CAE 208 Thermal-Fluids Engineering I
MMAE 320: Thermodynamics
Fall 2022

September 22, 2022
Properties of Pure Substances (II)

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ANNOUNCEMENTS

Announcement

- Do not forget about assignment 3 submission by tonight

- Assignment 4 is posted and is due next Thursday

Announcement

Callan CONSULTING ENGINEERS

ASHRAE Illinois Institute of Technology Student Branch

Mechanical Design Advise & Professional Networking

SPEAKER

Mechanical Designer **Aaron Horta**

WHEN

September 22nd, 2022
12:40pm – 1:40pm

WHERE

John T. Rettaliata Engineering Center, RE 124

TALK ABOUT

- ✓ Work Experiences
- ✓ Mechanical Design
- ✓ Tips & IIT Courses

For more information, feel free to contact ASHRAE official email ashrae_iit@iit.edu

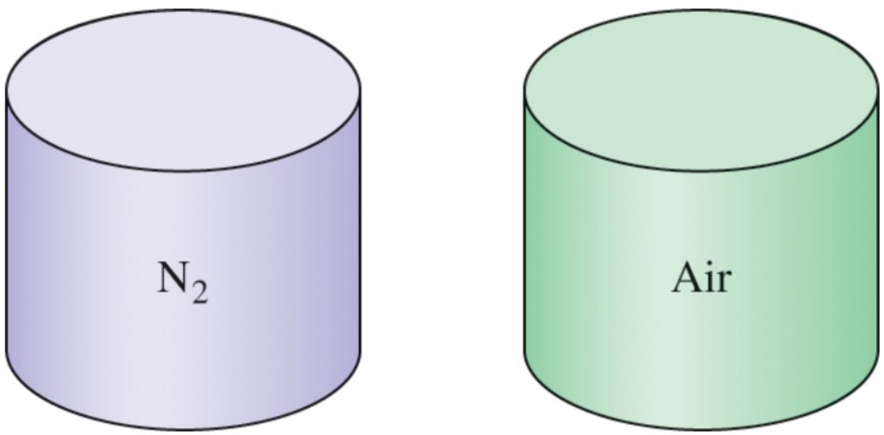
Interested in Joining

Lunch will be provided!

RECAP

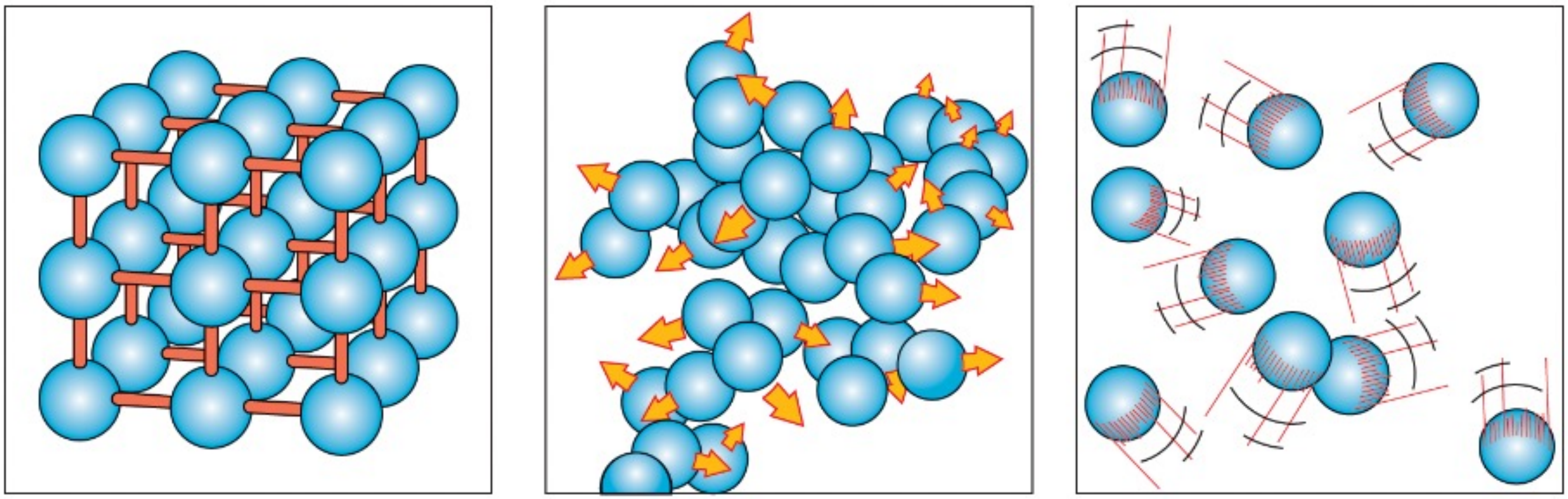
Recap

- *Pure substance*: A substance that has a fix chemical composition throughout (e.g., water, nitrogen, carbon dioxide):
  - ❑ Does not have to be a single chemical element or compound
  - ❑ A mixture of various chemical elements or compounds qualifies as a pure substance as long as the mixture is homogenous (e.g., air as a mixture of several gases)
  - ❑ A mixture of oil and water is not a pure substance (i.e., oil is not soluble in water)



Recap

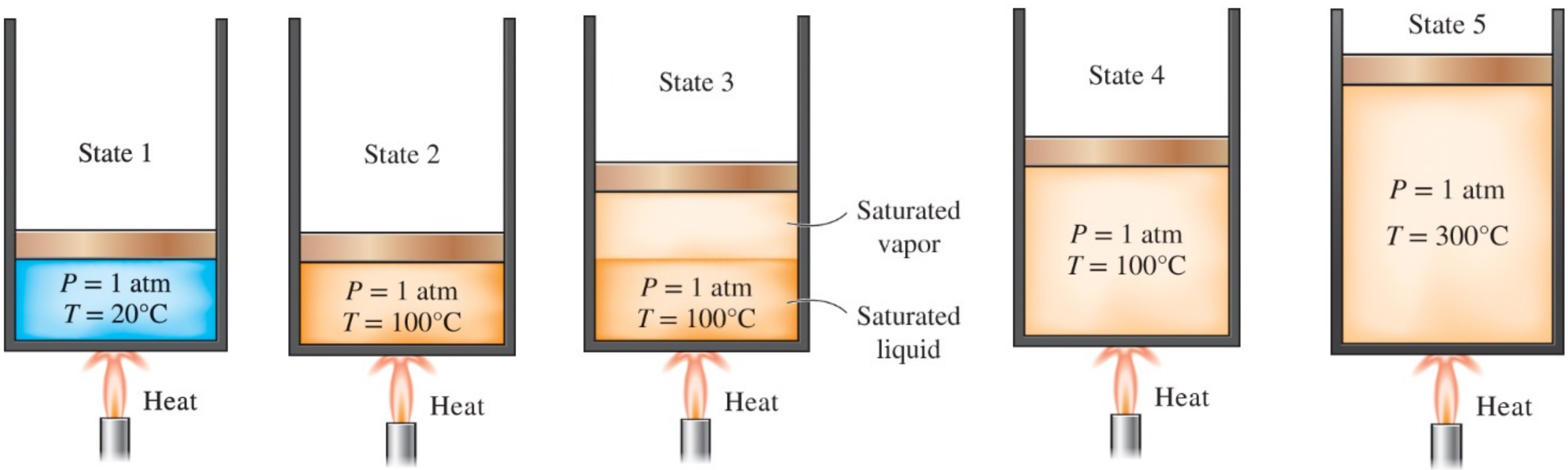
- We have three phases
  - ❑ Solid
  - ❑ Liquid
  - ❑ Gas



(a) (b) (c)

