2.7 n-Hydrogen

Equations for thermodynamic properties have been cited from reference [1], one for surface tension from Miller et al.[2], and those for viscosity and thermal conductivity from reference [3].

2.7.1 Temperature Scale

International practical temperature scale 1968 (IPTS-1968)

2.7.2 The Names of Substance, Library File and Single Shot Program

Name of Substance:	n-Hydrogen
Library File for UNIX:	libjh2.a
Library File for DOS,Windows95/NT:	JH2.LIB
Single Shot Program for UNIX:	h2-ss
Single Shot Program for DOS,Windows95/NT:	H2–SS.EXE

2.7.3 Important Constants and Others

Molecular Formula:	n-H_2
Relative Molecular Mass:	2.016
Gas Constant:	4124.62 J/(kg·K)

Critical Constants:

Critical Pressure:	1.315×10^6Pa (13.15 bar)
Critical Temperature:	33.19 K (−239.96°C)
Critical Specific Volume:	0.0332 m^3/kg

Triple Point:

Pressure:	7.199×10^3 Pa (0.07199 bar)
Temperature:	13.96 K (−259.19°C)

Reference State:

At 1.01325 bar(1 atm) and 25.01°C(298.16 K), 142.196 J/(mol·K) and 8.473×10^3 J/mol are assigned to the specific entropy and the specific enthalpy, respectively.

2.7.4 Formula

Equation of State:

Equations (4.8) and (4.14) in a function form of $P = P(\rho, T)$ in reference [1]. Here P=pressure, ρ=density and T=temperature.

Vapor Pressure:

Equation (4.14) and Table 31 in reference [1].

Properties on Bubble-Point Curve:

Equation (7.2) in reference [1].

Properties at Vapor-Liquid Equilibrium:

saturated liquid: Equation (8.1) and Table 31 for specific volume, equation (4.14) and Table 19 for specific entropy and for specific enthalpy.

saturated liquid: Equations (4.14) and (4.15) and Table 19 for specific volume. Equations (5.1) and (5.3) for the calculation of specific entropy and specific enthalpy. Equations (5.7) and (5.8) for isochoric specific heat and isobaric specific heat.

All of these have been cited from reference [1].

Transport Properties:
Thermal conductivity and viscosity from reference [3].

The Other Properties:
Surface tension from reference [2].

References

[1] Wooly, H.W., Scott, R.B. and Brickwedde, F.C., Compilation of Thermal Properties of Hydrogen in Its Various Isotopic and Ortho-Para Modifications, J. Res. Nat. Bur. Stand., vol.41, (1948), pp.379–475.
[2] J.W. Miller, Jr. and C.L. Yaws, Chemical Engineering, vol.83, No.23, (1976), p.127.
[3] RC–72 Committee Report, Japan Society of Mechanical Engineers, (1987), pp.527–531.

Table II–2.7–1 n−Hydrogen Function

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
1	AIPPT(P,T)		
94	AJTPT(P,T)		
8A	AKPD(P)		
8B	AKPDD(P)		
82	AKPT(P,T)	AKPT: Isentropic Exponent [–] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $273.15\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $0\leq T\leq400$ [°C]
8C	AKTD(T)		
8D	AKTDD(T)		
2	ALAPP(P)	ALAPP: Laplace Coefficient [m] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
3	ALAPT(T)	ALAPT: Laplace Coefficient [m] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
4	ALHP(P)	ALHP: Latent Heat of Vaporization [J/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
5	ALHT(T)	ALHT: Latent Heat of Vaporization [J/kg] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
6	ALMPD(P)		
7	ALMPDD(P)		
8	ALMPT(P,T)	ALMPT: Thermal Conductivity [W/(m·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $273.15\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $0\leq T\leq400$ [°C]
9	ALMTD(T)		
10	ALMTDD(T)		
11	AMUPD(P)		
12	AMUPDD(P)		
13	AMUPT(P,T)	AMUPT: Coefficient of Viscosity [Pa·s] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $273.15\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $0\leq T\leq400$ [°C]
14	AMUTD(T)		
15	AMUTDD(T)		
92	BPPT(P,T)		
90	BSPT(P,T)		
91	BTPT(P,T)		
93	BVPT(P,T)		
16	CPPD(P)		
17	CPPDD(P)		
18	CPPT(P,T)	CPPT: Isobaric Specific Heat [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $56\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $-217.15\leq T\leq400$ [°C]
19	CPTD(T)		
20	CPTDD(T)		
21	CRP('A')	CRP: Critical Constants H: 'A'='H': 0.86902×10^6 [J/kg] Specific Enthalpy P∗: 'A'='P': 1.3152×10^6 [Pa], 13.152 [bar] Pressure S: 'A'='S': 44.760×10^3 [J/(kg·K)] Specific Entropy T∗: 'A'='T': 33.19 [K], −239.96 [°C] Temperature V: 'A'='V': 33.20×10^{-3} [m^3/kg] Specific Volume	one of 'H', 'P', 'S', 'T' and 'V'
7A	CVPD(P)		
76	CVPDD(P)		

