Improved International Formulations for the Viscosity and Thermal Conductivity of Water Substance

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This paper describes improved international formulations for the viscosity and thermal conductivity of water substance recently adopted by the International Association for the Properties of Steam.

Key words: IAPS; steam; thermal conductivity; transport properties; viscosity; water; water vapor.

Contents

1. Introduction

The first international formulation for the viscosity and thermal conductivity of fluid H_2O (ordinary water substance) was prepared in 1964 by a panel elected for the purpose by the Sixth International Conference on the Properties of Steam held in Providence and New York in 1963.[1] The Sixth International Conference on the Properties of Steam also established an International Formulation Committee which completed a Formulation for the Thermodynamic Properties of Water Substance for Industrial Use in 1967 (IFC 67 Formulation)[2,3] and a Formulation for the Thermodynamic Properties of Water Substance for Scientific and General Use in 1968 (IFC 68 Formulation).[4,5]

The Seventh Conference on the Properties of Steam held in Tokyo in 1968 authorized the creation of an International Association for the Properties of Steam (IAPS). During the past fifteen years, IAPS has coordinated an active international research program with the goal of obtaining improved formulations for the thermophysical properties of both ordinary and heavy water substance. The Eighth International Conference on the Properties of Steam held in 1974 established a Special Committee for the purpose of preparing new formulations for the viscosity and for the thermal conductivity of water substance. Based on the recommendations of this Special Committee, IAPS issued a document entitled "Release on Dynamic Viscosity of Water Substance" in 1975[2,6–9] and a document entitled "Release on Thermal Conductivity of Water Substance" in 1977.[2,9–11]

The Ninth International Conference on the Properties of Steam held in Munich in 1979 empowered the Executive Committee (EC) of IAPS to issue, among others, a release on the thermodynamic properties of ordinary water substance for the purpose of replacing the IFC 68 Formulation for Scientific and General Use and also to issue a release on the thermodynamic properties of heavy water substance. The resulting releases, prepared by Working Group I of IAPS, have been described in a previous publication in this journal.[12] The EC of IAPS adopted in 1982 a Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use and a Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Heavy Water Substance.[13] These formulations were based on a fundamental equation for the thermodynamic properties of H_2O developed by Haar, Gallagher, and Kell[14,15] and a fundamental equation for the thermodynamic properties of D_2O developed by Hill, MacMillan, and Lee.[16,17] Finally, the Tenth International Conference on the Properties of Steam held in Moscow in 1984 adopted the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use and the IAPS Formulation 1984 for the Thermodynamic Properties of Heavy Water Substance.[12] The formulations adopted in 1984 for the thermodynamic properties of H_2O and D_2O are identical with the provisional formulations earlier adopted in 1982, except that the equations were cast in dimensionless forms as proposed by Kestin *et al.*[18,19]

The task of further studying the transport properties of H_2O and D_2O had been assigned to Working Group II, established in 1977 after the Special Committee on Transport Properties had completed its assignment of preparing formulations for the viscosity and thermal conductivity of ordinary water substance. The names of the individual members of Working Group II are listed in Table 1. Working Group I, on the equilibrium properties of H_2O and D_2O, and Working Group II remained active until the reorganization of the working groups of IAPS, authorized by the Tenth International Conference on the Properties of Steam in 1984.[12]

The equations for the viscosity and thermal conductivity yield these transport properties as functions of temperature and density. One needs an equation of state to convert the pressures into densities. For this purpose the release on viscosity of ordinary water substance issued in 1975 and the release on thermal conductivity of ordinary water substance issued in 1977 were based on the IFC 68 Formulation for Scientific and General Use. Following the recommendations of Working Group II, IAPS amended these releases in 1982 so as to make them consistent with the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use which superseded the IFC 68 Formulation.[20,21] Also in 1982, IAPS adopted a formulation for the viscosity and thermal conductivity of heavy water substance.[22]

TABLE 1. Members of Working Group II of IAPS

N. A. Agayev, USSR	1980–1984
A. A. Aleksandrov, USSR	1978–1984
F. A. Gonçalves, Portugal	1979–1984
R. C. Hendricks, USA	1977–1984
J. Kestin,[a] USA	1977–1984
B. Le Neindre, France	1977–1984
T. Minamiyama, Japan	1977–1984
A. Nagashima, Japan	1977–1984
K. Scheffler, FRG	1977–1984
J. V. Sengers, USA	1977–1984
J. Straub, FRG	1979–1984
A. A. Tarzimanov, USSR	1978–1984
J. T. R. Watson, UK	1977–1984
J. Yata, Japan	1977–1984

[a] Chairman.

In the intervening period, it had become evident that some improvements could be made in the formulations for the viscosity and thermal conductivity of ordinary water substance. Firstly, the equations for these transport properties adopted in 1975 and 1977 were restricted to the range of validity of the IFC 68 Formulation: namely, from 0 to 800 °C in temperature and up to 100 MPa in pressure. Since the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance is valid in a wider range of temperatures and pressures, it became possible to check to what extent the equations for the viscosity and thermal conductivity can be extrapolated outside the range for which they were originally developed. Secondly, using improved methods for the statistical analysis of data, Watson and coworkers[23] had noted that the number of terms in the international equation for the viscosity could be reduced significantly, while at the same time obtaining an improved agreement with experimental data.[20,23,24] Finally, it had become possible to account for the singular behavior of the viscosity near the critical point,[23,25] an effect which had not been incorporated in the international equation. When IAPS completed the task of providing a new formulation for the thermodynamic properties of water substance in 1984, the Tenth International Conference on the Properties of Steam empowered the EC of IAPS to issue also revised releases for the transport properties incorporating the improvements mentioned above. Accordingly, at its meeting in 1985, the EC of IAPS issued a *Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance*, and a *Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance*. The purpose of this paper is to present these new releases which supersede the releases on the transport properties issued in 1975 and 1977 and amended in 1982. Since the research leading to these new releases has been documented in previous publications in this journal,[20,21,23] we restrict ourselves here to an explanation of the new releases with the purpose of clarifying the nature of the revisions.

2. IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance

A verbatim copy of the Release on the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance is attached as Appendix I to this publication.

The release contains three parts. Appendix A of the release contains a table of critically evaluated experimental data. This table was originally prepared by Scheffler, Straub, and Grigull[26] and it is the same as the one contained in the old release on viscosity.[20]

Appendix B of the release contains a recommended interpolating equation which is a representative equation developed by Watson, Basu, and Sengers,[23] but cast in a dimensionless form as proposed by Kestin *et al.*[18] For this purpose the temperature T, the density ρ, the pressure P, and the viscosity μ are made dimensionless by defining

$$\bar{T} = T/T^*, \quad \bar{\rho} = \rho/\rho^*, \quad \bar{P} = P/P^*, \tag{1}$$

$$\bar{\mu} = \mu/\mu^*, \tag{2}$$

in terms of the reference values

$$T^* = 647.27 \text{ K}, \quad \rho^* = 317.763 \text{ kg/m}^3,$$

$$P^* = 22.115 \times 10^6 \text{ Pa}, \tag{3}$$

$$\mu^* = 55.071 \times 10^{-6} \text{ Pa s}. \tag{4}$$

The dimensionless temperature, density, and pressure defined by Eq. (1) are the same as those adopted in the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.[12] The reference constants T^*, ρ^*, and P^* are close to but not identical with the critical parameters of steam.[27] The recommended interpolating equation for viscosity has the form

$$\bar{\mu} = \bar{\mu}_0(\bar{T}) \times \bar{\mu}_1(\bar{T},\bar{\rho}) \times \bar{\mu}_2(\bar{T},\bar{\rho}). \tag{5}$$

The function $\bar{\mu}_0(\bar{T})$ represents the viscosity of water vapor and steam in the ideal-gas limit

$$\bar{\mu}_0(\bar{T}) = \sqrt{\bar{T}} \Big/ \sum_{i=0}^{3} (H_i/\bar{T}^i) \tag{6}$$

The values of the coefficients in this function were originally determined by Aleksandrov, Ivanov, and Matveev[28]; except for a conversion factor due to the adoption of the reference value of Eq. (4) for μ^*, they are the same as in the old release.[7,20]

The function $\bar{\mu}_1(\bar{T},\bar{\rho})$ has the form

$$\bar{\mu}_1(\bar{T},\bar{\rho}) = \exp\left[\bar{\rho} \sum_{i=0}^{5} \sum_{j=0}^{6} H_{ij} \left(\frac{1}{\bar{T}} - 1\right)^i (\bar{\rho} - 1)^j\right]. \tag{7}$$

The previous recommended interpolating equation for viscosity[7,20] contained a factor similar to that defined by Eq. (7), but with 30 nonzero coefficients H_{ij}. The revised recommended interpolating equation contains 19 nonzero coefficients whose values were determined by Watson *et al.*[23] The product $\bar{\mu}_0(\bar{T}) \times \bar{\mu}_1(\bar{T},\bar{\rho})$ is equivalent to the equation designated as "Alternative equation for the viscosity of water substance" by Sengers and Kamgar-Parsi.[29]

The function $\bar{\mu}_2(\bar{T},\bar{\rho})$ is a correction factor to account for the singular behavior in the immediate vicinity of the critical point.[25] The factor $\bar{\mu}_2$ is equal to unity everywhere except in a small range of temperatures and densities specified by

$$0.9970 \leqslant \bar{T} \leqslant 1.0082, \quad 0.755 \leqslant \bar{\rho} \leqslant 1.290. \tag{8}$$

Inside the near-critical region, given by Eq. (8), $\bar{\mu}_2$ is to be calculated from the compressibilitylike quantity

$$\bar{\chi}_T = \bar{\rho}(\partial\bar{\rho}/\partial\bar{P})_{\bar{T}} \tag{9}$$

in accordance with Eq. (16) of Appendix I. For more details the reader is referred to a previous publication.[30]

For scientific and general use, the interpolating Eq. (5) for the viscosity is to be used in conjunction with the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.[12] Appendix C of the release gives tables of viscosity values at selected gridpoints thus calculated from the recommended interpolating equation. Two tables are presented: one table with values of the viscosity calculated at integral values of temperature and pressure and another table with values of the viscosity of the vapor and the liquid at saturation.

For the convenience of the user, we present in Appendix III the corresponding values of the density calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.[12] Similar tables have been included in a previous paper of Sengers and Kamgar-Parsi.[20] While preparing the new releases presented in this paper, we also developed a new computer program for calculating the thermodynamic properties from the equation of Haar *et al.*[15] which forms the basis of the IAPS Formulation 1984 for the Thermodynamic Properties. We found that some changes needed to be made in the original computer program of Haar *et al.*[15] to calculate the saturation densities correctly. These changes affect the values of the saturation density at 370 °C and above and have been incorporated in the tables of Appendix III.

