00037	0.04	0.05
10.0	0.99518	0.99855	1.00775	1.02123	1.03850	1.05938	1.08421	1.11347	1.14816	1.2410	1.3977	22.42
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00030	0.00034	0.0004	0.0006	0.04
12.5	0.99396	0.99745	1.00667	1.02011	1.03726	1.05801	1.08259	1.11157	1.1458	1.2368	1.3874	16.12
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00031	0.0004	0.0004	0.0006	0.04
15.0	0.99274	0.99636	1.00560	1.01899	1.03605	1.05665	1.08101	1.10969	1.1435	1.2328	1.3778	11.475
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00033	0.0004	0.0005	0.0006	0.034
17.5	0.99153	0.99527	1.00453	1.01788	1.03484	1.05529	1.07944	1.10785	1.1412	1.2289	1.3688	1.7150
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00033	0.0004	0.0005	0.0006	0.0017
20.0	0.99032	0.99420	1.00347	1.01678	1.03364	1.05396	1.07790	1.10602	1.1390	1.2251	1.3605	1.6654
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00033	0.0004	0.0005	0.0006	0.0016
22.5	0.98914	0.99313	1.00243	1.01570	1.03247	1.05264	1.07639	1.10418	1.1368	1.2215	1.3529	1.6290
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00033	0.0004	0.0005	0.0006	0.0016
25.0	0.98796	0.99205	1.00140	1.01462	1.03130	1.05133	1.07489	1.10235	1.1346	1.2179	1.3454	1.5986
	0.00010	0.00010	0.00010	0.00010	0.00010	0.00016	0.00021	0.00033	0.0004	0.0005	0.0006	0.0014
27.5	0.98678	0.99100	1.00036	1.01354	1.03014	1.05003	1.07340	1.10059	1.1324	1.2144	1.3384	1.5736
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00016	0.00024	0.00033	0.0004	0.0005	0.0007	0.0013
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

a This entry is for the metastable-state liquid.

b Except for this entry, the sign (±) of the tolerance is omitted.

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
30	0.98562	0.98995	0.99933	1.01247	1.02899	1.04875	1.07193	1.09884	1.1303	1.2111	1.3317	1.5524
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00016	0.00024	0.00033	0.0004	0.0005	0.0007	0.0012
35	0.98333	0.98789	0.99730	1.01037	1.02672	1.04623	1.06903	1.09544	1.1262	1.2046	1.3193	1.5170
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00024	0.00033	0.0004	0.0005	0.0007	0.0012
40	0.98108	0.98586	0.99529	1.00829	1.02448	1.04374	1.06619	1.09214	1.1222	1.1983	1.3079	1.4880
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00024	0.00033	0.0004	0.0005	0.0007	0.0012
45	0.97886	0.98385	0.99331	1.00624	1.02228	1.04131	1.06343	1.0888	1.1184	1.1924	1.2973	1.4636
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00024	0.0004	0.0004	0.0005	0.0007	0.0011
50	0.97666	0.98186	0.99137	1.00422	1.02011	1.03892	1.06072	1.0857	1.1145	1.1867	1.2875	1.4422
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00024	0.0004	0.0005	0.0005	0.0007	0.0011
55	0.97451	0.97992	0.98945	1.00224	1.01798	1.03656	1.05807	1.0826	1.1109	1.1813	1.2782	1.4233
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00025	0.0004	0.0005	0.0005	0.0007	0.0011
60	0.97240	0.97799	0.98756	1.00028	1.01588	1.03426	1.05548	1.0796	1.1074	1.1761	1.2696	1.4064
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00025	0.0004	0.0005	0.0005	0.0007	0.0010
65	0.97031	0.97609	0.98569	0.99835	1.01382	1.03199	1.05293	1.0767	1.1039	1.1711	1.2615	1.3911
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00025	0.0004	0.0005	0.0006	0.0008	0.0010
70	0.96826	0.97422	0.98384	0.99645	1.01180	1.02977	1.05043	1.0739	1.1006	1.1662	1.2538	1.3771
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00026	0.0004	0.0005	0.0006	0.0008	0.0010
75	0.96624	0.97237	0.98203	0.99458	1.00980	1.02758	1.04798	1.0711	1.0974	1.1616	1.2465	1.3643
	0.00010	0.00010	0.00010	0.00010	0.00012	0.00017	0.00026	0.0004	0.0005	0.0006	0.0008	0.0010
80	0.96426	0.97056	0.98023	0.99273	1.00783	1.02543	1.04557	1.0683	1.0942	1.1571	1.2395	1.3524
	0.00011	0.00011	0.00011	0.00012	0.00014	0.00019	0.00028	0.0004	0.0005	0.0007	0.0008	0.0010
85	0.96230	0.96875	0.97846	0.99091	1.00589	1.02331	1.04321	1.0656	1.0911	1.1527	1.2329	1.3412
	0.00011	0.00011	0.00011	0.00013	0.00016	0.00020	0.00029	0.0004	0.0005	0.0007	0.0009	0.0011
90	0.96037	0.96698	0.97671	0.98911	1.00398	1.02123	1.04089	1.0630	1.0881	1.1485	1.2265	1.3308
	0.00011	0.00012	0.00012	0.00014	0.00017	0.00021	0.00029	0.0004	0.0005	0.0007	0.0009	0.0012
95	0.95848	0.96522	0.97498	0.98733	1.00209	1.01918	1.03861	1.0604	1.0851	1.1444	1.2204	1.3210
	0.00012	0.00013	0.00013	0.00015	0.00018	0.00021	0.00030	0.0004	0.0005	0.0008	0.0010	0.0013
100	0.95660	0.96347	0.97326	0.98557	1.00023	1.01715	1.03636	1.0579	1.0822	1.1404	1.2146	1.3117
	0.00015	0.00015	0.00016	0.00016	0.00019	0.00024	0.00031	0.0004	0.0005	0.0008	0.0010	0.0013
110	0.95290	0.96004	0.96986	0.98209	0.99655	1.01319	1.03193	1.0529	1.0766	1.1327	1.2034	1.2945
	0.00020	0.00017	0.00017	0.00018	0.00022	0.00027	0.00036	0.0005	0.0006	0.0009	0.0011	0.0014
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
120	0.94940	0.95671	0.96656	0.97870	0.99299	1.00934	1.0277	1.0482	1.0711	1.1253	1.1930	1.2789
	0.00030	0.00020	0.00020	0.00020	0.00025	0.00031	0.0004	0.0005	0.0007	0.0009	0.0012	0.0015
130	0.9460	0.95347	0.96336	0.97541	0.98952	1.00560	1.0235	1.0436	1.0660	1.1184	1.1834	1.2647
	0.0004	0.00020	0.00020	0.00023	0.00027	0.00034	0.0005	0.0006	0.0008	0.0010	0.0013	0.0015
140	0.9426	0.95032	0.96024	0.97221	0.98614	1.00192	1.0196	1.0392	1.0609	1.1118	1.1744	1.2517
	0.0005	0.00022	0.00023	0.00025	0.00029	0.00035	0.0005	0.0006	0.0008	0.0011	0.0013	0.0016
150	0.9394	0.94725	0.95721	0.96908	0.98284	0.99832	1.0157	1.0349	1.0561	1.1055	1.1658	1.2396
	0.0006	0.00024	0.00025	0.00027	0.00032	0.00039	0.0005	0.0007	0.0008	0.0011	0.0014	0.0016
160	0.9362	0.94427	0.95424	0.96603	0.97961	0.9949	1.0119	1.0307	1.0515	1.0995	1.1578	1.2283
	0.0007	0.00029	0.00030	0.00029	0.00034	0.0004	0.0005	0.0007	0.0009	0.0011	0.0014	0.0017
170	0.9331	0.94134	0.95132	0.96303	0.97646	0.9915	1.0083	1.0267	1.0470	1.0938	1.1500	1.2178
	0.0008	0.00031	0.00031	0.00032	0.00037	0.0004	0.0006	0.0007	0.0009	0.0011	0.0014	0.0017
180	0.9301	0.93849	0.94847	0.96011	0.9733	0.9883	1.0048	1.0228	1.0426	1.0882	1.1426	1.2079
	0.0010	0.00033	0.00033	0.00033	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0014	0.0017
190	0.9272	0.93571	0.94569	0.95726	0.9704	0.9851	1.0013	1.0190	1.0384	1.0828	1.1356	1.1985
	0.0015	0.00034	0.00034	0.00034	0.0005	0.0005	0.0006	0.0007	0.0009	0.0011	0.0014	0.0017
200	0.9244	0.93299	0.94297	0.95441	0.9674	0.9820	0.9979	1.0153	1.0342	1.0775	1.1289	1.1896
	0.0020	0.00035	0.00036	0.00037	0.0005	0.0006	0.0006	0.0007	0.0009	0.0011	0.0014	0.0017
220	0.9189	0.9277	0.9376	0.9490	0.9618	0.9759	0.9913	1.0080	1.0261	1.0675	1.1162	1.1731
	0.0025	0.0006	0.0006	0.0006	0.0006	0.0006	0.0007	0.0008	0.0012	0.0014	0.0015	0.0018
240	0.9137	0.9226	0.9325	0.9437	0.9563	0.9700	0.9850	1.0011	1.0186	1.0583	1.1045	1.1579
	0.0030	0.0008	0.0008	0.0008	0.0008	0.0009	0.0009	0.0010	0.0012	0.0014	0.0016	0.0020
260	0.9088	0.9177	0.9276	0.9387	0.9510	0.9645	0.9790	0.9947	1.0116	1.0497	1.0937	1.1443
	0.0035	0.0010	0.0010	0.0010	0.0011	0.0011	0.0011	0.0012	0.0014	0.0016	0.0019	0.0023
280	0.904	0.9130	0.9228	0.9339	0.9460	0.9591	0.9733	0.9886	1.0050	1.0416	1.0836	1.1317
	0.004	0.0012	0.0012	0.0012	0.0013	0.0013	0.0013	0.0014	0.0015	0.0018	0.0021	0.0026
300	0.900	0.9085	0.9183	0.9292	0.9411	0.9540	0.9678	0.9828	0.9988	1.0339	1.0740	1.1197
	0.005	0.0014	0.0014	0.0014	0.0014	0.0015	0.0015	0.0015	0.0017	0.0019	0.0023	0.0028
320	0.895	0.9041	0.9138	0.9246	0.9364	0.9490	0.9626	0.9771	0.9927	1.0266	1.0651	1.1080
	0.006	0.0015	0.0015	0.0015	0.0016	0.0016	0.0016	0.0017	0.0019	0.0021	0.0025	0.0030
340	0.891	0.8999	0.9095	0.9202	0.9319	0.9443	0.9575	0.9717	0.9869	1.0198	1.0568	1.0980
	0.007	0.0016	0.0016	0.0016	0.0017	0.0017	0.0017	0.0018	0.0020	0.0023	0.0027	0.0032
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
360	0.887	0.8958	0.9054	0.9160	0.9275	0.9396	0.9526	0.9664	0.9813	1.0132	1.0488	1.0880
	0.008	0.0016	0.0017	0.0017	0.0017	0.0017	0.0018	0.0019	0.0020	0.0024	0.0029	0.0034
380	0.883	0.8918	0.9013	0.9119	0.9233	0.9352	0.9478	0.9613	0.9759	1.0069	1.0413	1.0790
	0.009	0.0017	0.0017	0.0017	0.0018	0.0018	0.0018	0.0019	0.0020	0.0025	0.0030	0.0035
400	0.880	0.8879	0.8973	0.9078	0.9191	0.9308	0.9432	0.9564	0.9707	1.0009	1.0341	1.0700
	0.010	0.0017	0.0017	0.0017	0.0018	0.0018	0.0019	0.0019	0.0020	0.0025	0.0031	0.0036
450	0.871	0.8788	0.8881	0.8984	0.9093	0.9205	0.9323	0.9449	0.9583	0.9867	1.0170	1.0500
	0.015	0.0017	0.0018	0.0018	0.0018	0.0019	0.0019	0.0020	0.0023	0.0027	0.0032	0.0038
500	0.863	0.8702	0.8795	0.8896	0.9002	0.9110	0.9222	0.9340	0.9468	0.9735	1.0020	1.033
	0.015	0.0018	0.0018	0.0019	0.0019	0.0019	0.0020	0.0022	0.0025	0.0030	0.0036	0.004
550	0.855	0.8620	0.8715	0.8814	0.8915	0.9020	0.9128	0.9241	0.9361	0.9614	0.9880	1.017
	0.020	0.0018	0.0019	0.0019	0.0020	0.0021	0.0021	0.0023	0.0026	0.0032	0.0039	0.005
600	0.848	0.8541	0.8639	0.8737	0.8834	0.8936	0.9040	0.9148	0.9263	0.9501	0.975	1.003
	0.020	0.0018	0.0019	0.0020	0.0021	0.0022	0.0022	0.0024	0.0027	0.0033	0.004	0.005
650	0.842	0.8465	0.8567	0.8664	0.8759	0.8857	0.8958	0.9062	0.9171	0.9398	0.964	0.990
	0.020	0.0018	0.0019	0.0021	0.0022	0.0022	0.0023	0.0025	0.0027	0.0033	0.004	0.005
700		0.8393	0.8499	0.8596	0.8687	0.8782	0.8879	0.8980	0.9086	0.9304	0.953	0.978
		0.0018	0.0019	0.0021	0.0022	0.0023	0.0024	0.0025	0.0027	0.0033	0.004	0.005
750		0.8326	0.8435	0.8532	0.8620	0.8712	0.8806	0.8903	0.9007	0.9215	0.943	0.967
		0.0018	0.0020	0.0021	0.0022	0.0023	0.0024	0.0025	0.0027	0.0033	0.004	0.005
800		0.8263	0.8373	0.8470	0.8555	0.8644	0.8735	0.8830	0.8931	0.9130	0.934	0.956
		0.0019	0.0021	0.0022	0.0023	0.0024	0.0025	0.0027	0.0029	0.0035	0.004	0.005
850		0.8200	0.8310	0.8410	0.8490	0.8580	0.8660	0.8760	0.8860	0.9050	0.924	0.945
		0.0022	0.0023	0.0024	0.0025	0.0026	0.0027	0.0028	0.0031	0.0036	0.004	0.005
900		0.8150	0.8250	0.8350	0.8430	0.8520	0.8600	0.8690	0.8790	0.8970	0.916	0.936
		0.0024	0.0025	0.0026	0.0027	0.0028	0.0028	0.0030	0.0032	0.0037	0.004	0.005
950			0.8200	0.8300	0.8380	0.8460	0.8540	0.8630	0.8720	0.8900	0.908	0.926
			0.0028	0.0029	0.0029	0.0030	0.0030	0.0032	0.0034	0.0038	0.004	0.005
1000			0.815	0.825	0.833	0.841	0.849	0.857	0.866	0.883	0.900	0.918
			0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.006
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

Table 1 (continued). The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
0.101325	2947.9	3062.2	3176.5	3290.8	3404.7	3519.2	3747.5	3975.7	4203.3	4430.3	4657.6	4885.6
	1.5	1.5	1.6	1.6	1.7	1.8	1.9	2.0	2.0	2.0	2.0	2.0
0.5	593.72	617.28	640.77	664.3	687.7	711.0	757.6	804.1	850.5	896.7	943.0	989.3
	0.36	0.37	0.38	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
1.0	294.54	306.55	318.52	330.42	342.28	354.10	377.65	401.11	424.45	447.69	470.93	494.19
	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2.5	114.94	120.06	125.11	130.10	135.04	139.95	149.66	159.26	168.79	178.24	187.67	197.10
	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
5.0	54.93	57.81	60.59	63.29	65.93	68.54	73.64	78.62	83.52	88.39	93.23	98.04
	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10
7.5	34.76	36.93	38.99	40.95	42.86	44.71	48.29	51.75	55.12	58.47	61.77	65.03
	0.05	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08
10.0	24.536	26.41	28.13	29.74	31.28	32.76	35.61	38.32	40.92	43.50	46.03	48.53
	0.037	0.04	0.04	0.04	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
12.5	18.251	20.010	21.567	22.983	24.324	25.59	27.99	30.26	32.41	34.53	36.60	38.64
	0.027	0.030	0.032	0.034	0.039	0.05	0.05	0.05	0.05	0.05	0.05	0.05
15.0	13.893	15.656	17.138	18.454	19.663	20.794	22.91	24.87	26.74	28.55	30.31	32.04
	0.025	0.023	0.026	0.028	0.031	0.037	0.04	0.04	0.04	0.04	0.05	0.05
17.5	10.560	12.455	13.924	15.184	16.316	17.364	19.284	21.03	22.69	24.28	25.83	27.34
	0.023	0.020	0.022	0.023	0.026	0.031	0.039	0.04	0.04	0.04	0.05	0.05
20.0	7.678	9.950	11.466	12.705	13.791	14.777	16.552	18.160	19.65	21.08	22.47	23.81
	0.018	0.018	0.021	0.021	0.022	0.027	0.030	0.035	0.04	0.04	0.05	0.05
22.5	2.45	7.870	9.506	10.753	11.812	12.756	14.425	15.917	17.296	18.59	19.85	21.07
	0.05	0.016	0.017	0.019	0.020	0.023	0.025	0.030	0.035	0.04	0.05	0.05
25.0	1.981	6.007	7.886	9.169	10.217	11.132	12.723	14.124	15.401	16.613	17.76	18.88
	0.005	0.013	0.015	0.017	0.018	0.020	0.020	0.020	0.030	0.035	0.04	0.05
27.5	1.8631	4.188	6.506	7.852	8.902	9.800	11.332	12.660	13.861	14.986	16.062	17.09
	0.0034	0.020	0.012	0.014	0.016	0.018	0.020	0.020	0.030	0.030	0.035	0.04
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
30	1.7923	2.799	5.305	6.738	7.798	8.685	10.171	11.441	12.582	13.636	14.644	15.60
	0.0026	0.014	0.010	0.012	0.014	0.016	0.018	0.020	0.020	0.030	0.035	0.04
35	1.7013	2.107	3.430	4.961	6.055	6.930	8.344	9.522	10.563	11.516	12.404	13.270
	0.0020	0.004	0.008	0.009	0.011	0.012	0.015	0.017	0.020	0.025	0.030	0.035
40	1.6409	1.9108	2.537	3.694	4.764	5.622	6.982	8.088	9.054	9.928	10.734	11.515
	0.0017	0.0031	0.005	0.006	0.008	0.010	0.014	0.016	0.018	0.020	0.025	0.030
45	1.5958	1.8034	2.1872	2.914	3.822	4.635	5.936	6.983	7.887	8.697	9.449	10.155
	0.0015	0.0022	0.0033	0.005	0.007	0.008	0.010	0.010	0.015	0.018	0.020	0.030
50	1.5594	1.7308	2.0089	2.4875	3.175	3.894	5.118	6.109	6.960	7.718	8.416	9.066
	0.0014	0.0018	0.0025	0.0038	0.005	0.007	0.010	0.010	0.014	0.018	0.018	0.025
55	1.5293	1.6765	1.8962	2.2420	2.751	3.349	4.471	5.406	6.208	6.922	7.577	8.192
	0.0014	0.0017	0.0024	0.0033	0.005	0.006	0.008	0.008	0.012	0.018	0.018	0.020
60	1.5034	1.6333	1.8163	2.0848	2.471	2.956	3.958	4.834	5.591	6.265	6.882	7.460
	0.0013	0.0016	0.0022	0.0030	0.004	0.005	0.007	0.008	0.010	0.016	0.018	0.018
65	1.4807	1.5973	1.7550	1.9753	2.2810	2.672	3.551	4.364	5.078	5.716	6.299	6.844
	0.0013	0.0015	0.0021	0.0028	0.0036	0.005	0.007	0.008	0.010	0.015	0.018	0.018
70	1.4606	1.5666	1.7057	1.8927	2.1438	2.464	3.228	3.977	4.648	5.251	5.803	6.320
	0.0012	0.0015	0.0020	0.0026	0.0034	0.004	0.006	0.007	0.009	0.010	0.015	0.018
75	1.4425	1.5400	1.6649	1.8276	2.0397	2.309	2.970	3.655	4.284	4.855	5.379	5.869
	0.0012	0.0015	0.0020	0.0025	0.0033	0.004	0.006	0.007	0.008	0.010	0.014	0.018
80	1.4260	1.5166	1.6301	1.7744	1.9585	2.1878	2.763	3.386	3.975	4.514	5.013	5.478
	0.0012	0.0015	0.0020	0.0024	0.0031	0.0039	0.006	0.006	0.008	0.010	0.010	0.016
85	1.4110	1.4955	1.5998	1.7298	1.8922	2.0917	2.596	3.161	3.710	4.220	4.693	5.136
	0.0013	0.0016	0.0020	0.0024	0.0030	0.0038	0.005	0.006	0.008	0.010	0.010	0.015
90	1.3971	1.4765	1.5730	1.6915	1.8370	2.0136	2.459	2.972	3.483	3.964	4.414	4.836
	0.0014	0.0017	0.0020	0.0024	0.0029	0.0036	0.005	0.006	0.007	0.008	0.010	0.015
95	1.3842	1.4592	1.5492	1.6581	1.7900	1.9482	2.345	2.811	3.286	3.740	4.167	4.570
	0.0015	0.0018	0.0021	0.0024	0.0029	0.0035	0.005	0.006	0.006	0.008	0.010	0.014
100	1.3721	1.4431	1.5276	1.6285	1.7492	1.8924	2.249	2.673	3.115	3.543	3.949	4.334
	0.0016	0.0019	0.0021	0.0024	0.0028	0.0034	0.005	0.005	0.006	0.007	0.010	0.013
110	1.3501	1.4144	1.4899	1.5781	1.6816	1.8022	2.097	2.453	2.835	3.215	3.582	3.933
	0.0016	0.0019	0.0022	0.0024	0.0027	0.0032	0.005	0.005	0.006	0.007	0.010	0.012
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
120	1.3306	1.3896	1.4580	1.5367	1.6276	1.7319	1.984	2.286	2.619	2.958	3.289	3.610
	0.0017	0.0020	0.0022	0.0025	0.0027	0.0031	0.005	0.005	0.006	0.007	0.009	0.011
130	1.3130	1.3678	1.4304	1.5017	1.5829	1.6751	1.893	2.156	2.447	2.750	3.051	3.345
	0.0018	0.0020	0.0023	0.0025	0.0027	0.0030	0.005	0.005	0.006	0.007	0.009	0.010
140	1.2971	1.3483	1.4062	1.4715	1.5450	1.6276	1.821	2.052	2.310	2.581	2.855	3.124
	0.0018	0.0021	0.0023	0.0025	0.0027	0.0030	0.005	0.005	0.006	0.007	0.008	0.009
150	1.2826	1.3307	1.3846	1.4449	1.5122	1.5872	1.760	1.966	2.196	2.441	2.690	2.939
	0.0019	0.0021	0.0023	0.0025	0.0027	0.0030	0.004	0.005	0.006	0.007	0.008	0.009
160	1.2692	1.3146	1.3651	1.4211	1.4833	1.5521	1.710	1.894	2.102	2.323	2.551	2.780
	0.0019	0.0021	0.0023	0.0025	0.0027	0.0030	0.004	0.005	0.006	0.007	0.007	0.008
170	1.2568	1.2997	1.3473	1.3997	1.4575	1.5212	1.665	1.834	2.022	2.224	2.433	2.646
	0.0019	0.0021	0.0023	0.0025	0.0027	0.0030	0.004	0.005	0.006	0.007	0.007	0.008
180	1.2451	1.2859	1.3310	1.3802	1.4343	1.4936	1.627	1.781	1.953	2.138	2.331	2.528
	0.0019	0.0022	0.0023	0.0025	0.0027	0.0030	0.004	0.005	0.006	0.007	0.007	0.008
190	1.2342	1.2731	1.3158	1.3623	1.4130	1.4687	1.593	1.735	1.893	2.063	2.242	2.425
	0.0019	0.0022	0.0023	0.0025	0.0027	0.0030	0.004	0.005	0.006	0.007	0.007	0.008
200	1.2240	1.2610	1.3014	1.3455	1.3935	1.4458	1.562	1.694	1.840	1.997	2.164	2.335
	0.0019	0.0022	0.0023	0.0025	0.0027	0.0030	0.004	0.005	0.006	0.007	0.008	0.009
220	1.2050	1.2388	1.2753	1.3153	1.3581	1.4052	1.508	1.625	1.752	1.888	2.033	2.183
	0.0020	0.0022	0.0029	0.0030	0.0031	0.0032	0.004	0.005	0.006	0.007	0.008	0.010
240	1.1879	1.2191	1.2521	1.2891	1.3281	1.370	1.463	1.568	1.680	1.800	1.927	2.060
	0.0022	0.0025	0.0029	0.0034	0.0035	0.004	0.004	0.005	0.006	0.007	0.008	0.010
260	1.1725	1.2011	1.2321	1.2661	1.3031	1.341	1.426	1.519	1.619	1.727	1.840	1.959
	0.0026	0.0028	0.0030	0.0035	0.0035	0.004	0.004	0.005	0.006	0.007	0.008	0.010
280	1.1584	1.1861	1.2151	1.2461	1.2801	1.316	1.393	1.478	1.569	1.666	1.769	1.876
	0.0029	0.0032	0.0034	0.0036	0.0038	0.004	0.005	0.005	0.006	0.007	0.008	0.010
300	1.1451	1.1711	1.1981	1.228	1.260	1.293	1.364	1.442	1.525	1.615	1.709	1.807
	0.0032	0.0036	0.0038	0.004	0.004	0.004	0.005	0.005	0.006	0.007	0.008	0.010
320	1.1320	1.1570	1.183	1.211	1.241	1.272	1.338	1.410	1.488	1.571	1.657	1.747
	0.0035	0.0038	0.004	0.004	0.005	0.005	0.005	0.006	0.006	0.007	0.008	0.010
340	1.1210	1.145	1.170	1.196	1.224	1.254	1.315	1.382	1.454	1.531	1.611	1.695
	0.0036	0.004	0.004	0.005	0.005	0.005	0.005	0.006	0.006	0.007	0.008	0.010
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 1. The most probable specific volumes with their associated tolerances

The specific volumes (upper figure) and their associated tolerances (lower figure) are given in dm^3/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
360	1.1100	1.133	1.157	1.182	1.209	1.236	1.294	1.357	1.424	1.496	1.571	1.649
	0.0038	0.004	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.007	0.008	0.011
380	1.1000	1.122	1.145	1.169	1.194	1.220	1.275	1.334	1.398	1.465	1.535	1.610
	0.0039	0.004	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.007	0.008	0.011
400	1.090	1.111	1.134	1.157	1.181	1.205	1.257	1.314	1.374	1.437	1.504	1.572
	0.004	0.004	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.007	0.008	0.011
450	1.069	1.087	1.108	1.130	1.151	1.172	1.218	1.268	1.321	1.376	1.433	1.492
	0.004	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.007	0.008	0.011
500	1.049	1.067	1.086	1.106	1.125	1.145	1.186	1.231	1.278	1.327	1.377	1.429
	0.005	0.005	0.005	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.011
550	1.032	1.049	1.067	1.086	1.103	1.120	1.158	1.199	1.241	1.286	1.332	1.379
	0.005	0.006	0.006	0.008	0.008	0.008	0.008	0.009	0.009	0.009	0.010	0.011
600	1.017	1.033	1.050	1.067	1.083	1.099	1.134	1.171	1.210	1.251	1.293	1.335
	0.006	0.006	0.007	0.008	0.009	0.009	0.009	0.009	0.010	0.010	0.010	0.012
650	1.004	1.018	1.034	1.050	1.065	1.081	1.113	1.147	1.183	1.220	1.258	1.297
	0.006	0.007	0.007	0.008	0.009	0.009	0.009	0.010	0.011	0.011	0.011	0.012
700	0.992	1.005	1.020	1.034	1.048	1.063	1.093	1.125	1.159	1.193	1.228	1.263
	0.006	0.007	0.007	0.008	0.009	0.009	0.010	0.011	0.012	0.012	0.013	0.013
750	0.980	0.993	1.007	1.020	1.033	1.047	1.075	1.105	1.137	1.169	1.201	1.235
	0.006	0.007	0.008	0.009	0.009	0.009	0.010	0.012	0.013	0.014	0.014	0.015
800	0.968	0.980	0.993	1.006	1.018	1.031	1.057	1.086	1.116	1.147	1.178	1.209
	0.006	0.007	0.008	0.009	0.009	0.009	0.010	0.012	0.015	0.016	0.017	0.019
850	0.956	0.968	0.980	0.992	1.004	1.016	1.040	1.067	1.097	1.126	1.155	1.185
	0.006	0.007	0.008	0.009	0.009	0.010	0.010	0.012	0.016	0.017	0.017	0.019
900	0.946	0.956	0.968	0.979	0.991	1.002	1.026	1.051	1.079	1.106	1.134	1.161
	0.006	0.007	0.008	0.009	0.009	0.010	0.011	0.012	0.016	0.016	0.017	0.019
950	0.936	0.946	0.956	0.967	0.979	0.990	1.013	1.036	1.063	1.088	1.114	1.140
	0.006	0.007	0.008	0.009	0.009	0.010	0.011	0.013	0.016	0.016	0.017	0.019
1000	0.927	0.936	0.946	0.957	0.968	0.979	1.000	1.022	1.047	1.071	1.096	1.120
	0.007	0.009	0.009	0.010	0.010	0.010	0.012	0.015	0.016	0.019	0.022	0.022
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
0.101325	0.06[a]	104.89	209.38	314.05	2675.8	2726.2	2775.8	2824.9	2874.4	2973.7	3073.8	3175.1
	±0.01[b]	0.07	0.10	0.11	1.6	2.0	2.0	2.0	2.0	2.0	3.0	3.0
				(liquid)	(gas)							
0.5	0.47	105.26	209.72	314.37	419.45	525.24	632.2	2800.2	2854.5	2959.9	3063.1	3167
	0.01	0.10	0.16	0.16	0.20	0.33	0.5	2.0	2.0	3.0	3.6	4
1.0	0.98	105.72	210.15	314.77	419.82	525.61	632.5	741.1	2827.0	2941.6	3050.1	3157
	0.01	0.12	0.19	0.28	0.33	0.35	0.5	0.7	2.0	3.0	3.9	4
2.5	2.50	107.11	211.45	315.98	420.95	526.6	633.5	741.9	852.6	2879	3007	3125
	0.01	0.15	0.19	0.28	0.33	0.4	0.5	0.7	0.9	4	4	4
5.0	5.04	109.41	213.60	318.00	422.83	528.3	635.0	743.2	853.6	1085.6	2923	3067
	0.03	0.16	0.19	0.28	0.33	0.4	0.5	0.7	0.9	1.8	4	4
7.5	7.57	111.72	215.75	320.02	424.71	530.1	636.6	744.5	854.7	1085.6	2813	3000
	0.04	0.16	0.19	0.28	0.34	0.4	0.5	0.7	0.9	1.8	4	4
10.0	10.09	114.01	217.90	322.03	426.60	531.8	638.0	745.9	855.7	1085.7	1343.1	2922
	0.05	0.17	0.19	0.29	0.34	0.4	0.5	0.7	0.9	1.8	2.0	4
12.5	12.59	116.31	220.05	324.05	428.49	533.5	639.6	747.3	856.8	1085.8	1340.4	2825
	0.06	0.17	0.19	0.29	0.34	0.4	0.5	0.7	0.9	1.8	2.0	4
15.0	15.09	118.60	222.19	326.06	430.37	535.3	641.2	748.6	858.0	1086.0	1338.1	2691
	0.07	0.17	0.20	0.29	0.34	0.4	0.5	0.7	0.9	1.8	2.0	5
17.5	17.58	120.88	224.33	328.08	432.26	537.0	642.8	750.0	859.1	1086.3	1336.0	1662.6
	0.08	0.18	0.30	0.30	0.34	0.4	0.5	0.7	0.9	1.8	2.0	3.0
20.0	20.06	123.16	226.48	330.09	434.15	538.8	644.4	751.4	860.2	1086.6	1334.2	1645.9
	0.10	0.18	0.30	0.30	0.34	0.4	0.5	0.7	0.9	1.8	2.0	3.0
22.5	22.53	125.44	228.61	332.11	436.05	540.6	646.0	752.8	861.4	1086.9	1332.5	1633.6
	0.11	0.18	0.30	0.30	0.34	0.4	0.5	0.7	0.9	1.8	2.0	3.0
25.0	25.00	127.71	230.75	334.12	437.94	542.3	647.6	754.3	862.6	1087.3	1331.1	1623.7
	0.12	0.19	0.30	0.30	0.35	0.4	0.5	0.7	0.9	1.8	2.0	3.0
27.5	27.45	129.98	232.89	336.14	439.83	544.1	649.2	755.7	863.8	1087.8	1329.8	1615.6
	0.13	0.19	0.30	0.30	0.35	0.4	0.5	0.7	0.9	1.8	2.0	3.0
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

a This entry is for the metastable-state liquid.

b Except for this entry, the sign (±) of the tolerance is omitted.

