

Thermodynamics

ENGR360-MEP112

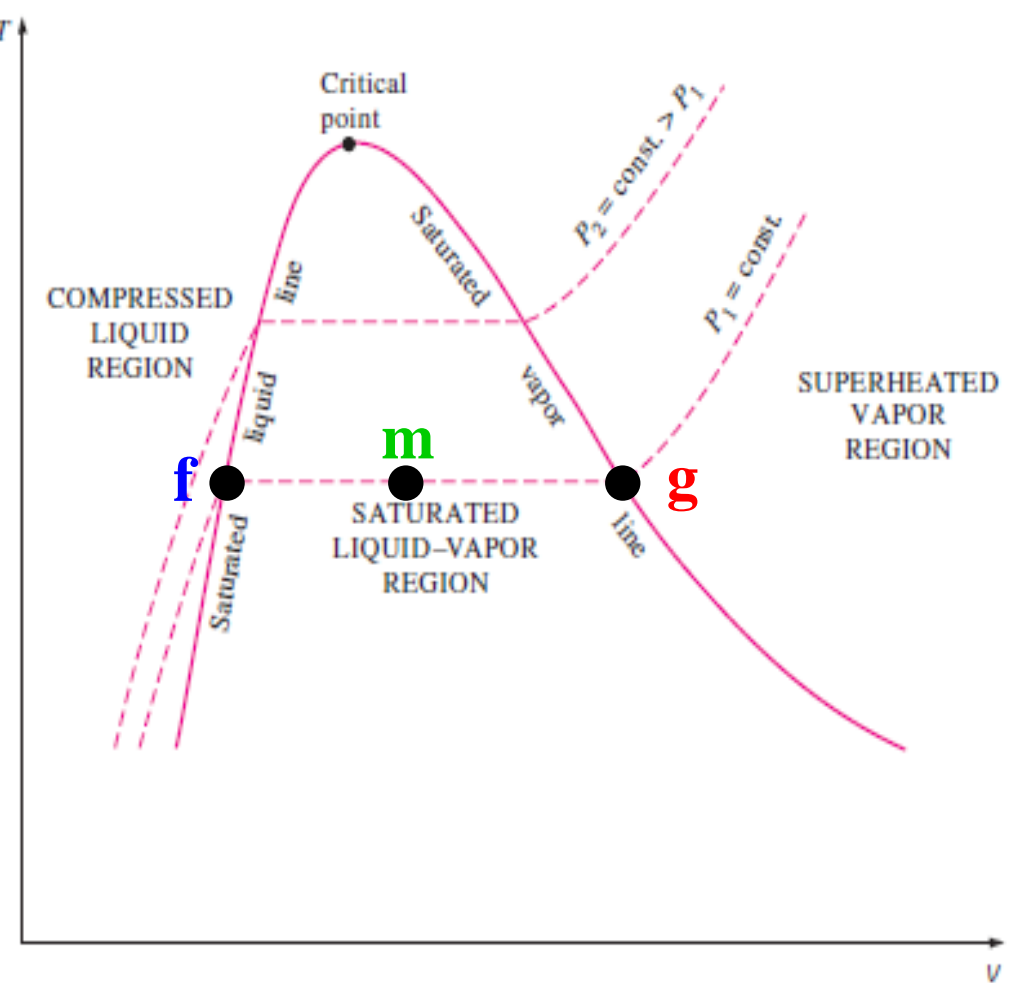
LECTURE 5

Objectives:

- 1. Determination of the state of H₂O.**
- 2. Thermodynamic property tables of H₂O and EES database.**
- 3. The hypothesis of an ideal-gas and ideal-gas equation of state.**

