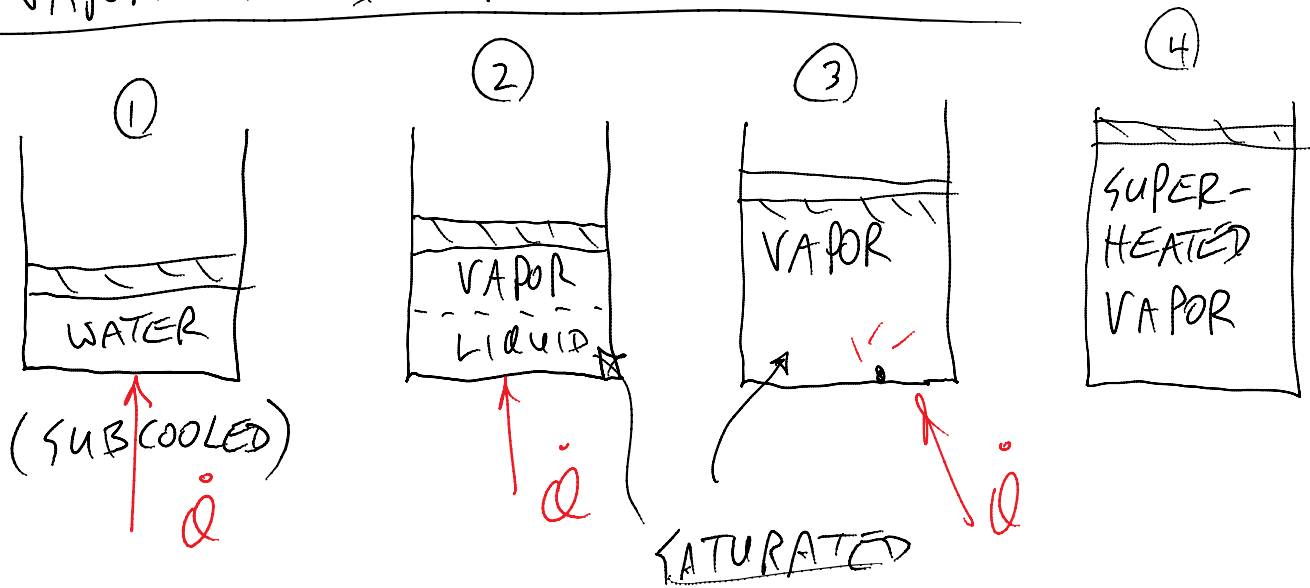


A PURE SUBSTANCE HAS A HOMOGENEOUS AND INVARIABLE CHEMICAL COMPOSITION.

WATER + ICE + WATER VAPOR

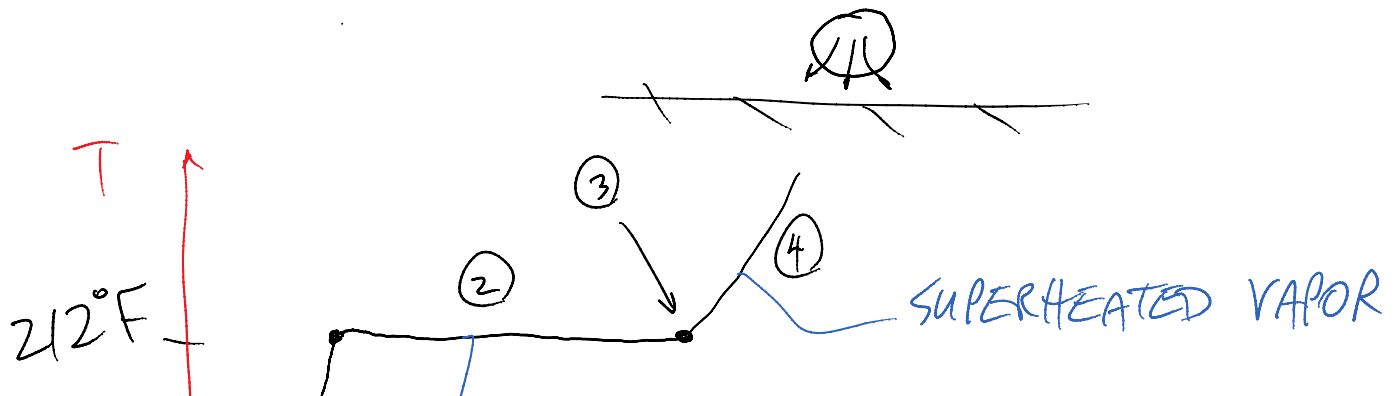
AIR: NOT A PURE SUBSTANCE, BUT BEHAVES LIKE ONE IF ONLY VAPOR PHASE IS PRESENT.

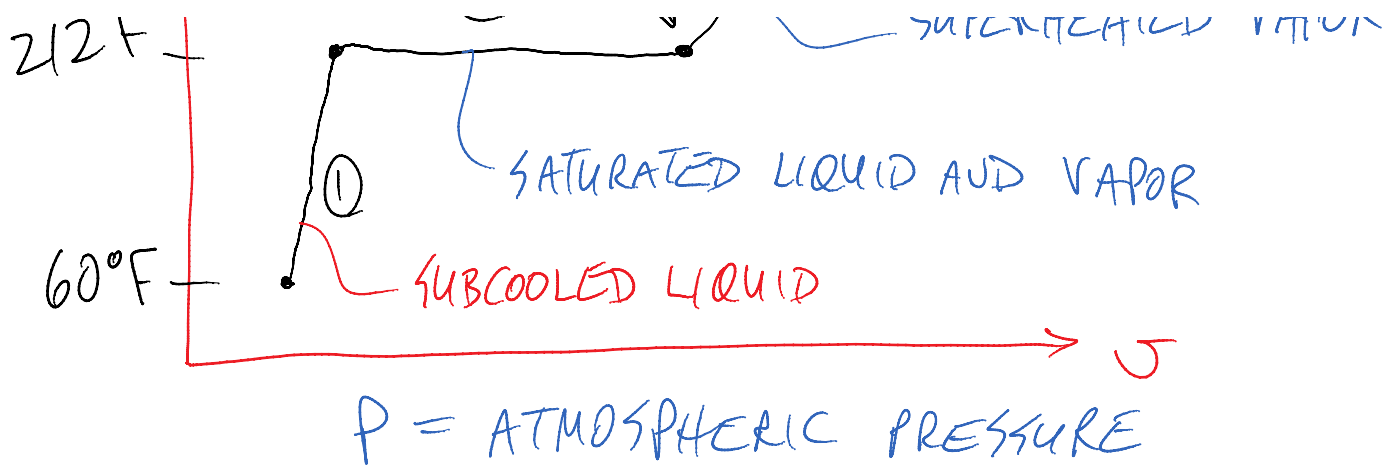
VAPOR-LIQUID PHASE EQUILIBRIUM



NUCLEATE BOILING

LEIDENFROST BOILING

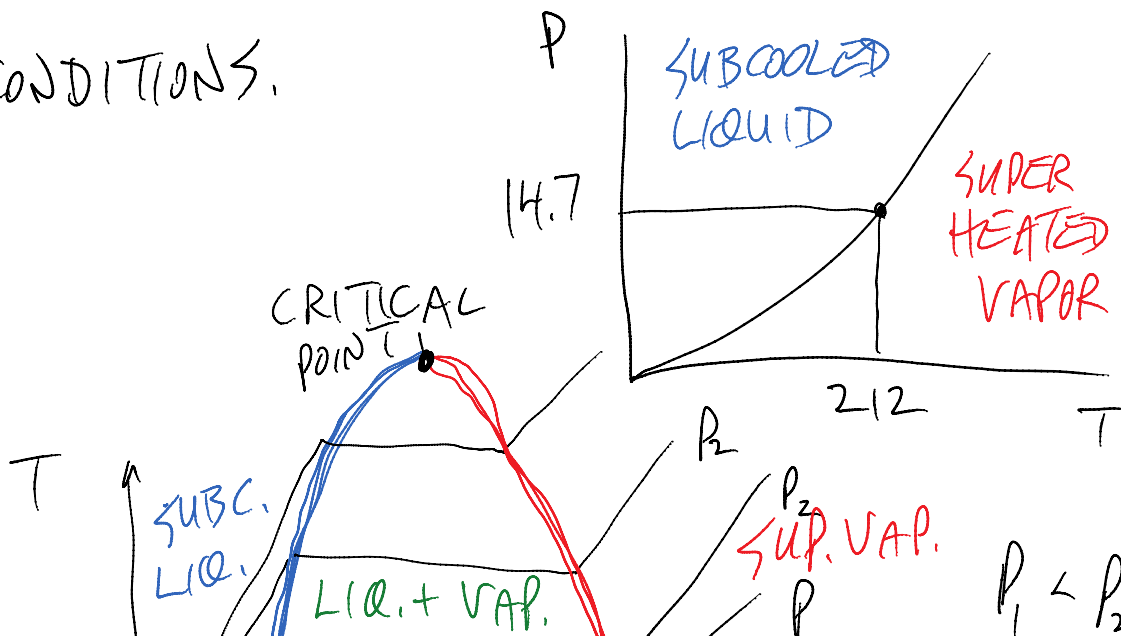




SATURATION TEMPERATURE IS THE TEMPERATURE AT WHICH VAPORIZATION OCCURS AT A GIVEN PRESSURE. THIS PRESSURE IS CALLED THE SATURATION PRESSURE.