As mentioned in the Introduction, the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance replaced the earlier IFC 1968 Formulation for the Thermodynamic Properties of Water Substance for Scientific and General Use.[4,5] However, the international status of the IFC 1967 Formulation for Industrial Use[2,3] remains in effect. For industrial use the interpolating Eq. (5) for viscosity can also be used in conjunction with the IFC 1967 Formulation for Industrial Use, provided that the factor $\bar{\mu}_2$ is taken to be unity everywhere, which means that the enhancement in viscosity near the critical point is neglected.

Comparisons of the interpolating Eq. (5) for viscosity with experimental data can be found in previous publications.[20,23,24] When the interpolating Eq. (5) for viscosity is used in conjunction with the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use, IAPS endorses the validity of the equation in the range of pressures P and temperatures t specified by[23]

$$\left.\begin{array}{l} P \leqslant 500 \text{ MPa and } 0\,^\circ\text{C} \leqslant t \leqslant 150\,^\circ\text{C}, \\ P \leqslant 350 \text{ MPa and } 150\,^\circ\text{C} \leqslant t \leqslant 600\,^\circ\text{C}, \\ P \leqslant 300 \text{ MPa and } 600\,^\circ\text{C} \leqslant t \leqslant 900\,^\circ\text{C}. \end{array}\right\} \tag{10}$$

For temperatures between 0 and 800 °C and at pressures up to 100 MPa the recommended interpolating equation reproduces the values of the critically evaluated experimental data in Appendix A of the release within the stated tolerances.[20] An evaluation of the accuracy of the equation at temperatures above 800 °C and at pressures above 100 MPa can be found in a previous publication.[23]

3. IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance

A verbatim copy of the Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance is attached as Appendix II to this publication. The release contains five parts. The information in Appendixes A and D is identical with that in the same Appendixes in the old release except for some minor editorial adjustments. Appendixes B, C, and E incorporate revisions.

Appendix A gives tables of critically evaluated experimental data. These tables were originally prepared by Scheffler, Rosner, and Grigull.[10] Table A.I in the release is identical with the corresponding table in the old release.[21] Table A.II in the old release also contained entries for the values of the saturation properties at 0, 374, and 374.15 °C. In the previous release no tolerance was assigned to the thermal conductivity of saturated vapor and liquid at 374 and 374.15 °C because of lack of reliable experimental information.[21] The saturation-property values previously listed at 0 °C correspond, strictly speaking, to a metastable state. For these reasons it was decided to delete the entries for 0, 374, and 374.15 °C in all tables of the saturation properties in both releases.

Appendix B of the release contains a recommended interpolating equation for industrial use. This thermal-conductivity equation is to be used in conjunction with the IFC 1967 Formulation for Industrial Use. The recommended interpolating equation for industrial use was developed by Yata and Minamiyama[31] and is identical with the recommended interpolating equation for industrial use in the old release,[21] except that the coefficients have been made dimensionless. As discussed in a previous publication,[21] the thermal-conductivity equation for industrial use is not in good agreement with the experimental thermal-conductivity data of Tsederberg *et al.*[32] at high pressures and temperatures. For this reason it was decided to reduce the recommended region of validity to

$$\left.\begin{array}{l} P\leqslant 100\ \text{MPa and } 0\ ^\circ\text{C}\leqslant t\leqslant 500\ ^\circ\text{C}, \\ P\leqslant 70\ \text{MPa and } 500\ ^\circ\text{C}\leqslant t\leqslant 650\ ^\circ\text{C}, \\ P\leqslant 40\ \text{MPa and } 650\ ^\circ\text{C}\leqslant t\leqslant 800\ ^\circ\text{C}. \end{array}\right\} \tag{11}$$

Appendix C of the release contains a recommended interpolating equation for scientific use to be used in conjunction with the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance. This thermal-conductivity equation is identical with the "Alternative thermal-conductivity equation for scientific use" discussed in a previous publication,[32] except that it has been cast in the dimensionless form proposed by Kestin *et al.*[18] The reduced temperature $\overline{T}$, reduced density $\bar{\rho}$, and reduced pressure $\overline{P}$ are again as those defined by Eq. (1), while the thermal conductivity λ is made dimensionless by defining

$$\bar{\lambda} = \lambda / \lambda^* \tag{12}$$

with

$$\lambda^* = 0.4945\ \text{W m}^{-1}\ \text{K}^{-1}. \tag{13}$$

We note in passing that the dimensionless temperature, density, and thermal conductivity in the thermal-conductivity equation for industrial use, described in Appendix B of the release, are defined in terms of different reference values for T^*, ρ^*, and λ^*.

