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In this release, including the title, the term seawater is used to represent the description *IAPWS Standard Seawater* [1]. The solute in seawater is referred to as sea salt, the solvent as H₂O. The equation of state for seawater provided in this release is a fundamental equation for the Gibbs energy as a function of salinity, temperature and pressure, relative to the Gibbs energy of H₂O (in this release, H₂O refers to ordinary water substance); details of the equation can be found in the article “A Gibbs function for seawater thermodynamics for –6 to 80 °C and salinity up to 120 g kg⁻¹” by R. Feistel [2]. This equation is consistent with the IAPWS-95 formulation for the fluid phase of water [3, 4] and the IAPWS Release on an equation of state of H₂O ice Ih [5, 6].

Further information about this release and other releases issued by IAPWS can be obtained from the Executive Secretary of IAPWS or from <http://www.iapws.org>.

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1 Nomenclature

Symbol	Physical quantity	Unit
b	Mass fraction of brine in sea ice	
c_p	Specific isobaric heat capacity of seawater	$\text{J kg}^{-1} \text{K}^{-1}$
c_p^S	Saline part of the specific isobaric heat capacity c_p	$\text{J kg}^{-1} \text{K}^{-1}$
f	Specific Helmholtz energy of seawater	J kg^{-1}
g	Specific Gibbs energy of seawater	J kg^{-1}
g^{Ih}	Specific Gibbs energy of ice Ih	J kg^{-1}
g^S	Saline part of the specific Gibbs energy of seawater	J kg^{-1}
g^{SI}	Specific Gibbs energy of sea ice	J kg^{-1}
g^{vap}	Specific Gibbs energy of water vapor	J kg^{-1}
g^*	Reducing specific Gibbs energy, $g^* = 1 \text{ J kg}^{-1}$	J kg^{-1}
$g_{100} \dots g_{765}$	Coefficients of the Gibbs potential function, Table 2	
h	Specific enthalpy of seawater	J kg^{-1}
k	Uncertainty coverage factor	
M_S	Molar mass of sea salt, $M_S = 31.403\,8218 \text{ g mol}^{-1}$	g mol^{-1}
m	Molality of seawater	mol kg^{-1}
m_W	Mass of water	kg
m_{SW}	Mass of seawater	kg
p	Absolute pressure	Pa
p_0	Normal pressure, $p_0 = 101\,325 \text{ Pa}$	Pa
p_{osm}	Osmotic pressure of seawater	Pa
p_t	IAPWS-95 calculated triple-point pressure, $p_t = 611.654\,771\,007\,894 \text{ Pa}$	Pa

Symbol	Physical quantity	Unit
p^{vap}	Vapor pressure of seawater	Pa
p^*	Reducing pressure, $p^* = 10^8$ Pa	Pa
R_m	Molar gas constant, $R_m = 8.314\,472$ J mol ⁻¹ K ⁻¹	J mol ⁻¹ K ⁻¹
S	Reference-Composition Salinity	kg kg ⁻¹
S_n	Normal salinity, $S_n = 0.035\,165\,04$	kg kg ⁻¹
S^{SI}	Sea-ice salinity	kg kg ⁻¹
S^*	Reducing salinity, $S^* = S_n \times 40 / 35$	kg kg ⁻¹
s	Specific entropy of seawater	J kg ⁻¹ K ⁻¹
T	Absolute temperature (ITS-90)	K
T_0	Celsius zero point, $T_0 = 273.15$ K	K
T_f	Freezing temperature of seawater	K
T_b	Boiling temperature of seawater	K
T_t	Triple-point temperature, $T_t = 273.16$ K	K
T^*	Reducing temperature, $T^* = 40$ K	K
t	Celsius temperature	°C
u	Specific internal energy of seawater	J kg ⁻¹
U	Expanded uncertainty	
u_c	Combined standard uncertainty	
v	Specific volume of seawater	m ³ kg ⁻¹
w	Sound speed of seawater	m s ⁻¹
α	Thermal expansion coefficient of seawater	K ⁻¹
β	Haline contraction coefficient of seawater	kg kg ⁻¹
β_s	Isentropic temperature-pressure coefficient	K Pa ⁻¹
ϕ	Osmotic coefficient of seawater	
κ_s	Isentropic compressibility of seawater	Pa ⁻¹
κ_T	Isothermal compressibility of seawater	Pa ⁻¹
μ	Relative chemical potential of seawater	J kg ⁻¹
μ_s	Chemical potential of salt in seawater	J kg ⁻¹
μ_w	Chemical potential of water in seawater	J kg ⁻¹
π	Reduced pressure, $\pi = (p - p_0) / p^*$	
ρ	Density of seawater	kg m ⁻³
τ	Reduced temperature, $\tau = (T - T_0) / T^*$	
ξ	Reduced salinity root, $\xi = \sqrt{S / S^*}$	

Superscript W denotes properties of liquid water.

2 Introductory Remarks and Special Constants

Seawater is an aqueous electrolyte solution of several solutes referred to as sea salt. The chemical composition of sea salt is very similar in all oceans, and varies negligibly with time. The mass fraction of dissolved material in seawater is termed its absolute salinity. No established method is available for the practical determination of the absolute salinity. Due to chemical reactions between solvent and solute, “dissolved material” is not a strictly specified notion, and the implied value of the absolute salinity is not necessarily conserved with respect to changes of temperature, pressure, or addition or removal of H₂O. For these reasons, three different main salinity scales have been introduced in oceanography: the chlorinity scale of 1937 [7], the Practical Salinity Scale of 1978 (PSS-78) [8], and the Reference-Composition Salinity Scale of 2008 [9]. A review of the different salinity scales is given in the paper “The composition of Standard Seawater and the definition of the Reference-Composition Salinity Scale” by F.J. Millero *et al.* [9].

The term KCl-normalized seawater is used to describe a seawater sample that has the same specific electric conductivity as a solution of potassium chloride (KCl) in H₂O with the KCl mass fraction of 32.4356 g kg⁻¹ when both are at the ITS-90 temperature $t = 14.996$ °C and at normal pressure, $p = p_0$.

To KCl-normalize a given seawater sample of the mass m_{SW} , the mass m_{W} of H₂O is added to the solution ($m_{\text{W}} \geq 0$), or removed from it ($0 \leq -m_{\text{W}} < m_{\text{SW}}$). The Reference-Composition Salinity, S , referred to simply as “salinity” in this Release, of the original sample is computed from Eq. (1) as

$$S = \frac{m_{\text{SW}} + m_{\text{W}}}{m_{\text{SW}}} \times S_{\text{n}}. \quad (1)$$

The salinity of KCl-normalized seawater, S_{n} , referred to simply as normal salinity, is given in Table 1.

The Practical Salinity of KCl-normalized seawater equals 35. In its range of definition, Practical Salinity differs from S by a constant factor. At the time of formulation of this Release, commercial instruments in use for in-situ or in-vitro salinity measurements regularly produce values of Practical Salinity (PSS-78).

The chlorinity is defined as 0.328 523 4 times the ratio of the mass of pure silver required to precipitate all dissolved chloride, bromide and iodide in seawater to the mass of seawater.

The Reference Composition of sea salt is defined from the most accurate determinations of the main chemical constituents of IAPSO Standard Seawater which is sampled from North Atlantic surface water [1, 5]. IAPSO is the abbreviation for International Association for the Physical Sciences of the Oceans.