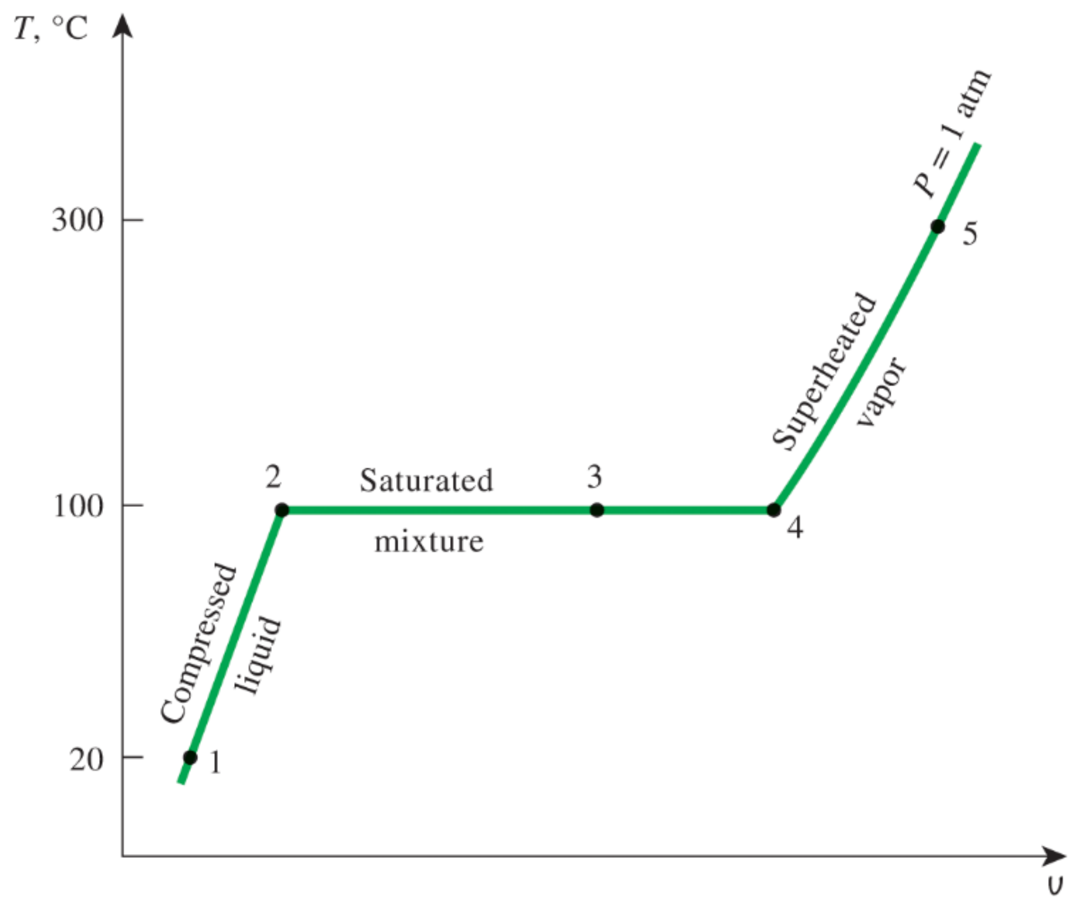
Recap

- A material has several phases:



Recap

- Now let's create the the T-v process diagram:



Recap

- The temperature at which water starts boiling depends on the pressure and therefore pressure is fixed, so the boiling temperature

- At a given pressure, the temperature at which a pure substance changes phase is called the saturation temperature (T_{sat}) (e.g., at a pressure of 101.325 kPa, T_{sat} is 99.97 °C

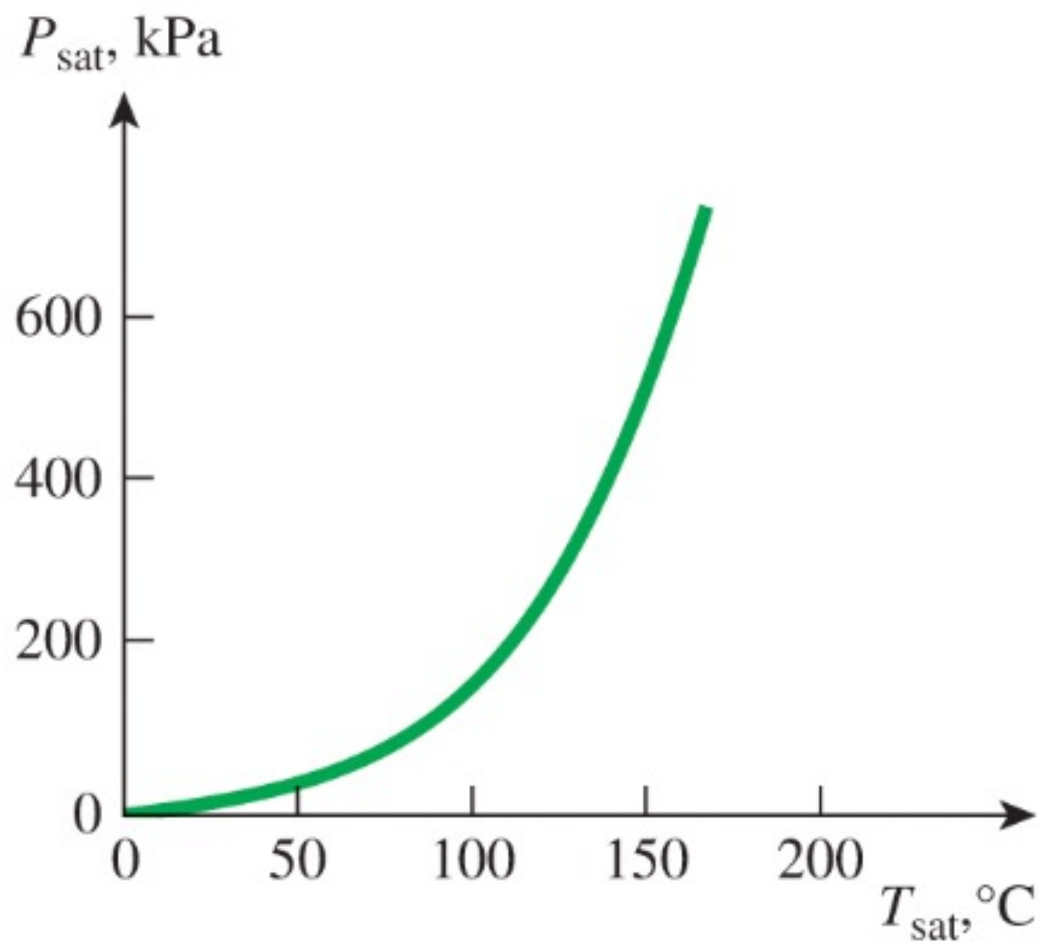
What's the saturation pressure at a temperature of 99.7 °C?

Recap

- It takes a large amount of energy to melt a solid or vaporize a liquid. The amount of energy absorbed or released during a phase-change process is called the *latent heat*
  - ❑ The amount of energy absorbed during melting is called the *latent heat of fusion* is equivalent to the amount of energy released during freezing
  - ❑ The amount of energy absorbed during vaporization is called the *latent heat of vaporization* is equivalent to the amount of energy released during condensation

Recap

- The liquid-vapor saturation vapor of a pure substance:



Recap

- Variation of the standard atmospheric pressure and the boiling (saturation) temperature of water with altitude

TABLE 4–2

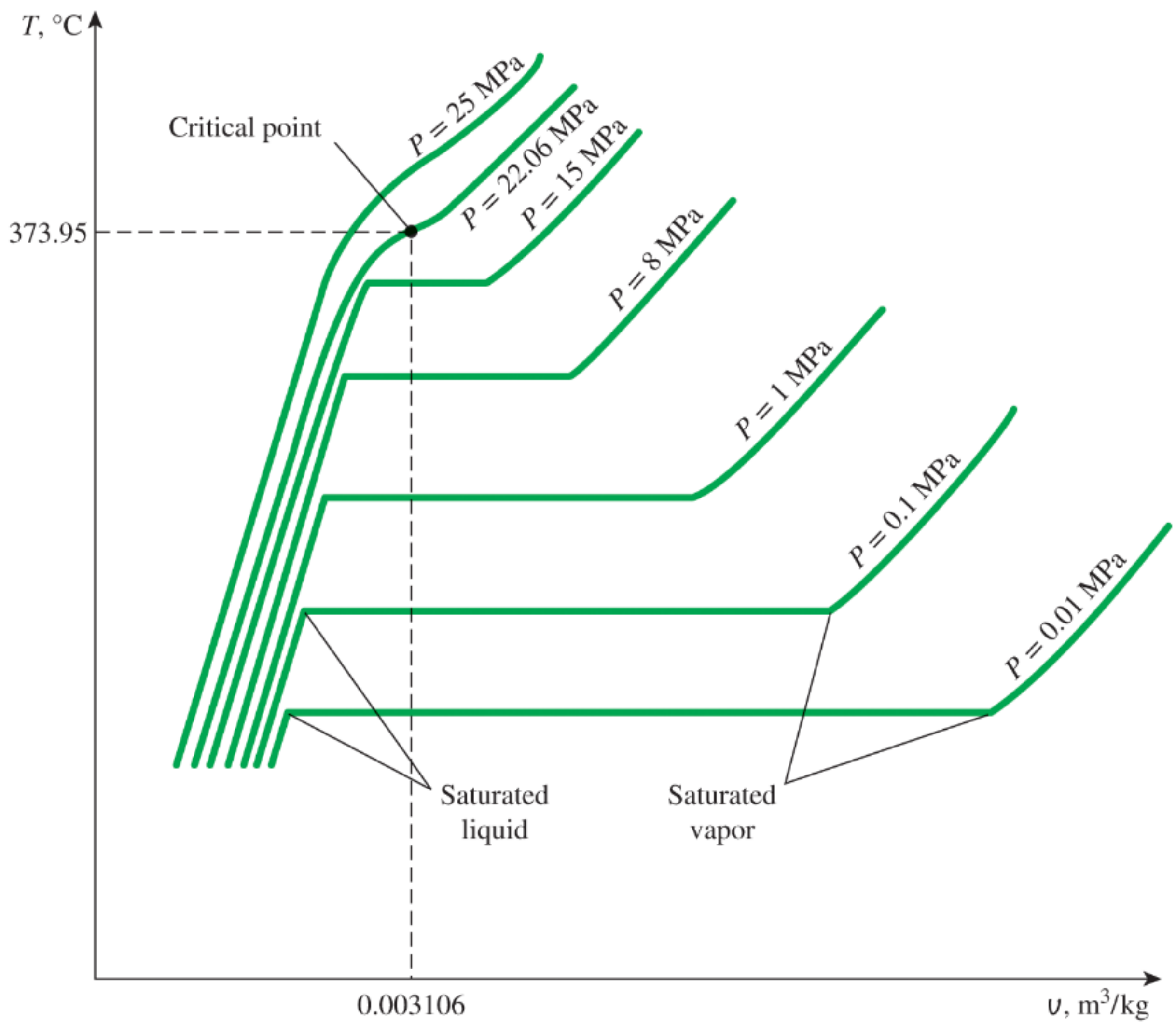
Variation of the standard atmospheric pressure and the boiling (saturation) temperature of water with altitude