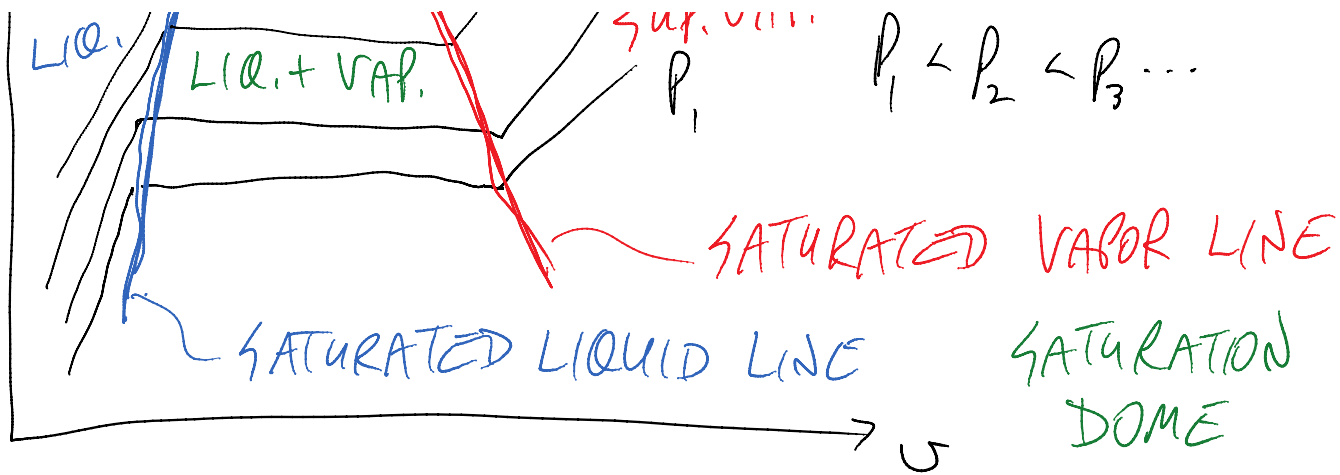
FOR WATER, $P_{sat} = 14.7 \frac{LBF}{IN^2}$, $T_{sat} = 212^\circ F$

P AND T ARE NOT THERMODYNAMICALLY INDEPENDENT PROPERTIES FOR SATURATION CONDITIONS.

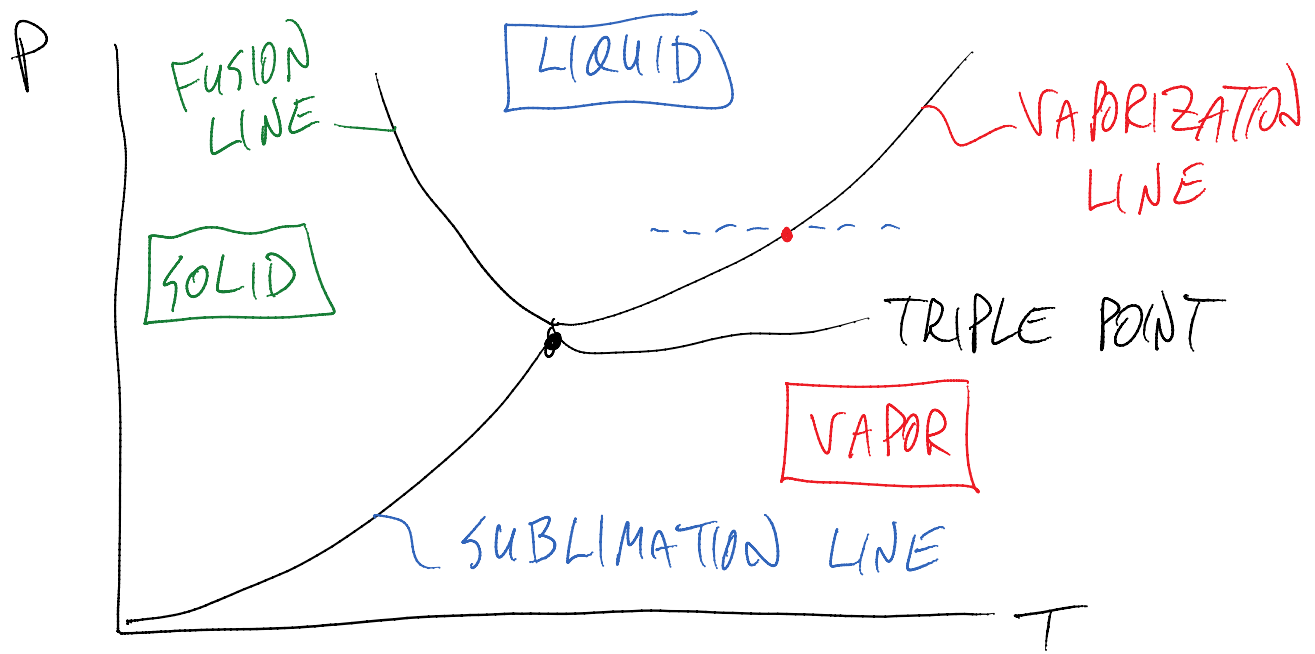


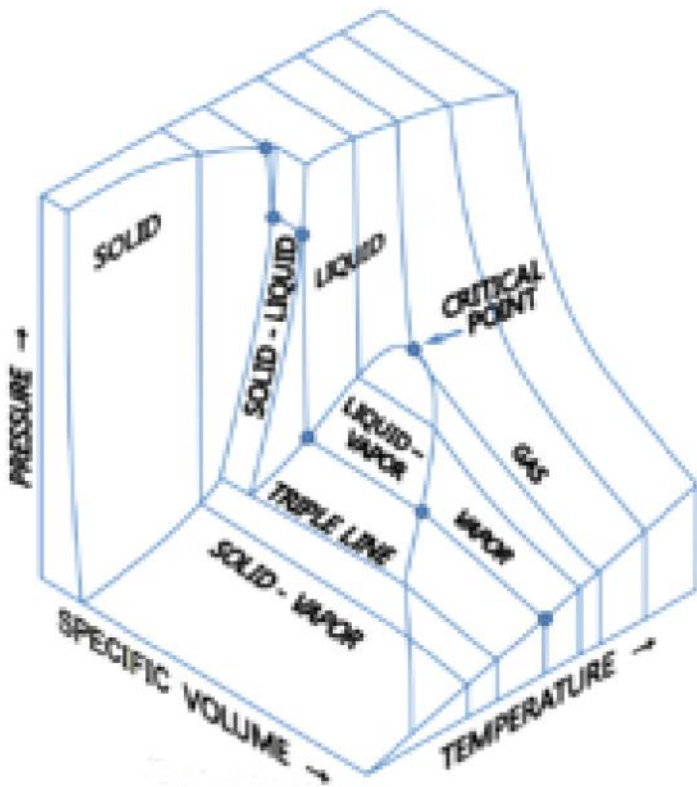
HANDY-DANDY ALL-PURPOSE MNEMONIC DEVICE OF THERMO

$$P_1 < P_2 < P_3 \dots$$



CRITICAL POINT: SATURATED LIQUID AND SATURATED VAPOR STATES ARE IDENTICAL.

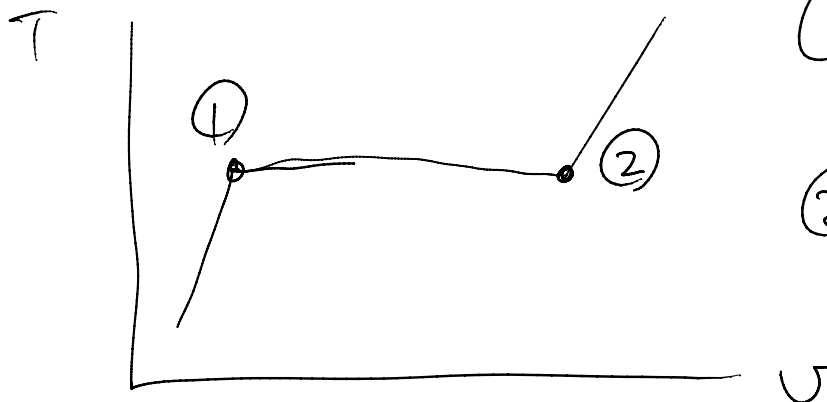




INDEPENDENT PROPERTIES

STATE POSTULATE: THE STATE OF A SIMPLE COMPRESSIBLE PURE SUBSTANCE IS DEFINED BY TWO THERMODYNAMICALLY INDEPENDENT PROPERTIES.

CONSIDER THE SATURATED STATE:



① : SATURATED LIQUID

② : SATURATED VAPOR

$$P_1 = P_2, \quad T_1 = T_2$$

P & T ARE NOT INDEPENDENT FOR SATURATED CONDITIONS.

P & U, T & U ARE INDEPENDENT.