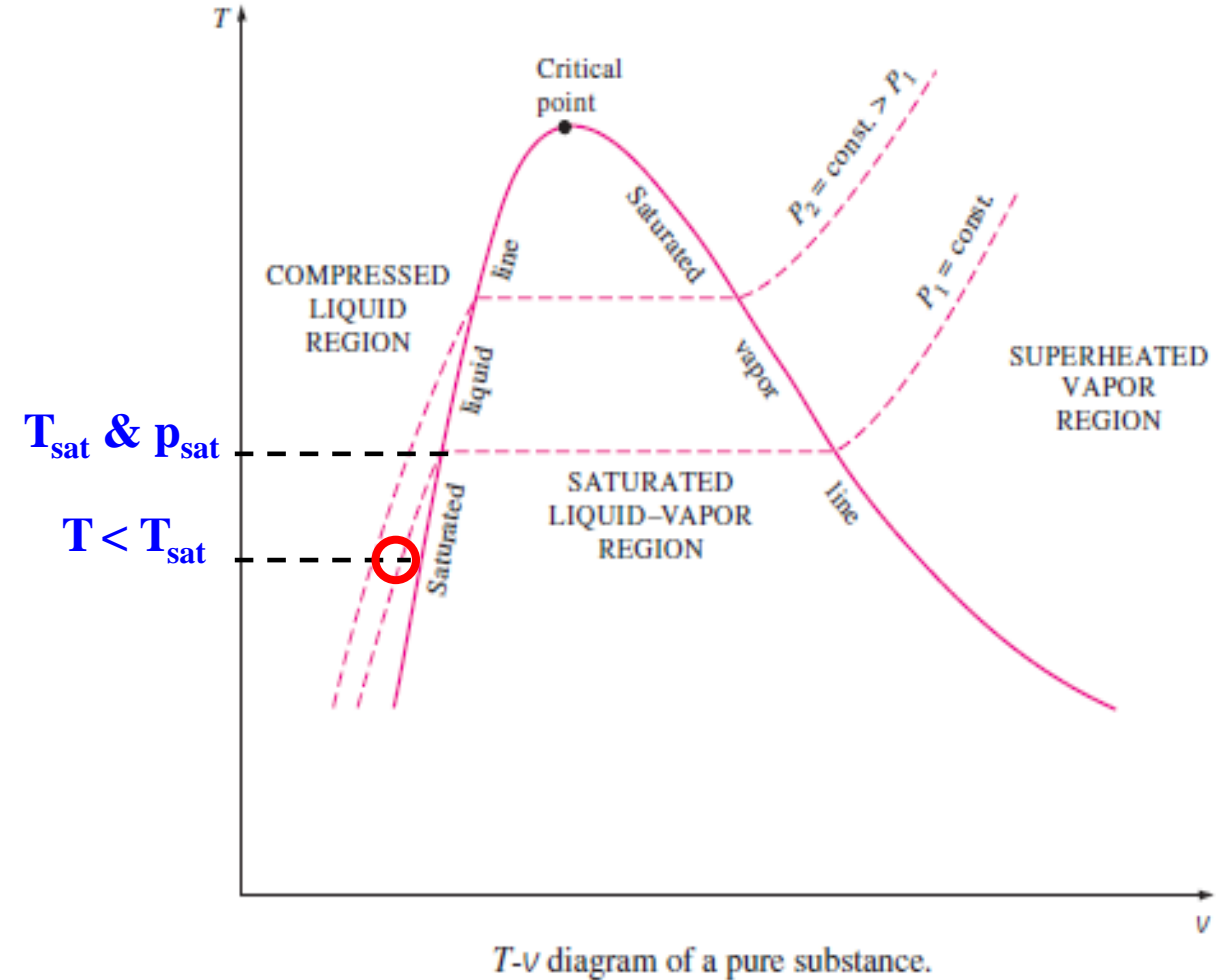
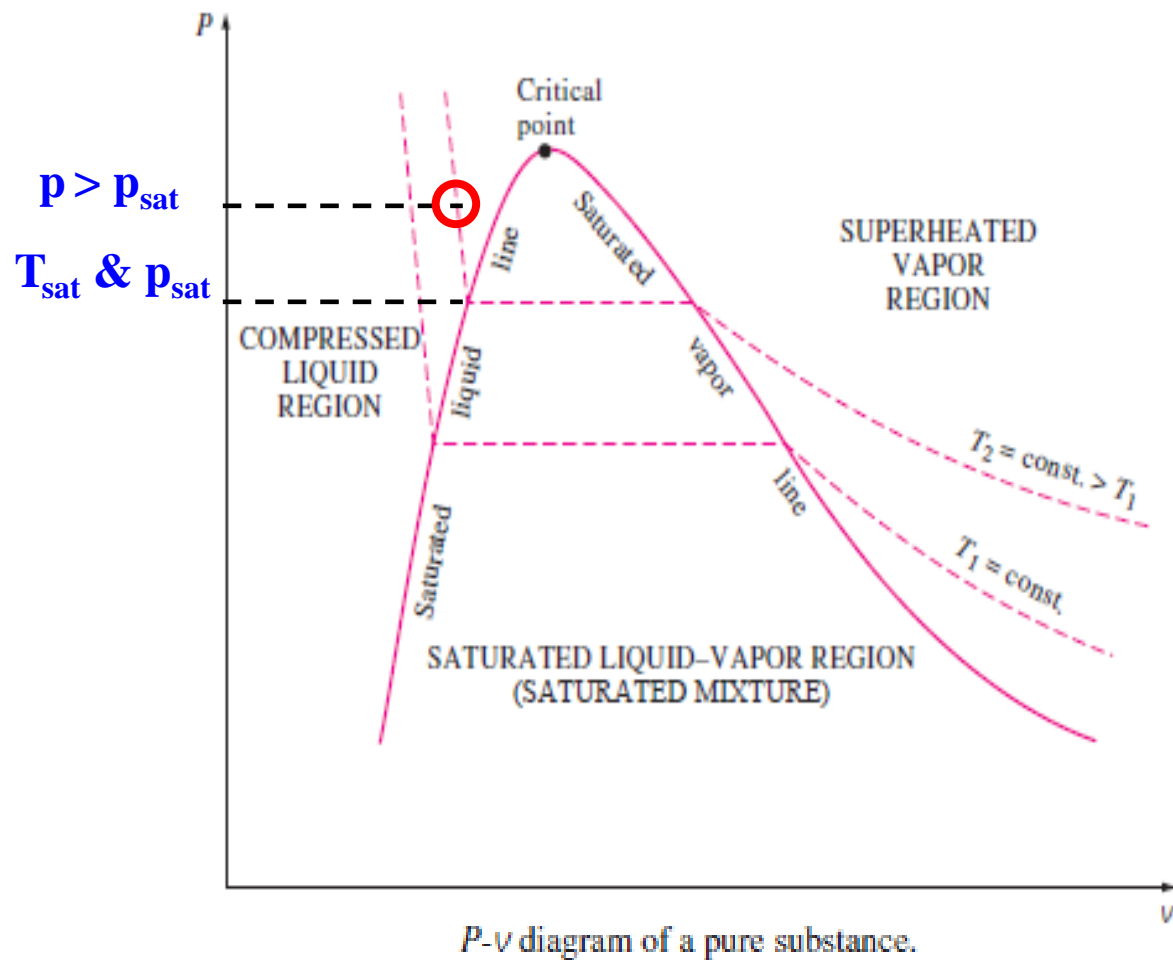
STATE OF H₂O

