Library of Psychrometric, Thermodynamic, and Transport Properties for *Real* Humid Air, Steam, Water, and Ice
I-P & SI Units

LibHuAirProp

Based on ASHRAE Research Projects RP-1485 and RP-1767

Prepared by

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Part I-P Units

Property Functions – I-P Units

Function Overview for Real Moist Air

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$a = \mathrm{f}(p,t,W)$	a_ptW_HAP_IP	Thermal diffusivity	ft^2/s	3/2
$\alpha_\mathrm{p} = \mathrm{f}(p,t,W)$	alphap_ptW_HAP_IP	Relative pressure coefficient	1/°R	3/3
$\beta_\mathrm{p} = \mathrm{f}(p,t,W)$	betap_ptW_HAP_IP	Isothermal stress coefficient	lb/ft^3	3/4
$c = \mathrm{f}(p,t,W)$	c_ptW_HAP_IP	Speed of sound	ft/s	3/5
$c_p = \mathrm{f}(p,t,W)$	cp_ptW_HAP_IP	Specific isobaric heat capacity	Btu/(lb·°R)	3/6
$c_v = \mathrm{f}(p,t,W)$	cv_ptW_HAP_IP	Specific isochoric heat capacity	Btu/(lb·°R)	3/7
$f = \mathrm{f}(p,t)$	f_pt_HAP_IP	Enhancement factor (decimal ratio)	-	3/8
$h = \mathrm{f}(p,t,W)$	h_ptW_HAP_IP	Air-specific enthalpy	Btu/lb_a	3/9
$\eta = \mathrm{f}(p,t,W)$	Eta_ptW_HAP_IP	Dynamic viscosity	$lb{\cdot}s/ft^2$	3/10
$\kappa = \mathrm{f}(p,t,W)$	Kappa_ptW_HAP_IP	Isentropic exponent	-	3/11
$\lambda = \mathrm{f}(p,t,W)$	Lambda_ptW_HAP_IP	Thermal conductivity	Btu/(h·ft·°R)	3/12
$\nu = \mathrm{f}(p,t,W)$	Ny_ptW_HAP_IP	Kinematic viscosity	ft^2/s	3/13
$p = \mathrm{f}(t,s,W)$	p_tsW_HAP_IP	Pressure of humid air	psi	3/14
$p = \mathrm{f}(z_\mathrm{ele})$	p_zele_HAP_IP	Pressure of humid air from elevation	psi	3/15
$p_\mathrm{Air} = \mathrm{f}(p,t,W)$	pAIR_ptW_HAP_IP	Partial pressure of dry air in moist air	psi	3/16
$p_\mathrm{H2O} = \mathrm{f}(p,t,W)$	pH2O_ptW_HAP_IP	Partial pressure of water vapor in moist air	psi	3/17
$p_\mathrm{H2Os} = \mathrm{f}(p,t)$	pH2Os_pt_HAP_IP	Partial saturation pressure of water vapour in moist air	psi	3/18

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$\varphi = f(p,t,W)$	phi_ptW_HAP_IP	Relative humidity (decimal ratio)	-	3/19
$Pr = f(p,t,W)$	Pr_ptW_HAP_IP	PRANDTL number	-	3/20
$\psi_{Air} = f(W)$	PsiAir_W_HAP_IP	Mole fraction of dry air in moist air	mol_a/mol	3/21
$\psi_{H2O} = f(W)$	PsiH2O_W_HAP_IP	Mole fraction of water vapor in moist air	mol_w/mol	3/22
$\rho = f(p,t,W)$	Rho_ptW_HAP_IP	Density	lb/ft^3	3/23
$s = f(p,t,W)$	s_ptW_HAP_IP	Air-specific entropy	$Btu/(lb_a \cdot °R)$	3/24
$t = f(p,h,\varphi)$	t_phphi_HAP_IP	Backward function: temperature from total pressure, air-specific enthalpy and relative humidity	°F	3/25
$t = f(p,h,W)$	t_phW_HAP_IP	Backward function: temperature from total pressure, enthalpy and humidity ratio	°F	3/26
$t = f(p,s,W)$	t_psW_HAP_IP	Backward function: temperature from total pressure, entropy and humidity ratio	°F	3/27
$t = f(p,t_{wb},W)$	t_ptwbW_HAP_IP	Backward function: temperature from total pressure, wet-bulb temperature and humidity ratio	°F	3/28
$t_d = f(p,W)$	td_pW_HAP_IP	Dew-point/frost-point temperature	°F	3/29
$t_s = f(p,p_{H2O})$	ts_ppH2O_HAP_IP	Backward function: saturation temperature of water from total pressure and partial pressure of water vapor	°F	3/30
$t_{wb} = f(p,t,W)$	twb_ptW_HAP_IP	Wet-bulb/ice-bulb temperature	°F	3/31
$u = f(p,t,W)$	u_ptW_HAP_IP	Air-specific internal energy	Btu/lb_a	3/32
$v = f(p,t,W)$	v_ptW_HAP_IP	Air-specific volume	ft^3/lb_a	3/33
$W = f(p,t,p_{H2O})$	W_ptpH2O_HAP_IP	Humidity ratio from total pressure, temperature, and partial pressure of water vapor	lb_w/lb_a	3/34
$W = f(p,t,\varphi)$	W_ptphi_HAP_IP	Humidity ratio from total pressure, temperature, and relative humidity	lb_w/lb_a	3/35
$W = f(p,t_d)$	W_ptd_HAP_IP	Humidity ratio from total pressure and dew-point temperature	lb_w/lb_a	3/36