Table II–2.7–1 n−Hydrogen Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
77	CVPT(P,T)	CVPT: Isochoric Specific Heat [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $56\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $-217.15\leq T\leq400$ [°C]
7B	CVTD(T)		
78	CVTDD(T)		
2A	EPSPD(P)		
2B	EPSPDD(P)		
22	EPSPT(P,T)		
2C	EPSTD(T)		
2D	EPSTDD(T)		
89	FC('A')	FC: Fundamental Constants M: 'A'='M': 2.016 Relative Molecular Mass R: 'A'='R': 4124.62 [J/(kg·K)] Gas Constant	one of 'M' and 'R'
9A	GAMPD(P)		
96	GAMPDD(P)		
95	GAMPT(P,T)		
9B	GAMTD(T)		
97	GAMTDD(T)		
23	HPD(P)	HPD: Specific Enthalpy of Saturated Liquid [J/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
24	HPDD(P)	HPDD: Specific Enthalpy of Saturated Vapor [J/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
71	HPS(P,S)	HPS: Specific Enthalpy [J/kg] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] SPT(P,13.96K)≤S≤ SPT(P,673.15K) [J/(kg·K)] $0.07199\leq P\leq500$ [bar] SPT(P,−259.19°C)≤S≤ SPT(P,400°C) [J/(kg·K)]
25	HPT(P,T)	HPT: Specific Enthalpy [J/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $13.96\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $-259.19\leq T\leq400$ [°C]
26	HPX(P,X)	HPX: Specific Enthalpy of Mixture [J/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar] $0\leq X\leq1.0$ [–]
27	HTD(T)	HTD: Specific Enthalpy of Saturated Liquid [J/kg] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
28	HTDD(T)	HTDD: Specific Enthalpy of Saturated Vapor [J/kg] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
29	HTX(T,X)	HTX: Specific Enthalpy of Mixture [J/kg] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C] $0\leq X\leq1.0$ [–]
84	IDENTF('A')	IDENTF: CHARACTER TYPE FUNCTION for Package Identification (Length 20) C: 'A'='C': 'N-H2' Molecular Formula S: 'A'='S': 'N-HYDROGEN' Name of Substance V: 'A'='V': '10.1' Version Number	one of 'C', 'S' and 'V'
66	PLDT(T)		
68	PMLT(T)		
85	PRPD(P)		
86	PRPDD(P)		

