Thermodynamic Properties are Measurements

p,T,v, u ,h,s - measure directly

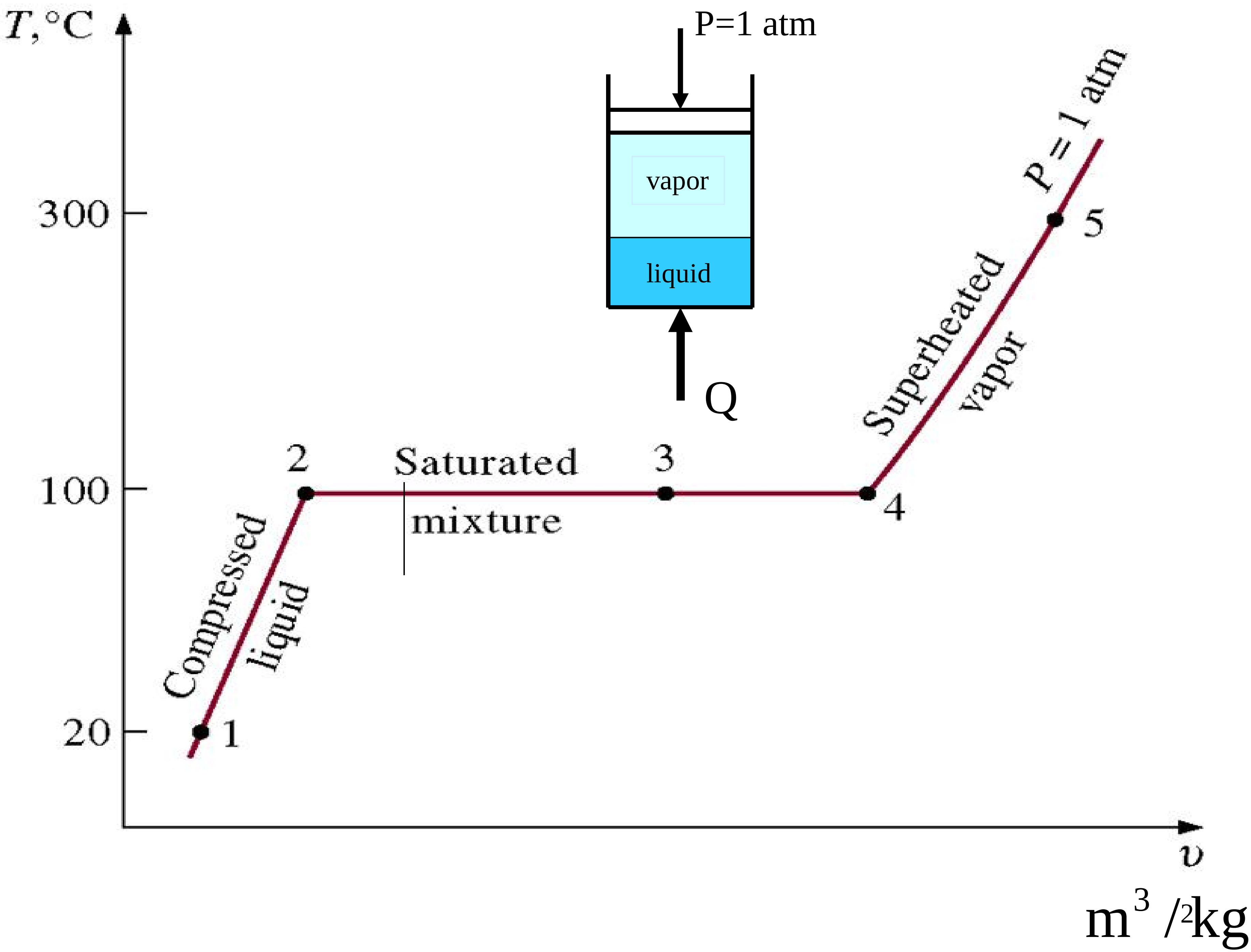
-measure by change $\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial p}{\partial T}\right)_v$

Property Data → Tables

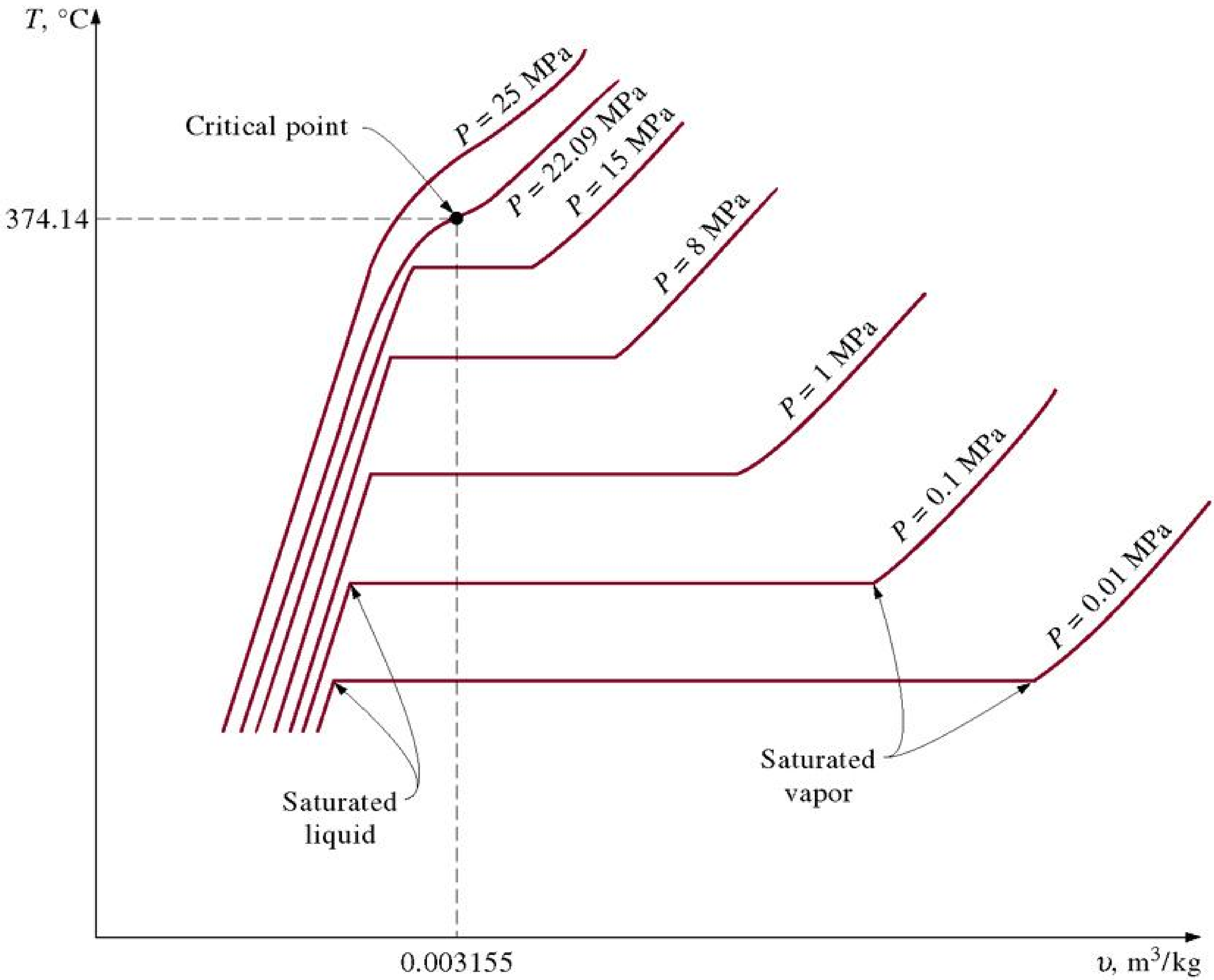
Property Data → Curve fits → Tables

Property Data → Correlation's, Boyles Law pv=c @ T=c → Tables; → limited hand calculations

Property Data → Equations of State, pv=RT → Tables; → Calculation Modules NIST, EES, HYSYM interactive, callable



T, °C
300
100
20
P=1 atm
vapor
liquid
Q
1
2
3
4
5
Compressed liquid
Saturated mixture
Superheated vapor
P = 1 atm
υ
m3 /2kg



T, °C
374.14
Critical point
P = 25 MPa
P = 22.09 MPa
P = 15 MPa
P = 8 MPa
P = 1 MPa
P = 0.1 MPa
P = 0.01 MPa
Saturated liquid
Saturated vapor
0.003155
υ, m³/kg