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$W = \mathrm{f}(p,t,t_{wb})$	W_pttwb_HAP_IP	Humidity ratio from total pressure, (dry bulb) temperature, and wet-bulb temperature	lb_w/lb_a	3/37
$W_s = \mathrm{f}(p,t)$	Ws_pt_HAP_IP	Saturation humidity ratio	lb_w/lb_a	3/38
$\xi_{Air} = \mathrm{f}(W)$	XiAir_W_HAP_IP	Mass fraction of dry air in moist air	lb_a/lb	3/39
$\xi_{H2O} = \mathrm{f}(W)$	XiH2O_W_HAP_IP	Mass fraction of water vapor in moist air	lb_w/lb	3/40
$Z = \mathrm{f}(p,t,W)$	Z_ptW_HAP_IP	Compression factor (decimal ratio)	-	3/41

Range of Validity of Thermodynamic Properties

Property	Range of Validity					
Pressure:	0.00145	≤	p	≤	1450.4	psi
Temperature:	–225.67	≤	t	≤	662	°F
Humidity ratio:	0	≤	W	≤	10	lb_w/lb_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)
Dew-point temperature:	–225.67	≤	t_d	≤	662	°F
Wet-bulb temperature:	–225.67	≤	t_{wb}	≤	662	°F

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°F
W	Humidity ratio	lb_w/lb_a (lb water / lb dry air)
φ	Relative humidity	(decimal ratio)
t_d	Dew point temperature	°F
t_{wb}	Wet bulb temperature	°F

Range of Validity of Transport Properties

Property	Range of Validity					
Pressure:	0.00145	≤	p	≤	1450.4	psi
Temperature:	–99.67	≤	t	≤	662	°F
Humidity ratio:	0	≤	W	≤	10	lb_w/lb_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)

Molar Masses

Component	Molar Mass	Reference
Dry Air	63.859 lb/kmol	[17]
Water	39.7168998 lb/kmol	[5], [6]

Reference States

Property	Dry Air	Steam, Water, and Ice
Pressure	14.6959 psi	p_s(32.018°F) = 0.088714 psi
Temperature	32°F	32.018°F
Enthalpy	0 Btu/lb	0.00026301926 Btu/lb
Entropy	0 Btu/(lb·°R)	0 Btu/(lb·°R)

Function Overview for Steam and Water for Temperatures $t \geq 32°F$

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$h_{liq} = f(p,t)$	hliq_pt_97_IP	Specific enthalpy of liquid water	Btu/lb	3/43
$h_{liq,s} = f(t)$	hliqs_t_97_IP	Specific enthalpy of saturated liquid water	Btu/lb	3/44
$h_{vap,s} = f(t)$	hvaps_t_97_IP	Specific enthalpy of saturated water vapor	Btu/lb	3/45
$p_s = f(t)$	ps_t_97_IP	Saturation pressure of water	psi	3/46
$s_{liq} = f(p,t)$	sliq_pt_97_IP	Specific entropy of liquid water	Btu/(lb·°R)	3/47
$s_{liq,s} = f(t)$	sliqs_t_97_IP	Specific entropy of saturated liquid water	Btu/(lb·°R)	3/48
$s_{vap,s} = f(t)$	svaps_t_97_IP	Specific entropy of saturated water vapor	Btu/(lb·°R)	3/49
$t_s = f(p)$	ts_p_97_IP	Saturation temperature of water	°F	3/50
$v_{liq} = f(p,t)$	vliq_pt_97_IP	Specific volume of liquid water	ft³/lb	3/51
$v_{liq,s} = f(t)$	vliqs_t_97_IP	Specific volume of saturated liquid water	ft³/lb	3/52
$v_{vap,s} = f(t)$	vvaps_t_97_IP	Specific volume of saturated water vapor	ft³/lb	3/53

