KCE

ThermoFluidProperties

Property Library for Ice, Water, and Steam

LibIce

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Property Functions

Property Functions of LibICE

Functional Dependence	Function Name	Fortran Program	Property or Function	Unit of the Result
$a = f(p,t,x)$	a_ptx_ICE	APTXICE(P,T,X)	Thermal diffusivity	m^2/s
$\alpha_v = f(p,t,x)$	alphav_ptx_ICE	ALPHAVPTXICE(P,T,X)	Isobaric cubic expansion coefficient	1/K
$c_p = f(p,t,x)$	cp_ptx_ICE	CPPTXICE(P,T,X)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x)$	cv_ptx_ICE	CVPTXICE(P,T,X)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x)$	eta_ptx_ICE	ETAPTXICE(P,T,X)	Dynamic viscosity (only for liquid and steam)	Pa s
$h = f(p,t,x)$	h_ptx_ICE	HPTXICE(P,T,X)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x)$	kappa_ptx_ICE	KAPPAPTXICE(P,T,X)	Isentropic exponent	-
$\kappa_T = f(p,t,x)$	kappaT_ptx_ICE	KAPPATPTXICE(P,T,X)	Isothermal compressibility	1/kPa
$\lambda = f(p,t,x)$	lambda_ptx_ICE	LAMBDAPTXICE(P,T,X)	Thermal conductivity	W/(m K)
$p_{mel} = f(t)$	pmel_t_08_ICE	PMEL_T_08_ICE(T)	Melting pressure	bar
$p_s = f(t)$	ps_t_97_ICE	PS_T_97_ICE(T)	Vapor pressure	bar
$p_{sub} = f(t)$	psub_t_08_ICE	PSUB_T_08_ICE(T)	Sublimation pressure	bar
$\rho = f(p,t,x)$	rho_ptx_ICE	RHOPTXICE(P,T,X)	Density	kg/m^3

Functional Dependence	Function Name	Fortran Program	Property or Function	Unit of the Result
$s = f(p,t,x)$	s_ptx_ICE	SPTXICE(P,T,X)	Specific entropy	kJ/(kg K)
$t = f(p,h)$	t_ph_ICE	TPHICE(P,H)	Backward function: Temperature from pressure and specific enthalpy	°C
$t = f(p,s)$	t_ps_ICE	TPSICE(P,S)	Backward function: Temperature from pressure and specific entropy	°C
$t_{mel} = f(p)$	tmel_p_08_ICE	TMEL_P_08_ICE(P)	Melting temperature	°C
$t_s = f(p)$	ts_p_97_ICE	TS_P_97_ICE(P)	Saturation temperature	°C
$t_{sub} = f(p)$	tsub_p_08_ICE	TSUB_P_08_ICE(P)	Sublimation temperature	°C
$u = f(p,t,x)$	u_ptx_ICE	UPTXICE(P,T,X)	Specific internal energy	kJ/kg
$v = f(p,t,x)$	v_ptx_ICE	VPTXICE(P,T,X)	Specific volume	m³/kg
$w = f(p,t,x)$	w_ptx_ICE	WPTXICE(P,T,X)	Isentropic speed of sound	m/s
$x = f(p,h)$	x_ph_ICE	XPHICE(P,H)	Backward function: Phase fraction from pressure and specific enthalpy	kg/kg
$x = f(p,s)$	x_ps_ICE	XPSICE(P,S)	Backward function: Phase fraction from pressure and specific entropy	kg/kg

Units: p in bar
t in °C
x in kg/kg (Phase fraction; see description in the following)

Reference State:

h = 0.0006118 kJ/kg and s = 0 kJ/(kg K)
at p_t = 6.11657·10^{-3} bar and t_t = 0.01 °C (273.16 K)

Details on the Phase Fraction x

If the state point to be calculated is located in one of the single phase regions ice, liquid, superheated steam or gas, $x = -1$ must be entered as a pro-forma value. Here the backward functions will result in $x = -1$.

The two phase regions wet stem region, melting region and sublimation region (see log p-h diagram in Chapter 1.2) are divided automatically by the subprograms. Please consider the following facts:

1. Wet Stem Region ($0 \leq x \leq 1$):

The phase fraction x equates to the vapor fraction x in the wet steam region $x = \dfrac{m''}{(m' + m'')}$. Its unit is (kg saturated steam)/(kg wet steam).

When calculating properties of wet steam, a value between 0 and 1 ($x = 0$ for saturated liquid, $x = 1$ for saturated steam) has to be entered for x. In this case, the backward functions result in the appropriate value between 0 and 1 for x.

In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 0 and 1. If values for both p and t are entered when calculating wet steam, the program will consider p and t to be appropriate to represent the vapor pressure curve. If it is not the case the calculation for the quantity of the chosen function results in -1000.