Elevation, m	Atmospheric pressure, kPa	Boiling temperature, °C
0	101.33	100.0
1,000	89.55	96.5
2,000	79.50	93.3
5,000	54.05	83.3
10,000	26.50	66.3
20,000	5.53	34.7

PROPERTY DIAGRAMS FOR PHASE-CHANGE PROCESSES

Property Diagrams For Phase-Change Processes

- We always look at the property diagrams in this course



Property Diagrams For Phase-Change Processes

- Critical point is the point at which the saturated liquid and saturated vapor states are identical
  - ❑ Critical pressure (P_{cr})
  - ❑ Critical temperature (T_{cr})
  - ❑ Critical specific volume (v_{cr})

Property Diagrams For Phase-Change Processes

- For the following materials

Material	P_{cr} (MPa)	T_{cr} (K)	v_{cr} (m^3/kg)
Water	22.06	373.95	0.003106
Helium	0.23	-267.85	0.01444

Property Diagrams For Phase-Change Processes

- Table A-1

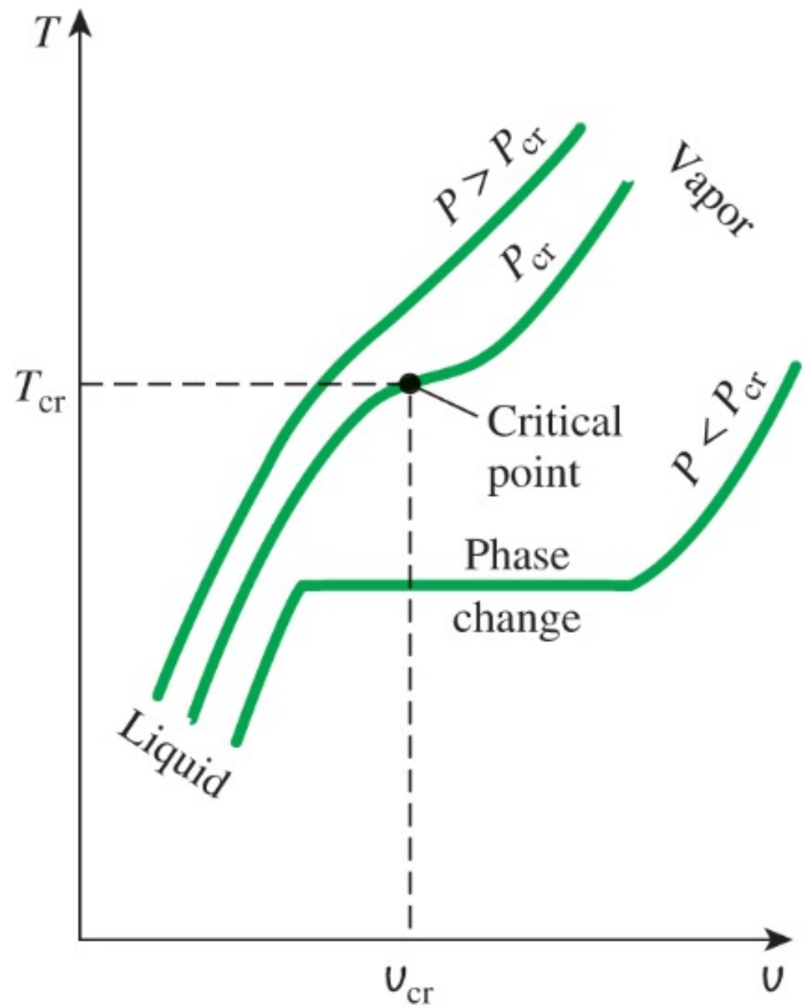
TABLE A–1

Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, M kg/kmol	Gas constant, R kJ/kg · K*	Critical-point properties: Temperature, K	Critical-point properties: Pressure, MPa	Critical-point properties: 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_6H_6	78.115	0.1064	562	4.92	0.2603
Bromine	Br_2	159.808	0.0520	584	10.34	0.1355

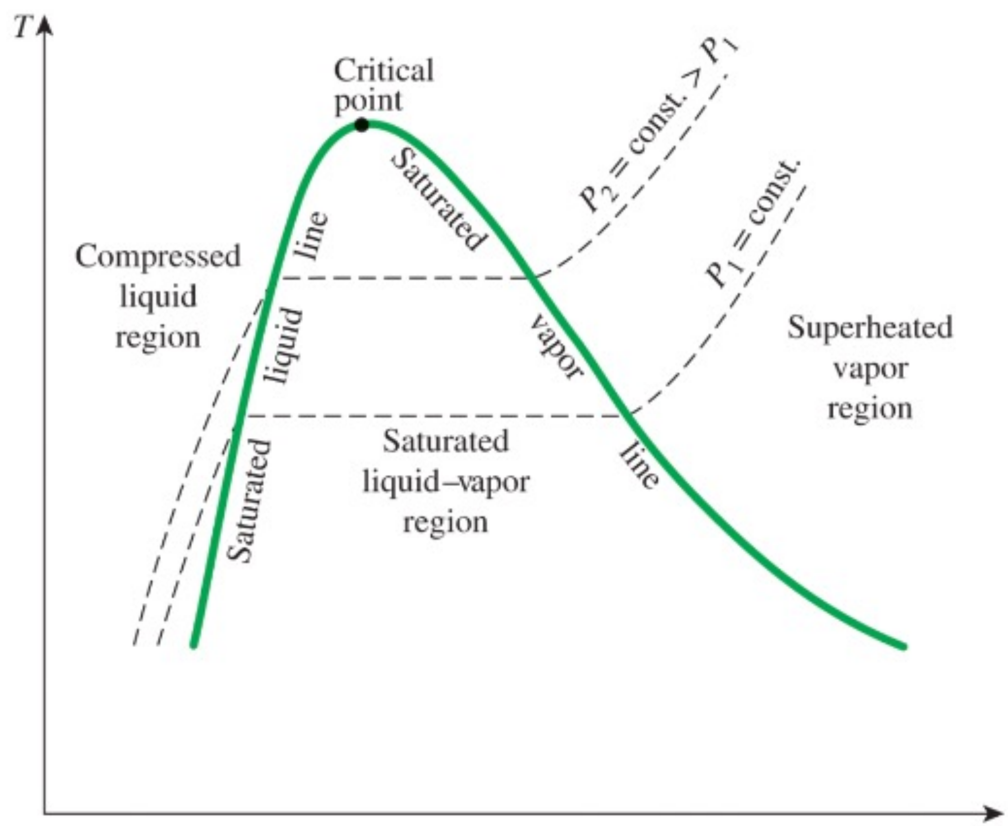
Property Diagrams For Phase-Change Processes

- At pressure above the critical pressure there is not a distinct phase-change process



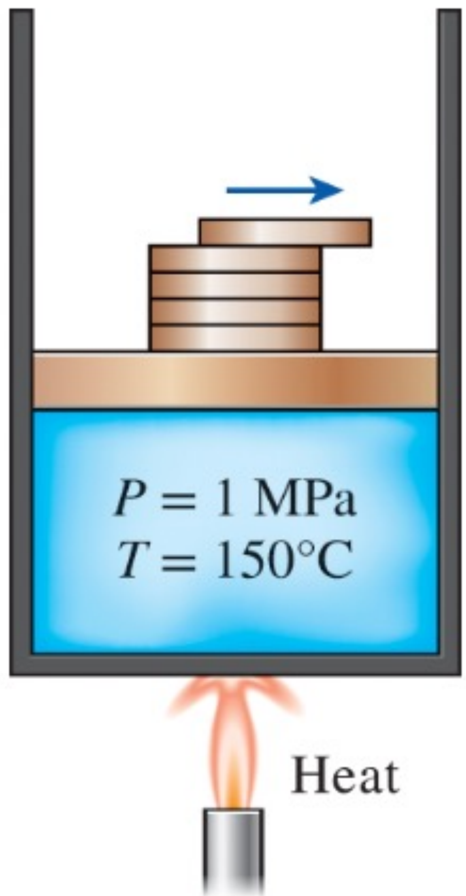
Property Diagrams For Phase-Change Processes

- The saturated liquid states can be connected by a line called saturated liquid line and similarly the saturated vapor line