- ❑ Two independent properties are enough to identify the state.
- ❑ Available properties are (p, v, T, u) .
- ❑ All properties of the **saturated liquid** are denoted by **f**, like v_f and u_f .
- ❑ All properties of the **saturated vapor** are denoted by **g**, like v_g and u_g .
- ❑ All properties of the **saturated mixture** are denoted by **m**, like v_m and u_m .
- ❑ There is no denotation for **p** and **T** !!!



T-v diagram of a pure substance.

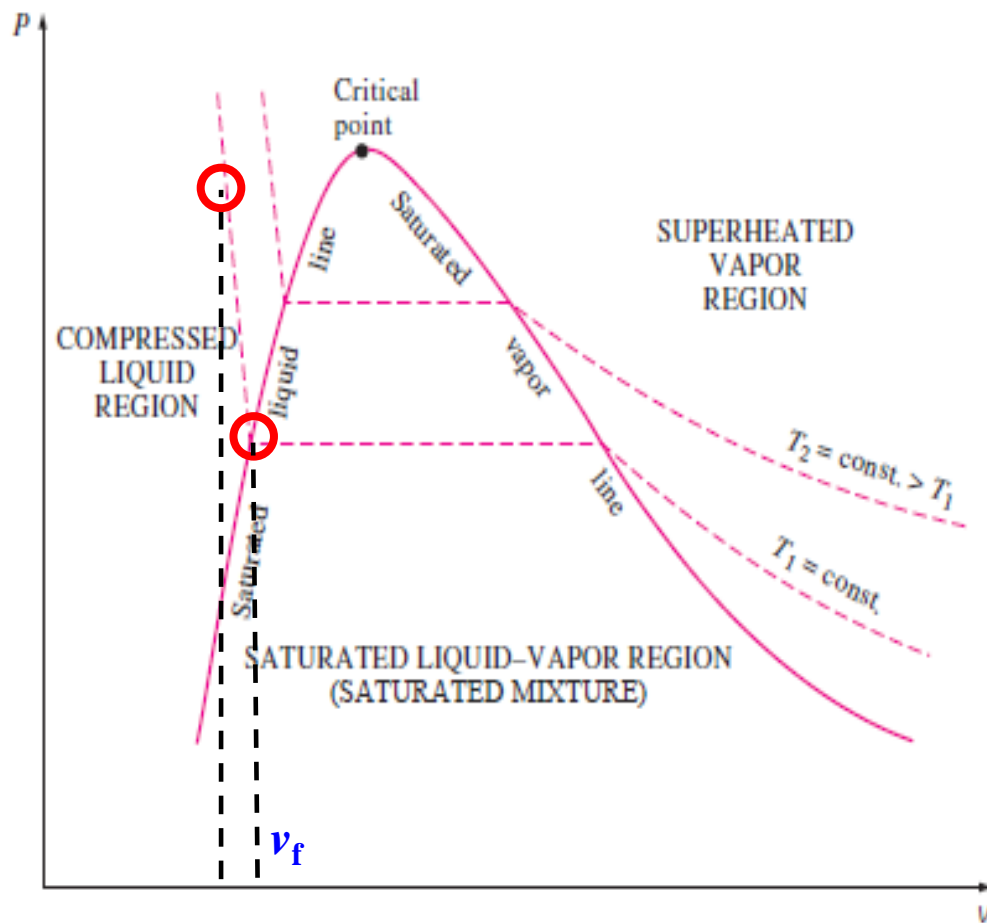
A. COMPRESSED LIQUID



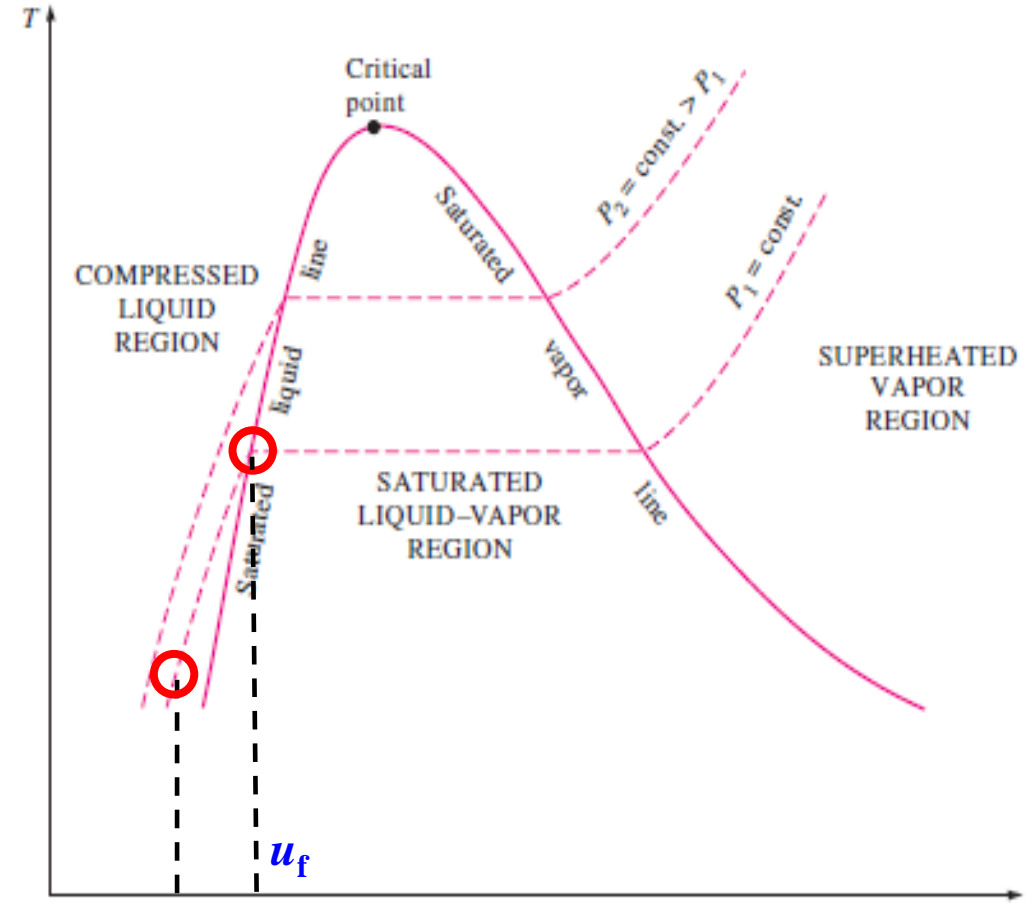
1. At a given Temperature T , if $p > p_{sat}$

2. At a given pressure p , if $T < T_{sat}$

A. COMPRESSED LIQUID



$v < v_f$ P-v diagram of pure substance.