Range of Validity

Property	Range of Validity					
Pressure:	0.00145	≤	p	≤	1450.4	psi
Temperature:	32	≤	t	≤	662	°F

Reference State

Property	Water Vapor and Liquid Water
Pressure	p_s(32.018°F) = 0.088714 psi
Temperature	32.018°F
Enthalpy	0.00026301926 Btu/lb
Entropy	0 Btu/(lb·°R)

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°F

Function Overview for Steam and Ice for Temperatures $t \leq 32$°F

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{ice,sub} = f(t)$	hicesub_t_06_IP	Specific enthalpy of saturated ice	Btu/lb	3/55
$h_{vap,sub} = f(t)$	hvapsub_t_95_IP	Specific enthalpy of saturated water vapor	Btu/lb	3/56
$p_{mel} = f(t)$	pmel_t_08_IP	Melting pressure of ice	psi	3/57
$p_{sub} = f(t)$	psub_t_08_IP	Sublimation pressure of ice	psi	3/58
$s_{ice,sub} = f(t)$	sicesub_t_06_IP	Specific entropy of saturated ice	Btu/(lb·°R)	3/59
$s_{vap,sub} = f(t)$	svapsub_t_95_IP	Specific entropy of saturated water vapor	Btu/(lb·°R)	3/60
$t_{mel} = f(p)$	tmel_p_08_IP	Melting temperature of ice	°F	3/61
$t_{sub} = f(p)$	tsub_p_08_IP	Sublimation temperature of ice	°F	3/62
$v_{ice,sub} = f(t)$	vicesub_t_06_IP	Specific volume of saturated ice	ft^3/lb	3/63
$v_{vap,sub} = f(t)$	vvapsub_t_95_IP	Specific volume of saturated water vapor	ft^3/lb	3/64

Range of Validity

Property	Range of Validity					
Pressure:	p_{sub}(–225.67°F) = 1.7407E-12	≤	*p*	≤	1450.4	psi
Temperature:	–225.67	≤	*t*	≤	32	°F

Units

Symbol	Quantity	Unit
p	Pressure	psi
t	Temperature	°F

Reference State

Property	Water Vapor and Ice
Pressure	p_s(32.018°F) = 0.088714 psi
Temperature	32.018°F
Enthalpy	0.00026301926 Btu/lb
Entropy	0 Btu/(lb·°R)

Calculation Algorithms

Algorithms for Real Moist Air

The properties of moist air are calculated from the modified Hyland-Wexler model given in Herrmann, Kretzschmar, and Gatley (HKG) [1], [2]. The modifications incorporate:

- the value for the universal molar gas constant from the CODATA standard by Mohr and Taylor [22]
- the value for the molar mass of dry air from Gatley et al. [17] and that of water from IAPWS-95 [5], [6]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for dry air from the fundamental equation of Lemmon et al. [14]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for water vapor from IAPWS-IF97 [7], [8], [9] for $t \geq 32°\text{F}$ and from IAPWS-95 [5], [6] for $t \leq 32°\text{F}$
- the calculation of the vapor-pressure enhancement factor from the equation given by the models of Hyland and Wexler [21]
- the calculation of the second and third molar virial coefficients B_{aa} and C_{aaa} for dry air from the fundamental equation of Lemmon et al. [14] according to Feistel et al. [24]
- the calculation of the second and third molar virial coefficients B_{ww} and C_{www} for water and steam from IAPWS-95 [5], [6] according to Feistel et al. [24]
- the calculation of the air-water second molar cross-virial coefficient B_{aw} from Harvey and Huang [15]
- the calculation of the air-water third molar cross-virial coefficients C_{aaw} and C_{aww} from Nelson and Sauer [12], [13]
- the calculation of the saturation pressure of water from IAPWS-IF97 [7], [8], [9] for $t \geq 32°\text{F}$ and of the sublimation pressure of water from IAPWS-08 [11] for $t \leq 32°\text{F}$
- the calculation of the isothermal compressibility of saturated liquid water from IAPWS-IF97 [7], [8], [9] for $t \geq 32°\text{F}$ and that of ice from IAPWS-06 [10] for $t \leq 32°\text{F}$ in the determination of the vapor-pressure enhancement factor
- the calculation of Henry's constant from the IAPWS Guideline 2004 [16] in the determination of the enhancement factor. The mole fractions for the three main components of dry air were taken from Lemmon et al. [14]. Argon was not considered in the calculation of Henry’s constant in the former research projects, but it is now the third component of dry air.