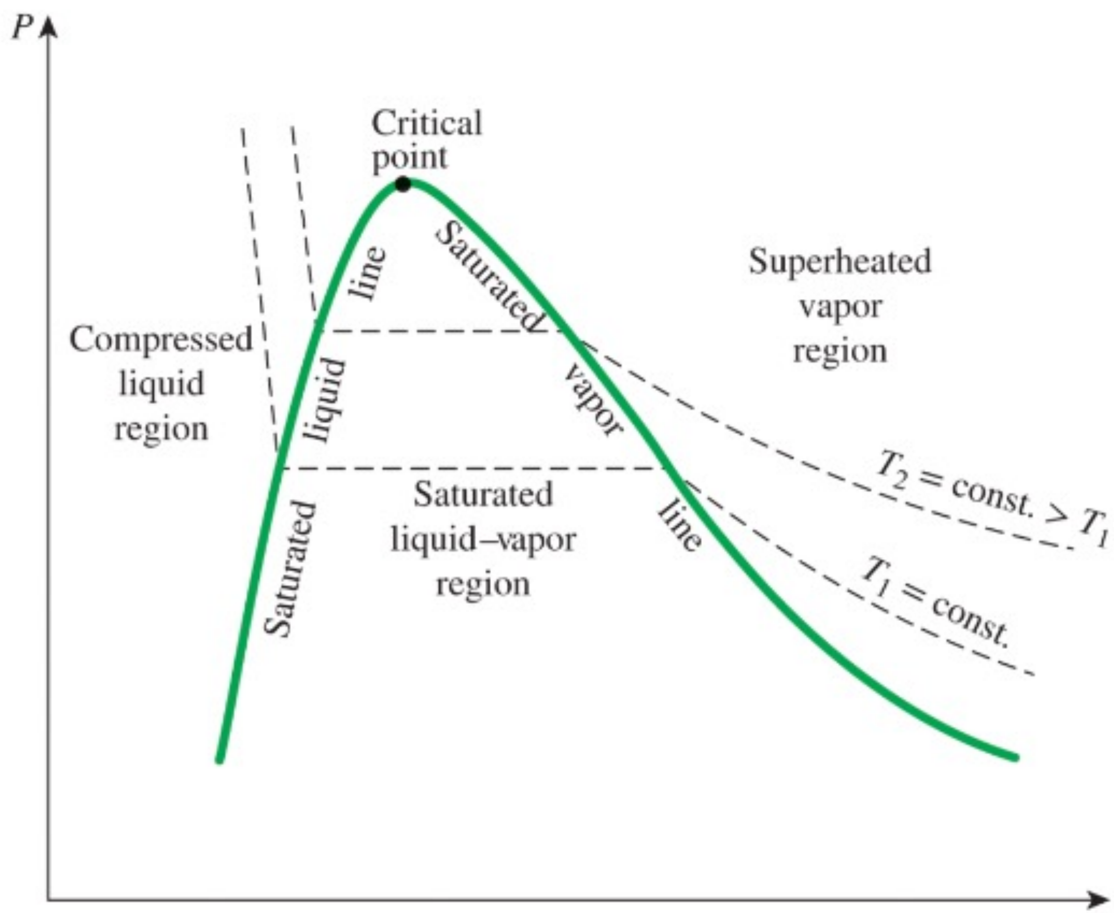
Property Diagrams For Phase-Change Processes

- Repeat the experiment to get the P-v diagram



Property Diagrams For Phase-Change Processes

- The P-v diagram of a pure substance is very much like the T-v diagram but T = constant lines on this diagram have a downward trend

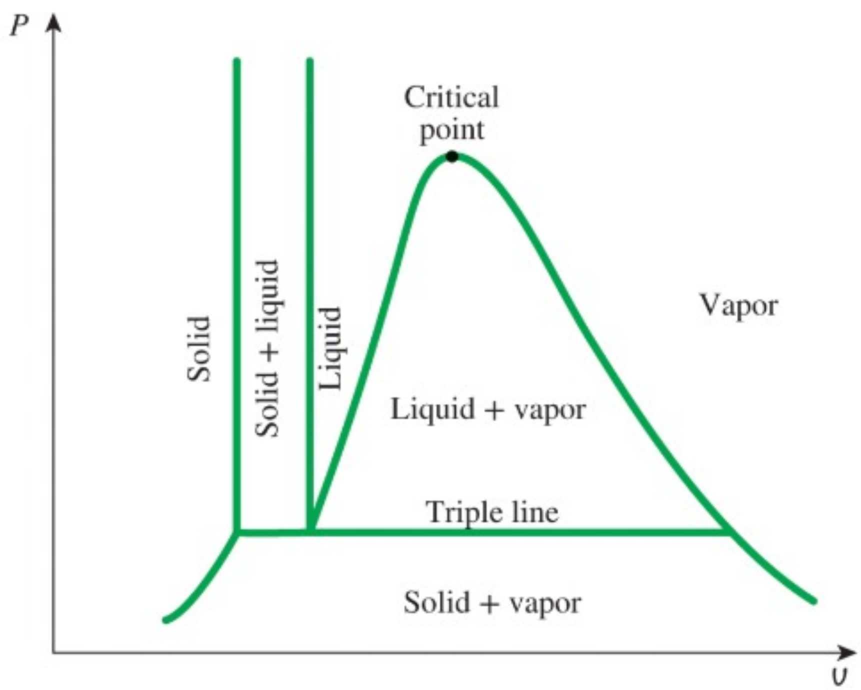


Property Diagrams For Phase-Change Processes

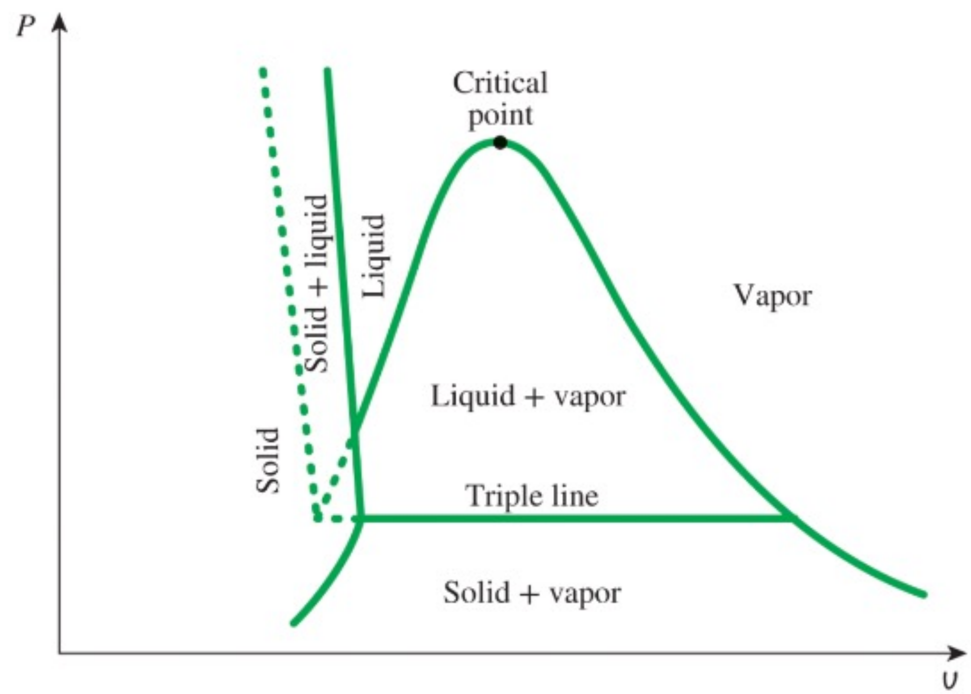
- The states on the triple line of a substance have the same pressure and temperature but different specific volumes

Property Diagrams For Phase-Change Processes

- Extending the diagram to include solid phase:



(a) P-υ diagram of a substance that contracts on freezing



(b) P-υ diagram of a substance that expands on freezing (such as water)

Property Diagrams For Phase-Change Processes

- Triple point temperatures and pressures of various substances:

TABLE 4–3

Triple-point temperatures and pressures of various substances

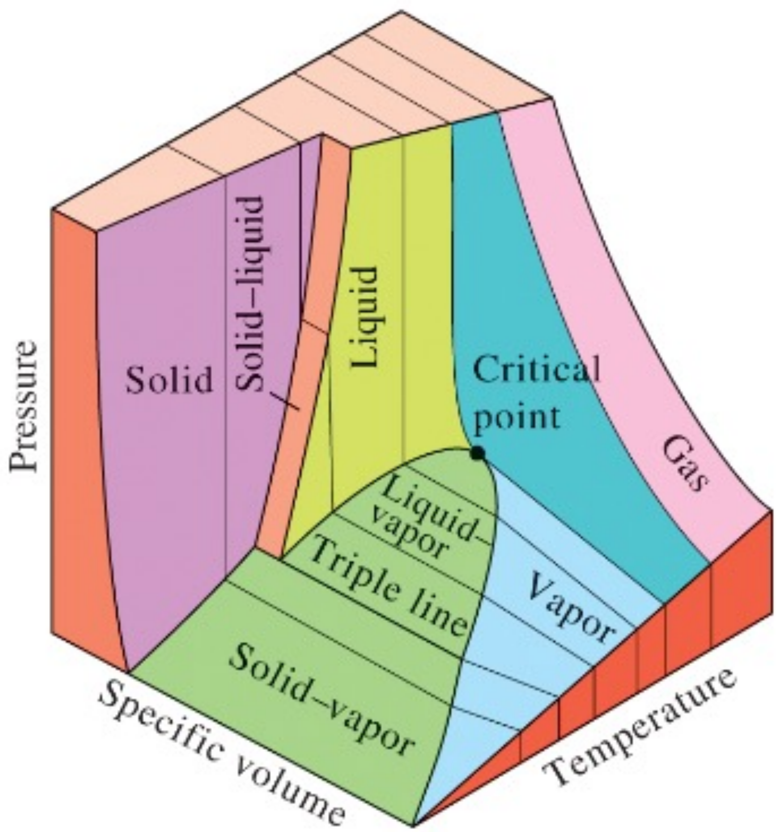
Substance	Formula	T_{tp}, K	P_{tp}, kPa
Acetylene	C_2H_2	192.4	120
Ammonia	NH_3	195.40	6.076
Argon	A	83.81	68.9
Carbon (graphite)	C	3900	10,100
Carbon dioxide	CO_2	216.55	517
Carbon monoxide	CO	68.10	15.37
Deuterium	D_2	18.63	17.1
Ethane	C_2H_6	89.89	8×10^{-4}
Ethylene	C_2H_4	104.0	0.12
Helium 4 (λ point)	He	2.19	5.1
Hydrogen	H_2	13.84	7.04
Hydrogen chloride	HCl	158.96	13.9
Mercury	Hg	234.2	1.65×10^{-7}
Water	H_2O	273.16	0.61
Xenon	Xe	161.3	81.5
Zinc	Zn	692.65	0.065