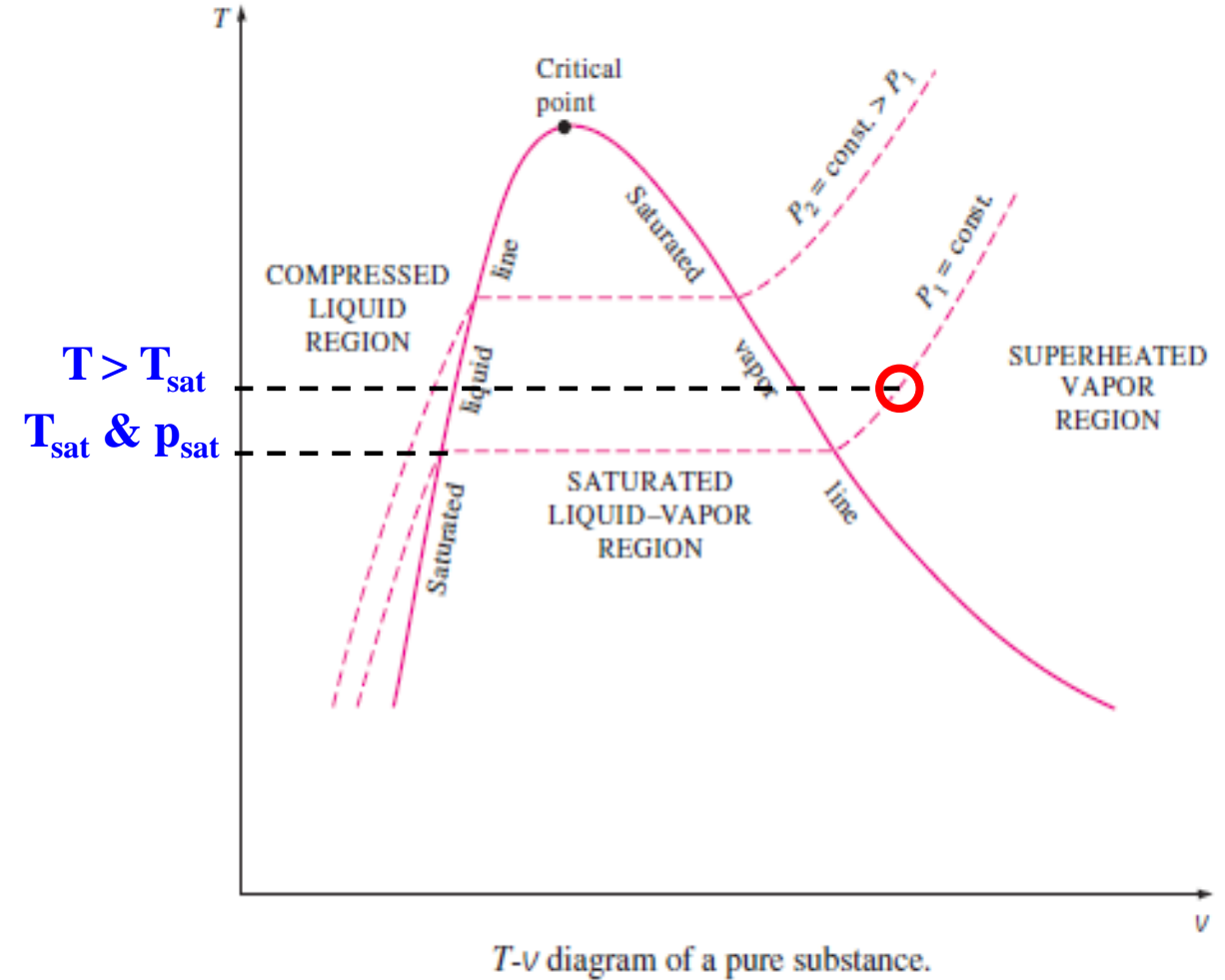
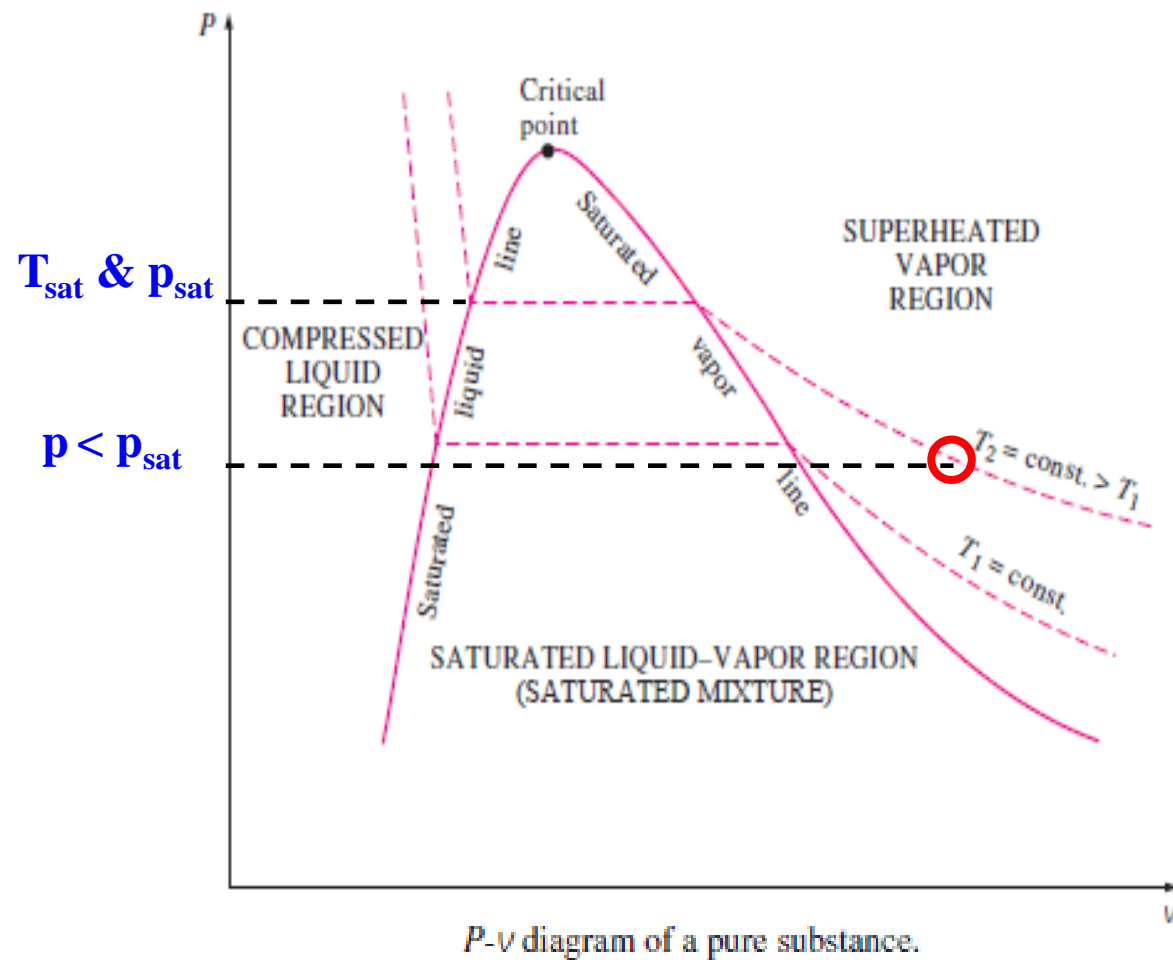


$u < u_f$ T-u diagram of pure substance.