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
30	29.90	132.24	235.02	338.15	441.73	545.8	650.8	757.1	865.0	1088.3	1328.7	1608.7
	0.15	0.19	0.30	0.30	0.35	0.4	0.5	0.7	0.9	1.8	2.0	3.0
35	34.76	136.76	239.28	342.18	445.52	549.4	654.1	760.0	867.5	1089.4	1326.8	1597.4
	0.17	0.25	0.30	0.30	0.35	0.4	0.5	0.7	0.9	1.8	2.0	3.0
40	39.60	141.26	243.53	346.20	449.31	552.9	657.4	763.0	870.0	1090.6	1325.5	1588.7
	0.19	0.26	0.30	0.30	0.36	0.4	0.5	0.7	0.9	1.8	2.0	3.0
45	44.40	145.74	247.77	350.22	453.11	556.5	660.7	766.0	872.6	1092.0	1324.5	1581.6
	0.22	0.29	0.30	0.30	0.36	0.4	0.5	0.7	0.9	1.8	2.0	3.0
50	49.17	150.20	252.00	354.24	456.91	560.1	664.0	769.0	875.2	1093.5	1323.8	1575.9
	0.24	0.31	0.30	0.30	0.36	0.4	0.5	0.7	0.9	1.8	2.0	3.0
55	53.91	154.66	256.23	358.26	460.71	563.7	667.3	772.0	877.9	1095.1	1323.4	1571.2
	0.27	0.34	0.30	0.30	0.36	0.4	0.5	0.7	0.9	1.8	2.0	2.9
60	58.62	159.09	260.45	362.28	464.51	567.3	670.7	775.1	880.6	1096.8	1323.3	1567.3
	0.29	0.36	0.35	0.35	0.37	0.4	0.5	0.7	0.9	1.8	2.0	2.9
65	63.30	163.51	264.65	366.28	468.31	570.9	674.0	778.1	883.3	1098.6	1323.4	1564.1
	0.31	0.39	0.35	0.35	0.37	0.4	0.5	0.7	0.9	1.8	2.0	2.9
70	67.96	167.9	268.9	370.3	472.2	574.5	677.4	781.2	886.1	1100.5	1323.8	1561.4
	0.34	0.4	0.5	0.5	0.5	0.5	0.5	0.7	0.9	1.8	2.0	3.0
75	72.60	172.3	273.1	374.3	476.0	578.1	680.8	784.4	888.9	1102.5	1324.3	1559.3
	0.36	0.4	0.6	0.6	0.5	0.5	0.5	0.8	0.9	1.8	2.0	3.0
80	77.20	176.7	277.3	378.3	479.8	581.7	684.2	787.5	891.8	1104.5	1324.9	1557.5
	0.38	0.4	0.6	0.6	0.7	0.7	0.7	0.8	0.9	1.8	2.0	3.0
85	81.8	181.0	281.5	382.3	483.6	585.3	687.6	790.7	894.7	1106.6	1325.8	1556.1
	0.4	0.4	0.6	0.7	0.8	0.8	0.8	0.9	1.0	1.8	2.0	3.0
90	86.3	185.4	285.6	386.3	487.4	589.0	691.0	793.9	897.6	1108.7	1326.7	1555.0
	0.4	0.4	0.7	0.7	0.9	0.9	0.9	1.0	1.0	1.8	2.0	3.0
95	90.9	189.7	289.8	390.3	491.3	592.6	694.5	797.1	900.5	1111.0	1327.8	1554.3
	0.4	0.4	0.7	0.8	1.0	1.0	1.0	1.1	1.3	1.9	2.5	3.2
100	95.4	194.0	294.0	394.3	495.1	596.2	697.9	800.3	903.5	1113.2	1329.0	1553.7
	0.4	0.4	0.7	0.8	1.1	1.1	1.2	1.5	1.5	2.0	2.8	3.3
110	104.4	202.6	302.3	402.3	502.7	603.5	704.8	806.8	909.5	1117.9	1331.8	1553.4
	0.6	0.5	0.7	0.9	1.2	1.3	1.5	1.7	1.9	2.4	3.0	3.4
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperatusre, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
120	113.3	211.2	310.5	410.2	510.4	610.8	711.8	813.3	915.5	1122.8	1334.9	1553.3
	0.6	0.5	0.7	1.0	1.2	1.4	1.6	1.8	2.2	2.6	3.1	3.5
130	122.1	219.7	318.7	418.2	518.0	618.2	718.7	819.9	921.7	1127.9	1338.3	1554.3
	0.7	0.7	0.8	1.0	1.3	1.4	1.8	1.9	2.3	2.7	3.2	3.5
140	130.9	228.2	327.0	426.1	525.7	625.5	725.7	826.5	927.9	1133.1	1342.0	1555.9
	0.7	0.7	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.7	3.2	3.6
150	139.6	236.6	335.1	434.0	533.3	632.8	732.7	833.1	934.1	1138.4	1346.0	1557.9
	0.8	0.7	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.8	3.2	3.6
160	148.2	244.9	343.3	441.9	540.9	640.2	739.8	839.9	940.5	1143.8	1350.2	1560.3
	1.0	0.7	0.8	1.1	1.3	1.6	1.8	2.1	2.3	2.8	3.3	3.6
170	156.8	253.3	351.4	449.8	548.6	647.5	746.9	846.6	946.9	1149.3	1354.6	1563.1
	1.1	0.7	0.8	1.1	1.3	1.6	1.8	2.1	2.3	2.8	3.3	3.6
180	165.3	261.6	359.5	457.7	556.2	654.9	754.0	853.4	953.3	1155.0	1359.1	1566.1
	1.1	0.7	0.9	1.1	1.4	1.6	1.8	2.1	2.3	2.8	3.3	3.6
190	173.8	269.9	367.6	465.6	563.8	662.3	761.1	860.2	959.9	1160.7	1363.8	1569.5
	1.2	0.8	0.9	1.1	1.4	1.6	1.9	2.1	2.4	2.8	3.3	3.6
200	182.2	278.1	375.7	473.4	571.5	669.7	768.2	867.1	966.4	1166.5	1368.7	1573.0
	1.4	1.0	1.0	1.1	1.4	1.6	1.9	2.1	2.4	2.8	3.3	3.6
220	198.9	294.5	391.7	489.1	586.7	684.5	782.5	880.8	979.6	1178.4	1378.8	1580.9
	1.8	1.1	1.1	1.2	1.4	1.7	1.9	2.2	2.4	2.9	3.4	3.7
240	215.5	310.7	407.7	504.7	601.9	699.2	796.9	894.6	993.0	1190.5	1389.3	1589.4
	2.1	1.3	1.3	1.4	1.6	1.8	2.2	2.2	2.4	2.9	3.4	3.7
260	232.0	326.9	423.6	520.3	617.1	714.0	811.3	908.6	1006.4	1202.9	1400.3	1598.6
	2.7	1.4	1.4	1.5	1.7	2.0	2.3	2.3	2.5	2.9	3.4	3.7
280	248.4	342.9	439.3	535.8	632.3	728.8	825.7	922.6	1020.0	1215.4	1411.5	1608.3
	3.7	1.8	1.6	1.6	1.8	2.0	2.3	2.5	2.7	3.0	3.4	3.7
300	265	358.8	455.0	551.2	647.4	743.6	840.1	936.7	1033.6	1228.1	1423.1	1618.4
	5	2.0	1.8	1.8	1.8	2.1	2.4	2.7	2.8	3.0	3.5	3.8
320	281	374.7	470.7	566.7	662.6	758.4	854.6	950.8	1047.4	1241.0	1435.0	1628.9
	7	2.1	1.8	1.8	1.9	2.1	2.4	2.7	2.8	3.1	3.5	3.8
340	297	390.5	486.3	582.0	677.7	773.2	869.0	964.9	1061.2	1254.0	1447.0	1639.8
	9	2.1	1.9	1.9	1.9	2.2	2.5	2.8	2.9	3.1	3.5	3.8
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15
360	314	406.2	501.8	597.3	692.7	788.0	883.5	979.1	1075.0	1267.1	1459.2	1650.9
	11	2.2	2.0	2.0	2.0	2.2	2.5	2.8	2.9	3.1	3.6	3.8
380	330	421.8	517.3	612.6	707.8	802.8	898.0	993.3	1088.9	1280.3	1471.6	1662.4
	13	2.5	2.0	2.0	2.0	2.3	2.6	2.8	3.0	3.2	3.6	3.9
400	346	437.4	532.7	627.9	722.8	817.5	912.5	1007.6	1102.9	1293.6	1484.2	1674.0
	15	3.0	2.1	2.1	2.1	2.3	2.6	2.9	3.0	3.2	3.6	3.9
450	387	476	570.9	665.8	760.2	854.3	948.7	1043.3	1137.8	1327.2	1516.1	1704
	19	4	2.2	2.2	2.2	2.4	2.7	3.0	3.1	3.3	3.7	4
500	428	514	608.8	703.5	797.4	891.0	984.9	1079.0	1173.1	1361.3	1548.8	1735
	25	5	3.0	2.3	2.3	2.5	2.8	3.1	3.2	3.4	3.8	4
550	469	552	646.3	740.9	834.5	927.7	1021.1	1114.8	1208.4	1395.6	1581.8	1767
	33	6	3.2	2.4	2.4	2.6	2.9	3.2	3.3	3.4	3.9	4
600	510	590	683.4	778.1	871.4	964.2	1057.2	1150.7	1243.8	1430.1	1615.4	1799
	41	7	3.4	2.5	2.5	2.8	3.0	3.3	3.4	3.5	3.9	4
650	550	627	720	815.0	908.2	1000.5	1093.2	1186.5	1279.3	1464.9	1649	1832
	50	8	4	2.7	2.7	3.0	3.2	3.4	3.6	3.7	4	4
700		663	756	852	944.8	1036.8	1129.1	1222.3	1314.9	1499.7	1683	1866
		9	5	4	3.5	3.4	3.4	3.6	3.7	3.8	4	4
750		700	792	888	981.3	1073.1	1165.1	1258.1	1350.3	1534.7	1718	1899
		10	6	5	3.9	3.8	3.8	3.9	3.9	3.9	4	4
800		736	828	924	1017	1109	1201	1294	1386	1570	1752	1933
		12	7	6	5	5	5	4	4	4	4	4
850		772	862	960	1054	1145	1236	1329	1421	1605	1787	1967
		14	8	6	6	6	5	4	4	4	4	4
900		808	897	996	1089	1181	1272	1365	1457	1640	1821	2002
		16	9	7	7	7	5	4	4	4	4	4
950			931	1031	1125	1216	1307	1401	1492	1675	1856	2036
			10	8	8	7	5	4	4	4	4	4
1000			965	1066	1161	1252	1343	1436	1527	1710	1891	2071
			15	10	9	8	6	5	5	5	5	5
	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15	523.15	573.15	623.15

Table 2 (continued). The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
0.101325	3226.3	3277.8	3329.8	3382.1	3434.8	3488.1	3595.6	3705.0	3815.8	3928.0	4042	4158
	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.8	3.9	4	4
0.5	3219	3271	3324	3377	3430	3484	3592	3702	3813	3926	4040	4156
	4	4	4	4	4	4	4	4	4	4	4	4
1.0	3210	3263	3317	3370	3424	3478	3587	3698	3810	3923	4037	4154
	4	4	4	4	4	4	5	5	5	5	6	6
2.5	3182	3239	3295	3350	3406	3462	3574	3686	3800	3915	4030	4148
	4	4	4	4	4	4	5	5	5	5	6	6
5.0	3132	3195	3256	3316	3375	3434	3550	3666	3783	3900	4017	4136
	4	4	4	4	4	4	5	5	5	5	6	6
7.5	3077	3147	3215	3279	3342	3404	3526	3646	3765	3885	4004	4125
	4	4	4	4	4	4	5	5	5	5	6	6
10.0	3014	3095	3170	3241	3308	3374	3501	3625	3748	3870	3991	4113
	4	4	4	4	4	4	5	5	5	6	6	8
12.5	2942	3038	3122	3200	3273	3342	3476	3604	3730	3855	3978	4102
	4	4	4	4	4	5	5	5	7	7	8	10
15.0	2858	2974	3071	3156	3235	3309	3449	3583	3712	3838	3964	4090
	4	4	4	4	4	5	6	6	7	8	8	10
17.5	2751	2901	3014	3110	3196	3275	3422	3561	3693	3823	3951	4079
	4	4	4	4	4	5	6	7	8	9	9	11
20.0	2602	2816	2952	3060	3154	3240	3395	3538	3675	3807	3937	4067
	5	5	4	4	4	5	6	8	9	9	9	11
22.5	1969	2713	2883	3007	3111	3203	3367	3515	3656	3791	3924	4055
	9	5	5	5	5	5	6	8	9	10	10	12
25.0	1850	2579	2805	2950	3065	3164	3338	3492	3637	3775	3910	4043
	5	5	5	5	5	5	6	8	9	10	10	13
27.5	1814	2381	2716	2888	3017	3124	3308	3469	3618	3759	3896	4031
	4	5	5	5	5	5	6	8	9	10	10	13
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
30	1791	2153	2614	2821	2966	3083	3278	3445	3598	3743	3883	4020
	4	4	5	5	5	5	6	8	10	10	11	13
35	1762.2	1989	2374	2673	2857	2997	3216	3397	3559	3710	3855	3996
	3.5	4	5	5	5	5	6	8	10	11	12	13
40	1742.4	1931	2199	2513	2742	2906	3153	3348	3520	3677	3827	3972
	3.4	4	4	5	5	5	6	8	10	11	12	13
45	1727.7	1897	2111	2378	2625	2814	3088	3299	3481	3645	3800	3948
	3.4	4	4	5	5	5	6	8	10	11	12	13
50	1716.3	1874	2060	2285	2521	2724	3024	3250	3441	3612	3772	3925
	3.4	4	4	5	5	5	6	8	10	11	12	13
55	1707.0	1857	2026	2224	2439	2642	2962	3202	3403	3580	3745	3901
	3.4	4	4	4	5	5	6	8	10	11	12	13
60	1699.5	1843	2001	2180	2376	2572	2902	3156	3364	3548	3718	3878
	3.4	4	4	4	5	5	6	8	10	11	12	13
65	1693.2	1832	1982	2148	2329	2514	2846	3110	3327	3517	3692	3855
	3.4	4	4	4	5	5	6	8	10	11	12	13
70	1688.0	1822	1967	2123	2291	2467	2796	3067	3291	3487	3666	3833
	3.4	4	4	4	5	5	6	8	10	11	12	13
75	1683.6	1815	1954	2104	2262	2429	2750	3026	3256	3457	3640	3811
	3.5	4	4	4	5	5	6	8	10	11	12	13
80	1679.9	1808.6	1944	2087	2239	2398	2711	2988	3223	3429	3616	3790
	3.5	3.9	4	4	5	5	6	8	10	11	12	13
85	1676.7	1803.0	1935	2074	2220	2371	2676	2953	3192	3402	3592	3769
	3.5	3.9	4	4	4	5	6	8	10	11	12	13
90	1674.1	1798.2	1927	2063	2204	2349	2646	2921	3163	3376	3569	3749
	3.5	3.9	4	4	4	5	6	8	10	11	12	13
95	1671.9	1794.2	1921	2053	2190	2331	2619	2892	3135	3351	3547	3729
	3.5	3.9	4	4	4	5	6	8	10	11	12	13
100	1670.1	1790.7	1915	2045	2178	2316	2596	2865	3109	3326	3524	3709
	3.6	3.9	4	4	4	5	6	8	10	11	12	13
110	1667.5	1785.3	1906	2031	2159	2290	2558	2820	3063	3283	3485	3673
	3.7	3.9	4	4	4	5	6	8	10	11	12	13
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
120	1666.0	1781.4	1899	2021	2145	2271	2528	2782	3023	3244	3449	3639
	3.7	3.9	4	4	4	5	6	8	10	11	12	13
130	1665.4	1778.8	1894	2013	2133	2256	2504	2752	2989	3210	3417	3609
	3.7	3.9	4	4	4	5	6	8	10	11	12	13
140	1665.5	1777.2	1891	2007	2124	2244	2485	2727	2960	3180	3388	3581
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
150	1666.2	1776.4	1888	2002	2118	2234	2469	2706	2935	3154	3362	3555
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
160	1667.5	1776.4	1887	1999	2112	2226	2457	2689	2915	3132	3340	3533
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
170	1669.3	1776.9	1886	1996	2108	2220	2447	2675	2898	3113	3320	3514
	3.8	3.9	4	4	4	5	6	8	10	11	13	13
180	1671.4	1778.0	1886	1995	2105	2216	2438	2663	2883	3096	3302	3496
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
190	1673.9	1779.5	1886	1994	2103	2212	2432	2652	2870	3082	3287	3480
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
200	1676.7	1781.4	1887	1994	2101	2209	2426	2644	2860	3070	3274	3466
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
220	1683.1	1786.3	1890	1995	2101	2206	2418	2631	2843	3050	3251	3442
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
240	1690.5	1792.4	1895	1998	2102	2206	2414	2623	2831	3035	3234	3423
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
260	1698.6	1799.3	1900	2002	2105	2207	2412	2618	2823	3024	3222	3409
	3.8	3.9	4	4	4	5	6	8	10	11	12	13
280	1707.4	1807.1	1907	2008	2109	2210	2412	2615	2817	3016	3212	3398
	3.9	3.9	4	4	4	5	6	8	10	11	12	13
300	1716.7	1815	1915	2014	2114	2214	2414	2614	2815	3011	3206	3390
	3.9	4	4	5	5	5	6	8	10	11	12	13
320	1726.5	1824	1923	2022	2121	2220	2417	2616	2814	3009	3201	3385
	3.9	4	4	5	5	6	7	8	10	11	12	13
340	1736.7	1834	1931	2029	2128	2226	2422	2618	2814	3008	3199	3381
	3.9	4	5	5	5	6	7	9	10	11	12	13
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Table 2. The most probable specific enthalpies with their associated tolerances

The specific enthalpies (upper figure) and their associated tolerances (lower figure) are given in kJ/kg.

Pressure	Temperature, K (ITS-90)											
MPa	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15
360	1747	1844	1941	2038	2135	2233	2427	2622	2816	3008	3198	3379
	4	4	5	5	5	6	7	9	10	11	12	17
380	1758	1854	1950	2047	2144	2240	2433	2626	2819	3010	3199	3379
	4	4	5	5	5	6	7	9	10	11	12	20
400	1769	1865	1960	2056	2152	2248	2440	2632	2824	3013	3201	3380
	4	4	5	5	5	6	7	9	10	11	16	20
450	1798	1892	1987	2081	2176	2271	2459	2648	2837	3024	3210	3387
	4	4	5	5	5	6	7	9	10	12	16	23
500	1828	1921	2015	2108	2202	2295	2482	2668	2855	3040	3223	3399
	4	4	5	5	6	6	7	9	10	15	19	23
550	1859	1952	2044	2137	2230	2322	2506	2691	2876	3059	3240	3414
	4	4	5	5	6	6	8	9	10	15	19	24
600	1891	1983	2074	2167	2258	2350	2533	2716	2899	3080	3260	3432
	4	4	5	5	6	7	8	9	10	15	19	24
650	1923	2014	2106	2197	2288	2379	2560	2742	2923	3103	3281	3453
	4	4	5	6	6	7	8	9	11	15	19	27
700	1956	2047	2137	2228	2319	2409	2589	2769	2949	3127	3305	3475
	4	5	5	6	6	7	8	11	14	21	26	34
750	1989	2079	2170	2260	2350	2440	2619	2797	2976	3153	3329	3499
	4	5	5	6	6	7	9	11	14	25	33	40
800	2023	2113	2203	2292	2382	2471	2649	2827	3004	3180	3359	3519
	4	5	5	6	6	7	9	14	18	31	40	50
850	2057	2146	2236	2325	2414	2503	2680	2857	3033	3207	3379	3549
	4	5	5	6	7	7	10	17	24	38	50	60
900	2091	2180	2269	2358	2447	2536	2711	2887	3062	3239	3409	3569
	4	5	6	6	9	10	13	20	30	50	50	60
950	2125	2214	2303	2392	2480	2568	2743	2918	3090	3259	3429	3599
	4	5	7	7	12	12	16	23	40	50	60	70
1000	2159	2248	2337	2425	2514	2601	2776	2949	3120	3289	3459	3619
	5	5	8	9	13	15	22	29	50	60	70	80
	648.15	673.15	698.15	723.15	748.15	773.15	823.15	873.15	923.15	973.15	1023.15	1073.15

Part II: Skeleton Tables 1985 of Thermodynamic Properties along the Saturation Curve of Ordinary Water Substance.

Table 3. The most probable thermodynamic property values with their associated tolerances

Temperature	Pressure		Specific volume				Specific enthalpy			
			Saturated water		Saturated steam		Saturated water		Saturated steam	
K (ITS-90)	MPa		dm^3/kg		dm^3/kg		kJ/kg		kJ/kg	
273.16	0.000611657	±0.000000010[b]	1.000211	±0.000010	206005	±150	0.000611786[c]	±0.000000010	2500.5	±1.6
278.15	0.00087253	0.00000005	1.000086	0.000010	147031	100	21.021	0.010	2510.0	1.6
283.15	0.00122811	0.00000009	1.000349	0.000010	106319	80	42.021	0.021	2519.3	1.6
288.15	0.00170568	0.00000017	1.000948	0.000010	77885	60	62.980	0.029	2528.5	1.6
293.15	0.00233919	0.00000029	1.001845	0.000010	57762	40	83.913	0.036	2537.7	1.6
298.15	0.0031698	0.0000005	1.003010	0.000015	43340	30	104.83	0.04	2546.7	1.6
303.15	0.0042469	0.0000006	1.004417	0.000015	32879	25	125.73	0.05	2555.7	1.6
308.15	0.0056291	0.0000008	1.006050	0.000015	25205	20	146.63	0.06	2564.7	1.6
313.15	0.0073851	0.0000010	1.007891	0.000015	19515	15	167.53	0.06	2573.6	1.6
318.15	0.0095953	0.0000012	1.009930	0.000015	15251	10	188.44	0.07	2582.5	1.6
323.15	0.0123525	0.0000015	1.012155	0.000015	12026	8	209.34	0.07	2591.3	1.6
328.15	0.0157628	0.0000017	1.014559	0.000015	9564	7	230.26	0.08	2600.1	1.6
333.15	0.0199474	0.0000021	1.017134	0.000015	7667	6	251.18	0.09	2608.9	1.6
338.15	0.0250427	0.0000024	1.019876	0.000015	6193	5	272.12	0.10	2617.6	1.6
343.15	0.0312022	0.0000028	1.022780	0.000015	5040	4	293.07	0.10	2626.2	1.6
348.15	0.0385967	0.0000033	1.025842	0.000020	4129.1	3.0	314.03	0.11	2634.7	1.6
353.15	0.0474158	0.0000038	1.029060	0.000020	3405.3	2.5	335.01	0.11	2643.1	1.6
358.15	0.057868	0.000004	1.032432	0.000020	2826.0	2.0	356.01	0.12	2651.5	1.6
363.15	0.070183	0.000005	1.035957	0.000020	2359.3	1.7	377.04	0.13	2659.7	1.6
368.15	0.084609	0.000005	1.039634	0.000020	1980.8	1.4	398.09	0.14	2667.8	1.6
373.124[d]	0.101325	0.000006	1.043444	0.000020	1673.4	1.2	419.05	0.14	2675.7	1.6
373.15	0.101418	0.000030	1.043464	0.000020	1672.0	1.2	419.16	0.14	2675.8	1.6
383.15	0.14338	0.00004	1.051583	0.000020	1209.4	0.9	461.41	0.18	2691.3	1.6
393.15	0.19867	0.00005	1.060324	0.000025	891.3	0.7	503.80	0.22	2706.1	1.6
398.15	0.23223	0.00006	1.064934	0.000025	770.1	0.6	525.06	0.24	2713.3	1.6

b Except for the entries in the first line, the sign (±) of the tolerance is omitted.

c At the triple point (273.16 K), the values of the specific internal energy and the specific entropy of saturated water have been set to zero according to a resolution adopted at the fifth International Conference on the Properties of Steam in London, England, 1956.

d At the normal boiling point, the temperature of 373.1243 K corresponds to 0.101325 MPa in the vapor pressure equation of IAPWS Supplementary Release on Saturation Properties of Ordinary Water Substance (September 1992).

Table 3. The most probable thermodynamic property values with their associated tolerances

Temperature	Pressure		Specific volume				Specific enthalpy			
			Saturated water		Saturated steam		Saturated water		Saturated steam	
K (ITS-90)	MPa		dm^3/kg		dm^3/kg		kJ/kg		kJ/kg	
403.15	0.27028	0.00007	1.069707	0.000025	668.1	0.5	546.37	0.26	2720.3	1.6
413.15	0.36153	0.00009	1.079755	0.000025	508.5	0.4	589.14	0.30	2733.6	1.6
423.15	0.47616	0.00012	1.090501	0.000030	392.48	0.28	632.15	0.35	2746.0	1.6
433.15	0.61823	0.00015	1.10199	0.00005	306.80	0.22	675.4	0.4	2757.5	1.7
443.15	0.79218	0.00020	1.11426	0.00007	242.60	0.19	719.0	0.4	2767.9	1.8
448.15	0.89260	0.00022	1.12072	0.00008	216.59	0.17	741.0	0.4	2772.7	1.8
453.15	1.00281	0.00025	1.12739	0.00009	193.84	0.16	763.0	0.5	2777.2	1.9
463.15	1.25524	0.00030	1.14145	0.00010	156.36	0.14	807.3	0.5	2785.2	1.9
473.15	1.5549	0.0004	1.15651	0.00015	127.21	0.12	852.2	0.5	2792.0	2.0
483.15	1.9077	0.0005	1.17269	0.00015	104.29	0.10	897.5	0.6	2797.2	2.1
493.15	2.3196	0.0006	1.19012	0.00020	86.09	0.09	943.5	0.6	2800.9	2.2
503.15	2.7971	0.0007	1.20894	0.00020	71.51	0.08	990.1	0.7	2802.8	2.4
513.15	3.3470	0.0008	1.22936	0.00025	59.71	0.07	1037.4	0.7	2802.9	2.5
523.15	3.9762	0.0010	1.25159	0.00030	50.09	0.06	1085.6	0.7	2800.9	2.6
533.15	4.6923	0.0012	1.27593	0.00035	42.18	0.06	1134.8	0.8	2796.5	2.8
543.15	5.5030	0.0014	1.3028	0.0004	35.62	0.05	1185.1	0.8	2789.6	3.0
553.15	6.4166	0.0016	1.3326	0.0005	30.15	0.04	1236.7	0.9	2779.7	3.1
563.15	7.4418	0.0018	1.3660	0.0005	25.55	0.04	1289.8	0.9	2766.4	3.2
573.15	8.5879	0.0022	1.4038	0.0006	21.659	0.033	1344.8	1.0	2749.3	3.4
583.15	9.8650	0.0025	1.4475	0.0007	18.333	0.033	1402.0	1.0	2727.6	3.6
593.15	11.2843	0.0028	1.4987	0.0007	15.470	0.033	1462.0	1.1	2700.3	3.8
603.15	12.8581	0.0032	1.5604	0.0008	12.979	0.032	1525.6	1.1	2666	4
613.15	14.601	0.004	1.6377	0.0009	10.783	0.029	1594.4	1.2	2622	4
623.15	16.529	0.004	1.7407	0.0010	8.806	0.026	1671.0	1.2	2564	5
633.15	18.666	0.005	1.895	0.008	6.950	0.035	1761.4	1.9	2482	6
643.15	21.044	0.005	2.217	0.020	4.95	0.04	1890.8	3.5	2334	7
644.15	21.297	0.005	2.283	0.020	4.70	0.04	1910.8	3.5	2308	7
645.15	21.554	0.005	2.370	0.020	4.41	0.04	1935.0	3.5	2276	7
646.15	21.814	0.005	2.504	0.025	4.05	0.04	1968	4	2231	10
647.096[e]	22.064	0.005	3.106	0.030	3.106	0.030	2087	15	2087	15

[e] At the critical point, the value of the temperature, pressure, and density of ordinary water substance are $(647.096 + \delta_1)$ K in ITS-90, where $\delta_1 = 0.000 \pm 0.100$, $(22.064 + 0.27\delta_1 \pm 0.005)$ MPa, and (322 ± 3) kg/m^3, respectively. (Ref. IAPWS Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points (September 1992)) .

Release on
The IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance

Issued by
The International Association for the Properties of Steam

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This release is issued by the International Association for the Properties of Steam (IAPS) on the authority of the Tenth International Conference on the Properties of Steam, held in Moscow, USSR, September 2-7, 1984. The members of IAPS are: Canada, the Czechoslovak Socialist Republic, the Federal Republic of Germany, France, Japan, the Union of Soviet Socialist Republics, the United Kingdom and the United States of America.

Contents of this Release

Appendix A contains a Table of Critically Evaluated Experimental Data. The original experimental data have been collected in the document "International Input of the Dynamic Viscosity of Water Substance", K. Scheffler, N. Rosner and M. Reimann (Institut A fuer Thermodynamik, Technische Universitaet Muenchen, revised ed., 1974). The tables give values reduced to a uniform grid with the aid of the algorithm described in the paper "The Dynamic Viscosity of Water Substance", K. Scheffler, J. Straub and U. Grigull, published in the Proceedings of the 7th Symposium on Thermophysical Properties, edited by A. Cezairliyan (American Society of Mechanical Engineers, New York, 1977), pp. 684-694.

The table in Appendix A also gives tolerances which constitute estimates of the reliability of the values given as agreed upon by IAPS.

Appendix B contains a Recommended Interpolating Equation. This equation reproduces the data given in Appendix A within the assigned tolerances. It is a slightly modified version of an interpolating equation issued by IAPS in September 1975. A discussion of the equation can be found in Sections 3 and 4 of the paper "Representative Equations for the Viscosity of Water Substance", J. V. Sengers and B. Kamgar-Parsi, Journal of Physical and Chemical Reference Data 13 (1984), pp. 185-205.

Appendix C gives tables of viscosity values calculated at selected grid points from the recommended interpolating equation defined in Appendix B. These represent smoothed and internally consistent viscosity values and are included for practical convenience.

Appendix A: Table of Critically Evaluated Experimental Data (reduced to a uniform grid).

Upper value: viscosity of water and steam, μ in μPa s ($\equiv 10^{-6}$ kg/m s).

Lower value: uncertainty in the viscosity, $\pm \Delta\mu$ in μPa s ($\equiv 10^{-6}$ kg/m s).

Pressure P in MPa.

Temperature t in °C.

Appendix A - Viscosity of Water and Steam

P/t	0	25	50	75	100	150	200
0.1	1791	890.9	547.1	377.3	12.42	14.29	16.26
	18	8.9	5.5	3.8	0.25	0.29	0.33
0.5	1790	891.2	546.7	378.0	281.7	182.3	16.05
	18	8.9	5.5	3.8	2.8	1.8	0.32
1.0	1789	891.1	546.8	378.2	281.9	182.4	15.92
	18	8.9	5.5	3.8	2.8	1.8	0.32
2.5	1786	890.8	547.1	378.5	282.3	182.8	134.6
	18	8.9	5.5	3.8	2.8	1.8	1.4
5.0	1780	890.3	547.7	379.2	283.1	183.4	135.2
	18	8.9	5.5	3.8	2.8	1.8	1.4
7.5	1774	889.8	548.3	379.8	283.8	184.1	135.9
	18	8.9	5.5	3.8	2.8	1.8	1.4
10.0	1768	889.4	548.7	380.4	284.7	184.7	136.4
	18	8.9	5.5	3.8	2.9	1.9	1.4
12.5	1762	889.1	549.1	381.0	285.3	185.3	137.0
	18	8.9	5.5	3.8	2.9	1.9	1.4
15.0	1756	888.7	549.5	381.6	286.0	185.0	137.6
	18	8.9	5.5	3.8	2.9	1.9	1.4
17.5	1750	888.5	550.0	382.3	286.7	186.6	138.2
	18	8.9	5.5	3.8	2.9	1.9	1.4
20.0	1744	888.2	550.4	382.9	287.4	187.3	138.8
	17	8.9	5.5	3.8	2.9	1.9	1.4
22.5	1738	887.9	550.9	383.5	288.0	187.9	139.4
	17	8.9	5.5	3.8	2.9	1.9	1.4
25.0	1733	887.6	551.3	384.2	288.7	189.5	140.0
	17	8.9	5.5	3.8	2.9	1.9	1.4
27.5	1728	887.4	551.8	384.8	289.4	189.1	140.6
	17	8.9	5.5	3.9	2.9	1.9	1.4
30.0	1723	887.2	552.3	385.5	290.0	189.8	141.2
	17	8.9	5.5	3.9	2.9	1.9	1.4
35.0	1713	886.8	553.3	386.7	291.4	191.0	142.3
	17	8.9	5.5	3.9	2.9	1.9	1.4
40.0	1705	886.6	554.3	388.0	292.7	192.2	143.5
	17	8.9	5.5	3.9	2.9	1.9	1.4
45.0	1697	886.5	555.3	389.3	294.0	193.4	144.6
	17	8.9	5.6	3.9	2.9	1.9	1.5
50.0	1690	886.4	556.3	390.6	295.4	194.6	145.8
	17	8.9	5.6	3.9	3.0	2.0	1.5
55.0	1684	886.5	557.4	392.0	296.7	195.8	146.9
	17	8.9	5.6	3.9	3.0	2.0	1.5
60.0	1679	886.7	558.5	393.3	298.0	197.0	148.0
	17	8.9	5.6	3.9	3.0	2.0	1.5
65.0	1674	886.9	559.7	394.6	299.4	198.2	149.0
	17	8.9	5.6	4.0	3.0	2.0	1.5
70.0	1670	887.3	560.9	395.9	300.7	199.4	150.1
	17	8.9	5.6	4.0	3.0	2.0	1.5
75.0	1666	887.7	562.0	397.3	302.0	200.6	151.2
	17	8.9	5.6	4.0	3.0	2.0	1.5
80.0	1662	888.3	563.3	398.6	303.4	201.8	152.3
	17	8.9	5.6	4.0	3.0	2.0	1.5
85.0	1659	888.8	564.5	400.0	304.6	203.0	153.3
	17	8.9	5.7	4.0	3.1	2.0	1.5
90.0	1656	889.5	565.8	401.4	305.9	204.2	154.3
	17	8.9	5.7	4.0	3.1	2.0	1.5
95.0	1653	890.3	567.1	402.8	307.3	205.4	155.4
	17	8.9	5.7	4.0	3.1	2.1	1.6
100.0	1651	891.1	568.4	404.2	308.6	206.5	156.4
	17	8.9	5.7	4.0	3.1	2.1	1.6

Appendix A (continued)

P/t	250	300	350	375	400	425	450
0.1	18.30	20.36	22.43	23.45	24.47	25.49	26.50
	0.37	0.41	0.45	0.47	0.49	0.51	0.53
0.5	18.16	20.25	22.32	23.43	24.44	25.49	26.53
	0.36	0.41	0.45	0.47	0.49	0.51	0.53
1.0	18.09	20.21	22.29	23.40	24.43	25.49	26.53
	0.36	0.40	0.45	0.47	0.49	0.51	0.53
2.5	17.85	20.07	22.22	23.37	24.41	25.49	26.54
	0.36	0.40	0.44	0.47	0.49	0.51	0.53
5.0	106.5	19.88	22.15	23.33	24.42	25.52	26.60
	1.1	0.40	0.44	0.47	0.49	0.51	0.53
7.5	107.2	19.75	22.12	23.34	24.46	25.58	26.68
	1.1	0.40	0.44	0.47	0.49	0.51	0.53
10.0	107.8	87.1	22.16	23.39	24.52	25.65	26.75
	1.1	1.7	0.44	0.47	0.49	0.51	0.53
12.5	108.5	88.0	22.35	23.57	24.69	25.81	26.91
	1.1	1.8	0.45	0.47	0.49	0.52	0.54
15.0	109.1	89.0	22.84	23.88	24.98	26.06	27.13
	1.1	1.8	0.46	0.48	0.50	0.52	0.54
17.5	109.8	89.9	67.3	24.49	25.37	26.38	27.42
	1.1	1.8	2.0	0.49	0.51	0.53	0.55
20.0	110.4	90.8	69.5	25.85	26.03	26.83	27.80
	1.1	1.8	2.1	0.52	0.52	0.54	0.56
22.5	111.1	91.6	71.4	48.2	27.11	27.50	28.31
	1.1	1.8	2.1	3.9	0.54	0.55	0.57
25.0	111.7	92.4	73.0	58.8	29.10	28.43	28.99
	1.1	1.9	2.2	1.2	0.58	0.57	0.58
27.5	112.3	93.1	74.4	62.4	33.88	29.81	29.84
	1.1	1.9	2.2	1.2	0.68	0.60	0.60
30.0	112.9	93.9	75.7	64.9	43.97	31.84	30.97
	1.1	1.9	2.3	1.3	0.88	0.64	0.62
35.0	114.1	95.3	78.0	68.6	56.4	39.47	34.19
	1.1	1.9	2.3	1.4	1.1	0.79	0.68
40.0	115.3	96.5	79.9	71.3	62.1	49.26	39.16
	1.2	1.9	2.4	1.4	1.2	0.99	0.78
45.0	116.4	97.8	81.7	73.7	65.8	55.6	44.87
	1.2	2.0	2.5	1.5	1.3	1.1	0.90
50.0	117.6	99.0	83.4	75.9	68.2	60.1	50.5
	1.2	2.0	2.5	2.3	2.0	1.8	1.5
55.0	118.7	100.2	84.9	77.8	70.9	63.6	55.3
	1.2	2.0	2.6	2.3	2.1	1.9	1.7
60.0	119.7	101.3	86.3	79.5	73.1	66.1	59.2
	1.2	2.0	2.6	2.4	2.2	2.0	1.8
65.0	120.8	102.5	87.7	81.1	75.2	68.1	62.3
	1.2	2.1	2.6	2.4	2.3	2.0	1.9
70.0	121.9	103.6	89.0	82.5	76.9	70.5	64.9
	1.2	2.1	2.7	2.5	2.3	2.1	2.0
75.0	122.9	104.6	90.3	83.9	78.5	72.2	66.9
	1.2	2.1	2.7	2.5	2.4	2.2	2.0
80.0	123.9	105.6	91.4	85.2	79.9	74.0	68.3
	1.2	2.1	2.7	2.6	2.4	2.2	2.1
85.0	124.9	106.6	92.6	86.4	81.4	75.8	70.2
	1.3	2.1	2.8	2.6	2.4	2.3	2.1
90.0	125.9	107.6	93.7	87.5	82.7	77.2	72.3
	1.3	2.2	2.8	2.6	2.5	2.3	2.2
95.0	126.9	108.6	94.7	88.7	83.6	78.6	73.8
	1.3	2.2	2.8	2.7	2.5	2.4	2.2
100.0	127.9	109.6	95.8	89.8	85.0	79.8	74.6
	1.3	2.2	2.9	2.7	2.6	2.4	2.2

Appendix A (continued)

P/t	475	500	550	600	650	700	750	800
0.1	27.51	28.52	30.53	32.55	34.6	36.6	38.6	40.5
	0.55	0.86	0.92	0.98	1.0	1.1	1.2	1.2
0.5	27.57	28.64	30.67	32.77	34.7	36.7	38.5	40.3
	0.55	0.86	0.92	0.98	1.0	1.1	1.2	1.2
1.0	27.58	28.65	30.68	32.79	34.8	36.8	38.5	40.4
	0.55	0.86	0.92	0.98	1.0	1.1	1.2	1.2
2.5	27.59	28.66	30.72	32.84	34.8	36.8	38.6	40.4
	0.55	0.86	0.92	0.99	1.0	1.1	1.2	1.2
5.0	27.66	28.73	30.82	32.77	34.9	36.9	38.7	40.6
	0.55	0.86	0.92	0.98	1.1	1.1	1.2	1.2
7.5	27.76	28.81	30.94	32.87	34.9	37.0	38.8	40.7
	0.56	0.86	0.93	0.99	1.1	1.1	1.2	1.2
10.0	27.82	28.95	31.08	33.02	35.1	37.2	39.0	40.9
	0.56	0.87	0.93	0.99	1.1	1.1	1.2	1.2
12.5	27.98	29.09	31.19	33.2	35.2	37.4	39.2	41.1
	0.56	0.87	0.94	1.0	1.1	1.1	1.2	1.2
15.0	28.18	29.30	31.44	33.4	35.5	37.6	39.4	41.2
	0.56	0.88	0.94	1.0	1.1	1.1	1.2	1.2
17.5	28.42	29.49	31.70	33.7	35.7	37.8	39.6	41.4
	0.57	0.88	0.95	1.0	1.1	1.1	1.2	1.2
20.0	28.76	29.81	31.98	33.9	35.9	38.0	39.8	41.6
	0.58	0.89	0.96	1.0	1.1	1.1	1.2	1.3
22.5	29.17	30.17	32.38	34.2	36.2	38.2	39.8	41.9
	0.58	0.91	0.97	1.0	1.1	1.2	1.2	1.3
25.0	29.70	30.56	32.73	34.5	36.5	38.5	40.2	41.9
	0.59	0.92	0.98	1.0	1.1	1.2	1.2	1.3
27.5	30.33	31.08	33.11	34.9	36.8	38.7	40.4	42.2
	0.61	0.93	0.99	1.1	1.1	1.2	1.2	1.3
30.0	31.06	31.68	33.6	35.3	37.2	39.0	40.7	42.5
	0.62	0.95	1.0	1.1	1.1	1.2	1.2	1.3
35.0	33.17	33.10	34.6	36.1	37.9	39.8	41.3	43.0
	0.66	0.99	1.0	1.1	1.1	1.2	1.2	1.3
40.0	36.06	35.2	35.7	37.5	38.8	40.4	42.0	43.7
	0.72	1.1	1.1	1.1	1.2	1.2	1.3	1.3
45.0	39.90	37.6	37.4	38.6	40.0	41.2	43.1	44.4
	0.80	1.1	1.1	1.2	1.2	1.2	1.3	1.3
50.0	44.0	40.5	39.1	40.0	40.6	42.2	43.7	45.3
	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.4
55.0	48.4	43.9	41.0	41.4	41.8	42.5	44.6	45.9
	1.5	1.3	1.2	1.2	1.3	1.3	1.3	1.4
60.0	52.3	47.6	43.1	41.7	42.9	43.2	44.8	46.6
	1.6	1.4	1.3	1.3	1.3	1.3	1.3	1.4
65.0	55.5	50.8	45.1	43.2	43.9	44.2	45.4	46.8
	1.7	1.5	1.4	1.3	1.3	1.3	1.4	1.4
70.0	58.8	53.7	47.5	44.8	44.3	44.4	46.2	47.4
	1.8	1.6	1.4	1.3	1.3	1.3	1.4	1.4
75.0	61.3	56.2	49.7	45.7	45.5	45.6	46.8	48.1
	1.8	1.7	1.5	1.4	1.4	1.4	1.4	1.4
80.0	63.6	58.7	52.1	47.4	47.0	46.6	47.3	48.6
	1.9	1.8	1.6	1.4	1.4	1.4	1.4	1.5
85.0	65.5	60.8	54.0	49.9	47.6	47.6	48.1	49.0
	2.0	1.8	1.6	1.5	1.4	1.4	1.4	1.5
90.0	67.3	62.8	55.8	51.4	48.9	49.1	48.9	49.7
	2.0	1.9	1.7	1.5	1.5	1.5	1.5	1.5
95.0	69.1	64.6	57.7	53.6	50.9	49.5	49.8	50.3
	2.1	1.9	1.7	1.6	1.5	1.5	1.5	1.5
100.0	69.8	66.1	59.3	55.1	52.1	50.5	51.1	51.0
	2.1	2.0	1.8	1.7	1.6	1.5	1.5	1.5

Appendix B: Recommended Interpolating Equation

B.1 Nomenclature

T denotes absolute temperature on the International Practical Temperature Scale of 1968

ρ denotes density[†]

P denotes pressure

μ denotes viscosity

B.2 Reference constants

Reference temperature: $T^* = 647.27$ K (1)

reference density: $\rho^* = 317.763$ kg/m^3 (2)

reference pressure: $P^* = 22.115 \times 10^6$ Pa (3)

reference viscosity: $\mu^* = 55.071 \times 10^{-6}$ Pa s (4)

The three reference constants T^*, ρ^*, P^* are close to but not identical with the critical constants.