Given T and P

Super Heat Region if,

$P < P_{sat}$

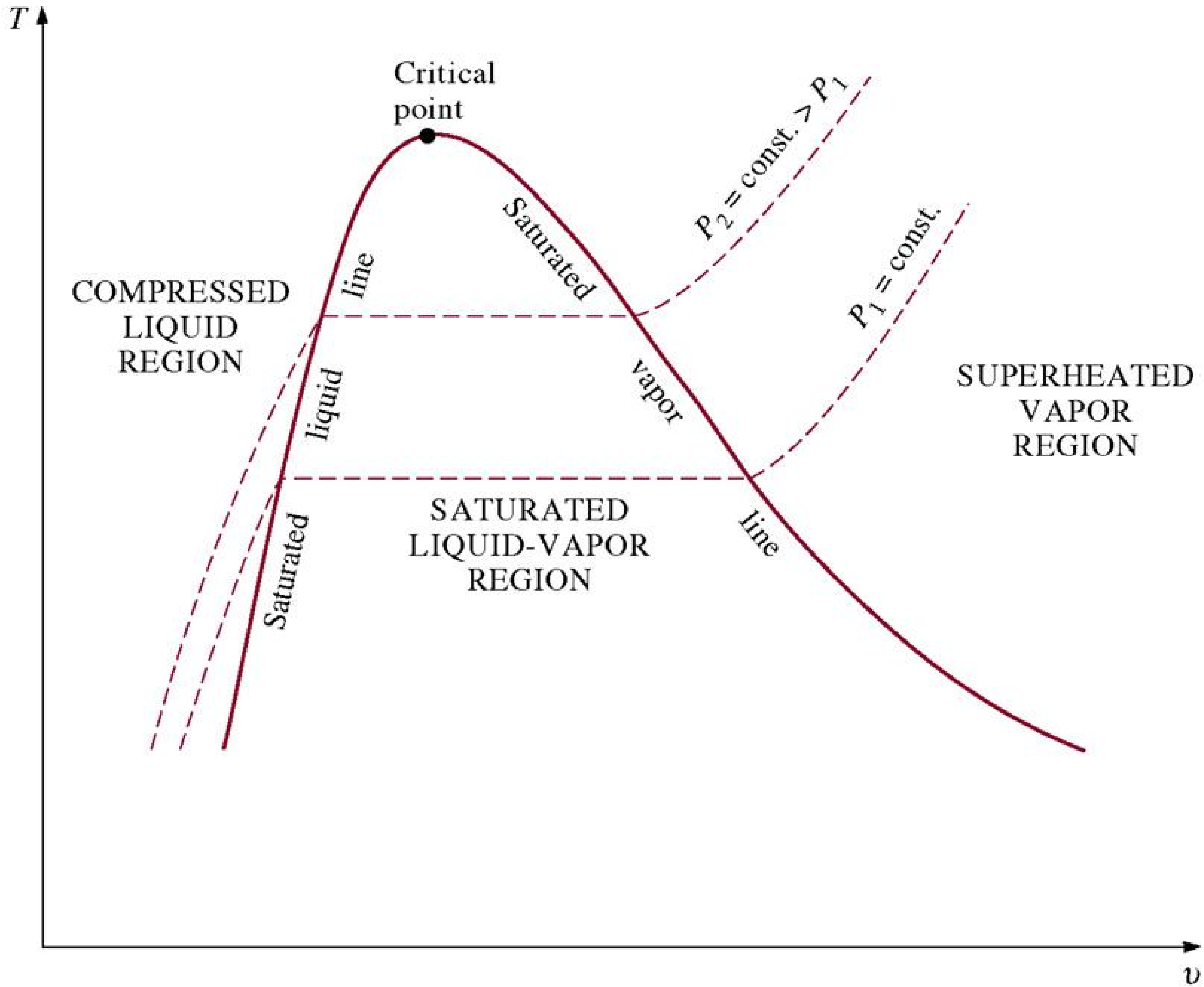
$T > T_{sat}$

Compressed

Liquid Region if,

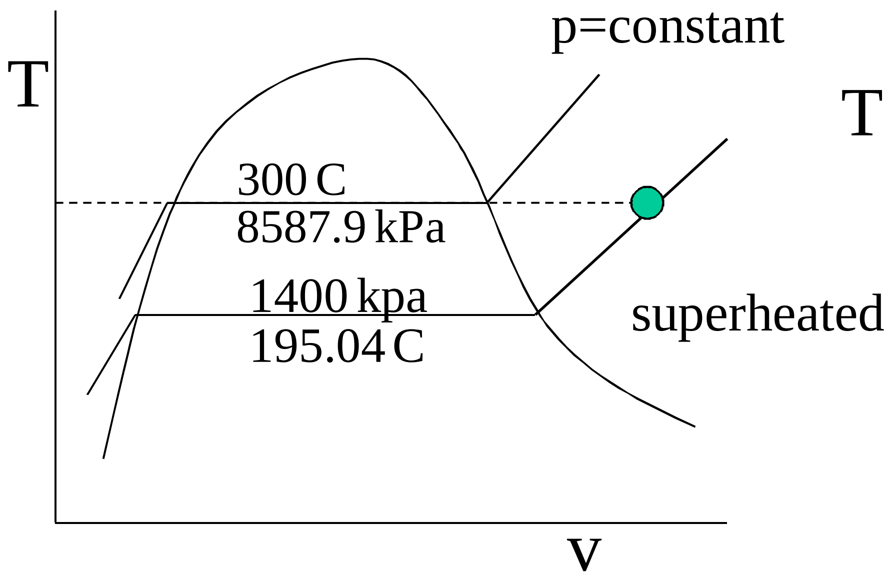
$P > P_{sat}$

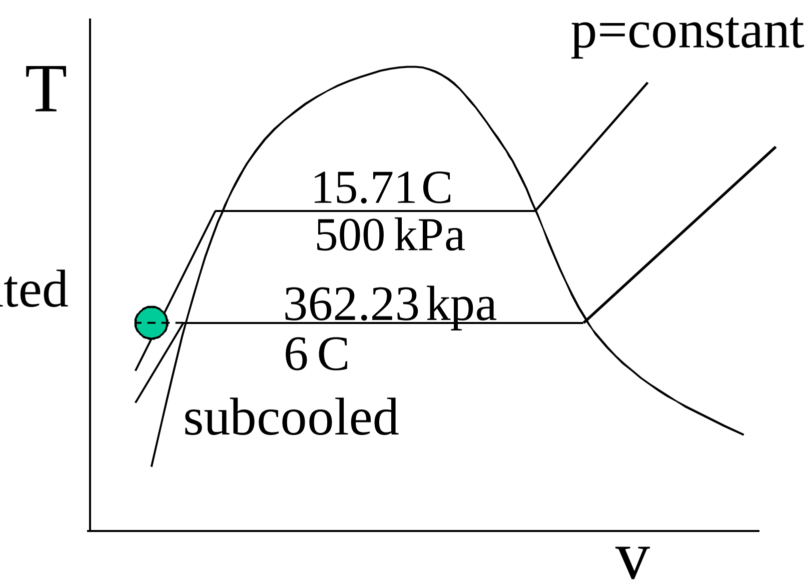
$T < T_{sat}$

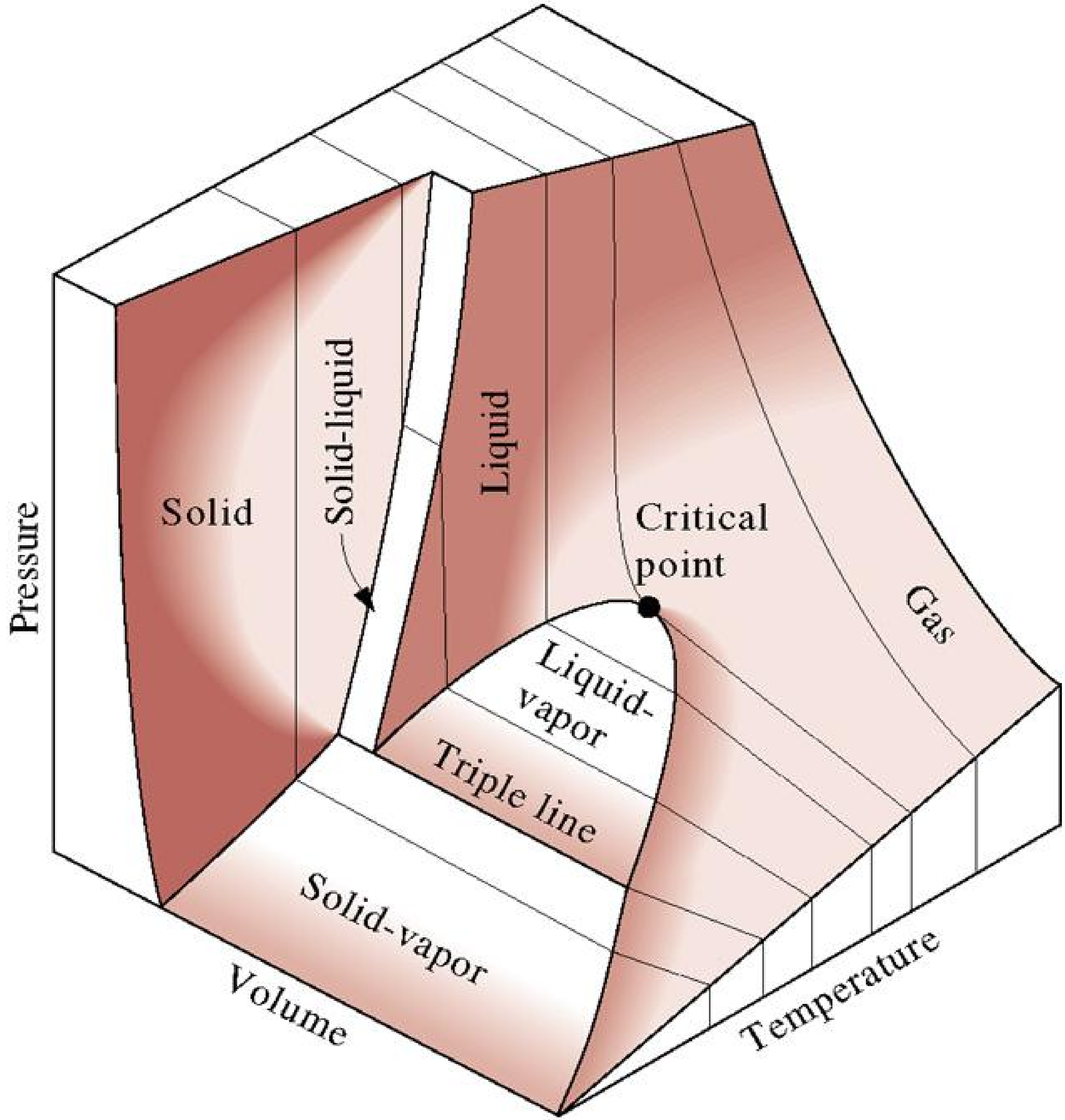


$$\text{water at } 1400 \text{ kpa and } 300 \text{ C}$$
$$T_{saturation} @ 1400 \text{ kpa} = 195.04 \text{ C}$$
$$p_{saturation} @ 300 \text{ C} = 8587.9 \text{ kPa}$$

$$\text{R} - 134\text{a at } 500 \text{ kPa and } 6 \text{ C}$$
$$T_{saturation} @ 500 \text{ kpa} = 15.71 \text{ C}$$
$$p_{saturation} @ 6 \text{ C} = 362.23 \text{ kpa}$$







Pressure
Solid
Solid-liquid
Liquid
Critical
point
Gas
Liquid-
vapor
Triple line
Solid-vapor
Volume
Temperature

Three Tables

- Temperature Table
  at spaced Tôs
- Pressure Table
  at spaced Pôs
- Superheat Table
  at spaced T and P

6 Properties

Temperature
Pressure
Volume
Internal Energy
Enthalpy
Entropy

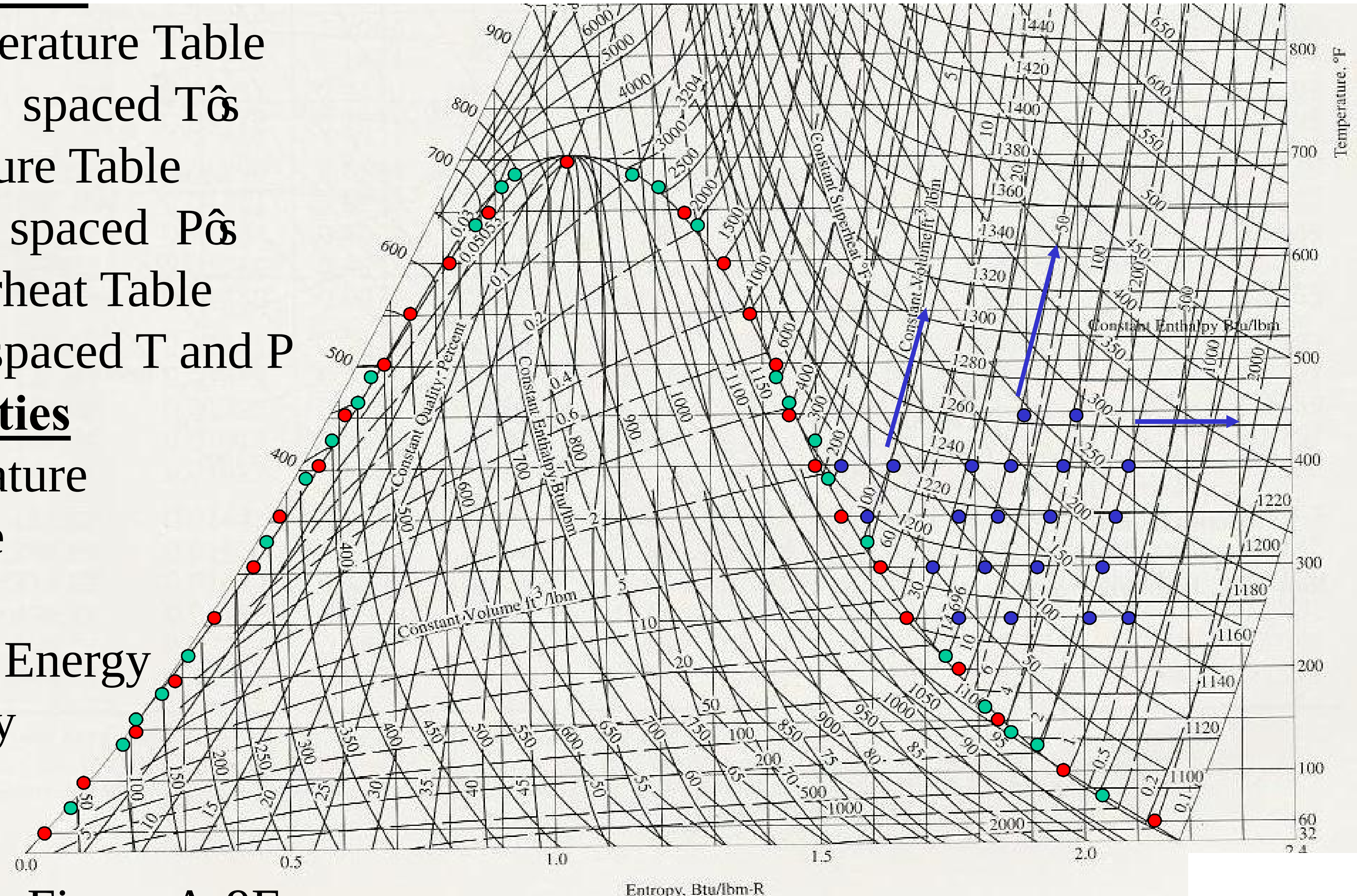


Figure A-9E

T-s diagram for water. [*Source:* Joseph H. Keenan, Frederick G. Keyes, Philip G. Hill, and Joan G. Moore, *Steam Tables* (New York: John Wiley & Sons, 1969).]

TEMPERATURE TABLE

Saturation properties only as a function of temperature

TABLE A–4

Saturated water—Temperature table

		Specific volume, m³/kg		*Internal energy, kJ/kg*			*Enthalpy, kJ/kg*			*Entropy, kJ/kg · K*		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296

PRESSURE TABLE

saturation properties only as a function of pressure

TABLE A–5

Saturated water—Pressure table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9	0.8320	7.0752	7.9073
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5	0.8932	6.9370	7.8302
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6	0.9441	6.8234	7.7675
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1	1.0261	6.6430	7.6691

TABLE A–4

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg: Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg · K: Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661

Saturation liquid internal energy at .01 C. — 0. kJ/kg Table Base

Saturation vapor internal energy at 15 C. — 2395.5 kJ/kg

Saturation vapor entropy at 10 C. — 8.8999 kJ/kg K

Enthalpy at 5 C, 1 bar

<u>approximate</u> saturated liquid enthalpy at 5 C — 21.020 kJ/kg

Temperature of saturated vapor at 2381.8 kJ/kg internal energy. — 5 C

Enthalpy of vaporization at 5 C — 2489.1 kJ/kg

Volume at 10 C, 1 bar

<u>approximate</u> saturated liquid volume at 6 C — .001000 cubic m/kg

Two Phase Real Gas Properties

$$V = V_f + V_g$$

$$mv = m_f v_l + m_g v_g$$

$$x = \frac{m_g}{m}$$

$$v = (1 - x)v_f + x \times v_g$$

$$v = v_f + x \times v_{fg}$$

$$x = \left(\frac{v - v_f}{v_{fg}}\right)$$

$$h = h_f + x \times h_{fg}$$

$$u = u_f + x \times u_{fg}$$

$$s = s_f + x \times s_{fg}$$

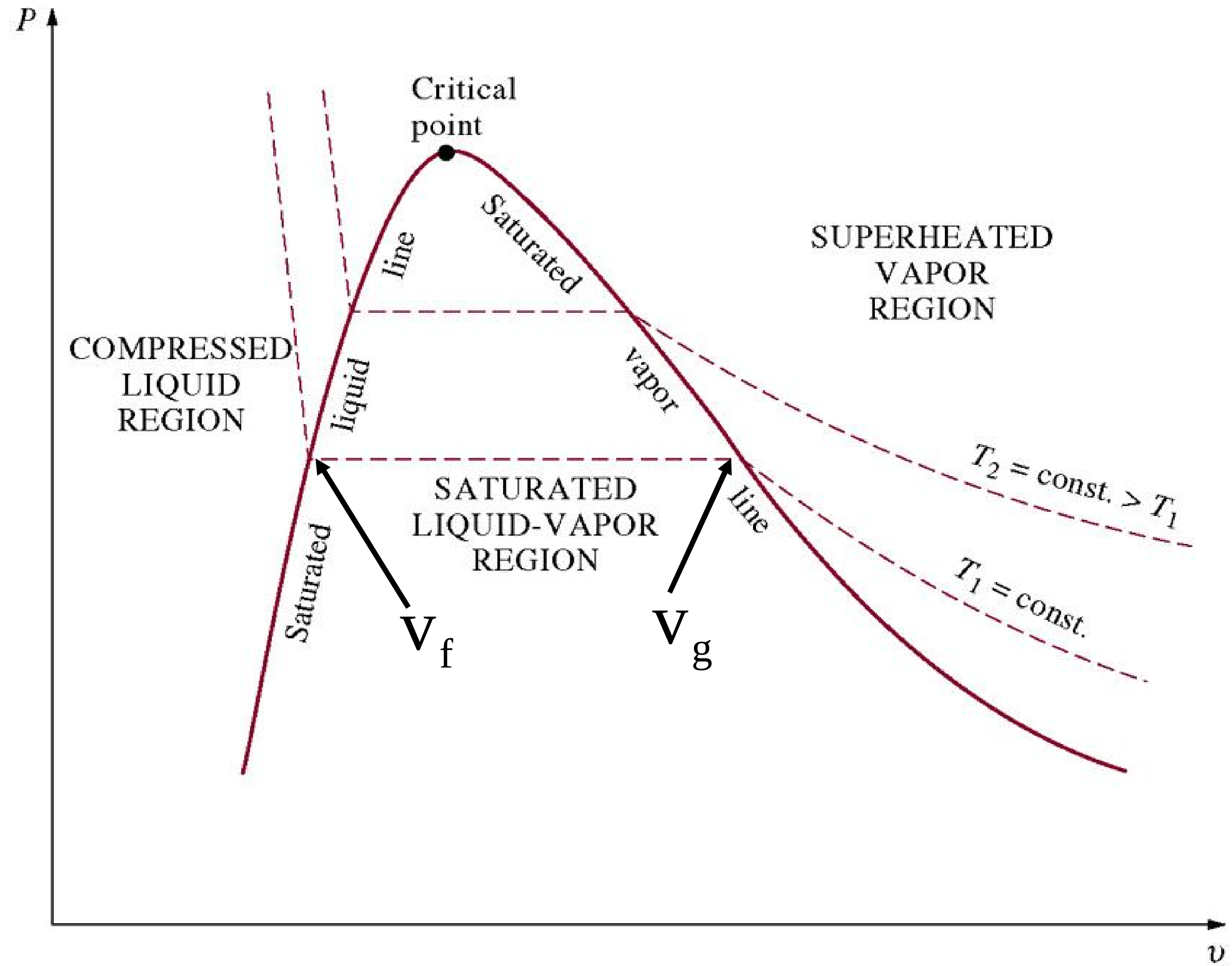


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TABLE A–4

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg: Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg · K: Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661