3. At a given p & T , if $v < v_f$

4. At a given p & T , if $u < u_f$

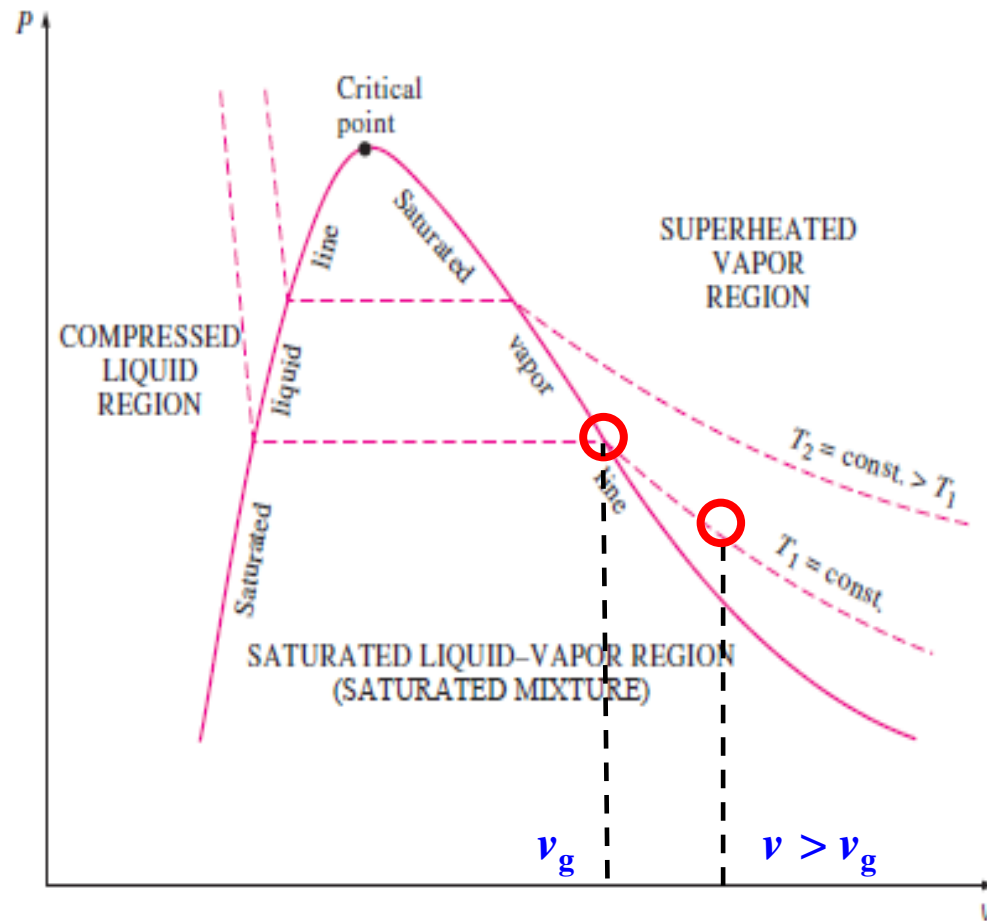
B. SUPERHEATED VAPOR



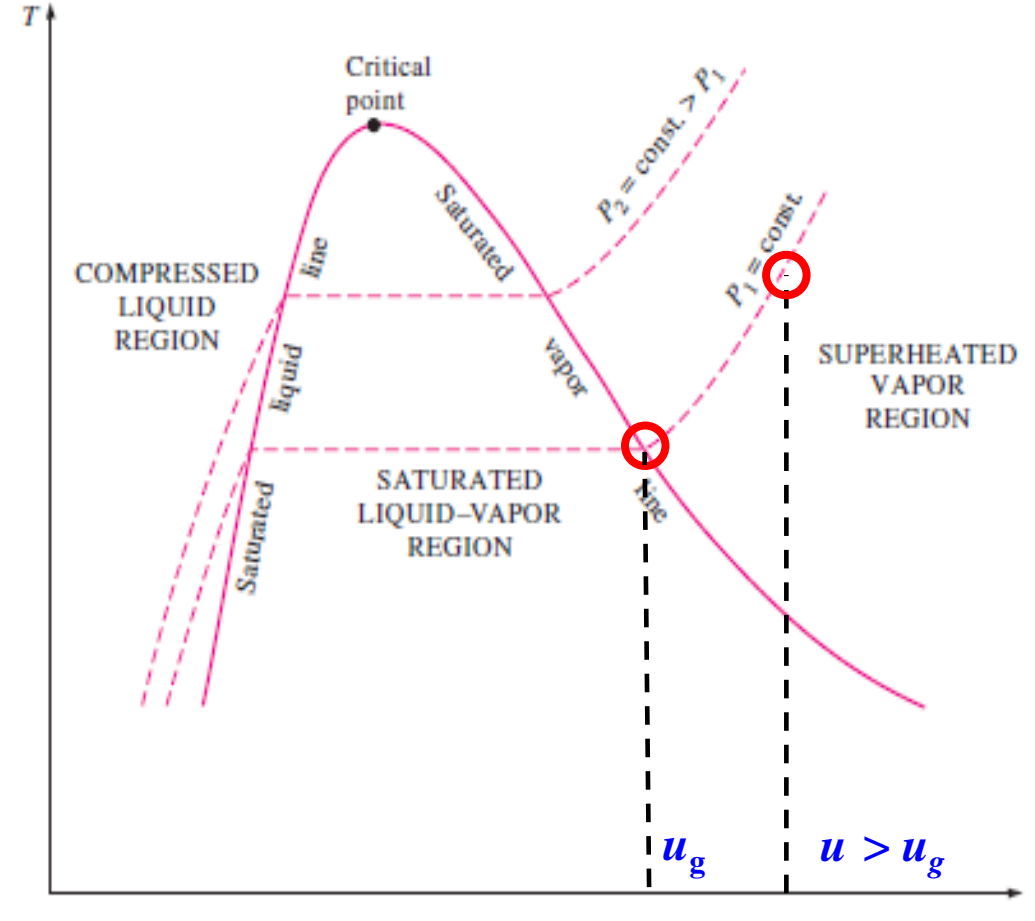
1. At a given Temperature T , if $p < p_{\text{sat}}$