B.3 Dimensionless variables

Temperature: $\bar{T} = T/T^*$ (5)

density: $\bar{\rho} = \rho/\rho^*$ (6)

pressure: $\bar{P} = P/P^*$ (7)

viscosity: $\bar{\mu} = \mu/\mu^*$ (8)

[†]For preference and to reproduce the values given in Appendix C, the density should be computed with the aid of the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use. If another density formulation is used, a relative departure of $\Delta\rho/\rho$ induces at most a relative departure $\pm \Delta\mu/\mu = 2.5\ \Delta\rho/\rho$ in viscosity.

B.4 Range of validity of equation

IAPS endorses the validity of Eq. (10) for the viscosity in the following range of pressures P and temperatures t

$$\begin{aligned} P \le 500 \text{ MPa} \quad &\text{for} \quad 0°C \le t \le 150°C \ , \\ P \le 350 \text{ MPa} \quad &\text{for} \quad 150°C \le t \le 600°C \ , \\ P \le 300 \text{ MPa} \quad &\text{for} \quad 600°C \le t \le 900°C \ . \end{aligned} \tag{9}$$

B.5 Interpolating equation

The viscosity is represented by the equation

$$\bar{\mu} = \bar{\mu}_o(\bar{T}) \times \bar{\mu}_1(\bar{T},\bar{\rho}) \times \bar{\mu}_2(\bar{T},\bar{\rho}) \ . \tag{10}$$

The first term of the product gives the viscosity of steam in the ideal-gas limit and has the form

$$\bar{\mu}_o(\bar{T}) = \frac{\sqrt{\bar{T}}}{\sum_{i=0}^{3} \frac{H_i}{\bar{T}^i}} \tag{11}$$

with the coefficients H_i given in Table B.1. The second multiplicative factor is

$$\bar{\mu}_1(\bar{T},\bar{\rho}) = \exp\left[\bar{\rho} \sum_{i=0}^{5} \sum_{j=0}^{6} H_{ij} \left(\frac{1}{\bar{T}} - 1\right)^i (\bar{\rho} - 1)^j\right] \tag{12}$$

with the coefficients H_{ij} given in Table B.II. For industrial use the function $\bar{\mu}_2$ may be taken to be unity everywhere in the range specified by (9):

$$\bar{\mu}_2 = 1 \quad . \tag{13}$$

For scientific use the function $\bar{\mu}_2$ is again given by (13) except for a very narrow near-critical range circumscribed by

$$0.9970 \leqslant \bar{T} \leqslant 1.0082 \quad , \quad 0.755 \leqslant \bar{\rho} \leqslant 1.290 \quad . \tag{14}$$

Inside the near-critical region (14) it is first necessary to calculate

$$\bar{\chi}_T \equiv \bar{\rho}\left(\frac{\partial\bar{\rho}}{\partial\bar{P}}\right)_{\bar{T}} \tag{15}$$

and then to interpret $\bar{\mu}_2$ as

$$\bar{\mu}_2 = 0.922\ \bar{\chi}_T^{\ 0.0263} \quad , \quad \text{if } \bar{\chi}_T \geqslant 21.93$$

$$\bar{\mu}_2 = 1 \quad , \quad \text{if } \bar{\chi}_T < 21.93. \tag{16}$$

Table B.I. Coefficients H_i for $\bar{\mu}_o(\bar{T})$

$$H_0 = 1.000\ 000$$

$$H_1 = 0.978\ 197$$

$$H_2 = 0.579\ 829$$

$$H_3 = -0.202\ 354$$

Table B.II. Coefficients H_{ij} for $\bar{\mu}_1(\bar{T},\bar{\rho})$

i	j	H_{ij}
0	0	H_{00} = 0.513 204 7
1	0	H_{10} = 0.320 565 6
4	0	H_{40} =-0.778 256 7
5	0	H_{50} = 0.188 544 7
0	1	H_{01} = 0.215 177 8
1	1	H_{11} = 0.731 788 3
2	1	H_{21} = 1.241 044
3	1	H_{31} = 1.476 783
0	2	H_{02} =-0.281 810 7
1	2	H_{12} =-1.070 786
2	2	H_{22} =-1.263 184
0	3	H_{03} = 0.177 806 4
1	3	H_{13} = 0.460 504 0
2	3	H_{23} = 0.234 037 9
3	3	H_{33} =-0.492 417 9
0	4	H_{04} =-0.041 766 10
3	4	H_{34} = 0.160 043 5
1	5	H_{15} =-0.015 783 86
3	6	H_{36} =-0.003 629 481

Note: Coefficients H_{ij} omitted from the table are all equal to zero identically.

Appendix C: Viscosity Calculated for Water and Steam

Table C.I. Smoothed Values of the Viscosity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation.

Viscosity μ in μPa.s ($\hat{=} 10^{-6}$ kg/m s).

Pressure P in MPa.

Temperature t in °C.

Table C.I lists smoothed values for the viscosity calculated with the aid of the interpolating equation defined in Appendix B and with density values from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

Note: For the purpose of program verification the tabular entries contain more digits than justified by the tolerances listed in the Table in Appendix A.

Table C.I. Smoothed values of the viscosity of ordinary water substance obtained with the aid of the recommended interpolating equation.[a] The viscosity, μ, is given in μPa·s[b]

p/MPa	Temperature, t/°C										
	0	25	50	75	100	150	200	250	300	350	375
0.1	1793.	890.5	547.0	377.9	12.27	14.18	16.18	18.22	20.29	22.37	23.41
0.5	1792.	890.4	547.1	378.0	281.9	182.5	16.05	18.14	20.24	22.34	23.39
1.0	1790.	890.3	547.2	378.1	282.1	182.6	15.89	18.04	20.18	22.31	23.37
2.5	1787.	889.9	547.5	378.5	282.5	183.0	134.6	17.76	20.02	22.23	23.31
5.0	1781.	889.4	547.9	379.1	283.1	183.7	135.2	106.4	19.80	22.12	23.25
7.5	1775.	888.9	548.4	379.8	283.8	184.3	135.8	107.1	19.66	22.09	23.25
10.0	1769.	888.4	548.8	380.4	284.5	184.9	136.4	107.8	86.51	22.15	23.33
12.5	1763.	888.0	549.3	381.1	285.2	185.5	137.1	108.5	87.48	22.37	23.51
15.0	1758.	887.5	549.8	381.7	285.8	186.1	137.7	109.2	88.39	22.94	23.86
17.5	1753.	887.2	550.3	382.4	286.5	186.8	138.3	109.8	89.27	67.00	24.51
20.0	1748.	886.8	550.8	383.1	287.2	187.4	138.8	110.4	90.11	69.33	25.92
22.5	1743.	886.5	551.3	383.7	287.8	188.0	139.4	111.1	90.92	71.20	47.98
25.0	1738.	886.2	551.8	384.4	288.5	188.6	140.0	111.7	91.71	72.80	58.22
27.5	1733.	885.9	552.3	385.0	289.2	189.2	140.6	112.3	92.47	74.22	61.96
30.0	1729.	885.7	552.8	385.7	289.8	189.8	141.2	112.9	93.21	75.50	64.57
35.0	1720.	885.3	553.9	387.1	291.2	191.0	142.3	114.1	94.63	77.78	68.39
40.0	1712.	885.1	555.0	388.4	292.5	192.2	143.4	115.2	95.98	79.79	71.31
45.0	1705.	884.9	556.2	389.8	293.8	193.4	144.5	116.4	97.27	81.59	73.73
50.0	1698.	884.9	557.4	391.1	295.1	194.6	145.6	117.5	98.52	83.26	75.85
55.0	1691.	884.9	558.6	392.5	296.5	195.7	146.7	118.5	99.72	84.80	77.74
60.0	1685.	885.1	559.8	393.9	297.8	196.9	147.8	119.6	100.9	86.25	79.46
65.0	1679.	885.4	561.1	395.3	299.1	198.1	148.8	120.6	102.0	87.62	81.06
70.0	1674.	885.8	562.4	396.7	300.5	199.2	149.9	121.7	103.1	88.92	82.54
75.0	1670.	886.2	563.7	398.1	301.8	200.4	150.9	122.7	104.2	90.16	83.95
80.0	1666.	886.8	565.0	399.5	303.1	201.5	151.9	123.7	105.2	91.36	85.27
85.0	1662.	887.5	566.4	400.9	304.4	202.6	153.0	124.6	106.2	92.50	86.54
90.0	1658.	888.2	567.8	402.3	305.7	203.7	154.0	125.6	107.2	93.61	87.74
95.0	1655.	889.1	569.3	403.8	307.1	204.9	155.0	126.6	108.2	94.68	88.90
100.0	1653.	890.0	570.7	405.2	308.4	206.0	155.9	127.5	109.1	95.72	90.01

[a] Table C.I lists smoothed values for the viscosity calculated with the aid of the interpolating equation defined in Appendix B and with density values from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

[b] μPa·s (≡ 10^{-6} kg/m·s)

Table C.I. (continued). Smoothed values of the viscosity of ordinary water substance obtained with the aid of the recommended interpolating equation.

p/MPa	Temperature, t/°C										
	400	425	450	475	500	550	600	650	700	750	800
0.1	24.45	25.49	26.52	27.55	28.57	30.61	32.61	34.60	36.55	38.48	40.37
0.5	24.44	25.48	26.52	27.55	28.58	30.62	32.63	34.61	36.57	38.49	40.39
1.0	24.42	25.47	26.51	27.55	28.58	30.63	32.64	34.63	36.59	38.52	40.41
2.5	24.39	25.46	26.52	27.57	28.61	30.67	32.70	34.69	36.65	38.58	40.48
5.0	24.37	25.46	26.55	27.62	28.68	30.76	32.81	34.81	36.78	38.71	40.60
7.5	24.40	25.52	26.62	27.71	28.78	30.88	32.94	34.95	36.92	38.84	40.73
10.0	24.48	25.62	26.73	27.83	28.91	31.02	33.09	35.10	37.07	38.99	40.88
12.5	24.65	25.78	26.90	28.00	29.08	31.20	33.26	35.27	37.24	39.16	41.04
15.0	24.93	26.03	27.13	28.21	29.29	31.40	33.46	35.46	37.42	39.34	41.21
17.5	25.36	26.37	27.42	28.49	29.54	31.63	33.68	35.67	37.62	39.53	41.39
20.0	26.03	26.85	27.81	28.82	29.85	31.90	33.92	35.90	37.84	39.73	41.58
22.5	27.14	27.52	28.31	29.24	30.21	32.21	34.19	36.15	38.07	39.95	41.79
25.0	29.18	28.45	28.96	29.75	30.64	32.55	34.49	36.42	38.32	40.18	42.00
27.5	33.97	29.81	29.78	30.36	31.14	32.94	34.82	36.71	38.58	40.42	42.23
30.0	43.99	31.86	30.85	31.10	31.73	33.37	35.17	37.02	38.86	40.68	42.47
35.0	55.78	39.42	34.03	33.08	33.19	34.37	35.97	37.70	39.47	41.23	42.97
40.0	61.31	48.61	39.02	35.88	35.11	35.59	36.90	38.47	40.13	41.83	43.52
45.0	65.07	54.96	45.05	39.58	37.56	37.03	37.95	39.32	40.86	42.47	44.10
50.0	68.01	59.39	50.50	43.84	40.48	38.71	39.14	40.26	41.65	43.16	44.71
55.0	70.48	62.80	54.89	48.07	43.72	40.59	40.44	41.27	42.49	43.89	45.36
60.0	72.64	65.60	58.45	51.89	47.03	42.64	41.85	42.35	43.38	44.65	46.04
65.0	74.57	68.01	61.42	55.22	50.19	44.81	43.36	43.50	44.32	45.45	46.75
70.0	76.32	70.13	63.97	58.13	53.12	47.02	44.93	44.70	45.30	46.28	47.47
75.0	77.94	72.04	66.23	60.69	55.79	49.23	46.56	45.95	46.31	47.14	48.22
80.0	79.45	73.79	68.25	62.97	58.22	51.39	48.20	47.22	47.34	48.01	48.98
85.0	80.87	75.40	70.10	65.04	60.43	53.46	49.85	48.52	48.39	48.90	49.76
90.0	82.21	76.91	71.80	66.93	62.45	55.44	51.49	49.82	49.46	49.81	50.54
95.0	83.49	78.33	73.38	68.67	64.32	57.32	53.09	51.13	50.53	50.71	51.33
100.0	84.70	79.67	74.86	70.29	66.06	59.10	54.66	52.42	51.61	51.63	52.12

Table C.II. Smoothed Values of the Viscosity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation, Calculated along the Saturation Line.

Viscosity of saturated vapor, μ'', and viscosity of saturated liquid, μ', in μPa s ($\hat{=} 10^{-6}$ kg/m s).

Pressure P in MPa.

Temperature t in °C.

Table C.II lists smoothed values for the viscosity calculated with the aid of the interpolating equation defined in Appendix B with saturation pressures and saturation densities from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

Table C.II. Smoothed values of the viscosity of ordinary water substance obtained with the aid of the recommended interpolating equation, calculated along the saturation line.[c] The viscosity of the saturated vapor, μ", and the viscosity of saturated liquid, μ', are given in μPa·s[d]

t °C	p MPa	μ' μPa s	μ'' μPa s
0.01	0.0006117	1792.	9.22
10.00	0.001228	1307.	9.46
20.00	0.002339	1002.	9.73
30.00	0.004246	797.7	10.01
40.00	0.007381	653.2	10.31
50.00	0.01234	547.0	10.62
60.00	0.01993	466.5	10.93
70.00	0.03118	404.0	11.26
80.00	0.04737	354.4	11.59
90.00	0.07012	314.5	11.93
100.00	0.10132	281.8	12.27
110.00	0.14324	254.8	12.61
120.00	0.19848	232.1	12.96
130.00	0.27002	213.0	13.30
140.00	0.36119	196.6	13.65
150.00	0.47572	182.5	13.99
160.00	0.61766	170.3	14.34
170.00	0.79147	159.6	14.68
180.00	1.002	150.2	15.02
190.00	1.254	141.8	15.37
200.00	1.554	134.4	15.71
210.00	1.906	127.6	16.06
220.00	2.318	121.6	16.41
230.00	2.795	116.0	16.76
240.00	3.345	110.9	17.12
250.00	3.974	106.2	17.49
260.00	4.689	101.7	17.88
270.00	5.500	97.55	18.27
280.00	6.413	93.56	18.70
290.00	7.438	89.71	19.15
300.00	8.584	85.95	19.65
310.00	9.861	82.21	20.20
320.00	11.279	78.45	20.84
330.00	12.852	74.57	21.60
340.00	14.594	70.45	22.55
350.00	16.521	65.87	23.81
360.00	18.655	60.39	25.71
370.00	21.030	52.25	29.57
371.00	21.283	50.97	30.33
372.00	21.539	49.38	31.30
373.00	21.799	48.01	33.13

[c] Table C.II lists smoothed values for the viscosity calculated with the aid of the interpolating equation defined in Appendix B with saturation pressures and saturation densities from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.

[d] μPa·s (≡ 10^{-6} kg/m·s)

The IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance

Issued by the International Association for the Properties of Steam

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This release is issued by the International Association for the Properties of Steam (IAPS) on the authority of the Tenth International Conference on the Properties of Steam, held in Moscow, USSR, September 2-7, 1984. The members of IAPS are: Canada, the Czechoslovak Socialist Republic, the Federal Republic of Germany, France, Japan, the Union of Soviet Socialist Republics, the United Kingdom and the United States of America.

Contents of this Release

The original experimental data have been collected in the document "Available Input of the Thermal Conductivity of Water Substance", K. Scheffler, M. Rosner and M. Reimann (Institut A für Thermodynamik, Technische Universität, München, revised ed. 1977).

The material contained in this release is identical to that contained in the Release on Thermal Conductivity of Water Substance, issued by IAPS in December 1977 except for some minor revisions to make the information consistent with the equations contained in the Release on the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use and in the Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.

Appendix A

Table A.I. Critically Evaluated Experimental Data Reduced to a Uniform Grid

Upper value: Thermal conductivity of water or steam, λ in mW/K m
Lower value: Uncertainty in the thermal conductivity, $\pm\Delta\lambda$ in mW/K m
Pressure, p, in MPa
Temperature t in °C

Extrapolated values distinguished by parentheses.

The isotherms and isobars represented by this table are not smooth but reflect the trends existing in the experimental data used in its construction.

Table A.II. Critically Evaluated Experimental Data Reduced to the Saturation Line

Thermal conductivity of saturated liquid, λ' , in mW/K m. Thermal conductivity of saturated vapor, λ'' , in mW/K m.

$\pm\Delta\lambda'$, $\pm\Delta\lambda''$ uncertainty in the above values in mW/K m. Pressure, p, in MPa
Temperature, t, in °C

Saturation pressures calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.

Table A.I. Critically Evaluated Experimental Data Reduced to a Uniform Grid

Pressure p, MPa	Temperature, t, °C											
	0.	25.	50.	75.	100.	150.	200.	250.	300.	350.	375.	400.
0.1	563	610	643	664	25.0	28.9	33.3	38.1	43.3	49.0	52.0	54.9
	11	9	9	10	0.5	0.6	0.7	0.8	0.9	1.0	1.0	1.1
0.5	563	610	643	664	680	688	34.1	38.7	43.7	49.1	52.6	55.5
	11	9	9	10	10	10	1.0	1.2	1.3	1.5	1.6	1.7
1.0	564	611	643	666	681	689	35.9	39.5	44.3	49.5	53.0	56.0
	11	9	9	10	10	10	1.4	1.2	1.3	1.5	1.6	1.7
2.5	566	611	644	666	682	690	668	43.8	46.5	50.9	54.7	56.9
	11	9	9	10	10	10	10	1.4	1.4	1.5	1.6	1.7
5.0	567	613	645	668	683	691	671	625	52.7	54.1	56.5	58.6
	11	12	12	13	13	13	13	12	1.6	1.9	1.7	1.8
7.5	570	614	647	669	685	694	673	628	63.6	59.6	60.5	62.7
	11	12	12	13	13	13	13	12	1.9	1.8	1.8	1.9
10.0	571	615	648	669	686	695	675	631	557	68.2	65.3	66.9
	11	12	13	13	13	13	13	12	11	2.0	2.1	2.0
12.5	571	616	649	672	687	697	678	634	562	81.2	73.6	72.4
	11	12	13	13	13	13	13	12	11	2.4	2.2	2.2
15.0	573	617	650	673	689	700	680	638	566	107.5	84.8	79.9
	11	12	13	13	13	14	13	12	11	6.7	2.5	2.4
17.5	573	618	651	674	691	701	682	639	571	452	104.2	90.0
	11	12	13	13	13	14	13	12	11	13	3.1	2.7
20.0	574	619	653	676	691	703	684	641	576	465	144.0	104.9
	11	12	13	13	13	14	13	12	11	14	4.7	3.1
22.5	574	620	654	678	692	705	686	646	581	476	478	124.1
	11	12	13	13	13	14	13	12	11	14	39	4.6
25.0	577	621	655	679	694	707	689	648	588	482	400	166.4
	11	12	13	13	13	14	13	13	11	14	14	6.7
27.5	578	622	656	680	696	708	690	651	589	490	413	240.8
	11	12	13	13	13	14	13	13	11	14	14	8.4
30.0	578	623	658	681	697	710	692	653	593	498	426	337
	11	12	13	13	13	14	13	13	11	15	13	12
35.0	580	625	660	684	700	714	696	660	601	511	453	384
	11	12	13	13	14	14	13	13	12	15	13	12
40.0	583	626	662	686	702	717	700	664	608	526	471	399
	11	12	13	13	14	14	14	13	12	15	14	16
45.0	584	629	664	690	705	721	704	670	615	537	486	425
	11	12	13	13	14	14	14	13	12	16	14	12
50.0	586	630	666	692	708	724	708	673	621	547	498	444
	11	12	13	13	14	14	14	13	12	44	40	36
55.0	589	633	667	694	710	726	712	678	629	558	510	461
	11	12	13	13	14	14	14	13	12	45	41	37
60.0	590	635	670	697	713	729	715	682	634	566	525	476
	11	12	13	13	14	14	14	13	12	45	42	38
65.0	592	638	673	699	715	733	718	688	639	574	535	489
	11	12	13	14	14	14	14	13	12	46	43	39
70.0	597	639	674	702	718	735	721	691	645	582	546	499
	11	12	13	14	14	14	14	13	12	47	44	40
75.0	599	641	675	705	720	738	725	696	643	589	554	511
	12	12	13	14	14	14	14	13	13	47	44	41
80.0	599	645	677	707	723	739	729	699	653	598	564	521
	12	12	13	14	14	14	14	14	13	48	45	42
85.0	601	646	680	706	726	742	732	702	659	604	571	532
	12	12	13	14	14	14	14	14	13	48	46	43
90.0	604	648	681	710	728	745	735	707	665	611	578	544
	12	13	13	14	14	14	14	14	13	49	46	44
95.0	608	650	685	713	731	748	739	711	669	615	586	553
	12	13	13	14	14	15	14	14	13	49	47	44
100.0	609	650	686	716	735	749	742	715	672	624	594	561
	12	13	13	14	14	15	14	14	13	50	47	45

Table A.I. (continued)

Pressure p, MPa	Temperature, t, °C									
	425.	450.	475.	500.	550.	600.	650.	700.	750.	800.
0.1	57.9	60.6	63.8	67.1	73.1	79.9	86.4	93.4	100.5	107.5
	1.2	1.2	1.3	1.3	1.5	2.4	2.6	2.8	3.0	3.2
0.5	58.5	61.4	64.5	67.7	74.0	80.5	87.2	93.8	100.9	108.0
	1.8	1.8	1.9	2.0	2.2	3.2	3.5	3.8	4.0	4.3
1.0	58.6	61.7	64.7	68.0	74.3	81.0	87.7	94.3	101.4	108.6
	1.8	1.9	1.9	2.0	2.2	3.2	3.5	3.8	4.1	4.3
2.5	59.6	62.6	65.6	68.7	75.1	81.5	88.8	95.3	102.4	109.5
	1.8	1.9	2.0	2.1	2.3	3.3	3.6	3.8	4.1	4.4
5.0	60.9	64.0	66.4	69.3	75.4	81.5	91.4	95.7	103.6	109.6
	1.8	1.9	2.0	2.1	2.3	3.3	3.7	3.8	4.1	4.4
7.5	64.0	66.7	69.5	73.3	80.0	87.3	96.4	101.0	108.1	112.4
	1.9	2.0	2.1	2.2	2.4	3.5	5.3	4.0	4.3	4.5
10.0	67.4	69.4	72.1	75.6	82.5	89.4	97.5	102.9	111.2	118.1
	2.0	2.1	2.2	2.3	2.5	3.6	4.6	4.1	5.1	5.2
12.5	72.0	74.1	76.1	79.4	85.0	90.7	97.9	102.9	109.9	116.3
	2.2	2.2	2.3	2.4	2.6	3.6	3.9	4.1	4.4	4.7
15.0	77.8	78.4	79.3	82.4	87.5	93.4	100.3	105.6	112.7	118.0
	2.3	2.4	2.4	2.5	2.6	3.7	4.0	4.2	4.5	4.7
17.5	84.8	84.0	84.2	85.7	90.2	96.2	102.5	106.0	114.4	119.7
	2.5	2.5	2.5	2.6	2.7	3.8	4.1	4.2	4.6	4.8
20.0	93.7	90.8	90.1	91.6	94.9	98.6	105.5	109.3	116.8	122.7
	2.8	2.7	2.7	2.7	3.0	3.9	4.2	4.4	4.7	4.9
22.5	105.9	98.6	95.9	96.0	98.1	102.6	107.6	112.1	119.2	123.7
	3.2	3.0	2.9	2.9	2.9	4.1	4.3	4.5	4.8	4.9
25.0	120.6	108.3	102.8	101.5	102.3	105.7	110.7	114.5	121.5	126.2
	3.6	3.2	3.1	3.0	3.1	4.2	4.4	4.6	4.9	5.0
27.5	139.2	120.3	111.1	107.3	106.1	108.7	113.0	118.0	123.4	127.8
	6.3	3.6	3.3	3.2	3.2	4.3	4.5	4.7	4.9	5.1
30.0	175.0	133.8	119.4	114.1	110.6	112.3	116.2	119.9	125.7	130.2
	8.1	4.0	3.6	3.4	3.3	4.5	4.6	4.8	5.0	5.2
35.0	260.5	176.3	144.3	129.7	121.1	119.8	122.7	125.1	130.0	134.6
	7.8	5.5	4.3	3.9	3.6	4.8	4.9	5.0	5.2	5.4
40.0	331	233.2	178.9	152.9	133.9	129.2	129.5	131.8	135.8	139.3
	11	7.2	5.5	4.6	4.0	5.2	5.2	5.3	5.4	5.6
45.0	365	287	219.0	180.1	148.2	138.5	136.4	137.7	141.1	144.5
	11	12	7.9	5.4	4.4	5.5	5.5	5.5	5.6	5.8
50.0	381	325	263	211	164	150	145	145	146	149
	30	26	21	17	13	12	12	12	12	12
55.0	401	354	297	244	184	162	154	152	153	155
	32	28	24	20	15	13	12	12	12	12
60.0	423	366	322	277	207	176	164	159	159	161
	34	29	26	22	16	14	13	13	13	13
65.0	438	387	332	299	228	191	175	168	166	167
	35	31	26	24	18	15	14	13	13	13
70.0	453	406	355	322	253	205	186	178	173	173
	36	32	28	26	21	16	15	14	14	14
75.0	467	421	376	327	269	218	198	186	180	178
	37	34	30	26	22	17	16	15	14	15
80.0	480	435	393	346	298	235	209	(196)	(190)	(185)
	38	35	31	28	34	19	17	16	15	15
85.0	488	448	410	366	312	246	222	(206)	(196)	(194)
	39	36	33	29	33	20	18	17	16	15
90.0	500	460	424	385	308	259	233	(215)	(205)	(201)
	40	37	34	31	25	21	19	17	16	16
95.0	510	473	434	396	322	273	243	(226)	(214)	(207)
	41	38	35	32	26	22	19	18	17	17
100.0	519	484	445	412	338	288	255	(236)	(221)	(215)
	42	39	36	33	27	23	20	19	18	17

Table A.II. Critically Evaluated Experimental Data Reduced to the Saturation Line.

t	p	λ'	$\pm\Delta\lambda'$	λ''	$\pm\Delta\lambda''$
0.01	0.0006117	565	11	16.7	0.5
10	0.001228	584	12	17.4	0.5
20	0.002339	602	12	18.1	0.5
30	0.004246	617	12	19.0	0.6
40	0.007381	631	13	19.7	0.6
50	0.01234	642	13	20.4	0.6
60	0.01993	652	13	21.2	0.6
70	0.03118	660	13	22.2	0.7
80	0.04737	669	13	23.1	0.7
90	0.07012	675	14	24.0	0.7
100	0.1013	679	14	25.0	0.8
110	0.1432	681	14	25.7	0.8
120	0.1985	685	14	26.8	0.8
130	0.2700	686	14	28.7	0.9
140	0.3612	686	14	29.7	0.9
150	0.4757	686	14	31.0	0.9
160	0.6177	682	14	31.9	1.3
170	0.7915	678	14	33.6	1.3
180	1.002	674	13	35.2	1.3
190	1.254	670	13	37.2	1.2
200	1.554	664	13	38.8	1.4
210	1.906	654	13	40.5	1.7
220	2.318	643	13	43.2	1.3
230	2.795	632	13	45.3	1.4
240	3.345	626	12	47.9	1.4
250	3.974	615	12	51.0	1.5
260	4.689	602	12	54.2	1.6
270	5.500	590	12	57.7	1.7
280	6.413	577	11	61.3	1.8
290	7.438	564	11	67.3	2.8
300	8.584	547	11	73.2	3.8
310	9.861	532	11	79.8	4.3
320	11.279	512	10	88.3	4.8
330	12.852	485	10	99.1	5.9
340	14.594	455	14	116.7	7.9
350	16.521	447	14	138	11
360	18.655	425	23	174	15
370	21.030	418	36	293	55
371	21.283	429	38	331	62
372	21.539	450	42	377	83
373	21.799	520	50	464	141

Appendix B: Recommended Interpolating Equation for Industrial Use

B.1. Nomenclature

T denotes absolute temperature on the International Practical Temperature Scale of 1968

ρ denotes density[†]

λ denotes thermal conductivity

B.2. Reference constants

Reference temperature: $T^* = 647.3\ K$ (1)

reference density: $\rho^* = 317.7\ kg/m^3$ (2)

reference thermal conductivity: $\lambda^* = 1\ W\ m^{-1}K^{-1}$ (3)

The two reference constants T^* and ρ^* are close to but not identical with the critical constants.

B.3. Dimensionless variables

Temperature: $\bar{T} = T/T^*$ (4)

density: $\bar{\rho} = \rho/\rho^*$ (5)

thermal conductivity: $\bar{\lambda} = \lambda/\lambda^*$ (6)

B.4 Range of Validity of equation

IAPS endorses the validity of Eq. (8) for the thermal conductivity in the following range of pressures P and temperatures t

$P \leqslant 100$ MPa for $0°C \leqslant t \leqslant 500°C$

$P \leqslant 70$ MPa for $500°C < t \leqslant 650°C$

$P \leqslant 40$ MPa for $650°C < t \leqslant 800°C$ (7)

[†]For preference, and to reproduce the values given in Appendix D, the density should be computed with the aid of the 1967 IFC Formulation for Industrial Use. If another density formulation is used, a relative departure of $\Delta\rho/\rho$ induces at most a relative departure $\pm\Delta\lambda/\lambda = 2\Delta\rho/\rho$ outside the near-critical region.

B.5. Interpolating equation

The values appearing in Tables A.I and A.II may be reproduced within the stated tolerances by the use of the following empirical interpolating equation which is recommended for industrial use. This equation yields a finite value of the thermal conductivity at the critical point instead of the theoretically justified infinity.

The interpolating equation for industrial use is defined by

$$\bar{\lambda} = \bar{\lambda}_o(\bar{T}) + \bar{\lambda}_1(\bar{\rho}) + \bar{\lambda}_2(\bar{T},\bar{\rho}) \quad . \tag{8}$$

The function $\bar{\lambda}_o(\bar{T})$ represents the thermal conductivity of steam in the ideal-gas limit and has the form

$$\bar{\lambda}_o(\bar{T}) = \sqrt{\bar{T}} \sum_{k=0}^{3} a_k \bar{T}^{\,k} \tag{9}$$

with the coefficients a_k given in Table B.I. The function $\bar{\lambda}_1(\rho)$ is defined by

$$\bar{\lambda}_1(\rho) = b_o + b_1\bar{\rho} + b_2 \exp\{B_1(\bar{\rho} + B_2)^2\} \tag{10}$$

with coefficients b_i and B_i given in Table B.II. The function $\bar{\lambda}_2(\bar{T},\bar{\rho})$ is defined by

$$\bar{\lambda}_2(\bar{T},\bar{\rho}) = \left(\frac{d_1}{\bar{T}^{\,10}} + d_2\right)\bar{\rho}^{\,9/5} \exp[C_1(1-\bar{\rho})^{14/5}]$$

$$+ d_3 S\, \bar{\rho}^{\,Q} \exp\left[\left(\frac{Q}{1+Q}\right)\left(1-\bar{\rho}^{\,1+Q}\right)\right] + d_4 \exp\left(C_2 \bar{T}^{\,3/2} + \frac{C_3}{\bar{\rho}^{\,5}}\right) \quad . \tag{11}$$

Here Q and S are functions of

$$\Delta\bar{T} = |\bar{T} - 1| + C_4 \quad , \tag{12}$$

where

$$Q = 2 + \frac{C_5}{\Delta\bar{T}^{3/5}} \tag{13}$$

$$S = \begin{cases} \dfrac{1}{\Delta\bar{T}} \text{ for } \bar{T} \geqslant 1 \\ \dfrac{C_6}{\Delta\bar{T}^{3/5}} \text{ for } \bar{T} < 1 \end{cases} \quad . \tag{14}$$

The coefficients d_i and C_i are given in Table B.III.

B.6. Remarks

Users should be aware of the fact that the above equation is subject to exponential underflows which most computers set to zero; this causes no errors in the final result.

The equation adopted in this Appendix is not the only possible, relatively simple, empirical interpolation formula. An alternative form has been proposed in Engineering Sciences Data Item No. 78039 (Engineering Sciences Data Unit, London, 1978), Appendix A.4.