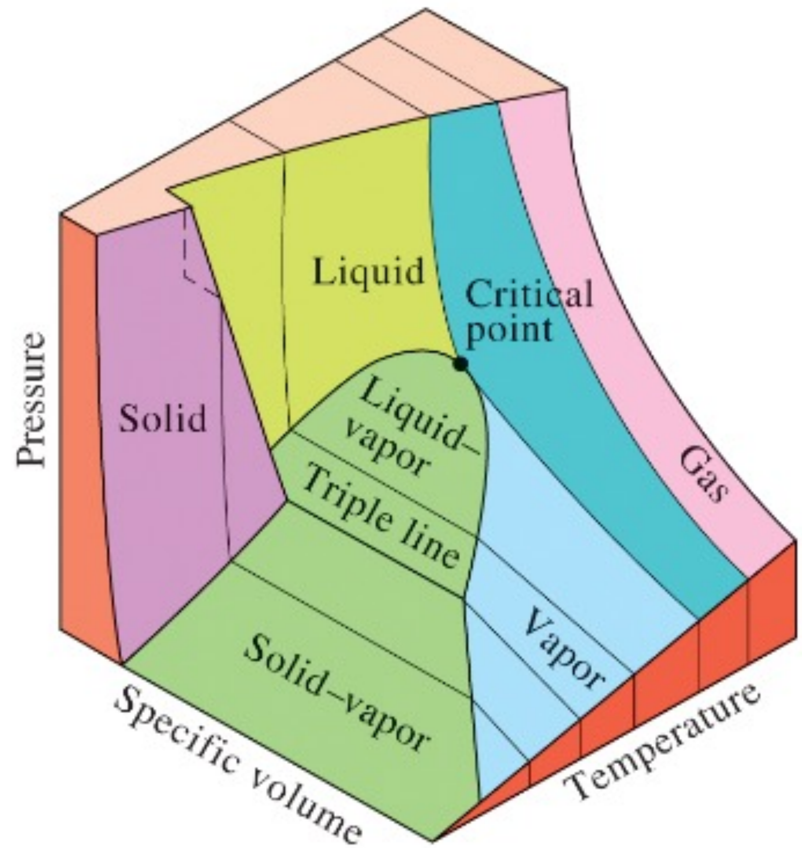
Property Diagrams For Phase-Change Processes

- There are two ways a substance can pass from the solid to the vapor phase:
  - ❑ It melts first into a liquid and subsequently evaporates
  - ❑ It evaporates directly without melting first known as sublimation (occurs below at the triple-point value since a pure substance cannot exist in the liquid phase at those pressure)