The chlorinity of KCl-normalized seawater with composition equal to the Reference Composition is (35/1.806 55) g kg⁻¹. Chlorinity differs from S by a constant factor.

From the molar mass M_{S} of sea salt, given in Table 1 for the Reference Composition, the molality m of seawater, i.e. the moles of solute per mass of solvent, is computed as

$$m = \frac{S}{(1-S)M_{\text{S}}}. \quad (2)$$

The molality of KCl-normalized seawater with Reference Composition is 1.160 581 mol kg⁻¹.

TABLE 1 Special constants and values used in this release

Quantity	Symbol	Value	Unit	Reference
Triple-point pressure ^a	p_t	611.654 771 007 894	Pa	[3]
Normal pressure	p_0	101 325	Pa	[11]
Reducing pressure	p^*	10^8	Pa	[2]
Triple-point temperature	T_t	273.16	K	[12]
Celsius zero point	T_0	273.15	K	[12]
Reducing temperature	T^*	40	K	[2]
Normal salinity ^b	S_n	0.035 165 04	kg kg ⁻¹	[9]
Reducing salinity $S^* = S_n \times 40 / 35$	S^*	0.040 188 617...	kg kg ⁻¹	[2]
Molar mass of sea salt	M_S	31.403 821 8	g mol ⁻¹	[9]
Molar gas constant	R_m	8.314 472	J mol ⁻¹ K ⁻¹	[13]

^aNumerical triple-point pressure value computed from IAPWS-95 [1], being well within the uncertainty of the experimental value of 611.657(10) Pa [10]

^bNormal salinity represents the salinity of KCl-normalized seawater [9]

3 The Equation of State

The equation of state presented here is in the form of the specific Gibbs energy as a function of salinity, temperature and pressure, $g(S, T, p)$, corresponding to a Gibbs potential. The temperatures are based on the temperature scale ITS-90, the salinities on the Reference-Composition Salinity Scale [9]. This equation of state for seawater is given by Eq. (3) as a sum of a H₂O part, $g^w(T, p)$, and a saline part, $g^s(S, T, p)$, subject to the condition $g^s(0, T, p) = 0$,

$$g(S, T, p) = g^w(T, p) + g^s(S, T, p). \quad (3)$$

The H₂O part is computed from the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, IAPWS-95 [3]. Reduced by $g^* = 1 \text{ J kg}^{-1}$, the saline part is the dimensionless polynomial-like function given by Eq. (4)

$$g^s(S, T, p) / g^* = \sum_{k=0}^5 \sum_{j=0}^6 \left(g_{1,jk} \xi^2 \ln \xi + \sum_{i=2}^7 g_{i,jk} \xi^i \right) \tau^j \pi^k, \quad (4)$$

with the reduced temperature $\tau = (T - T_0) / T^*$, the reduced pressure $\pi = (p - p_0) / p^*$, and the square root of the reduced salinity, $\xi = \sqrt{S / S^*}$. The reduced quantities τ , π and ξ vary from 0 to 1 in the oceanographic standard range. The constants T_0 , p_0 , T^* , p^* and S^* are given in Table 1.

The coefficients of Eq. (4) are given in Table 2. Two of these 64 parameters (g_{100} and g_{110} , for the logarithmic term) are computed from Planck's theory of ideal solutions, while two additional parameters (g_{200} and g_{210}) are arbitrary and are determined by the reference-state conditions,

$$s(S_n, T_0, p_0) = s^W(T_t, p_t), \quad (5)$$

$$h(S_n, T_0, p_0) = u^W(T_t, p_t). \quad (6)$$

Here, s and h are the specific entropy and the specific enthalpy of seawater, and s^W and u^W are the specific entropy and the specific internal energy of H_2O at the triple point, Table 1.

TABLE 2 Coefficients of the saline part of the Gibbs function, as given by Eq. (4). Coefficients not contained in this table have the value $g_{ijk} = 0$.

i	j	k	g_{ijk}	i	j	k	g_{ijk}
1	0	0	$0.581\ 281\ 456\ 626\ 732 \times 10^4$	2	2	1	$-0.860\ 764\ 303\ 783\ 977 \times 10^3$
2	0	0	$0.141\ 627\ 648\ 484\ 197 \times 10^4$	3	2	1	$0.383\ 058\ 066\ 002\ 476 \times 10^3$
3	0	0	$-0.243\ 214\ 662\ 381\ 794 \times 10^4$	2	3	1	$0.694\ 244\ 814\ 133\ 268 \times 10^3$
4	0	0	$0.202\ 580\ 115\ 603\ 697 \times 10^4$	3	3	1	$-0.460\ 319\ 931\ 801\ 257 \times 10^3$
5	0	0	$-0.109\ 166\ 841\ 042\ 967 \times 10^4$	2	4	1	$-0.297\ 728\ 741\ 987\ 187 \times 10^3$
6	0	0	$0.374\ 601\ 237\ 877\ 840 \times 10^3$	3	4	1	$0.234\ 565\ 187\ 611\ 355 \times 10^3$
7	0	0	$-0.485\ 891\ 069\ 025\ 409 \times 10^2$	2	0	2	$0.384\ 794\ 152\ 978\ 599 \times 10^3$
1	1	0	$0.851\ 226\ 734\ 946\ 706 \times 10^3$	3	0	2	$-0.522\ 940\ 909\ 281\ 335 \times 10^2$
2	1	0	$0.168\ 072\ 408\ 311\ 545 \times 10^3$	4	0	2	$-0.408\ 193\ 978\ 912\ 261 \times 10$
3	1	0	$-0.493\ 407\ 510\ 141\ 682 \times 10^3$	2	1	2	$-0.343\ 956\ 902\ 961\ 561 \times 10^3$
4	1	0	$0.543\ 835\ 333\ 000\ 098 \times 10^3$	3	1	2	$0.831\ 923\ 927\ 801\ 819 \times 10^2$
5	1	0	$-0.196\ 028\ 306\ 689\ 776 \times 10^3$	2	2	2	$0.337\ 409\ 530\ 269\ 367 \times 10^3$
6	1	0	$0.367\ 571\ 622\ 995\ 805 \times 10^2$	3	2	2	$-0.541\ 917\ 262\ 517\ 112 \times 10^2$
2	2	0	$0.880\ 031\ 352\ 997\ 204 \times 10^3$	2	3	2	$-0.204\ 889\ 641\ 964\ 903 \times 10^3$
3	2	0	$-0.430\ 664\ 675\ 978\ 042 \times 10^2$	2	4	2	$0.747\ 261\ 411\ 387\ 560 \times 10^2$
4	2	0	$-0.685\ 572\ 509\ 204\ 491 \times 10^2$	2	0	3	$-0.965\ 324\ 320\ 107\ 458 \times 10^2$
2	3	0	$-0.225\ 267\ 649\ 263\ 401 \times 10^3$	3	0	3	$0.680\ 444\ 942\ 726\ 459 \times 10^2$
3	3	0	$-0.100\ 227\ 370\ 861\ 875 \times 10^2$	4	0	3	$-0.301\ 755\ 111\ 971\ 161 \times 10^2$
4	3	0	$0.493\ 667\ 694\ 856\ 254 \times 10^2$	2	1	3	$0.124\ 687\ 671\ 116\ 248 \times 10^3$
2	4	0	$0.914\ 260\ 447\ 751\ 259 \times 10^2$	3	1	3	$-0.294\ 830\ 643\ 494\ 290 \times 10^2$
3	4	0	$0.875\ 600\ 661\ 808\ 945$	2	2	3	$-0.178\ 314\ 556\ 207\ 638 \times 10^3$
4	4	0	$-0.171\ 397\ 577\ 419\ 788 \times 10^2$	3	2	3	$0.256\ 398\ 487\ 389\ 914 \times 10^2$
2	5	0	$-0.216\ 603\ 240\ 875\ 311 \times 10^2$	2	3	3	$0.113\ 561\ 697\ 840\ 594 \times 10^3$
4	5	0	$0.249\ 697\ 009\ 569\ 508 \times 10$	2	4	3	$-0.364\ 872\ 919\ 001\ 588 \times 10^2$
2	6	0	$0.213\ 016\ 970\ 847\ 183 \times 10$	2	0	4	$0.158\ 408\ 172\ 766\ 824 \times 10^2$
2	0	1	$-0.331\ 049\ 154\ 044\ 839 \times 10^4$	3	0	4	$-0.341\ 251\ 932\ 441\ 282 \times 10$
3	0	1	$0.199\ 459\ 603\ 073\ 901 \times 10^3$	2	1	4	$-0.316\ 569\ 643\ 860\ 730 \times 10^2$
4	0	1	$-0.547\ 919\ 133\ 532\ 887 \times 10^2$	2	2	4	$0.442\ 040\ 358\ 308\ 000 \times 10^2$
5	0	1	$0.360\ 284\ 195\ 611\ 086 \times 10^2$	2	3	4	$-0.111\ 282\ 734\ 326\ 413 \times 10^2$
2	1	1	$0.729\ 116\ 529\ 735\ 046 \times 10^3$	2	0	5	$-0.262\ 480\ 156\ 590\ 992 \times 10$
3	1	1	$-0.175\ 292\ 041\ 186\ 547 \times 10^3$	2	1	5	$0.704\ 658\ 803\ 315\ 449 \times 10$
4	1	1	$-0.226\ 683\ 558\ 512\ 829 \times 10^2$	2	2	5	$-0.792\ 001\ 547\ 211\ 682 \times 10$