The recommended interpolating equation for scientific use has the form

$$\bar{\lambda} = \bar{\lambda}_0(\overline{T}) \times \bar{\lambda}_1(\overline{T},\bar{\rho}) + \bar{\lambda}_2(\overline{T},\bar{\rho}). \tag{14}$$

The functions $\bar{\lambda}_0(\overline{T})$ and $\bar{\lambda}_1(\overline{T},\bar{\rho})$ are the same as the corresponding functions in the old release, except that the function $\bar{\lambda}_0(\overline{T})$ has now been made dimensionless. The function $\bar{\lambda}_0(\overline{T})$ represents the thermal conductivity of water vapor and steam in the ideal-gas limit and has the form

$$\bar{\lambda}_0(\overline{T}) = \sqrt{\overline{T}} \Big/ \sum_{i=0}^{3} (L_i/\overline{T}^i). \tag{15}$$

The coefficients in this equation were orginally determined by Aleksandrov and Matveev.[33]

The function $\bar{\lambda}_1(\overline{T},\bar{\rho})$ has the form

$$\bar{\lambda}_1(\overline{T},\bar{\rho}) = \exp\left[\bar{\rho} \sum_{i=0}^{5} \sum_{j=0}^{6} H_{ij} \left(\frac{1}{\overline{T}} - 1\right)^i (\bar{\rho} - 1)^j\right], \tag{16}$$

with coefficients originally determined by Watson.[34]

The term $\bar{\lambda}_2(\overline{T},\bar{\rho})$ represents the enhancement of the thermal conductivity in the critical region and has the form

$$\bar{\lambda}_2(\overline{T},\bar{\rho}) = \frac{0.001\,384\,8}{\bar{\mu}_0(\overline{T}) \times \bar{\mu}_1(\overline{T},\bar{\rho})} \left(\frac{\overline{T}}{\bar{\rho}}\right)^2 \left(\frac{\partial \overline{P}}{\partial \overline{T}}\right)_{\bar{\rho}}^2 \bar{\chi}_T^{0.4678} \bar{\rho}^{1/2} \times \exp[-18.66(\overline{T} - 1)^2 - (\bar{\rho} - 1)^4]. \tag{17}$$

This function is a dimensionless version of the critical thermal-conductivity enhancement $\Delta\lambda$, adopted in the old release,[21] except that the product $\bar{\mu}_0(\overline{T}) \times \bar{\mu}_1(\overline{T},\bar{\rho})$ now has to be calculated from the equations in the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance as explained in the preceding section. We note that Eq. (17) for $\bar{\lambda}_2(\overline{T},\bar{\rho})$ does not contain the factor $\bar{\mu}_2(\overline{T},\bar{\rho})$ introduced in Eq. (5).

The thermal-conductivity Eq. (14) for scientific use is recommended in the range of pressures P and temperatures t specified by[21]

$$\left.\begin{array}{l} P\leqslant 400\ \text{MPa and } 0\ ^\circ\text{C}\leqslant t\leqslant 125\ ^\circ\text{C}, \\ P\leqslant 200\ \text{MPa and } 125\ ^\circ\text{C}\leqslant t\leqslant 250\ ^\circ\text{C}, \\ P\leqslant 150\ \text{MPa and } 250\ ^\circ\text{C}\leqslant t\leqslant 400\ ^\circ\text{C}, \\ P\leqslant 100\ \text{MPa and } 400\ ^\circ\text{C}\leqslant t\leqslant 800\ ^\circ\text{C}. \end{array}\right\} \tag{18}$$

An evaluation of the accuracy of the recommended thermal conductivity equations can be found in a previous publication.[21] For temperatures between 0 and 800 °C and at pressures up to 100 MPa it reproduces the critically evaluated experimental data in Appendix A of the release within the stated tolerances.[21]

There does not exist a formal international agreement on how to calculate the thermophysical properties of steam in the immediate vicinity of the critical point. The IAPS Formulation 1984 for the Thermodynamic Properties does not incorporate the known nonanalytic asymptotic critical behavior of these properties.[35] The IAPS Formulation 1984 for the Thermodynamic Properties, therefore, does not include a small region around the critical point where $|T-T^*| < 1$ K and $|\bar{\rho} - 1| < 0.3$. As recommended by Kestin *et al.*,[18] close to the critical point it is better to use the representative equations for the viscosity and thermal conductivity of steam in conjunction with the scaled equation of state of Levelt Sengers and co-workers.[36]

Appendix D of the release gives tables of thermal-conductivity values calculated from the recommended interpolating equation for industrial use.

Appendix E of the release gives tables of thermal-conductivity values calculated from the recommended interpolating equation for scientific use.

4. Acknowledgments

The authors express their appreciation to the members of Working Group II of IAPS listed in Table 1 for their extensive research towards the development of the formulations for the viscosity and thermal conductivity of H_2O. They are also indebted to J. S. Gallagher and J. C. Nieuwoudt for their assistance in checking the calculations and to J. Kestin for advice received from him throughout this project. The research at the University of Maryland was supported by the U.S. Office of Standard Reference Data and by National Science Foundation Grant No. DMR 82-05356. Computer time for this project was provided by the Computer Science Center of the University of Maryland. The research at the National Engineering Laboratory was supported by the Mechanical and Electrical Engineering Requirements Board of the Department of Industry (UK).

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Appendix I

The Tenth International Conference on the Properties of Steam

Moscow, USSR, September, 1984

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

Unrestricted publication allowed in all countries.

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, 2–7 September 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.

Further information can be obtained from the Executive Secretary of IAPS:

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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," by K. Scheffler, N. Rosner, and M. Reimann (Institut A für Thermodynamik, Technische Universität München, revised ed., 1974). The table gives values reduced to a uniform grid with the aid of the algorithm described in the paper, "The Dynamic Viscosity of Water Substance," by 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 Secs. 3 and 4 of the paper, "Representative Equations for the Viscosity of Water Substance," by J. V. Sengers and B. Kamgar-Parsi, J. Phys. Chem. Ref. Data **13**, 185 (1984).