Property Diagrams For Phase-Change Processes

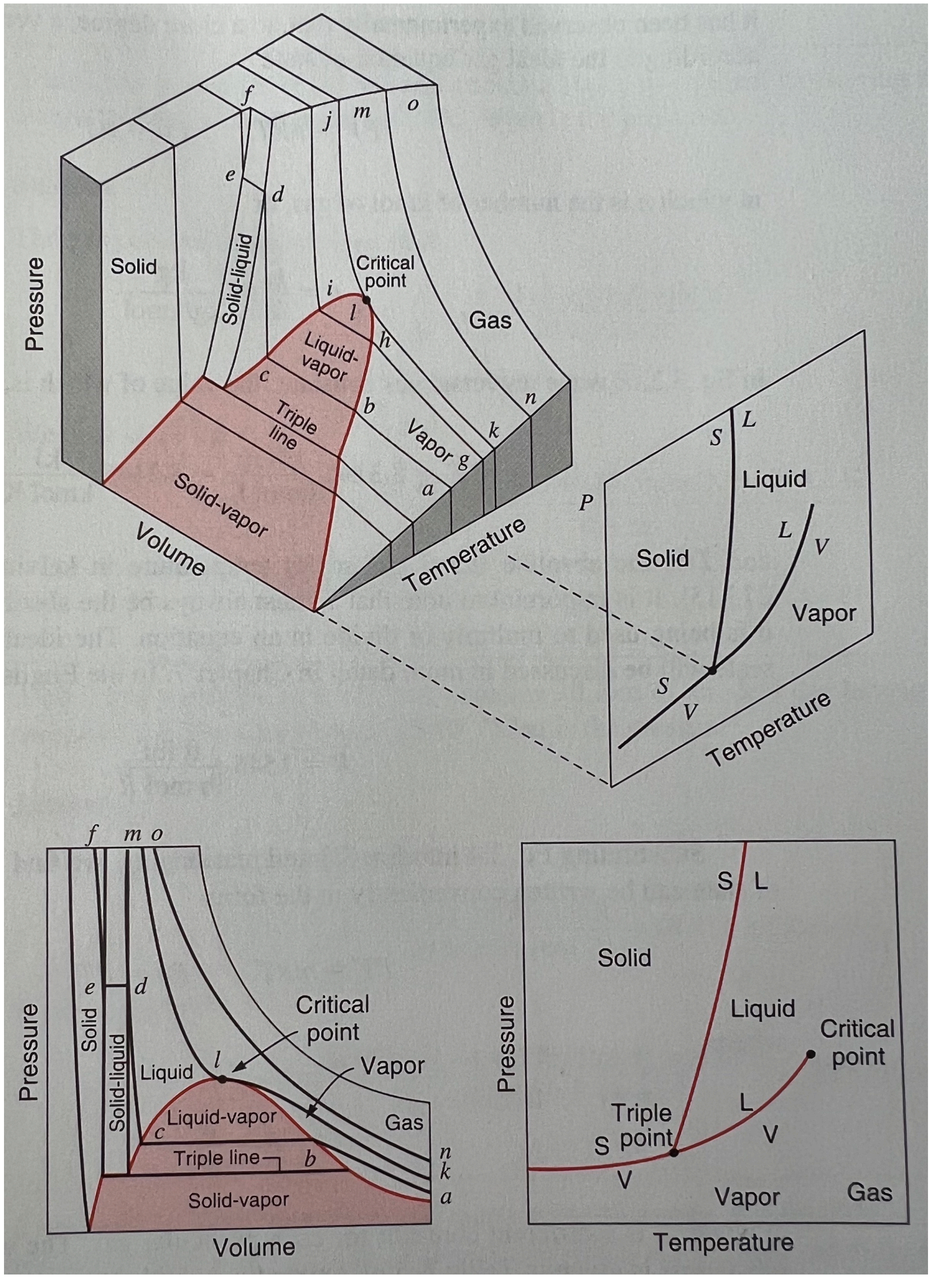
- P-v-T diagram





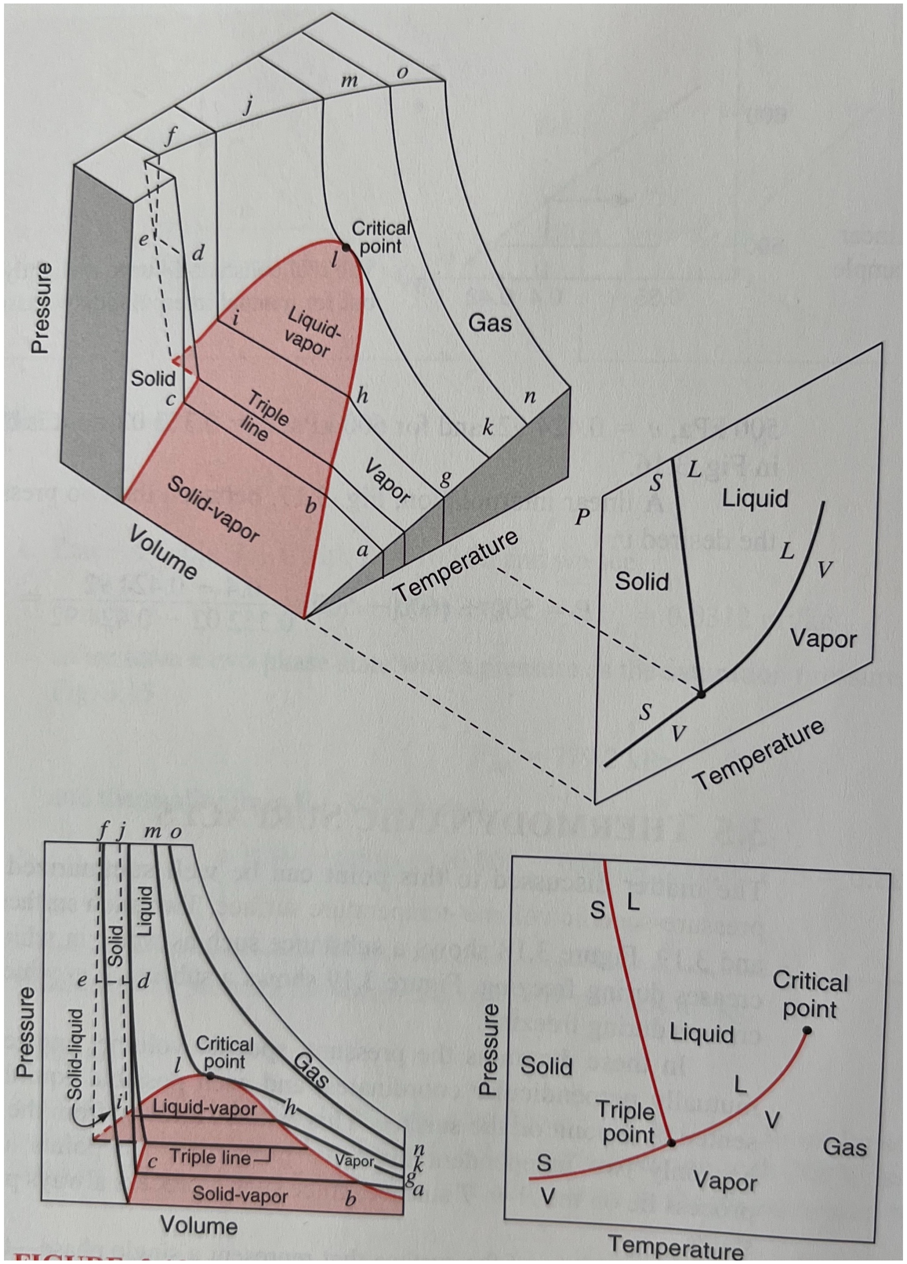
Property Diagrams For Phase-Change Processes

- P-v-T diagram



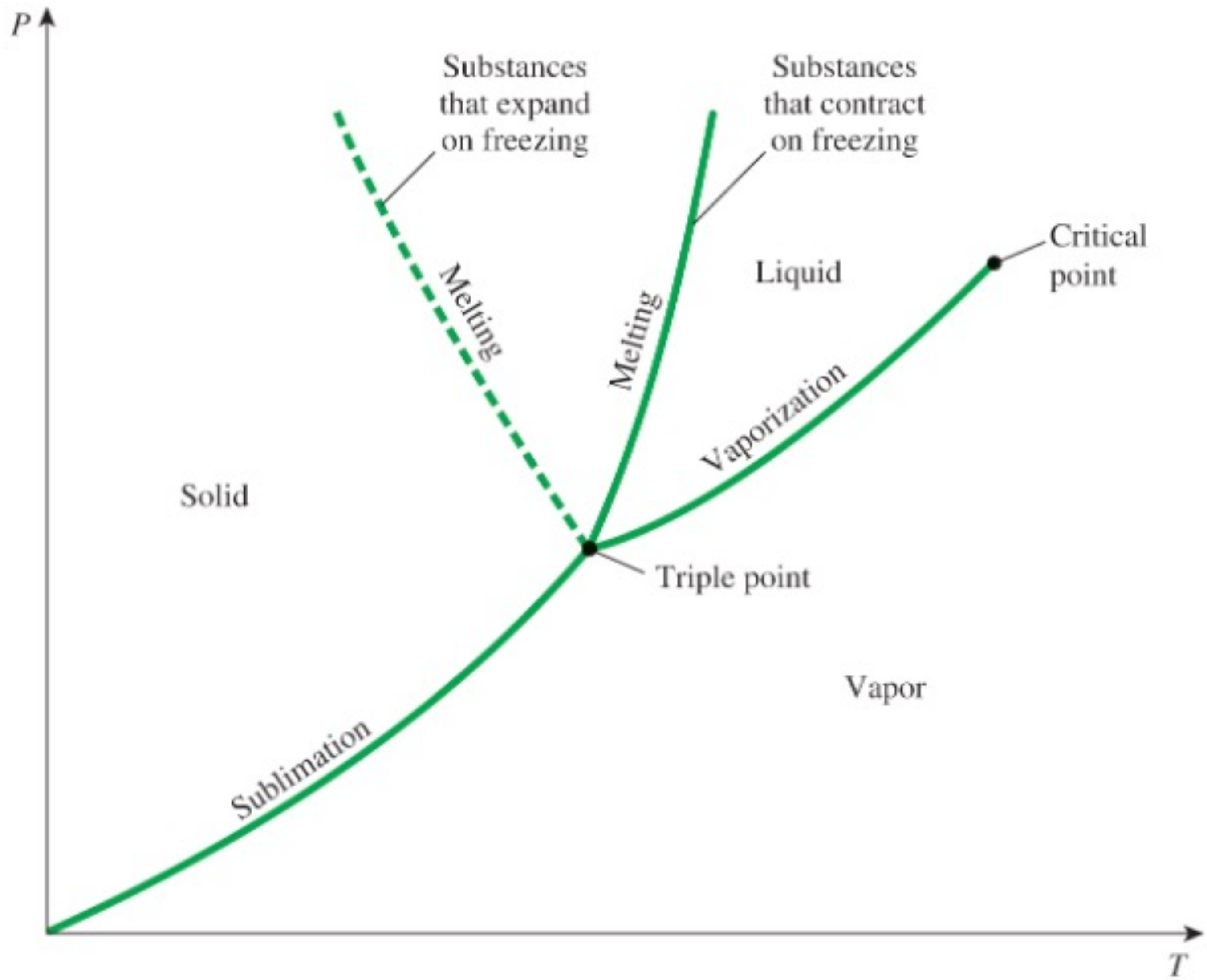
Property Diagrams For Phase-Change Processes

- P-v-T diagram



Property Diagrams For Phase-Change Processes

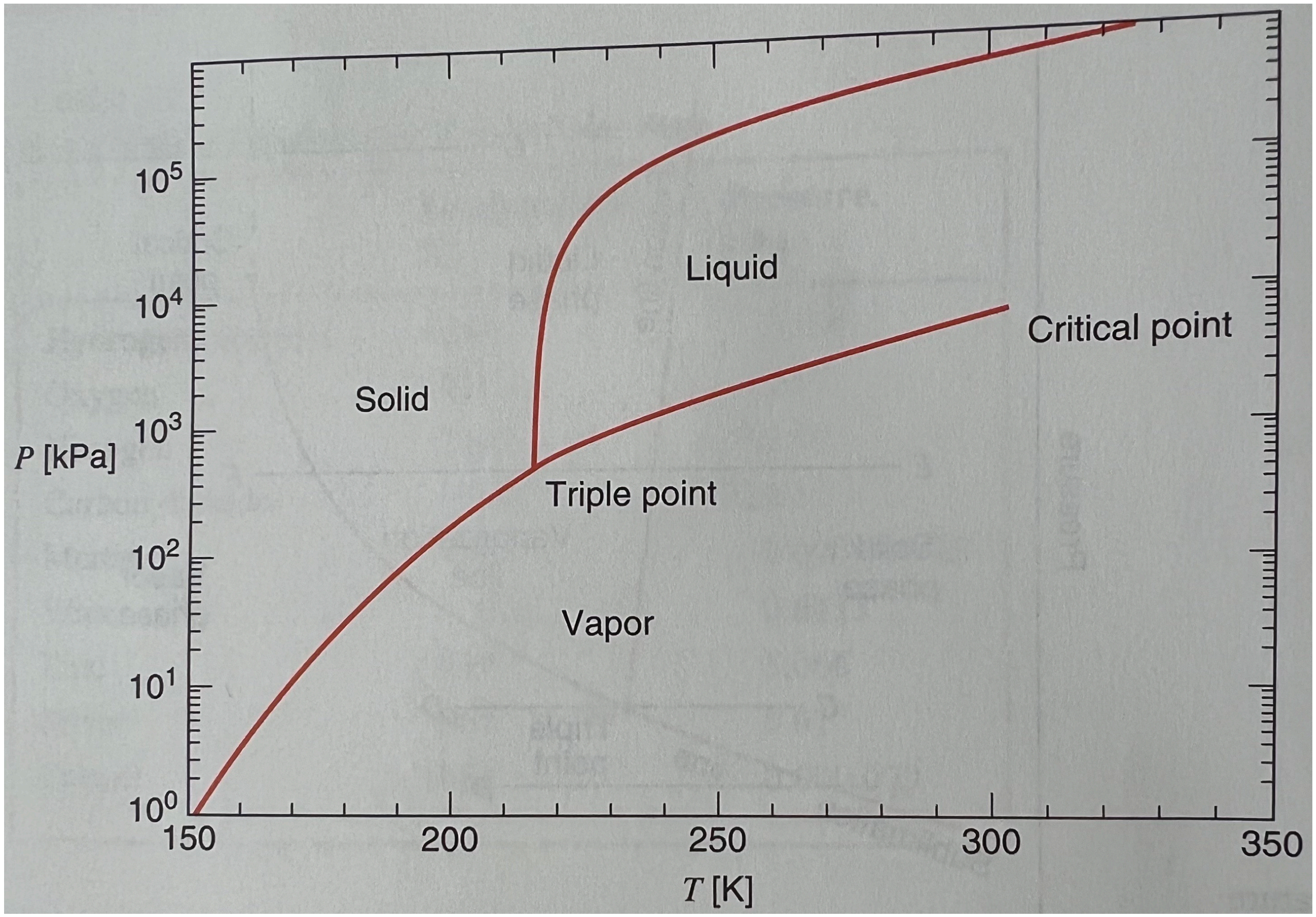
- P-T diagram is known as the phase diagram



CLASS ACTIVITY

Class Activity

- What's the common phase change in the atmospheric pressure for CO_2?