Table II–2.7–1 n−Hydrogen Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
81	PRPT(P,T)	PRPT: Prandtl Number [–] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $273.15\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $0\leq T\leq400$ [°C]
87	PRTD(T)		
88	PRTDD(T)		
99	PSBT(T)		
30	PST(T)	PST∗: Saturation Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
72	PSTD(T)		
73	PSTDD(T)		
31	SIGP(P)	SIGP: Surface Tension [N/m] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
32	SIGT(T)	SIGT: Surface Tension [N/m] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
33	SPD(P)	SPD: Specific Entropy of Saturated Liquid [J/(kg·K)] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
34	SPDD(P)	SPDD: Specific Entropy of Saturated Vapor [J/(kg·K)] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar]
35	SPT(P,T)	SPT: Specific Entropy [J/(kg·K)] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] $13.96\leq T\leq673.15$ [K] $0.07199\leq P\leq500$ [bar] $-259.19\leq T\leq400$ [°C]
36	SPX(P,X)	SPX: Specific Entropy of Mixture [J/(kg·K)] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] $0.07199\leq P\leq13.152$ [bar] $0\leq X\leq1.0$ [–]
37	STD(T)	STD: Specific Entropy of Saturated Liquid [J/(kg·K)] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
38	STDD(T)	STDD: Specific Entropy of Saturated Vapor [J/(kg·K)] T∗: Temperature [K], [°C]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C]
39	STX(T,X)	STX: Specific Entropy of Mixture [J/(kg·K)] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	$13.96\leq T\leq33.19$ [K] $-259.19\leq T\leq-239.96$ [°C] $0\leq X\leq1.0$ [–]
67	TLDP(P)		
69	TMLP(P)		
64	TPH(P,H)	TPH∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] H: Specific Enthalpy [J/kg]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] HPT(P,13.96K)≤H≤ HPT(P,673.15K) [J/kg] $0.07199\leq P\leq500$ [bar] HPT(P,−259.19°C)≤H≤ HPT(P,400°C) [J/kg]
6H	TPH2(P,H)		
65	TPS(P,S)	TPS∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] S: Specific Entropy [J/(kg·K)]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] SPT(P,13.96K)≤S≤ SPT(P,673.15K) [J/(kg·K)] $0.07199\leq P\leq500$ [bar] SPT(P,−259.19°C)≤S≤ SPT(P,400°C) [J/(kg·K)]

Table II–2.7–1 n−Hydrogen Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
6S	TPS2(P,S)		
98	TPSEUP(P)		
70	TPV(P,V)	TPV∗: Temperature [K], [°C] P∗: Pressure [Pa], [bar] V: Specific Volume [m^3/kg]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] VPT(P,13.96K)≤V≤ VPT(P,673.15K) [m^3/kg] 0.07199≤P≤500 [bar] VPT(P,−259.19°C)≤V≤ VPT(P,400°C) [m^3/kg]
41	TRPL('A')	TRPL∗: Properties at Triple Point P∗: 'A'='P': 7.199×10^3 [Pa], 0.07199 [bar] Pressure T∗: 'A'='T': 13.96 [K], −259.19 [°C] Temperature	one of 'P' and 'T'
100	TSBP(P)		
40	TSP(P)	TSP∗: Saturation Temperature [K], [°C] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar]
74	TSPD(P)		
75	TSPDD(P)		
42	UPD(P)	UPD: Specific Internal Energy of Saturated Liquid [J/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar]
43	UPDD(P)	UPDD: Specific Internal Energy of Saturated Vapor [J/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar]
79	UPS(P,S)		
44	UPT(P,T)	UPT: Specific Internal Energy [J/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] 13.96≤T≤673.15 [K] 0.07199≤P≤500 [bar] −259.19≤T≤400 [°C]
45	UPX(P,X)	UPX: Specific Internal Energy of Mixture [J/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar] 0≤X≤1.0 [–]
46	UTD(T)	UTD: Specific Internal Energy of Saturated Liquid [J/kg] T∗: Temperature [K], [°C]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C]
47	UTDD(T)	UTDD: Specific Internal Energy of Saturated Vapor [J/kg] T∗: Temperature [K], [°C]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C]
48	UTX(T,X)	UTX: Specific Internal Energy of Mixture [J/kg] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C] 0≤X≤1.0 [–]
49	VPD(P)	VPD: Specific Volume of Saturated Liquid [m^3/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar]
50	VPDD(P)	VPDD: Specific Volume of Saturated Vapor [m^3/kg] P∗: Pressure [Pa], [bar]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar]
80	VPS(P,S)		
51	VPT(P,T)	VPT: Specific Volume [m^3/kg] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	$7.199\times10^3\leq P\leq50\times10^6$ [Pa] 13.96≤T≤673.15 [K] 0.07199≤P≤500 [bar] −259.19≤T≤400 [°C]
52	VPX(P,X)	VPX: Specific Volume of Mixture [m^3/kg] P∗: Pressure [Pa], [bar] X: Dryness Fraction [–]	$7.199\times10^3\leq P\leq1.3152\times10^6$ [Pa] 0.07199≤P≤13.152 [bar] 0≤X≤1.0 [–]