The transport properties of moist air are calculated from the model given in Herrmann et al. [3], [4].

Algorithms for Steam and Water for Temperatures *t* ≥ 32°F

The *p*-*T* diagram in Fig. 1 shows the formulations used for water and water vapor. The temperature range above 32°F is covered by IAPWS-IF97 [7], [8], [9]:

- The saturation line is calculated from the IAPWS-IF97 saturation pressure equation $p_s^{97}(t)$ and saturation temperature equation $t_s^{97}(p)$.
- The properties in the liquid region including saturated-liquid line are calculated from the fundamental equation of the IAPWS-IF97 region 1.
- The properties in the vapor region including saturated-vapor line are calculated from the fundamental equation of the IAPWS-IF97 region 2.

Algorithms for Steam and Ice for Temperatures *t* ≤ 32°F

- The sublimation curve is covered by the IAPWS-08 sublimation pressure equation $p_{subl}^{08}(t)$ [11] (see Fig. 1).
- The properties of ice including saturated ice are determined by the fundamental equation of the IAPWS-06 [10].
- The properties of vapor including saturated vapor are calculated from the fundamental equation of IAPWS-95 [5], [6].

Overview of the Applied Formulations for Steam, Water, and Ice

The following *p*-*T* diagram shows the used IAPWS Formulations and the ranges where they are applied.

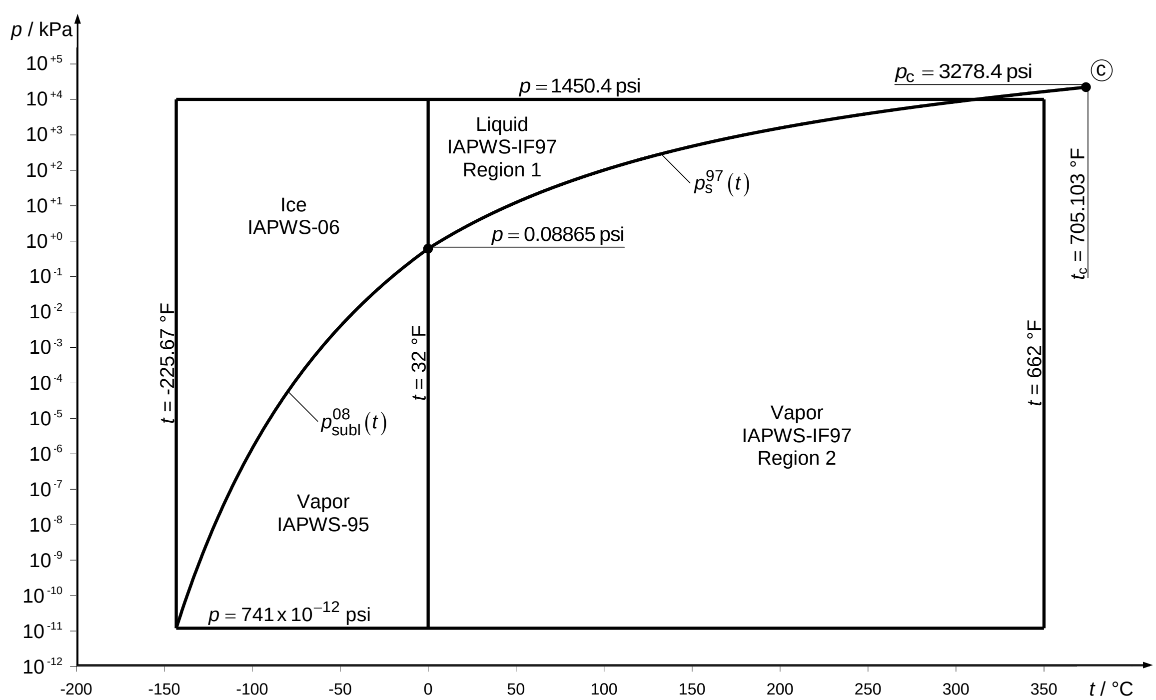

Figure 1: *p*-*T* diagram with used IAPWS formulations for steam, water, and ice.