PROPERTY TABLES

Property Tables

- For most substances, the relationships among thermodynamics properties are too complex to be expressed by simple equations
- We usually use a combination of measurable properties
- We rely on tables and a lot times we separate table for each region

Property Tables

APPENDIX 1

PROPERTY TABLES AND CHARTS (SI UNITS)

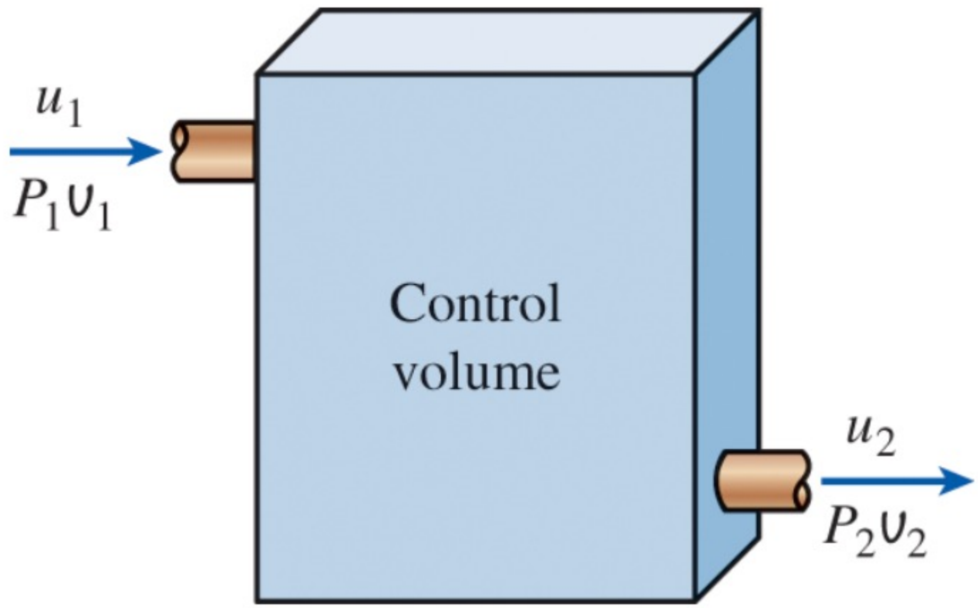
Property Tables

APPENDIX 2

PROPERTY TABLES AND CHARTS (ENGLISH UNITS)

Property Tables

- For certain processes (e.g., power generation and refrigeration), a property is defined named enthalpy which is a combination of



$$h = u + Pv$$

$$H = U + PV$$

Property Tables

- Table A-4 and Table A-5

$$v_{fg} = v_g - v_f$$

$$h_{fg} = h_g - h_f$$

Temp. °C T	Sat. press. kPa P_{sat}	Specific volume m^3/kg Sat. liquid v_f	Sat. vapor v_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808

Temperature

Corresponding saturation pressure

Specific volume of saturated liquid

Specific volume of saturated vapor

Property Tables

- Table A-4 and Table A-5

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

Property Tables

- Table A-4 and Table A-5

TABLE A–5

Saturated water—Pressure table

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
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7

Property Tables

- Table A-6 for superheated

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
	$P = 0.01$ MPa (45.81°C)*				$P = 0.05$ MPa (81.32°C)				
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2	7.5931	1.6941
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
150	19.513	2587.9	2783.0	8.6893	3.8897	2585.7	2780.2	7.9413	1.9367
200	21.826	2661.4	2879.6	8.9049	4.3562	2660.0	2877.8	8.1592	2.1724
250	24.136	2736.1	2977.5	9.1015	4.8206	2735.1	2976.2	8.3568	2.4062
300	26.446	2812.3	3076.7	9.2827	5.2841	2811.6	3075.8	8.5387	2.6389
400	31.063	2969.3	3280.0	9.6094	6.2094	2968.9	3279.3	8.8659	3.1027

Property Tables

- Table A-7 for compressed liquid

TABLE A–7

Compressed liquid 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
	P = 5 MPa (263.94°C)				*P* = 10 MPa (311.00°C)				
Sat.	0.0012862	1148.1	1154.5	2.9207	0.0014522	1393.3	1407.9	3.3603	0.0016572
0	0.0009977	0.04	5.03	0.0001	0.0009952	0.12	10.07	0.0003	0.0009928
20	0.0009996	83.61	88.61	0.2954	0.0009973	83.31	93.28	0.2943	0.0009951
40	0.0010057	166.92	171.95	0.5705	0.0010035	166.33	176.37	0.5685	0.0010013
60	0.0010149	250.29	255.36	0.8287	0.0010127	249.43	259.55	0.8260	0.0010105
80	0.0010267	333.82	338.96	1.0723	0.0010244	332.69	342.94	1.0691	0.0010221
100	0.0010410	417.65	422.85	1.3034	0.0010385	416.23	426.62	1.2996	0.0010361
120	0.0010576	501.91	507.19	1.5236	0.0010549	500.18	510.73	1.5191	0.0010522
140	0.0010769	586.80	592.18	1.7344	0.0010738	584.72	595.45	1.7293	0.0010708
160	0.0010988	672.55	678.04	1.9374	0.0010954	670.06	681.01	1.9316	0.0010920

CLASS ACTIVITY

Class Activity

- A rigid tank contains 50 kg of saturated liquid water at 90 °C. Determine the pressure in the tank and the volume of the tank.

Class Activity

- Solution:

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	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
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

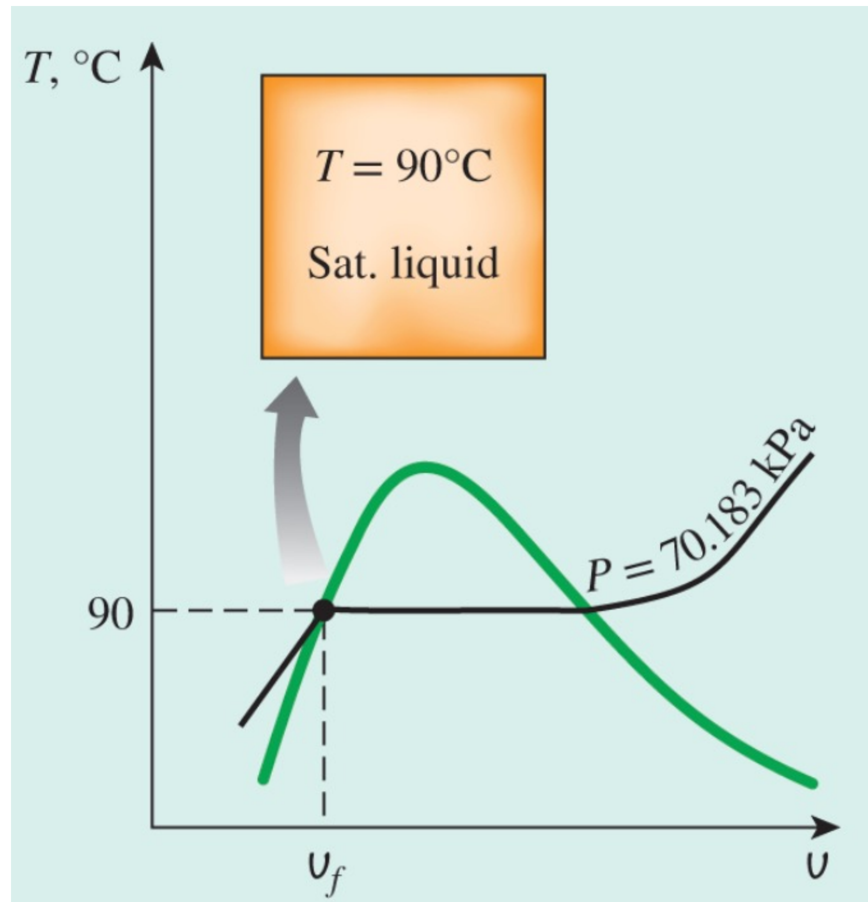
Class Activity

- Solution:

$$P = P_{sat\ at\ 90\,°C} = 79.183\ kPa$$

$$v = v_{f\ at\ 90\,°C} = 0.001036\,\frac{m^3}{kg}$$

$$V = (50kg)\left(0.001036\,\frac{m^3}{kg}\right) = 0.0518\,m^3$$



CLASS ACTIVITY

Class Activity

- A piston-cylinder device contains 2 ft^3 of saturated water vapor at 50-psia pressure. Determine the temperature and the mass of the vapor inside the cylinder