Table B.I Coefficients a_k for $\overline{\lambda}_0(\overline{T})$

a_0 = 0.0102 811

a_1 = 0.0299 621

a_2 = 0.0156 146

a_3 = -0.0042 2464

Table B.II. Coefficients b_i and B_i for $\overline{\lambda}_1(\overline{\rho})$

b_0 =	-0.397 070	B_1 =	-0.171 587
b_1 =	0.400 302	B_2 =	2.392 190
b_2 =	1.060 000		

Table B.III. Coefficients d_i and C_i for $\overline{\lambda}_2(\overline{T}, \overline{\rho})$

d_1 =	0.0701 309	C_1 =	0.642 857
d_2 =	0.0118 520	C_2 =	-4.117 17
d_3 =	0.0016 9937	C_3 =	-6.179 37
d_4 =	-1.0200	C_4 =	0.003 089 76
		C_5 =	0.082 299 4
		C_6 =	10.093 2

Appendix C: Recommended Interpolating Equation for Scientific Use

C.1. Nomenclature

T denotes temperature on the International Practical Temperature Scale of 1968

ρ denotes density

P denotes pressure

λ denotes thermal conductivity

C.2. Reference constants

Reference temperature: $T^* = 647.27\ K$ (15)

reference density: $\rho^* = 317.763\ kg/m^3$ (16)

reference pressure: $P^* = 22.115 \times 10^6\ Pa$ (17)

reference thermal conductivity: $\lambda^* = 0.4945\ W\ m^{-1}K^{-1}$ (18)

The three reference constants T^*, ρ^*, P^* are close to but not identical with the critical constants.

C.3. Dimensionless variables

Temperature: $\bar{T} = T/T^*$ (19)

density: $\bar{\rho} = \rho/\rho^*$ (20)

pressure: $\bar{P} = P/P^*$ (21)

(symmetrized) compressibility: $\bar{\chi}_T = \bar{\rho}\left(\frac{\partial\bar{\rho}}{\partial\bar{P}}\right)_{\bar{T}}$ (22)

thermal conductivity: $\bar{\lambda} = \lambda/\lambda^*$ (23)

C.4. Range of validity of equation

IAPS endorses the validity of Eq. (25) for the thermal conductivity in the following range of pressures P and temperatures t

$P \leqslant 400$ MPa for $0°C \leqslant t \leqslant 125°C$

$P \leqslant 200$ MPa for $125°C < t \leqslant 250°C$

$P \leqslant 150$ MPa for $250°C < t \leqslant 400°C$

$P \leqslant 100$ MPa for $400°C < t \leqslant 800°C$ (24)

C.5. Interpolating equation

The values appearing in Tables A.I and A.II may also be reproduced within the stated tolerances by the following alternative equation which incorporates in it the present-day understanding of the nature of the critical anomaly in thermal conductivity. In particular, the thermal conductivity becomes infinite at the critical point.

The interpolating equation for scientific use is defined by

$$\bar{\lambda} = \bar{\lambda}_o(\bar{T}) \times \bar{\lambda}_1(\bar{T},\bar{\rho}) + \bar{\lambda}_2(\bar{T},\bar{\rho}) \quad . \tag{25}$$

The factor $\bar{\lambda}_o(\bar{T})$ represents the thermal conductivity of steam in the ideal-gas limit and has the form

$$\bar{\lambda}_o(\bar{T}) = \frac{\sqrt{\bar{T}}}{\sum_{i=0}^{3} \frac{L_i}{\bar{T}^i}} \tag{26}$$

with coefficients L_i given in Table C.I. The factor $\bar{\lambda}_1(\bar{T},\bar{\rho})$ is

$$\bar{\lambda}_1(\bar{T},\bar{\rho}) = \exp\left[\bar{\rho} \sum_{i=0}^{4} \sum_{j=0}^{5} L_{ij} \left(\frac{1}{\bar{T}} - 1\right)^i (\bar{\rho} - 1)^j\right] \tag{27}$$

with coefficients L_{ij} given in Table C.II. The additive term $\bar{\lambda}_2(\bar{T},\bar{\rho})$ in (25) which accounts for an enhancement of the thermal conductivity in the critical region, is defined by

$$\bar{\lambda}_2(\bar{T},\bar{\rho}) = \frac{0.0013848}{\bar{\mu}_o(\bar{T}) \times \bar{\mu}_1(\bar{T},\bar{\rho})} \left(\frac{\bar{T}}{\bar{\rho}}\right)^2 \left(\frac{\partial \bar{P}}{\partial \bar{T}}\right)_{\bar{\rho}}^2 \bar{\chi}_T \, 0.4678 \, \bar{\rho}^{1/2}$$

$$\times \exp[-18.66(\bar{T} - 1)^2 - (\bar{\rho} - 1)^4] \quad , \qquad (28)$$

where the functions $\bar{\mu}_o(\bar{T})$ and $\bar{\mu}_1(\bar{T},\bar{\rho})$ are those defined in Appendix B.5 of the Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance.

C.6. Remarks

To produce the values given in Appendix E, the density, the isothermal compressibility as well as the partial derivative $(\partial P/\partial T)_\rho$ should be calculated with the aid of the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use; otherwise, a consistent formulation must be adhered to. However, the Recommended Interpolating Equation for Scientific Use should not be employed in conjunction with the 1967 IFC Formulation for Industrial Use. If another density formulation is used, a relative departure $\pm\Delta\rho/\rho$ induces at most a relative departure $\pm\,\Delta\lambda/\lambda = 2\Delta\rho/\rho$, except for the near-critical region.

A further discussion of this equation can be found in Appendix II of the paper "Representative Equations for the Thermal Conductivity of Water Substance", J. V. Sengers, J. T. R. Watson, R. S. Basu, B. Kamgar-Parsi and R. C. Hendricks, Journal of Physical and Chemical Reference Data 13 (1984), pp. 893-933.

Table C.I. Coefficients L_i for $\bar{\lambda}_0(\bar{T})$

L_0	=	1.000 000
L_1	=	6.978 267
L_2	=	2.599 096
L_3	=	-0.998 254

Table C.II. Coefficients L_{ij} for $\bar{\lambda}_1(\bar{T}, \bar{\rho})$

j	L_{0j}	L_{1j}	L_{2j}	L_{3j}	L_{4j}
0	+1.329 304 6	+1.701 836 3	+5.224 615 8	+8.712 767 5	-1.852 599 9
1	-0.404 524 37	-2.215 684 5	-10.124 111	-9.500 061 1	+0.934 046 90
2	+0.244 094 90	+1.651 105 7	+4.987 468 7	+4.378 660 6	0.0
3	+0.018 660 751	-0.767 360 02	-0.272 976 94	-0.917 837 82	0.0
4	-0.129 610 68	+0.372 833 44	-0.430 833 93	0.0	0.0
5	+0.044 809 953	-0.112 031 60	+0.133 338 49	0.0	0.0

Appendix D

Table D.I. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance obtained with the Aid of the Recommended Interpolating Equation for Industrial Use, Calculated Over a Uniform Grid

Thermal conductivity, λ, in mW/K m; Pressure, p, in MPa; Temperature, t, in °C

Smoothed values obtained with the aid of the interpolating equation defined in Appendix B together with the constants listed therein, and density values based on the 1967 IFC Formulation for Industrial Use.

(Note: To assist in programming the tabular entries contain more significant digits than is justified by the tolerances listed in Table A.I.)

Table D.II. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Industrial Use, Calculated along the Saturation Line.

Thermal conductivity of saturated vapor, λ'' , and thermal conductivity of saturated liquid, λ' , in mW/K m; Pressure, p, in MPa; Temperature, t, in °C

Smoothed values obtained with the aid of the interpolating equation defined in Appendix B together with the constants listed therein, saturation pressures and saturation densities from the 1967 IFC Formulation for Industrial Use.

(Note: To assist in programming the tabular entries contain more significant digits than is justified by the tolerances listed in Table A.II.)

Table D.I. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Industrial Use, Calculated over a Uniform Grid

p	TEMPERATURE, °C										
MPa	0	25	50	75	100	150	200	250	300	350	375
.1	562.0	607.6	640.5	663.3	24.8	28.8	33.4	38.3	43.5	49.0	51.8
.5	562.2	607.8	640.7	663.5	677.7	683.6	34.2	38.8	43.9	49.3	52.1
1.0	562.5	608.1	641.0	663.8	678.0	683.9	36.1	39.7	44.5	49.8	52.6
2.5	563.4	608.9	641.8	664.6	678.8	685.0	664.2	43.9	46.8	51.5	54.1
5.0	564.8	610.2	643.0	665.9	680.2	686.7	666.5	619.5	53.0	55.2	57.1
7.5	566.3	611.5	644.3	667.3	681.7	688.4	668.7	622.7	64.1	60.6	61.1
10.0	567.7	612.8	645.6	668.6	683.1	690.0	670.8	625.8	548.2	68.6	66.4
12.5	569.2	614.1	646.9	669.9	684.4	691.7	672.9	628.9	553.7	81.1	73.7
15.0	570.6	615.4	648.2	671.2	685.8	693.3	675.0	631.9	558.9	104.2	84.5
17.5	572.1	616.7	649.4	672.5	687.2	694.9	677.1	634.8	563.9	441.6	103.2
20.0	573.5	618.0	650.7	673.8	688.5	696.5	679.2	637.7	568.6	453.8	145.5
22.5	574.9	619.3	651.9	675.0	689.9	698.1	681.2	640.5	573.2	464.3	498.6
25.0	576.4	620.5	653.2	676.3	691.2	699.7	683.1	643.2	577.5	473.7	386.3
27.5	577.8	621.8	654.4	677.6	692.6	701.3	685.1	645.9	581.8	482.3	405.5
30.0	579.2	623.1	655.6	678.8	693.9	702.8	687.0	648.5	585.8	490.1	420.6
35.0	582.0	625.6	658.0	681.3	696.5	705.9	690.8	653.6	593.6	504.3	443.9
40.0	584.8	628.1	660.5	683.8	699.1	708.9	694.5	658.5	600.9	516.8	462.4
45.0	587.6	630.6	662.8	686.2	701.6	711.8	698.1	663.3	607.8	528.1	478.0
50.0	590.4	633.0	665.2	688.6	704.1	714.7	701.7	667.9	614.3	538.4	491.7
55.0	593.1	635.4	667.6	691.0	706.6	717.6	705.1	672.4	620.5	547.9	503.9
60.0	595.8	637.9	669.9	693.3	709.1	720.4	708.5	676.7	626.5	556.6	515.1
65.0	598.5	640.3	672.2	695.7	711.5	723.1	711.9	680.9	632.2	565.1	525.3
70.0	601.1	642.6	674.5	698.0	713.9	725.9	715.1	685.0	637.7	572.9	534.8
75.0	603.8	645.0	676.7	700.3	716.3	728.6	718.3	689.0	642.9	580.3	543.6
80.0	606.3	647.4	679.0	702.5	718.6	731.2	721.5	692.9	648.0	587.3	551.9
85.0	608.9	649.7	681.2	704.8	721.0	733.9	724.6	696.7	653.0	593.9	559.6
90.0	611.4	652.0	683.4	707.0	723.3	736.5	727.6	700.4	657.7	600.3	567.2
95.0	613.9	654.3	685.6	709.2	725.6	739.0	730.6	704.1	662.4	606.4	574.2
100.0	616.3	656.6	687.8	711.4	727.8	741.6	733.6	707.6	666.9	612.3	581.0

Table D.I (continued)

p	TEMPERATURE, °C										
MPa	400	425	450	475	500	550	600	650	700	750	800
.1	54.7	57.7	60.7	63.8	66.9	73.3	79.9	86.7	93.6	100.6	107.7
.5	55.0	58.0	61.0	64.0	67.2	73.5	80.1	86.9	93.8	100.8	107.9
1.0	55.4	58.4	61.3	64.4	67.5	73.9	80.4	87.2	94.0	101.0	108.1
2.5	56.8	59.6	62.5	65.5	68.6	74.9	81.4	88.0	94.9	101.8	108.9
5.0	59.5	62.1	64.8	67.6	70.6	76.7	83.0	89.6	96.3	103.2	110.2
7.5	62.9	65.1	67.5	70.1	72.8	78.7	84.8	91.2	97.8	104.6	111.5
10.0	67.3	68.6	70.6	72.8	75.3	80.8	86.8	93.0	99.5	106.1	112.9
12.5	72.8	73.0	74.2	76.0	78.2	83.2	88.9	94.9	101.2	107.7	114.4
15.0	80.0	78.3	78.5	79.7	81.4	85.9	91.1	96.9	103.0	109.4	116.0
17.5	89.6	85.0	83.7	83.9	85.0	88.8	93.6	99.1	105.0	111.2	117.6
20.0	103.4	93.4	89.8	88.8	89.1	91.9	96.2	101.4	107.0	113.1	119.3
22.5	124.3	104.3	97.2	94.5	93.8	95.4	99.1	103.8	109.2	115.0	121.1
25.0	159.7	118.9	106.3	101.1	99.1	99.3	102.2	106.4	111.5	117.0	123.0
27.5	234.5	138.9	117.6	108.9	105.1	103.5	105.5	109.2	113.9	119.2	124.9
30.0	326.0	167.0	131.6	118.1	111.9	108.1	109.0	112.1	116.4	121.4	126.9
35.0	372.6	254.6	170.9	141.7	128.6	118.6	116.9	118.5	121.8	126.2	131.2
40.0	398.8	320.2	226.0	173.5	149.9	131.2	125.9	125.7	127.8	131.3	135.8
45.0	420.4	354.6	278.0	212.7	176.1	146.0	136.2	133.6	134.3	136.9	140.7
50.0	438.8	379.7	315.3	251.9	205.8	163.0	147.6	142.3	141.4	142.9	145.9
55.0	454.8	400.6	342.8	285.2	236.6	181.9	160.3	151.8	149.0	149.3	151.5
60.0	469.0	418.6	365.4	312.4	264.6	202.1	174.0	162.0	157.2	156.2	157.3
65.0	481.8	434.6	384.8	335.3	289.4	222.6	188.7	172.8	165.8	163.3	163.5
70.0	493.5	448.9	401.9	355.1	311.2	242.7	203.9	184.3	174.9	170.9	169.9
75.0	504.2	461.9	417.3	372.8	330.6	261.8	219.4	196.2	184.4	178.7	176.7
80.0	514.2	473.9	431.3	388.7	348.2	279.8	234.8	208.5	194.2	186.9	183.6
85.0	523.5	484.9	444.2	403.2	364.1	296.8	249.9	221.0	204.3	195.2	190.7
90.0	532.3	495.2	456.1	416.6	378.8	312.7	264.4	233.4	214.6	203.8	198.0
95.0	540.6	504.9	467.2	429.0	392.3	327.6	278.5	245.8	225.0	212.5	205.5
100.0	548.4	514.0	477.6	440.6	404.8	341.7	292.1	257.9	235.6	221.3	213.0

Table D.II.

t	p	λ'	λ''
0.01	0.0006112	561.97	16.49
10.00	0.001227	581.94	17.21
20.00	0.002337	599.61	17.95
30.00	0.004241	615.05	18.70
40.00	0.007375	628.62	19.48
50.00	0.01233	640.47	20.28
60.00	0.01992	650.75	21.10
70.00	0.03116	659.49	21.96
80.00	0.04736	666.75	22.86
90.00	0.07011	672.80	23.80
100.00	0.1013	677.46	24.79
110.00	0.1433	680.91	25.84
120.00	0.1985	683.29	26.96
130.00	0.2701	684.47	28.15
140.00	0.3614	684.50	29.42
150.00	0.4760	683.54	30.77
160.00	0.6181	681.57	32.22
170.00	0.7920	678.46	33.77
180.00	1.003	674.47	35.42
190.00	1.255	669.41	37.20
200.00	1.555	663.37	39.10
210.00	1.908	656.35	41.14
220.00	2.320	648.29	43.35
230.00	2.798	639.31	45.74
240.00	3.348	629.22	48.34
250.00	3.978	618.11	51.18
260.00	4.694	605.93	54.33
270.00	5.506	592.56	57.84
280.00	6.420	578.00	61.82
290.00	7.446	562.22	66.40
300.00	8.593	545.01	71.78
310.00	9.870	526.40	78.26
320.00	11.29	506.27	86.34
330.00	12.86	484.49	96.93
340.00	14.60	461.10	111.79
350.00	16.53	436.27	134.59
360.00	18.67	411.84	176.79
370.00	21.05	416.36	306.42
371.00	21.31	429.03	342.42
372.00	21.56	454.72	396.08
373.00	21.82	517.54	490.23

Appendix E

Table E.I. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Scientific Use, Calculated Over a Uniform Grid

Thermal conductivity, λ, in mW/K m; Pressure, p, in MPa; Temperature, t, in °C

Smoothed values obtained with the aid of the interpolating equation defined in Appendix C together with the constants listed therein, and density values as well as the values of thermodynamic derivatives based on the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.

(Note: To assist in programming the tabular entries contain more significant digits than is justified by the tolerances listed in Table A.l.)

Table E.II. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Scientific Use, Calculated along the Saturation Line.

Thermal conductivity of saturated vapor, λ'' , and thermal conductivity of saturated liquid, λ' , in mW/K m; Pressure, p, in MPa; Temperature, t, in °C

Smoothed values obtained with the aid of the interpolating equation defined in Appendix C together with the constants listed therein with saturation pressures and saturation densities as well as the values of the thermodynamic derivatives based on the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Substance for Scientific and General Use.

(Note: To assist in programming the tabular entries contain more significant digits than is justified by the tolerances listed in Table A.ll.)

Table E.I. Smoothed values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Scientific Use Calculated Over a Uniform Grid.

p	TEMPERATURE, °C										
MPa	0	25	50	75	100	150	200	250	300	350	375
.1	561.0	607.2	643.6	666.8	25.08	28.85	33.28	38.17	43.42	48.96	51.83
.5	561.2	607.4	643.7	667.0	679.3	682.1	34.93	39.18	44.09	49.44	52.25
1.0	561.5	607.6	644.0	667.2	679.6	682.4	37.21	40.51	44.95	50.06	52.79
2.5	562.4	608.3	644.7	668.0	680.4	683.4	664.2	45.16	47.62	52.06	54.52
5.0	563.7	609.4	645.8	669.2	681.8	685.1	666.4	622.7	53.86	55.99	57.87
7.5	565.1	610.5	647.0	670.5	683.2	686.8	668.6	625.9	63.12	61.06	62.00
10.0	566.5	611.7	648.2	671.7	684.5	688.5	670.7	629.0	550.9	68.11	67.35
12.5	567.9	612.8	649.3	673.0	685.9	690.2	672.8	632.0	556.5	79.15	74.68
15.0	569.3	613.9	650.5	674.2	687.2	691.8	674.9	635.0	561.6	100.9	85.53
17.5	570.6	615.1	651.6	675.5	688.6	693.5	677.0	637.9	566.8	452.3	103.7
20.0	572.0	616.2	652.8	676.7	690.0	695.1	679.1	640.8	571.6	463.3	142.1
22.5	573.4	617.3	654.0	678.0	691.3	696.8	681.2	643.6	576.2	472.8	440.3
25.0	574.8	618.5	655.1	679.2	692.7	698.4	683.2	646.3	580.7	481.3	411.2
27.5	576.1	619.6	656.3	680.4	694.0	700.1	685.3	649.1	585.0	489.1	425.7
30.0	577.5	620.8	657.4	681.7	695.3	701.7	687.3	651.8	589.1	496.3	437.9
35.0	580.2	623.0	659.8	684.1	698.0	704.9	691.3	657.0	597.1	509.3	457.4
40.0	582.9	625.3	662.1	686.6	700.7	708.2	695.3	662.2	604.6	521.0	473.1
45.0	585.5	627.5	664.4	689.1	703.3	711.4	699.3	667.2	611.7	531.7	486.5
50.0	588.1	629.8	666.7	691.5	706.0	714.6	703.2	672.1	618.5	541.7	498.4
55.0	590.7	632.0	668.9	693.9	708.6	717.7	707.0	676.9	625.1	551.0	509.3
60.0	593.3	634.2	671.2	696.3	711.2	720.9	710.9	681.6	631.3	559.7	519.4
65.0	595.8	636.4	673.5	698.7	713.8	724.0	714.7	686.3	637.4	568.0	528.8
70.0	598.3	638.6	675.7	701.1	716.4	727.2	718.5	690.8	643.2	575.9	537.6
75.0	600.7	640.8	678.0	703.5	719.0	730.3	722.2	695.3	648.9	583.4	546.1
80.0	603.1	642.9	680.2	705.9	721.5	733.4	726.0	699.8	654.5	590.6	554.1
85.0	605.5	645.1	682.4	708.2	724.1	736.4	729.7	704.2	659.9	597.5	561.7
90.0	607.8	647.2	684.6	710.5	726.6	739.5	733.4	708.6	665.1	604.2	569.1
95.0	610.0	649.3	686.8	712.9	729.1	742.6	737.1	712.9	670.3	610.6	576.1
100.0	612.2	651.3	688.9	715.2	731.6	745.6	740.7	717.2	675.4	616.8	583.0

Table E.I. (continued)

p	TEMPERATURE, °C										
MPa	400	425	450	475	500	550	600	650	700	750	800
.1	54.76	57.74	60.77	63.85	66.97	73.35	79.89	86.57	93.37	100.3	107.3
.5	55.13	58.08	61.08	64.14	67.25	73.61	80.13	86.80	93.59	100.5	107.5
1.0	55.61	58.51	61.48	64.51	67.60	73.93	80.44	87.09	93.87	100.8	107.8
2.5	57.15	59.89	62.75	65.69	68.71	74.94	81.39	88.01	94.75	101.6	108.5
5.0	60.06	62.49	65.10	67.86	70.74	76.79	83.13	89.67	96.34	103.1	109.9
7.5	63.56	65.54	67.82	70.33	73.03	78.84	85.04	91.49	98.08	104.8	111.5
10.0	67.89	69.19	71.00	73.16	75.61	81.11	87.14	93.47	99.97	106.5	113.2
12.5	73.40	73.63	74.73	76.43	78.53	83.62	89.43	95.63	102.0	108.5	115.0
15.0	80.68	79.13	79.18	80.20	81.85	86.39	91.92	97.96	104.2	110.6	116.9
17.5	90.74	86.10	84.54	84.58	85.61	89.45	94.63	100.5	106.6	112.8	119.0
20.0	105.4	95.11	91.03	89.70	89.89	92.81	97.57	103.2	109.1	115.2	121.2
22.5	128.5	107.0	98.99	95.69	94.75	96.51	100.7	106.0	111.8	117.7	123.5
25.0	169.0	123.1	108.8	102.7	100.3	100.6	104.1	109.1	114.6	120.3	126.0
27.5	248.4	145.4	121.0	111.0	106.6	105.0	107.8	112.4	117.6	123.1	128.6
30.0	329.7	176.1	136.0	120.6	113.7	109.8	111.7	115.8	120.7	126.0	131.3
35.0	384.5	259.3	176.4	144.8	130.7	120.8	120.3	123.3	127.5	132.2	137.0
40.0	414.0	323.5	227.7	175.8	151.6	133.5	130.0	131.5	134.8	138.8	143.1
45.0	435.0	363.6	276.6	211.5	176.1	147.9	140.6	140.3	142.6	145.9	149.6
50.0	451.5	391.5	315.8	247.3	202.8	163.7	152.1	149.8	150.9	153.4	156.4
55.0	465.4	412.8	346.6	279.8	229.9	180.6	164.3	159.8	159.6	161.2	163.4
60.0	477.6	429.9	371.2	308.2	255.9	198.1	177.0	170.1	168.5	169.1	170.6
65.0	488.5	444.3	391.4	332.6	279.9	215.5	189.9	180.6	177.6	177.2	177.9
70.0	498.6	456.9	408.3	353.6	301.7	232.5	202.7	191.0	186.7	185.3	185.2
75.0	507.9	468.1	422.9	371.9	321.4	249.0	215.3	201.4	195.6	193.3	192.4
80.0	516.7	478.3	435.7	387.8	339.1	264.6	227.5	211.5	204.4	201.1	199.6
85.0	525.1	487.7	447.2	402.0	355.1	279.5	239.3	221.2	212.9	208.8	206.5
90.0	533.0	496.4	457.6	414.6	369.6	293.5	250.6	230.6	221.1	216.1	213.1
95.0	540.6	504.7	467.1	426.1	382.7	306.8	261.5	239.5	228.8	223.1	219.5
100.0	547.9	512.6	476.0	436.5	394.8	319.2	271.8	248.0	236.2	229.7	225.5

Table E.II

t	p	λ'	λ''
.01	.0006117	561.0	17.07
10.00	.001228	580.0	17.62
20.00	.002339	598.4	18.23
30.00	.004246	615.4	18.89
40.00	.007381	630.5	19.60
50.00	.01234	643.5	20.36
60.00	.01993	654.3	21.18
70.00	.03118	663.1	22.07
80.00	.04737	670.0	23.01
90.00	.07012	675.3	24.02
100.00	.1013	679.1	25.09
110.00	.1432	681.7	26.24
120.00	.1985	683.2	27.46
130.00	.2700	683.7	28.76
140.00	.3612	683.3	30.14
150.00	.4757	682.1	31.59
160.00	.6177	680.0	33.12
170.00	.7915	677.1	34.74
180.00	1.0019	673.4	36.44
190.00	1.254	668.8	38.23
200.00	1.554	663.4	40.10
210.00	1.906	657.1	42.07
220.00	2.318	649.8	44.15
230.00	2.795	641.4	46.35
240.00	3.345	632.0	48.70
250.00	3.974	621.4	51.23
260.00	4.689	609.4	53.98
270.00	5.500	596.1	57.04
280.00	6.413	581.4	60.52
290.00	7.438	565.2	64.59
300.00	8.584	547.7	69.49
310.00	9.861	529.0	75.61
320.00	11.279	509.4	83.59
330.00	12.852	489.2	94.48
340.00	14.594	468.6	110.2
350.00	16.521	447.6	134.7
360.00	18.655	427.2	178.0
370.00	21.030	428.0	299.4
371.00	21.283	438.4	334.9
372.00	21.539	461.6	394.2
373.00	21.799	544.0	532.1

Release on
The IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use

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The formulation provided in this release is recommended for scientific and general use; it is a dimensionless version of the formulation issued on January 20, 1984 as the "Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use". This formulation provides the most accurate representation of the thermodynamic properties of the fluid phases of water substance over a wide range of conditions currently attainable.

The 1967 IFC Formulation for Industrial Use retains its status and remains intact. Further information can be obtained from the Executive Secretary of IAPS.

Appendix: The IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.

1. Dimensionless variables and reference constants

All equations in this release are presented in non-dimensional form. The dimensionless version of each quantity is denoted by a symbol with a bar. The reference quantities consist of two classes: three primary reference quantities (denoted by an asterisk) and three secondary reference quantities (denoted by a double asterisk) which are simple combinations of the primary reference quantities.

1.1. Primary reference constants

Reference temperature: $T^* = 647.27\ K$ (1)

reference density: $\rho^* = 317.763\ kg/m^3$ (2)

reference pressure: $P^* = 22.115 \times 10^6\ Pa$ (3)

The three reference constants T^*, ρ^*, P^* are close to but not identical with the critical constants.

1.2. Secondary reference constants

Reference constant for Helmholtz function, internal energy, enthalpy, Gibbs function: $\bar{A}^{**} \equiv \frac{P^*}{\rho^*} = 69595.89\ J/kg$ (4)

reference constant for entropy, specific heats: $S^{**} \equiv \frac{P^*}{\rho^* T^*} = 107.5222\ J/kg\ K$ (5)

reference constant for sound velocity: $w^{**} \equiv \left[\frac{P^*}{\rho^*}\right]^{\frac{1}{2}} = 263.810\ m/s$ (6)

1.3 Thermodynamic properties in dimensionless form

Temperature[†]:	$\bar{T} = T/T^*$	(7)
pressure:	$\bar{P} = P/P^*$	(8)
density:	$\bar{\rho} = \rho/\rho^*$	(9)
specific volume:	$\bar{V} = V\rho^*$	(10)
specific Helmholtz function:	$\bar{A} = A/A^{**}$	(11)
specific energy	$\bar{U} = U/A^{**}$	(12)
specific enthalpy:	$\bar{H} = H/A^{**}$	(13)
specific Gibbs function:	$\bar{G} = G/A^{**}$	(14)
specific entropy:	$\bar{S} = S/S^{**}$	(15)
specific heat at constant volume:	$\bar{C}_v = C_v/S^{**}$	(16)
specific heat at constant pressure:	$\bar{C}_p = C_p/S^{**}$	(17)
isothermal compressibility:	$\bar{K}_T = K_T P^*$	(18)
speed of sound:	$w = w/w^{**}$	(19)

[†]Note: T denotes absolute temperature on the International Practical Temperature Scale of 1968. No distinction is made between this temperature scale and the thermodynamic temperature scale.

2. Equations for thermodynamic properties

The formulation is based on a fundamental equation for the Helmholtz function expressed in terms of temperature and density.

2.1. Fundamental equation in canonical form

The fundamental equation is defined as

$$\bar{A}(\bar{T},\bar{\rho}) = \bar{A}_0(\bar{T}) + \bar{A}_1(\bar{T},\bar{\rho}) + \bar{A}_2(\bar{T},\bar{\rho}) + \bar{A}_3(\bar{T},\bar{\rho}) + \bar{A}_4(\bar{T},\bar{\rho}) \quad (20)$$

with

$$\bar{A}_0(\bar{T}) = (A_{00} + A_{01}\bar{T}) \ln \bar{T} + \sum_{i=2}^{17} A_{0i} \bar{T}^{i-4} \quad . \tag{21}$$

$$\bar{A}_1(\bar{T},\bar{\rho}) = \bar{\rho} \sum_{i=0}^{4} A_{1i} \left[\frac{1}{\bar{T}}\right]^{i-1} \quad . \tag{22}$$

$$\bar{A}_2(\bar{T},\bar{\rho}) = A_{20} \bar{T} \left[\ln\left(\frac{\bar{\rho}}{1-y}\right) - \frac{130}{3(1-y)} + \frac{169}{6(1-y)^2} - 14y \right] \tag{23}$$

$$\text{with} \quad y = \bar{\rho} \left[y_0 + y_1 \ln \bar{T} + \frac{y_2}{\bar{T}^3} + \frac{y_3}{\bar{T}^5} \right] \quad .$$

$$\bar{A}_3(\bar{T},\bar{\rho}) = \sum_{i=0}^{35} A_{3i} \left[\frac{1}{\bar{T}}\right]^{\ell(i)} z^{k(i)} \quad , \tag{24}$$

$$\text{with} \quad z = 1 - e^{-z_0\bar{\rho}} \quad .$$

$$\bar{A}_4(\bar{T},\bar{\rho}) = \sum_{i=0}^{3} A_{4i} \delta_i^{n(i)} \exp\left[-\alpha_i \delta_i^{m(i)} - \beta_i \tau_i^2\right] \quad , \tag{25}$$

$$\text{with} \quad \delta_i = \frac{\bar{\rho} - \bar{\rho}_i}{\bar{\rho}_i} \quad , \quad \tau_i = \frac{\bar{T} - \bar{T}_i}{\bar{T}_i} \quad .$$

2.2. Coefficients in the equations for the Helmholtz function $\bar{A}(\bar{T},\bar{\rho})$

The coefficients in the equations for the Helmholtz function are listed in Tables 1 through 5. In all tables presented in this release the "E-notation" has been adopted. That is, the integer which follows E indicates the power of ten by which the listed coefficient should be multiplied. Thus E + 2 represents the factor $10^2 = 100$, etc.

Note: The specific internal energy of the liquid at the triple point, U_{tr}, and the specific entropy of the liquid at the triple point, S_{tr}, have been set equal to zero. As a consequence the specific enthalpy of the liquid at the triple point becomes different from zero. Thus for the liquid at the triple point

$$T_{tr} = 273.16 \text{ K} \ , \quad P_{tr} = 611.73 \text{ Pa} \ , \tag{26}$$

$$U_{tr} = 0 \ , \quad S_{tr} = 0 \ , \tag{27}$$

$$H_{tr} = 0.61187 \text{ J/kg} \ . \tag{28}$$

In the liquid-water region small changes in density along an isotherm cause large changes in pressure. For this reason, due to an accumulation of small errors, a particular computer code may fail to return the zeros (27) at the triple-point density which corresponds to the above values of P_{tr} and T_{tr}. In order to avoid this blemish it is advisable to adjust the constants A_{04} and A_{05} in (21) by imposing condition (27) with the desired accuracy.

2.3. Thermodynamic relations

All thermodynamic properties of interest can be derived from the fundamental equation (20) by the use of the following thermodynamic relations

$$\bar{V} = \bar{\rho}^{-1} \tag{29}$$

$$\bar{P} = \bar{\rho}^2 \left(\frac{\partial \bar{A}}{\partial \bar{\rho}}\right)_{\bar{T}} \tag{30}$$

$$\left(\frac{\partial \bar{P}}{\partial \bar{\rho}}\right)_{\bar{T}} = \frac{2\bar{P}}{\bar{\rho}} + \bar{\rho}^2 \left(\frac{\partial^2 \bar{A}}{\partial \bar{\rho}^2}\right)_{\bar{T}} \tag{31}$$

$$\bar{K}_T^{-1} = \bar{\rho} \left(\frac{\partial \bar{P}}{\partial \bar{\rho}}\right)_{\bar{T}} \tag{32}$$

$$\left(\frac{\partial \bar{P}}{\partial \bar{T}}\right)_{\bar{\rho}} = \bar{\rho}^2 \frac{\partial^2 \bar{A}}{\partial \bar{\rho} \partial \bar{T}} \tag{33}$$

$$\bar{S} = - \left(\frac{\partial \bar{A}}{\partial \bar{T}}\right)_{\bar{\rho}} \tag{34}$$

$$\bar{U} = \bar{A} + \bar{T}\bar{S} \tag{35}$$

$$\bar{H} = \bar{U} + \frac{\bar{P}}{\bar{\rho}} \tag{36}$$

$$\bar{G} = \bar{A} + \frac{\bar{P}}{\bar{\rho}} \tag{37}$$

$$\bar{C}_v = -\bar{T}\left[\frac{\partial^2 \bar{A}}{\partial \bar{T}^2}\right]_{\bar{\rho}} \tag{38}$$

$$\bar{C}_p = \bar{C}_v + \frac{\bar{T}}{\bar{\rho}^2}\,\frac{(\partial \bar{P}/\partial \bar{T})^2_{\bar{\rho}}}{(\partial \bar{P}/\partial \bar{\rho})_{\bar{T}}} \tag{39}$$

$$\bar{w} = \left[\frac{\bar{C}_p}{\bar{C}_v}\left[\frac{\partial \bar{P}}{\partial \bar{\rho}}\right]_{\bar{T}}\right]^{1/2} \tag{40}$$

2.4. Ideal-gas properties

The ideal-gas properties of gaseous H_2O are obtained from

$$\bar{A}_{id} = \bar{A}_o(\bar{T}) + A_{20}\,\bar{T}\,\ell n\,\bar{\rho} \tag{41}$$

as a function of temperature and density, or

$$\bar{A}_{id} = \bar{A}_o(\bar{T}) - A_{20}\,\bar{T}\,\ell n\,\bar{T} - A_{20}\,\bar{T}\,\ell n\,A_{20} + A_{20}\,\bar{T}\,\ell n\,\bar{P} \tag{42}$$

as a function of temperature and pressure.

3. Range of validity and estimated uncertainty

3.1. Range of validity for formulation

IAPS has tested the formulation and endorses its validity over the temperature range from 273.15 K to 1273.15 K and in the range of pressures described by the conditions

$$P \leq 1500 \text{ MPa} \quad \text{for } 423.15 \text{ K} \leq T \leq 1273.15 \text{ K} \ , \tag{43}$$

$$P \leq 100 \left[5 + \frac{T - 273.15 \text{ K}}{15 \text{ K}} \right] \text{MPa} \quad \text{for} \quad 273.15 \text{ K} \leq T < 423.15 \text{ K} \ .$$

The formulation is approved everywhere in this range except for an excluded region around the critical point bounded by

$$|T - T^*| \leq 1 \text{ K}, \quad |\bar{\rho} - 1| \leq 0.3 \ . \tag{44}$$

3.2. Estimates of uncertainty

Estimates of the uncertainty for calculated values of density as a function of pressure and temperature are given in Fig. 1. The numerical values in the various regions indicate estimated relative uncertainty $\delta\rho/\rho$ in parts per 10,000. For instance, the number 10 indicates that the estimated relative error $\delta\rho/\rho$ in the density ρ is less than 10 parts in 10^4.