TABLE 3 Relations of the thermodynamic properties to the equation for the Gibbs energy of seawater, Eq. (3), and its T - p derivatives^a

Property	Relation	Unit	Eq.
Density			
$\rho(S, T, p) = v^{-1} = (\partial g / \partial p)_{S,T}^{-1}$	$\rho(S, T, p) = g_p^{-1}$	$\frac{\text{kg}}{\text{m}^3}$	(7)
Specific entropy			
$s(S, T, p) = -(\partial g / \partial T)_{S,p}$	$s(S, T, p) = -g_T$	$\frac{\text{J}}{\text{kg K}}$	(8)
Specific isobaric heat capacity			
$c_p(S, T, p) = T(\partial s / \partial T)_{S,p}$	$c_p(S, T, p) = -T g_{TT}$	$\frac{\text{J}}{\text{kg K}}$	(9)
Specific enthalpy			
$h(S, T, p) = g + Ts$	$h(S, T, p) = g - T g_T$	$\frac{\text{J}}{\text{kg}}$	(10)
Specific internal energy			
$u(S, T, p) = g + Ts - pv$	$u(S, T, p) = g - T g_T - p g_p$	$\frac{\text{J}}{\text{kg}}$	(11)
Specific Helmholtz energy			
$f(S, T, p) = g - pv$	$f(S, T, p) = g - p g_p$	$\frac{\text{J}}{\text{kg}}$	(12)
Thermal expansion coefficient			
$\alpha(S, T, p) = v^{-1}(\partial v / \partial T)_{S,p}$	$\alpha(S, T, p) = g_{Tp} / g_p$	$\frac{1}{\text{K}}$	(13)
Isentropic temperature-pressure coefficient, adiabatic lapse rate			
$\beta_s(S, T, p) = (\partial T / \partial p)_{S,s}$	$\beta_s(S, T, p) = -g_{Tp} / g_{TT}$	$\frac{\text{K}}{\text{Pa}}$	(14)
Isothermal compressibility			
$\kappa_T(S, T, p) = -v^{-1}(\partial v / \partial p)_{S,T}$	$\kappa_T(S, T, p) = -g_{pp} / g_p$	$\frac{1}{\text{Pa}}$	(15)
Isentropic compressibility			
$\kappa_s(S, T, p) = -v^{-1}(\partial v / \partial p)_{S,s}$	$\kappa_s(S, T, p) = (g_{Tp}^2 - g_{TT} g_{pp}) / (g_p g_{TT})$	$\frac{1}{\text{Pa}}$	(16)
Sound speed			
$w(S, T, p) = \sqrt{(\partial p / \partial \rho)_{S,s}}$	$w(S, T, p) = g_p \sqrt{g_{TT} / (g_{Tp}^2 - g_{TT} g_{pp})}$	$\frac{\text{m}}{\text{s}}$	(17)

^a $g_T \equiv \left[\frac{\partial g}{\partial T} \right]_{S,p}$, $g_p \equiv \left[\frac{\partial g}{\partial p} \right]_{S,T}$, $g_{TT} \equiv \left[\frac{\partial^2 g}{\partial T^2} \right]_{S,p}$, $g_{Tp} \equiv \left[\frac{\partial^2 g}{\partial T \partial p} \right]_S$, $g_{pp} \equiv \left[\frac{\partial^2 g}{\partial p^2} \right]_{S,T}$

4 Relations of the Thermodynamic Properties to the Specific Gibbs Energy

Thermodynamic properties can be derived from Eq. (3) by using the appropriate combinations of the specific Gibbs energy and its derivatives. Relations between thermodynamic properties and $g(S, T, p)$ and its derivatives with respect to T and p are summarized in Table 3. In Table 4, the derivatives of the H₂O part g^W of g are expressed in terms of derivatives of the IAPWS-95 Helmholtz function, $f^W(T, \rho^W)$. Details of the mathematical conversion rules between Helmholtz and Gibbs potentials are provided in [14]. Derivatives of the saline part g^S of g with respect to S and p are given in Table 5. All required derivatives of the saline part of the specific Gibbs energy are explicitly given in Table 6.