2. At a given pressure p , if $T > T_{\text{sat}}$

B. SUPERHEATED VAPOR



P-v diagram of pure substance.



T-u diagram of pure substance.

3. At a given p & T , if $v > v_g$

4. At a given p & T , if $u > u_g$

C. SATURATED MIXTURE REGION

○ Quality or dryness fraction (X):

$$X = \frac{m_g}{m_f + m_g} = \frac{m_g}{m_m}$$

- $X = 0$, if saturated liquid (**f**)
- $X = 1$, if saturated liquid (**g**)

$$V_m = V_f + V_g$$

$$m_m = m_f + m_g$$

$$m_m v_m = m_f v_f + m_g v_g$$

$$m_m v_m = (m_m - m_g) v_f + m_g v_g$$

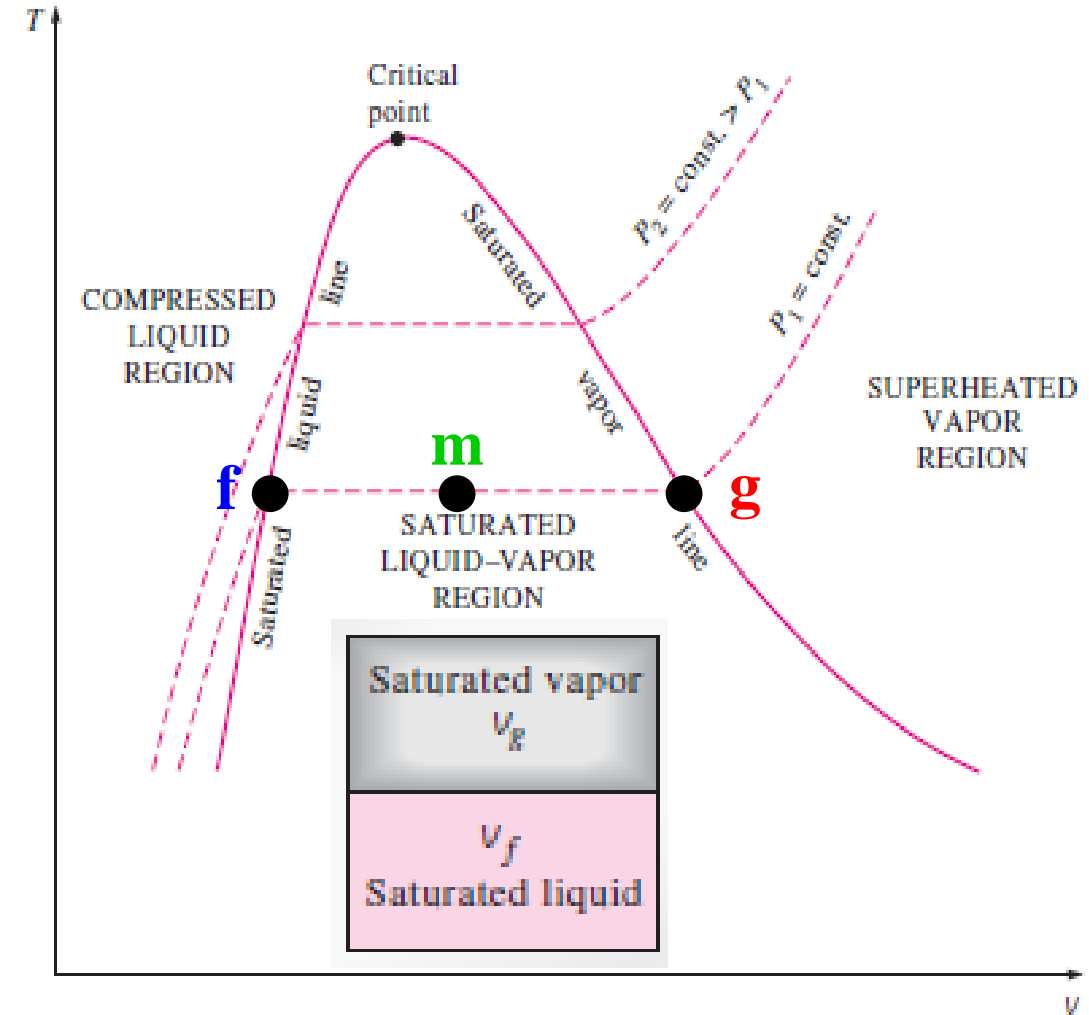
$$v_m = \left(1 - \frac{m_g}{m_m}\right) v_f + \frac{m_g}{m_m} v_g$$