DEFINE QUALITY OF A SATURATED PURE SUBSTANCE: (PROPERTY)

$$X = \frac{m_g}{m_T} = \frac{\text{MASS OF SATURATED VAPOR}}{\text{TOTAL SYSTEM MASS}}$$

$$0 \leq X \leq 1.0$$

X = 0 : SATURATED LIQUID

X = 1 : SATURATED VAPOR

FOR A SATURATED (TWO-PHASE) SYSTEM,

VOLUME IS:

$$V_T = V_f + V_g$$

SAT.

f = LIQUID, g = SAT. VAPOR

DIVIDE BY TOTAL SYSTEM MASS:

$$\frac{V_T}{m_T} = \frac{V_f}{m_T} + \frac{V_g}{m_T}$$

↑ QUALITY

$$\frac{V_T}{M_T} = \frac{V_f}{M_T} + \frac{V_g}{M_T}$$

$$U_T = \frac{V_T}{M_T} = \frac{M_f}{M_T} \cdot \frac{V_f}{M_f} + \frac{M_g}{M_T} \cdot \frac{V_g}{M_g}$$

$$M_T = M_f + M_g \Rightarrow M_f = M_T - M_g$$

$$U_T = \frac{(M_T - M_g)}{M_T} \cdot U_f + X \cdot U_g$$

$$U_T = (1 - X) \cdot U_f + X \cdot U_g$$

$$U_T = U_f + X(U_g - U_f) = U_f + X U_{fg}$$

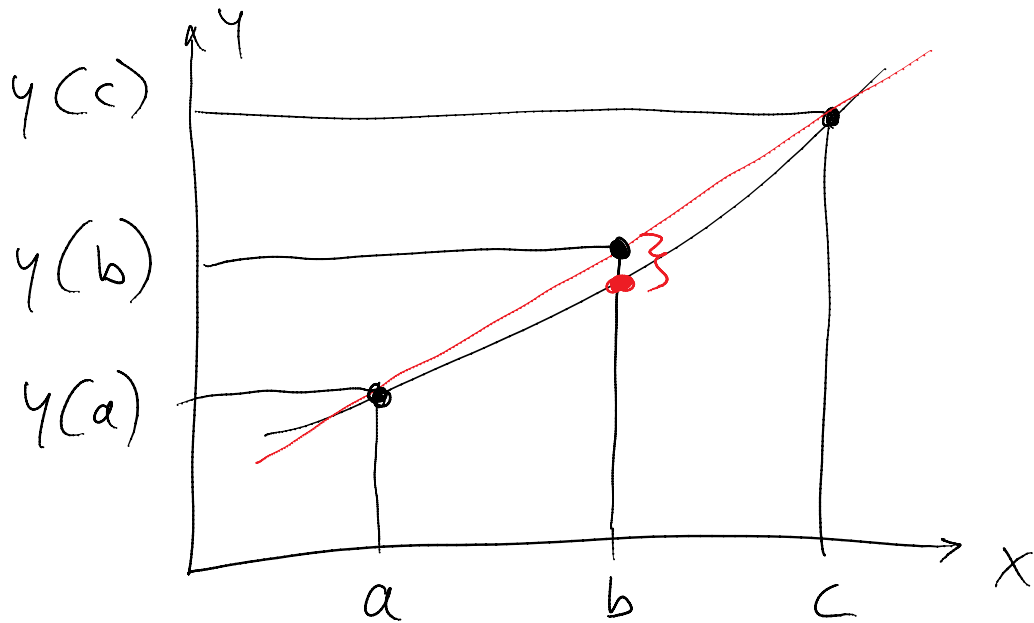
$U_{fg} = U_g - U_f =$ DIFFERENCE BETWEEN THE SPECIFIC VOLUMES OF SATURATED VAPOR AND SATURATED LIQUID,

$$u_T = u_f + X u_{fg} \quad \text{INTERNAL ENERGY}$$

$$h_T = h_f + X h_{fg} \quad \text{ENTHALPY}$$

$$s_T = s_f + X s_{fg} \quad \text{ENTROPY}$$

Linear Interpolation



$$Y - Y_1 = m(x - x_1) \quad \longrightarrow \quad m = \frac{Y_2 - Y_1}{X_2 - X_1}$$

$$Y - Y(a) = m(x - a)$$

$$m = \frac{Y(c) - Y(a)}{c - a}$$

$$Y(b) = Y(a) + \left[\frac{Y(c) - Y(a)}{c - a} \right] \cdot (b - a)$$

EXAMPLE FOR WATER AT $T_{sat} = 43.4^\circ\text{C}$
FIND P_{sat}

TABLE A-4

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m^3/kg	
		Sat. liquid, v_f	Sat. vapor, v_g
0.01	0.6117	0.001000	206.00
5	0.8725	0.001000	147.03
10	1.2281	0.001000	106.32
15	1.7057	0.001001	77.885
20	2.3392	0.001002	57.762
25	3.1698	0.001003	43.340
30	4.2469	0.001004	32.879
35	5.6291	0.001006	25.205
1. 40	7.3851	0.001008	19.515
2. 45	9.5953	0.001010	15.251
50	12.352	0.001012	12.026
55	15.763	0.001015	9.5639
60	19.947	0.001017	7.6670
65	25.043	0.001020	6.1935
70	31.202	0.001023	5.0396

} v

$$P = P_1 + \left(\frac{P_2 - P_1}{T_2 - T_1} \right) (T - T_1) *$$

$$T_1 = 40 \quad P_1 = 7.3851$$

$$T_2 = 45 \quad P_2 = 9.5953$$

$$P = (7.3851) + \left(\frac{9.5953 - 7.3851}{45 - 40} \right) (43.4 - 40)$$

$$P = 8.886 \text{ kPa}$$

2-28E Complete the following table for H₂O:

	T, °F	P, psia	u, Btu/lbm	Phase description
a	300		782	
b		40		Saturated liquid
c	500	120		
d	400	400		

a) $T = 300^\circ\text{F}$, $u = 782 \frac{\text{Btu}}{\text{lbm}}$ (INTERNAL ENERGY)

SATURATED WATER (TEMPERATURE) TABLE

TABLE A-4E

Saturated water—Temperature table

Temp., T °F	Sat. press., P _{sat} psia	Specific volume, ft ³ /lbm		Internal energy, Btu/lbm			
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g	
250	29.844	0.01700	13.816	218.54	869.21	1087.7	218.63
260	35.447	0.01708	11.760	228.68	861.62	1090.3	228.79
270	41.877	0.01717	10.059	238.85	853.94	1092.8	238.98
280	49.222	0.01726	8.6439	249.04	846.16	1095.2	249.20
290	57.573	0.01735	7.4607	259.26	838.27	1097.5	259.45
300	67.028	0.01745	6.4663	269.51	830.25	1099.8	269.73
310	77.691	0.01755	5.6266	279.79	822.11	1101.9	280.05
320	89.667	0.01765	4.9144	290.11	813.84	1104.0	290.40
330	103.07	0.01776	4.3076	300.46	805.43	1105.9	300.80
340	118.02	0.01787	3.7885	310.85	796.87	1107.7	311.24

For $T_{\text{sat}} = 300^\circ\text{F}$, $u_f = 269.51$ ~~269.51~~ $u_g = 1099.8 \frac{\text{Btu}}{\text{lbm}}$

$$u = 782 \frac{\text{Btu}}{\text{lbm}}$$

SINCE $u_f \leq u \leq u_g$, THE SYSTEM IS SATURATED,
 "THE THREE IF-THEN STATEMENTS OF THERMO":

IF $u < u_f$, THEN SYSTEM IS SUBCOOLED
 OR COMPRESSED LIQUID,

IF $u_f \leq u \leq u_g$, THEN SYSTEM IS SATURATED,

IF $u > u_g$, THEN SYSTEM IS SUPERHEATED VAPOR.

$$P = P_{\text{sat}}(T_{\text{sat}} = 300^\circ\text{F}) = 67.03 \text{ psia}$$

b) $P = 40 \text{ psia}$, PHASE: SATURATED LIQUID,

FIND T , u

SATURATED WATER (PRESSURE) TABLE A-5E

TABLE A-5E

Saturated water—Pressure table

Press	Sat. temp	Specific volume, ft^3/lbm		Internal energy, Btu/lbm	
		Sat. liquid	Sat. vapor	Sat. liquid	Sat. vapor

$$T = T_{\text{sat}}(P_{\text{sat}} = 40 \text{ psia})$$

$$T = 267.77^\circ\text{F}$$

Press., P psia	Sat. temp., T _{sat} °F	ft ³ /lbm		Btu/lbm		
		Sat. liquid, v _f	Sat. vapor, v _g	Sat. liquid, u _f	Evap., u _{fg}	Sat. vapor, u _g
1	101.69	0.01614	333.49	69.72	973.99	1043.7
2	126.02	0.01623	173.71	94.02	957.45	1051.5
3	141.41	0.01630	118.70	109.39	946.90	1056.3
4	152.91	0.01636	90.629	120.89	938.97	1059.9
5	162.18	0.01641	73.525	130.17	932.53	1062.7
6	170.00	0.01645	61.982	138.00	927.08	1065.1
8	182.81	0.01652	47.347	150.83	918.08	1068.9
10	193.16	0.01659	38.425	161.22	910.75	1072.0
14.696	211.95	0.01671	26.805	180.12	897.27	1077.4
15	212.99	0.01672	26.297	181.16	896.52	1077.7
20	227.92	0.01683	20.093	196.21	885.63	1081.8
25	240.03	0.01692	16.307	208.45	876.67	1085.1
30	250.30	0.01700	13.749	218.84	868.98	1087.8
35	259.25	0.01708	11.901	227.80	862.19	1090.1
40	267.22	0.01715	10.501	236.02	856.09	1092.1