TABLE 4 The partial derivatives of the Gibbs energy of H₂O, Eq. (3), expressed as functions of the derivatives of the Helmholtz function, and of the properties provided in IAPWS-95 [3]

Expression in $g^W(T, p)^a$	Equivalence in $f^W(T, \rho^W)^b$	Relation to IAPWS-95 thermodynamic properties	Unit	Eq.
p	$p(T, \rho^W) = (\rho^W)^2 f_\rho^W$	p	Pa	(18)
$g^W(T, p)$	$f^W + \rho^W f_\rho^W$	$h^W - T s^W$	$\frac{\text{J}}{\text{kg}}$	(19)
$g_T^W(T, p)$	f_T^W	$-s^W$	$\frac{\text{J}}{\text{kg K}}$	(20)
$g_p^W(T, p)$	$(\rho^W)^{-1}$	$(\rho^W)^{-1}$	$\frac{\text{m}^3}{\text{kg}}$	(21)
$g_{TT}^W(T, p)$	$f_{TT}^W - \frac{\rho^W (f_{T\rho}^W)^2}{(2f_\rho^W + \rho^W f_{\rho\rho}^W)}$	$-\frac{c_p^W}{T}$	$\frac{\text{J}}{\text{kg K}}$	(22)
$g_{Tp}^W(T, p)$	$\frac{f_{T\rho}^W}{\rho^W (2f_\rho^W + \rho^W f_{\rho\rho}^W)}$	$\beta_s^W \frac{c_p^W}{T}$	$\frac{\text{m}^3}{\text{kg K}}$	(23)
$g_{pp}^W(T, p)$	$-\frac{1}{(\rho^W)^3 (2f_\rho^W + \rho^W f_{\rho\rho}^W)}$	$-\frac{1}{(\rho^W w^W)^2} - (\beta_s^W)^2 \frac{c_p^W}{T}$	$\frac{\text{m}^3}{\text{kg Pa}}$	(24)

$$^a g_T^W \equiv \left[\frac{\partial g^W}{\partial T} \right]_p, g_p^W \equiv \left[\frac{\partial g^W}{\partial p} \right]_T, g_{TT}^W \equiv \left[\frac{\partial^2 g^W}{\partial T^2} \right]_p, g_{Tp}^W \equiv \left[\frac{\partial^2 g^W}{\partial T \partial p} \right], g_{pp}^W \equiv \left[\frac{\partial^2 g^W}{\partial p^2} \right]_T$$

$$^b f_T^W \equiv \left[\frac{\partial f^W}{\partial T} \right]_\rho, f_\rho^W \equiv \left[\frac{\partial f^W}{\partial \rho} \right]_T, f_{TT}^W \equiv \left[\frac{\partial^2 f^W}{\partial T^2} \right]_\rho, f_{T\rho}^W \equiv \left[\frac{\partial^2 f^W}{\partial T \partial \rho} \right], f_{\rho\rho}^W \equiv \left[\frac{\partial^2 f^W}{\partial \rho^2} \right]_T$$

The H₂O part of Eq. (3) is available from the Helmholtz function $f^w(T, \rho^w)$. For the computation of the expressions given in Table 3, the T - p derivatives of the Gibbs function of H₂O, g^w , must be computed from equivalent expressions in terms of the Helmholtz energy, f^w , available from IAPWS-95. The required formulas are given in Table 4.

TABLE 5 Relations of the thermodynamic properties to the equation for the Gibbs energy of seawater, Eq. (3), and its S - p derivatives^a

Property	Relation	Unit	Eq.
Relative chemical potential			
$\mu(S, T, p) = (\partial g / \partial S)_{T,p}$	$\mu(S, T, p) = g_s$	$\frac{\text{J}}{\text{kg}}$	(25)
Chemical potential of H ₂ O			
$\mu_w(S, T, p) = g - S\mu$	$\mu_w(S, T, p) = g - Sg_s$	$\frac{\text{J}}{\text{kg}}$	(26)
Chemical potential of sea salt			
$\mu_s = \mu + \mu_w$	$\mu_s(S, T, p) = g + (1 - S)g_s$	$\frac{\text{J}}{\text{kg}}$	(27)
Osmotic coefficient			
$\phi(S, T, p) = (g^w - \mu_w) / (mR_m T)$	$\phi(S, T, p) = -(g^s - Sg_s) / (mR_m T)$	1	(28)
Haline contraction coefficient			
$\beta(S, T, p) = \rho^{-1}(\partial \rho / \partial S)_{T,p}$	$\beta(S, T, p) = -g_{sp} / g_p$	$\frac{\text{kg}}{\text{kg}}$	(29)

$$^a g_s \equiv \left[\frac{\partial g}{\partial S} \right]_{T,p}, g_{sp} \equiv \left[\frac{\partial^2 g}{\partial S \partial p} \right]_T$$

5 Colligative Properties

For the computation of equilibria between seawater and the different phases of H₂O, the required thermodynamic condition is equality of the chemical potential of H₂O in seawater, Eq. (26), with the specific Gibbs energy of that particular phase. In this work, chemical potentials are expressed on a mass basis, which is the usual (molar) chemical potential divided by molar mass.

At the boiling point of seawater, the brine salinity S , the boiling temperature T , and the vapor pressure p obey the equilibrium condition between seawater and vapor,

$$\mu_w(S, T, p) = g^{\text{vap}}(T, p), \quad (30)$$

which can be written equivalently in terms of the osmotic coefficient, Eq. (28), as

$$mR_m T \phi(S, T, p) = g^w(T, p) - g^{\text{vap}}(T, p). \quad (31)$$

Here, g^{vap} is the Gibbs energy of vapor, available from IAPWS-95 [3].

TABLE 6 Equations for the saline part of the Gibbs energy, Eq. (4), and its derivatives^a

Equation	Unit
$g^S(S, T, p) = g^* \sum_{k=0}^5 \sum_{j=0}^6 \left(g_{1,jk} \xi^2 \ln \xi + \sum_{i=2}^7 g_{ijk} \xi^i \right) \tau^j \pi^k$	
<p>with $g^* = 1 \text{ J kg}^{-1}$,</p> $\xi = \sqrt{S/S^*}, \quad S^* = 0.035 \, 165 \, 04 \text{ kg kg}^{-1} \times 40 / 35,$ $\tau = (T - T_0) / T^*, \quad T_0 = 273.15 \text{ K}, \quad T^* = 40 \text{ K},$ $\pi = (p - p_0) / p^*, \quad p_0 = 101325 \text{ Pa}, \quad p^* = 10^8 \text{ Pa}$	$\frac{\text{J}}{\text{kg}}$
$g_T^S(S, T, p) = \frac{g^*}{T^*} \sum_{k=0}^5 \sum_{j=1}^6 j \left(g_{1,jk} \xi^2 \ln \xi + \sum_{i=2}^7 g_{ijk} \xi^i \right) \tau^{j-1} \pi^k$	$\frac{\text{J}}{\text{kg K}}$
$g_p^S(S, T, p) = \frac{g^*}{p^*} \sum_{k=1}^5 \sum_{j=0}^6 \sum_{i=2}^7 k g_{ijk} \xi^i \tau^j \pi^{k-1}$	$\frac{\text{m}^3}{\text{kg}}$
$g_{TT}^S(S, T, p) = \frac{g^*}{(T^*)^2} \sum_{k=0}^5 \sum_{j=2}^6 \sum_{i=2}^7 j(j-1) g_{ijk} \xi^i \tau^{j-2} \pi^k$	$\frac{\text{J}}{\text{kg K}^2}$
$g_{Tp}^S(S, T, p) = \frac{g^*}{T^* p^*} \sum_{k=1}^5 \sum_{j=1}^6 \sum_{i=2}^7 jk g_{ijk} \xi^i \tau^{j-1} \pi^{k-1}$	$\frac{\text{m}^3}{\text{kg K}}$
$g_{pp}^S(S, T, p) = \frac{g^*}{(p^*)^2} \sum_{k=2}^5 \sum_{j=0}^6 \sum_{i=2}^7 k(k-1) g_{ijk} \xi^i \tau^j \pi^{k-2}$	$\frac{\text{m}^3}{\text{kg Pa}}$
$g_S^S(S, T, p) = \frac{g^*}{2S^*} \sum_{k=0}^5 \sum_{j=0}^6 \left[g_{1,jk} (2 \ln \xi + 1) + \sum_{i=2}^7 i g_{ijk} \xi^{i-2} \right] \tau^j \pi^k$	$\frac{\text{J}}{\text{kg}}$
$g_{Sp}^S(S, T, p) = \frac{g^*}{2S^* p^*} \sum_{k=1}^5 \sum_{j=0}^6 \sum_{i=2}^7 ik g_{ijk} \xi^{i-2} \tau^j \pi^{k-1}$	$\frac{\text{m}^3}{\text{kg}}$