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. Table of critically evaluated experimental data (reduced to a uniform grid)

$P\backslash t$	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	186.0	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. Table of critically evaluated experimental data (reduced to a uniform grid)—Continued

$P\backslash t$	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. Table of critically evaluated experimental data (reduced to a uniform grid)—Continued

$P \setminus t$	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	34.6	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.[a]

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^*, and 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)

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:

$$P\leqslant 500\ \text{MPa for}\ 0\ ^\circ\text{C}\leqslant t\leqslant 150\ ^\circ\text{C},$$
$$P\leqslant 350\ \text{MPa for}\ 150\ ^\circ\text{C}\leqslant t\leqslant 600\ ^\circ\text{C}, \qquad (9)$$
$$P\leqslant 300\ \text{MPa for}\ 600\ ^\circ\text{C}\leqslant t\leqslant 900\ ^\circ\text{C}.$$

B.5. Interpolating Equation

The viscosity is represented by the equation

$$\bar{\mu} = \bar{\mu}_0(\bar{T})\times\bar{\mu}_1(\bar{T},\bar{\rho})\times\bar{\mu}_2(\bar{T},\bar{\rho}). \qquad (10)$$

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

$$\bar{\mu}_0(\bar{T}) = \sqrt{\bar{T}}\Big/\sum_{i=0}^{3}\frac{H_i}{\bar{T}^i}, \qquad (11)$$

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

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

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 Eq. (9):

$$\bar{\mu}_2 = 1. \qquad (13)$$

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

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

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

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

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

$$\bar{\mu}_2 = 0.922\bar{\chi}_T^{0.0263}, \quad \text{if}\ \bar{\chi}_T\geqslant 21.93,$$
$$\bar{\mu}_2 = 1, \quad \text{if}\ \bar{\chi}_T < 21.93. \qquad (16)$$

[a] 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.

TABLE B.I. Coefficients H_i for $\bar{\mu}_0(\bar{T})$

$H_0 =$	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 ($\equiv 10^{-6}$ kg/m s).

Pressure P in MPa.

Temperature t in °C.

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

PRESSURE, MPa \ TEMPERATURE, °C	0	25	50	75	100	150	200	250	300	350	375
.1	1793.	890.5	547.0	377.9	12.27	14.18	16.18	18.22	20.29	22.37	23.41
.5	1792.	890.4	547.1	378.0	281.9	182.5	16.05	18.14	20.24	22.34	23.39
1.0	1791.	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	186.2	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	75.51	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	81.60	73.74
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

PRESSURE, MPa \ TEMPERATURE, °C	400	425	450	475	500	550	600	650	700	750	800
.1	24.45	25.49	26.52	27.55	28.57	30.61	32.61	34.60	36.55	38.48	40.37
.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	36.66	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	40.74
10.0	24.49	25.62	26.73	27.83	28.91	31.03	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	44.72
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	50.54	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.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.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($\equiv 10^{-6}$ 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.

t	P	μ'	μ''
0.01	0.000 611 7	1792	9.22
10.00	0.001 228	1307	9.46
20.00	0.002 339	1002	9.73
30.00	0.004 246	797.7	10.01
40.00	0.007 381	653.2	10.31
50.00	0.012 34	547.0	10.62
60.00	0.019 93	466.5	10.93
70.00	0.031 18	404.0	11.26
80.00	0.047 37	354.4	11.59
90.00	0.070 12	314.5	11.93
100.00	0.101 3	281.8	12.27
110.00	0.143 2	254.8	12.61
120.00	0.198 5	232.1	12.96
130.00	0.270 0	213.0	13.30
140.00	0.361 2	196.6	13.65
150.00	0.475 7	182.5	13.99
160.00	0.617 7	170.3	14.34
170.00	0.791 5	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

Appendix II

The Tenth International Conference on the Properties of Steam

Moscow, USSR, September 1984

Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance

Unrestricted publication allowed in all countries.

Issued by the International Association for the Properties of Steam.

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National Bureau of Standards
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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, 2–7 September 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.

Further information can be obtained from the Executive Secretary of IAPS:

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Contents of this Release

The original experimental data have been collected in the document, "Available Input of the Thermal Conductivity of Water Substance," by 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. Critically Evaluated Experimental Data

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

P \ t	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. Critically evaluated experimental data reduced to a uniform grid--Continued

P \ t	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	0.000 611 7	565	11	16.7	0.5
10	0.001 228	584	12	17.4	0.5
20	0.002 339	602	12	18.1	0.5
30	0.004 246	617	12	19.0	0.6
40	0.007 381	631	13	19.7	0.6
50	0.012 34	642	13	20.4	0.6
60	0.019 93	652	13	21.2	0.6
70	0.031 18	660	13	22.2	0.7
80	0.047 37	669	13	23.1	0.7
90	0.070 12	675	14	24.0	0.7
100	0.101 3	679	14	25.0	0.8
110	0.143 2	681	14	25.7	0.8
120	0.198 5	685	14	26.8	0.8
130	0.270 0	686	14	28.7	0.9
140	0.361 2	686	14	29.7	0.9
150	0.475 7	686	14	31.0	0.9
160	0.617 7	682	14	31.9	1.3
170	0.791 5	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.[b)]