The estimated uncertainty of the formulation in the critical region is indicated in Fig. 2. In the near-critical region the error in density becomes a rapidly varying function of pressure and temperature and the accuracy of the formulation is better characterized by the quoted estimated relative error $\delta P/P$ in the pressure P for a given ρ and T.

Estimates of the uncertainty for calculated values of specific enthalpy as a function of pressure and temperature are given in Fig. 3. H(T,P) is the specific enthalpy at temperature T and pressure P minus the specific enthalpy at the triple point. In the various regions in Fig. 3 the numerical values indicate the maximum error δH in terms of kJ/kg, except for the liquid at pressures below 100 MPa and temperatures between 50°C and 330°C, where the maximum relative error $\delta H/H$ is 3 parts in 10^4. For pressures above 100 MPa, the estimates of uncertainty are given by the equations contained in the figure, where $\delta H(T,P=100\ \text{MPa})$ refers to the estimated uncertainty δH at 100 MPa at the same temperature T. In the region marked A the estimated uncertainty δH is twice the amount calculated from the equation applicable at the same pressure but at temperatures above 25°C. Again in the near-critical region the error in the density, and hence in H, becomes sensitive to small changes in pressure and temperature. The error $\delta H < 3$kJ/kg quoted for the triangle that includes the critical point refers to the estimated error in H for given ρ and T.

4. Computer-program verification

To assist the user in computer-program verification Table 6 lists values for $\bar{A}$, $\bar{P}$, and $\bar{C}_v$ calculated at selected values of $\bar{T}$ and $\bar{\rho}$. The dimensionless formulation presented in this Release yields thermodynamic property values identical with those calculated from the provisional dimensional IAPS formulation 1982 up to the six digits included in Table 6.

Table 1. Coefficients for $\bar{A}_o(\bar{T})$

i	A_{0i}
0	-0.130840393653E+2
1	-0.857020420940E+2
2	0.765192919131E-2
3	-0.620600116069E+0
4	-0.106924329402E+2
5	-0.280671377296E+1
6	0.119843634845E+3
7	-0.823907389256E+2
8	0.555864146443E+2
9	-0.310698122980E+2
10	0.136200239305E+2
11	-0.457116129409E+1
12	0.115382128188E+1
13	-0.214242224683E+0
14	0.282800597384E-1
15	-0.250384152737E-2
16	0.132952679669E-3
17	-0.319277411208E-5

Table 2. Coefficients for $\overline{A}_1(\overline{T},\overline{\rho})$

i	A_{1i}
0	0.15383053E+1
1	-0.81048367E+0
2	-0.68305748E+1
3	0.00000000
4	0.86756271E+0

Table 3. Coefficients for $\overline{A}_2(\overline{T},\overline{\rho})$

A_{20} = 0.42923415E+1

i	y_i
0	0.59402227E-1
1	-0.28128238E-1
2	0.56826674E-3
3	-0.27987451E-3

Table 4. Coefficients for $\overline{A}_3(\overline{T},\overline{\rho})$

z_o = 0.317763E+0

i	k(i)	ℓ(i)	A_{3i}
0	1	1	-0.76221190138079E+1
1	1	2	0.32661493707555E+2
2	1	4	0.11305763156821E+2
3	1	6	-0.10015404767712E+1
4	2	1	0.12830064355028E+3
5	2	2	-0.28371416789846E+3
6	2	4	0.24256279839182E+3
7	2	6	-0.99357645626725E+2
8	3	1	-0.12275453013171E+4
9	3	2	0.23077622506234E+4
10	3	4	-0.16352219929859E+4
11	3	6	0.58436648297764E+3
12	4	1	0.42365441415641E+4
13	4	2	-0.78027526961828E+4
14	4	4	0.38855645739589E+4
15	4	6	-0.91225112529381E+3
16	5	1	-0.90143895703666E+4
17	5	2	0.15196214817734E+5
18	5	4	-0.39616651358508E+4
19	5	6	-0.72027511617558E+3
20	6	1	0.11147126705990E+5
21	6	2	-0.17412065252210E+5
22	6	4	0.99918281207782E+3
23	6	6	0.33504807153854E+4
24	7	1	-0.64752644922631E+4
25	7	2	0.98323730907847E+4
26	7	4	0.83877854108422E+3
27	7	6	-0.27919349903103E+4
28	9	1	0.11112410081192E+4
29	9	2	-0.17287587261807E+4
30	9	4	-0.36233262795423E+3
31	9	6	0.61139429010144E+3
32	3	0	0.32968064728562E+2
33	3	3	0.10411239605066E+3
34	1	3	-0.38225874712590E+2
35	5	3	-0.20307478607599E+3

Table 5. Coefficients for $\bar{A}_4(\bar{T},\bar{\rho})$

i	m(i)	n(i)	α_i	β_i	$\bar{\rho}_i$	$\bar{T}_i$	A_{4i}
0	2	0	34	20000	0.10038928E+1	0.98876821E+0	-0.32329494E-2
1	2	2	40	20000	0.10038928E+1	0.98876821E+0	-0.24139355E-1
2	2	0	30	40000	0.10038928E+1	0.99124013E+0	0.79027651E-3
3	4	0	1050	25	0.48778492E+1	0.41713659E+0	-0.13362857E+1

Table 6. Thermodynamic property values calculated for selected values of $\bar{T}$ and $\bar{\rho}$.

$\bar{T}$	$\bar{\rho}$	$\bar{A}$	$\bar{P}$	$\bar{C}_v$
0.50	3.20	-0.250554E+0	0.324936E+1	0.359788E+2
0.75	2.85	-0.400493E+1	0.391145E+1	0.299897E+2
0.90	0.08	-0.127371E+2	0.260476E+0	0.196868E+2
1.00	1.50	-0.116979E+2	0.105315E+1	0.306178E+2
1.20	0.40	-0.237304E+2	0.146688E+1	0.214850E+2
1.20	1.20	-0.203908E+2	0.304551E+1	0.248417E+2
1.40	0.20	-0.383216E+2	0.108246E+1	0.182170E+2
1.40	0.90	-0.309982E+2	0.387225E+1	0.218535E+2
1.60	0.10	-0.551985E+2	0.664893E+0	0.178744E+2
1.60	0.70	-0.429449E+2	0.408739E+1	0.206189E+2

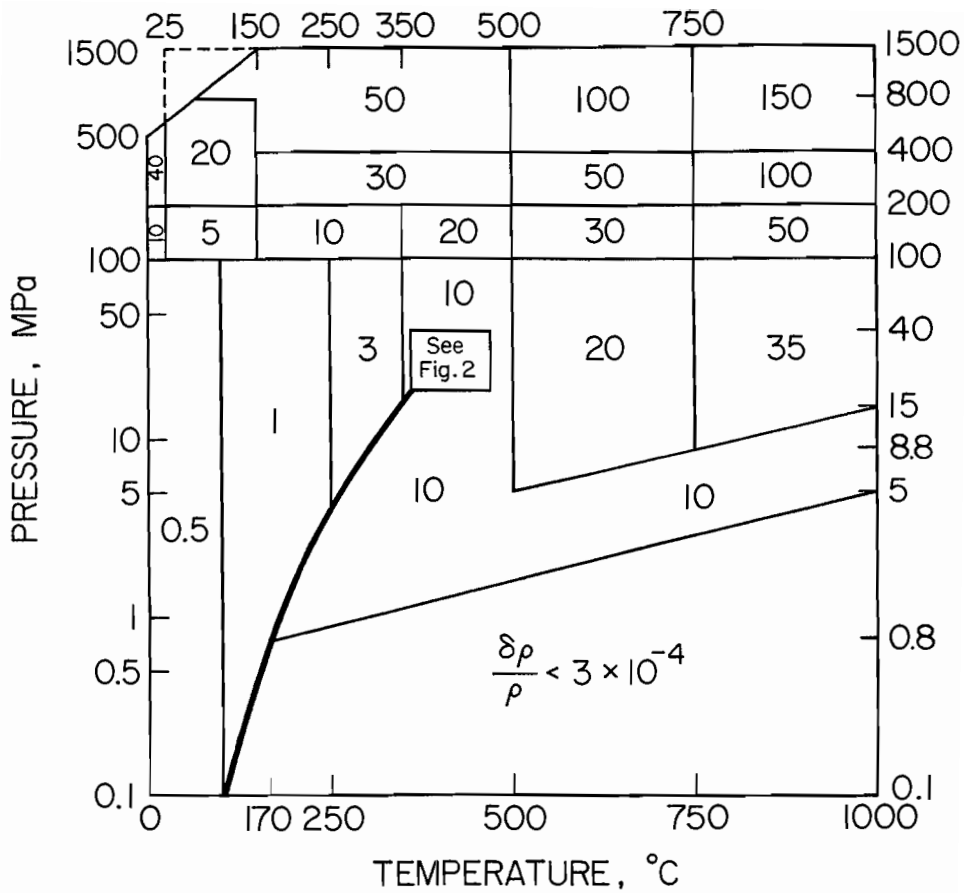

Fig. 1. Estimated relative uncertainty in calculated values of density as a function of pressure and temperature. The numerical values in the various regions indicate estimated relative density errors $\delta\rho/\rho$ in parts per 10,000.

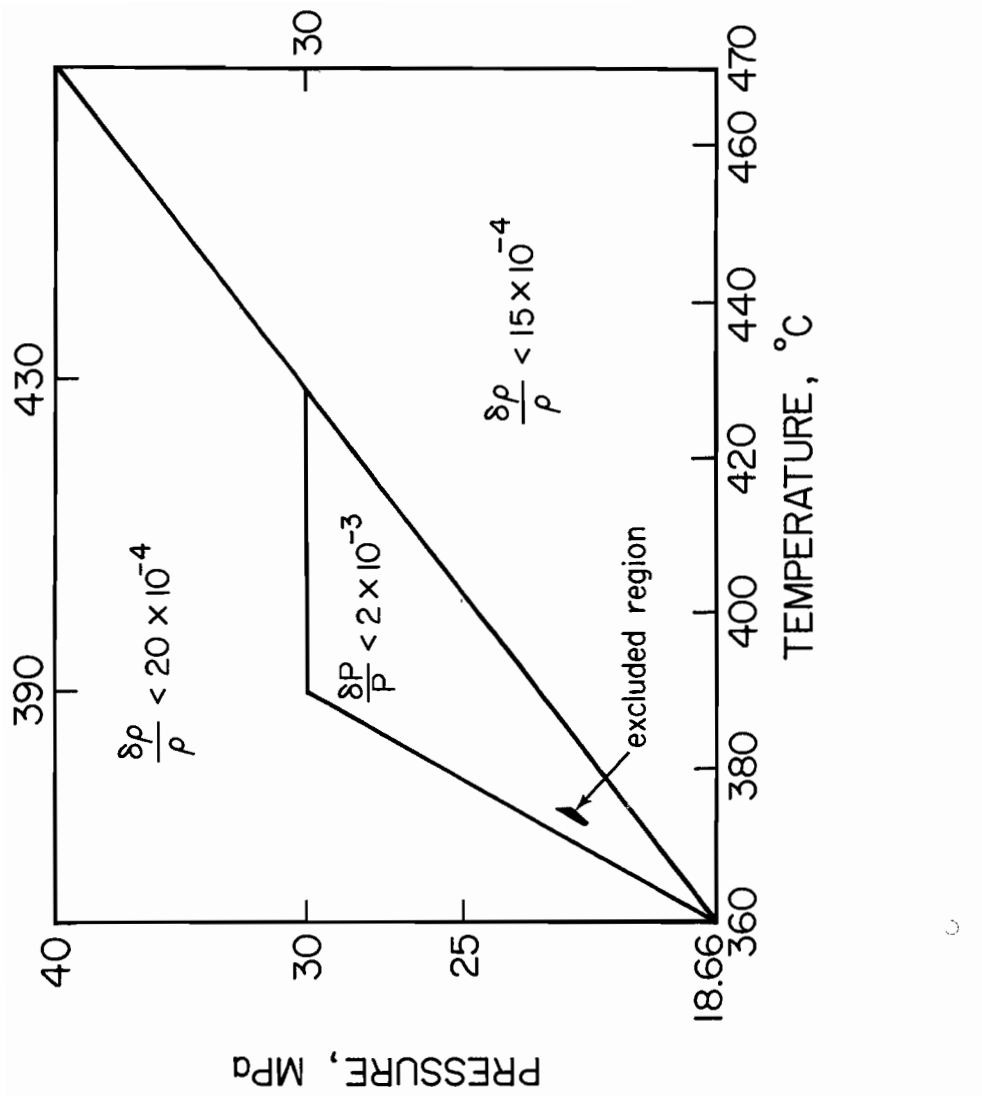

Fig. 2. Estimated uncertainty of the formulation in the critical region: $\delta\rho/\rho$ indicates estimated relative uncertainty in density; $\delta P/P$ indicates estimated relative uncertainty in pressure for given ρ and T.

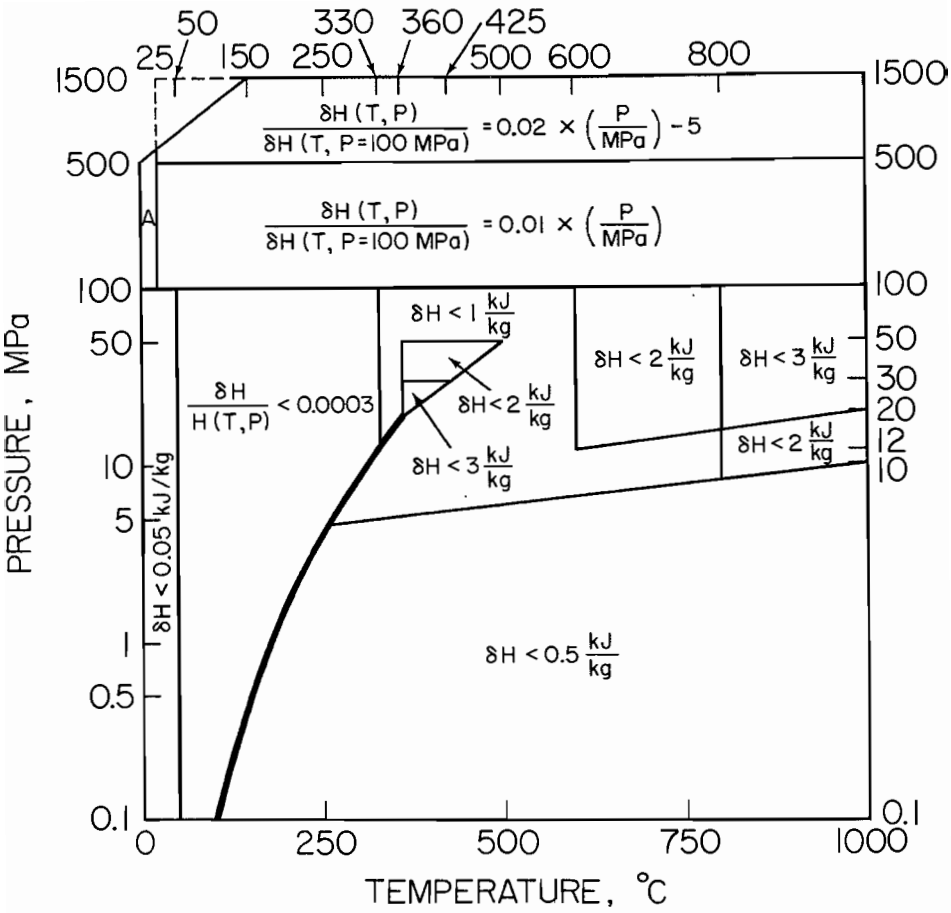

Fig. 3. Estimated uncertainty in calculated values of specific ehthalpy H(T,P) as a function of temperature T and pressure P. (As noted in the text the reference state of zero specific energy and entropy is the liquid at the triple point). In region A the estimated error is twice the estimate calculated from the equation for $\delta H(T,P)$ at the same pressure but at temperatures above 25°C. In the small triangle that includes the critical point the error $\delta H < 3$kJ/kg refers to the estimated error for a given density ρ and temperature T.

Release on The IAPS Formulation 1984 for the Thermodynamic Properties of Heavy Water Substance

Issued by the International Association for the Properties of Steam

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This release is issued by the International Association for the Properties of Steam (IAPS) on the authority of the Tenth International Conference on the Properties of Steam, held in Moscow, USSR, September 2-7, 1984. The members of IAPS are: Canada, the Czechoslovak Socialist Republic, the Federal Republic of Germany, France, Japan, the Union of Soviet Socialist Republics, the United Kingdom and the United States of America.

The formulation provided in this release is a dimensionless version of "A Fundamental Equation of State for Heavy Water" published by P. G. Hill, R. D. Chris MacMillan and V. Lee in the *Journal of Physical Chemical Reference Data*, Vol. 11, pp. 1-14 (1982) and Vol. 12, p. 1065 (1983).

Appendix: The IAPS Formulation 1984 for the Thermodynamic Properties of Heavy Water Substance.†

1. Dimensionless variables and reference constants

All equations in this release are presented in nondimensional form. The dimensionless version of each quantity is denoted by a symbol with a bar. The reference quantities consist of two classes: three primary reference quantities (denoted by an asterisk) and three secondary reference quantities (denoted by a double asterisk) which are simple combinations of the primary reference quantities.

1.1 Primary reference constants

Reference temperature: $T^* = 643.89\ K$, (1)

reference density: $\rho^* = 358\ kg/m^3$, (2)

reference pressure: $P^* = 21.671 \times 10^6\ Pa$, (3)

1.2 Secondary reference constants

Reference constant for Helmholtz function, energy, enthalpy, Gibbs function: $A^{**} \equiv \frac{P^*}{\rho^*} = 60533.52 J/kg$, (4)

reference constant for entropy, specific heats: $S^{**} \equiv \frac{P^*}{\rho^* T^*} = 94.01221\ J/kg\ K.$ (5)

reference constant for sound velocity: $w^{**} \equiv \left[\frac{P^*}{\rho^*}\right]^{\frac{1}{2}} = 246.036\ m/s$. (6)

†Ordinary water substance, "H_2O", has normal naturally occurring isotopic abundances. Heavy water substance, "D_2O", is ^2H_2O with the oxygen isotopes in the same abundances as in H_2O.

1.3 Thermophysical properties in dimensionless form

Temperature†:	$\bar{T} = T/T^*$	(7)
pressure:	$\bar{P} = P/P^*$	(8)
density:	$\bar{\rho} = \rho/\rho^*$	(9)
specific volume:	$\bar{V} = V\rho^*$	(10)
specific Helmholtz function:	$\bar{A} = A/A^{**}$	(11)
specific energy:	$\bar{U} = U/A^{**}$	(12)
specific enthalpy:	$\bar{H} = H/A^{**}$	(13)
specific Gibbs function:	$\bar{G} = G/A^{**}$	(14)
specific entropy:	$\bar{S} = S/S^{**}$	(15)
specific heat at constant volume:	$\bar{C}_v = C_v/S^{**}$	(16)
specific heat at constant pressure:	$\bar{C}_p = C_p/S^{**}$	(17)
isothermal compressibility:	$\bar{K}_T = K_T P^*$	(18)
speed of sound:	$\bar{w} = w/w^{**}$	(19)

†Note: T denotes absolute temperature on the International Practical Scale of 1968. No distinction is made between this temperature scale and the thermodynamic temperature.

2. Equations for thermodynamic properties

The formulation is based on a fundamental equation for the Helmholtz function as a function of temperature and density.

2.1 Fundamental equation in canonical form

The fundamental equation is defined as

$$\bar{A}(\bar{T},\bar{\rho}) = \bar{A}_0(\bar{T},\bar{\rho}) + \bar{A}_1(\bar{T},\bar{\rho}) \qquad (20)$$

with

$$\bar{A}_0(\bar{T},\bar{\rho}) = (A_{00} + A_{01}\bar{T})\ell n\bar{T} + \sum_{j=2}^{7} A_{0j}\,\bar{T}^{j-2} + A_{08}\,\bar{T}\,\ell n\,\bar{\rho} \quad , \quad (21)$$

$$\bar{A}_i(\bar{T},\bar{\rho}) = \bar{T}\bar{\rho}\left(\frac{1}{\bar{T}} - \frac{1}{\bar{T}_1}\right) \sum_{i=1}^{7} \left(\frac{1}{\bar{T}} - \frac{1}{\bar{T}_i}\right)^{i-2} \times$$

$$\times\left[\sum_{j=1}^{8} A_{ij}(\bar{\rho} - \bar{\rho}_i)^{j-1} + e^{-1.5394\,\bar{\rho}} \sum_{j=9}^{10} A_{ij}\,\bar{\rho}^{\,j-9}\right] \quad . \quad (22)$$

2.2 Coefficients in the equations for the Helmholtz function $\bar{A}(\bar{T},\bar{\rho})$

The values of the parameters A_{ij}, $\bar{T}_i$ and $\bar{\rho}_i$ in the equations for $\bar{A}_0(\bar{T},\bar{\rho})$ and $\bar{A}_1(\bar{T},\bar{\rho})$ are listed in Tables 1, 2 and 3. In all tables presented in this release the "E-notation" has been adopted. That is, the integer which follows E indicates the power of ten by which the listed coefficient should be multiplied. Thus E + 2 represents the factor $10^2 = 100$, etc.

The choice of the coefficients A_{02} and A_{03} in (21) is related to the convention adopted for the zero points of energy and entropy. In the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use the values of the specific energy and the specific entropy of the liquid at the triple point are set equal to zero. In the case of H_2O the temperature of the triple point need not be measured, because it constitutes the (single) fixed point on the internationally accepted temperature scale. In the case of D_2O the triple-point temperature must be obtained from accurate measurements which are subject to improvement. In this release the specific energy and entropy are set equal to zero for the liquid state in equilibrium with the vapor at T_R = 276.95 K. At this reference state

$$T_R = 276.95 \text{ K} \quad , \quad P_R = 660.066 \text{ Pa} \tag{23}$$

$$U_R = 0 \quad , \quad S_R = 0 \tag{24}$$

$$H_R = 0.597 \text{ J/kg} \quad . \tag{25}$$

This reference state is close to (but not necessarily equal to) the liquid state at the triple point.

In the liquid region small changes in density along an isotherm cause large changes in pressure. For this reason, due to an accumulation of small errors, a particular computer code may fail to return the zeros (24) at the reference state. This problem can be solved by adjusting the constants A_{02} and A_{03} in (21) so that condition (24) is satisfied with the desired accuracy.

2.3 Thermodynamic relations

All thermodynamic properties of interest can be derived from the fundamental equation (20) by the use of the following thermodynamic relations

$$\bar{V} = \bar{\rho}^{-1} \tag{26}$$

$$\bar{P} = \bar{\rho}^2 \left(\frac{\partial \bar{A}}{\partial \bar{\rho}}\right)_{\bar{T}} \tag{27}$$

$$\left(\frac{\partial \bar{P}}{\partial \bar{\rho}}\right)_{\bar{T}} = \frac{2\bar{P}}{\bar{\rho}} + \bar{\rho}^2 \left(\frac{\partial^2 \bar{A}}{\partial \bar{\rho}^2}\right)_{\bar{T}} \tag{28}$$

$$\bar{K}_T^{-1} = \bar{\rho} \left(\frac{\partial \bar{P}}{\partial \bar{\rho}}\right)_{\bar{T}} \tag{29}$$

$$\left(\frac{\partial \bar{P}}{\partial \bar{T}}\right) = \bar{\rho}^2 \frac{\partial^2 \bar{A}}{\partial \bar{\rho} \partial \bar{T}} \tag{30}$$

$$\bar{S} = -\left(\frac{\partial \bar{A}}{\partial \bar{T}}\right)_{\bar{\rho}} \tag{31}$$

$$\bar{U} = \bar{A} + \bar{T}\bar{S} \tag{32}$$

$$\bar{H} = \bar{U} + \frac{\bar{P}}{\bar{\rho}} \tag{33}$$

$$\bar{G} = \bar{A} + \frac{\bar{P}}{\bar{\rho}} \tag{34}$$

$$\bar{C}_v = -\bar{T}\left(\frac{\partial^2 \bar{A}}{\partial \bar{T}^2}\right)_{\bar{\rho}} \tag{35}$$

$$\bar{C}_p = \bar{C}_v + \frac{\bar{T}}{\bar{\rho}^2}\,\frac{(\partial \bar{P}/\partial \bar{T})^2_{\bar{\rho}}}{(\partial \bar{P}/\partial \bar{\rho})_{\bar{T}}} \tag{36}$$

$$\bar{w} = \left[\frac{\bar{C}_p}{\bar{C}_v}\left(\frac{\partial \bar{P}}{\partial \bar{\rho}}\right)_{\bar{T}}\right]^{1/2} . \tag{37}$$

2.4 Ideal-gas properties

The ideal-gas properties of gaseous D_2O are obtained from

$$\bar{A}_{id} = \bar{A}_0(\bar{T},\bar{\rho}) = (A_{00} + A_{01}\,\bar{T})\ell n\,\bar{T} + \sum_{j=2}^{7} A_{0j}\,\bar{T}^{\,j-2} + A_{08}\,\bar{T}\ell n\bar{\rho} \tag{38}$$

as a function of temperature and density, or from

$$\bar{A}_{id} = (A_{00} + A_{01}\,\bar{T} - A_{08}\,\bar{T})\ell n\,\bar{T} + \sum_{j=2}^{7} A_{0j}\,\bar{T}^{j-2} \tag{39}$$

$$- A_{08}\,\bar{T}\ell n\,A_{08} + A_{08}\,\bar{T}\,\ell n\,\bar{P}$$

as a function of temperature and pressure.

3. Range of validity and estimated uncertainty

3.1. Range of validity

IAPS has tested the formulation and endorses its validity in the range of temperatures and pressures defined by

$$T_R \leqslant T \leqslant 800 \text{ K} , \qquad 0 \leqslant P \leqslant 100 \text{ MPa} \quad . \tag{40}$$

The formulation is not recommended in a region around the critical point bounded by[†]

$$|T - T^*| \leqslant 10 \text{ K} \quad , \qquad |\bar{\rho} - 1| \leqslant 0.3 \quad . \tag{41}$$

3.2 Estimates of uncertainty

Table 4 lists calculated values of the specific volume as a function of pressure and temperature together with the estimated uncertainties.

4. Computer-program verification

To assist the user in computer-program verification Table 5 lists values for $\bar{A}$, $\bar{P}$ and $\bar{C}_v$ calculated at selected values of $\bar{T}$ and $\bar{\rho}$. The dimensionless fundamental equation presented in this Release yields thermodynamic property values identical to those calculated from the dimensional equation published by Hill et al., J. Phys. Chem. Ref. Data 11, 1 (1982); 12, 1065 (1983) up to the six digits included in Table 5.

[†]A fundamental equation for D_2O in the critical region can be found in a paper "Thermodynamic Properties of D_2O in the Critical Region", B. Kamgar-Parsi, J.M.H. Levelt Sengers and J.V. Sengers, *Journal of Physical and Chemical Reference Data*, Vol. 12, pp. 513-529 (1983).

Table 1. Coefficients A_{oj}

j	A_{oj}
0	0.5399322597E-2
1	-0.1288399716E+2
2	0.3087284587E+2
3	-0.3827563059E+2
4	0.4424799189E+0
5	-0.1256336874E+1
6	0.2843343470E+0
7	-0.2401555088E-1
8	0.4415884023E+1

Table 2. Coefficients A_{ij}

i	j	A_{ij}
1	1	0.115623643567E+3
1	2	-0.161413392951E+3
1	3	0.108543003981E+3
1	4	-0.471342021238E+2
1	5	0.149218685173E+2
1	6	-0.360628259650E+1
1	7	0.686743026455E+0
1	8	-0.951913721401E-1
1	9	-0.157513472656E+4
1	10	-0.433677787466E+3
2	1	0.607446060304E+2
2	2	-0.927952190464E+2
2	3	0.632086750422E+2
2	4	-0.264943219184E+2
2	5	0.905675051855E+1
2	6	-0.578949005123E+0
2	7	0.665590447621E+0
2	8	-0.525687146109E-1
2	9	-0.341048601697E+4
2	10	-0.146971631028E+4
3	1	0.444139703648E+2
3	2	-0.580410482641E+2
3	3	0.354090438940E+2
3	4	-0.144432210128E+2
3	9	-0.102135518748E+4
3	10	-0.136324396122E+4
4	1	0.157859762687E+2
4	2	-0.194973173813E+2
4	3	0.114841391216E+2
4	4	-0.196956103010E+1
4	9	-0.277379051954E+3
4	10	-0.481991835255E+3
5	1	-0.619344658242E+2
5	2	0.791406411518E+2
5	3	-0.484238027539E+2
5	4	0.191546335463E+2
5	9	0.128039793871E+4
5	10	0.186367898973E+4
6	1	-0.749615505949E+2
6	2	0.947388734799E+2
6	3	-0.575266970986E+2
6	4	0.173229892427E+2
6	9	0.137572687525E+4
6	10	0.231749018693E+4
7	1	-0.260841561347E+2
7	2	0.328640711440E+2
7	3	-0.186464444026E+2
7	4	0.484262639275E+1
7	9	0.430179479063E+3
7	10	0.822507844138E+3

Note: Coefficients A_{ij} omitted from table are zero identically.

Table 3. Parameters $\bar{T}_i$ and $\bar{\rho}_i$

	$\bar{T}_i$	$\bar{\rho}_i$
1	0.1000038832E+1	0.1955307263E+1
2	0.6138578282E+0	0.3072625698E+1
3	0.6138578282E+0	0.3072625698E+1
4	0.6138578282E+0	0.3072625698E+1
5	0.6138578282E+0	0.3072625698E+1
6	0.6138578282E+0	0.3072625698E+1
7	0.6138578282E+0	0.3072625698E+1

Table 4

SPECIFIC VOLUMES OF HEAVY WATER AND TOLERANCES (cm^3/g)

P	Temperature, °C													
bar	3.8	20.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	375.0	400.0	450.0	500.0	550.0
1	0.9045	0.9047	0.9127	0.9404	1741.4	1953.8	2164.2	2373.6	2582.4	2686.7	2790.9	2999.1	3207.2	3415.1
	.0001	.0001	.0001	.0001	.2	.1	.1	.2	.4	.8	1.0	1.0	1.0	1.0
5	0.9044	0.9045	0.9125	0.9402	0.9830	381.9	426.6	470.0	512.8	534.0	555.2	597.4	639.4	681.3
	.0001	.0001	.0001	.0001	.0001	.1	.1	.2	.2	.3	.3	.3	.3	.4
10	0.9041	0.9043	0.9123	0.9400	0.9827	184.9	209.2	232.0	254.0	264.9	275.7	297.1	318.4	339.6
	.0001	.0001	.0001	.0001	.0001	.1	.1	.1	.1	.2	.2	.2	.2	.2
25	0.9034	0.9036	0.9117	0.9393	0.9818	1.0427	78.1	88.9	98.7	103.4	108.0	117.0	125.0	134.6
	.0001	.0001	.0001	.0001	.0001	.0001	.1	.1	.1	.1	.1	.1	.1	.1
50	0.9023	0.9026	0.9107	0.9382	0.9803	1.0404	1.1298	40.68	46.68	49.375	51.958	56.886	61.612	66.210
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.1	.1	.05	.05	.05	.06	.06
75	0.9011	0.9015	0.9096	0.9370	0.9788	1.0381	1.1257	23.9401	29.125	31.239	33.195	36.812	40.189	43.422
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.1	.05	.03	.03	.04	.05	.04
100	0.9000	0.9005	0.9086	0.9359	0.9773	1.0359	1.1217	1.2685	20.135	22.047	23.737	26.742	29.464	32.025
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.03	.03	.03	.04	.05	.04
125	0.8989	0.8994	0.9077	0.9348	0.9758	1.0337	1.1179	1.2586	14.486	16.406	17.990	20.673	23.017	25.183
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.02	.02	.02	.03	.05	.02
150	0.8977	0.8984	0.9067	0.9337	0.9744	1.0316	1.1142	1.2495	10.332	12.502	14.088	16.602	18.711	20.618
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.01	.01	.01	.02	.05	.02
200	0.8955	0.8963	0.9047	0.9315	0.9716	1.0275	1.1071	1.2332	1.5286	6.982	8.987	11.452	13.305	14.905
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.01	.01	.01	.02	.02
225	0.8944	0.8953	0.9038	0.9305	0.9702	1.0255	1.1037	1.2258	1.4902	3.765	7.135	9.705	11.493	12.997
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.2	.02	.01	.02	.02

Table 4 -- SPECIFIC VOLUMES OF HEAVY WATER AND TOLERANCES (continued)

P	Temperature, °C													
bar	3.8	20.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	375.0	400.0	450.0	500.0	550.0
250	0.8933	0.8943	0.9028	0.9294	0.9688	1.0235	1.1004	1.2188	1.4603	1.8639	5.494	8.287	10.038	11.469
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.01	.01	.01	.02
300	0.8912	0.8924	0.9010	0.9273	0.9661	1.0196	1.0941	1.2060	1.4147	1.6489	2.705	6.110	7.842	9.174
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.03	.01	.01	.02
350	0.8890	0.8904	0.8991	0.9253	0.9635	1.0159	1.0882	1.1944	1.3802	1.5569	1.959	4.517	6.265	7.533
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.01	.005	.01	.02
400	0.8869	0.8885	0.8973	0.9232	0.9610	1.0123	1.0825	1.1837	1.3524	1.4976	1.7569	3.3901	5.090	6.307
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.002	.002	.01	.02
450	0.8849	0.8866	0.8955	0.9213	0.9585	1.0088	1.0771	1.1739	1.3289	1.4538	1.6510	2.6928	4.204	5.364
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.0006	.002	.01	.02
500	0.8829	0.8848	0.8937	0.9193	0.9560	1.0054	1.0719	1.1648	1.3087	1.4190	1.5806	2.2954	3.544	4.629
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.0006	.002	.01	.02
600	0.8789	0.8812	0.8902	0.9155	0.9512	0.9989	1.0622	1.1483	1.2750	1.3655	1.4871	1.9115	2.711	3.597
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.0006	.002	.01	.02
700	0.8750	0.8776	0.8868	0.9118	0.9467	0.9927	1.0531	1.1337	1.2475	1.3250	1.4240	1.7286	2.263	2.951
	.0001	.0001	.0001	.0001	.0001	.0001	.0003	.0002	.0008	.0008	.0006	.002	.01	.02
800	0.8713	0.8742	0.8835	0.[illegible]82	0.9423	0.9869	1.0447	1.1205	1.2242	1.2925	1.3767	1.6171	2.005	2.536
	.0001	.0001	.0001	.0001	.0001	.0002	.0003	.0002	.0008	.0008	.0006	.002	.01	.02
900	0.8677	0.8708	0.8803	0.9047	0.9380	0.9812	1.0368	1.1085	1.2041	1.2653	1.3390	1.5392	1.841	2.257
	.0001	.0001	.0001	.0001	.0001	.0004	.0003	.0002	.0008	.0008	.0006	.002	.01	.02
1000	0.8643	0.8675	0.8771	0.9013	0.9339	0.9759	1.0294	1.0975	1.1864	1.2420	1.3078	1.4802	1.727	2.063
	.0001	.0001	.0001	.0001	.0001	.0005	.0003	.0002	.0008	.0008	.0006	.002	.01	.02

Table 5. Thermophysical property values calculated for selected values of $\bar{T}$ and $\bar{\rho}$.

$\bar{T}$	$\bar{\rho}$	$\bar{A}$	$\bar{P}$	$\bar{C}_v$
0.50	0.0002	-0.264519E+1	0.440215E-3	0.142768E+2
0.50	3.1800	-0.217597E+0	0.435497E+1	0.414463E+2
0.75	0.0295	-0.727350E+1	0.870308E-1	0.201586E+2
0.75	2.8300	-0.429366E+1	0.447530E+1	0.334367E+2
1.00	0.3000	-0.151650E+2	0.801404E+0	0.308587E+2
1.00	1.5500	-0.126455E+2	0.109763E+1	0.330103E+2
1.20	0.4000	-0.254738E+2	0.149910E+1	0.236594E+2
1.20	1.6100	-0.212805E+2	0.456438E+1	0.254800E+2

Release on The Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at Their Respective Critical Points

Issued by the
International Association for the Properties of Water and Steam

Saint Petersburg, Russia
September 1992

(Revision of the 1983 Release)

This revised release has been authorized by the International Association for the Properties of Water and Steam (IAPWS) at its meeting in Sankt Petersburg, Russia, September 6-12, 1992, for issue by its Secretariat. The members of IAPWS are Canada, Czechoslovakia, Denmark, the Federal Republic of Germany, France, Japan, Russia, the United Kingdom and the United States of America.