$$^a g_S^S \equiv \left[\frac{\partial g^S}{\partial S} \right]_{T,p}, \quad g_T^S \equiv \left[\frac{\partial g^S}{\partial T} \right]_{S,p}, \quad g_p^S \equiv \left[\frac{\partial g^S}{\partial p} \right]_{S,T},$$

$$g_{Sp}^S \equiv \left[\frac{\partial^2 g^S}{\partial S \partial p} \right]_T, \quad g_{TT}^S \equiv \left[\frac{\partial^2 g^S}{\partial T^2} \right]_{S,p}, \quad g_{Tp}^S \equiv \left[\frac{\partial^2 g^S}{\partial T \partial p} \right]_S, \quad g_{pp}^S \equiv \left[\frac{\partial^2 g^S}{\partial p^2} \right]_{S,T}$$

At the freezing point of seawater, the brine salinity S , the freezing temperature T and the pressure p obey the equilibrium condition between seawater and ice,

$$\mu_w(S, T, p) = g^{\text{lh}}(T, p), \quad (32)$$

or equivalently,

$$mR_m T \phi(S, T, p) = g^{\text{w}}(T, p) - g^{\text{lh}}(T, p). \quad (33)$$

The Gibbs energy of ice Ih, g^{lh} , is available from the IAPWS Release [5].

Properties of the mixture of seawater and ice, termed sea ice, can be computed from the combined Gibbs function g^{SI} of sea ice [15]

$$g^{\text{SI}}(S^{\text{SI}}, T, p) = b g(S, T, p) + (1-b)g^{\text{lh}}(T, p), \quad (34)$$

where the mass fraction of the liquid phase, *i.e.*, the brine, $b(S^{\text{SI}}, T, p) = S^{\text{SI}} / S(T, p)$, follows from the brine salinity, $S(T, p)$, given by Eq. (32), and the mass fraction of salt in sea ice, *i.e.*, the sea-ice salinity S^{SI} . Sea-ice properties can be computed from the function g^{SI} in analogy to Table 3. The Gibbs energy $g^{\text{SI}}(S^{\text{SI}}, T, p)$ is a linear function of the sea-ice salinity S^{SI} . Due to the latent contributions, sea ice possesses extremely high values of heat capacity and thermal expansion.

On the two sides of a membrane permeable to water but not to sea salt, equilibrium between liquid water and seawater causes an excess pressure of seawater, the osmotic pressure p_{osm} , computed from the condition

$$\mu_w(S, T, p + p_{\text{osm}}) = g^{\text{w}}(T, p), \quad (35)$$

or equivalently,

$$mR_m T \phi(S, T, p + p_{\text{osm}}) = g^{\text{w}}(T, p + p_{\text{osm}}) - g^{\text{w}}(T, p). \quad (36)$$

In Eqs. (30)-(33), the Gibbs energy of liquid water is evaluated from IAPWS-95 at conditions where the liquid phase of pure water is metastable.

6 Range of Validity and Brief Discussion

The equation of state, Eq. (3), is valid for IAPSO Standard Seawater in certain phase diagram regions inside the salinity, temperature and pressure range

$$0 \leq S \leq 0.12 \text{ kg kg}^{-1}, \quad 261 \text{ K} \leq T \leq 353 \text{ K} \quad \text{and} \quad 0 < p \leq 10^8 \text{ Pa},$$

as shown in Fig. 1. This includes in particular the ‘‘Neptunian’’ validity region (A) of ambient ocean water in the range

$$0 \leq S \leq 0.042 \text{ kg kg}^{-1}, \quad T_f \leq T \leq 313 \text{ K} \quad \text{and} \quad 101\,325 \text{ Pa} \leq p \leq 10^8 \text{ Pa}.$$

The freezing temperature $T_f(S, p)$ is defined by Eq. (32).

The low-pressure region (B) of validity is restricted to the intervals

$$0 \leq S \leq 0.05 \text{ kg kg}^{-1}, \quad T_f \leq T \leq 313 \text{ K} \quad \text{and} \quad p^{\text{vap}} \leq p \leq 101\,325 \text{ Pa}.$$

The vapor pressure $p^{\text{vap}}(S, T)$ is defined by Eq. (30).

The validity region (C) is the extension to concentrated seawater and to high temperature at atmospheric pressure,

$$0 \leq S \leq 0.12 \text{ kg kg}^{-1}, \quad T_f \leq T \leq 353 \text{ K} \quad \text{and} \quad p = 101\,325 \text{ Pa}.$$

In this two-dimensional S - T region, outside its intersection with the regions (A), (B) or (D), the pressure derivatives of the Gibbs function, g_p , g_{Sp} , g_{Tp} and g_{pp} , of Tables 3 and 5 give values extrapolated beyond their range of validity for the density and its derivatives.

As summarized in Table 7, the saline part of the Gibbs energy at normal pressure, $g^s(S, T, p_0)$, represents the experimental thermal and colligative data for salinity from pure water to 0.12 kg kg^{-1} and for temperatures from the freezing point to 353 K in the region (C) of Fig. 1 [2]. The pressure-dependent part of the Gibbs function, $g^s(S, T, p) - g^s(S, T, p_0)$, represents highly accurate experimental data of density and sound speed in the regions (A) and (B) of Fig. 1 [16].