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)] 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.3. Dimensionless Variables

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

Density: $\overline{\rho} = \rho/\rho^*$, (5)

Thermal conductivity: $\overline{\lambda} = \lambda/\lambda^*$. (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:

$$P \leqslant 100 \text{ MPa for } 0\,^\circ\text{C} \leqslant t \leqslant 500\,^\circ\text{C},$$
$$P \leqslant 70 \text{ MPa for } 500\,^\circ\text{C} < t \leqslant 650\,^\circ\text{C},$$
$$P \leqslant 40 \text{ MPa for } 650\,^\circ\text{C} < t \leqslant 800\,^\circ\text{C}. \quad (7)$$

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

$$\overline{\lambda} = \overline{\lambda}_0(\overline{T}) + \overline{\lambda}_1(\overline{\rho}) + \overline{\lambda}_2(\overline{T},\overline{\rho}). \quad (8)$$

The function $\overline{\lambda}_0(\overline{T})$ represents the thermal conductivity of steam in the ideal-gas limit and has the form

$$\overline{\lambda}_0(\overline{T}) = \sqrt{\overline{T}} \sum_{k=0}^{3} a_k \overline{T}^k, \quad (9)$$

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

$$\overline{\lambda}_1(\rho) = b_0 + b_1\overline{\rho} + b_2 \exp\{B_1(\overline{\rho} + B_2)^2\}, \quad (10)$$

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

$$\overline{\lambda}_2(\overline{T},\overline{\rho}) = \left(\frac{d_1}{\overline{T}^{10}} + d_2\right)\overline{\rho}^{9/5} \exp[C_1(1-\overline{\rho})^{14/5}]$$
$$+ d_3 S \overline{\rho}^Q \exp\left[\left(\frac{Q}{1+Q}\right)(1-\overline{\rho}^{1+Q})\right]$$
$$+ d_4 \exp\left(C_2 \overline{T}^{3/2} + \frac{C_3}{\overline{\rho}^5}\right). \quad (11)$$

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

$a_0 =$	0.010 281 1
$a_1 =$	0.029 962 1
$a_2 =$	0.015 614 6
$a_3 =$	− 0.004 224 64

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 $\bar{\lambda}_2(\bar{T},\bar{\rho})$

$d_1 =$	0.070 130 9	$C_1 =$	0.642 857
$d_2 =$	0.011 852 0	$C_2 =$	− 4.117 17
$d_3 =$	0.001 699 37	$C_3 =$	− 6.179 37
$d_4 =$	− 1.020 0	$C_4 =$	0.003 089 76
		$C_5 =$	0.082 299 4
		$C_6 =$	10.093 2

Here Q and S are functions of

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

where

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

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

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.

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^*, and 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)
Compressibility (symmetrized):	$\bar{\chi}_T = \bar{\rho}(\partial\bar{\rho}/\partial\bar{P})_{\bar{T}}$,	(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 $0\,°\text{C} \leqslant t \leqslant 125\,°\text{C}$,

$P \leqslant 200$ MPa for $125\,°\text{C} < t \leqslant 250\,°\text{C}$,

$P \leqslant 150$ MPa for $250\,°\text{C} < t \leqslant 400\,°\text{C}$,

$P \leqslant 100$ MPa for $400\,°\text{C} < t \leqslant 800\,°\text{C}$. (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

$$\bar{\lambda} = \bar{\lambda}_0(\bar{T}) \times \bar{\lambda}_1(\bar{T},\bar{\rho}) + \bar{\lambda}_2(\bar{T},\bar{\rho}). \tag{25}$$

The factor $\bar{\lambda}_0(\bar{T})$ represents the thermal conductivity of steam in the ideal-gas limit and has the form

$$\bar{\lambda}_0(\bar{T}) = \sqrt{\bar{T}} \Big/ \sum_{i=0}^{3} \frac{L_i}{\bar{T}^i}, \tag{26}$$

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 Eq. (25) which accounts for an enhancement of the thermal conductivity in the critical region, is defined by

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 \ i	0	1	2	3	4
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

$$\bar{\lambda}_2(\bar{T},\bar{\rho}) = \frac{0.001\,384\,8}{\bar{\mu}_0(\bar{T})\times\bar{\mu}_1(\bar{T},\bar{\rho})}\left(\frac{\bar{T}}{\bar{\rho}}\right)^2\left(\frac{\partial\bar{P}}{\partial\bar{T}}\right)_{\bar{\rho}}^2 \bar{\chi}_T^{0.4678}\,\bar{\rho}^{1/2} \times\exp[-18.66(\bar{T}-1)^2-(\bar{\rho}-1)^4], \quad (28)$$

where the functions $\bar{\mu}_0(\bar{T})$ 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," by J. V. Sengers, J. T. R. Watson, R. S. Basu, B. Kamgar-Parsi, and R. C. Hendricks, J. Phys. Chem. Ref. Data 13, 893 (1984).