Steam at 20 C has an enthalpy of 1800 kJ/kg. What is the internal energy?

$$h = h_f + x\, h_{fg}$$

$$1800 \text{ kJ/kg}$$

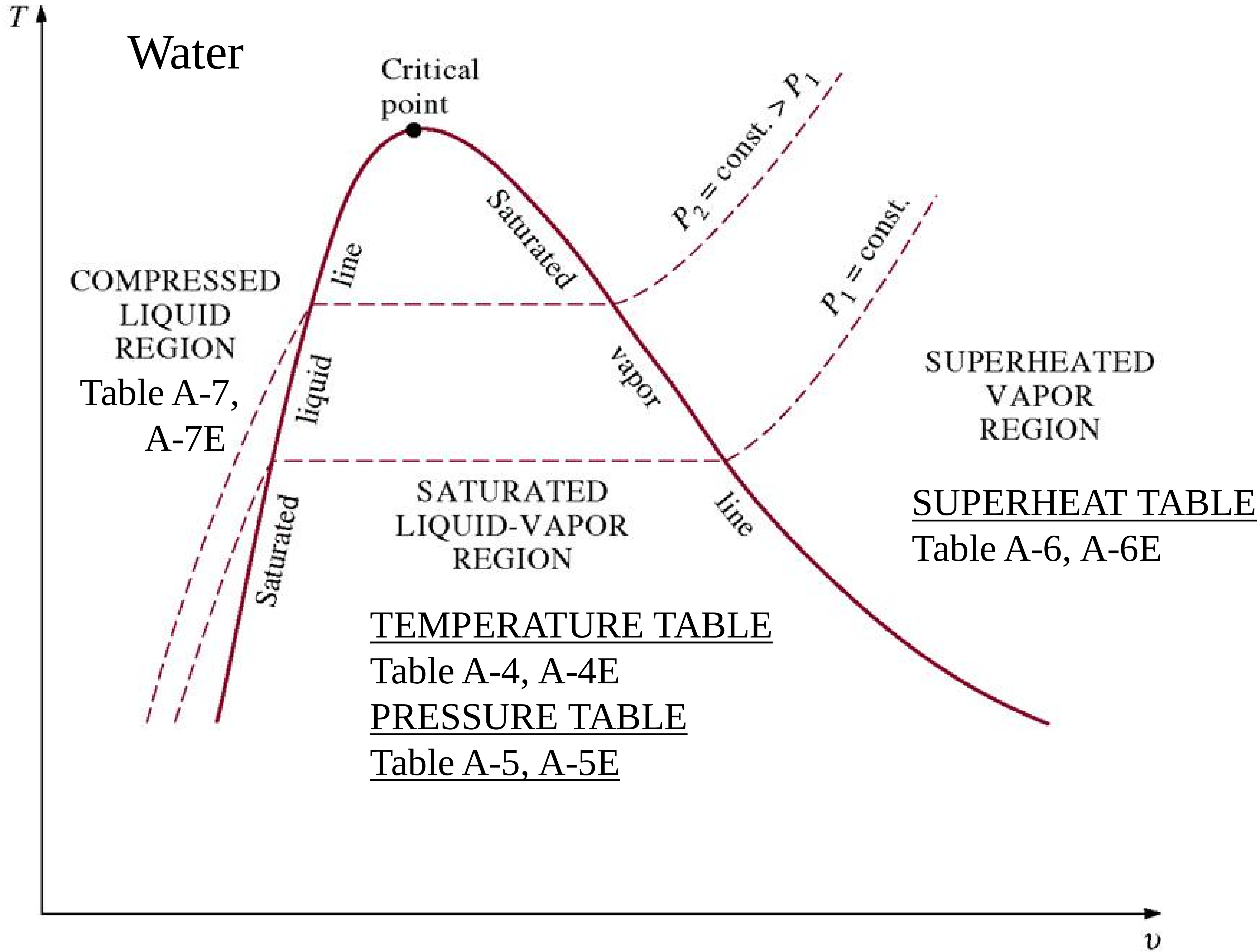
$$= 83.915 + x \times 2453.5$$

$$x = .7$$

$$u = u_f + x\, u_{fg}$$

$$u = 83.913 + .7 \times (2402.3 - 83.913)$$

$$u = 1706.78 \text{ kJ/kg}$$


T
Water
Critical
point
P_2 = const. > P_1
P_1 = const.
Saturated liquid line
Saturated vapor line
COMPRESSED
LIQUID
REGION
Table A-7,
A-7E
SATURATED
LIQUID-VAPOR
REGION
SUPERHEATED
VAPOR
REGION
SUPERHEAT TABLE
Table A-6, A-6E
TEMPERATURE TABLE
Table A-4, A-4E
PRESSURE TABLE
Table A-5, A-5E
υ

Engineering Equation Solver - EES

Fluid Property Information - 69 fluids available

Thermophysical Functions - 25 properties calculated

Available from Text Student Resources CD

EQUATION WINDOW

h=enthalpy(steam, T=200.,P=200) superheated vapor

h=enthalpy(steam,T=200.,X=1) saturated vapor

u=intenergy(steam,T=200.,X=0.) saturated liquid

p=pressure(steam,T=200.,X=0.) saturation pressure

Thermophysical Functions

- entropy
- intenergy
- pressure
- quality
- density
- enthalpy
- isidealgas
- temperature
- volume

Function Arguments

- H specific enthalpy
- P pressure
- S specific entropy
- T temperature
- U specific internal energy
- V specific volume
- X quality

EES

FLUIDS

Fluid Property Information

EES provided built-in property data for the fluids listed below. Click on a fluid name to access additional information for that fluid. All names in EES are case-insensitive. Additional fluid property data can be added by the user.

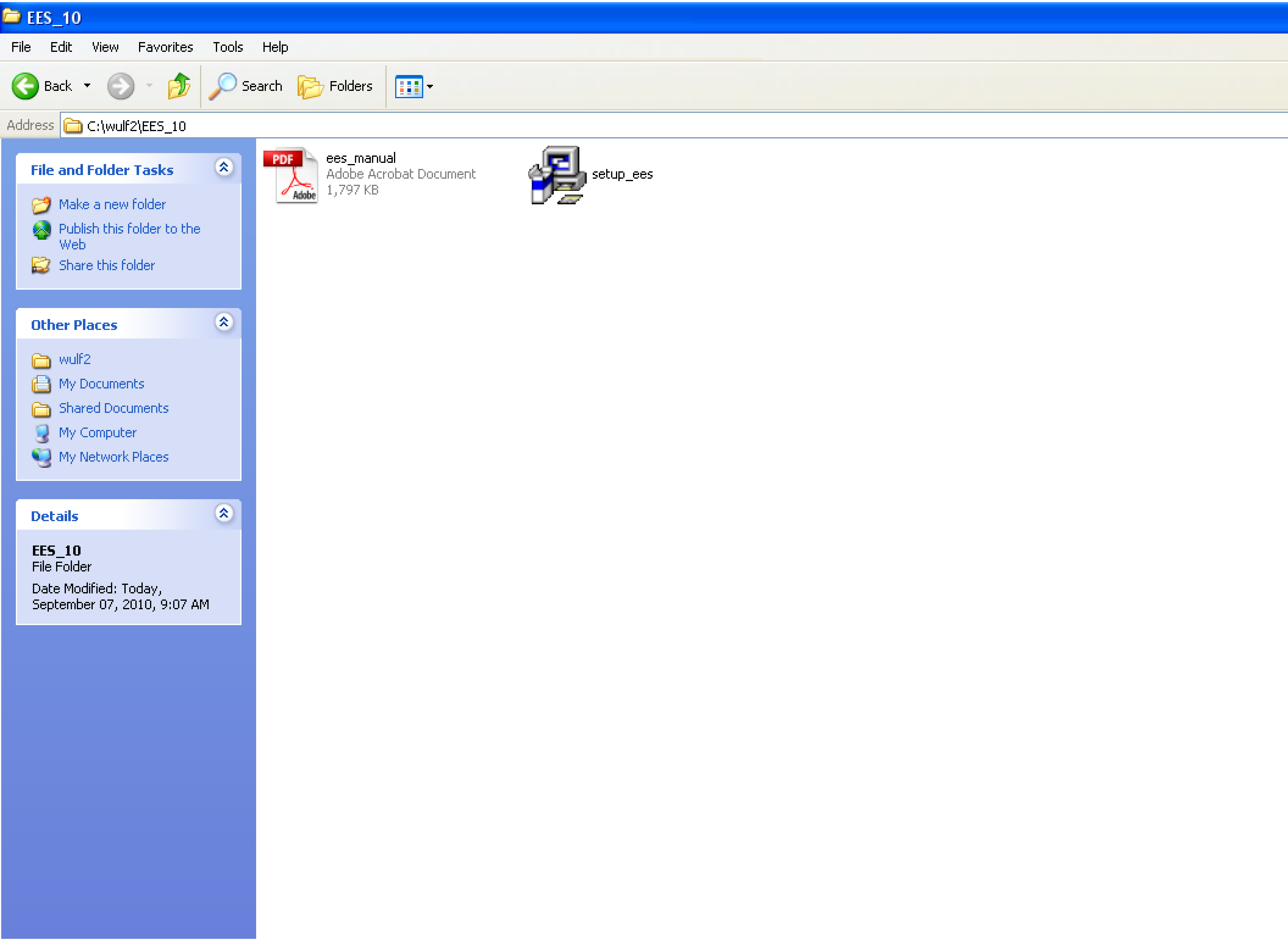
---- Ideal Gas ----	---- Real Fluid ----			
Air	Ammonia	Oxygen*	R11	R290
AirH2O	Ammonia_ha*	n-Butane*	R12	R404A
CH4	Argon*	n-HEXANE*	R13	R407C
C2H2	Carbondioxide*	n-Pentane*	R14	R410A
C2H4	Carbonmonoxide*	Neon*	R22	R500
C2H6	Ethane*	Nitrogen*	R22_ha*	R502
C3H8	Ethylene*	Propane	R23	R600
C4H10	Helium*	Propane_ha*	R32	R600a
CO	Hydrogen*	Propylene*	R114	R717
CO2	Isobutane*	Steam*	R123	R718
H2	Isopentane*	Steam_IAPWS*	R134a	R744
H2O	Methane*	Steam_NBS*	R134a_ha*	RC318*
N2	Methanol*	Water	R141b*	
NO			R152a*	
NO2				
O2				
SO2				

FUNCTIONS

Thermophysical Functions

The built-in thermophysical property functions are listed below in alphabetical order.