$$T = 267.22 \text{ } ^\circ\text{F}$$

$$u = u_f (P_{sat} = 40 \text{ PSIA})$$

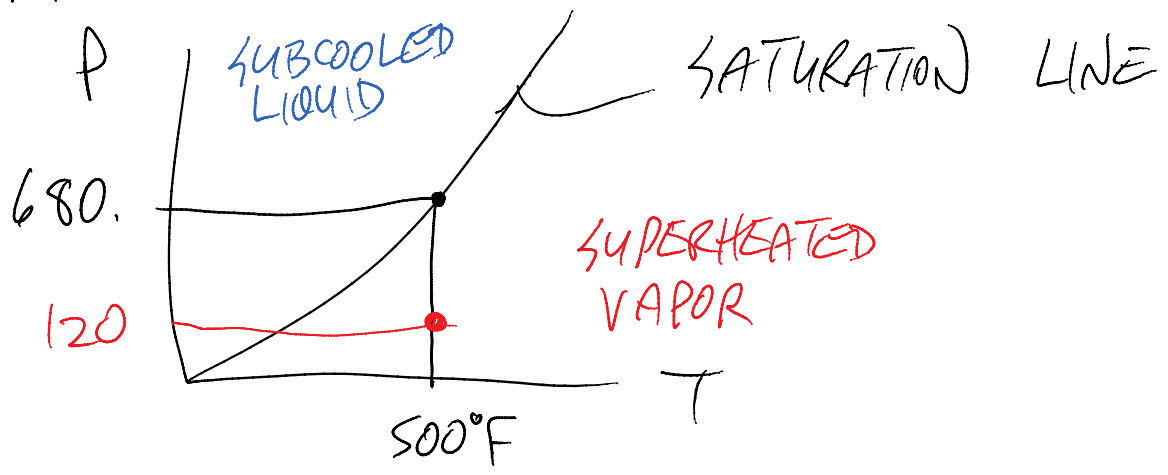
$$u = 236.02 \frac{\text{Btu}}{\text{LBM}}$$

c) $T = 500 \text{ } ^\circ\text{F}$, $P = 120 \text{ PSIA}$

SATURATED TEMP. TABLE:

FOR $T_{sat} = 500 \text{ } ^\circ\text{F}$, $P_{sat} = 680.56 \text{ PSIA}$

H.D.A.P.M.D.O.T. :



PHASE: SUPERHEATED VAPOR

GO TO THE SUPERHEATED VAPOR TABLE

TABLE A-4E

TABLE A-4E

Saturated water—Temperature table (*Concluded*)

Temp., T °F	Sat. press., P_{sat} psia	Specific volume, ft ³ /lbm		Internal energy, Btu/lbm		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g
400	247.26	0.01864	1.8639	374.19	741.97	1116.2
410	276.69	0.01878	1.6706	384.94	732.14	1117.1
420	308.76	0.01894	1.5006	395.76	722.08	1117.8
430	343.64	0.01910	1.3505	406.65	711.80	1118.4
440	381.49	0.01926	1.2178	417.61	701.26	1118.9
450	422.47	0.01944	1.0999	428.66	690.47	1119.1
460	466.75	0.01962	0.99510	439.79	679.39	1119.2
470	514.52	0.01981	0.90158	451.01	668.02	1119.0
480	565.96	0.02001	0.81794	462.34	656.34	1118.7
490	621.24	0.02022	0.74296	473.77	644.32	1118.1
500	680.56	0.02044	0.67558	485.32	631.94	1117.3
510	744.11	0.02067	0.61489	496.99	619.17	1116.2
520	812.11	0.02092	0.56009	508.80	605.99	1114.8
530	884.74	0.02118	0.51051	520.76	592.35	1113.1
540	962.24	0.02146	0.46553	532.88	578.23	1111.1

TABLE A-6E

Superheated water (Continued)

T °F	v ft ³ /lbm	u Btu/lbm	h Btu/lbm	s Btu/ lbm · R
<i>P</i> = 120 psia (341.25°F)				
Sat.	3.7289	1107.9	1190.8	1.5883
360	3.8446	1116.7	1202.1	1.6023
400	4.0799	1134.0	1224.6	1.6292
450	4.3613	1154.5	1251.4	1.6594
500	4.6340	1174.4	1277.3	1.6872
550	4.9010	1193.9	1302.8	1.7131
600	5.1642	1213.4	1328.0	1.7375
700	5.6829	1252.2	1378.4	1.7829
800	6.1950	1291.4	1429.0	1.8247
1000	7.2083	1371.7	1531.8	1.9005
1200	8.2137	1455.3	1637.7	1.9684
1400	9.2149	1542.3	1746.9	2.0305
1600	10.2135	1633.0	1859.8	2.0881
1800	11.2106	1727.2	1976.1	2.1420
2000	12.2067	1824.8	2095.8	2.1928

FOR $P = 120$ PSIA

$T = 500$ °F

$u = 1174.4 \frac{\text{Btu}}{\text{lbm}}$

d) $T = 400$ °F, $P = 400$ PSIA

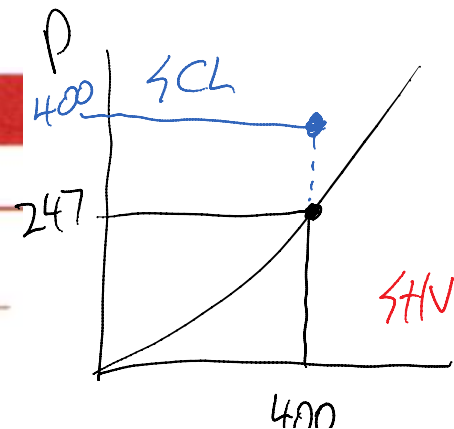
GO TO SATURATED TEMPERATURE TABLE:

FOR $T_{\text{sat}} = 400$ °F, $P_{\text{sat}} = 247.26$ PSIA

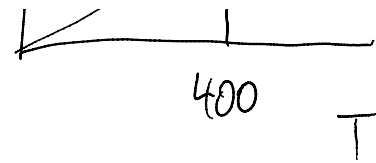
TABLE A-4E

Saturated water—Temperature table (Concluded)

Temp., °F	Sat. press., psia	Specific volume, ft ³ /lbm		Internal energy, Btu/lbm		
		Sat. liquid,	Sat. vapor,	Sat. liquid,	Evap.,	Sat. vapor,
...



Temp., T °F	Sat. press., P_{sat} psia	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g
400	247.26	0.01864	1.8639	374.19	741.97	1116.2
410	276.69	0.01878	1.6706	384.94	732.14	1117.1
420	308.76	0.01894	1.5006	395.76	722.08	1117.8
430	343.64	0.01910	1.3505	406.65	711.80	1118.4
440	381.49	0.01926	1.2178	417.61	701.26	1118.9



PHASE:
SUBCOOLED
LIQUID.

GO TO SUBCOOLED OR COMPRESSED LIQUID TABLE:

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TABLE A-7E

Compressed liquid water

T °F	v ft ³ /lbm	u Btu/lbm	h Btu/lbm	s Btu/lbm · R	v ft ³ /lbm	u Btu/lbm	h Btu/lbm	s Btu/lbm · R
$P = 500$ psia (467.04°F)					$P = 1000$ psia (544.65°F)			
Sat.	0.019750	447.68	449.51	0.64900	0.021595	538.58	542.57	0.74341
32	0.015994	0.01	1.49	0.00001	0.015966	0.03	2.99	0.00005
50	0.015998	18.03	19.51	0.03601	0.015972	17.99	20.95	0.03593
100	0.016107	67.86	69.35	0.12930	0.016083	67.69	70.67	0.12899
150	0.016317	117.70	119.21	0.21462	0.016292	117.42	120.43	0.21416
200	0.016607	167.70	169.24	0.29349	0.016580	167.31	170.38	0.29289
250	0.016972	218.04	219.61	0.36708	0.016941	217.51	220.65	0.36634
300	0.017417	268.92	270.53	0.43641	0.017380	268.24	271.46	0.43551
350	0.017954	320.64	322.30	0.50240	0.017910	319.77	323.08	0.50132
400	0.018609	373.61	375.33	0.56595	0.018552	372.48	375.91	0.56463
450	0.019425	428.44	430.24	0.62802	0.019347	426.93	430.51	0.62635
500					0.020368	484.03	487.80	0.68764
550								

AT $T = 400$ °F:

$P = 500$ PSIA

$u = 373.61 \frac{\text{Btu}}{\text{lbm}}$

$$P_2 = 1000 \text{ psia}, \quad u_2 = 372.48$$

$$u = u_1 + \left(\frac{u_2 - u_1}{P_2 - P_1} \right) (P - P_1)$$

$$u = (373.61) + \left(\frac{372.48 - 373.61}{1000 - 500} \right) (400 - 500)$$

$$u = 373.91 \frac{\text{Btu}}{\text{LBM}}$$

2-30 Complete the following table for H₂O:

<i>T</i> , °C	<i>P</i> , kPa	<i>h</i> , kJ/kg	<i>x</i>	Phase description
	200		0.7	
140		1800		
	950		0.0	
80	500			
	800	3161.7		

a
b
c
d
e

a) $P = 200 \text{ kPa}$, $x = 0.7$, FIND T , h , PHASE
 PHASE DESCRIPTION: SATURATED SYSTEM

$$0 \leq x \leq 1 \quad x = \frac{m_g}{m_T}$$

$$T = T_{\text{sat}} (P_{\text{sat}} = 200 \text{ kPa}) = 120.21^\circ\text{C}$$

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TABLE A-5 Saturated water—Pressure table

Press., <i>P</i> kPa	Sat. temp., <i>T</i> _{sat} °C	Specific volume, m ³ /kg			Internal energy, kJ/kg			Enthalpy, kJ/kg		
		Sat. liquid, <i>v</i> _f	Sat. vapor, <i>v</i> _g	Sat. liquid, <i>u</i> _f	Evap., <i>u</i> _{fg}	Sat. vapor, <i>u</i> _g	Sat. liquid, <i>h</i> _f	Evap., <i>h</i> _{fg}	Sat. vapor, <i>h</i> _g	
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	