Table II–2.7–1 n−Hydrogen Function (cont'd)

No.	Name of Function	Function and Argument(s)	Range of Argument(s)
53	VTD(T)	VTD: Specific Volume of Saturated Liquid [m^3/kg] T∗: Temperature [K], [°C]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C]
54	VTDD(T)	VTDD: Specific Volume of Saturated Vapor [m^3/kg] T∗: Temperature [K], [°C]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C]
55	VTX(T,X)	VTX: Specific Volume of Mixture [m^3/kg] T∗: Temperature [K], [°C] X: Dryness Fraction [–]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C] 0≤X≤1.0 [–]
8E	WPD(P)		
8F	WPDD(P)		
83	WPT(P,T)	WPT: Velocity of Sound [m/s] P∗: Pressure [Pa], [bar] T∗: Temperature [K], [°C]	7.199×10^3≤P≤50×10^6 [Pa] 273.15≤T≤673.15 [K] 0.07199≤P≤500 [bar] 0≤T≤400 [°C]
8G	WTD(T)		
8H	WTDD(T)		
56	XPH(P,H)	XPH: Dryness Fraction [–] P∗: Pressure [Pa], [bar] H: Specific Enthalpy of Mixture [J/kg]	7.199×10^3≤P≤1.3152×10^6 [Pa] 0.07199≤P≤13.152 [bar] HPD(P)≤H≤HPDD(P) [J/kg]
57	XPS(P,S)	XPS: Dryness Fraction [–] P∗: Pressure [Pa], [bar] S: Specific Entropy of Mixture [J/(kg·K)]	7.199×10^3≤P≤1.3152×10^6 [Pa] 0.07199≤P≤13.152 [bar] SPD(P)≤S≤SPDD(P) [J/(kg·K)]
58	XPU(P,U)	XPU: Dryness Fraction [–] P∗: Pressure [Pa], [bar] U: Specific Internal Energy of Mixture [J/kg]	7.199×10^3≤P≤1.3152×10^6 [Pa] 0.07199≤P≤13.152 [bar] UPD(P)≤U≤UPDD(P) [J/kg]
59	XPV(P,V)	XPV: Dryness Fraction [–] P∗: Pressure [Pa], [bar] V: Specific Volume of Mixture [m^3/kg]	7.199×10^3≤P≤1.3152×10^6 [Pa] 0.07199≤P≤13.152 [bar] VPD(P)≤V≤VPDD(P) [m^3/kg]
60	XTH(T,H)	XTH: Dryness Fraction [–] T∗: Temperature [K], [°C] H: Specific Enthalpy of Mixture [J/kg]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C] HTD(T)≤H≤HTDD(T) [J/kg]
61	XTS(T,S)	XTS: Dryness Fraction [–] T∗: Temperature [K], [°C] S: Specific Entropy of Mixture [J/(kg·K)]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C] STD(T)≤S≤STDD(T) [J/(kg·K)]
62	XTU(T,U)	XTU: Dryness Fraction [–] T∗: Temperature [K], [°C] U: Specific Internal Energy of Mixture [J/kg]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C] UTD(T)≤U≤UTDD(T) [J/kg]
63	XTV(T,V)	XTV: Dryness Fraction [–] T∗: Temperature [K], [°C] V: Specific Volume of Mixture [m^3/kg]	13.96≤T≤33.19 [K] −259.19≤T ≤−239.96 [°C] VTD(T)≤V≤VTDD(T) [m^3/kg]