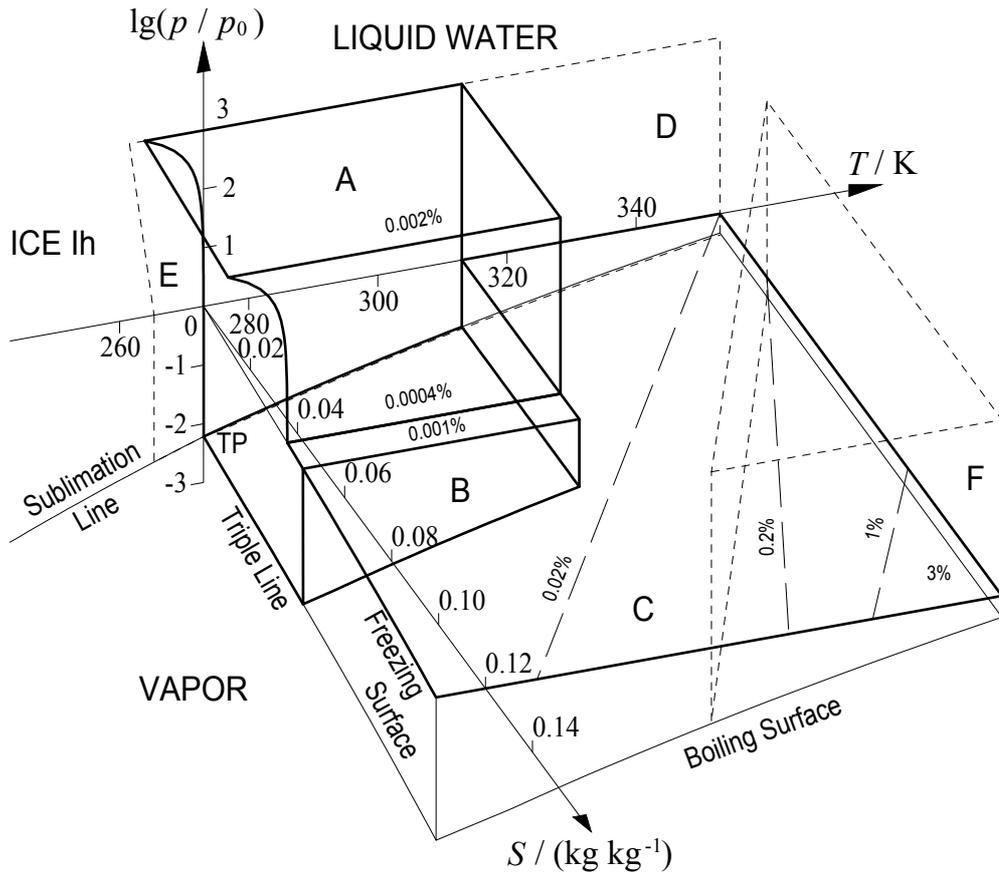


Fig. 1 Phase diagram of seawater with the regions (A) - (F) of the S - T - p space, explained in the text. The range of validity of the equation of state, Eq. (3), is in bold. Percentage values provide estimated relative combined standard uncertainties of seawater density, $u_c(\rho)/\rho$. Dashed lines indicate uncertainty ranges of extrapolated density, Table 7. TP is the triple point gas-liquid-solid of pure water. The freezing surface is defined by Eq. (32), the boiling surface by Eq. (30); the triple line obeys both equations. The sublimation line is the phase equilibrium between vapor and ice.

The validity region (D) is the zero-salinity limit of dilute seawater in the range,

$$S = 0, \quad T_f \leq T \leq 353 \text{ K} \quad \text{and} \quad p^{\text{vap}} \leq p \leq 10^8 \text{ Pa},$$

which is inside the validity range of the IAPWS-95 formulation [3]. In this two-dimensional T - p region (D), outside its intersection with the regions (A), (B) or (C), the salinity derivatives of the Gibbs function, g_S and g_{Sp} , of Table 5 give values extrapolated beyond their validity range. For physical reasons, from $(\partial g^S / \partial S)_{T,p}$ of Table 6, the relative chemical potential, Eq. (25), and the chemical potential of sea salt, Eq. (27), possess logarithmic singularities for $S \rightarrow 0$.

The region (E) is the extrapolation range of liquid pure-water properties beyond their validity range into the solid-phase region, between the freezing temperatures of pure water and of seawater, and into the gas-phase region, between the vapor pressures of pure water and of seawater. For the pure-water reference function, g^W , of Eq. (3), this mathematical extrapolation is required to values of T or p where seawater is a stable liquid phase but pure water is a subcooled or superheated metastable liquid phase. Due to salinity, the freezing-point depression can be up to 8 K, the boiling point elevation up to 2 K.

In the prism-shaped region (F), the numerical extrapolation of the density derivatives g_{Sp} , g_{Tp} and g_{pp} [which appear in Eqs. (13)-(17) and (29)] outside their validity range results in values that are obviously unreasonable or even invalid. For the pressure range $p^{\text{vap}} \leq p \leq 10^8$ Pa, this region is found inside a triangle given by the conditions $T / \text{K} + 450 S / (\text{kg kg}^{-1}) > 362$, $S \leq 0.12 \text{ kg kg}^{-1}$, and $T \leq 353 \text{ K}$. In particular, the use of these derivatives is restricted to $T < 308 \text{ K}$ at the highest salinity, $S = 0.12 \text{ kg kg}^{-1}$, and to $S < 0.02 \text{ kg kg}^{-1}$ at the highest temperature, $T = 353 \text{ K}$.

The logarithmic term of Eq. (4) follows from Planck's theory of ideal solutions. The series expansion of Eq. (4) in terms of the salinity root is consistent with the Debye-Hückel limiting law of dilute electrolytes. In this formulation, both theoretical expressions support the correct description of seawater properties in the limiting case of vanishing salinity.

In several regions of the world's oceans, in particular in coastal waters or estuaries, the composition of the local seawater differs from that of IAPSO Standard Seawater. The related deviation between the directly measured density and the density computed from Eq. (3), based on measured conductivity, is up to 0.005% in the open ocean and up to 0.013% in the Baltic Sea.

This range of validity given here does not consider the solubility of sea salt components such as gypsum (CaSO_4) or lime (CaCO_3) which may become supersaturated or precipitate at a salinity even less than 0.12 kg kg^{-1} . At the time of preparation of this release, saturation concentrations (discussed in [17]) are not sufficiently well known.

This formulation for the thermodynamic properties of seawater was developed in cooperation with the IAPSO/SCOR Working Group 127 on Thermodynamics and Equation of State of Seawater.

7 Estimates of Uncertainty

Combined standard uncertainties u_c reported in the following, estimated directly or indirectly from experimental data, were obtained during the numerical construction of the equation of state and exploiting its inherent consistency. Here, estimated combined standard uncertainties u_c [18] are reported, from which expanded uncertainties $U = k u_c$ can be obtained

by multiplying with the coverage factor $k = 2$, corresponding to a 95% confidence level. The term “uncertainty” used in the following refers to combined standard uncertainties or to relative combined standard uncertainties.

TABLE 7 Summary of estimated combined standard uncertainties of selected quantities in certain regions of the S - T - p space, derived from corresponding experiments

Quantity	S interval kg kg^{-1}	T interval K	p interval 10^6 Pa	Uncertainty value	Unit
$u_c(\rho)/\rho$	0 - 0.04	273 - 313	0.1	4×10^{-6}	
$u_c(\rho)/\rho$	0.04 - 0.05	288 - 303	0.1	1×10^{-5}	
$u_c(\rho)/\rho$	0.005 - 0.04	273 - 313	0.1 - 10	1×10^{-5}	
$u_c(\rho)/\rho$	0.005 - 0.04	273 - 313	10 - 100	2×10^{-5}	
$u_c(\rho)/\rho$	0.04 - 0.12	293 - 313	0.1	3×10^{-4}	
$u_c(\rho)/\rho$	0 - 0.04	313 - 333	0.1	4×10^{-4}	
$u_c(\rho)/\rho$	0.04 - 0.08	313 - 333	0.1	9×10^{-4}	
$u_c(\rho)/\rho$	0 - 0.04	333 - 353	0.1	1.4×10^{-3}	
$u_c(\rho)/\rho$	0.08 - 0.12	313 - 333	0.1	3×10^{-3}	
$u_c(\rho)/\rho$	0.04 - 0.08	333 - 353	0.1	4×10^{-3}	
$u_c(\rho)/\rho$	0.08 - 0.12	333 - 353	0.1	1.3×10^{-2}	
$u_c(\alpha)$	0.01 - 0.03	267 - 274	0.7 - 33	6×10^{-7}	K^{-1}
$u_c(w)/w$	0.029 - 0.043	273 - 308	0.1 - 2	3×10^{-5}	
$u_c(w)/w$	0.029 - 0.043	273 - 303	0.1 - 5	3×10^{-5}	
$u_c(w)/w$	0.033 - 0.037	273 - 278	0.1 - 100	5×10^{-5}	
$u_c(p^{\text{vap}})/p^{\text{vap}}$	0.02 - 0.12	293 - 353	0.002 - 0.05	1×10^{-3}	
$u_c(p^{\text{vap}})/p^{\text{vap}}$	0.018 - 0.04	298	0.003	2×10^{-4}	
$u_c(T_{\text{f}})$	0.004 - 0.04	271 - 273	0.1	2	mK
$u_c(T_{\text{b}})$	0.006 - 0.07	333 - 353	0.02 - 0.05	2	mK
$u_c(\phi)/\phi$	0.004 - 0.04	273	0.1	2×10^{-3}	
$u_c(\phi)/\phi$	0.017 - 0.038	298	0.1	2×10^{-3}	
$u_c(\phi)/\phi$	0.01 - 0.12	273 - 298	0.1	3×10^{-3}	
$u_c(c_p^{\text{S}})$	0 - 0.04	273 - 313	0.1	0.5	$\text{J kg}^{-1} \text{ K}^{-1}$
$u_c(c_p)$	0 - 0.12	273 - 353	0.1	4	$\text{J kg}^{-1} \text{ K}^{-1}$