Part SI Units

Property Functions – SI Units

Function Overview for Real Moist Air

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$a = \mathrm{f}(p,t,W)$	a_ptW_HAP_SI	Thermal diffusivity	m^2/s	3/2
$\alpha_p = \mathrm{f}(p,t,W)$	alphap_ptW_HAP_SI	Relative pressure coefficient	1/K	3/3
$\beta_p = \mathrm{f}(p,t,W)$	betap_ptW_HAP_SI	Isothermal stress coefficient	kg/m^3	3/4
$c = \mathrm{f}(p,t,W)$	c_ptW_HAP_SI	Speed of sound	m/s	3/5
$c_p = \mathrm{f}(p,t,W)$	cp_ptW_HAP_SI	Specific isobaric heat capacity	kJ/(kg·K)	3/6
$c_v = \mathrm{f}(p,t,W)$	cv_ptW_HAP_SI	Specific isochoric heat capacity	kJ/(kg·K)	3/7
$f = \mathrm{f}(p,t)$	f_pt_HAP_SI	Enhancement factor (decimal ratio)	-	3/8
$h = \mathrm{f}(p,t,W)$	h_ptW_HAP_SI	Air-specific enthalpy	kJ/kg_a	3/9
$\eta = \mathrm{f}(p,t,W)$	Eta_ptW_HAP_SI	Dynamic viscosity	Pa·s	3/10
$\kappa = \mathrm{f}(p,t,W)$	Kappa_ptW_HAP_SI	Isentropic exponent	-	3/11
$\lambda = \mathrm{f}(p,t,W)$	Lambda_ptW_HAP_SI	Thermal conductivity	W/(m·K)	3/12
$\nu = \mathrm{f}(p,t,W)$	Ny_ptW_HAP_SI	Kinematic viscosity	m^2/s	3/13
$p = \mathrm{f}(t,s,W)$	p_tsW_HAP_SI	Pressure of humid air	kPa	3/14
$p = \mathrm{f}(z_{\mathrm{ele}})$	p_zele_HAP_SI	Pressure of humid air from elevation	kPa	3/15
$p_{\mathrm{Air}} = \mathrm{f}(p,t,W)$	pAIR_ptW_HAP_SI	Partial pressure of dry air in moist air	kPa	3/16
$p_{\mathrm{H2O}} = \mathrm{f}(p,t,W)$	pH2O_ptW_HAP_SI	Partial pressure of water vapor in moist air	kPa	3/17
$p_{\mathrm{H2Os}} = \mathrm{f}(p,t)$	pH2Os_pt_HAP_SI	Partial saturation pressure of water vapor	kPa	3/18

Functional Dependence	Function Name	Property or Function	Unit of the Result	Page
$\varphi = f(p,t,W)$	phi_ptW_HAP_SI	Relative humidity (decimal ratio)	-	3/19
$Pr = f(p,t,W)$	Pr_ptW_HAP_SI	PRANDTL number	-	3/20
$\psi_{Air} = f(W)$	PsiAir_W_HAP_SI	Mole fraction of dry air in moist air	mol_a/mol	3/21
$\psi_{H2O} = f(W)$	PsiH2O_W_HAP_SI	Mole fraction of water vapor in moist air	mol_w/mol	3/22
$\rho = f(p,t,W)$	Rho_ptW_HAP_SI	Density	kg/m^3	3/23
$s = f(p,t,W)$	s_ptW_HAP_SI	Air-specific entropy	$kJ/(kg_a \cdot K)$	3/24
$t = f(p,h,\varphi)$	t_phphi_HAP_SI	Backward function: temperature from total pressure, air-specific enthalpy and relative humidity	°C	3/25
$t = f(p,h,W)$	t_phW_HAP_SI	Backward function: temperature from total pressure, air-specific enthalpy and humidity ratio	°C	3/26
$t = f(p,s,W)$	t_psW_HAP_SI	Backward function: temperature from total pressure, air-specific entropy and humidity ratio	°C	3/27
$t = f(p,t_{wb},W)$	t_ptwbW_HAP_SI	Backward function: temperature from total pressure, wet-bulb temperature and humidity ratio	°C	3/28
$t_d = f(p,W)$	td_pW_HAP_SI	Dew-point/frost-point temperature	°C	3/29
$t_s = f(p,p_{H2O})$	ts_ppH2O_HAP_SI	Backward function: saturation temperature of water from total pressure and partial pressure of water vapor	°C	3/30
$t_{wb} = f(p,t,W)$	twb_ptW_HAP_SI	Wet-bulb/ice-bulb temperature	°C	3/31
$u = f(p,t,W)$	u_ptW_HAP_SI	Air-specific internal energy	kJ/kg_a	3/32
$v = f(p,t,W)$	v_ptW_HAP_SI	Air-specific volume	m^3/kg_a	3/33
$W = f(p,t,p_{H2O})$	W_ptpH2O_HAP_SI	Humidity ratio from total pressure, temperature, and partial pressure of water vapor	kg_w/kg_a	3/34
$W = f(p,t,\varphi)$	W_ptphi_HAP_SI	Humidity ratio from total pressure, temperature, and relative humidity	kg_w/kg_a	3/35
$W = f(p,t_d)$	W_ptd_HAP_SI	Humidity ratio from total pressure and dew-point temperature	kg_w/kg_a	3/36

