The International Association for the Properties of Water and Steam

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

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This release is a revision of the edition of 1989 and contains 4 numbered pages.

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 In the second revision, Equation (6) has been replaced by a simpler equation which better represents the derivatives of the sublimation pressure.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, 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 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