CONDUCTIVITY	CP
CV	DENSITY
DEWPOINT	ENTHALPY
ENTROPY	HUMRAT
INTENERGY	ISIDEALGAS
MOLARMASS	PRANDTL
PRESSURE	P_CRIT
QUALITY	RELHUM
SOUNDSPEED	SPECHEAT
SURFACETENSION	TEMPERATURE
T_CRIT	VISCOSITY
WETBULB	VOLUME
V_CRIT	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Make a new folder
Publish this folder to the Web
Share this folder
Other Places
wulf2
My Documents
Shared Documents
My Computer
My Network Places
Details
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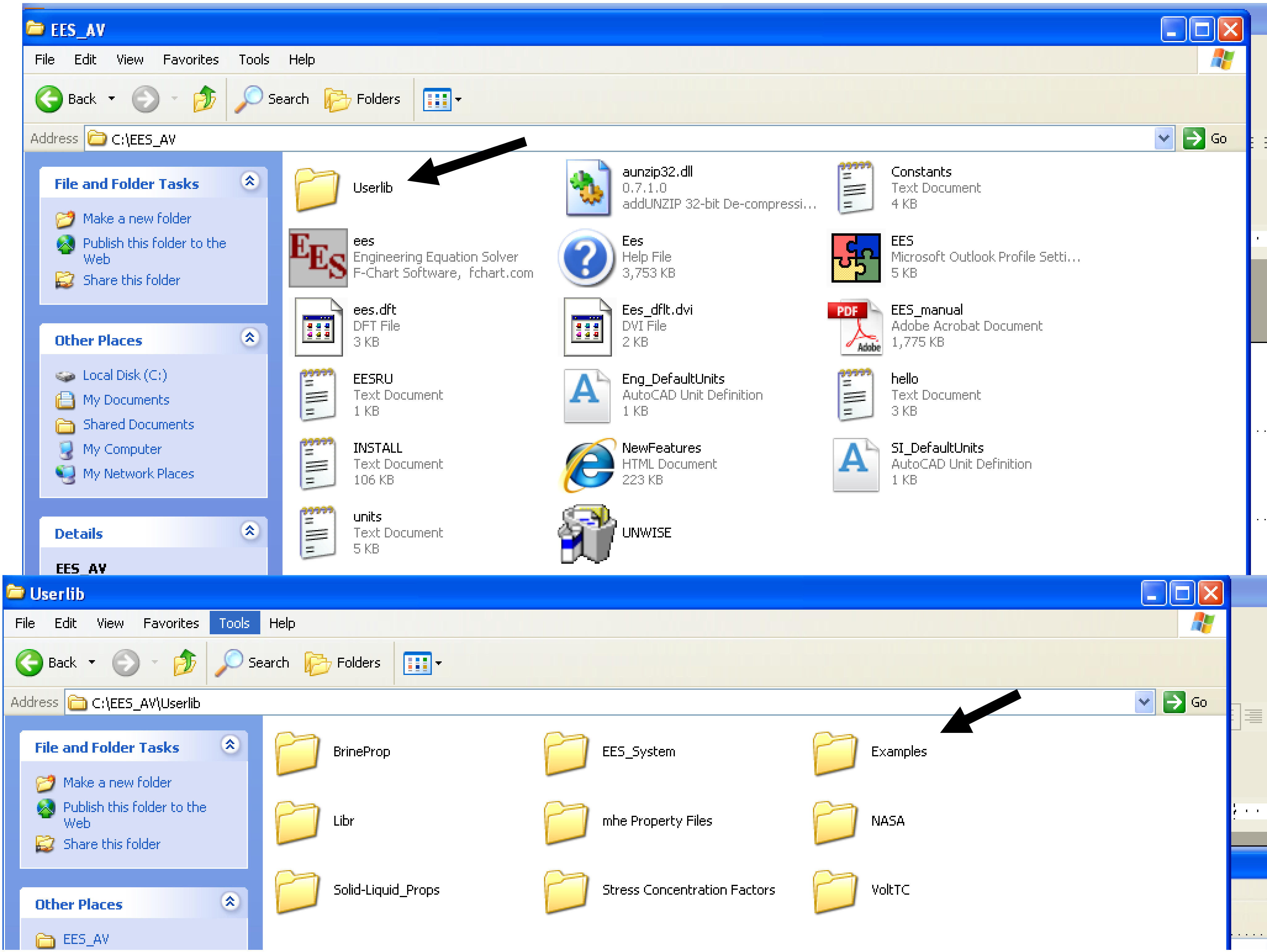
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Share this folder
Other Places
Local Disk (C:)
My Documents
Shared Documents
My Computer
My Network Places
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Help File
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AutoCAD Unit Definition
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5 KB
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Userlib
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Publish this folder to the Web
Share this folder
Other Places
EES_AV
BrineProp
EES_System
Examples
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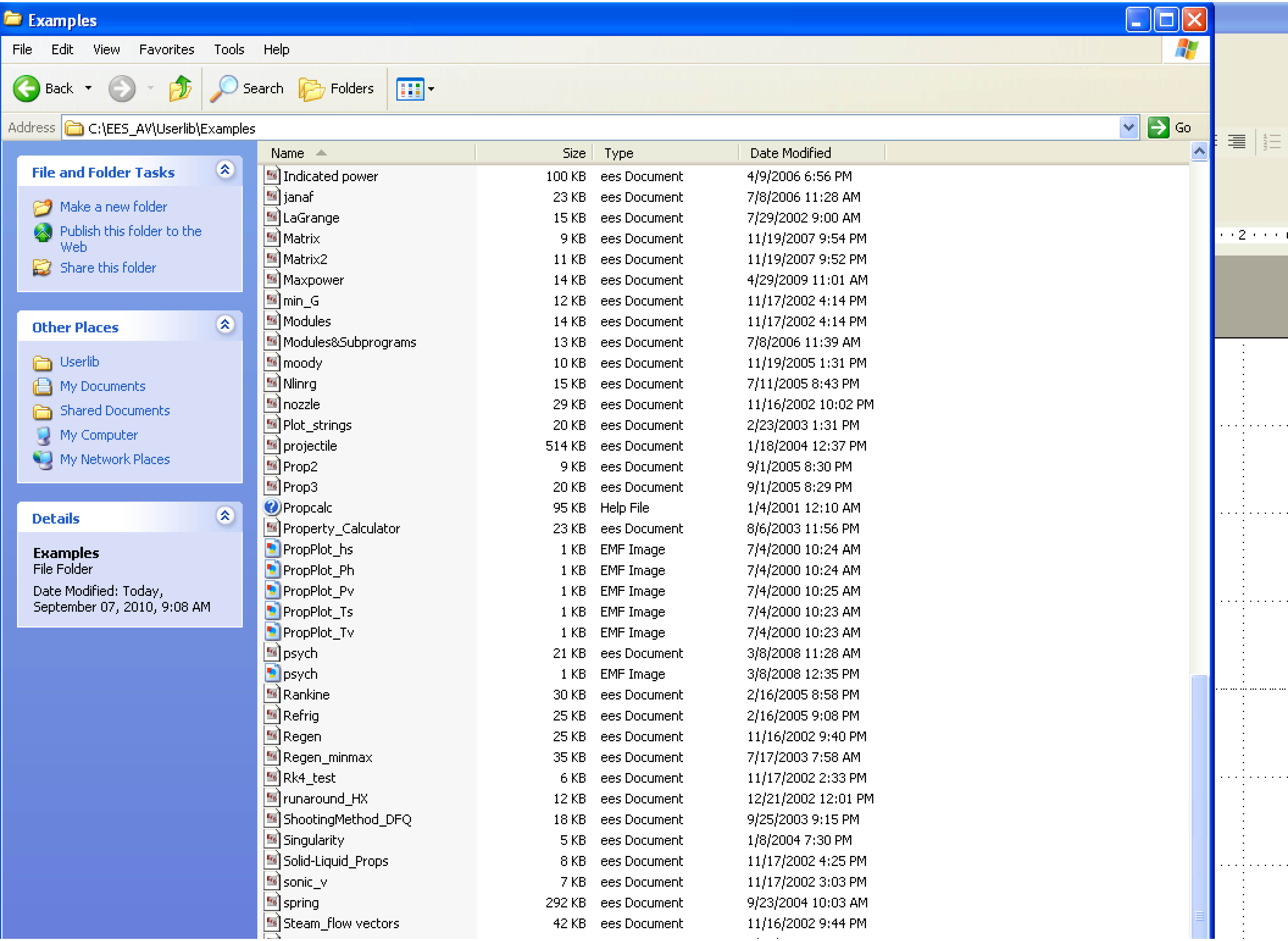
NASA
Solid-Liquid_Props
Stress Concentration Factors
VoltTC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Back
Search
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Go
File and Folder Tasks
Make a new folder
Publish this folder to the Web
Share this folder
Other Places
Userlib
My Documents
Shared Documents
My Computer
My Network Places
Details
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janaf 23 KB ees Document 7/8/2006 11:28 AM
LaGrange 15 KB ees Document 7/29/2002 9:00 AM
Matrix 9 KB ees Document 11/19/2007 9:54 PM
Matrix2 11 KB ees Document 11/19/2007 9:52 PM
Maxpower 14 KB ees Document 4/29/2009 11:01 AM
min_G 12 KB ees Document 11/17/2002 4:14 PM
Modules 14 KB ees Document 11/17/2002 4:14 PM
Modules&Subprograms 13 KB ees Document 7/8/2006 11:39 AM
moody 10 KB ees Document 11/19/2005 1:31 PM
Nlinrg 15 KB ees Document 7/11/2005 8:43 PM
nozzle 29 KB ees Document 11/16/2002 10:02 PM
Plot_strings 20 KB ees Document 2/23/2003 1:31 PM
projectile 514 KB ees Document 1/18/2004 12:37 PM
Prop2 9 KB ees Document 9/1/2005 8:30 PM
Prop3 20 KB ees Document 9/1/2005 8:29 PM
Propcalc 95 KB Help File 1/4/2001 12:10 AM
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Rk4_test 6 KB ees Document 11/17/2002 2:33 PM
runaround_HX 12 KB ees Document 12/21/2002 12:01 PM
ShootingMethod_DFQ 18 KB ees Document 9/25/2003 9:15 PM
Singularity 5 KB ees Document 1/8/2004 7:30 PM
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sonic_v 7 KB ees Document 11/17/2002 3:03 PM
spring 292 KB ees Document 9/23/2004 10:03 AM
Steam_flow vectors 42 KB ees Document 11/16/2002 9:44 PM

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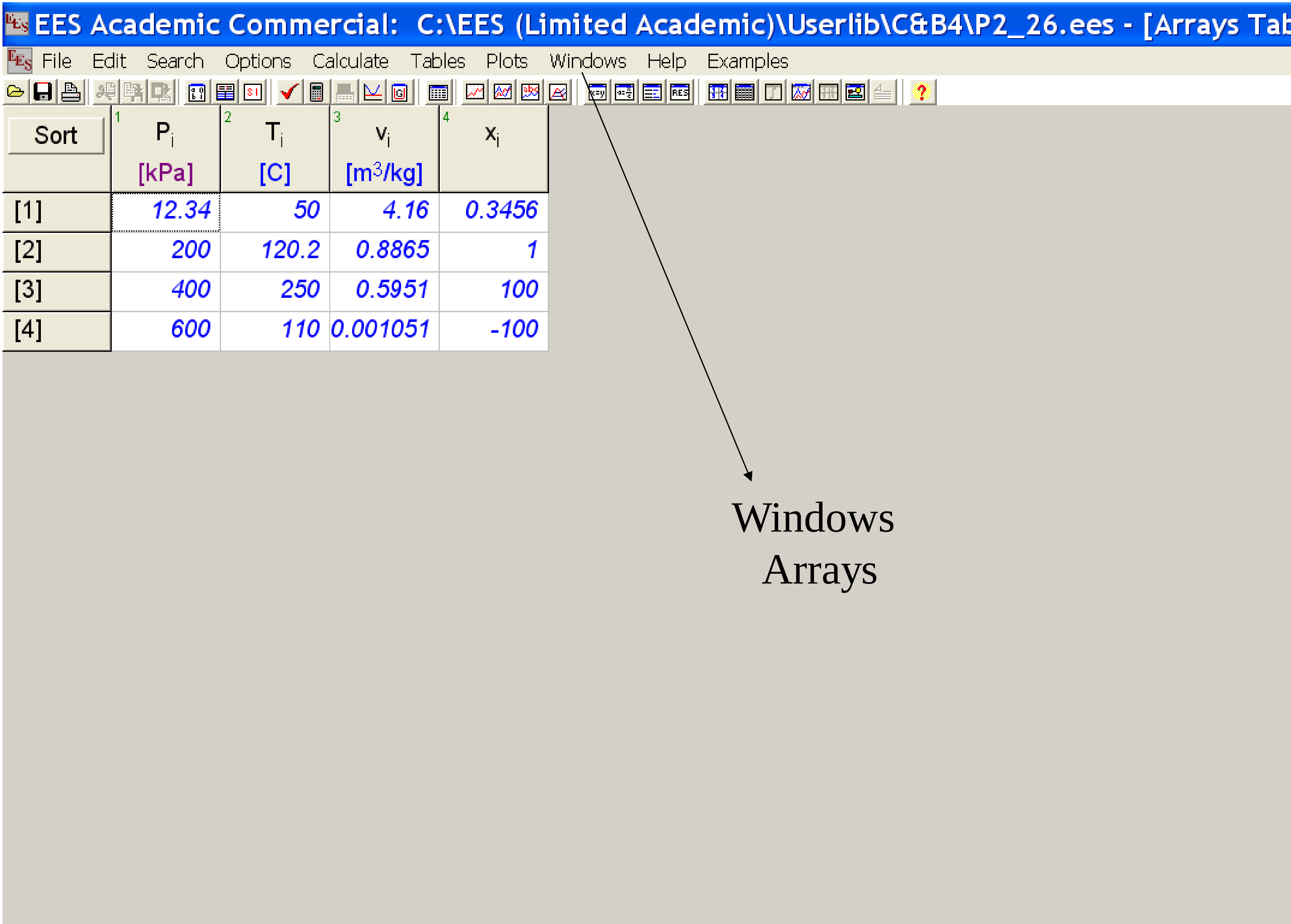
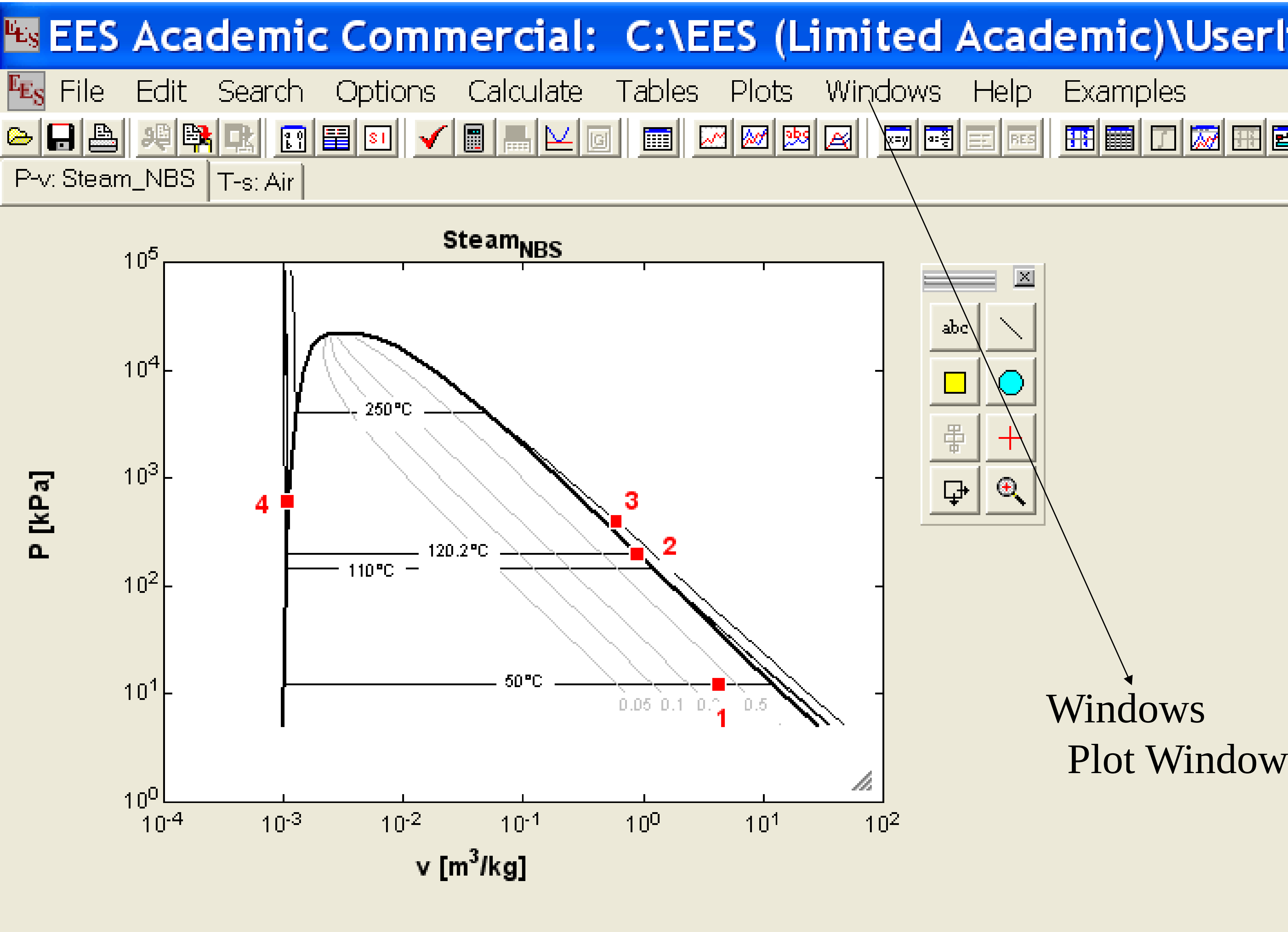
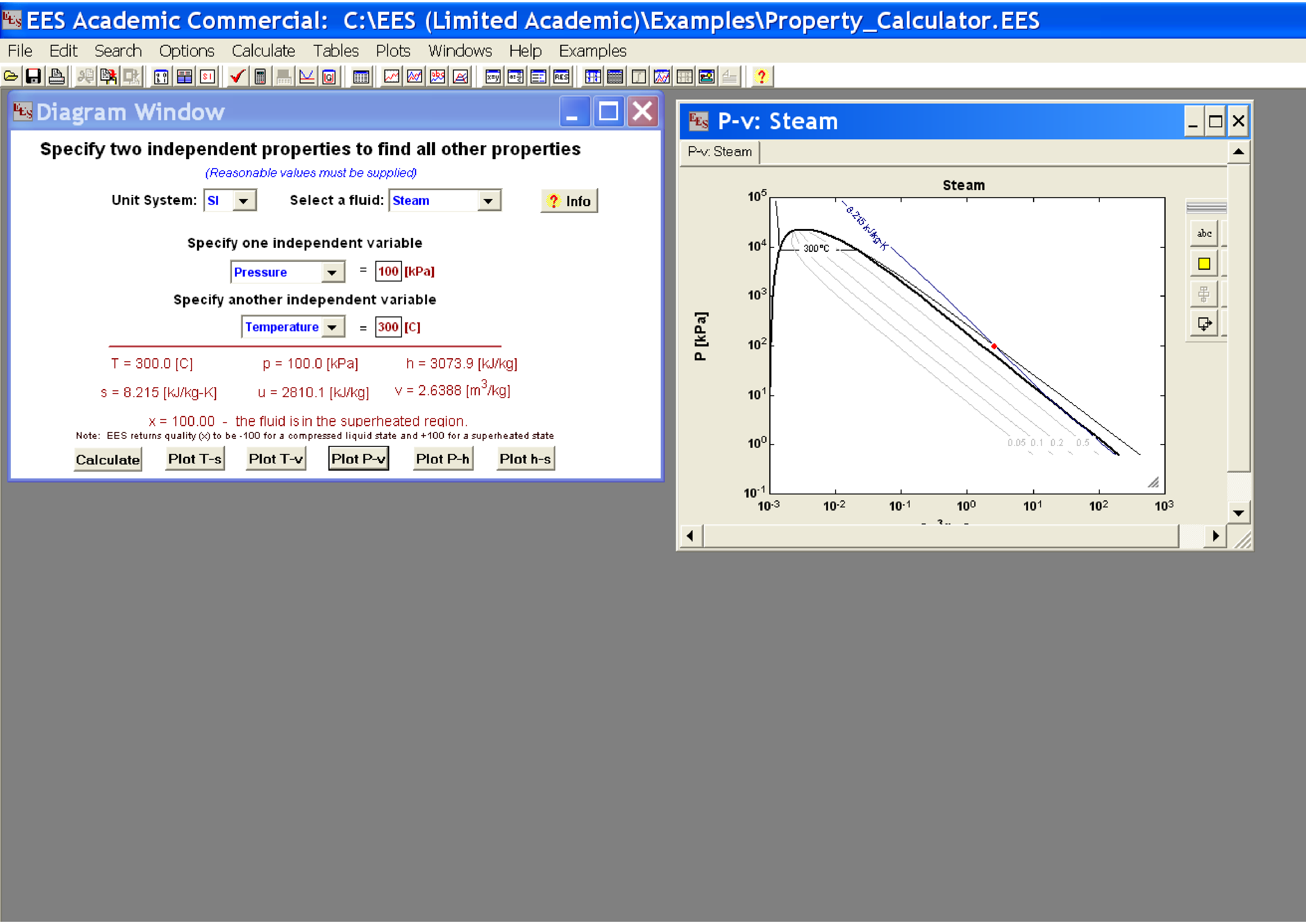
```
" Determine the properties of water at 4 conditions. 1) T=50 C, v=4. 16 m^3/kg,  2) p=200 kPa, quality=100%"
 ", 3) T=250 C, p=400 kPa, 4) T=110 C,  p=600 kPa"

Fluid$='Steam_NBS'

"Set 1"
T[1]=50                                          "[C]"
v[1]=4.16                     "[m^3/kg]"
P[1]=pressure(Fluid$, T=T[1], v=v[1])
x[1]=quality(Fluid$, T=T[1], v=v[1])

"Set 2"
P[2]=200                      "[kPa]"
x[2]=1
v[2]=volume(Fluid$, p=P[2], x=x[2])
T[2]=Temperature(Fluid$, p=P[2], x=x[2])

"Set 3"
T[3]=250                                         "[C]"
p[3]=400                                         "[kPa]"
v[3]=volume(Fluid$, T=T[3], p=P[3])
x[3]=quality(Fluid$, T=T[3], p=P[3])

"Set 4"
T[4]=110                                         "[C]"
p[4]=600                                         "[kPa]"
v[4]=volume(Fluid$, T=T[4], p=P[4])
x[4]=quality(Fluid$, T=T[4], p=P[4])
```