Functional Dependence	**Function Name**	**Property or Function**	**Unit of the Result**	**Page**
$W = \mathrm{f}(p,t,t_{\mathrm{wb}})$	W_pttwb_HAP_SI	Humidity ratio from total pressure, (dry bulb) temperature, and wet-bulb temperature	kg_w/kg_a	3/37
$W_{\mathrm{s}} = \mathrm{f}(p,t)$	Ws_pt_HAP_SI	Saturation humidity ratio	kg_w/kg_a	3/38
$\xi_{\mathrm{Air}} = \mathrm{f}(W)$	XiAir_W_HAP_SI	Mass fraction of dry air in moist air	kg_a/kg	3/39
$\xi_{\mathrm{H2O}} = \mathrm{f}(W)$	XiH2O_W_HAP_SI	Mass fraction of water vapor in moist air	kg_w/kg	3/40
$Z = \mathrm{f}(p,t,W)$	Z_ptW_HAP_SI	Compression factor (decimal ratio)	-	3/41

Range of Validity of Thermodynamic Properties

Property	Range of Validity					
Pressure:	0.01	≤	p	≤	10 000	kPa
Temperature:	–143.15	≤	t	≤	350	°C
Humidity ratio:	0	≤	W	≤	10	kg_w/kg_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)
Dew-point temperature:	–143.15	≤	t_d	≤	350	°C
Wet-bulb temperature:	–143.15	≤	t_{wb}	≤	350	°C

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C
W	Humidity ratio	kg_w/kg_a (kg water / kg dry air)
φ	Relative humidity	(decimal ratio)
t_d	Dew point temperature	°C
t_{wb}	Wet bulb temperature	°C

Range of Validity of Transport Properties

Property	Range of Validity					
Pressure:	0.01	≤	p	≤	10 000	kPa
Temperature:	–73.15	≤	t	≤	350	°C
Humidity ratio:	0	≤	W	≤	10	kg_w/kg_a
Relative humidity:	0	≤	φ	≤	1	(decimal ratio)

Molar Masses

Component	Molar Mass	Reference
Dry Air	28.966 kg/kmol	[17]
Water	18.015268 kg/kmol	[5], [6]

Reference States

Property	Dry Air	Steam, Water, and Ice
Pressure	101.325 kPa	p_s(0.01°C) = 0.611657 kPa
Temperature	0°C	0.01°C
Enthalpy	0 kJ/kg	0.000611782 kJ/kg
Entropy	0 kJ/(kg K)	0 kJ/(kg K)

Function Overview for Steam and Water for Temperatures $t \geq 0°C$

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{liq} = f(p,t)$	hliq_pt_97_SI	Specific enthalpy of liquid water	kJ/kg	3/43
$h_{liq,s} = f(t)$	hliqs_t_97_SI	Specific enthalpy of saturated liquid water	kJ/kg	3/44
$h_{vap,s} = f(t)$	hvaps_t_97_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/45
$p_s = f(t)$	ps_t_97_SI	Saturation pressure of water	kPa	3/46
$s_{liq} = f(p,t)$	sliq_pt_97_SI	Specific entropy of liquid water	kJ/(kg·K)	3/47
$s_{liq,s} = f(t)$	sliqs_t_97_SI	Specific entropy of saturated liquid water	kJ/(kg·K)	3/48
$s_{vap,s} = f(t)$	svaps_t_97_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/49
$t_s = f(p)$	ts_p_97_SI	Saturation temperature of water	°C	3/50
$v_{liq} = f(p,t)$	vliq_pt_97_SI	Specific volume of liquid water	m^3/kg	3/51
$v_{liq,s} = f(t)$	vliqs_t_97_SI	Specific volume of saturated liquid water	m^3/kg	3/52
$v_{vap,s} = f(t)$	vvaps_t_97_SI	Specific volume of saturated water vapor	m^3/kg	3/53

