

# Property Library for Hydrogen

## LibH2

Prof. Hans-Joachim Kretzschmar  
Dr. Sebastian Herrmann  
Prof. Matthias Kunick  
Ines Jaehne

## Property Functions

Functional Dependence	Function Name	Call from Fortran program	Property or Function	Unit of the result
$a = f(p,t,x,NP)$	a_ptx_H2	APTXH2(P,T,X,NP)	Thermal diffusivity	m <sup>2</sup> /s
$c_p = f(p,t,x,NP)$	cp_ptx_H2	CPPTXH2(P,T,X,NP)	Specific isobaric heat capacity	kJ/(kg K)
$c_v = f(p,t,x,NP)$	cp_ptx_H2	CVPTXH2(P,T,X,NP)	Specific isochoric heat capacity	kJ/(kg K)
$\eta = f(p,t,x,NP)$	eta_ptx_H2	ETAPTXH2(P,T,X,NP)	Dynamic viscosity	Pa s
$h = f(p,t,x,NP)$	h_ptx_H2	HPTXH2(P,T,X,NP)	Specific enthalpy	kJ/kg
$\kappa = f(p,t,x,NP)$	kappa_ptx_H2	KAPPTXH2(P,T,X,NP)	Isentropic exponent	-
$\lambda = f(p,t,x,NP)$	lambda_ptx_H2	LAMPTXH2(P,T,X,NP)	Thermal conductivity	W/(m K)
$\nu = f(p,t,x,NP)$	ny_ptx_H2	NYPTXH2(P,T,X,NP)	Kinematic viscosity	m <sup>2</sup> /s
$p_{mel} = f(t,NP)$	pmel_t_H2	PMELTH2(T,NP)	Melting pressure from temperature	bar
$p_s = f(t,NP)$	ps_t_H2	PSTH2(T,NP)	Vapor pressure from temperature	bar
$Pr = f(p,t,x,NP)$	Pr_ptx_H2	PRPTXH2(P,T,X,NP)	Prandtl-Number	-
$\rho = f(p,t,x,NP)$	rho_ptx_H2	RHOPTXH2(P,T,X,NP)	Density	kg/m <sup>3</sup>
$s = f(p,t,x,NP)$	s_ptx_H2	SPTXH2(P,T,X,NP)	Specific entropy	kJ/(kg K)
$t = f(p,h,NP)$	t_ph_H2	TPHH2(P,H,NP)	Backward function: Temperature from pressure and enthalpy	°C
$t = f(p,s,NP)$	t_ps_H2	TPSH2(P,S,NP)	Backward function: Temperature from pressure and entropy	°C
$t_{mel} = f(p,NP)$	tmel_p_H2	TMELPH2(P,NP)	Melting temperature from pressure	°C
$t_s = f(p,NP)$	ts_p_H2	TSPH2(P,NP)	Boiling temperature from pressure	°C
$u = f(p,t,x,NP)$	u_ptx_H2	UPTXH2(P,T,X,NP)	Internal energy	kJ/kg
$v = f(p,t,x,NP)$	v_ptx_H2	VPTXH2(P,T,X,NP)	Specific volume	m <sup>3</sup> /kg
$w = f(p,t,x,NP)$	w_ptx_H2	WPTXH2(P,T,X,NP)	Isentropic speed of sound	m/s <sup>2</sup>
$x = f(p,h,NP)$	x_ph_H2	XPHH2(P,H,NP)	Backward function: Vapor fraction from pressure and enthalpy	kg/kg
$x = f(p,s,NP)$	x_ps_H2	XPSH2(P,S,NP)	Backward function: Vapor fraction from pressure and entropy	kg/kg
$z = f(p,t,x,NP)$	z_ptx_H2	ZPTXH2(P,T,X,NP)	Compression factor	-

**Units:**  $t$  in °C  
 $p$  in bar  
 $x$  in (kg of saturated steam)/(kg wet steam)  
 NP is a non-dimensional parameter

### Hints for the parameter NP

Hydrogen can be calculated as H<sub>2</sub>-Normal and H<sub>2</sub>-Para. The form is specified by the parameter NP.

The parameter NP can take the following values: NP = 1, for H<sub>2</sub>-Normal,  
 NP = 0, for H<sub>2</sub>-Para.