The fundamental information about the uncertainty of a particular quantity in a certain region of the S - T - p space is adopted from the uncertainties reported or estimated for the most accurate related experimental data.

Density is very well extrapolated by this formulation up to the highest salinity values at low temperatures [19], Fig. 1. In the range of higher salinity and higher temperature at normal pressure, density is described with lower accuracy and quantities computed from its extrapolated derivatives may even be invalid. Due to the lack of experimental data, no statements can be made about the accuracy at high pressures outside the ‘Neptunian’ range of S or T . A summary of estimated combined standard uncertainties of selected quantities in certain regions of the S - T - p space is given in Table 7.

The uncertainty of the salinity scale is $7 \times 10^{-6} \text{ kg kg}^{-1}$, estimated from the uncertainties of relative atomic masses, in particular of chlorine, of the determination of the sea salt constituents, of the conductivity measurements, and of the preparation of IAPSO Standard Seawater samples [9].

8 Computer-Program Verification

To assist the user in computer-program verification, Table 8 with test values is given. It contains values for the specific Gibbs energy, $g(S, T, p)$, together with the corresponding derivatives and some thermodynamic properties. For an easy check of the conversion of the IAPWS-95 Helmholtz function to the related Gibbs function given in Table 4, and of the saline part formulation given in Table 6, the zero-salinity as well as the saline contributions to the particular seawater properties are reported separately in Table 8.

For the computation of the water-part values in Table 8, the coefficients n_1^0 and n_2^0 of the IAPWS-95 formulation were adjusted to realize the reference state conditions at the triple point, Table 1, using a quadruple-precision implementation of IAPWS-95. The adjusted values are $n_1^0 = -8.320\,446\,483\,749\,693$ and $n_2^0 = 6.683\,210\,527\,593\,226$.

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TABLE 8 Numerical check values for the water part computed from g^W and its derivatives, Table 4, for the saline part computed from g^S and its derivatives, Eq. (4), and for the seawater property computed from the Gibbs function $g = g^W + g^S$ and its derivatives, Eq. (3). The numerical functions evaluated here at given points (S, T, p) are defined in Tables 3-6.

a) Properties at $S = S_n = 0.035\ 165\ 04\ \text{kg kg}^{-1}$, $T = T_0 = 273.15\ \text{K}$, $p = p_0 = 101\ 325\ \text{Pa}$

Quantity	Water part	Saline part	Property of seawater	Unit
g	$0.101\ 342\ 742 \times 10^3$	$-0.101\ 342\ 742 \times 10^3$	0.0	J kg^{-1}
$(\partial g/\partial S)_{T,p}$	0.0	$0.639\ 974\ 067 \times 10^5$	$0.639\ 974\ 067 \times 10^5$	J kg^{-1}
$(\partial g/\partial T)_{S,p}$	0.147 643 376	-0.147 643 376	0.0	$\text{J kg}^{-1}\ \text{K}^{-1}$
$(\partial g/\partial p)_{S,T}$	$0.100\ 015\ 694 \times 10^{-2}$	$-0.274\ 957\ 224 \times 10^{-4}$	$0.972\ 661\ 217 \times 10^{-3}$	$\text{m}^3\ \text{kg}^{-1}$
$(\partial^2 g/\partial S \partial p)_T$	0.0	$-0.759\ 615\ 412 \times 10^{-3}$	$-0.759\ 615\ 412 \times 10^{-3}$	$\text{m}^3\ \text{kg}^{-1}$
$(\partial^2 g/\partial T^2)_{S,p}$	$-0.154\ 473\ 542 \times 10^2$	0.852 861 151	$-0.145\ 944\ 931 \times 10^2$	$\text{J kg}^{-1}\ \text{K}^{-2}$
$(\partial^2 g/\partial T \partial p)_S$	$-0.677\ 700\ 318 \times 10^{-7}$	$0.119\ 286\ 787 \times 10^{-6}$	$0.515\ 167\ 556 \times 10^{-7}$	$\text{m}^3\ \text{kg}^{-1}\ \text{K}^{-1}$
$(\partial^2 g/\partial p^2)_{S,T}$	$-0.508\ 928\ 895 \times 10^{-12}$	$0.581\ 535\ 172 \times 10^{-13}$	$-0.450\ 775\ 377 \times 10^{-12}$	$\text{m}^3\ \text{kg}^{-1}\ \text{Pa}^{-1}$
h	$0.610\ 139\ 535 \times 10^2$	$-0.610\ 139\ 535 \times 10^2$	0.0	J kg^{-1}
f	$0.183\ 99 \times 10^{-2}$	$-0.985\ 567\ 377 \times 10^2$	$-0.985\ 548\ 978 \times 10^2$	J kg^{-1}
u	$-0.403\ 269\ 484 \times 10^2$	$-0.582\ 279\ 494 \times 10^2$	$-0.985\ 548\ 978 \times 10^2$	J kg^{-1}
s	-0.147 643 376	0.147 643 376	0.0	$\text{J kg}^{-1}\ \text{K}^{-1}$
ρ	$0.999\ 843\ 086 \times 10^3$	- ^a	$0.102\ 810\ 720 \times 10^4$	kg m^{-3}
c_p	$0.421\ 944\ 481 \times 10^4$	$-0.232\ 959\ 023 \times 10^3$	$0.398\ 648\ 579 \times 10^4$	$\text{J kg}^{-1}\ \text{K}^{-1}$
w	$0.140\ 238\ 253 \times 10^4$	- ^a	$0.144\ 900\ 246 \times 10^4$	m s^{-1}
μ_w	$0.101\ 342\ 742 \times 10^3$	$-0.235\ 181\ 411 \times 10^4$	$-0.225\ 047\ 137 \times 10^4$	J kg^{-1}

^aThis value cannot be computed from g^S alone because it is a nonlinear expression in g

b) Properties at $S = 0.1 \text{ kg kg}^{-1}$, $T = 353 \text{ K}$, $p = p_0 = 101\,325 \text{ Pa}$. This point is located in the regions (C) and (F) of Fig. 1 with restricted validity, Section 6