$$v_m = (1 - X)v_f + Xv_g$$

$$v_m = v_f + X(v_g - v_f)$$

Similarly

$$u_m = u_f + X(u_g - u_f) = u_f + Xu_{fg}$$



T-v diagram of a pure substance.

ENTHALPY

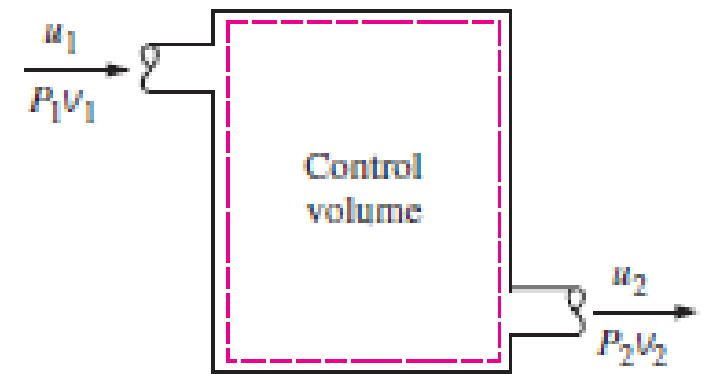
In control volume (open system) analysis of certain types of processes, we frequently encounter the combination of properties $U + pV$. This combination is defined as a new property, **enthalpy**, and given the symbol **h**:

$$H = U + pV$$

Or

$$h = u + pv$$

$$h_m = h_f + X(h_g - h_f) = h_f + Xh_{fg}$$



The combination $u + Pv$ is frequently encountered in the analysis of control volumes.

→ Latent heat of vaporization

PROPERTY TABLES**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			Entropy, kJ/kg·K		
		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

PROPERTY TABLES**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			Entropy, kJ/kg·K		
		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	Sat. liquid, <i>s</i> _f	Evap., <i>s</i> _{fg}	Sat. vapor, <i>s</i> _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

PROPERTY TABLES

TABLE A-6

Superheated 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
	$P = 0.01 \text{ MPa (45.81°C)*}$				$P = 0.05 \text{ MPa (81.32°C)}$				$P = 0.10 \text{ MPa (99.61°C)}$			
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

PROPERTY TABLES

TABLE A-7

Compressed liquid water

<i>T</i> °C	<i>v</i> m ³ /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg·K	<i>v</i> m ³ /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg·K	<i>v</i> m ³ /kg	<i>u</i> kJ/kg	<i>h</i> kJ/kg	<i>s</i> kJ/kg·K
<i>P</i> = 5 MPa (263.94°C)					<i>P</i> = 10 MPa (311.00°C)				<i>P</i> = 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

Approximation:

Treat the compressed liquid as saturated liquid at the given temperature.

Example:

Water at 1 bar and 80°C

$$v = v_{f@80^\circ\text{C}}$$

$$u = u_{f@80^\circ\text{C}}$$

$$h = h_{f@80^\circ\text{C}}$$

IDEAL GAS

□ An **ideal gas** is an imaginary substance that obeys the relation:

$$pv = RT$$

□ At **low pressures** and **high temperatures**, the density of a gas decreases, and the gas behaves as an **ideal gas** under these conditions.

□ **Nitrogen, oxygen, hydrogen, helium, argon, neon**, and even heavier gases such as **air** and **carbon dioxide** can be treated as **ideal gases** with negligible error (often less than 1 percent).

□ Dense gases such as **water vapor** in steam power plants and **refrigerant** vapor in refrigerators, however, should not be treated as ideal gases. Instead, the property tables should be used for these substances.

IDEAL-GAS EQUATION OF STATE

$$pV = mRT$$

$$pV = NR_u T$$

$$pv = RT$$

p is the gas pressure, **V** is the gas volume and **T** is its temperature.

R is the gas constant (J/kg.K)

$$R = \frac{R_u \text{ (Universal gas constant)}}{M \text{ (Molecular weight)}} = \frac{8314.4 \text{ (J/kmol. K)}}{M}$$

$$m = NM = \text{No. of Moles} \times \text{Molecular weight}$$