Range of Validity

Property	Range of Validity
Pressure:	$0.01 \le p \le 10\,000$ kPa
Temperature:	$0 \le t \le 350$ °C

Reference State

Property	Water Vapor and Liquid Water
Pressure	p_s(0.01°C) = 0.611657 kPa
Temperature	0.01°C
Enthalpy	0.000611782 kJ/kg
Entropy	0 kJ/(kg K)

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C

Function Overview for Steam and Ice for Temperatures $t \leq 0°C$

Functional Dependence	Function Name	Property	Unit of the Result	Page
$h_{ice,sub} = f(t)$	hicesub_t_06_SI	Specific enthalpy of saturated ice	kJ/kg	3/55
$h_{vap,sub} = f(t)$	hvapsub_t_95_SI	Specific enthalpy of saturated water vapor	kJ/kg	3/56
$p_{mel} = f(t)$	pmel_t_08_SI	Melting pressure of ice	kPa	3/57
$p_{sub} = f(t)$	psub_t_08_SI	Sublimation pressure of ice	kPa	3/58
$s_{ice,sub} = f(t)$	sicesub_t_06_SI	Specific entropy of saturated ice	kJ/(kg·K)	3/59
$s_{vap,sub} = f(t)$	svapsub_t_95_SI	Specific entropy of saturated water vapor	kJ/(kg·K)	3/60
$t_{mel} = f(p)$	tmel_p_08_SI	Melting temperature of ice	°C	3/61
$t_{sub} = f(p)$	tsub_p_08_SI	Sublimation temperature of ice	°C	3/62
$v_{ice,sub} = f(t)$	vicesub_t_06_SI	Specific volume of saturated ice	m³/kg	3/63
$v_{vap,sub} = f(t)$	vvapsub_t_95_SI	Specific volume of saturated water vapor	m³/kg	3/64

Range of Validity

Property	Range of Validity
Pressure:	$p_{sub}(-143.15°C) = 1.2002 \times 10^{-11} \le p \le 10\,000$ kPa
Temperature:	$-143.15 \le t \le 0$ °C

Units

Symbol	Quantity	Unit
p	Pressure	kPa
t	Temperature	°C

Reference State

Property	Water Vapor and Ice
Pressure	$p_s(0.01°C) = 0.611657$ kPa
Temperature	0.01°C
Enthalpy	0.000611782 kJ/kg
Entropy	0 kJ/(kg K)

Calculation Algorithms

Algorithms for Real Moist Air

The properties of moist air are calculated from the modified Hyland-Wexler model given in Herrmann, Kretzschmar, and Gatley (HKG) [1], [2]. The modifications incorporate:

- the value for the universal molar gas constant from the CODATA standard by Mohr and Taylor [22]
- the value for the molar mass of dry air from Gatley et al. [17] and that of water from IAPWS-95 [5], [6]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for dry air from the fundamental equation of Lemmon et al. [14]
- the calculation of the ideal-gas parts of the heat capacity, enthalpy, and entropy for water vapor from IAPWS-IF97 [7], [8], [9] for $t \geq 0°C$ and from IAPWS-95 [5], [6] for $t \leq 0°C$
- the calculation of the vapor-pressure enhancement factor from the equation given by the models of Hyland and Wexler [21]
- the calculation of the second and third molar virial coefficients B_{aa} and C_{aaa} for dry air from the fundamental equation of Lemmon et al. [14] according to Feistel et al. [24]
- the calculation of the second and third molar virial coefficients B_{ww} and C_{www} for water and steam from IAPWS-95 [5], [6] according to Feistel et al. [24]
- the calculation of the air-water second molar cross-virial coefficient B_{aw} from Harvey and Huang [15]
- the calculation of the air-water third molar cross-virial coefficients C_{aaw} and C_{aww} from Nelson and Sauer [12], [13]
- the calculation of the saturation pressure of water from IAPWS-IF97 [7], [8], [9] for $t \geq 0°C$ and of the sublimation pressure of water from IAPWS-08 [11] for $t \leq 0°C$
- the calculation of the isothermal compressibility of saturated liquid water from IAPWS-IF97 [7], [8], [9] for $t \geq 0°C$ and that of ice from IAPWS-06 [10] for $t \leq 0°C$ in the determination of the vapor-pressure enhancement factor
- the calculation of Henry's constant from the IAPWS Guideline 2004 [16] in the determination of the enhancement factor. The mole fractions for the three main components of dry air were taken from Lemmon et al. [14]. Argon was not considered in the calculation of Henry's constant in the former research projects, but it is now the third component of dry air.