In 1983, The International Association for the Properties of Water and Steam (IAPS) issued a "Statement of the Values, and their Tolerances, of the Critical Pressure, Temperature and Density of Ordinary and Heavy Water Substance[11], based on the IPTS-68 temperature scale. In this revised release, the critical temperature values have been converted to ITS-90. Conversion to the temperature scale of 1990 (ITS-90) is achieved with equations given in Table 1.6 of the report "Supplementary Information for the ITS-90" prepared by the Comité Consultatif de Thermometrie (CCT) and published by the Bureau International des Poids et des Mesures (BIPM). Compared with the IPTS-68 temperatures given in the original release, one more decimal place has been given to the converted ITS-90 temperatures. This ensures that any recalculation to the original IPTS-68 temperatures produces the same figures as given in the original source after rounding to the same number of decimal places. This increase by one decimal place in the conversion of the values to ITS-90 does not imply that reference temperatures such as critical-point values, triple points, etc. have been redetermined or are more accurate than as previously stated on IPTS-68. The material included in the 1983 release was prepared by the "Subcommittee to Study the Situation with respect to Critical Constants and Various Pseudocritical Constants" convened by Dr. J.M.H. Levelt Sengers, National Bureau of Standards, Washington, DC, U.S.A. In accordance with the statutes of IAPS, the material in the release has been presented to and was approved by Deputies of the Members of IAPS (Canada, Czechoslovakia, Federal Republic of Germany, France, Japan, United Kingdom, United States of America and Union of Soviet Socialist Republics).

This method by which the parameter values were obtained and the uncertainties assigned is described in the paper "Assessment of Critical Parameter Values for H_2O and D_2O", by J.M.H. Levelt Sengers, J. Straub, K. Watanabe and P. G. Hill, *Journal of Physical and Chemical Reference Data*, Vol. 14, pp. 193-207 (1985).

Revised Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points

Ordinary water substance, called H_2O, is of normal isotopic constitution. Heavy water substance, called D_2O, is ^2H_2O with the oxygen isotopes in the same abundance as in ordinary water substance. [See Kell, G.S., *J. Phys. Chem. Ref. Data*, Vol. 6, No. 4, 1977]. The values of the critical temperature, pressure and density, with their estimated uncertainties, are listed in Table 1 for ordinary and for heavy water substance.

TABLE 1

H_2O Ordinary Water Substance		D_2O Heavy Water Substance
$(647.096 + \delta_1)$	T_c/K (ITS-90)	$(643.847 + \delta_2)$
$\delta_1 = 0.0 \pm 0.100$		$\delta_2 = 0.0 \pm 0.200$
$(22.064 + 0.27\delta_1 \pm 0.005)$	P_c/MPa	$(21.671 + 0.27\delta_2 \pm 0.010)$
(322 ± 3)	ρ_c/kg m^{-3}	$(356 + 5)$

T_c is the temperature, P_c is the pressure, and ρ_c is the density at the critical point.

As stated in the preamble, the number of decimal places used in the statement of temperature bears no relation to the accuracy with which the critical temperature is known. The unusual way in which the uncertainties in the critical temperature and pressure values are connected results from the fact that these values, though not known with high precision, are related by the accurately known vapor pressure curve.

IAPWS Release on Surface Tension of Heavy Water Substance

Issued by the International Association for the Properties of Water and Steam

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September 1994

(Revision of the 1983 Release)

This release is issued by the International Association for the Properties of Water and Steam (IAPWS) on the authority of the Executive Committee meeting in Orlando, FL, USA, 11-16 September 1994. The members of IAPWS are Argentina, Canada, Czech Republic, Denmark, France, Germany, Japan, Russia, the United Kingdom and the United States of America, and associate member Italy.

IAPS issued a Release on the Surface Tension of Heavy Water Substance, in 1983, based on the International Practical Temperature Scale of 1968 (IPTS-68). A revision of this release has been prepared to provide the values corresponding to the International Temperature Scale of 1990 (ITS-90).

The critical point temperature used for the reference temperature in the equation for the surface tension of heavy water has been taken from the IAPWS Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points (1992). In this revised critical point release, compared with the IPTS-68 temperatures in the original critical point release, one more decimal place is given to the converted ITS-90 temperatures. This ensures that any recalculation to the original IPTS-68 temperatures produces the same figures as given in the original source after rounding to the same number of decimal places. This increase by one decimal place in the conversion of the values to ITS-90 does not imply that the critical point temperature has been redetermined or is more accurate than as previously stated on IPTS-68.

The information provided with this release is recommended as the most accurate representation of the surface tension of heavy water substance from the triple point to the critical point.

International Representation of the Surface Tension of Heavy Water Substance 1994

Experimental values of surface tension of Heavy Water Substance

Working Group III (on Special Properties) of IAPS, in 1983, had critically examined the experimental results of the surface tension of the interface between the liquid and vapor phases of heavy water and recommended the surface tension values (σ) and values ($\Delta\sigma$) of the uncertainty associated with each value of the surface tension.

In this revision, the values of surface tension have been examined and values adjusted for the temperature change from (IPTS-68) to (ITS-90) and are given in column 2 of Table 1. The corresponding uncertainty values are given in column 3 of Table 1.

Equation for the surface tension of Heavy Water Substance

The following recommended interpolating equation gives values of surface tension within the stated uncertainty:

$$\sigma = B\tau^{\mu}(1+b\tau)$$

where
σ = surface tension
τ = $1 - T / T_c$
T = temperature
T_c = 643.847 K
B = 238 mN/m
b = –0.639
μ = 1.25

This equation is valid between the triple point (3.8 °C) and reference temperature, T_c.

Values of surface tension calculated from this equation are given in column 4 of Table 1.

Notes: (i) T denotes absolute temperature, ITS-90.

(ii) The reference temperature is the critical point temperature given in the IAPWS Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points 1992.

(iii) The values of the constants B, b and μ are those presented in the release of 1983. Adjustment of the reference temperature produces values of surface tension from the equation for ITS-90 temperatures with improved root mean square deviation compared with the original equation and the surface tension values for the IPTS-68 temperatures in the release of 1983.

Table 1 Surface Tension of Heavy Water Substance

(1)	(2)	(3)	(4)	(5)
Temp. t, °C	Surf. Tension experimental	Uncertainty	Surf. Tension calculated	difference
	σ mN/m	$\Delta\sigma$ mN/m	σ_{calc} mN/m	$\sigma_{calc}-\sigma$ mN/m
3.8	74.98	0.53	74.93	- 0.05
5	74.80	0.52	74.76	- 0.04
10	74.10	0.51	74.06	- 0.04
15	73.37	0.51	73.34	- 0.03
20	72.63	0.51	72.61	- 0.02
25	71.87	0.50	71.86	- 0.01
30	71.10	0.50	71.09	- 0.01
35	70.32	0.49	70.32	- 0.00
40	69.52	0.49	69.52	0.00
45	68.70	0.48	68.71	0.01
50	67.87	0.48	67.89	0.02
55	67.03	0.47	67.06	0.03
60	66.18	0.47	66.21	0.03
65	65.31	0.46	65.34	0.03
70	64.43	0.45	64.47	0.04
75	63.54	0.45	63.58	0.04
80	62.63	0.44	62.67	0.04
85	61.72	0.43	61.75	0.03
90	60.79	0.43	60.82	0.03
95	59.85	0.42	59.88	0.03
100	58.90	0.41	58.93	0.03
105	57.93	0.41	57.96	0.03
110	56.95	0.40	56.98	0.03
115	55.96	0.39	55.99	0.03
120	54.96	0.39	54.99	0.03
125	53.95	0.38	53.98	0.03
130	52.93	0.37	52.95	0.02
135	51.90	0.36	51.92	0.02
140	50.87	0.36	50.87	0.00
145	49.82	0.35	49.82	- 0.00
150	48.77	0.34	48.75	- 0.02
155	47.70	0.33	47.67	- 0.03
160	46.63	0.33	46.59	- 0.04
165	45.55	0.32	45.50	- 0.05
170	44.46	0.31	44.39	- 0.07
175	43.36	0.30	43.28	- 0.08
180	42.25	0.30	42.16	- 0.09
185	41.13	0.29	41.03	- 0.10
190	40.00	0.29	39.90	- 0.10
195	38.86	0.27	38.76	- 0.10
200	37.71	0.26	37.61	- 0.10

Table 1 continued

(1) Temp. t, °C	(2) Surf. Tension experimental σ mN/m	(3) Uncertainty $\Delta\sigma$ mN/m	(4) Surf. Tension calculated σ_{calc} mN/m	(5) difference $\sigma_{calc}-\sigma$ mN/m
205	36.55	0.26	36.45	- 0.10
210	35.38	0.26	35.29	- 0.09
215	34.21	0.26	34.12	- 0.09
220	33.03	0.26	32.95	- 0.08
225	31.83	0.26	31.77	- 0.06
230	30.62	0.26	30.59	- 0.03
235	29.40	0.26	29.41	0.01
240	28.19	0.26	28.22	0.03
245	26.99	0.26	27.03	0.04
250	25.79	0.26	25.84	0.05
255	24.59	0.25	24.65	0.06
260	23.40	0.25	23.45	0.05
265	22.20	0.24	22.26	0.06
270	21.01	0.23	21.07	0.06
275	19.82	0.23	19.88	0.06
280	18.64	0.22	18.69	0.05
285	17.46	0.21	17.51	0.05
290	16.27	0.20	16.33	0.06
295	15.09	0.19	15.15	0.06
300	13.94	0.18	13.99	0.05
305	12.79	0.17	12.83	0.04
310	11.66	0.17	11.68	0.02
315	10.54	0.16	10.55	0.01
320	9.43	0.15	9.43	- 0.00
325	8.33	0.14	8.32	- 0.01
330	7.24	0.14	7.24	- 0.00
335	6.18	0.13	6.18	- 0.00
340	5.14	0.12	5.14	0.00
345	4.14	0.11	4.14	- 0.00
350	3.17	0.10	3.17	0.00
355	2.24	0.10	2.26	0.02
360	1.39	0.10	1.40	0.01
365	0.64	0.10	0.64	0.00
370	0.06	0.10	0.05	- 0.01

Release on
Viscosity and Thermal Conductivity
of Heavy Water Substance

Issued by
The International Association for The Properties of Steam

President: Professor Ichimatsu Tanishita
Ikutoku Technical University
1030 Shimo-ogino, Atsugi, Kanagawa, 243-02, Japan

September 1982

This Release on the transport properties of heavy water (deuterium oxide) has been authorized by the International Association for the Properties of Steam for issue by its Secretariat. This Release contains in the accompanying Appendices the *International Representation of the Viscosity of Heavy Water Substance* (Deuterium Oxide, D_2O) and the *International Representation of the Thermal Conductivity of Heavy Water Substance* (Deuterium Oxide, D_2O), 1982.

The material included in the Release was prepared by Working Group II of IAPS under the chairmanship of the late Joseph Kestin, Professor of Engineering at Brown University, Providence, RI, U.S.A. In accordance with the Statutes of IAPS, the material in the Release has been circulated to and approved by the Members of IAPS (Canada, Czechoslovakia, Federal Republic of Germany, France, Japan, United Kingdom, United States of America and Union of Soviet Socialist Republics).

Contains: Appendix A and Appendix B.

Appendix A

International Representation of the Viscosity of Heavy Water Substance (Deuterium Oxide, D_2O) 1982

IAPS Working Group II (on Transport Properties) has critically examined the experimental results on the viscosity of liquid and gaseous heavy water and recommends that the values implied by the equation given below should be used for this property. This equation represents the said quantity as a function of temperature and density. For a conversion to a representation as a function of temperature and pressure, values of density should be computed from the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Heavy Water Substance, contained in the reference given in the footnote†.

The recommended equation is:

$$\eta = \eta_0(T_r)\cdot\exp\left\{\rho_r\left[\sum_{i=0}^{5}\sum_{j=0}^{6} A_{ij}(T_r^{-1}-1)^i(\rho_r-1)^j\right]\right\} , \qquad (A1)$$

where

$$\eta_0(T_r) = H\cdot T_r^{1/2}\left(\sum_{k=0}^{3} B_k\cdot T_r^{-k}\right)^{-1} . \qquad (A2)$$

The reduced variables are

$$T_r = T/T^* \quad \text{and} \quad \rho_r = \rho/\rho^* , \qquad (A3)$$

and the meaning of the symbols is as follows:

η - dynamic viscosity

T - temperature on the International Practical Temperature Scale of 1968

ρ - density

T^* - reference temperature

ρ^* - reference density

The reference constants T^* and ρ^* are close, but not necessarily equal, to the actual critical parameters of heavy water. For the purpose of this representation they play the part of correlation constants and need not be amended when improved values of the actual critical constants become available.

†Hill, P.G., MacMillan, R.D., and Lee, V., "A Fundamental Equation of State for Heavy Water," Journal of Physical and Chemical Reference Data 11, 1-14 (1982), 12, 1065 (1983).

The constants appearing in Eqs. (A1), (A2) and (A3) are listed below.

$$T^* = 643.89 \text{ K} ,$$

$$\rho^* = 358 \text{ kg/m}^3 ,$$

$$H = 55.2651 \times 10^{-6} \text{ Pa·s} .$$

Table A1. The coefficients A_{ij}

i=	0	1	2	3	4	5
j=0	0.4864 192	-0.2448 372	-0.8702 035	0.8716 056	-1.0511 26	0.3458 395
1	0.3509 007	1.3154 36	1.2977 52	1.3534 48	0.0	0.0
2	-0.2847 572	-1.0370 26	-1.2878 46	0.0	0.0	-0.0214 8229
3	0.0701 3759	0.4660 127	0.2292 075	-0.4857 462	0.0	0.0
4	0.0164 1220	-0.0288 4911	0.0	0.1607 171	0.0	-0.0096 0384 6
5	-0.0116 3815	-0.0082 3958 7	0.0	0.0	0.0	0.0045 5991 4
6	0.0	0.0	0.0	-0.0038 8665 9	0.0	0.0

Table A2. The coefficients B_k

$$B_0 = 1.0000\ 0$$

$$B_1 = 0.9406\ 95$$

$$B_2 = 0.5783\ 77$$

$$B_3 = -0.2020\ 44$$

Range

The representation of the viscosity of heavy water by Eqs. (A1), (A2), (A3) together with the numerical constants listed above is valid in the rectangle defined by

$$0 \text{ MPa} \leqslant P \leqslant 100 \text{ MPa},$$
$$277 \text{ K (melting point)} \leqslant T \leqslant 775 \text{ K}.$$

Tolerances

The equation represents the viscosity within an uncertainty of ±1% to ±5% as indicated in Figure A1. However, no tolerances are assigned in the region contained within

$$0.995 < T_r < 1.005 ,$$

$$0.9 < \rho_r < 1.1 ,$$

because critical-point effects on the viscosity are not contained in the equation.

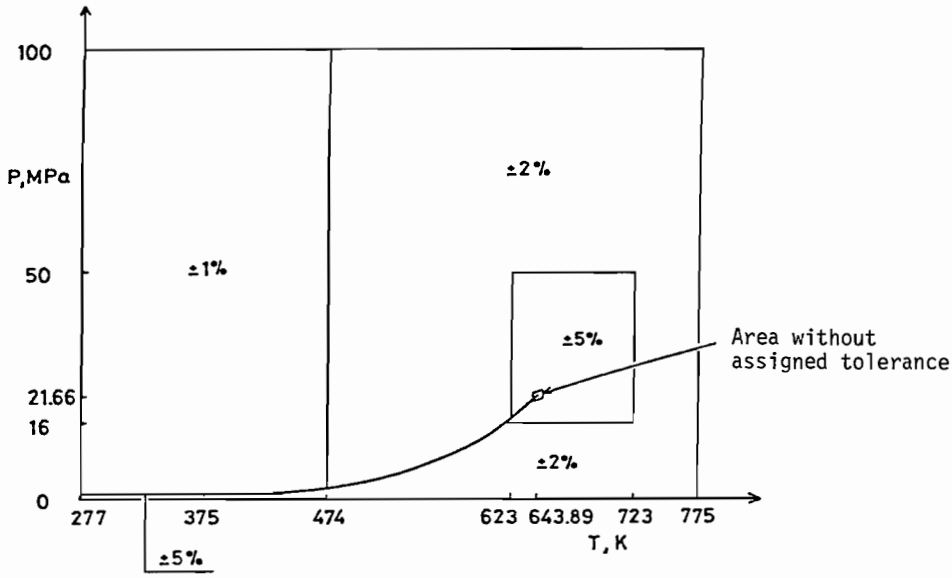

Figure A1. Tolerances of the representation of the viscosity of heavy water

Tables

Three Tables are given in this Appendix. Table A3 contains recommended values of viscosity calculated at the nodal points of the international grid accepted for the publications emanating from IAPS. Table A4 contains recommended values of viscosity calculated along the saturation line. Table A5 contains selected values of the function η/H in terms of T_r and ρ_r quoted to 8 significant digits to serve as an aid in checking computer programs.

Table A3 Recommended values of the dynamic viscosity of D_2O, η in units of 10^{-6} Pa·s, temperature T in °C, pressure P in MPa.

Table A4 Recommended values of the dynamic viscosity of D_2O along the saturation line, η in units of 10^{-6} Pa·s, temperature T in °C, pressure P in MPa.

Table A5 Check-values of the dynamic viscosity ratio η/H in terms of T_r, ρ_r. All entries are dimensionless.

Table A3 Recommended values of the dynamic viscosity of D_2O, η in units of 10^{-6} Pa·s, temperature T in °C, pressure P in MPa.

P (MPa) \ T(°C)	3.79	25.0	50.0	75.0	100.0	150.0	200.0	250.0
0.1	2088	1095	651.2	444.1	328.8	14.58	16.63	18.72
0.5	2086	1095	651.3	444.2	329.0	210.1	16.45	18.61
1.0	2085	1095	651.4	444.4	329.2	210.2	16.24	18.48
2.5	2080	1094	651.8	444.9	329.7	210.7	152.2	18.08
5.0	2072	1093	652.4	445.8	330.6	211.6	153.0	118.1
7.5	2065	1092	653.0	446.7	331.5	212.4	153.8	119.0
10.0	2058	1092	653.6	447.6	332.4	213.2	154.5	119.8
12.5	2051	1091	654.2	448.5	333.3	214.0	155.3	120.6
15.0	2044	1090	654.8	449.3	334.2	214.8	156.1	121.4
17.5	2037	1089	655.5	450.2	335.1	215.6	156.8	122.2
20.0	2031	1089	656.1	451.0	335.9	216.4	157.5	123.0
22.5	2025	1088	656.7	451.9	336.8	217.2	158.2	123.7
25.0	2019	1087	657.3	452.7	337.7	217.9	159.0	124.4
27.5	2013	1087	657.9	453.6	338.5	218.7	159.7	125.1
30.0	2007	1086	658.6	454.4	339.4	219.5	160.4	125.8
35.0	1997	1085	659.8	456.1	341.0	221.0	161.7	127.2
40.0	1987	1085	661.1	457.8	342.7	222.4	163.1	128.5
45.0	1978	1084	662.4	459.4	344.3	223.9	164.4	129.8
50.0	1969	1083	663.7	461.0	346.0	225.3	165.6	131.0
55.0	1962	1083	665.0	462.7	347.6	226.7	166.9	132.2
60.0	1955	1083	666.3	464.3	349.1	228.1	168.1	133.3
65.0	1948	1082	667.6	465.9	350.7	229.5	169.3	134.5
70.0	1943	1082	669.0	467.4	352.3	230.8	170.5	135.6
75.0	1938	1082	670.3	469.0	353.8	232.2	171.7	136.6
80.0	1934	1083	671.7	470.6	355.3	233.5	172.8	137.6
85.0	1930	1083	673.1	472.1	356.8	234.7	173.9	138.7
90.0	1927	1083	674.5	473.7	358.3	236.0	175.0	139.6
95.0	1925	1084	675.9	475.2	359.8	237.3	176.1	140.6
100.0	1923	1085	677.4	476.8	361.2	238.5	177.1	141.5

Table A3 (continued)

P(MPa) \ T(°C)	300.0	350.0	375.0	400.0	425.0	450.0	475.0	500.0
0.1	20.84	22.97	24.03	25.09	26.15	27.20	28.25	29.29
0.5	20.78	22.94	24.01	25.08	26.15	27.21	28.26	29.31
1.0	20.70	22.90	23.99	25.08	26.15	27.22	28.29	29.34
2.5	20.48	22.80	23.94	25.06	26.17	27.27	28.36	29.43
5.0	20.13	22.66	23.87	25.06	26.22	27.37	28.49	29.60
7.5	19.81	22.56	23.85	25.09	26.31	27.49	28.65	29.78
10.0	94.3	22.52	23.87	25.17	26.43	27.65	28.83	29.99
12.5	95.5	22.60	23.98	25.31	26.59	27.84	29.05	30.22
15.0	96.6	22.92	24.21	25.53	26.82	28.08	29.30	30.49
17.5	97.7	70.2	24.7	25.9	27.1	28.38	29.60	30.78
20.0	98.7	73.6	25.7	26.4	27.5	28.75	29.94	31.12
22.5	99.6	76.1	31.9	27.3	28.1	29.21	30.36	31.51
25.0	100.6	78.2	58.9	29.0	29.0	29.81	30.85	31.95
27.5	101.5	80.0	64.6	33.1	30.2	30.57	31.44	32.45
30.0	102.3	81.6	68.2	42.3	32.0	31.56	32.15	33.03
35.0	103.9	84.3	73.2	57.5	39.3	34.60	34.07	34.48
40.0	105.4	86.7	76.8	64.9	49.5	39.62	36.87	36.40
45.0	106.8	88.7	79.7	69.6	57.4	46.13	40.70	38.91
50.0	108.2	90.6	82.2	73.2	63.0	52.5	45.30	42.00
55.0	109.5	92.2	84.3	76.1	67.2	57.9	50.1	45.50
60.0	110.7	93.8	86.1	78.5	70.5	62.2	54.6	49.17
65.0	111.8	95.2	87.8	80.6	73.3	65.8	58.5	52.8
70.0	112.9	96.5	89.3	82.5	75.6	68.7	62.0	56.2
75.0	114.0	97.7	90.8	84.2	77.7	71.2	64.9	59.3
80.0	115.0	98.9	92.1	85.7	79.5	73.4	67.5	62.1
85.0	116.0	99.9	93.3	87.1	81.1	75.4	69.8	64.5
90.0	117.0	101.0	94.4	88.3	82.6	77.1	71.8	66.8
95.0	117.9	101.9	95.4	89.5	83.9	78.6	73.6	68.8
100.0	118.8	102.9	96.4	90.6	85.2	80.1	75.2	70.5

Table A4 Recommended values of the dynamic viscosity of D_2O along the saturation line, η in units of 10^{-6} Pa·s, temperature T in °C, pressure P in MPa.

T	P	η'	η''
3.79	0.0006596	2088	9.60
3.80	0.0006601	2087	9.60
10.00	0.001026	1679	9.76
20.00	0.001999	1247	10.03
30.00	0.003701	971.8	10.32
40.00	0.006549	784.8	10.63
50.00	0.01112	651.2	10.94
60.00	0.01820	551.8	11.27
70.00	0.02880	475.7	11.60
80.00	0.04423	415.9	11.94
90.00	0.06607	367.9	12.28
100.00	0.09625	328.8	12.62
110.00	0.13706	296.5	12.96
120.00	0.19115	269.4	13.31
130.00	0.26154	246.5	13.65
140.00	0.35167	226.9	13.99
150.00	0.46532	210.0	14.33
160.00	0.60669	195.3	14.67
170.00	0.78034	182.4	15.00
180.00	0.99119	171.1	15.33
190.00	1.245	160.9	15.66
200.00	1.546	151.9	15.99
210.00	1.902	143.8	16.32
220.00	2.317	136.4	16.64
230.00	2.800	129.7	16.98
240.00	3.357	123.5	17.31
250.00	3.995	117.8	17.66
260.00	4.722	112.5	18.01
270.00	5.546	107.5	18.39
280.00	6.476	102.7	18.78
290.00	7.520	98.1	19.21
300.00	8.688	93.6	19.68
310.00	9.992	89.2	20.20
320.00	11.44	84.7	20.81
330.00	13.05	80.0	21.53
340.00	14.84	74.9	22.45
345.00	15.80	72.1	23.02
350.00	16.82	69.0	23.7
355.00	17.89	65.7	24.6
360.00	19.02	61.6	25.7
361.00	19.25	60.7	26.0
362.00	19.48	59.8	26.4
363.00	19.72	58.7	26.7
364.00	19.96	57.6	27.1
365.00	20.21	56.4	27.6
366.00	20.45	55.1	28.1
367.00	20.70	53.6	28.8
368.00	20.95	51.9	29.6
369.00	21.21	49.6	30.8
370.00	21.47	46.4	32.9

Table A5 Check-values of the dynamic viscosity ratio η/H in terms of T_r, ρ_r. All entries are dimensionless.

VISCOSITY VALUES OF HEAVY WATER SUBSTANCE

AT SELECTED POINTS FOR PROGRAM TESTING

CALCULATED FROM

INTERNATIONAL REPRESENTATION OF THE VISCOSITY OF

HEAVY WATER SUBSTANCE (DEUTERIUM OXIDE, D_2O), 1982

REDUCED ABSOLUTE TEMPERATURE (T_r)	REDUCED DENSITY (ρ_r)	REDUCED VISCOSITY (η/H)
0.43100000D+00	0.30900000D+01	0.36912317D+02
0.43100000D+00	0.32300000D+01	0.34153155D+02
0.50000000D+00	0.20000000D-03	0.19729842D+00
0.50000000D+00	0.30700000D+01	0.12060491D+02
0.50000000D+00	0.31800000D+01	0.12467941D+02
0.60000000D+00	0.27000000D-02	0.23658290D+00
0.60000000D+00	0.29500000D+01	0.52437250D+01
0.60000000D+00	0.30700000D+01	0.57578400D+01
0.75000000D+00	0.29500000D-01	0.29514798D+00
0.75000000D+00	0.26500000D+01	0.26275044D+01
0.75000000D+00	0.28300000D+01	0.30417584D+01
0.90000000D+00	0.80000000D-01	0.36854726D+00
0.90000000D+00	0.16300000D+00	0.36196491D+00
0.90000000D+00	0.21600000D+01	0.16561616D+01
0.90000000D+00	0.25200000D+01	0.21041365D+01
0.10000000D+01	0.30000000D+00	0.44248168D+00
0.10000000D+01	0.70000000D+00	0.55286939D+00
0.10000000D+01	0.15500000D+01	0.11038442D+01
0.10000000D+01	0.22600000D+01	0.17569586D+01
0.11000000D+01	0.49000000D+00	0.56330381D+00
0.11000000D+01	0.98000000D+00	0.78163879D+00
0.11000000D+01	0.14700000D+01	0.11169457D+01
0.11000000D+01	0.19600000D+01	0.15001421D+01
0.12000000D+01	0.40000000D+00	0.60945391D+00
0.12000000D+01	0.80000000D+00	0.76510992D+00
0.12000000D+01	0.12000000D+01	0.99378701D+00
0.12000000D+01	0.16100000D+01	0.12711900D+01

The calculations were made utilizing 17 significant figures and the results were rounded as shown.

Appendix B

International Representation of the Thermal Conductivity of Heavy Water Substance (Deuterium Oxide, D_2O)

1982

IAPS Working Group II (on Transport Properties) has critically examined the experimental results on the thermal conductivity of liquid and gaseous heavy water and recommends that the values implied by the equation given below should be used for this property. The equation represents the said quantity as a function of temperature and density. For a conversion to a representation as a function of temperature and pressure, values of density should be computed from the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Heavy Water Substance in the reference given in the footnote†.

The recommended equation is:

$$\lambda = \Lambda[\lambda_0 + \Delta\lambda + \Delta\lambda_c + \Delta\lambda_L] \quad , \tag{B1}$$

where

$$\lambda_0 = \sum_{i=0}^{5} A_i T_r^{\,i} \quad , \tag{B2}$$

$$\Delta\lambda = B_0[1-\exp(B_e\rho_r)] + \sum_{j=1}^{4} B_j \rho_r^{\,j} \quad , \tag{B3}$$

$$\Delta\lambda_c = C_1 f_1(T_r) f_2(\rho_r) \left(1+[f_2(\rho_r)]^2 \left\{ \frac{C_2[f_1(T_r)]^4}{f_3(T_r)} + \frac{3.5 f_2(\rho_r)}{f_4(T_r)} \right\} \right) , \tag{B4}$$

$$\Delta\lambda_L = D_1[f_1(T_r)]^{1.2} \left\{ 1-\exp\left[-\left(\frac{\rho_r}{2.5} \right)^{10} \right] \right\} \quad , \tag{B5}$$

and

$$f_1(T_r) = \exp(C_{T1} T_r + C_{T2} T_r^{\,2}) \quad , \tag{B6}$$

$$f_2(\rho_r) = \exp[C_{R1}(\rho_r-1)^2] + C_{R2}\exp[C_{R3}(\rho_r-\rho_{r1})^2] \quad , \tag{B7}$$

---

† Hill, P. G., MacMillan, R. D., and Lee, V., "A Fundamental Equation of State for Heavy Water," Journal of Physical and Chemical Reference Data 11, 1-14 (1982), 12 1065 (1983).

$$f_3(T_r) = 1 + \exp[60(\tau-1) + 20] \quad , \tag{B8}$$

$$f_4(T_r) = 1 + \exp[100(\tau-1) + 15] \quad , \tag{B9}$$

$$\tau = \frac{T_r}{|T_r-1.1| + 1.1} \quad . \tag{B10}$$

The reduced variables are

$$T_r = T/T^* \qquad \text{and} \qquad \rho_r = \rho/\rho^* \tag{B11}$$

and the meaning of the symbols is as follows:

λ - thermal conductivity

T - temperature on the International Practical Temperature Scale of 1968

ρ - density

T* - reference temperature

ρ^* - reference density

The reference constants T* and ρ^* are close, but not necessarily equal, to the actual critical parameters of heavy water. For the purpose of this representation they play the part of correlation constants and need not be amended when improved values of the actual critical constants become available.

The constants appearing in Eqs. (B1) - (B11) are listed below.

$$T^* = 643.89 \text{ K} \quad ,$$

$$\rho^* = 358 \text{ kg/m}^3 \quad ,$$

$$\Lambda = 0.7421\,28 \times 10^{-3} \text{ W/(m·K)}.$$

Table of coefficients for thermal conductivity equation

$A_0 = 1.0000\ 0$

$A_1 = 37.3223$

$A_2 = 22.5485$

$A_3 = 13.0465$

$A_4 = 0.0$

$A_5 = -2.6073\ 5$

$B_e = -2.5060\ 0$

$B_0 = -167.310$

$B_1 = 483.656$

$B_2 = -191.039$

$B_3 = 73.0358$

$B_4 = -7.5746\ 7$

$C_1 = 0.3542\ 96 \times 10^5$

$C_2 = 0.5000\ 00 \times 10^{10}$

$C_{T1} = 0.1448\ 47$

$C_{T2} = -5.6449\ 3$

$C_{R1} = -2.8000\ 0$

$C_{R2} = -0.0807\ 3854\ 3$

$C_{R3} = -17.9430$

$\rho_{r1} = 0.1256\ 98$

$D_1 = -741.112$

Range

The representation of the thermal conductivity of heavy water by Eqs. (B1) - (B11) together with the numerical constants listed above is valid in the rectangle defined by

$$0 \text{ MPa} \leq P \leq 100 \text{ MPa} ,$$

$$277 \text{ K (melting point} \leq T \leq 825 \text{ K} .$$

Tolerances

The equation represents the thermal conductivity within an uncertainty of ±2% to ±10% as indicated in Figure B1. However, no tolerances are assigned in the region contained within

$$0.99 < T_r < 1.05 ,$$

$$0.8 < \rho_r < 1.2 ,$$

because the actual thermal conductivity diverges at the critical point while the thermal conductivity calculated from the equation remains finite at the critical point.

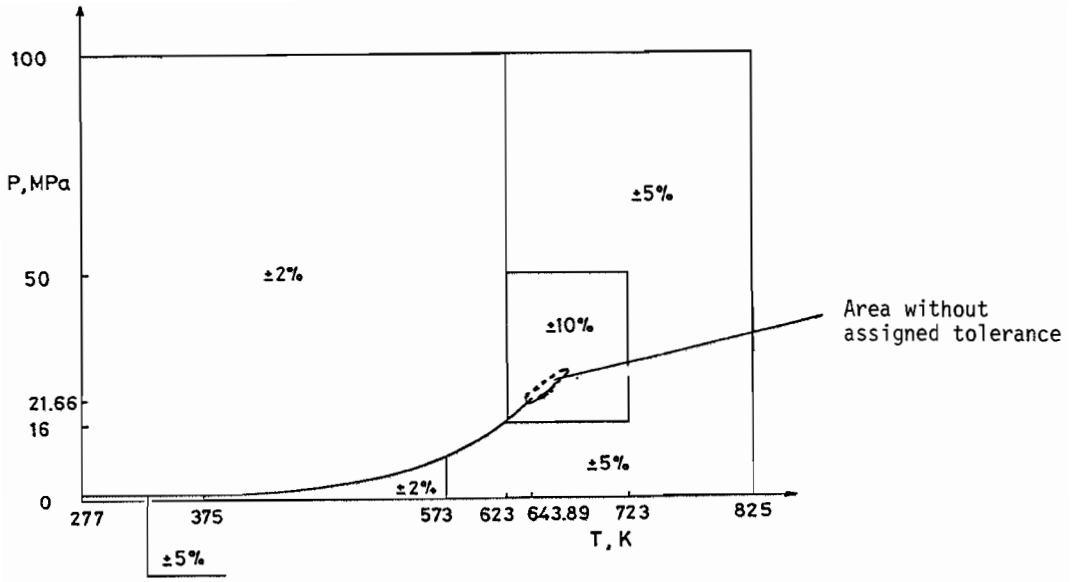

Figure B1. Tolerances of the representation of the thermal conductivity of heavy water

Tables

Three Tables are given in this Appendix. Table B1 contains recommended values of thermal conductivity calculated at the nodal points of the international grid accepted for the publications of IAPS. Table B2 contains recommended values of thermal conductivity calculated along the saturation line. Table B3 contains selected values of the function λ/Λ in terms of T_r and ρ_r quoted to 8 significant digits to serve as an aid in checking computer programs.

Table B1 Recommended values of the thermal conductivity of D_2O, λ in units of 10^{-3} W/(m·K), temperature T in °C, pressure P in MPa.

Table B2 Recommended values of the thermal conductivity of D_2O along the saturation line, λ in units of 10^{-3} W/(m·K), temperature T in °C, pressure P in MPa.

Table B3 Check-values of the thermal conductivity ratio λ/Λ in terms of T_r, ρ_r. All entries are dimensionless.