Wet steam region: Temperature ranges from $t_t = 0.01$ °C (273.16 K) to $t_{max} = 350$ °C (623.15 K)

Pressure ranges from $p_t = 6.11657 \cdot 10^{-3}$ bar to p_s $(t_{max}) = 165.291643$ bar

2. Melting Region ($10 \leq x \leq 11$):

The phase fraction x equates to the liquid fraction x in the melting region $x = 10 + \dfrac{m_{liq}}{\left(m_{ice} + m_{liq}\right)}$. Its unit is (kg solidified liquid)/(kg melt), whereas melt is a

mixture of melting ice and solidified liquid.

When calculating properties of the melting region, a value between 10 and 11 ($x = 10$ for melted solid, $x = 11$ for solidified liquid) has to be entered for x. In this case, the backward functions result in the appropriate value between 10 and 11 for x.

In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 10 and 11. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the melting pressure curve. If it is not the case the calculation for the quantity of the chosen function results in -1000.

Melting region: Temperature ranges from $t_{mel}(p_{max}) = -8.9412$ °C (264.2088 K) to $t_t = 0.01$ °C (273.16 K)

Pressure ranges from $p_t = 6.11657 \cdot 10^{-3}$ bar to $p_{max} = 1000$ bar

3. Sublimation Region (100 ≤ x ≤ 101):

The phase fraction x equates to the gas fraction x in the sublimation region $x = 100 + \dfrac{m_{gas}}{\left(m_{ice} + m_{gas}\right)}$. Its unit is (kg desublimated gas)/(kg sublimation powder), whereas sublimation powder is a mixture of sublimated ice and desublimated gas.

When calculating properties of sublimation region, a value between 100 and 101 ($x = 100$ for sublimated ice, $x = 101$ for desublimated gas) has to be entererd for x. In this case, the backward functions result in the appropriate value between 100 and 101 for x.

In this case it is adequate to enter either the given value for t and $p = -1000$, or the given value for p and $t = -1000$, plus the value for x between 100 and 101. If values for both p and t are entered, the program will consider p and t to be appropriate to represent the sublimation pressure curve. If it is not the case the calculation for the quantity of the chosen function results in -1000.

Sublimation region: Temperature ranges from t_{min} = –223.15 °C (50 K) to t_t = 0.01 °C (273.16 K)

Pressure ranges from $p_{min} = p_{sub}(t_{min})$ = $1.9349584868 \cdot 10^{-45}$ bar to p_t = $6.11657 \cdot 10^{-3}$ bar

Note:

If the input values are located outside the range of validity, the calculated function will always result in –1000. Please find more exact details on every function and its corresponding range of validity in the enclosed program documentation in Chapter 3. The same information may also be accessed via the online help pages.

Range of Validity of LibICE

The LibICE property library calculates the thermodynamic and transport properties of ice Ih, water and steam. As shown in the following *p-T* and log *p-h* diagrams, different formulations are used to describe the entire Range of validity of LibICE.
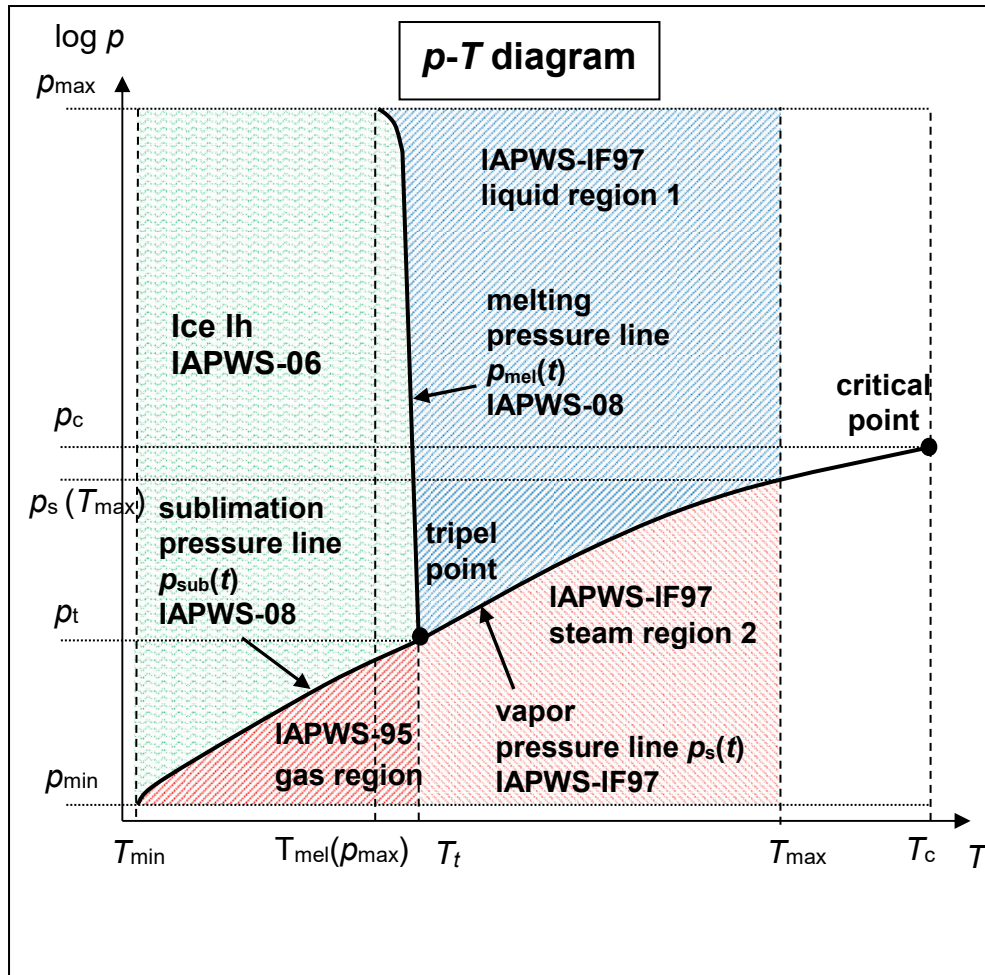
The thermodynamic properties of ice Ih are calculated by the IAPWS Formulation 2006 [7]. This region is marked with green color in the following log *p-T* diagram. This region ranges from minimum pressure to maximum pressure and from minimum temperature to the melting temperature for pressures $p \geq p_{\mathrm{t}}$ and to the sublimation temperature for pressures $p < p_{\mathrm{t}}$. The melting and sublimation pressures are calculated from the IAPWS 2008 Formulation [8].