Solve

Windows Equations


EES Academic Commercial: C:\EES (Limited Academic)\Userlib\C&B4\P2_26.ees - [Arrays Tab
File Edit Search Options Calculate Tables Plots Windows Help Examples
Sort
1 Pi [kPa]
2 Ti [C]
3 vi [m3/kg]
4 xi
[1] 12.34 50 4.16 0.3456
[2] 200 120.2 0.8865 1
[3] 400 250 0.5951 100
[4] 600 110 0.001051 -100
Windows
Arrays


EES Academic Commercial: C:\EES (Limited Academic)\UserI
File Edit Search Options Calculate Tables Plots Windows Help Examples
P-v: Steam_NBS
T-s: Air
Steam_NBS
250°C
120.2°C
110°C
50°C
0.05 0.1 0.5
1
2
3
4
P [kPa]
v [m^3/kg]
abc
Windows
Plot Window



EES Academic Commercial: C:\EES (Limited Academic)\Examples\Property_Calculator.EES
File Edit Search Options Calculate Tables Plots Windows Help Examples
Diagram Window
Specify two independent properties to find all other properties
(Reasonable values must be supplied)
Unit System: SI
Select a fluid: Steam
Info
Specify one independent variable
Pressure = 100 [kPa]
Specify another independent variable
Temperature = 300 [C]
T = 300.0 [C]
p = 100.0 [kPa]
h = 3073.9 [kJ/kg]
s = 8.215 [kJ/kg-K]
u = 2810.1 [kJ/kg]
v = 2.6388 [m3/kg]
x = 100.00 - the fluid is in the superheated region.
Note: EES returns quality (x) to be -100 for a compressed liquid state and +100 for a superheated state
Calculate
Plot T-s
Plot T-v
Plot P-v
Plot P-h
Plot h-s
P-v: Steam
P-v: Steam
Steam
P [kPa]
8.215 kJ/kg-K
300°C
0.05
0.1
0.2
0.5
abc

Steam at 300^{O}C with a quality of 50% is expanded at constant enthalpy to 20 kPa. What is the temperature, phase and internal energy of the expanded steam?

BEFORE THE EXPANSION

$h = h_f + x \times h_{fg}$

$h = h_f @ 300^{O}\,C + x \times h_{fg} @ 300^{O}$ Temperature Table A - 4

$h = 1344.8\ kJ/kg + .5 \times 1404.8\ kJ/kg$

$h = 2047.2\ kJ/kg$

AFTER THE EXPANSION

$2047.2\ kJ/kg = h_f @ 20\ kPa + x \times h_{fg} @ 20\ kPa$ Pressure Table A - 5

$2047.2 = 251.42\ kJ/kg + x \times 2357.5\ kJ/kg$

$x = .762 \Rightarrow$ two phase

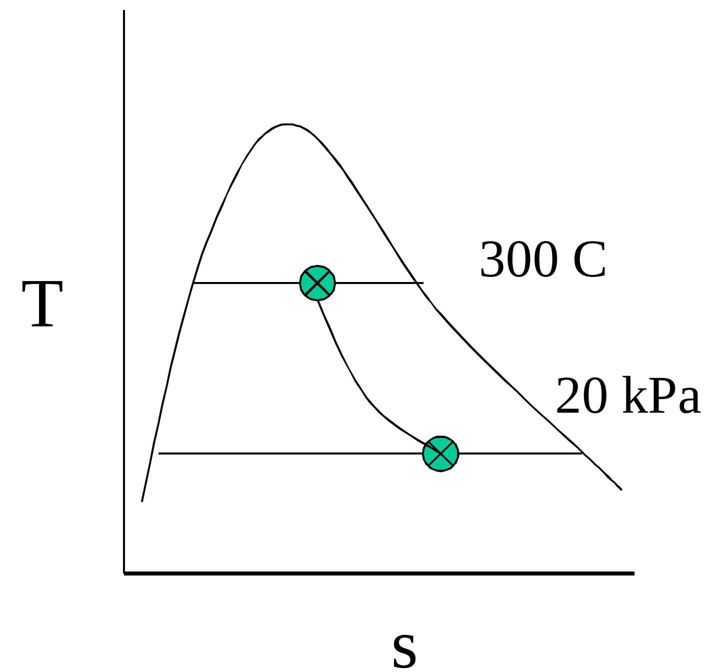
$T =$ saturation temperature @ 20 kPa $= 60.06^{O}\,C$

$u = u_f + x \times u_{fg}$

$u = u_f @ 20\ kPa + x \times u_{fg} @ 20\ kPa$ Pressure Table A - 5

$u = 251.4\ kJ/kg + .762 \times 2204.6\ kJ/kg$

$u = 1931.3\ kJ/kg$



SUPERHEATED TABLE

superheat properties as a function of temperature and pressure

920 | Thermodynamics

TABLE A–6

Superheated water

T °C	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K
	P = 0.01 MPa (45.81°C)*				*P* = 0.05 MPa (81.32°C)				*P* = 0.10 MPa (99.61°C)			
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931	1.6941	2505.6	2675.0	7.3589
50	14.867	2443.3	2592.0	8.1741								
100	17.196	2515.5	2687.5	8.4489	3.4187	2511.5	2682.4	7.6953	1.6959	2506.2	2675.8	7.3611
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413	1.9367	2582.9	2776.6	7.6148
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592	2.1724	2658.2	2875.5	7.8356
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568	2.4062	2733.9	2974.5	8.0346
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387	2.6389	2810.7	3074.5	8.2172
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659	3.1027	2968.3	3278.6	8.5452
500	35.680	3132.9	3489.7	9.8998	7.1338	3132.6	3489.3	9.1566	3.5655	3132.2	3488.7	8.8362
600	40.296	3303.3	3706.3	10.1631	8.0577	3303.1	3706.0	9.4201	4.0279	3302.8	3705.6	9.0999
700	44.911	3480.8	3929.9	10.4056	8.9813	3480.6	3929.7	9.6626	4.4900	3480.4	3929.4	9.3424
800	49.527	3665.4	4160.6	10.6312	9.9047	3665.2	4160.4	9.8883	4.9519	3665.0	4160.2	9.5682
900	54.143	3856.9	4398.3	10.8429	10.8280	3856.8	4398.2	10.1000	5.4137	3856.7	4398.0	9.7800
1000	58.758	4055.3	4642.8	11.0429	11.7513	4055.2	4642.7	10.3000	5.8755	4055.0	4642.6	9.9800
1100	63.373	4260.0	4893.8	11.2326	12.6745	4259.9	4893.7	10.4897	6.3372	4259.8	4893.6	10.1698
1200	67.989	4470.9	5150.8	11.4132	13.5977	4470.8	5150.7	10.6704	6.7988	4470.7	5150.6	10.3504
1300	72.604	4687.4	5413.4	11.5857	14.5209	4687.3	5413.3	10.8429	7.2605	4687.2	5413.3	10.5229

TABLE A–6

Superheated water (*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	P = 4.0 MPa (250.35°C)				*P* = 4.5 MPa (257.44°C)			
Sat.	0.04978	2601.7	2800.8	6.0696	0.04406	2599.7	2798.0	6.0198
275	0.05461	2668.9	2887.3	6.2312	0.04733	2651.4	2864.4	6.1429
300	0.05887	2726.2	2961.7	6.3639	0.05138	2713.0	2944.2	6.2854
350	0.06647	2827.4	3093.3	6.5843	0.05842	2818.6	3081.5	6.5153
400	0.07343	2920.8	3214.5	6.7714	0.06477	2914.2	3205.7	6.7071
450	0.08004	3011.0	3331.2	6.9386	0.07076	3005.8	3324.2	6.8770
500	0.08644	3100.3	3446.0	7.0922	0.07652	3096.0	3440.4	7.0323
600	0.09886	3279.4	3674.9	7.3706	0.08766	3276.4	3670.9	7.3127

Enthalpy at 600 C and 4.5. MPa 3670.9kJ/kg

Temperature at entropy of 6.7714 and 4. MPa 400 C

Internl energy at 4.5 MPa and entropy of 7.0323 3096. kJ/kg

COMPRESSED LIQUID (SUBCOOLED LIQUID) TABLE

Subcooled properties as a function of temperature and pressure

TABLE A–7

Compressed liquid water

T °C	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg · K
	P = 5 MPa (263.94°C)				*P* = 10 MPa (311.00°C)				*P* = 15 MPa (342.16°C)			
Sat.	0.0012862	1148.1	1154.5	2.9207	0.0014522	1393.3	1407.9	3.3603	0.0016572	1585.5	1610.3	3.6848
0	0.0009977	0.04	5.03	0.0001	0.0009952	0.12	10.07	0.0003	0.0009928	0.18	15.07	0.0004
20	0.0009996	83.61	88.61	0.2954	0.0009973	83.31	93.28	0.2943	0.0009951	83.01	97.93	0.2932
40	0.0010057	166.92	171.95	0.5705	0.0010035	166.33	176.37	0.5685	0.0010013	165.75	180.77	0.5666
60	0.0010149	250.29	255.36	0.8287	0.0010127	249.43	259.55	0.8260	0.0010105	248.58	263.74	0.8234
80	0.0010267	333.82	338.96	1.0723	0.0010244	332.69	342.94	1.0691	0.0010221	331.59	346.92	1.0659
100	0.0010410	417.65	422.85	1.3034	0.0010385	416.23	426.62	1.2996	0.0010361	414.85	430.39	1.2958
120	0.0010576	501.91	507.19	1.5236	0.0010549	500.18	510.73	1.5191	0.0010522	498.50	514.28	1.5148
140	0.0010769	586.80	592.18	1.7344	0.0010738	584.72	595.45	1.7293	0.0010708	582.69	598.75	1.7243
160	0.0010988	672.55	678.04	1.9374	0.0010954	670.06	681.01	1.9316	0.0010920	667.63	684.01	1.9259
180	0.0011240	759.47	765.09	2.1338	0.0011200	756.48	767.68	2.1271	0.0011160	753.58	770.32	2.1206
200	0.0011531	847.92	853.68	2.3251	0.0011482	844.32	855.80	2.3174	0.0011435	840.84	858.00	2.3100
220	0.0011868	938.39	944.32	2.5127	0.0011809	934.01	945.82	2.5037	0.0011752	929.81	947.43	2.4951
240	0.0012268	1031.6	1037.7	2.6983	0.0012192	1026.2	1038.3	2.6876	0.0012121	1021.0	1039.2	2.6774
260	0.0012755	1128.5	1134.9	2.8841	0.0012653	1121.6	1134.3	2.8710	0.0012560	1115.1	1134.0	2.8586
280					0.0013226	1221.8	1235.0	3.0565	0.0013096	1213.4	1233.0	3.0410
300					0.0013980	1329.4	1343.3	3.2488	0.0013783	1317.6	1338.3	3.2279
320									0.0014733	1431.9	1454.0	3.4263
340									0.0016311	1567.9	1592.4	3.6555