Table B1 Recommended values of the thermal conductivity of D_2O, λ in units of 10^{-3} W/(m.K), temperature T in °C, pressure P in MPa.

p(MPa) \ T(°C)	3.79	25.0	50.0	75.0	100.0	150.0	200.0	250.0	300.0
0.1	565	595	618	631	636	29.04	33.77	38.93	44.49
0.5	565	595	618	632	636	625	34.70	39.47	44.85
1.0	565	595	619	632	636	625	36.27	40.28	45.35
2.5	566	596	619	633	637	626	593	43.94	47.33
5.0	567	597	621	634	639	628	595	542	52.9
7.5	569	599	622	635	640	629	596	545	64.3
10.0	570	600	623	636	641	631	598	547	475.5
12.5	572	601	624	638	642	632	600	550	479.7
15.0	573	603	626	639	644	633	602	552	483.7
17.5	575	604	627	640	645	635	604	555	487.5
20.0	576	605	628	641	646	636	605	557	491.2
22.5	578	607	629	642	647	638	607	559	494.7
25.0	579	608	631	644	649	639	609	562	498.1
27.5	580	609	632	645	650	641	610	564	501
30.0	582	610	633	646	651	642	612	566	505
35.0	585	613	635	648	654	645	615	570	511
40.0	587	615	638	651	656	647	619	574	517
45.0	590	618	640	653	658	650	622	578	522
50.0	593	620	642	655	661	653	625	582	528
55.0	596	623	645	658	663	655	628	586	533
60.0	598	625	647	660	665	658	631	590	538
65.0	601	627	649	662	668	660	634	593	542
70.0	604	630	651	664	670	663	637	597	547
75.0	606	632	654	666	672	665	640	600	551
80.0	609	635	656	669	674	668	642	604	556
85.0	611	637	658	671	677	670	645	607	560
90.0	614	639	660	673	679	673	648	610	564
95.0	616	641	662	675	681	675	651	614	568
100.0	619	644	665	677	683	677	653	617	572

Table B1 (continued)

P(MPa) \ T(°C)	350.0	375.0	400.0	425.0	450.0	475.0	500.0	550.0
0.1	50.4	53.5	56.7	59.9	63.3	66.7	70.1	77.2
0.5	50.7	53.8	56.9	60.1	63.5	66.8	70.3	77.3
1.0	51.0	54.1	57.2	60.4	63.7	67.1	70.5	77.5
2.5	52.4	55.2	58.2	61.3	64.6	67.9	71.3	78.2
5.0	55.5	57.8	60.4	63.3	66.3	69.5	72.8	79.6
7.5	60.4	61.5	63.4	65.8	68.5	71.5	74.6	81.2
10.0	68.0	66.7	67.4	69.0	71.3	73.9	76.8	83.1
12.5	80.4	74.3	72.7	73.1	74.7	76.8	79.4	85.2
15.0	103	85.6	79.9	78.4	78.8	80.3	82.4	87.7
17.5	393	103	89.6	85.0	83.8	84.3	85.8	90.4
20.0	401	137	103	93.3	89.8	89.1	89.8	93.5
22.5	408	349	122	104	97.0	94.6	94.3	96.9
25.0	414	370	152	117	105.7	101.0	99.4	100.6
27.5	420	370	206	135	116.1	108.3	105.1	104.7
30.0	425	376	279	159	128.6	116.8	111.6	109.1
35.0	436	390	332	227	161.8	137.5	126.7	119.2
40.0	445	403	353	284	205	164.0	145.2	130.8
45.0	453	414	369	314	247	194.8	166.8	144.0
50.0	461	424	382	335	279	226	190.4	158.5
55.0	469	433	394	351	303	253	214	174.0
60.0	476	441	404	364	321	276	237	190.0
65.0	482	449	414	376	337	295	257	206
70.0	488	456	423	387	350	312	275	222
75.0	494	463	431	397	362	326	291	237
80.0	500	470	439	406	373	339	306	251
85.0	506	476	446	415	383	350	319	265
90.0	511	482	453	422	392	361	331	278
95.0	516	488	459	430	400	371	342	290
100.0	521	494	466	437	408	380	352	301

Table B2 Recommended values of the thermal conductivity of D_2O along the saturation line, λ in units of 10^{-3} W/(m·K), temperature T in °C, pressure P in MPa.

T	P	λ'	λ''
3.79	0.0006596	565	16.53
3.80	0.0006601	565	16.53
10.00	0.001026	575	16.99
20.00	0.001999	589	17.75
30.00	0.003701	600	18.52
40.00	0.006549	610	19.33
50.00	0.01112	618	20.2
60.00	0.01820	625	21.0
70.00	0.02880	629	21.9
80.00	0.04423	633	22.8
90.00	0.06607	635	23.8
100.00	0.09625	636	24.8
110.00	0.1371	636	25.88
120.00	0.1911	635	27.01
130.00	0.2615	632	28.19
140.00	0.3517	629	29.45
150.00	0.4653	625	30.78
160.00	0.6067	620	32.20
170.00	0.7803	614	33.72
180.00	0.9912	607	35.34
190.00	1.245	600	37.10
200.00	1.546	592	39.00
210.00	1.902	583	41.07
220.00	2.317	574	43.36
230.00	2.800	564	45.92
240.00	3.357	553	48.79
250.00	3.995	541	52.0
260.00	4.722	529	55.8
270.00	5.546	516	60.1
280.00	6.476	502	64.8
290.00	7.520	488.2	69.8
300.00	8.688	473.3	75.2
310.00	9.992	457.7	81.9
320.00	11.44	441.6	90.9
330.00	13.05	424.9	102.7
340.00	14.84	407.9	118.8
345.00	15.80	399.5	129.4
350.00	16.82	391	143
355.00	17.89	385	162
360.00	19.02	382	191
361.00	19.25	383	199
362.00	19.48	385	209
363.00	19.72	388	220
364.00	19.96	392	233
365.00	20.21	399	249
366.00	20.45	408	269
367.00	20.70	422	295
368.00	20.95	443	330
369.00	21.21	478	382
370.00	21.47	538	475

Table B3 Check-values of the thermal conductivity ratio λ/Λ in terms of T_r, ρ_r. All entries are dimensionless.

THERMAL CONDUCTIVITY VALUES OF HEAVY WATER SUBSTANCE

AT SELECTED POINTS FOR PROGRAM TESTING

CALCULATED FROM

INTERNATIONAL REPRESENTATION OF THE THERMAL CONDUCTIVITY OF

HEAVY WATER SUBSTANCE (DEUTERIUM OXIDE, D_2O), 1982

REDUCED ABSOLUTE TEMPERATURE (T_r)	REDUCED DENSITY (ρ_r)	REDUCED THERMAL CONDUCTIVITY (λ/Λ)
0.43100000D+00	0.30900000D+01	0.76291571D+03
0.43100000D+00	0.32300000D+01	0.83391205D+03
0.50000000D+00	0.20000000D-03	0.27006537D+02
0.50000000D+00	0.30700000D+01	0.83578642D+03
0.50000000D+00	0.31800000D+01	0.89118175D+03
0.60000000D+00	0.27000000D-02	0.35339950D+02
0.60000000D+00	0.29500000D+01	0.86124079D+03
0.60000000D+00	0.30700000D+01	0.91985909D+03
0.75000000D+00	0.29500000D-01	0.55216750D+02
0.75000000D+00	0.26500000D+01	0.79044256D+03
0.75000000D+00	0.28300000D+01	0.86967229D+03
0.90000000D+00	0.80000000D-01	0.74522283D+02
0.90000000D+00	0.16300000D+00	0.10630197D+03
0.90000000D+00	0.21600000D+01	0.62777759D+03
0.90000000D+00	0.25200000D+01	0.76105504D+03
0.10000000D+01	0.30000000D+00	0.14342200D+03
0.10000000D+01	0.70000000D+00	0.46901512D+03
0.10000000D+01	0.15500000D+01	0.50284695D+03
0.10000000D+01	0.22600000D+01	0.66874352D+03
0.11000000D+01	0.49000000D+00	0.18481346D+03
0.11000000D+01	0.98000000D+00	0.32665238D+03
0.11000000D+01	0.14700000D+01	0.43837031D+03
0.11000000D+01	0.19600000D+01	0.57201441D+03
0.12000000D+01	0.40000000D+00	0.16005940D+03
0.12000000D+01	0.80000000D+00	0.25960524D+03
0.12000000D+01	0.12000000D+01	0.36217957D+03
0.12000000D+01	0.16100000D+01	0.47174773D+03
0.12700000D+01	0.30000000D+00	0.14524991D+03
0.12700000D+01	0.60000000D+00	0.21199630D+03
0.12700000D+01	0.95000000D+00	0.29925147D+03
0.12700000D+01	0.13700000D+01	0.40935968D+03

The calculations were made utilizing 17 significant figures and the results were rounded as shown.

Release on
The Ion Product of Water Substance

Issued by the
International Association for the Properties of Steam

President: U. Grigull
Technical University of Munich
8 Munich 2
Federal Republic of Germany

May 1980

The General Meeting of the International Association for the Properties of Steam (IAPS) held during the Ninth International Conference on the Properties of Steam in Munich, Federal Republic of Germany, September 10-14, 1979, authorized the preparation of an official representation for the ion product of water substance. The task of preparing this representation was assigned to Working Group III of IAPS which had already carried out preliminary-work leading toward preparation of a representation.

This release has been authorized by the IAPS for issue by its Secretariat and presents the International Representation of the Ion Product of Water Substance, 1980. In accordance with the Statutes of IAPS, the representation has been circulated to and approved by the Members of. the IAPS (Canada, Czechoslovakia, Federal Republic of Germany, France, Japan, USSR, United Kingdom, and United States of America).

The deliberations of Working Group III are given briefly in Appendix A. in Appendix B an equation for the ion product (K_w), defined as (molality of hydrogen ion) times (molality of hydroxide ion), is given as a function of temperature and density. Auxiliary tables (Appendices C, D, and E) present values of K_w calculated by the equation at selected temperatures and pressures.

Contents: Appendices A, B, C, D, and E

APPENDIX A

Working Group III of the International Association for the Properties of Steam has collected from the literature existing experimental data and treatments for the ion product of water. References were compiled and descriptions given in several documents presented at the annual meetings of working groups. These documents are: "Consideration of Present Knowledge of the Ionization Behavior of Water as a Function of Temperature and Pressure" (W. L. Marshall, Ottawa, Canada, September 15-19, 1975); "Further Evaluation of the Ionization Constant of Water; Description from 0 to 1000 °C and from 1 to above 10,000 Bars" (W. L. Marshall, Kyoto, Japan, September 5-10, 1976); "Revised Evaluation of the Ion Product of Water; Description from 0 to 1000 °C and from 1 to 10,000 Bars" (W. L. Marshall, Moscow, USSR, September 10-16, 1977).

Working Group III considers that enough independent determinations of K_w at saturated vapor pressure from 0 to 374 °C have been made to describe K_w, under this condition, within ±0.01 logarithmic units (base 10). It would appear that sufficient experimental values have been obtained throughout the range of pressure, 1-10,000 bars, and temperature, 0-1,000 °C, together with a correlation by the form of equation used (Appendix B), to yield values of log K_w^* (base 10), where K_w^* equals $K_w/(\text{mol kg}^{-1})^2$, within uncertainties of ±0.01 near the saturated vapor pressure and to ±0.3 at the extreme of temperature and pressure. Selected literature references and estimated uncertainties for particular ranges are included with the equation.

APPENDIX B

Recommended Interpolation Equation

The available data are reproduced by the equation given below, wherein,

K_w: ion product, molality of H^+ ion times molality of OH^-, which may be expressed by the symbols, $m_{H^+} \cdot m_{OH^-}$.

K_w^*: $K_w/(\text{mol kg}^{-1})^2$

T: temperature in degrees K on the 1968 International Practical Temperature Scale.

ρ_w: density in g/cm^3.

ρ_w^*: $\rho_w/(\text{g cm}^{-3})$

Logarithms of K_w^* and of ρ_w^* are in units of base 10.

$$\log K_w^* = A + B/T + C/T^2 + D/T^3 + (E + F/T + G/T^2) \cdot \log \rho_w^*$$

The constants in the above equation are:

$A = -4.098$ $\quad$ $E = +13.957$

$B = -3245.2\ K$ $\quad$ $F = -1262.3\ K$

$C = +2.2362 \times 10^5\ K^2$ $\quad$ $G = +8.5641 \times 10^5\ K^2$

$D = -3.984 \times 10^7\ K^3$

The equation will describe $\log K_w^*$ at saturated vapor pressure up to 250°C within ±0.004 to 0.014 units of critically determined values of Sweeton, Mesmer, and Baes (J. Soln. Chem. 3, 191 (1974)) (Appendix C). Generally described within their uncertainties are experimental values of Kryukov, Larionov, and Starostina, 25-150°C, 1-8000 bars (Ninth Intl. Conf. Prop. Steam, Munich, FRG, September 10-14, 1979), of Linov and Kryukov, 25-75°C, 1-8000 bars (Izv. Sib. Otb. Akad. Nauk. SSSR, Ser. Khim. Nauk., 1972 (4), 10 (1972)), of Hamann, 25°C, 1-2000 bars (J. Phys. Chem., 67, 2233 (1963)), and of Whitfield, 25°C, 1-2000 bars (J. Chem. Eng. Data, 17, 124 (1972)). Some values of Hamann and Linton, 45-373°C, 7500-71000 bars (Trans. Faraday Soc., 65, 2186 (1969)), are calculated to within 0.10-0.35 units although not used in obtaining the parameters. At high temperatures, the equation describes values of Quist, 300-800°C, 1000-4000 bars (J. Phys. Chem., 74, 3396 (1970)), generally within 0.1-0.2 units, or better than stated uncertainties of ±0.3 to 0.5 units.

Accuracies of $\log K_w^*$ calculated by the equation are estimated to be within ± 0.01 units at saturated vapor pressure and within ± 0.03 units at pressures up to 10,000 bars when the temperature is below 250°C. At temperatures from 250 to 1000°C and pressures up to 10,000 bars the equation may still provide accuracies of ± 0.03 to 0.05 units although upper limits of uncertainty should probably be increased from ± 0.05 to 0.30 units of $\log K_w^*$ as the highest temperatures and pressures are approached.

APPENDIX C

Comparisons of Log K_w^* at Saturated Vapor Pressure Calculated by the Equation (Appendix B) with Those Calculated by Sweeton, Mesmer, and Baes (SMB).[a,b]

t°C	log K_w^* (SMB)	log K_w^* (Eqn., Appendix B)	Difference
0	-14.941	-14.938	-0.003
25	-13.993	-13.995	+0.002
50	-13.272	-13.275	+0.003
75	-12.709	-12.712	+0.003
100	-12.264	-12.265	+0.001
125	-11.914	-11.912	-0.002
150	-11.642	-11.638	-0.004
175	-11.441	-11.432	-0.009
200	-11.302	-11.289	-0.013
225	-11.222	-11.208	-0.014
250	-11.196	-11.191	-0.005
275	-11.224	-11.251	+0.027
300	-11.301	-11.406	+0.105

[a]Densities used were obtained from the 1967 IFC Formulation for Industrial Use as prepared by the International Formulation Committee (IFC). This committee was established by the Sixth International Conference on the Properties of Steam (New York, October, 1963). Steam tables based upon the 1967 IFC formulation are published in several member countries of the International Association for the Properties of Steam.

[b]$K_w^* = K_w/(\text{mol kg}^{-1})^2$; K_w in (molality)^2.

APPENDIX D

The Negative Logarithm (Base 10) of the Ion Product of Water Divided by $(\text{mol kg}^{-1})^2$, $-\text{Log } K_w^*$; 0-1000°C, 1-10,000 Bars.[a,b]

Pressure (Bars)	Temperature (°C) 0	25	50	75	100	150	200
Saturated Vapor	14.938	13.995	13.275	12.712	12.265	11.638	11.289
250	14.83	13.90	13.19	12.63	12.18	11.54	11.16
500	14.72	13.82	13.11	12.55	12.10	11.45	11.05
750	14.62	13.73	13.04	12.48	12.03	11.36	10.95
1,000	14.53	13.66	12.96	12.41	11.96	11.29	10.86
1,500	14.34	13.53	12.85	12.29	11.84	11.16	10.71
2,000	14.21	13.40	12.73	12.18	11.72	11.04	10.57
2,500	14.08	13.28	12.62	12.07	11.61	10.92	10.45
3,000	13.97	13.18	12.53	11.98	11.53	10.83	10.34
3,500	13.87	13.09	12.44	11.90	11.44	10.74	10.24
4,000	13.77	13.00	12.35	11.82	11.37	10.66	10.16
5,000	13.60	12.83	12.19	11.66	11.22	10.52	10.00
6,000	13.44	12.68	12.05	11.53	11.09	10.39	9.87
7,000	13.31	12.55	11.93	11.41	10.97	10.27	9.75
8,000	13.18	12.43	11.82	11.30	10.86	10.17	9.64
9,000	13.04	12.31	11.71	11.20	10.77	10.07	9.54
10,000	12.91	12.21	11.62	11.11	10.68	9.98	9.45

[a] Values were calculated by the equation of Appendix B. Densities used were obtained from the 1967 IFC formulation (Footnote a of Appendix C) and from the smoothed experimental values, up to the highest temperatures and pressures, of Burnham, Holloway, and Davis (Amer. J. of Sci. 267A, 70 (1969)), of Köster and Franck (Ber. Bunsenges. physik. Chem. 73, 716 (1969)), and of Maier and Franck (Ber. Bunsenges. physik. Chem. 70, 639 (1966)). These sets of densities generally agree with each other to much better than 1%. A 1% deviation in density corresponds to a difference of 0.06 units in calculated log K_w at 1000°C, well within the projected uncertainties (Appendices A and B) in the higher range of temperature and pressure.

[b] $K_w^* = K_w/(\text{mol kg}^{-1})^2$; K_w in $(\text{molality})^2$.

APPENDIX D (Cont'd)

The Negative Logarithm (Base 10) of the Ion Product of Water Divided by $(\text{mol kg}^{-1})^2$, $-\text{Log } K_w^*$, 0-1000°C, 1-10,000 Bars,[a,b]

Pressure (Bars)	Temperature (°C)						
	250	300	350	400	450	500	600
Saturated Vapor	11.191	11.406	12.30	----	----	----	----
250	11.01	11.14	11.77	19.43	21.59	22.40	23.27
500	10.85	10.86	11.14	11.88	13.74	16.13	18.30
750	10.72	10.66	10.79	11.17	11.89	13.01	15.25
1,000	10.60	10.50	10.54	10.77	11.19	11.81	13.40
1,500	10.43	10.26	10.22	10.29	10.48	10.77	11.59
2,000	10.27	10.08	9.98	9.98	10.07	10.23	10.73
2,500	10.12	9.91	9.79	9.74	9.77	9.86	10.18
3,000	9.99	9.76	9.61	9.54	9.53	9.57	9.78
3,500	9.88	9.63	9.47	9.37	9.33	9.34	9.48
4,000	9.79	9.52	9.34	9.22	9.16	9.15	9.23
5,000	9.62	9.34	9.13	8.99	8.90	8.85	8.85
6,000	9.48	9.18	8.96	8.80	8.69	8.62	8.57
7,000	9.35	9.04	8.81	8.64	8.51	8.42	8.34
8,000	9.24	8.93	8.68	8.50	8.36	8.25	8.13
9,000	9.13	8.82	8.57	8.37	8.22	8.10	7.95
10,000	9.04	8.71	8.46	8.25	8.09	7.96	7.78

APPENDIX D (Cont'd)

The Negative Logarithm (Base 10) of the Ion Product of Water Divided by $(mol.kg^{-1})^2$, $-Log\ K_w^*$; 0-1000°C, 0-10,000 Bars.[a,b]

Pressure (Bars)	Temperature (°C) 700	800	900	1000
Saturated Vapor	----	----	----	----
250	23.81	24.23	24.59	24.93
500	19.29	19.92	20.39	20.80
750	16.55	17.35	17.93	18.39
1,000	14.70	15.58	16.22	16.72
1,500	12.50	13.30	13.97	14.50
2,000	11.36	11.98	12.54	12.97
2,500	10.63	11.11	11.59	12.02
3,000	10.11	10.49	10.89	11.24
3,500	9.71	10.02	10.35	10.62
4,000	9.41	9.65	9.93	10.13
5,000	8.95	9.11	9.30	9.42
6,000	8.61	8.72	8.86	8.97
7,000	8.34	8.40	8.51	8.64
8,000	8.10	8.13	8.21	8.38
9,000	7.89	7.89	7.95	8.12
10,000	7.70	7.68	7.70	7.85

APPENDIX E

The Negative Logarithm (Base 10) of the Ion Product of Water Divided by $(\text{mol kg}^{-1})^2$; $-\text{Log } K_w^*$; 340-600°C, 50-500 Bars.[a,b]

Pressure (Bars)	Temperature (°C)								
	340	360	380	400	440	480	520	560	600
50	33.14	33.15	33.17	33.18	33.20	33.24	33.29	33.35	33.44
100	27.85	28.11	28.29	28.42	28.63	28.79	28.92	29.05	29.18
150	11.97 ‡	24.33 ‡	24.91	25.22	25.71	26.02	26.25	26.44	26.62
200	11.74	12.51	21.55	22.46	23.40	23.92	24.26	24.53	24.76
250	11.57	12.06	13.64	19.43	21.33	22.14	22.63	22.98	23.27
300	11.44	11.80	12.57	14.78	19.33	20.55	21.23	21.67	22.02
350	11.32	11.62	12.17	13.10	17.24	19.08	19.96	20.52	20.93
400	11.22	11.47	11.88	12.49	15.35	17.69	18.81	19.48	19.96
450	11.13	11.35	11.68	12.14	13.99	16.42	17.75	18.53	19.09
500	11.06	11.24	11.51	11.88	13.26	15.32	16.78	17.67	18.30

‡Demarcation Line Between Values for Vapor (Above) and Liquid (Below). Values of $-\log K_w^*$ at 340 and 360°C at saturated vapor pressure are 12.01 and 12.73, respectively.

[a]Footnote a of Appendix D applies. This table encompasses usual ranges of temperature and pressure of operating steam cycles.

[b]$K_w^* = K_w/(\text{mol kg}^{-1})^2$; K_w in $(\text{molality})^2$.

Release on
Static Dielectric Constant of Water Substance

Issued by
The International Association for the Properties of Steam

President: Mr. H. W. Bradly
Bradly Associates
3 Belleville Drive
Oadby, Theicester LE2 4HA
United Kingdom

The Eighth International Conference on The Properties of Steam
Giens, France
September 1974

Release issued September 1977

The Eighth International Conference on the Properties of Steam designated a Working Group III, consisting of representatives of France, the Federal Republic of Germany, Japan, the USA and the USSR, for the purpose of establishing representations of miscellaneous properties.

Working Group III met in Schliersee near Munich in April, 1975, in Ottawa in September, 1975, in Kyoto in September, 1976, and in Moscow in September, 1977, and completed its work with respect to the representation of the static dielectric constant (permittivity), ε, which is valid for electric fields of very low frequency and moderate intensity, of water substance.

In accordance with a resolution of the Eighth Conference, the material included in the present release was circulated to and approved by the Heads of all National Delegations attending the Eighth Conference (Canada, Czechoslovakia, Federal Republic of Germany, France, Hong Kong, Hungary, Japan, Netherlands, Poland, Switzerland, United Kingdom, United States of America, and the Union of Soviet Socialist Republics).

This Release on static dielectric constant is now issued by the Secretariat under the full authority of the Eighth Conference, and presents in the accompanying Appendices the International Representation of the Static Dielectric Constant of Water Substance, 1977.

Attachments:

Appendices A, B, and C

Appendix A

Working Group III has collected the existing experimental data from the literature, which were included in the document, "Survey of the Experimental Studies of the Static Dielectric Constant of Water", by E.U.Franck, W.Harder and W.Hill, presented to the meeting of Working Group III of the International Association for the Properties of Steam (IAPS), Schliersee, near Munich, Federal Republic of Germany, April, 1975. Working Group III considers that these data are not sufficiently accurate and precise to allow definition of a two-dimensional representation that satisfies all of the criteria for smoothness and physical plausibility that logically can be required of it. Working Group III hopes that additional measurements of superior quality will become available in the future. At the present time, in this release, Working Group III issues a formulation consisting of an equation and one table. This equation is considered to be as good as possible a representation of these available data.

Appendix B

Recommended Interpolation Equation

The available experimental data are reproduced with a standard deviation of 0.33 in ε-units by the use of the formula given below, wherein

ε : static dielectric constant

ρ : density in kg/m^3 +)

T : temperature in K on the 1968 Practical Temperature Scale

$T^* = T / T_0$

$\rho^* = \rho / \rho_0$

a_i, T_0, ρ_0 : numerical constants

$$\varepsilon = 1 + (a_1 / T^*) \rho^* + (a_2 / T^* + a_3 + a_4 T^*) \rho^{*2} + (a_5 / T^* + a_6 T^* + a_7 T^{*2}) \rho^{*3} + (a_8 / T^{*2} + a_9 / T^* + a_{10}) \rho^{*4}$$

The constants appearing in the preceding equation have the numerical values given below:

$a_1 = 7.625\ 71 \times 10^0$

$a_2 = 2.440\ 03 \times 10^2$

$a_3 = -1.405\ 69 \times 10^2$

$a_4 = 2.778\ 41 \times 10^1$

$a_5 = -9.628\ 05 \times 10^1$

$a_6 = 4.179\ 09 \times 10^1$

$a_7 = -1.020\ 99 \times 10^1$

$a_8 = -4.520\ 59 \times 10^1$

+) For preference and to reproduce the values given in Appendix C, the density should be computed with the aid of the 1968 IFC Formulation for Scientific and General Use for pressures up to 100 MPa and with the equation of state proposed by Juza (Roz. Cesk. Akad. Ved Rada Tech. Ved, 1966, vol.76, No.1) for pressures above 100 MPa.

$$a_9 = 8.463\ 95 \times 10^{1}$$

$$a_{10} = -3.586\ 44 \times 10^{1}$$

$$T_0 = 298.15\ K$$

$$\rho_0 = 1000\ kg/m^3$$

This equation is valid in the range

$$273.15\ K \leq T \leq 823.15\ K$$

in temperature, and

$$0 \leq \rho \leq 1150\ kg/m^3$$

in density, which corresponds to an approximate pressure range

$$0 \leq P \leq 500\ MPa.$$

A discussion of the equation and its derivation is given in the document, "The Static Dielectric Constant of Water in the Range of Temperatures from 0 to 550°C and Pressures up to 5 kbar", by M.Uematsu, W.Harder and E.U.Franck, presented to the meeting of Working Group III of IAPS, Kyoto, Japan, September, 1976; and also in a presentation, "The Equation of State for the Static Dielectric Constant of Water in the Range of Temperatures from 0 to 550°C and Pressures up to 5 kbar", by M.Uematsu and E.U. Franck, in the Proceedings of the 6th AIRAPT International High Pressure Conference, Boulder, Colorado, U.S.A., July, 1977.

Appendix C

Static dielectric constant of water substance

A table of values is given at selected points of pressure P in MPa and temperature T in K obtained from the equation given in Appendix B.

Table Static Dielectric Constant of Water and Steam

P/T	273.15	298.15	323.15	348.15	373.15	398.15	423.15	448.15	473.15
10	88.28	78.85	70.27	62.59	55.76	49.70	44.30	39.47	35.11
20	88.75	79.24	70.63	62.94	56.11	50.05	44.66	39.85	35.52
30	89.20	79.63	70.98	63.28	56.44	50.39	45.01	40.22	35.91
40	89.64	80.00	71.32	63.61	56.77	50.72	45.34	40.56	36.28
50	90.07	80.36	71.66	63.93	57.08	51.03	45.67	40.89	36.63
60	90.49	80.72	71.98	64.24	57.39	51.34	45.98	41.21	36.96
70	90.90	81.07	72.30	64.54	57.69	51.64	46.28	41.52	37.28
80	91.29	81.42	72.62	64.84	57.98	51.93	46.57	41.82	37.59
90	91.67	81.75	72.92	65.13	58.27	52.21	46.86	42.11	37.89
100	92.04	82.08	73.22	65.42	58.55	52.49	47.14	42.39	38.17
125	92.89	82.84	73.93	66.09	59.19	53.12	47.78	43.05	38.86
150	93.71	83.57	74.62	66.74	59.82	53.75	48.40	43.68	39.50
175	94.48	84.28	75.27	67.36	60.42	54.34	48.98	44.27	40.10
200	95.20	84.94	75.89	67.95	61.00	54.90	49.54	44.83	40.66
225	95.87	85.58	76.50	68.53	61.55	55.44	50.08	45.36	41.20
250	96.51	86.20	77.08	69.08	62.08	55.96	50.59	45.87	41.70
300	97.69	87.34	78.17	70.14	63.10	56.94	51.55	46.82	42.65
350	98.75	88.40	79.19	71.12	64.05	57.86	52.45	47.70	43.52
400	99.72	89.39	80.13	72.03	64.94	58.74	53.30	48.53	44.33
450	100.60	90.30	81.02	72.89	65.78	59.56	54.10	49.31	45.10
500	101.42	91.16	81.84	73.69	66.57	60.33	54.85	50.05	45.82

Table (Continued)

P/T	498.15	523.15	548.15	573.15	623.15	673.15	723.15	773.15	823.15
10	31.13	27.43	23.90	20.39	1.23	1.17	1.14	1.11	1.10
20	31.58	27.95	24.54	21.24	14.07	1.64	1.42	1.32	1.26
30	32.01	28.43	25.11	21.95	15.66	5.91	2.07	1.68	1.51
40	32.40	28.87	25.61	22.56	16.72	10.46	3.84	2.34	1.90
50	32.78	29.28	26.08	23.10	17.55	12.16	6.57	3.45	2.48
60	33.13	29.67	26.50	23.58	18.24	13.28	8.53	4.90	3.26
70	33.47	30.03	26.90	24.02	18.84	14.16	9.87	6.31	4.20
80	33.79	30.37	27.27	24.43	19.37	14.88	10.88	7.50	5.16
90	34.10	30.70	27.62	24.81	19.85	15.50	11.70	8.47	6.06
100	34.40	31.01	27.95	25.17	20.29	16.05	12.39	9.29	6.88
125	35.13	31.78	28.76	26.03	21.26	17.21	13.77	10.88	8.53
150	35.78	32.46	29.47	26.77	22.09	18.16	14.85	12.07	9.80
175	36.39	33.09	30.12	27.45	22.83	18.98	15.74	13.04	10.81
200	36.97	33.67	30.72	28.07	23.49	19.69	16.51	13.86	11.65
225	37.51	34.22	31.28	28.64	24.09	20.33	17.19	14.56	12.38
250	38.02	34.74	31.81	29.17	24.65	20.91	17.80	15.19	13.01
300	38.97	35.69	32.77	30.15	25.65	21.94	18.85	16.25	14.07
350	39.83	36.56	33.64	31.02	26.53	22.83	19.74	17.14	14.93
400	40.64	37.36	34.43	31.81	27.32	23.62	20.52	17.89	15.66
450	41.38	38.09	35.16	32.54	28.04	24.32	21.20	18.55	16.28
500	42.09	38.78	35.84	33.21	28.70	24.96	21.82	19.14	16.83

Release on
The Surface Tension of Ordinary Water Substance

Issued by the
International Association for the Properties of Water and Steam

President: J.R. Cooper
Department of Mechanical Engineering
Queen Mary and Westfield College
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September 1994

Revision of 1983 Release

This release is issued by the International Association for the Properties of Water and Steam (IAPWS) on the authority of the Executive Committee meeting in Orlando, FL, USA, 11-16 September 1994. The members of IAPWS are Argentina, Canada, Czech Republic, Denmark, France, Germany, Japan, Russia, the United Kingdom and the United States of America, and associate member Italy.

IAPS issued a Release on the Surface Tension of Ordinary Water Substance, in 1975, based on the International Practical Temperature Scale of 1968 (IPTS-68). A revision of this release has been prepared to provide the values corresponding to the International Temperature Scale of 1990 (ITS-90).

The critical point temperature used for the reference temperature in the equation for the surface tension of ordinary water has been taken from the IAPWS Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points (1992). In this revised critical point release, compared with the IPTS-68 temperatures in the original critical point release, one more decimal place is given to the converted ITS-90 temperatures. This ensures that any recalculation to the original IPTS-68 temperatures produces the same figures as given in the original source after rounding to the same number of decimal places. This increase by one decimal place in the conversion of the values to ITS-90 does not imply that the critical point temperature has been redetermined or is more accurate than as previously stated on IPTS-68.

The information provided with this release is recommended as the most accurate representation of the surface tension of ordinary water substance from the triple point to the critical point.

International Representation of the Surface Tension of Ordinary Water Substance 1994

Experimental values of surface tension of Ordinary Water Substance

Working Group III (on Special Properties) of IAPS, in 1983, had critically examined the experimental results of the surface tension of the interface between the liquid and vapor phases of ordinary water and recommended the surface tension values (σ) and values ($\Delta\sigma$) of the uncertainty associated with each value of the surface tension.

In this revision, the values of surface tension have been examined and values adjusted for the temperature change from (IPTS-68) to (ITS-90) and are given in column 2 of Table 1. The corresponding uncertainty values are given in column 3 of Table 1.

Equation for the surface tension of Ordinary Water Substance

The following recommended interpolating equation gives values of surface tension within the stated uncertainty:

$$\sigma = B\tau^{\mu}(1+b\tau)$$

where
σ = surface tension
τ = $1 - T / T_c$
T = temperature
T_c = 647.096 K
B = 235.8 mN/m
b = –0.625
μ = 1.256

This equation is valid between the triple point (0.01 °C) and reference temperature, T_c.

Values of surface tension calculated from this equation are given in column 4 of Table 1.

Notes: (i) T denotes absolute temperature, ITS-90.

(ii) The reference temperature is the critical point temperature given in the IAPWS Release on the Values of Temperature, Pressure and Density of Ordinary and Heavy Water Substances at their Respective Critical Points 1992.

(iii) The values of the constants B, b and μ are those presented in the release of 1975. Adjustment of the reference temperature produces values of surface tension from the equation for ITS-90 temperatures with improved root mean square deviation compared with the original equation and the surface tension values for the IPTS-68 temperatures in the release of 1975.

Table 1 Surface Tension of Ordinary Water Substance

(1)	(2)	(3)	(4)	(5)
Temp. t, °C	Surf. Tension experimental	Uncertainty	Surf. Tension calculated	difference
	σ mN/m	$\Delta\sigma$ mN/m	σ_{calc} mN/m	$\sigma_{calc}-\sigma$ mN/m
0.01	75.64	0.38	75.63	- 0.01
5	74.94	0.37	74.93	- 0.01
10	74.23	0.37	74.21	- 0.02
15	73.49	0.37	73.48	- 0.01
20	72.74	0.36	72.73	- 0.01
25	71.98	0.36	71.97	- 0.01
30	71.19	0.36	71.19	- 0.00
35	70.41	0.35	70.40	- 0.01
40	69.59	0.35	69.60	0.01
45	68.78	0.34	68.78	0.00
50	67.93	0.34	67.95	0.02
55	67.09	0.34	67.10	0.01
60	66.24	0.33	66.25	0.01
65	65.36	0.33	65.37	0.01
70	64.47	0.32	64.49	0.02
75	63.57	0.32	63.59	0.02
80	62.68	0.31	62.68	0.00
85	61.76	0.31	61.76	0.00
90	60.82	0.30	60.83	0.01
95	59.88	0.30	59.88	0.00
100	58.92	0.29	58.92	0.00
105	57.95	0.29	57.95	0.00
110	56.97	0.28	56.97	0.00
115	55.98	0.28	55.98	0.00
120	54.97	0.27	54.98	0.01
125	53.96	0.27	53.97	0.01
130	52.94	0.26	52.94	0.00
135	51.90	0.26	51.91	0.01
140	50.86	0.25	50.86	0.00
145	49.81	0.25	49.81	0.00
150	48.75	0.24	48.75	- 0.00
155	47.67	0.24	47.68	0.01
160	46.58	0.23	46.59	0.01
165	45.49	0.23	45.51	0.02
170	44.40	0.22	44.41	0.01
175	43.30	0.22	43.30	0.00
180	42.19	0.22	42.19	- 0.00
185	41.07	0.22	41.07	- 0.00
190	39.95	0.22	39.94	- 0.01
195	38.82	0.22	38.81	- 0.01
200	37.68	0.22	37.67	- 0.01

Table 1 continued

(1) Temp. t, °C	(2) Surf. Tension experimental σ mN/m	(3) Uncertainty Δσ mN/m	(4) Surf. Tension calculated σ_{calc} mN/m	(5) difference $\sigma_{calc}-\sigma$ mN/m
205	36.54	0.22	36.52	- 0.02
210	35.40	0.22	35.37	- 0.03
215	34.24	0.22	34.22	- 0.02
220	33.09	0.22	33.06	- 0.03
225	31.92	0.22	31.89	- 0.03
230	30.76	0.22	30.72	- 0.04
235	29.58	0.22	29.55	- 0.03
240	28.40	0.22	28.38	- 0.02
245	27.22	0.22	27.20	- 0.02
250	26.05	0.22	26.02	- 0.03
255	24.86	0.21	24.85	- 0.01
260	23.66	0.21	23.67	0.01
265	22.46	0.21	22.49	0.03
270	21.29	0.20	21.31	0.02
275	20.14	0.20	20.14	- 0.00
280	18.93	0.20	18.97	0.04
285	17.76	0.19	17.80	0.04
290	16.60	0.19	16.64	0.04
295	15.45	0.19	15.48	0.03
300	14.30	0.18	14.33	0.03
305	13.18	0.18	13.19	0.01
310	12.04	0.17	12.06	0.02
315	10.92	0.16	10.94	0.02
320	9.81	0.16	9.84	0.03
325	8.73	0.15	8.75	0.02
330	7.66	0.14	7.68	0.02
335	6.61	0.13	6.63	0.02
340	5.59	0.12	5.60	0.01
345	4.60	0.11	4.61	0.01
350	3.64	0.10	3.65	0.01
355	2.74	0.10	2.73	- 0.01
360	1.89	0.10	1.86	- 0.03
365	1.12	0.10	1.07	- 0.05
370	0.45	0.10	0.38	- 0.07

Supplementary Release on Saturation Properties of Ordinary Water Substance

Issued by the International Association for the Properties of Steam

President: Dr. J. M. H. Levelt Sengers
Thermophysics Division
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Supplementary Release revised September 1992

This release has been authorized by the International Association for the Properties of Water and Steam (IAPWS) at its meeting in St. Petersburg, Russia, 6-12 September 1992, for issue by its Secretariat. The member of IAPWS are Canada, Czechoslovakia, Denmark, the Federal Republic of Germany, France, Japan, Russia, the United Kingdom, and the United States of America.