The liquid-water region ranges from triple point pressure to maximum pressure and from melting temperature to saturation temperature for $p \leq p_{\mathrm{s}}(T_{\max})$ and the maximum temperature for $p > p_{\mathrm{s}}(T_{\max})$. In this region, the fundamental equation of IAPWS-IF97 Region 1 [1,2] is used. This region is marked with blue color in the following *p-T* diagram.

The vapor region covers the range from minimum pressure to saturation pressure and from triple point temperature to the maximum temperature for pressures $p < p_{\mathrm{t}}$ and from saturation temperature to maximum temperature for pressures $p \geq p_{\mathrm{t}}$. The thermodynamic properties are calculated by the fundamental equation of IAPWS-IF97 Region 2 [1,2]. This region is marked with light red color in the following *p-T* diagram.

The red region in the *p-T* diagram is covered by the Scientific Formulation IAPWS-95 [6]. This region covers the range from minimum pressure to the sublimation pressure and from sublimation temperature to the triple point temperature.

For given property values, the region is chosen automatically by the subprograms. The two-phase regions wet steam region, melting region and sublimation region are also chosen automatically.

log p

p-T diagram

IAPWS-IF97
liquid region 1

melting
pressure line
$p_{mel}(t)$
IAPWS-08

critical
point

Ice Ih
IAPWS-06

p_c

$p_s(T_{max})$ sublimation
pressure line
$p_{sub}(t)$
IAPWS-08

tripel
point

IAPWS-IF97
steam region 2

p_t

vapor
pressure line $p_s(t)$
IAPWS-IF97

IAPWS-95
gas region

p_{min}

T_{min} $T_{mel}(p_{max})$ T_t T_{max} T_c T

Values at Important State Points

Property	Variable	Value and Unit
Minimum temperature	T_{min}	50 K (– 223.15 °C)
Maximum temperature	T_{max}	623.15 K (350 °C)
Triple temperature	T_t	273.16 K (0.01 °C)
Temperature at the critical point	T_c	647.096 K (373.946 °C)
Melting temperature at maximum pressure	$T_{mel}(p_{max})$	264.2088 K (–8.9412 °C)
Minimum pressure	$p_{min}=p_{sub}(T_{min})$	$1.9349584868 \cdot 10^{-46}$ MPa
Maximum pressure	p_{max}	100 MPa
Triple pressure	p_t	$6.11657 \cdot 10^{-4}$ MPa
Pressure at the critical point	p_c	22.064 MPa
Vapor pressure at maximum temperature	$p_s(T_{max})$	16.5291643 MPa

log *p-h* diagram

log *p*

p_{max}

melted
solid line
x = 10

solidified
liquid line
x = 11

**IAPWS-IF97
liquid region 1**

T_{max}

critical
point

p_c

$p_s(T_{max})$

saturated
vapor line
x = 1

**Ice Ih
IAPWS-06**

saturated
liquid line
x = 0

T_{min}

melting region
10 < *x* < 11

liquid
triple
state

wet-steam region
0 < *x* < 1

**IAPWS-IF97
steam region 2**

vapor
triple
state

solid
triple
state

p_t

sublimated
solid line
x = 100

**IAPWS-95
gas region**

sublimation region
100 < *x* < 101

desublimated
gas line
x = 101

p_{min}

h