FOR A SATURATED SYSTEM,

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

$$h = (504.71) + (0.7)(2201.6) = 2046 \frac{\text{kJ}}{\text{kg}}$$

$$h = (504.71) + (0.7)(2201.6) = 2076 \text{ kJ/kg}$$

b) $T = 140^\circ\text{C}$, $h = 1800 \frac{\text{kJ}}{\text{kg}}$

FOR $T_{\text{sat}} = 140^\circ\text{C}$, $h_f = 589.16$ $h_g = 2733.5$
 $h_f \leq h \leq h_g \therefore$ SATURATED SYSTEM

TABLE A-4

Saturated water—Temperature table

Temp., $T^\circ\text{C}$	Sat. press., P_{sat} kPa	Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
		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
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9
140	361.53	0.001080	0.50850	588.77	1960.9	2549.6	589.16	2144.3	2733.5
145	415.68	0.001085	0.44600	610.19	1944.2	2554.4	610.64	2129.2	2739.8

$$P = P_{\text{sat}} (T_{\text{sat}} = 140^\circ\text{C}) = 361.53 \text{ kPa}$$

FIND QUALITY: $h = h_f + X h_{fg}$

$$X = \frac{h - h_f}{h_{fg}} = \frac{1800 - 589.16}{2733.5} = 0.564$$

c) $P = 950 \text{ kPa}$, $X = 0.0$

SATURATED LIQUID

$$T = T_{\text{sat}} (P_{\text{sat}} = 950 \text{ kPa}) = 177.66^\circ\text{C}$$

TABLE A-5

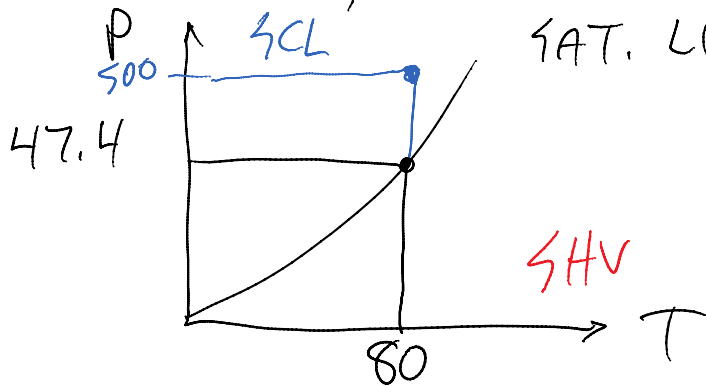
Saturated water—Pressure table (Continued)

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m ³ /kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
		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
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87	2047.5	2768.3
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1

$$h = h_f (P_{sat} = 950 \text{ kPa}) = 752.74 \frac{\text{kJ}}{\text{kg}}$$

d) $T = 80^\circ\text{C}$, $P = 500 \text{ kPa}$

FOR $T_{sat} = 80^\circ\text{C}$, $P_{sat} = 47.416 \text{ kPa}$



PHASE: SCL

TABLE A-4

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg		
		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
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6

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
	<u>P = 5 MPa (263.94°C)</u>				<u>P = 10 MPa (311.00°C)</u>			
Sat.	0.0012862	1148.1	1154.5	2.9207	0.0014522	1393.3	1407.9	3.3603
0	0.0009977	0.04	5.03	0.0001	0.0009952	0.12	10.07	0.0003
20	0.0009996	83.61	88.61	0.2954	0.0009973	83.31	93.28	0.2943
40	0.0010057	166.92	171.95	0.5705	0.0010035	166.33	176.37	0.5685
60	0.0010149	250.29	255.36	0.8287	0.0010127	249.43	259.55	0.8260
80	0.0010267	333.82	338.96	1.0723	0.0010244	332.69	342.94	1.0691
100	0.0010410	417.65	422.85	1.3034	0.0010385	416.23	426.62	1.2996
120	0.0010576	501.91	507.19	1.5236	0.0010549	500.18	510.73	1.5191
140	0.0010769	586.80	592.18	1.7344	0.0010738	584.72	595.45	1.7293
160	0.0010988	672.55	678.04	1.9374	0.0010954	670.06	681.01	1.9316
180	0.0011240	759.47	765.09	2.1338	0.0011200	756.48	767.68	2.1271
200	0.0011531	847.92	853.68	2.3251	0.0011482	844.32	855.80	2.3174
220	0.0011868	938.39	944.32	2.5127	0.0011809	934.01	945.82	2.5037
240	0.0012268	1031.6	1037.7	2.6983	0.0012192	1026.2	1038.3	2.6876
260	0.0012755	1128.5	1134.9	2.8841	0.0012653	1121.6	1134.3	2.8710
280					0.0013226	1221.8	1235.0	3.0565
300					0.0013980	1329.4	1343.3	3.2488

$P_1 = 5 \text{ MPa}, h_1 = 338.96, P_2 = 10 \text{ MPa}, h_2 = 342.94$

$$h = h_1 + \left(\frac{h_2 - h_1}{P_2 - P_1} \right) (P - P_1)$$

$P = (500 \text{ kPa}) \left(\frac{\text{MPa}}{1000 \text{ kPa}} \right)$
 $P = 0.5 \text{ MPa}$

$$h = (338.96) + \left(\frac{342.94 - 338.96}{10 - 5} \right) (0.5 - 5)$$

$h = 335.3 \frac{\text{kJ}}{\text{kg}}$

FIND QUALITY: ONLY DEFINED FOR SATURATED SYSTEMS.

$X = \text{UNDEFINED}$

e) $P = 800 \text{ kPa}$, $h = 3162.2 \frac{\text{kJ}}{\text{kg}}$, FIND T , x , PHASE

SATURATED PRESSURE TABLE:

FOR $P_{\text{sat}} = 800 \text{ kPa}$, $h_f = 720.87$, $h_g = 2768.3 \frac{\text{kJ}}{\text{kg}}$

$h > h_g$: SUPERHEATED VAPOR

TABLE A-5
Saturated water—Pressure table (Continued)

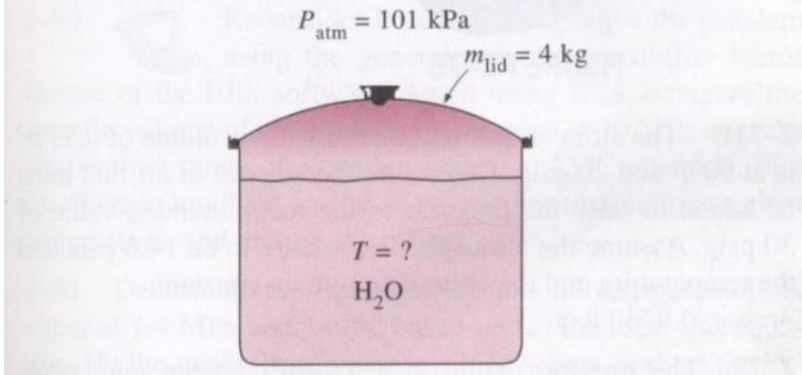
Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m^3/kg			Internal energy, kJ/kg			Enthalpy, kJ/kg		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	
800	170.41	0.001115	0.24035	719.97	1856.1	2576.0	720.87	2047.5	2768.3	
850	172.94	0.001118	0.22690	731.00	1846.9	2577.9	731.95	2038.8	2770.8	
900	175.35	0.001121	0.21489	741.55	1838.1	2579.6	742.56	2030.5	2773.0	
950	177.66	0.001124	0.20411	751.67	1829.6	2581.3	752.74	2022.4	2775.2	
1000	179.88	0.001127	0.19436	761.39	1821.4	2582.8	762.51	2014.6	2777.1	

$T = 350^\circ\text{C}$

$x = \text{UNDEFINED}$

	$P = 0.50 \text{ MPa (151.83}^\circ\text{C)}$				$P = 0.60 \text{ MPa (158.83}^\circ\text{C)}$				$P = 0.80 \text{ MPa (170.41}^\circ\text{C)}$			
Sat.	0.37483	2560.7	2748.1	6.8207	0.31560	2566.8	2756.2	6.7593	0.24035	2576.0	2768.3	6.6616
200	0.42503	2643.3	2855.8	7.0610	0.35212	2639.4	2850.6	6.9683	0.26088	2631.1	2839.8	6.8177
250	0.47443	2723.8	2961.0	7.2725	0.39390	2721.2	2957.6	7.1833	0.29321	2715.9	2950.4	7.0402
300	0.52261	2803.3	3064.6	7.4614	0.43442	2801.4	3062.0	7.3740	0.32416	2797.5	3056.9	7.2345
350	0.57015	2883.0	3168.1	7.6346	0.47428	2881.6	3166.1	7.5481	0.35442	2878.6	3162.2	7.4107
400	0.61731	2963.7	3272.4	7.7956	0.51374	2962.5	3270.8	7.7097	0.38429	2960.2	3267.7	7.5735
500	0.71095	3129.0	3484.5	8.0893	0.59200	3128.2	3483.4	8.0041	0.44332	3126.6	3481.3	7.8692
600	0.80409	3300.4	3702.5	8.3544	0.66976	3299.8	3701.7	8.2695	0.50186	3298.7	3700.1	8.1354
700	0.89696	3478.6	3927.0	8.5978	0.74725	3478.1	3926.4	8.5132	0.56011	3477.2	3925.3	8.3794
800	0.98966	3663.6	4158.4	8.8240	0.82457	3663.2	4157.9	8.7395	0.61820	3662.5	4157.0	8.6061
900	1.08227	3855.4	4396.6	9.0362	0.90179	3855.1	4396.2	8.9518	0.67619	3854.5	4395.5	8.8185
1000	1.17480	4054.0	4641.4	9.2364	0.97893	4053.8	4641.1	9.1521	0.73411	4053.3	4640.5	9.0189
1100	1.26728	4259.0	4892.6	9.4263	1.05603	4258.8	4892.4	9.3420	0.79197	4258.3	4891.9	9.2090
1200	1.35972	4470.0	5149.8	9.6071	1.13309	4469.8	5149.6	9.5229	0.84980	4469.4	5149.3	9.3898
1300	1.45214	4686.6	5412.6	9.7797	1.21012	4686.4	5412.5	9.6955	0.90761	4686.1	5412.2	9.5625