Appendix D. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Industrial Use

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 pressure 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

PRESSURE, MPa \ TEMPERATURE, °C	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	556.8	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	559.8
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

PRESSURE, MPa \ TEMPERATURE, °C	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. 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

t	P	λ'	λ''
0.01	0.000 611 2	561.97	16.49
10.00	0.001 227	581.94	17.21
20.00	0.002 337	599.61	17.95
30.00	0.004 241	615.05	18.70
40.00	0.007 375	628.62	19.48
50.00	0.012 33	640.47	20.28
60.00	0.019 92	650.75	21.10
70.00	0.031 16	659.49	21.96
80.00	0.047 36	666.75	22.86
90.00	0.070 11	672.80	23.80
100.00	0.101 3	677.46	24.79
110.00	0.143 3	680.91	25.84
120.00	0.198 5	683.29	26.96
130.00	0.270 1	684.47	28.15
140.00	0.361 4	684.50	29.42
150.00	0.476 0	683.54	30.77
160.00	0.618 1	681.57	32.22
170.00	0.792 0	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. Smoothed Values of the Thermal Conductivity of Ordinary Water Substance Obtained with the Aid of the Recommended Interpolating Equation for Scientific Use

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.I.)

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.II.)

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

PRESSURE, MPa \ TEMPERATURE, °C	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	47.82	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	561.8	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

PRESSURE, MPa \ TEMPERATURE, °C	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. 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

t	P	λ'	λ''
0.01	0.000 611 7	561.0	17.07
10.00	0.001 228	580.0	17.62
20.00	0.002 339	598.4	18.23
30.00	0.004 246	615.4	18.89
40.00	0.007 381	630.5	19.60
50.00	0.012 34	643.5	20.36
60.00	0.019 93	654.3	21.18
70.00	0.031 18	663.1	22.07
80.00	0.047 37	670.0	23.01
90.00	0.070 12	675.3	24.02
100.00	0.101 3	679.1	25.09
110.00	0.143 2	681.7	26.24
120.00	0.198 5	683.2	27.46
130.00	0.270 0	683.7	28.76
140.00	0.361 2	683.3	30.14
150.00	0.475 7	682.1	31.59
160.00	0.617 7	680.0	33.12
170.00	0.791 5	677.1	34.74
180.00	1.001 9	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

Appendix III. Tables of Densities Calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use

Table III.1. Table of densities calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use, calculated over a uniform grid.

Density ρ in kg/m^3.

Pressure P in MPa.

Temperature t in °C.

Table III.2. Table of densities calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use, calculated along the saturation line.

Density of saturated vapor ρ'' and density of saturated liquid ρ' in kg/m^3.

Pressure P in MPa.

Temperature t in °C.

TABLE III. 1. Table of densities calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use, calculated over a uniform grid

Pressure (MPa) \ Temperature, °C	0	25	50	75	100	150	200	250	300	350	375
0.1	999.8	997.1	988.0	974.9	0.5896	0.5164	0.4604	0.4156	0.3790	0.3483	0.3348
0.5	1000	997.2	988.2	975.0	958.6	917.1	2.354	2.108	1.914	1.754	1.684
1.0	1000	997.5	988.4	975.3	958.8	917.4	4.857	4.298	3.877	3.540	3.395
2.5	1001	998.1	989.1	975.9	959.5	918.2	865.5	11.50	10.11	9.112	8.698
5.0	1002	999.3	990.2	977.0	960.7	919.6	867.4	800.3	22.07	19.25	18.20
7.5	1004	1000	991.2	978.1	961.8	921.0	869.2	803.1	37.43	30.85	28.77
10.0	1005	1001	992.3	979.2	963.0	922.4	871.0	805.9	715.6	44.61	40.76
12.5	1006	1003	993.4	980.3	964.1	923.7	872.8	808.6	720.9	62.03	54.80
15.0	1007	1004	994.4	981.4	965.2	925.1	874.6	811.2	725.9	87.19	72.00
17.5	1009	1005	995.5	982.4	966.4	926.4	876.3	813.8	730.6	583.3	94.75
20.0	1010	1006	996.5	983.5	967.5	927.7	878.1	816.3	735.0	600.8	130.4
22.5	1011	1007	997.6	984.6	968.6	929.0	879.8	818.7	739.3	614.4	410.4
25.0	1012	1008	998.6	985.6	969.7	930.3	881.4	821.1	743.3	625.7	505.2
27.5	1013	1009	999.6	986.6	970.8	931.6	883.1	823.4	747.2	635.6	537.0
30.0	1015	1010	1001	987.7	971.9	932.9	884.7	825.7	750.9	644.3	558.3
35.0	1017	1012	1003	989.7	974.0	935.4	887.9	830.2	758.0	659.3	588.0
40.0	1019	1014	1005	991.8	976.1	937.9	891.0	834.4	764.6	672.1	609.6
45.0	1022	1016	1007	993.8	978.2	940.3	894.0	838.6	770.8	683.3	626.8
50.0	1024	1018	1009	995.8	980.3	942.7	897.0	842.5	776.6	693.4	641.3
55.0	1026	1020	1011	997.7	982.3	945.0	899.9	846.4	782.2	702.5	653.9
60.0	1028	1022	1013	999.7	984.3	947.4	902.8	850.1	787.5	710.9	665.2
65.0	1031	1024	1014	1002	986.3	949.6	905.6	853.8	792.6	718.7	675.3
70.0	1033	1026	1016	1004	988.3	951.9	908.3	857.3	797.4	726.0	684.6
80.0	1037	1030	1020	1007	992.2	956.3	913.6	864.1	806.6	739.3	701.1
90.0	1041	1034	1024	1011	996.0	960.6	918.7	870.5	815.2	751.3	715.6
100.0	1045	1038	1027	1015	999.7	964.8	923.7	876.7	823.2	762.2	728.5