Quantity	Water part	Saline part	Property of seawater	Unit
g	$-0.446\,114\,969 \times 10^5$	$0.150\,871\,740 \times 10^5$	$-0.295\,243\,229 \times 10^5$	J kg^{-1}
$(\partial g/\partial S)_{T,p}$	0.0	$0.251\,957\,276 \times 10^6$	$0.251\,957\,276 \times 10^6$	J kg^{-1}
$(\partial g/\partial T)_{S,p}$	$-0.107\,375\,993 \times 10^4$	$0.156\,230\,907 \times 10^3$	$-0.917\,529\,024 \times 10^3$	$\text{J kg}^{-1} \text{K}^{-1}$
$(\partial g/\partial p)_{S,T}$	$0.102\,892\,956 \times 10^{-2}$	$-0.579\,227\,286 \times 10^{-4}$	$0.971\,006\,828 \times 10^{-3}$	$\text{m}^3 \text{kg}^{-1}$
$(\partial^2 g/\partial S \partial p)_T$	0.0	$-0.305\,957\,802 \times 10^{-3}$	$-0.305\,957\,802 \times 10^{-3}$	$\text{m}^3 \text{kg}^{-1}$
$(\partial^2 g/\partial T^2)_{S,p}$	$-0.118\,885\,000 \times 10^2$	$0.127\,922\,649 \times 10$	$-0.106\,092\,735 \times 10^2$	$\text{J kg}^{-1} \text{K}^{-2}$
$(\partial^2 g/\partial T \partial p)_S$	$0.659\,051\,552 \times 10^{-6}$	$0.803\,061\,596 \times 10^{-6}$	$0.146\,211\,315 \times 10^{-5}$	$\text{m}^3 \text{kg}^{-1} \text{K}^{-1}$
$(\partial^2 g/\partial p^2)_{S,T}$	$-0.474\,672\,819 \times 10^{-12}$	$0.213\,086\,154 \times 10^{-12}$	$-0.261\,586\,665 \times 10^{-12}$	$\text{m}^3 \text{kg}^{-1} \text{Pa}^{-1}$
h	$0.334\,425\,759 \times 10^6$	$-0.400\,623\,363 \times 10^5$	$0.294\,363\,423 \times 10^6$	J kg^{-1}
f	$-0.447\,157\,532 \times 10^5$	$0.150\,930\,430 \times 10^5$	$-0.296\,227\,102 \times 10^5$	J kg^{-1}
u	$0.334\,321\,503 \times 10^6$	$-0.400\,564\,673 \times 10^5$	$0.294\,265\,035 \times 10^6$	J kg^{-1}
s	$0.107\,375\,993 \times 10^4$	$-0.156\,230\,907 \times 10^3$	$0.917\,529\,024 \times 10^3$	$\text{J kg}^{-1} \text{K}^{-1}$
ρ	$0.971\,883\,832 \times 10^3$	- ^a	$0.102\,985\,888 \times 10^4$	kg m^{-3}
c_p	$0.419\,664\,050 \times 10^4$	$-0.451\,566\,952 \times 10^3$	$0.374\,507\,355 \times 10^4$	$\text{J kg}^{-1} \text{K}^{-1}$
w	$0.155\,446\,297 \times 10^4$	- ^a	$0.396\,127\,835 \times 10^4$	m s^{-1}
μ_w	$-0.446\,114\,969 \times 10^5$	$-0.101\,085\,536 \times 10^5$	$-0.547\,200\,505 \times 10^5$	J kg^{-1}

^aThis value cannot be computed from g^S alone because it is a nonlinear expression in g

c) Properties at $S = S_n = 0.035\,165\,04\text{ kg kg}^{-1}$, $T = T_0 = 273.15\text{ K}$, $p = 10^8\text{ Pa}$

Quantity	Water part	Saline part	Property of seawater	Unit
g	$0.977\,303\,862 \times 10^5$	$-0.260\,093\,051 \times 10^4$	$0.951\,294\,557 \times 10^5$	J kg^{-1}
$(\partial g/\partial S)_{T,p}$	0.0	$-0.545\,861\,581 \times 10^4$	$-0.545\,861\,581 \times 10^4$	J kg^{-1}
$(\partial g/\partial T)_{S,p}$	$0.851\,466\,502 \times 10$	$0.754\,045\,685 \times 10$	$0.160\,551\,219 \times 10^2$	$\text{J kg}^{-1}\text{ K}^{-1}$
$(\partial g/\partial p)_{S,T}$	$0.956\,683\,329 \times 10^{-3}$	$-0.229\,123\,842 \times 10^{-4}$	$0.933\,770\,945 \times 10^{-3}$	$\text{m}^3\text{ kg}^{-1}$
$(\partial^2 g/\partial S\partial p)_T$	0.0	$-0.640\,757\,619 \times 10^{-3}$	$-0.640\,757\,619 \times 10^{-3}$	$\text{m}^3\text{ kg}^{-1}$
$(\partial^2 g/\partial T^2)_{S,p}$	$-0.142\,969\,873 \times 10^2$	0.488 076 974	$-0.138\,089\,104 \times 10^2$	$\text{J kg}^{-1}\text{ K}^{-2}$
$(\partial^2 g/\partial T\partial p)_S$	$0.199\,079\,571 \times 10^{-6}$	$0.466\,284\,412 \times 10^{-7}$	$0.245\,708\,012 \times 10^{-6}$	$\text{m}^3\text{ kg}^{-1}\text{ K}^{-1}$
$(\partial^2 g/\partial p^2)_{S,T}$	$-0.371\,530\,889 \times 10^{-12}$	$0.357\,345\,736 \times 10^{-13}$	$-0.335\,796\,316 \times 10^{-12}$	$\text{m}^3\text{ kg}^{-1}\text{ Pa}^{-1}$
h	$0.954\,046\,055 \times 10^5$	$-0.466\,060\,630 \times 10^4$	$0.907\,439\,992 \times 10^5$	J kg^{-1}
f	$0.206\,205\,330 \times 10^4$	$-0.309\,692\,089 \times 10^3$	$0.175\,236\,121 \times 10^4$	J kg^{-1}
u	$-0.263\,727\,446 \times 10^3$	$-0.236\,936\,788 \times 10^4$	$-0.263\,309\,532 \times 10^4$	J kg^{-1}
s	$-0.851\,466\,502 \times 10$	$-0.754\,045\,685 \times 10$	$-0.160\,551\,219 \times 10^2$	$\text{J kg}^{-1}\text{ K}^{-1}$
ρ	$0.104\,527\,796 \times 10^4$	- ^a	$0.107\,092\,645 \times 10^4$	kg m^{-3}
c_p	$0.390\,522\,209 \times 10^4$	$-0.133\,318\,225 \times 10^3$	$0.377\,190\,387 \times 10^4$	$\text{J kg}^{-1}\text{ K}^{-1}$
w	$0.157\,542\,240 \times 10^4$	- ^a	$0.162\,198\,998 \times 10^4$	m s^{-1}
μ_w	$0.977\,303\,862 \times 10^5$	$-0.240\,897\,806 \times 10^4$	$0.953\,214\,082 \times 10^5$	J kg^{-1}

^aThis value cannot be computed from g^S alone because it is a nonlinear expression in g