2-46 A cooking pan whose inner diameter is 20 cm is filled with water and covered with a 4-kg lid. If the local atmospheric pressure is 101 kPa, determine the temperature at which the water will start boiling when it is heated. **Answer: 100.2°C**



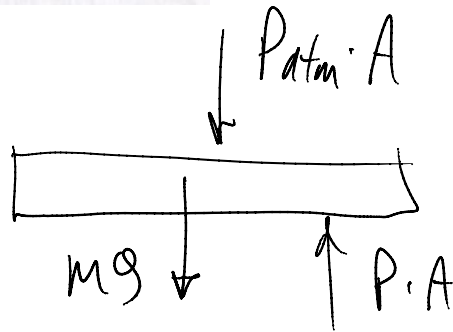
$$H_2O, M_{LID} = 4 \text{ kg}$$

$$P_{atm} = 101 \text{ kPa}$$

$$D = (20 \text{ cm}) \left(\frac{m}{100 \text{ cm}} \right) = 0.2 \text{ m}$$

FIND BOILING TEMPERATURE

FBD OF LID



$$P = \frac{F}{A}$$

$$A = \frac{\pi}{4} D^2$$

$$P \cdot A - P_{atm} \cdot A - mg = 0$$

$$P = P_{atm} + \frac{mg}{A} = P_{atm} + \frac{4mg}{\pi D^2}$$

$$P = (101 \text{ kPa}) + \frac{4(4 \text{ kg})(9.81 \frac{m}{s^2})}{\pi (0.2 \text{ m})^2} \cdot \left(\frac{N \cdot s^2}{kg \cdot m} \right) \left(\frac{kPa}{1000 \frac{N}{m^2}} \right)$$

$$P = 102.2 \text{ kPa} = P_{sat}$$

$$T = T_{sat} (P_{sat} = 102.2 \text{ kPa})$$

TABLE A-5

Saturated water—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m^3/kg	
		Sat. liquid, v_f	Sat. vapor, v_g
1.0	6.97	0.001000	129.19
1.5	13.02	0.001001	87.964
2.0	17.50	0.001001	66.990
2.5	21.08	0.001002	54.242
3.0	24.08	0.001003	45.654
4.0	28.96	0.001004	34.791
5.0	32.87	0.001005	28.185
7.5	40.29	0.001008	19.233
10	45.81	0.001010	14.670
15	53.97	0.001014	10.020
20	60.06	0.001017	7.6481
25	64.96	0.001020	6.2034
30	69.09	0.001022	5.2287
40	75.86	0.001026	3.9933
50	81.32	0.001030	3.2403
75	91.76	0.001037	2.2172
100	99.61	0.001043	1.6941
101.325	99.97	0.001043	1.6734
125	105.97	0.001048	1.3750
150	111.35	0.001053	1.1594

$$P_1 = 101.325, \quad T_1 = 99.97$$

$$P_2 = 125, \quad T_2 = 105.97$$

$$T = T_1 + \left(\frac{T_2 - T_1}{P_2 - P_1} \right) (P - P_1)$$

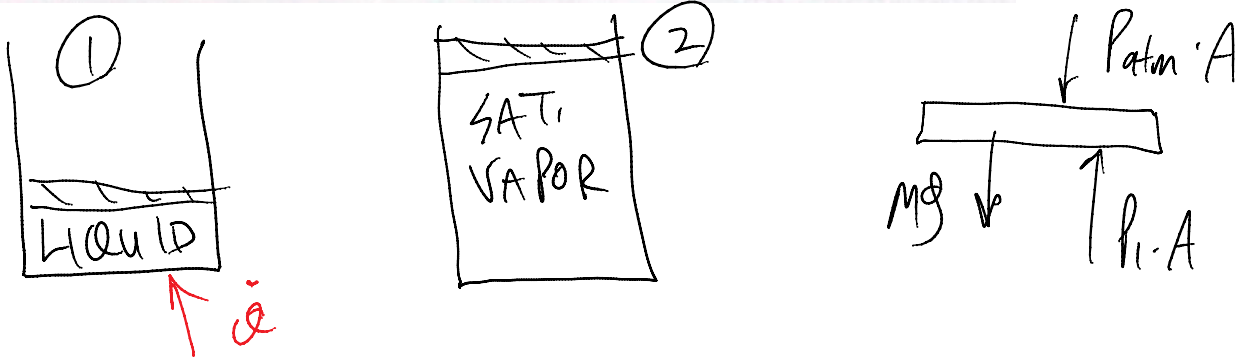
$$T = 100.2^\circ\text{C}$$

2-57 A piston-cylinder device initially contains 50 L of liquid water at 25°C and 300 kPa. Heat is added to the water at constant pressure until the entire liquid is vaporized.

- (a) What is the mass of the water?
- (b) What is the final temperature?
- (c) Determine the total enthalpy change.

(d) Show the process on a $T-v$ diagram with respect to saturation lines.

Answers: (a) 49.85 kg, (b) 133.55°C, (c) 130,627 kJ

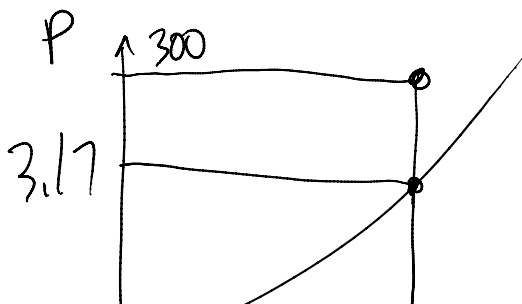


STATE ①: $V_1 = 50^L$ LIQUID H_2O , $T_1 = 25^\circ C$,
 $P_1 = 300 \text{ kPa}$

STATE ②: $P_2 = P_1 = 300 \text{ kPa}$, SATURATED VAPOR

FIND m : START AT STATE 1:

AT $T_{sat} = 25^\circ C$, $P_{sat} = 3.169 \text{ kPa}$



PHASE: SCL



APPROXIMATE COMPRESSED LIQUID AS A SATURATED LIQUID AT THE SAME TEMPERATURE.

$$h_{scl}(T) \approx h_f(T) \quad \text{VERY WEAK FUNCTION OF PRESSURE}$$

$$v_{scl}(T) \approx v_f(T) \quad \text{INCOMPRESSIBLE NATURE OF LIQUIDS.}$$

$$v_1 \approx v_f(T_{sat} = 25^\circ\text{C}) = 0.001003 \frac{\text{m}^3}{\text{kg}}$$

$$v = \frac{V}{m}, \quad m = \frac{V_1}{v_1} = \frac{(50\text{L}) \left(\frac{\text{m}^3}{1000\text{L}} \right)}{\left(0.001003 \frac{\text{m}^3}{\text{kg}} \right)} = 49.85 \text{ kg}$$

$$h_1 \approx h_f(T_{sat} = 25^\circ\text{C}) = 104.89 \frac{\text{kJ}}{\text{kg}}$$

FIND T_2 :

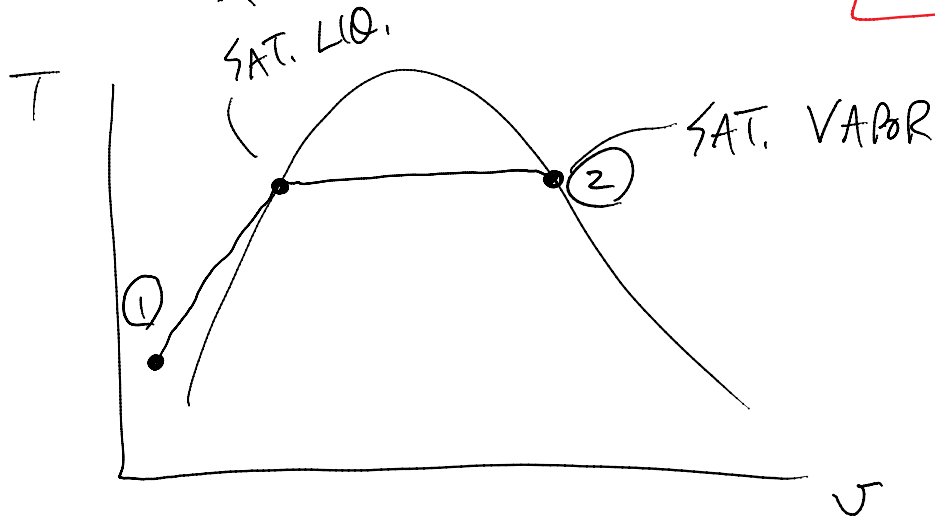
$$T_2 = T_{sat}(P_{sat} = 300 \text{ kPa}) = 133.55^\circ\text{C}$$

$$h_2 = h_g(P_{sat} = 300 \text{ kPa}) = 2725.3 \frac{\text{kJ}}{\text{kg}}$$

$$v = \frac{V}{m}, \quad h = \frac{H}{m}, \quad H = m \cdot h$$

$$\Delta H = H_2 - H_1 = m \cdot h_2 - m \cdot h_1 = m (h_2 - h_1)$$

$$\Delta H = (49.85 \text{ kg}) \left(2729.3 - 104.89 \frac{\text{kJ}}{\text{kg}} \right) = 1.31 \times 10^5 \text{ kJ}$$



2-61E A 15-ft³ rigid tank contains saturated mixture of refrigerant-134a at 30 psia. If the saturated liquid occupies 10 percent of the volume, determine the quality and the total mass of the refrigerant in the tank.