TABLE III. 1. Table of densities calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use, calculated over a uniform grid—Continued

Pressure (MPa) \ Temperature, °C	400	425	450	475	500	550	600	650	700	750	800
0.1	0.3223	0.3107	0.2999	0.2899	0.2805	0.2634	0.2483	0.2348	0.2227	0.2118	0.2019
0.5	1.620	1.561	1.506	1.454	1.407	1.320	1.244	1.176	1.115	1.060	1.010
1.0	3.262	3.139	3.026	2.922	2.824	2.648	2.493	2.356	2.233	2.123	2.023
2.5	8.327	7.991	7.685	7.403	7.144	6.681	6.278	5.923	5.608	5.325	5.071
5.0	17.30	16.50	15.80	15.16	14.59	13.57	12.71	11.96	11.30	10.71	10.19
7.5	27.07	25.65	24.41	23.33	22.36	20.69	19.30	18.11	17.08	16.16	15.35
10.0	37.87	35.55	33.61	31.95	30.50	28.06	26.07	24.39	22.94	21.68	20.56
12.5	49.99	46.38	43.50	41.10	39.06	35.70	33.02	30.79	28.90	27.26	25.82
15.0	63.89	58.37	54.20	50.86	48.08	43.63	40.15	37.32	34.94	32.90	31.12
17.5	80.31	71.84	65.88	61.30	57.61	51.86	47.49	43.99	41.08	38.61	36.47
20.0	100.5	87.23	78.73	72.55	67.71	60.43	55.04	50.80	47.32	44.39	41.87
22.5	127.2	105.2	93.02	84.71	78.45	69.35	62.80	57.74	53.65	50.23	47.31
25.0	166.6	126.8	109.1	97.93	89.90	78.64	70.79	64.84	60.08	56.14	52.80
27.5	239.2	153.7	127.4	112.4	102.1	88.33	79.02	72.08	66.61	62.12	58.34
30.0	358.1	188.7	148.4	128.3	115.3	98.44	87.48	79.47	73.23	68.16	63.92
35.0	474.9	291.9	201.6	165.2	144.4	120.0	105.1	94.71	86.78	80.45	75.21
40.0	523.7	394.6	270.9	210.0	178.0	143.4	123.8	110.5	100.7	92.99	86.68
45.0	554.8	457.5	343.4	261.7	215.9	168.7	143.4	127.0	115.0	105.8	98.31
50.0	578.0	498.2	402.3	315.1	256.9	195.6	164.0	143.9	129.6	118.8	110.1
55.0	596.7	527.7	446.3	363.8	298.7	223.9	185.3	161.3	144.6	132.0	122.0
60.0	612.5	550.9	479.9	404.8	338.4	252.9	207.2	179.1	159.8	145.3	134.0
65.0	626.1	570.0	506.6	438.6	374.3	281.8	229.4	197.2	175.1	158.8	146.1
70.0	638.3	586.4	528.6	466.7	405.8	309.9	251.7	215.4	190.6	172.4	158.3
80.0	659.3	613.5	563.7	510.7	457.0	361.9	295.5	251.8	221.7	199.7	182.7
90.0	677.0	635.5	591.1	544.4	496.5	406.6	336.5	287.3	252.5	226.8	207.0
100.0	692.6	654.3	613.8	571.5	528.2	444.4	373.9	321.0	282.4	253.4	231.0

TABLE III.2. Table of densities calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use, calculated along the saturation line

t	P	ρ'	ρ''
0.01	0.000 611 7	999.8	0.004 855
10.00	0.001 228	999.7	0.009 405
20.00	0.002 339	998.2	0.017 31
30.00	0.004 246	995.6	0.030 40
40.00	0.007 381	992.2	0.051 21
50.00	0.012 34	988.0	0.083 08
60.00	0.019 93	983.2	0.130 3
70.00	0.031 18	977.7	0.198 2
80.00	0.047 37	971.8	0.293 4
90.00	0.070 12	965.3	0.423 4
100.00	0.101 3	958.4	0.597 5
110.00	0.143 2	951.0	0.826 0
120.00	0.198 5	943.2	1.121
130.00	0.270 0	934.9	1.495
140.00	0.361 2	926.2	1.965
150.00	0.475 7	917.1	2.545
160.00	0.617 7	907.5	3.256
170.00	0.791 5	897.5	4.118
180.00	1.002	887.1	5.154
190.00	1.254	876.1	6.390
200.00	1.554	864.7	7.854
210.00	1.906	852.8	9.581
220.00	2.318	840.3	11.61
230.00	2.795	827.3	13.98
240.00	3.345	813.5	16.74
250.00	3.974	799.1	19.96
260.00	4.689	783.8	23.70
270.00	5.500	767.7	28.06
280.00	6.413	750.5	33.15
290.00	7.438	732.2	39.12
300.00	8.584	712.4	46.15
310.00	9.861	691.0	54.52
320.00	11.279	667.4	64.62
330.00	12.852	641.0	77.01
340.00	14.594	610.8	92.69
350.00	16.521	574.7	113.5
360.00	18.655	528.1	143.6
370.00	21.030	453.1	200.3
371.00	21.283	440.7	210.6
372.00	21.539	425.3	223.7
373.00	21.799	402.4	242.7