The transport properties of moist air are calculated from the model given in Herrmann et al. [3], [4].

Algorithms for Steam and Water for Temperatures $t \geq 0°C$

The *p-T* diagram in Fig. 1 shows the formulations used for water and water vapor. The temperature range above 0°C is covered by IAPWS-IF97 [7], [8], [9]:

- The saturation line is calculated from the IAPWS-IF97 saturation pressure equation $p_s^{97}(t)$ and saturation temperature equation $t_s^{97}(p)$.
- The properties in the liquid region including saturated-liquid line are calculated from the fundamental equation of the IAPWS-IF97 region 1.
- The properties in the vapor region including saturated-vapor line are calculated from the fundamental equation of the IAPWS-IF97 region 2.

Algorithms for Steam and Ice for Temperatures $t \leq 0°C$

- The sublimation curve is covered by the IAPWS-08 sublimation pressure equation $p_{subl}^{08}(t)$ [11] (see Fig. 1).
- The properties of ice including saturated ice are determined by the fundamental equation of the IAPWS-06 [10].
- The properties of vapor including saturated vapor are calculated from the fundamental equation of IAPWS-95 [5], [6].

Overview of the Applied Formulations for Steam, Water, and Ice

The following *p-T* diagram shows the used IAPWS Formulations and the ranges where they are applied.

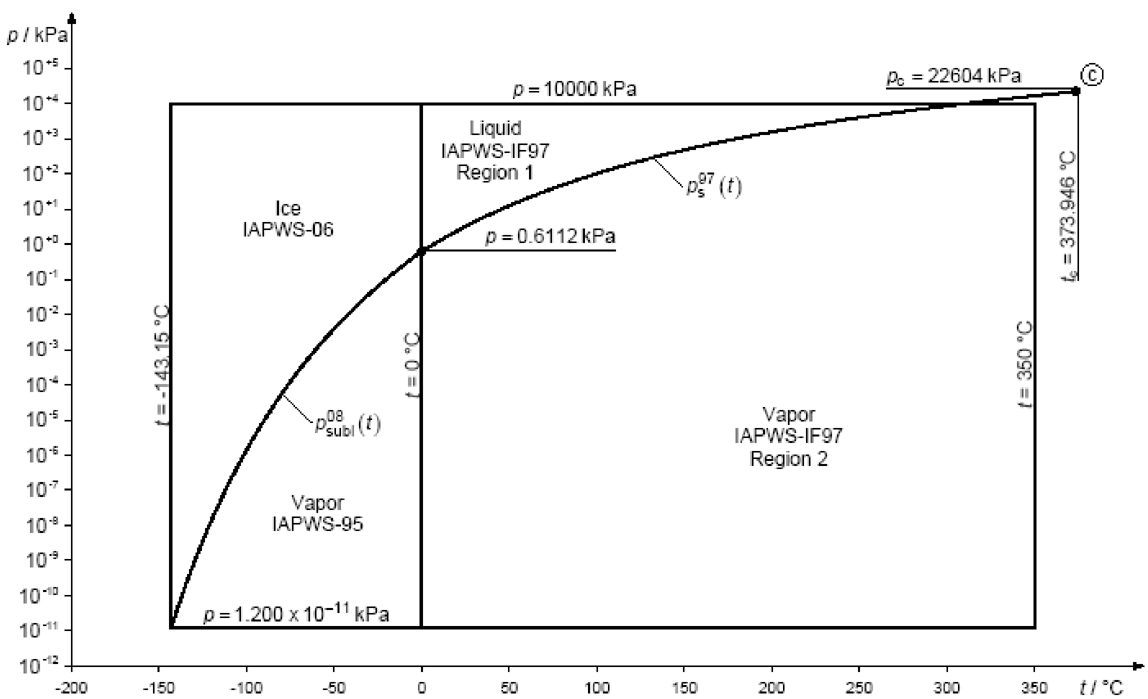

Figure 1: *p-T* diagram with used IAPWS formulations for steam, water, and ice.