### Details on the vapor fraction $x$

The wet steam region is calculated automatically by the subprograms. For this purpose the following fixed details on the vapor fraction  $x$  are to be considered:

If the state point to be calculated is located in the single-phase region (liquid or superheated steam)  $x = -1$  must be entered as a pro-forma value.

If the state point to be calculated is located in the two phase region (wet steam), either the value 0 or 1 has to be entered for  $x$  ( $x = 0$  for boiling liquid,  $x = 1$  for saturated steam). Here the backward functions will result in  $x = 0$  or  $x = 1$ .

If the state point to be calculated is located in the two phase region, 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. When calculating wet steam and  $p$  and  $t$  and  $x$  are entered as given values, the program will consider  $p$  and  $t$  to be appropriate to represent the saturation-pressure curve. If it is not the case the calculation for the quantity of the chosen function to be calculated results in  $-1000$ .

Wet steam region:

H<sub>2</sub>-Para (NP = 0): Temperature range from  $t_t = -259.35$  °C to  $t_c = -240.212$  °C  
 Pressure range from  $p_t = 0.0703991859$  bar to  $p_c = 12.837878$  bar

H<sub>2</sub>-Normal (NP = 1): Temperature range from  $t_t = -259,193$  °C to  $t_c = -240.212$  °C  
 Pressure range from  $p_t = 0.0770478607$  bar to  $p_c = 12.837878$  bar

### Range of validity

Temperature range:

H<sub>2</sub>-Para (NP = 0):

from  $t_{\text{mel}}(p)$  or  $t_{\text{min}} = t(p, \rho_{\text{max}})$  to 726.85 °C at  $p \geq p_t = 0.0703991859$  bar,

with  $\rho_{\text{max}} = 44.0$  mol/l ( $v_{\text{min}} = 0.0112737843$  m<sup>3</sup>/kg)

from  $t_{\text{trip}} = -259.35$  °C to 726.85 °C at  $p \leq p_t = 0.0703991859$  bar

H<sub>2</sub>-Normal (NP = 1):

from  $t_{\text{mel}}(p)$  or  $t_{\text{min}} = t(p, \rho_{\text{max}})$  to 726.85 °C at  $p \geq p_t = 0.0770478607$  bar,

with  $\rho_{\text{max}} = 38.148$  mol/l ( $v_{\text{min}} = 0.0130032114$  m<sup>3</sup>/kg)

from  $t_{\text{trip}} = -259.193$  °C to 726.85 °C at  $p \leq p_t = 0.0770478607$  bar

Pressure range: from 0.001 bar to 1210 bar

### Specifications for calculating the state variables of hydrogen

The calculation of the state variables of H<sub>2</sub>-Normal und H<sub>2</sub>-Para is based upon the following approximations:

- The specific volume  $v = f(p, t)$  for H<sub>2</sub>-Normal is also calculated according to the equation of H<sub>2</sub>-Para from Younglove [22].
- The equation of vapor pressure from Lemmon [24] for H<sub>2</sub>-Para is also used for H<sub>2</sub>-Normal.
- The same critical point is taken for H<sub>2</sub>-Normal and H<sub>2</sub>-Para:  $p_c = 12.837878$  bar,  $t_c = -240.212$  °C.
- An equation of the melting pressure  $p_{\text{mel}} = f(t)$  for H<sub>2</sub>-Normal does not exist. The calculable range of state of H<sub>2</sub>-Normal is determined by the maximum molar density  $\rho_{\text{max}} = 38.148$  mol/l. This corresponds to a minimum specific volume of  $v_{\text{min}} = 0.01300321$  m<sup>3</sup>/kg.
- The range of validity of the equation of state of H<sub>2</sub>-Para is confined by the maximum molar density  $\rho_{\text{max}} = 44.0$  mol/l. This corresponds to a minimum specific volume of  $v_{\text{min}} = 0.0112737843$  m<sup>3</sup>/kg.

The calculation of the state variables H<sub>2</sub>-Normal and H<sub>2</sub>-Para varies only in the different equations of the isobaric heat capacity of the ideal gas.

**Reference state**

$$h = 0 \text{ and } s = 0$$

$$\text{at } p = 1.01325 \text{ bar}$$

$$\text{and } t = -252.8731 \text{ }^\circ\text{C}$$

**Hint!**

*If the calculation results in  $-1000$ , the values entered represent a state point beyond the range of validity of LibH2. For further information on each function and its range of validity see Chapter 3. The same information may also be accessed via the online help pages.*