2-63 A rigid tank contains water vapor at 300°C and an unknown pressure. When the tank is cooled to 180°C , the vapor starts condensing. Estimate the initial pressure in the tank.

Answer: 1.325 MPa

2-120 A rigid tank with a volume of 0.07 m^3 contains 1 kg of refrigerant-134a vapor at 400 kPa . The refrigerant is now allowed to cool. Determine the pressure when the refrigerant first starts condensing. Also, show the process on a P - v diagram with respect to saturation lines.

$V = 0.07 \text{ m}^3$, $m = 1 \text{ kg}$ R-134a, $P_1 = 400 \text{ kPa}$

FIND PRESSURE WHEN CONDENSATION OCCURS.

$v_1 = \frac{V_1}{m_1} = \frac{(0.07 \text{ m}^3)}{(1 \text{ kg})} = 0.07 \frac{\text{m}^3}{\text{kg}}$

$v_2 = \frac{V}{m} = v_1 = 0.07 \frac{\text{m}^3}{\text{kg}} \Rightarrow$ SATURATED VAPOR (SAT. SYSTEM).

FIND $P_2 = P_{\text{sat}}(v_g = 0.07 \frac{\text{m}^3}{\text{kg}})$

TABLE A-12
Saturated refrigerant-134a—Pressure table

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m^3/kg		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liq v_f
60	-36.95	0.0007098	0.31121	3.

$v_1 = 0.07235$, $P_1 = 280$

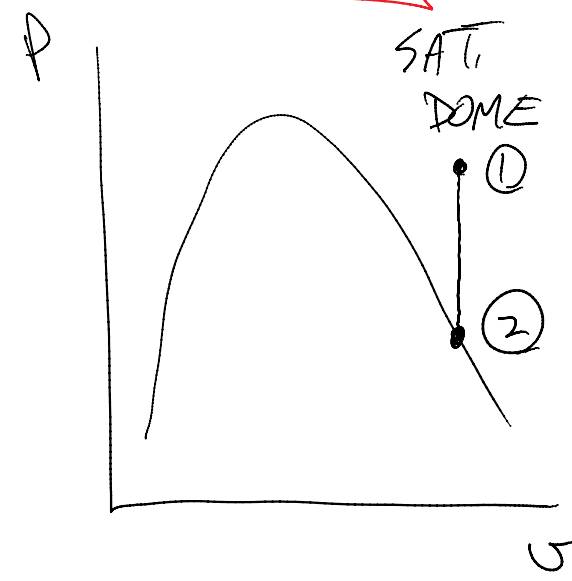
	sat	v_f	v_g	v_f
60	-36.95	0.0007098	0.31121	3.
70	-33.87	0.0007144	0.26929	7.
80	-31.13	0.0007185	0.23753	11.
90	-28.65	0.0007223	0.21263	14.
100	-26.37	0.0007259	0.19254	17.
120	-22.32	0.0007324	0.16212	22.
140	-18.77	0.0007383	0.14014	26.
160	-15.60	0.0007437	0.12348	31.
180	-12.73	0.0007487	0.11041	34.
200	-10.09	0.0007533	0.099867	38.
240	-5.38	0.0007620	0.083897	44.
280	-1.25	0.0007699	0.072352	49.
320	2.46	0.0007772	0.063604	54.
360	5.82	0.0007841	0.056738	59.
400	8.91	0.0007907	0.051201	63.

$$v_1 = 0.07235, P_1 = 280$$

$$v_2 = 0.06360, P_2 = 320$$

$$P = P_1 + \left(\frac{P_2 - P_1}{v_2 - v_1} \right) (v - v_1)$$

$$P = 288.7 \text{ kPa}$$



$$PV = n\bar{R}T$$

$$n = \# \text{ MOLES}$$

$$\bar{R} = \text{UNIVERSAL GAS CONSTANT}$$

PARTICULAR GAS CONSTANT:

$$R = \frac{\bar{R}}{M}$$

$M = \text{MOLAR MASS (MOLECULAR WEIGHT)}$

$$n = \frac{m}{M}$$

$$PV = mRT \quad \text{OR} \quad P\rho = RT$$

ASSUMPTIONS:

- FRACTION OF THE TOTAL VOLUME OCCUPIED BY THE MOLECULES IS SMALL
- MOLECULES DO NOT INTERACT
- NO ENERGY IS DISSIPATED DURING COLLISIONS

TABLE A – 1

Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, M kg/kmol	Gas constant, R kJ/kg · K*	<i>Critical-point properties</i>		
				Temperature, K	Pressure, MPa	Volume, m ³ /kmol
Air	—	28.97	0.2870	132.5	3.77	0.0883
Ammonia	NH ₃	17.03	0.4882	405.5	11.28	0.0724
Argon	Ar	39.948	0.2081	151	4.86	0.0749
Benzene	C ₆ H ₆	78.115	0.1064	562	4.92	0.2603
Bromine	Br ₂	159.808	0.0520	584	10.34	0.1355
<i>n</i> -Butane	C ₄ H ₁₀	58.124	0.1430	425.2	3.80	0.2547
Carbon dioxide	CO ₂	44.01	0.1889	304.2	7.39	0.0943
Carbon monoxide	CO	28.011	0.2968	133	3.50	0.0930
Carbon tetrachloride	CCl ₄	153.82	0.05405	556.4	4.56	0.2759
Chlorine	Cl ₂	70.906	0.1173	417	7.71	0.1242

2-71E The air in an automobile tire with a volume of 0.53 ft^3 is at 90°F and 20 psig . Determine the amount of air that must be added to raise the pressure to the recommended value of 30 psig . Assume the atmospheric pressure to be 14.6 psia and the temperature and the volume to remain constant.

Answer: 0.0260 lbm

$$V = 0.53 \text{ ft}^3, \quad T = 90^\circ\text{F}, \quad P_1 = 20 \text{ psig}, \quad P_2 = 30 \text{ psig},$$

$$P_{\text{atm}} = 14.6 \text{ psia}, \quad \text{FIND } M_{\text{AIR}}$$

$$PV = mRT$$

$$\frac{P}{m} = \frac{RT}{V} = \text{CONSTANT}$$

$$\frac{P_1}{m_1} = \frac{P_2}{m_2} \Rightarrow m_2 = \frac{P_2}{P_1} \cdot m_1$$

$$M_{\text{AIR}} = m_2 - m_1, \quad m_2 = m_1 + M_{\text{AIR}}$$

$$\frac{P_2}{P_1} \cdot m_1 = m_1 + M_{\text{AIR}}$$

$$M_{\text{AIR}} = m_1 \left(\frac{P_2}{P_1} - 1 \right)$$

$$m_1 = \frac{P_1 V}{RT}$$

$$M_1 = \frac{P_1 V}{RT}$$

$$M_{air} = \left(\frac{P_1 V}{RT} \right) \left(\frac{P_2}{P_1} - 1 \right)$$

$$M_{air} = \frac{\left(\frac{20 + 14.6 \text{ PSIA}}{0.3704 \frac{\text{PSIA} \cdot \text{ft}^3}{\text{LBM} \cdot ^\circ\text{R}}} \right) (0.53 \text{ ft}^3)}{(90 + 460^\circ\text{R})} \left[\left(\frac{30 + 14.6}{20 + 14.6} \right) - 1 \right]$$

$$M_{air} = 0.0260 \text{ LBM}$$

2-115 The gage pressure of an automobile tire is measured to be 200 kPa before a trip and 220 kPa after the trip at a location where the atmospheric pressure is 90 kPa. Assuming the volume of the tire remains constant at 0.022 m^3 , determine the percent increase in the absolute temperature of the air in the tire.

HOW GOOD IS THE IDEAL GAS RELATION?

IT IS AN APPROXIMATION,
THE COMPRESSIBILITY FACTOR
CAN QUANTIFY THE DEVIATION
FROM IDEAL GAS BEHAVIOR.