A saturated mixture of 2 kg water and 3 kg vapor in contained in a piston cylinder device at 100 kpa. Heat is added and the piston, initially resting on stops, begins to move at a pressure of 200 kpa. Heating is stopped when the total volume in increased by 20%. Find:

a) the initial and final temperatures.

b) the mass of liquid water when the pressure reaches 200 kPa and the piston starts to move.

c) the work done by the expansion.

$$\text{at } 100\text{kPa},\ x = \frac{3\,\text{kg vapor}}{5\,\text{kg total}} = .6$$

$$T = 99.61$$

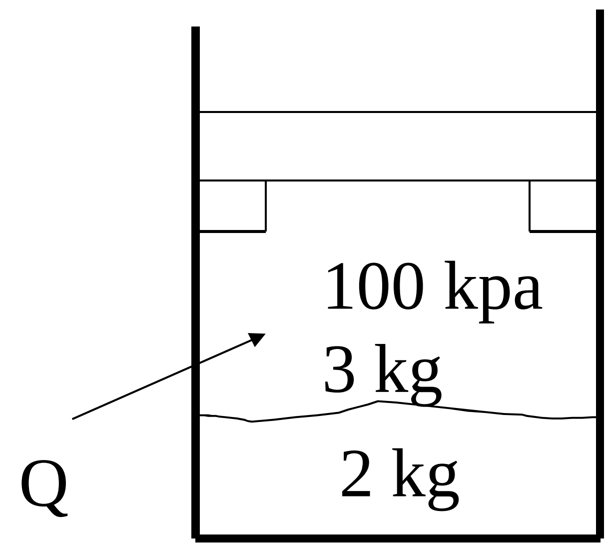
$$v_1 = v_f + x \times v_{fg}$$

$$v_1 = .001043 + .6 \times (1.694 - .001043)$$

$$v_1 = 1.0168\,\text{m}^3/\text{kg}$$

$$u_1 = u_f + x \times u_{fg}$$

$$u_1 = 417.40 + .6 \times 2088.2 = 1670.62\,\text{kJ/kg}$$



3.88

$$\text{Point 2} \quad \text{at} .2\ \text{MPa}, \quad v_1 = v_2$$

$$V_2 = 5\ \text{kg} \times 1.0161 = 5.08\ \text{m}^3$$

Interpolation from Table $A-6$

$$u_2 = u@(v = 1.0161, P = .2\ \text{MPa})$$

$$u_2 = 2613.23\ \text{kJ/kg}$$

$$h_2 = h@(v = 1.0168, P = .2\ \text{MPa}))$$

$$h_2 = 2816.47\ \text{kJ/kg}$$

$$V_3 = 1.2 \times V_2 = 6.096$$

$$v_3 = \frac{6.096\ \text{m}^3}{5\ \text{kg}} = 1.2192$$

$$v_g = .8857 \Rightarrow \text{superheated}$$

Point 3 at .2 MPa

$$h_3 = h\ @\ (v_3 = 1.2192, P = .2\ \text{MPa})$$

$$h_3 = 2988.65\ \text{kJ/kg}$$

$$W = \int_1^2 p dV + \int_2^3 p dV = 0 + p_2 (V_3 - V_2)$$

$$W = 0 + 200\ \text{kPa} \times (6.096\ \text{m}^3 - 5.08\ \text{m}^3) = 203.2\ \text{kJ}$$

$$p = \text{constant}, 2-3$$

$$Q = \varphi E + W$$

$$Q = \varphi E + p\Delta V$$

$$Q = \varphi H$$

$$Q = m(h_3 - h_2)$$

$$Q = 5 \times (2988.65 - 2816.47)$$

$$Q_{2\text{-}3} = 860.9\ \text{kJ}$$

alteratively,

$$W_{1\text{-}3} = Q_{1\text{-}3} - m \times (u_3 - u_2)$$

$$v = \text{constant}, 1-2$$

$$Q = \varphi E + W$$

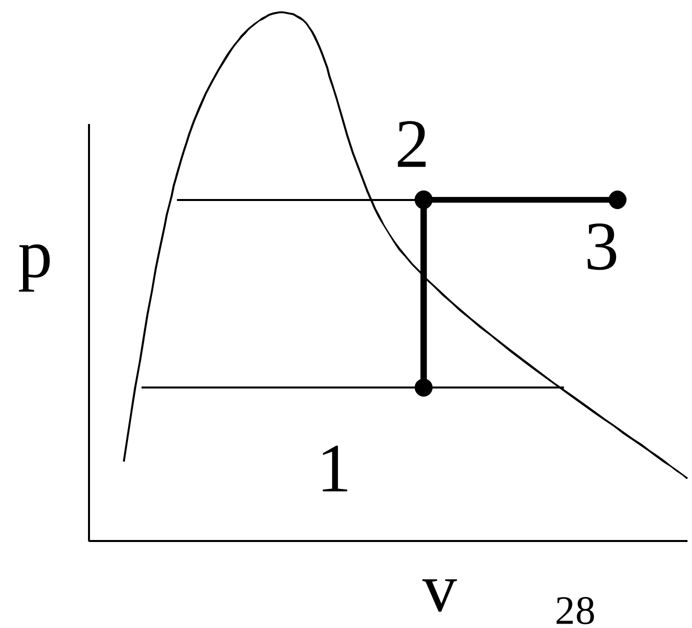
$$W = 0$$

$$Q = \varphi E = \varphi U$$

$$Q = m(u_2 - u_1)$$

$$Q = 5 \times (2613.23 - 1670.62)$$

$$Q = 4713.05\ \text{kJ}$$



Interpolation for h_3

Superheat Table A - 6 enthalpy @ (p = .2 MPa, v = 1.2192)

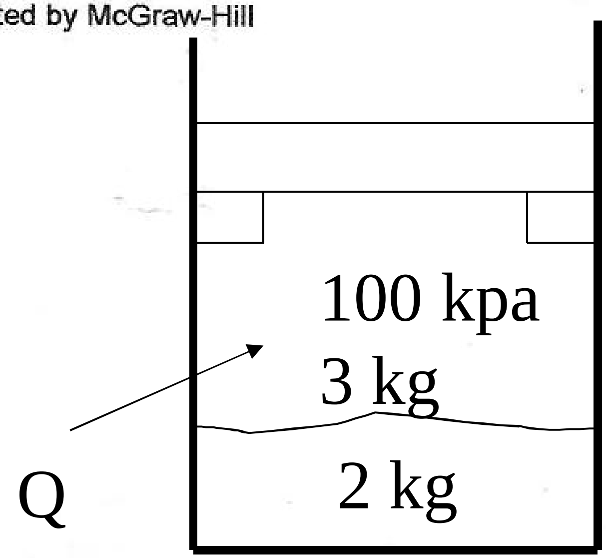
T	v	h
250	1.1989	2971.2
	1.2192	
300	1.31623	3092.1

$$\text{ratio of } v = \frac{1.2192 - 1.1989}{1.31623 - 1.1989} = .173$$

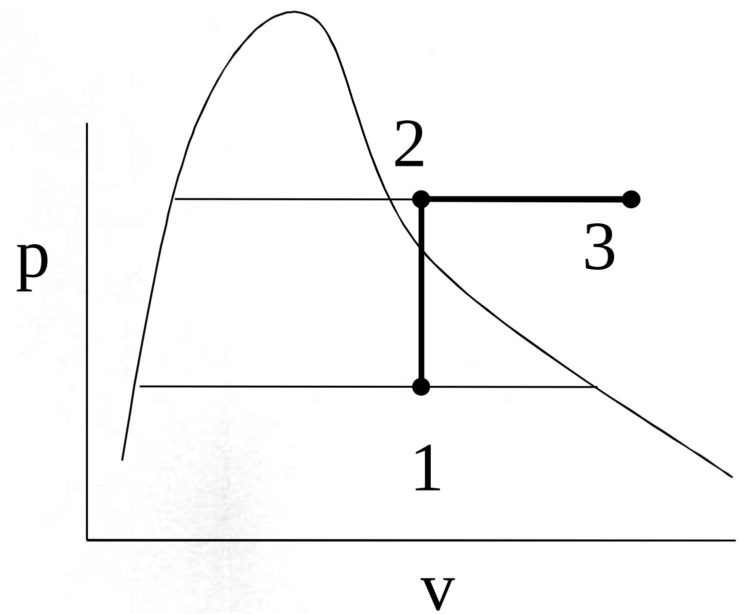
$$h_3 = 2988.65 \text{ kJ/kg}$$

EES Solution

```
"INPUT Variables"
p1=100
mliquid=2
mvapor=3
p2=200
V2=V1
V3=1.2*V1

mtotal=mvapor+mliquid
x1=mvapor/mtotal
sv1=volume(Steam_IAPWS, p=p1,x=x1)
V1=mtotal*sv1
u1=intenergy(Steam_IAPWS,p=p1,x=x1)
sv2=sv1
u2=intenergy(Steam_IAPWS,p=p2,v=sv2)
h2=enthalpy(Steam_IAPWS,p=p2,v=sv2)
sv3=V3/(mliquid+mvapor)
h3=enthalpy(Steam_IAPWS,p=p2,v=sv3)
p3=p2

W13=p3*(V3-V2)
Q12=mtotal*(u2-u1)
Q23=mtotal*(H3-h2)
```



$$W = m \times \int p dv$$



SOLUTION

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

h2 = 2817	h3 = 2989	mliquid = 2	mtotal = 5	mvapor = 3	p1 = 100
p2 = 200	p3 = 200	Q12 = 4717	Q23 = 861.8	sv1 = 1.017	sv2 = 1.017
sv3 = 1.22	u1 = 1670	u2 = 2614	V1 = 5.084	V2 = 5.084	V3 = 6.101
W13 = 203.4	x1 = 0.6				

Linear Interpolation with 3 Variables

$\mathbf{h@(T = 470\,C, p = 27\,MPa)}$ **Steam Superheat Table**

	p = 25 MPa	p = 27 MPa	p = 30 MPa
T = 450	h = 2950.6	h = 2898.76	h = 2821.
T = 470		h = 2992.64	
T = 500	h = 3165.9	h = 3133.46	h = 3084.8

Interpolate first at 450 C and at 500 C between p = 25 and P = 30 to get h@ (T = 450 and 500, p = 27). Then interpolate at p = 27 MPa between 450 C and 500 C.

$$\text{pressure}\frac{27-25}{30-25} = \frac{2}{5} = .4$$

$$\text{Temperature}\frac{470-450}{500-450} = \frac{20}{50} = .4$$

Ideal Gas Law

AVOGADRO'S LAW

One (1) mole of any gas = 22.4 liters.

6.023×10^{23} molecules /mole of gas at

STP (1 atm and $0^o C$)

BOLYES LAW

$$p_1 \times v_1 = p_2 \times v_2$$

CHARLES LAW

$$\frac{v_1}{v_2} = \frac{T_1}{T_2}$$

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}$$

IDEAL (PERFECT) GAS LAW

$$pv = RT$$

$$pV = mRT$$

p - absolute pressure, psia, kPa

T - absolute temperatu re, ^oR, ^oK

$$R = \frac{R^*}{\text{molecular weight}}$$

$$R^* = 1545.15 \ \frac{\text{lbf/lbm } ^oR}{\text{lbmole}}$$

$$R^* = 8.314 \ \frac{\text{kJ}}{\text{kmole } ^oK} \text{ or } \frac{\text{kPa m}^3}{\text{kmole } ^oK}$$

$$\text{mass} = \text{moles} \times \text{Molecular Weight}$$

$$m = n \times \text{Molecular Weight}$$

$$pv = R^*T$$

$$pV = nR^*T$$

Ideal Gas Model

$pv = RT$

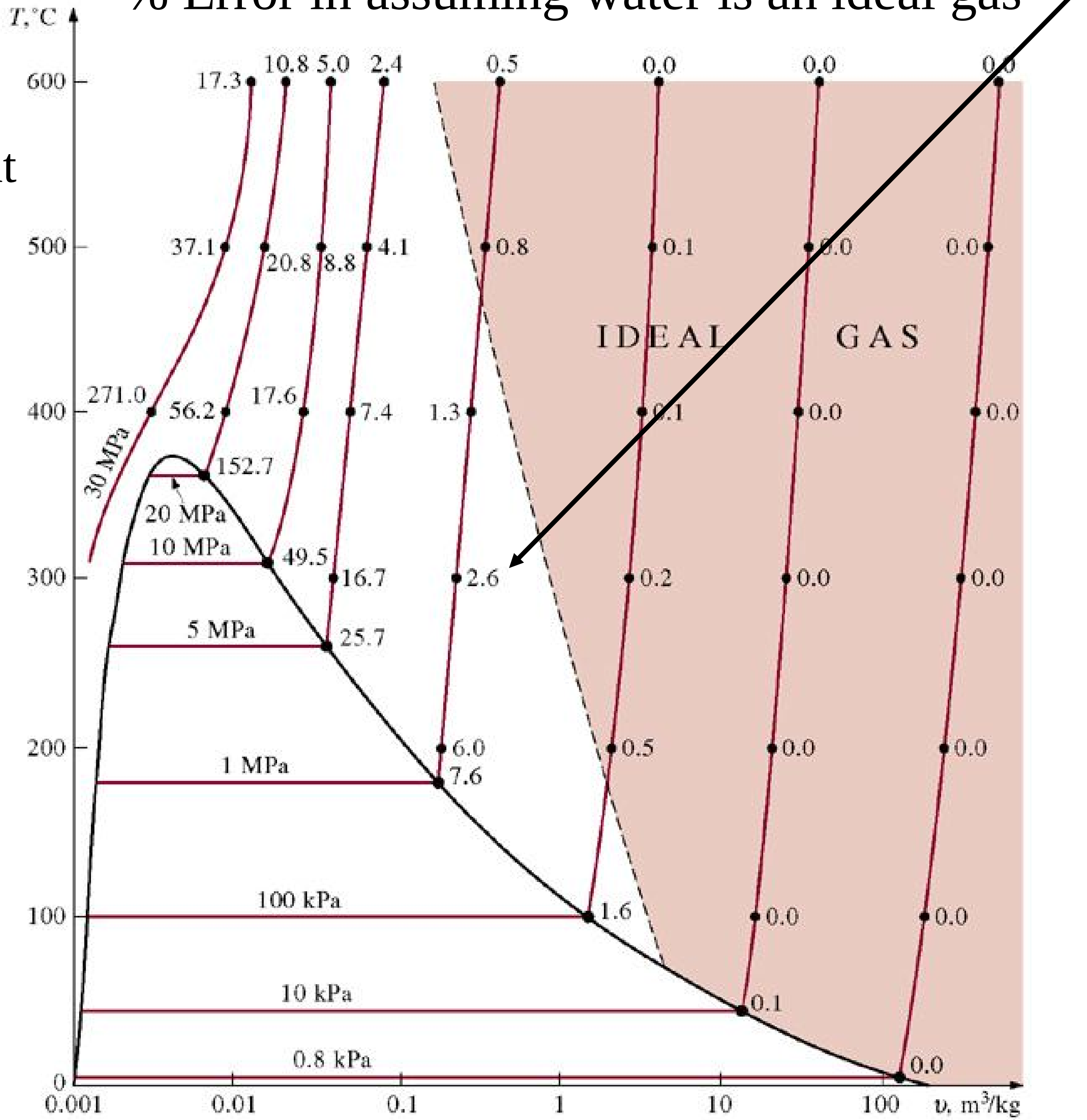
constant specific heat

for water:

$$pv = \frac{1545.15}{18} \times T$$

$$pv = \frac{8.314}{18} \times T$$

% Error in assuming water is an ideal gas



What is the mass of 1.2 m^3 of oxygen at 24^o C
and a gage pressure of 500 kPa.
Atmospheric pressure is 97 kPa

$$p = p_{gage} + p_{atmosphere} = 500 \text{ kPa} + 97 \text{ kPa} = 597 \text{ kPa}$$

$$R_{O_2} = \frac{8.314 \text{kJ/kmole } ^oK \text{ or kPa m}^3\text{/kmole } ^oK}{32} = .259813 \text{ kPa m}^3\text{/kg} \quad \text{also Table A} - 1$$

$$m = \frac{pV}{RT} = \frac{597 \text{ kPa} \times 1.2 \text{ m}^3}{.259813 \text{ kPa m}^3\text{/kg} \times \left(24^o C + 273.16^o K\right)} = 9.28 \text{ kg}$$

What is the volume of 1.2 lbm of air at 124^o F
and a gage pressure of 500 psia.
Atmospheric pressure is 14.7 psia.

$$p = p_{gage} + p_{atmosphere} = 500 \text{ psia} + 14.7 \text{ psia} = 514 \text{ psia}$$

$$R_{air} = \frac{1545.15 \text{ lbf / lbm } ^oR \text{ / lbmole}}{28.97} = 53.336 \frac{\text{ft lbf}}{\text{lbm } ^oR} \quad \text{also Table A} - 1\text{E in molar units}$$

$$V = \frac{m\,R\,T}{p} = \frac{1.2 \text{ lbm} \times 53.336 \text{ ft lbf/ lbm}^oR \times \left(124^o F + 459.69^o R\right)}{514 \text{ psia} \times 144 \text{ ft}^2\text{/in}^2}$$

$$V = .5047 \text{ft}^3$$

IDEAL GAS EQUATION FORMS - For Air

P	v	=	m	R	T	
kPa	m^3	=	kg mole	$8.314 \dfrac{kJ}{kg\ mole^{O}K}$	^{O}K	
kPa	m^3	=	kg	$.287 \dfrac{kPa\ m^3}{kg\ mole^{O}K}$	^{O}K	$\left(R = 8.314 \dfrac{kPa\ m^3}{kg\ mole^{o}K} / 28.96\right)$
$\dfrac{lb}{ft^2}$	ft^3	=	lbmole	$1545.15 \dfrac{ft\ lbf}{lbm\ ^{O}R}$	^{O}R	
$\dfrac{lb}{ft^2}$	ft^3	=	lbm	$53.35 \dfrac{ft\ lbf}{lbm\ ^{O}R}$	^{O}R	$\left(R = 1545.15 \dfrac{ft\ lbf^{3}}{lbm\ ^{O}R} /28.96\right)$
psi	ft^3	=	lbmole	$10.73 \dfrac{psi\ lbf}{lbmole\ ^{O}R}$	^{O}R	$\left(R = 1545.15 \dfrac{ft\ lbf}{lbm\ ^{O}R} /144\right)$
$\dfrac{lb}{ft^2}$	ft^3	=	lbm	$.06855 \dfrac{BTU}{lbm\ ^{O}R}$	^{O}R	$\left(R = 1545.15 \dfrac{ft\ lbf}{lbm\ ^{O}R} /28.96/778\right)$

Air initially at a volume of $12\ m^3$ and a pressure of $225\ kPa$ expands at a constant temperature to a volume of $23\ m^3$. What is the final pressure?

$$\text{mass} = \text{constant}, \qquad T = \text{constant}$$

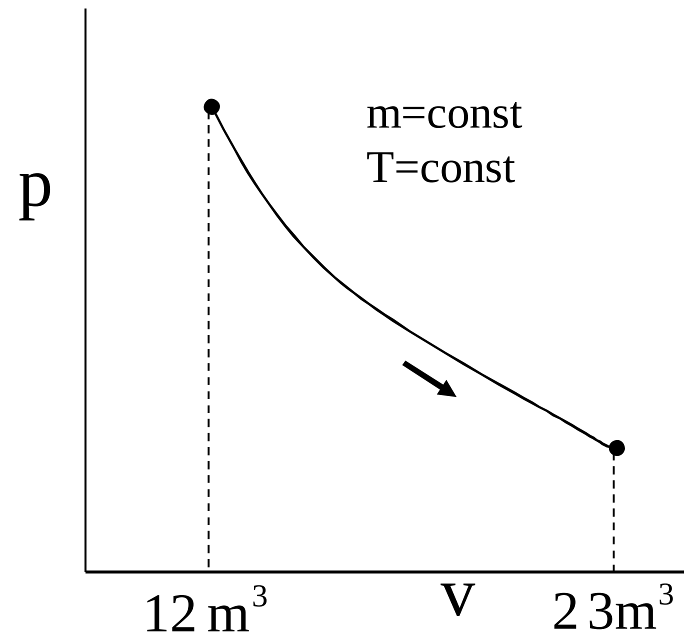
$$m = \frac{RT_1}{p_1 V_1} = \frac{.286 \times (273.15 + T_1)}{224\ kPa \times 23\ m^3}$$

$$m = \frac{R\ T_1}{p_1 V_1} = \frac{R\ T_2}{p_2 V_2}$$

$$p_2 = \frac{R\ T_2\ p_1\ V_1}{R\ T_1\ V_2} = p_1 \frac{V_1}{V_2}$$

$$p_2 = 225\ kPa\ \frac{12\ m^3}{23\ m^3}$$

$$p_2 = 117.39\ kPa$$



SPECIFIC HEAT

$$c_p = \left(\frac{\partial h}{\partial T}\right)_{p=\text{const}} \qquad c_v = \left(\frac{\partial u}{\partial T}\right)_{v=\text{const}}$$

$$\varphi h = \int c_p(T)\,dT \qquad \varphi u = \int c_v(T)\,dT$$

$$\text{Ideal Gas} \quad \varphi h = c_p \int dT \qquad \varphi u = c_v \int dT$$

$$h = u + pv$$

$$pv = RT$$

$$h = u + RT$$

$$dh = du + RdT$$

$$c_p dT = c_v dT + RdT$$

$$c_p - c_v = R \quad \text{with same units FOR IDEAL GAS ONLY} \quad \text{Eq (4-29)}$$

$$k = \frac{c_p}{c_v}$$

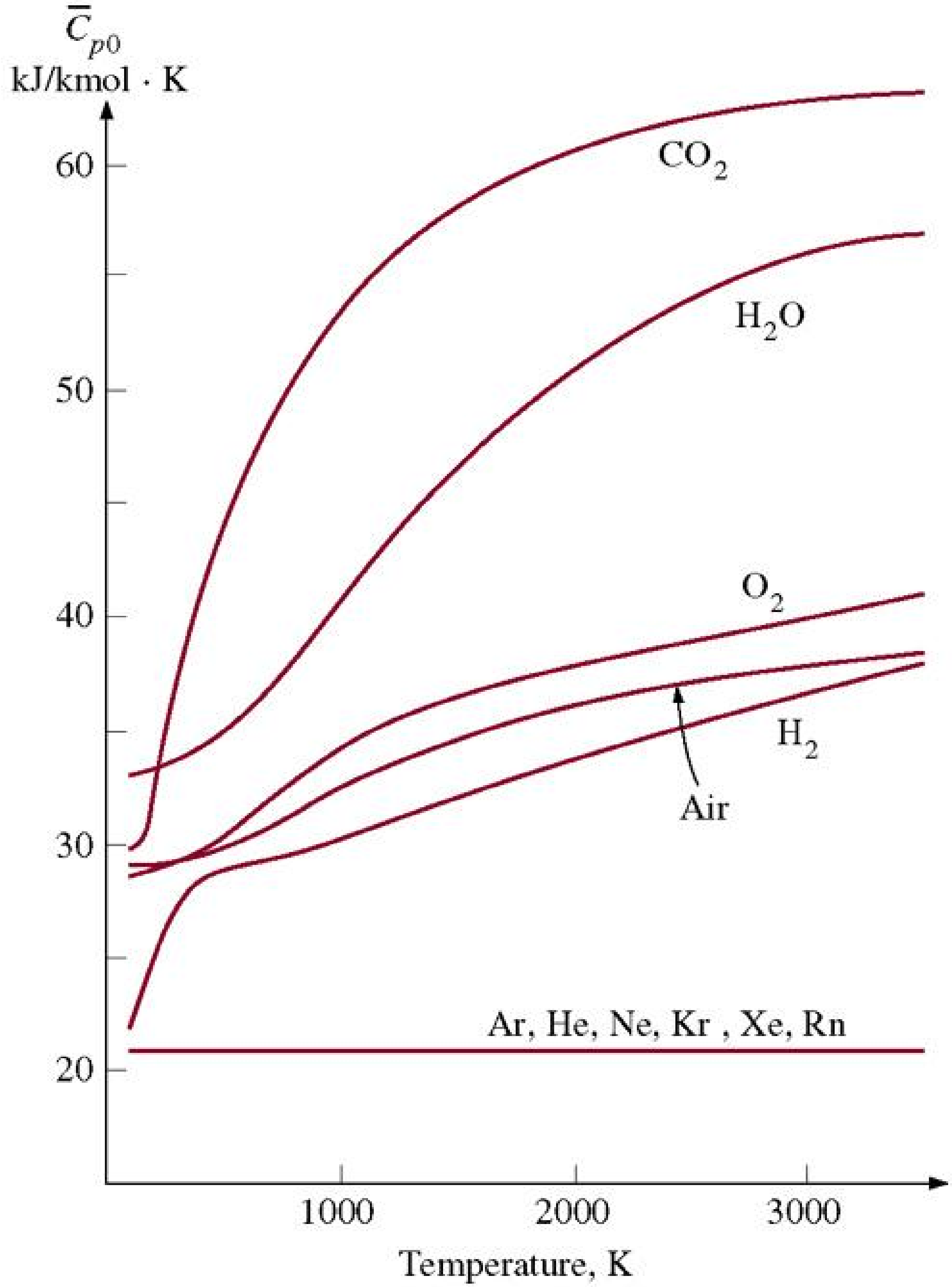
$$k - 1 = \frac{R}{c_v}$$

IDEAL GAS IMPROVEMENTS

$$h = \int c_p(T)\,dT$$

$$u = \int c_v(T)\,dT$$

Figure 4-24



AIR TABLE

air properties as a function of temperature
with variable temperature dependent specfic heat

TABLE A–17

Ideal-gas properties of air

T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/kg · K	T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/kg · K
200	199.97	0.3363	142.56	1707.0	1.29559	580	586.04	14.38	419.55	115.7	2.37348
210	209.97	0.3987	149.69	1512.0	1.34444	590	596.52	15.31	427.15	110.6	2.39140
220	219.97	0.4690	156.82	1346.0	1.39105	600	607.02	16.28	434.78	105.8	2.40902
230	230.02	0.5477	164.00	1205.0	1.43557	610	617.53	17.30	442.42	101.2	2.42644
240	240.02	0.6355	171.13	1084.0	1.47824	620	628.07	18.36	450.09	96.92	2.44356
250	250.05	0.7329	178.28	979.0	1.51917	630	638.63	19.84	457.78	92.84	2.46048
260	260.09	0.8405	185.45	887.8	1.55848	640	649.22	20.64	465.50	88.99	2.47716
270	270.11	0.9590	192.60	808.0	1.59634	650	659.84	21.86	473.25	85.34	2.49364
280	280.13	1.0889	199.75	738.0	1.63279	660	670.47	23.13	481.01	81.89	2.50985
285	285.14	1.1584	203.33	706.1	1.65055	670	681.14	24.46	488.81	78.61	2.52589
290	290.16	1.2311	206.91	676.1	1.66802	680	691.82	25.85	496.62	75.50	2.54175
295	295.17	1.3068	210.49	647.9	1.68515	690	702.52	27.29	504.45	72.56	2.55731
298	298.18	1.3543	212.64	631.9	1.69528	700	713.27	28.80	512.33	69.76	2.57277
300	300.19	1.3860	214.07	621.2	1.70203	710	724.04	30.38	520.23	67.07	2.58810
305	305.22	1.4686	217.67	596.0	1.71865	720	734.82	32.02	528.14	64.53	2.60319

Vapor and Liquid Phase Data - Microsoft Internet Explorer

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Thermophysical Properties of Fluid Systems

Accurate thermophysical properties are available for several fluids. These data include the following:

- Density
- C_p
- Enthalpy
- Internal energy
- Viscosity
- Joule-Thomson coefficient
- Specific volume
- C_v
- Entropy
- Speed of Sound
- Thermal conductivity
- Surface tension (saturation curve only)

NIST Webbook Properties

fttp://webbook.nist/gov/chemistry/fluid

Temperature Table for Water in .1 degree increments from 40 to 40 degrees.

Please follow the steps below to select the data required.

1. Please select the species of interest:
   Water
2. Please choose the units you wish to use:

Quantity	Units
Temperature	○ Kelvin ○ Celsius ◉ Fahrenheit ○ Rankine
Pressure	○ MPa ○ bar ○ atm. ○ torr ◉ psia
Density	○ mol/l ○ mol/m3 ○ g/ml ○ kg/m3 ○ lb-mole/ft3 ◉ lbm/ft3
Energy	○ kJ/mol ○ kJ/kg ○ kcal/mol ○ Btu/lb-mole ○ kcal/g ◉ Btu/lbm
Velocity	○ m/s ◉ ft/s ○ mph
Viscosity	○ uPa*s ○ Pa*s ○ cP ◉ lbm/ft*s
Surface tension*	○ N/m ○ dyn/cm ◉ lb/ft ○ lb/in

*Surface tension values are only available along the saturation curve.