IAPS previously issued a *Release on the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use* and a *Release on the IAPS Skeleton Tables 1985 for the Thermodynamic Properties of Ordinary Water Substance.* Both releases yield values for the saturation properties of ordinary water substance which are not identical but which agree within the mutual tolerances quoted in the two releases. IAPS also issued a *Supplementary Release on the Saturation Properties of Ordinary Water Substance* containing a set of simple equations which yield for ordinary water substance the vapor pressure as well as the density, specific enthalpy and specific entropy of the saturated vapor and liquid. The values calculated from these equations for the vapor pressure, the density and the specific enthalpy of the vapor and liquid at saturation are identical to the values tabulated for these properties in the IAPS Skeleton Tables 1985.

This *Supplementary Release on Saturation Properties of Ordinary Water Substance* issued in 1986 was based on the IPTS-68 temperature scale. The temperatures of the triple point, the critical point, and the temperature dependence of all correlation equations presented are known to an accuracy that require parameters to be adjusted for the use of the current Temperature Scale of 1990 (ITS-90). In this revised release the temperature values of the critical point, and the parameters in the correlation equations have been changed to comply with the Temperature Scale of 1990 (ITS-90).

The equations in this revised Supplementary Release have been adjusted to ITS-90 by refitting all equations from the Supplementary Release issued in 1986 to the same input data whose temperature values had been converted to ITS-90 temperatures. Compared to the IPTS-68 temperature values given in the original release, one more decimal place is given here to the converted ITS-90 temperature values. This ensures that any recalculation to the original IPTS-68 temperature values produces the same figures as given in the original source after rounding to the same number of decimal places. This increase by one decimal in the converted ITS-90 temperatures does not imply that these values have been redetermined or are more accurate than previously stated on IPTS-68.

Further details about the equations presented in the release can be found in "International Equations for the Saturation Properties of Ordinary Water Substance – Revised according to the New Temperature Scale of 1990" by W. Wagner and A. Pruß, to be published in the Journal of Physical and Chemical Reference Data.

Further information about this release and other releases issued by IAPWS can be obtained from the Executive Secretary of IAPWS.

EQUATIONS FOR THE THERMODYNAMIC PROPERTIES OF ORDINARY WATER SUBSTANCE AT SATURATION

1. Nomenclature

Thermodynamic quantities:

h = Specific enthalpy
p = Vapor pressure
s = Specific entropy
T = Temperature
u = Specific internal energy
ρ = Density (mass divided by volume)
α = Auxiliary quantity for specific enthalpy
ϕ = Auxiliary quantity for specific entropy
θ = T/T_c
τ = $1-\theta$

Subscripts:

c Denotes value at the critical point
t Denotes value at the (ice I, liquid, vapor) triple point

Superscripts:

' Denotes value of the saturated liquid

" Denotes value of the saturated vapor

Note: T denotes absolute temperature on the International Temperature Scale of 1990.

2. Reference constants

T_c = 647.096 K

p_c = 22.064 MPa

ρ_c = 322 kg/m^3

α_0 = 1000 J/kg

$\phi_0 = \alpha_0/T_c$

Note: The numerical values for the critical parameters p_c and ρ_c are identical to those given in *IAPS Statement, 1983, of the Values of the Temperature, Pressure and Density of the Pure Ordinary and Heavy Water Substances at their Respective Critical Points*. The value for T_c corresponds to the IAPS value converted to the current Temperature Scale of 1990 (ITS-90).

3. Vapor pressure

$$\ln\left(\frac{p}{p_c}\right) = \frac{T_c}{T}\left[a_1\tau + a_2\tau^{1.5} + a_3\tau^3 + a_4\tau^{3.5} + a_5\tau^4 + a_6\tau^{7.5}\right] \qquad (1)$$

with

a_1 = − 7.85951783

a_2 = 1.84408259

a_3 = − 11.7866497

a_4 = 22.6807411

a_5 = − 15.9618719

a_6 = 1.80122502

4. Densities

4.1 Density of the saturated liquid:

$$\frac{\rho'}{\rho_c} = 1 + b_1\tau^{1/3} + b_2\tau^{2/3} + b_3\tau^{5/3} + b_4\tau^{16/3} + b_5\tau^{43/3} + b_6\tau^{110/3} \qquad (2)$$

with

b_1 = 1.99274064

b_2 = 1.09965342

b_3 = − 0.510839303

b_4 = − 1.75493479

b_5 = − 45.5170352

b_6 = − 6.74694450 x 10^5

4.2 Density of the saturated vapor:

$$\ln\left(\frac{\rho''}{\rho_c}\right) = c_1\tau^{2/6} + c_2\tau^{4/6} + c_3\tau^{8/6} + c_4\tau^{18/6} + c_5\tau^{37/6} + c_6\tau^{71/6} \tag{3}$$

with

$c_1 = -2.03150240$
$c_2 = -2.68302940$
$c_3 = -5.38626492$
$c_4 = -17.2991605$
$c_5 = -44.7586581$
$c_6 = -63.9201063$

5. Specific enthalpy and specific entropy

5.1 Auxiliary equations:

$$\frac{\alpha}{\alpha_0} = d_\alpha + d_1\theta^{-19} + d_2\theta + d_3\theta^{4.5} + d_4\theta^5 + d_5\theta^{54.5} \tag{4}$$

$$\frac{\phi}{\phi_0} = d_\phi + \frac{19}{20}d_1\theta^{-20} + d_2\ln\theta + \frac{9}{7}d_3\theta^{3.5} + \frac{5}{4}d_4\theta^4 + \frac{109}{107}d_5\theta^{53.5} \tag{5}$$

with

$d_1 = -5.65134998 \times 10^{-8}$
$d_2 = 2690.66631$
$d_3 = 127.287297$
$d_4 = -135.003439$
$d_5 = 0.981825814$
$d_\alpha = -1135.905627715$
$d_\phi = 2319.5246$

5.2 Specific enthalpy of the saturated liquid:

$$h' = \alpha + \frac{T}{\rho'}\frac{dp}{dT} \tag{6}$$

Eq. (6) yields the specific enthalpy of the saturated liquid when used in conjunction with Eqs. (1), (2), and (4).

Note: The specific internal energy and the specific entropy of the liquid at the triple point u'_t and s'_t have been set equal to zero (5th ICPS 1956). As a consequence, from the relation $h'_t = p_s(T_t)/\rho'(T_t)$ one gets for the specific enthalpy of the liquid at the triple point has the value

$$h'_t = 0.611786 \text{ J/kg}.$$

In order to reproduce this numerical value for h'_t from Eq. (6), 13 significant figures are required for the constant d_α as quoted above. A decrease of the number of decimal places in d_α affects the enthalpy of the saturated liquid only near the triple point, but does not significantly affect the values of p, ρ', ρ'', h'', s' and s''. For example, a reduction of d_α to 10 significant figures changes h'/(J/kg) in the 4th decimal place at a temperature of 273.16 K.

5.3 Specific enthalpy of the saturated vapor:

$$h'' = \alpha + \frac{T}{\rho''}\frac{dp}{dT} \quad . \tag{7}$$

Eq. (7) yields the specific enthalpy of the saturated vapor when used in conjunction with Eqs. (1), (3), and (4).

5.4 Specific entropy of the saturated liquid:

$$s' = \phi + \frac{1}{\rho'}\frac{dp}{dT} \quad . \tag{8}$$

Eq. (8) yields the specific entropy of the saturated liquid when used in conjunction with Eqs. (1), (2), and (5).

5.5 Specific entropy of the saturated vapor:

$$s'' = \phi + \frac{1}{\rho''}\frac{dp}{dT} \quad . \tag{9}$$

Eq. (9) yields the specific entropy of the saturated vapor when used in conjunction with Eqs. (1), (3), and (5).

6. Range of validity of the equations

IAPWS endorses the validity of the equations presented in this revised supplementary release for vapor-liquid equilibrium from the triple point to the critical point. This corresponds to

$$273.16\ \mathrm{K} \leq T \leq 647.096\ \mathrm{K} \tag{10}$$

7. Estimates of uncertainty

Values calculated from the equations for p, $1/\rho'$, $1/\rho''$, h', and h'' have estimated uncertainties which are identical to the values in Table 3 of the *Release on the IAPS Skeleton Tables 1985 for the Thermodynamic Properties of Ordinary Water Substance.* The values calculated from the equation for p, $1/\rho'$, $1/\rho''$, h', and h'' together with their estimated uncertainties are identical to values in Table 3 of the forthcoming *Revised Release on the IAPWS Skeleton Tables 1985 for the Thermodynamic Properties of Ordinary Water Substance.*

8. Computer-program verification

To assist the user in computer-program verification, Table 1 lists values for p, dp/dT, ρ', ρ'', α, h', h'', ϕ, s' and s'' calculated at three temperatures. The results quoted in Table 1 were obtained with the aid of a computer having 14 significant figure accuracy and with the values of d_α and d_ϕ given in Section 5.1. If the calculations are performed with a computer with less than 14 significant figures, the results will be clearly within the estimated uncertainty of the various properties except for the enthalpy of the saturated liquid close to the triple point.

Table 1. Thermodynamic property values calculated at three selected temperatures

	$T = 273.16$ K	$T = 373.1243$ K	$T = 647.096$
p/Pa	611.657	0.101325×10^6	22.064×10^6
(dp/dT)/(Pa K^{-1})	44.436693	3.616×10^3	268×10^3
ρ'/(kg m^{-3})	999.789	958.365	322
ρ''/(kg m^{-3})	0.00485426	0.597586	322
α /(J kg^{-1})	−11.529101	417.65×10^3	1548×10^3
h'/(J kg^{-1})	0.611786	419.05×10^3	2086.6×10^3
h''/(J kg^{-1})	2500.5×10^3	2675.7×10^3	2086.6×10^3
ϕ/(J kg^{-1}K^{-1})	− 0.04	1.303×10^3	3.578×10^3
s'/(J kg^{-1}K^{-1})	0	1.307×10^3	4.410×10^3
s''/(J kg^{-1}K^{-1})	9.154×10^3	7.355×10^3	4.410×10^3

IAPWS GUIDELINE STATEMENT

Solubility of Simple Apolar Gases in Light and Heavy Water at High Temperature

Issued by the International Association for the Properties of Water and Steam

President: J.R. Cooper
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(September 1993)

This formulation of Henry's constants for gases dissolved in light water (H_2O) and in heavy water (D_2O) has been authorized by the International Association for the Properties of Water and Steam (IAPWS) for issuance as an IAPWS Guideline. In the judgement of IAPWS (September 1990, Buenos Aires, Argentina and September 1992, St. Petersburg, Russia), the formulation represents the best available and is recommended for use in the power industry with the understanding that new measurements or theoretical developments may lead to improved formulations.

This Guideline was prepared under the direction of Working Group B, "Chemical Thermodynamics in Power Cycles", under the co-chairmanship of O.I. Martynova (Russia) and Albert Bursik (FRG). The Guideline has been reviewed and approved by the National Committees of the members of IAPWS (Canada, Czechoslovakia, Denmark, Federal Republic of Germany, France, Japan, Uk, USA, Russia, and associate members Argentina, and Italy).

This guideline contains an equation yielding Henry's constant as function of temperature along the saturation curve of the solvent. A table with the coefficients of the equation for each gas-water system with the temperature range of validity and the standard deviation, is contained in the Guideline; the coefficients have been calculated with the IPTS'68 temperature scale. A table is provided to check calculations for each system. The material in this Guideline is based upon that published in the supporting document, and references to the work reviewed to produce this formulation are also contained in that document.

The supporting document for this Guideline is: R. Fernández-Prini and R. Crovetto, "Evaluation of Data on Solubility of Simple Apolar Gases in Light and Heavy Water at High Temperature", *Journal of Physical and Chemical Reference Data*, 1989, 18, 1231-1243. All published works contributing to the Guideline are referenced and discussed in this document.

DEFINITION OF SYMBOLS

B_i = coefficients eq (2)

k_H^{∞} = Henry's constant

f_2 = fugacity of solute

x = mole fraction of solute (dissolved gas)

T = temperature[1]

t = (T/K) = dimensionless temperature

σ = standard deviation

T_m = maximum experimental temperature

The basic thermodynamic quantity employed to describe the solubility of gases in liquids is Henry's constant, $k_H^{\infty}(T)$, defined by,

$$k_H^{\infty}(T) = \lim_{x \to 0} \frac{f_2}{x} \qquad (1)$$

Consequently for very dilute solutions, i.e. $x \ll 1$, $k_H^{\infty}(T) \simeq f_2/x$ The following equation has been found to fit the values of Henry's constants calculated from the experimental data for various solute-water systems,

$$\ln\left(\frac{k_H^{\infty}}{\text{GPa}}\right) = \sum_{i=0}^{n} \frac{B_{i+1}}{t^i} (1000)^i - \frac{647.3 - t}{t} \ln \frac{647.3 - t}{647.3} \qquad (2)$$

[1] Although the temperatures used at the time when the coefficients of eq. (2) were determined were on the IPTS-68, the difference in ln (k_H^{∞} / GPa) produced by using eq (2) with temperature on the ITS-90 are in the fourth decimal place and much less than the uncertainty.

Table 1 gives the coefficients of eq (2) and σ is the standard deviation from the set of experimental data. The last column reports T_m, the maximum temperature for which experimental data are available. The uncertainty is considered to be correctly represented by the standard deviation σ, it reflects essentially the discrepancies among different authors and is valid over all the temperature range. It is recommended that the formulation be used only within the experimental temperature range, i.e. $278.2 \leq t \leq t_m$.

Table 1: Coefficients of eq (1)

System	B_1	B_2	B_3	B_4	B_5	σ	T_m K
$He-H_2O$	-6.4859	5.2327	-0.8086			0.065	588.7
$Ne-H_2O$	-5.3238	4.7936	-0.7959			0.021	543.4
$Ar-H_2O$	-7.1874	6.2632	-1.1676			0.015	568.4
$Kr-H_2O$	-7.0173	6.2204	-1.2220			0.040	525.6
$Xe-H_2O$	-8.7307	7.2588	-1.4265			0.118	574.8
H_2-H_2O	-38.4512	53.4846	-27.4317	6.3522	-0.5590	0.106	636.0
N_2-H_2O	-47.7453	66.7623	-34.2820	7.9705	-0.7094	0.084	636.0
O_2-H_2O	-13.3190	12.8557	-3.4516	0.2592		0.047	616.0
CH_4-H_2O	-15.5767	14.5624	-3.8519	0.2838		0.025	633.0
$C_2H_6-H_2O$	-20.6180	19.3949	-5.2453	0.3956		0.027	473.0
$He-D_2O$	-6.6883	5.6197	-0.9357			0.025	553.0
$Ne-D_2O$	-4.9291	4.5256	-0.7600			0.018	550.0
$Ar-D_2O$	-8.3908	7.2331	-1.3623			0.020	583.0
$Kr-D_2O$	-6.8494	6.0574	-1.1901			0.017	523.0
$Xe-D_2O$	-18.2951	17.9143	-5.3081	0.4622		0.060	574.0
CH_4-D_2O	-8.1286	6.9889	-1.3062			0.011	517.0
D_2-D_2O	-2.8180	1.6148				0.100	575.0

Table 2: Calculated values of ln (k_H^{∞} / GPa) with eq (2)

t	$He-H_2O$	$Ne-H_2O$	$Ar-H_2O$	$Kr-H_2O$	$Xe-H_2O$	H_2-H_2O	N_2-H_2O
323.15	2.657	2.582	1.707	1.224	0.765	2.040	2.399
473.15	1.445	1.736	1.318	1.154	0.722	1.353	1.799
573.15	0.463	-	-	-	-0.128	0.198	0.419
t	O_2-H_2O	CH_4-H_2O	$C_2H_6-H_2O$				
323.15	1.785	1.705	1.587				
473.15	1.364	1.157	1.161				
573.15	0.261	-0.107	-				
t	$He-D_2O$	$Ne-D_2O$	$Ar-D_2O$	$Kr-D_2O$	$Xe-D_2O$	CH_4-D_2O	D_2-D_2O
323.15	2.435	2.491	1.640	1.193	0.701	1.684	2.873
473.15	1.492	1.724	1.294	1.120	0.703	1.291	1.078
573.15	-	-	0.362	-	-0.463	-	0.280

IAPWS Guideline Statement
Solubility of Sodium Sulfate in aqueous mixtures of sodium chloride and sulfuric acid from water to concentrated solutions, from 250 °C to 350 °C

September 1994

Issued by the
International Association for the Properties of Water and Steam

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Revision of the 1990 Guideline

This formulation of the solubility compositions of sodium sulfate in solutions of sodium chloride and sulfuric acid from pure water to concentrated solutions has been authorized by the International Association for the Properties of Water and Steam (IAPWS) for issuance as an IAPWS guideline. In the judgement of IAPWS, the formulation represents the best available at the time of issue.

The original Guideline was based on the International Practical Temperature Scale of 1968 (IPTS-68) considered in September, 1989, Prague, Czechoslovakia and was recommended for use in the power industry with the understanding that new measurements or theoretical developments may lead to improved formulations.

This Guideline has now been reviewed by IAPWS following the adoption of the International Temperature Scale of 1990 (ITS-90).

The maximum percentage error in the solubility of sodium sulfate resulting from differences in the temperature scales ITS-90 and IPTS-68 is 0.8% at 350 °C and zero molality of both sulfuric acid and sodium chloride. For other parts of the temperature and molality range the error is less than 0.1% and small compared with the precision of the experimental measurements and the differences between solubilities calculated from the equation presented in the Guideline and experimental values, (see Table 1). Thus, the formulation and solubilities in this Guideline are valid with ITS-90 temperatures.

The Guideline was prepared under the direction of Working Group B, "Chemical Thermodynamics in Power Cycles", under the co-chairmanship of O. I. Martynova (USSR) and Albert Bursik (FRG). The Guideline was reviewed and approved by the National Committees of the members of IAPWS (Canada, Czechoslovakia, FRG, France, Japan, UK, USA, USSR, and associate member Argentina).

Steam power cycles operate with demineralized water that generally contain in practice unavoidable "parts per billion" of natural impurities. Sulfate, chloride, and sodium are among the major solute impurity ions present. There may be an acidic environment (H^+/OH^- greater than unity). Temperature gradients in steam generators may concentrate impurities by many orders of magnitude through localized boiling. Sodium sulfate decreases in solubility under particular conditions of boiling concentration. Since other impurities concentrate also, knowledge of the solubility behaviour of sodium sulfate ranging from that in (pure) water to concentrated $NaCl\text{-}H_2S0_4$ solutions provides information for efficient modelling of steam-cycle conditions. With these models, steam-cycle systems may be designed to prevent or reduce precipitation of sodium sulfate in crevices. Present-day nuclear steam cycles operate in the 250 °C - 350 °C temperature range. Since published experimental measurements covering wide ranges of solution compositions are limited for temperatures outside this range, it is recommended that use of the Guideline be restricted to this range of power plant application.

The Guideline contains an Equation for calculating the solubility of anhydrous sodium sulfate solid in (i) water and in condensed aqueous solutions of (ii) sodium chloride, of (iii) sulfuric acid, and of (iv) both sodium chloride and sulfuric acid over wide ranges of composition. The application range of temperature is from 250 °C to 350 °C, which encompasses the general range of operating temperatures for most subcritical steam generators.

The Equation for the solubility of sodium sulfate in water and the above electrolyte solutions is given on the third page of this Guideline. The estimated uncertainties in the supporting experimental measurements, the ranges of application of the Equation and its ability in reproducing the measurements, and a reference to the supporting document where the Equation and experimental data were originally reported are given on the fourth page of this Guideline. A comparison of representative values of solubility calculated by the Equation and observed (interpolated) from the experimental data reported, referenced, and applied in the supporting document is presented in Table 1.

Recommended interpolation equation for the solubility of sodium sulfate in aqueous mixtures of sodium chloride and sulfuric acid

The available data are reproduced by the equation given below, wherein:

S = Molal Solubility of Sodium Sulfate (Na_2SO_4, anhydrous), [mol kg^{-1} (water)];
$\overline{S}$ = S/(mol kg^{-1});
m_1 = Molality of Sulfuric Acid (H_2SO_4), [mol kg^{-1} (water)];
$\overline{m}_1$ = m_1 /(mol kg^{-1});
m_2 = Molality of Sodium Chloride (NaCl, anhydrous), [mol kg^{-1} (water)];
$\overline{m}_2$ = m_2/(mol kg^{-1});
T = Absolute temperature, ITS-90*; and
$\overline{T}$ = T/K.

The recommended equation is:

$$\overline{S} = A_{00} + A_{10}\cdot\overline{m}_1 + A_{20}\cdot\overline{m}_1^{\,2} + A_{30}\cdot\overline{m}_1^{\,3} + A\cdot\overline{m}_2 + A_{02}\cdot\overline{m}_2^{\,2} + A_{03}\cdot\overline{m}_2^{\,3} + A_{11}\cdot\overline{m}_1\cdot\overline{m}_2,$$

where the A_{ij} are the following functions of temperature:

$$A_{00} = -0.8085987\,\overline{T} + 81.461375 + 0.10537803\,\overline{T}\ln\overline{T},$$
$$A_{10} = 3.4636364\,\overline{T} - 281.63322 - 0.46779874\,\overline{T}\ln\overline{T},$$
$$A_{20} = -6.0029634\,\overline{T} + 480.60108 + 0.81382854\,\overline{T}\ln\overline{T},$$
$$A_{30} = 4.4540258\,\overline{T} - 359.36872 - 0.60306734\,\overline{T}\ln\overline{T},$$
$$A_{01} = 0.4909061\,\overline{T} - 46.556271 - 0.064612393\,\overline{T}\ln\overline{T},$$
$$A_{02} = -0.002781314\,\overline{T} + 1.722695 + 0.0000013319698\,\overline{T}\ln\overline{T},$$
$$A_{03} = -0.014074108\,\overline{T} + 0.99020227 + 0.0019397832\,\overline{T}\ln\overline{T},$$
$$A_{11} = -0.87146573\,\overline{T} + 71.808756 + 0.11749585\,\overline{T}\ln\overline{T}.$$

* See page 1 for comments on the small effect caused by the change from IPTS-68 to ITS-90.

The Equation reproduces the experimental solubilities in the temperature range 250 °C to 350 °C. The applicable ranges of solution compositions saturated by sodium sulfate are from 0 to 0.75 mol kg^{-1} sulfuric acid, from 0 to 2.25 mol kg^{-1} sodium chloride, and up to 4.5 mol kg^{-1} sodium chloride in the absence of sulfuric acid, which are the ranges of the original experimental study in the supporting document listed below.

The precision of the experimental measurements evaluated were generally within ± 1 to ± 4% as estimated by the original authors of the supporting document. The agreement of solubility values calculated by the Equation with experimental values is estimated by the original authors to be generally within ± 4% to ± 6% at temperatures between 250 °C and 275 °C, within ± 1% to ± 3% between 275 °C and 300 °C, and within ± 2% to ± 6% between 300 °C to 350 °C except for those measurements at 350 °C that are below 0.4 molal. In Table 1 representative calculated and observed (interpolated from experimental data) values are compared.

The supporting document for this Guideline is:

M H Lietzke and W L Marshall, "Sodium Sulfate Solubilities in High Temperature Aqueous Sodium Chloride and Sulfuric Acid Solutions - Predictions of Solubility, Vapor Pressure, and Speciation", Journal of Solution Chemistry, 1986, 15, 903-917. All published works contributing to the Guideline are referenced and discussed in this document.

TABLE 1 Calculated and observed molal solubilities $(\bar{S})$ of sodium sulfate in aqueous mixtures of sodium chloride and sulfuric acid

250 °C

$\bar{m}_1$	$\bar{m}_2$	$\bar{S}_{(Obs.)}$	$\bar{S}_{(Calcd.)}$
0.0	0.0	3.13	3.54
0.0	1.0	2.35	2.46
0.0	1.5	2.05	2.08
0.0	2.0	1.83	1.80
0.0	2.5	1.66	1.59
0.0	3.0	1.49	1.44
0.0	3.5	1.35	1.34
0.0	4.0	1.27	1.26
0.0	4.5	1.20	1.20
0.25	0.083	(3.20)*	3.31
0.50	0.167	(3.23)*	3.38
0.75	0.25	(3.35)*	3.37
0.25	0.25	(2.95)*	3.13
0.50	0.50	(2.95)*	3.11
0.75	0.75	(3.10)*	3.08
0.25	0.75	(2.50)*	2.68
0.50	1.50	(2.50)*	2.60
0.75	2.25	(2.80)*	2.85

275 °C

$\bar{m}_1$	$\bar{m}_2$	$\bar{S}_{(Obs.)}$	$\bar{S}_{(Calcd.)}$
0.0	0.0	2.47	2.51
0.0	1.0	1.85	1.87
0.0	1.5	1.67	1.66
0.0	2.0	1.55	1.52
0.0	2.5	1.44	1.42
0.0	3.0	1.35	1.35
0.0	3.5	1.27	1.29
0.0	4.0	1.23	1.24
0.0	4.5	1.20	1.18
0.25	0.083	2.60	2.58
0.50	0.167	--	2.83
0.75	0.25	--	3.04
0.25	0.25	2.46	2.46
0.50	0.50	2.66	2.65
0.75	0.75	2.82	2.83
0.25	0.75	2.12	2.18
0.50	1.50	--	2.31
0.75	2.25	2.62	2.62

300 °C

$\bar{m}_1$	$\bar{m}_2$	$\bar{S}_{(Obs.)}$	$\bar{S}_{(Calcd.)}$
0.0	0.0	1.67	1.61
0.0	1.0	1.36	1.33
0.0	1.5	1.28	1.26
0.0	2.0	1.25	1.23
0.0	2.5	1.22	1.22
0.0	3.0	1.20	1.22
0.0	3.5	1.18	1.21
0.0	4.0	1.18	1.19
0.0	4.5	1.17	1.15
0.25	0.083	1.95	1.87
0.50	0.167	2.26	2.28
0.75	0.25	2.72	2.66
0.25	0.25	1.86	1.82
0.50	0.50	2.14	2.18
0.75	0.75	2.48	2.54
0.25	0.75	1.68	1.68
0.50	1.50	2.06	2.02
0.75	2.25	2.44	2.42

325 °C

$\bar{m}_1$	$\bar{m}_2$	$\bar{S}_{(Obs.)}$	$\bar{S}_{(Calcd.)}$
0.0	0.0	0.67	0.81
0.0	1.0	0.89	0.84
0.0	1.5	0.90	0.88
0.0	2.0	0.95	0.93
0.0	2.5	0.99	0.99
0.0	3.0	1.03	1.04
0.0	3.5	1.07	1.09
0.0	4.0	1.10	1.11
0.0	4.5	1.13	1.11
0.033	0.0	0.84	0.85
0.066	0.0	0.90	0.89
0.102	0.0	0.97	0.94
0.334	0.0	1.47	1.37
0.675	0.0	2.27	2.12
0.25	0.083	1.10	1.20
0.50	0.167	1.70	1.73
0.75	0.25	2.20	2.25
0.25	0.25	1.15	1.19
0.50	0.50	1.61	1.71
0.75	0.75	2.18	2.23
0.25	0.75	1.18	1.19
0.50	1.50	1.77	1.73
0.75	2.25	2.27	2.26

*Values in parentheses at 250 °C are extrapolated over a 5 to 20 K range.

Table 1 (contd.)

350 °C			
$\overline{m}_1$	$\overline{m}_2$	$\overline{S}_{(Obs.)}$	$\overline{S}_{(Calcd.)}$
0.0	0.0	0.16	0.13
0.0	1.0	0.41	0.39
0.0	1.5	0.53	0.51
0.0	2.0	0.63	0.63
0.0	2.5	0.73	0.74
0.0	3.0	0.82	0.83
0.0	3.5	0.91	0.92
0.0	4.0	0.99	1.00
0.0	4.5	1.07	1.06
0.047	0.0	0.27	0.18
0.077	0.0	0.31	0.22
0.122	0.0	0.39	0.29
0.394	0.0	0.93	0.87
0.788	0.0	1.89	1.84
0.25	0.083	--	0.55
0.50	0.167	1.13	1.17
0.75	0.25	1.77	1.80
0.25	0.25	--	0.59
0.50	0.50	1.18	1.24
0.75	0.75	1.88	1.89
0.25	0.75	--	0.71
0.50	1.50	1.52	1.44
0.75	2.25	2.12	2.13

IAPWS GUIDELINE STATEMENT, 1990

Electrolytic Conductivity (Specific Conductance) of Liquid and Dense Supercritical Water from 0 °C to 800 °C and Pressures up to 1000 MPa

Issued by the International Association for the Properties of Water and Steam

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This formulation of the electrolytic conductivity (specific conductance) of water has been authorized by the International Association for the Properties of Water and Steam (IAPWS) for issuance as an IAPWS Guideline. In the judgement of IAPWS, the formulation represents the best available at the final time of consideration (September, 1989, Prague, Czechoslovakia) and is recommended for use in the power industry with the understanding that new measurements or theoretical developments may lead to improved formulations.

This Guideline was prepared under the direction of Working Group A, "Properties of Steam and Aqueous Systems", under the chairmanship of Dr. J. N. H. Levelt Sengers, National Institute of Standards and Technology, USA, and has been reviewed and approved by the national committees of the members of IAPWS (Canada, Czechoslovakia, FRG, France, Japan, UK, USA, USSR, and associate member, Argentina).

The dimensionless electrolytic conductivity ($\bar{\kappa}$) of water is calculated from:

$$\bar{\kappa} = 10^{-3}\ \bar{\Lambda}_o\ \bar{K}_w^{1/2}\ \bar{\rho} \qquad (1)$$

with dimensionless variables:

$$\bar{\kappa} = \kappa/\kappa^\circ \qquad \bar{\Lambda}_o = \Lambda_o/\Lambda^\circ \qquad (2)$$
$$\bar{K}_w = K_w/K_w^\circ \qquad \bar{\rho} = \rho/\rho^\circ$$

Here:

κ is the electrolytic conductivity (specific conductance) of water

K_w is the ion product of water

ρ is the density of water

Λ_o is the molar conductivity of H^+ plus OH^- ions in water

The superscripts $^\circ$ denote the following reference values:

$$\kappa^\circ = 10^2\ S\ m^{-1} \qquad \Lambda^\circ = 10^{-4}\ m^2\ S\ mol^{-1} \qquad (3)$$
$$K_w^\circ = 1\ (mol\ kg^{-1})^2 \qquad \rho^\circ = 10^3\ kg\ m^{-3}$$

In Eq. (1), the ion product of water (K_w) at a given density and temperature, is obtained from the IAPWS release on the Ion Product of Liquid Water [May 1980]. The dimensionless molar conductivity (Λ_o) is obtained from:

$$\bar{\Lambda}_o = [\bar{\rho}_h - \bar{\rho}]\bar{\Lambda}_{oo}/\bar{\rho}_h \quad (4)$$

with

$$\bar{\Lambda}_{oo} = A_o - [A_1^{-1} + \sum_{i=0}^{3} A_{(i+2)}\bar{t}^{(i+1)}]^{-1} \quad (5)$$

$$\bar{\rho}_h = B_o - [B_1^{-1} + \sum_{i=0}^{2} B_{(i+2)}\bar{t}^{(i+1)}]^{-1} \quad (6)$$

with the dimensionless variable:

$$\bar{t} = (T - T^\circ)/t^\circ$$

Here:

t is the Celsius temperature of water, $t = T - T^\circ$, with T the absolute temperature.

The superscripts ° denote the following reference values:

$$t^\circ = 1^\circ \text{ C}$$

$$T^\circ = 273.15 \text{ K}$$

The dimensionless coefficients are listed in Table I. The range of application is:

for temperature

$$0°C < t < 800°C$$

and density

$$600 \text{ kg m}^{-3} < \rho < 1200 \text{ kg m}^{-3}$$

with a maximum pressure of 1000 MPa.

The uncertainty is estimated by the original author of the supporting document not to exceed 5% for liquid water temperatures up to 374°C; or 15% for temperatures from 374°C to 800°C and 1000 MPa. The range of applicability and corresponding uncertainty are shown in Fig. 1. Some values of the electrolytic conductivity, calculated from Eqs. 1-6, are given in Table II.

Table I

Coefficients

A_o:	+1850.	B_o:	+16.0
A_1:	+1410.	B_1:	+11.6
A_2:	$+2.16417 \times 10^{-6}$	B_2:	$+3.26 \times 10^{-4}$
A_3:	$+1.81609 \times 10^{-7}$	B_3:	-2.30×10^{-6}
A_4:	-1.75297×10^{-9}	B_4:	$+1.10 \times 10^{-8}$
A_5:	$+7.20708 \times 10^{-12}$		

Table II

Dimensionless Electrolytic Conductivity ($\bar{\kappa}$) times 10^{+6} Calculated for Selected Values of Temperature and Density

$\bar{\rho}$: / $\bar{t}$	Saturated Liquid	0.60	0.80	0.90	1.00	1.10
0.01	0.0115					0.0333
25.	0.0550					0.153
100.	0.765				1.13	2.71
200.	2.99			4.19	10.2	22.8
300.	2.41		6.19	16.1	37.7	81.6
400.		1.57	15.4	39.2	90.2	
600.		5.30	49.6	124.	280.	
800.		11.2	103.			

The supporting document for the Guideline is:

W. L. Marshall, "Electrical Conductance of Liquid and Supercritical Water Evaluated from 0°C and 0.1 MPa to High Temperatures and Pressures. Reduced State Relationships", J. Chem. Eng. Data, 1987, 32, 221-226. All published works contributing to the Guideline are referenced and discussed in this document.

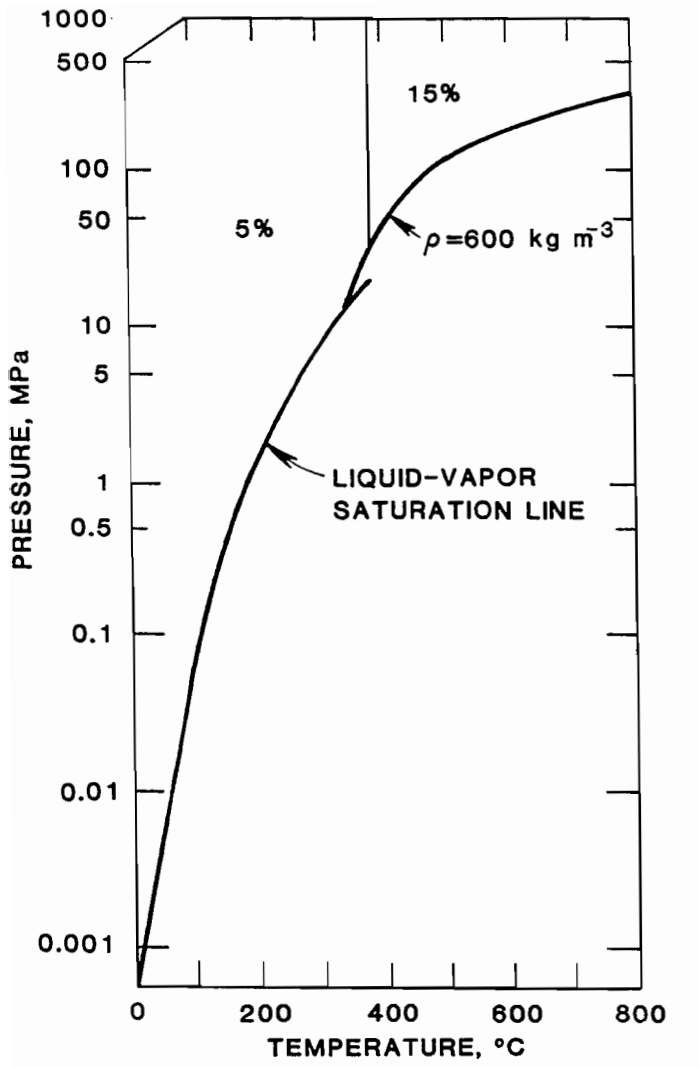

Fig. 1. Range of Application and Corresponding Uncertainty