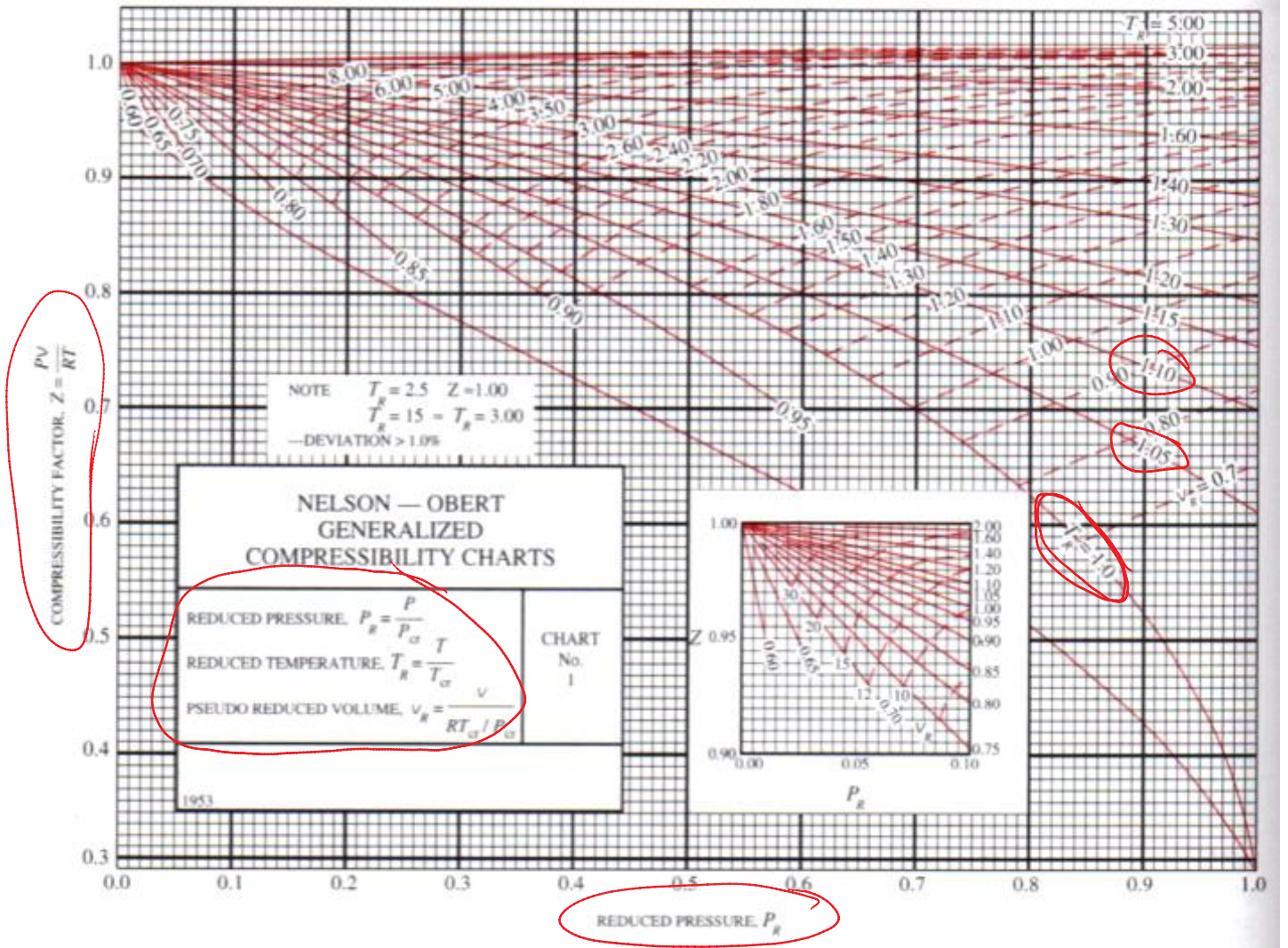


$$Z = \frac{PV}{RT} = \frac{V_{\text{ACTUAL}}}{V_{\text{IDEAL}}}$$

FOR IDEAL GAS, $Z=1$

Z CAN BE DETERMINED USING A-15:

(a) Low pressures, $0 < P_R < 1.0$



$$P_r = \frac{P}{P_{cr}}$$

P_{cr} = CRITICAL POINT PRESSURE

$$T_r = \frac{T}{T_{cr}}$$

T_{cr} = CRITICAL POINT TEMPERATURE

GOOD FOR ALL WORKING FLUIDS

2-79 Determine the specific volume of superheated water vapor at 10 MPa and 400°C, using (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) the steam tables. Also determine the error involved in the first two cases.

Answers: (a) 0.03106 m³/kg, 17.6 percent; (b) 0.02609 m³/kg, 1.2 percent; (c) 0.02641 m³/kg

FIND v FOR SHV H₂O AT 10 MPa, 400°C

a) IDEAL GAS RELATION:

$$Pv = RT$$

$$v = \frac{RT}{P} = \frac{\left(0.4615 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right) (400 + 273 \text{ K})}{(10 \text{ MPa}) \left(\frac{1000 \text{ kPa}}{\text{MPa}}\right)} \cdot \left(\frac{\text{kPa}}{\frac{\text{kJ}}{\text{m}^3}}\right) \left(\frac{\text{kJ}\cdot\text{m}}{\text{KJ}}\right)$$

$$v = 0.03106 \frac{\text{m}^3}{\text{kg}} \quad \text{IDEAL GAS}$$

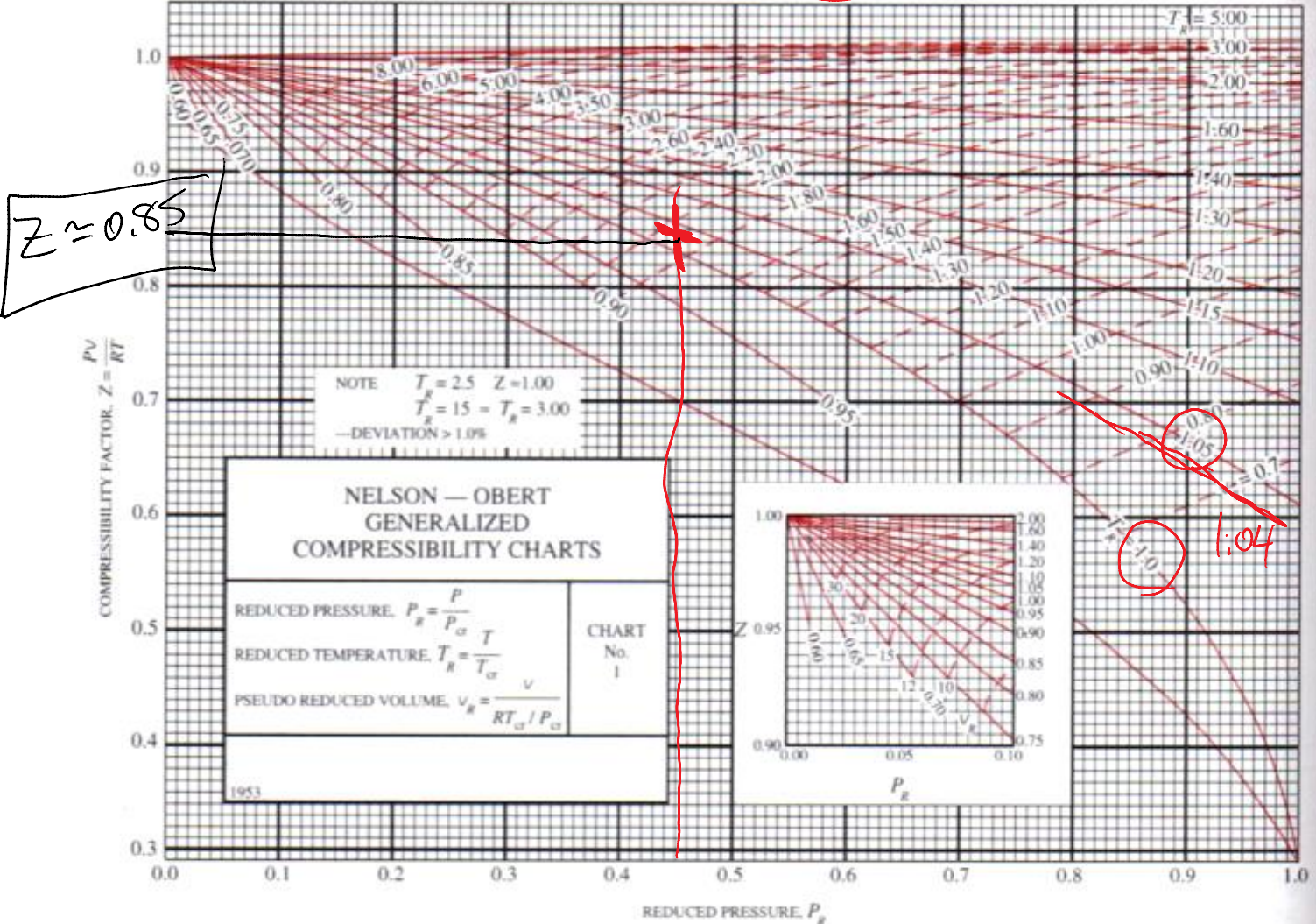
b) COMPRESSIBILITY CHART

$$P_{cr} = 22.09 \text{ MPa}, \quad T_{cr} = 647.3 \text{ K}$$

$$P_r = \frac{P}{P_{cr}} = \frac{10 \text{ MPa}}{22.09 \text{ MPa}} = 0.453$$

$$T_r = \frac{T}{T_{cr}} = \frac{(400 + 273 \text{ K})}{(647.3 \text{ K})} = 1.04$$

(a) Low pressures, $0 < P_R < 1.0$



$Z \approx 0.85$

1.05
 1.04

$$Z = \frac{V_{ACTUAL}}{V_{IDEAL}} \quad ; \quad V_{ACTUAL} = Z \cdot V_{IDEAL}$$

$$V_{ACTUAL} = (0.85) \left(0.03106 \frac{m^3}{kg} \right) = 0.02640 \frac{m^3}{kg}$$

c) STEAM TABLE = ?

2-83 Determine the specific volume of superheated water vapor at 1.6 MPa and 225°C based on (a) the ideal-gas equation, (b) the generalized compressibility chart, and (c) the steam tables. Determine the error involved in the first two cases.

(a) Low pressures, $0 < P_R < 1.0$