Select Units

3. Choose the desired type of data:
   - ○ Isothermal properties
   - ◉ Saturation properties -- temperature increments
   - ○ Isobaric properties
   - ○ Saturation properties -- pressure increments
   - ○ Isochoric properties
4. Please select the desired standard state convention:
   Default for fluid
5. Press to Continue

Select Table Type

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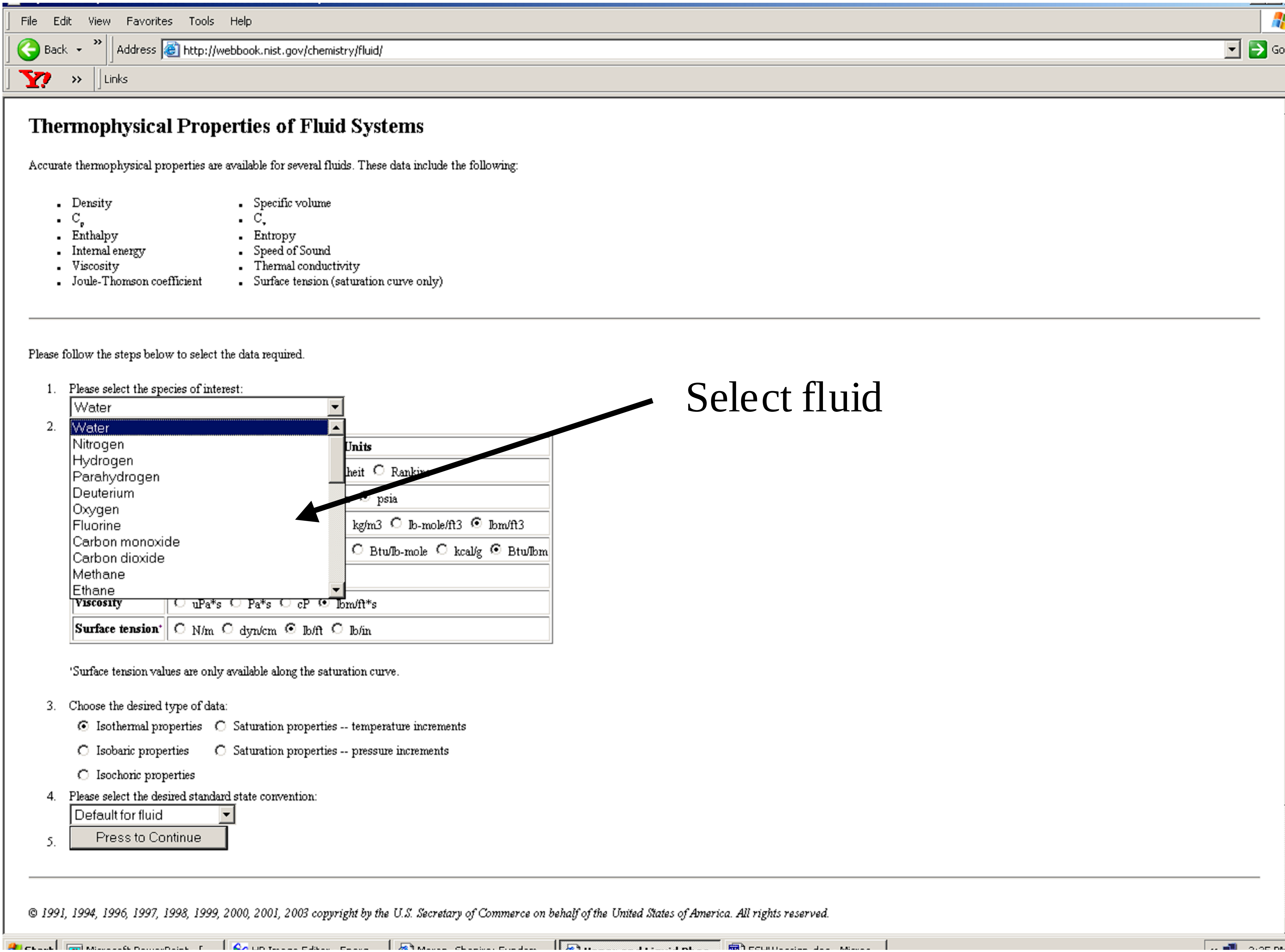
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Links
Thermophysical Properties of Fluid Systems
Accurate thermophysical properties are available for several fluids. These data include the following:
Density
Specific volume
Cp
Cv
Enthalpy
Entropy
Internal energy
Speed of Sound
Viscosity
Thermal conductivity
Joule-Thomson coefficient
Surface tension (saturation curve only)
Please follow the steps below to select the data required.
1. Please select the species of interest:
Water
Water
Nitrogen
Hydrogen
Parahydrogen
Deuterium
Oxygen
Fluorine
Carbon monoxide
Carbon dioxide
Methane
Ethane
2.
Units
heit Rankine
psia
kg/m3 lb-mole/ft3 lbm/ft3
Btu/lb-mole kcal/g Btu/lbm
Viscosity uPa*s Pa*s cP lbm/ft*s
Surface tension N/m dyn/cm lb/ft lb/in
Surface tension values are only available along the saturation curve.
3. Choose the desired type of data:
Isothermal properties
Saturation properties -- temperature increments
Isobaric properties
Saturation properties -- pressure increments
Isochoric properties
4. Please select the desired standard state convention:
Default for fluid
5. Press to Continue
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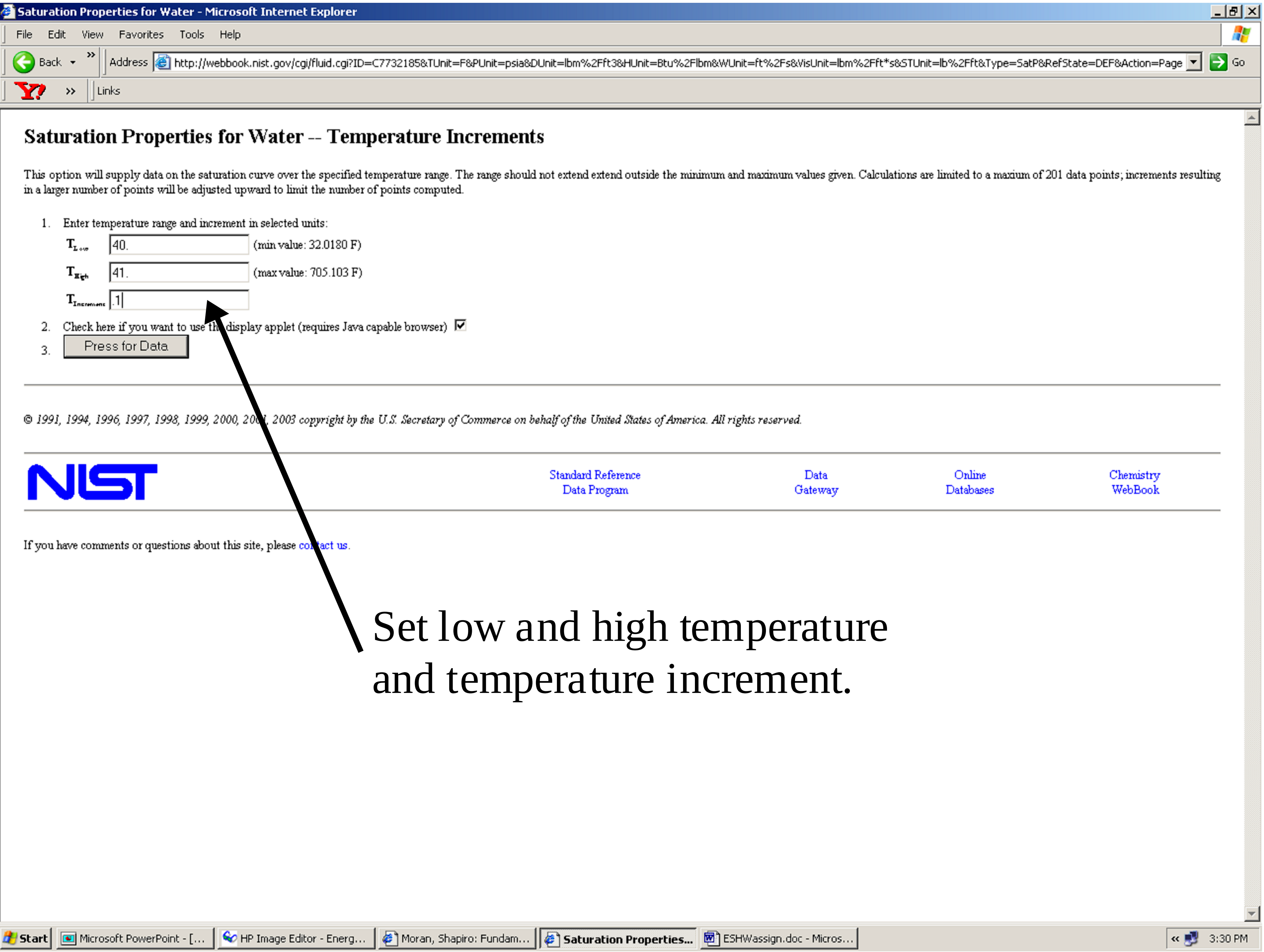
Select fluid



Set low and high temperature and temperature increment.

Saturation Properties for Water - Microsoft Internet Explorer

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Links

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Saturation Properties for Water -- Temperature Increments

- Fluid Data
- Auxiliary Data
- References
- Additional Information
- Notes
- **Other Data Available:**
  - View data in HTML table.
  - Download data as a tab-delimited text file.
  - Main NIST Chemistry WebBook page for this species.
  - Recommended citation for data from this page.
  - Fluid data for other species

Fluid Data

Data on Saturation Curve

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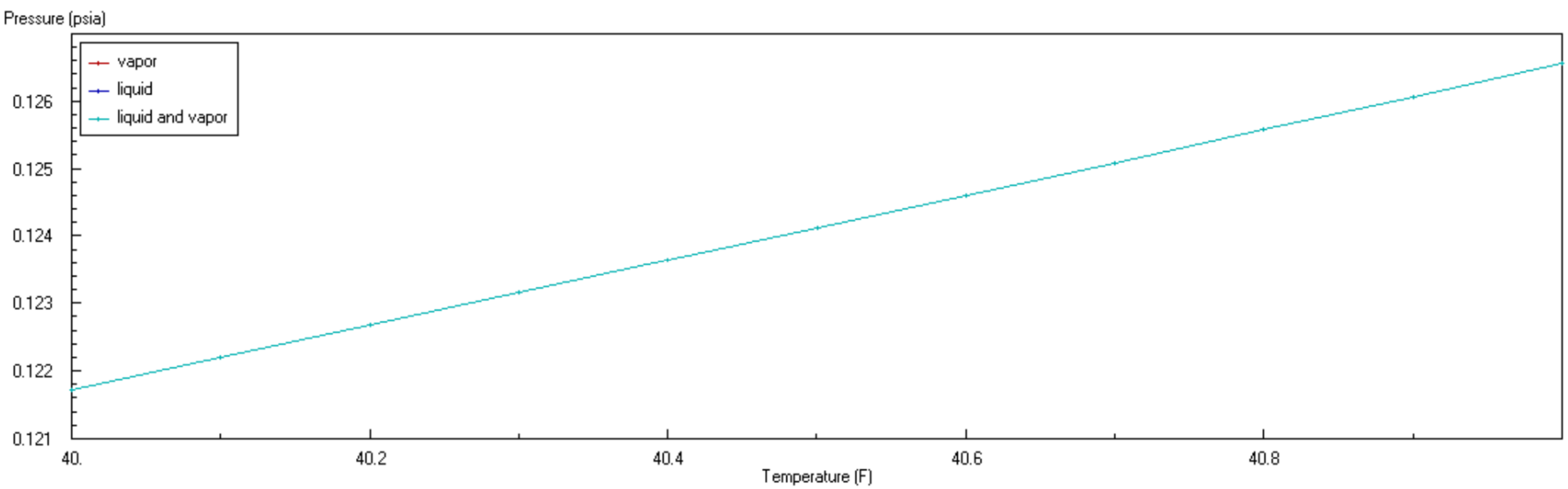

Y: Pressure (psia) X: Temperature (F)

Saturation Properties for Water - Microsoft Internet Explorer

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Saturation Properties for Water -- Temperature Increments

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  - Main NIST Chemistry WebBook page for this species.
  - Recommended citation for data from this page.
  - Fluid data for other species

Fluid Data

Data on Saturation Curve

View XY Plot

Temperature (F)	Pressure (psia)	Density (lbm/ft3)	Volume (ft3/lbm)	Internal Energy (Btu/lbm)	Enthalpy (Btu/lbm)
40.000	0.12173	undefined	undefined	undefined	undefined
40.000	0.12173	62.423	0.016020	8.0373	8.0377
40.000	0.12173	0.00040928	2443.3	1024.3	1079.4
40.100	0.12221	undefined	undefined	undefined	undefined
40.100	0.12221	62.423	0.016020	8.1379	8.1383
40.100	0.12221	0.00041079	2434.3	1024.4	1079.5
40.200	0.12269	undefined	undefined	undefined	undefined
40.200	0.12269	62.423	0.016020	8.2384	8.2388
40.200	0.12269	0.00041231	2425.3	1024.4	1079.5
40.300	0.12316	undefined	undefined	undefined	undefined
40.300	0.12316	62.423	0.016020	8.3390	8.3393
40.300	0.12316	0.00041384	2416.4	1024.4	1079.6
40.400	0.12364	undefined	undefined	undefined	undefined
40.400	0.12364	62.423	0.016020	8.4395	8.4399
40.400	0.12364	0.00041537	2407.5	1024.5	1079.6
40.500	0.12412	undefined	undefined	undefined	undefined
40.500	0.12412	62.423	0.016020	8.5400	8.5404
40.500	0.12412	0.00041690	2398.6	1024.5	1079.6
40.600	0.12461	undefined	undefined	undefined	undefined
40.600	0.12461	62.423	0.016020	8.6406	8.6409
40.600	0.12461	0.00041844	2389.8	1024.5	1079.7
40.700	0.12509	undefined	undefined	undefined	undefined
40.700	0.12509	62.423	0.016020	8.7411	8.7415
40.700	0.12509	0.00041998	2381.0	1024.6	1079.7
40.800	0.12558	undefined	undefined	undefined	undefined
40.800	0.12558	62.423	0.016020	8.8416	8.8420

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