Class Activity

- Solution:

TABLE A–5E

Saturated water—Pressure table

Press., P psia	Sat. temp., T_{sat} °F	*Specific volume,* ft^3/lbm Sat. liquid, v_f	Sat. vapor, v_g	*Internal energy,* Btu/lbm Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	*Enthalpy,* Btu/lbm Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	*Entropy,* Btu/lbm · R Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1	101.69	0.01614	333.49	69.72	973.99	1043.7	69.72	1035.7	1105.4	0.13262	1.84495	1.9776
2	126.02	0.01623	173.71	94.02	957.45	1051.5	94.02	1021.7	1115.8	0.17499	1.74444	1.9194
3	141.41	0.01630	118.70	109.39	946.90	1056.3	109.40	1012.8	1122.2	0.20090	1.68489	1.8858
4	152.91	0.01636	90.629	120.89	938.97	1059.9	120.90	1006.0	1126.9	0.21985	1.64225	1.8621
5	162.18	0.01641	73.525	130.17	932.53	1062.7	130.18	1000.5	1130.7	0.23488	1.60894	1.8438
6	170.00	0.01645	61.982	138.00	927.08	1065.1	138.02	995.88	1133.9	0.24739	1.58155	1.8289
8	182.81	0.01652	47.347	150.83	918.08	1068.9	150.86	988.15	1139.0	0.26757	1.53800	1.8056
10	193.16	0.01659	38.425	161.22	910.75	1072.0	161.25	981.82	1143.1	0.28362	1.50391	1.7875
14.696	211.95	0.01671	26.805	180.12	897.27	1077.4	180.16	970.12	1150.3	0.31215	1.44441	1.7566
15	212.99	0.01672	26.297	181.16	896.52	1077.7	181.21	969.47	1150.7	0.31370	1.44441	1.7549
20	227.92	0.01683	20.093	196.21	885.63	1081.8	196.27	959.93	1156.2	0.33582	1.39606	1.7319
25	240.03	0.01692	16.307	208.45	876.67	1085.1	208.52	952.03	1160.6	0.35347	1.36060	1.7141
30	250.30	0.01700	13.749	218.84	868.98	1087.8	218.93	945.21	1164.1	0.36821	1.33132	1.6995
35	259.25	0.01708	11.901	227.92	862.19	1090.1	228.03	939.16	1167.2	0.38093	1.30632	1.6872
40	267.22	0.01715	10.501	236.02	856.09	1092.1	236.14	933.69	1169.8	0.39213	1.28448	1.6766
45	274.41	0.01721	9.4028	243.34	850.52	1093.9	243.49	928.68	1172.2	0.40216	1.26506	1.6672
50	280.99	0.01727	8.5175	250.05	845.39	1095.4	250.21	924.03	1174.2	0.41125	1.24756	1.6588

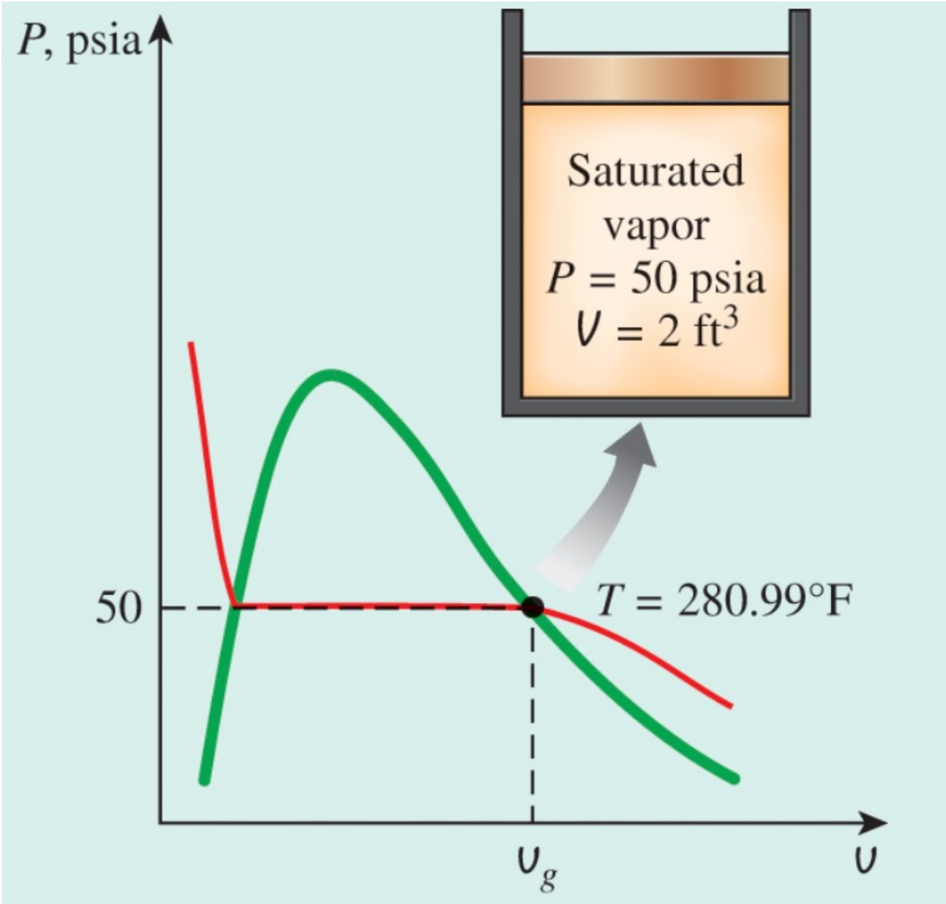
Class Activity

- Solution:

$$T = T_{sat\ at\ 50\ psia} = 280.99\ °F$$

$$v = v_{g\ at\ 50\ psia} = 8.5175\ \frac{ft^3}{lbm}$$

$$m = \frac{V}{v} = \frac{2\ ft^3}{8.5175\ \frac{ft^3}{lbm}} = 0.235\ lbm$$



CLASS ACTIVITY

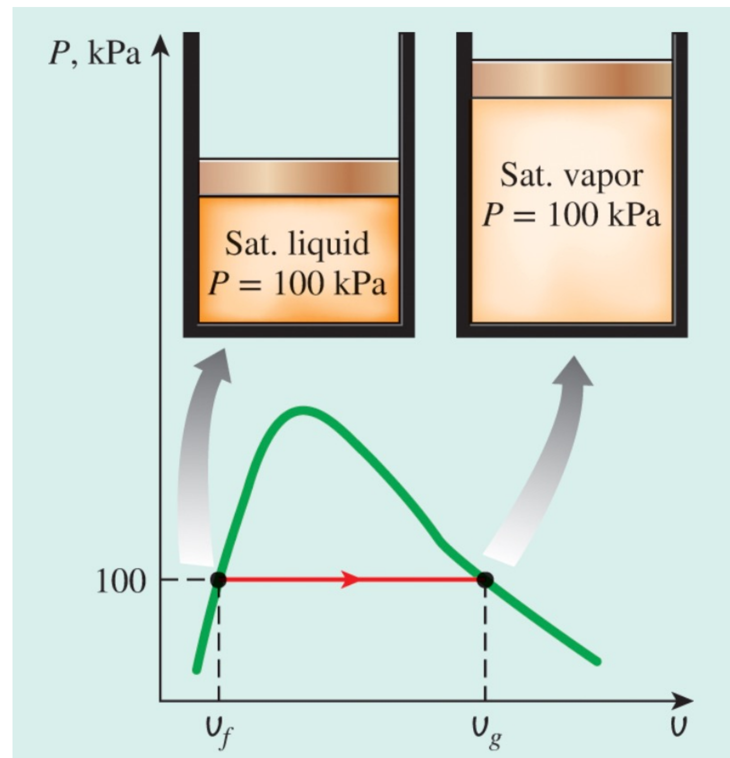
Class Activity

- A mass of 200 g of saturated liquid water is completely vaporized at a constant pressure of 100 kPa. Determine (a) the volume change and (b) the amount of energy transferred to the water

$$v_{fg} = v_g - v_f = 1.6941 - 0.001043 = 1.6931\, m^3/kg$$

$$\Delta V = mv_{fg} = (0.2\, kg)\left(1.6931\, \frac{m^3}{kg}\right) = 0.3386\, m^3$$

$$mh_{fg} = (0.2\, kg)\left(22575.5\, \frac{kJ}{kg}\right) = 451.5\, kJ$$



Class Activity

- Solution:

Press., P kPa	Sat. temp., T_{sat} °C	Specific volume, m^3/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
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3
20	60.06	0.001017	7.6481	251.40	2204.6	2456.0	251.42	2357.5	2608.9
25	64.96	0.001020	6.2034	271.93	2190.4	2462.4	271.96	2345.5	2617.5
30	69.09	0.001022	5.2287	289.24	2178.5	2467.7	289.27	2335.3	2624.6
40	75.86	0.001026	3.9933	317.58	2158.8	2476.3	317.62	2318.4	2636.1
50	81.32	0.001030	3.2403	340.49	2142.7	2483.2	340.54	2304.7	2645.2
75	91.76	0.001037	2.2172	384.36	2111.8	2496.1	384.44	2278.0	2662.4
100	99.61	0.001043	1.6941	417.40	2088.2	2505.6	417.51	2257.5	2675.0

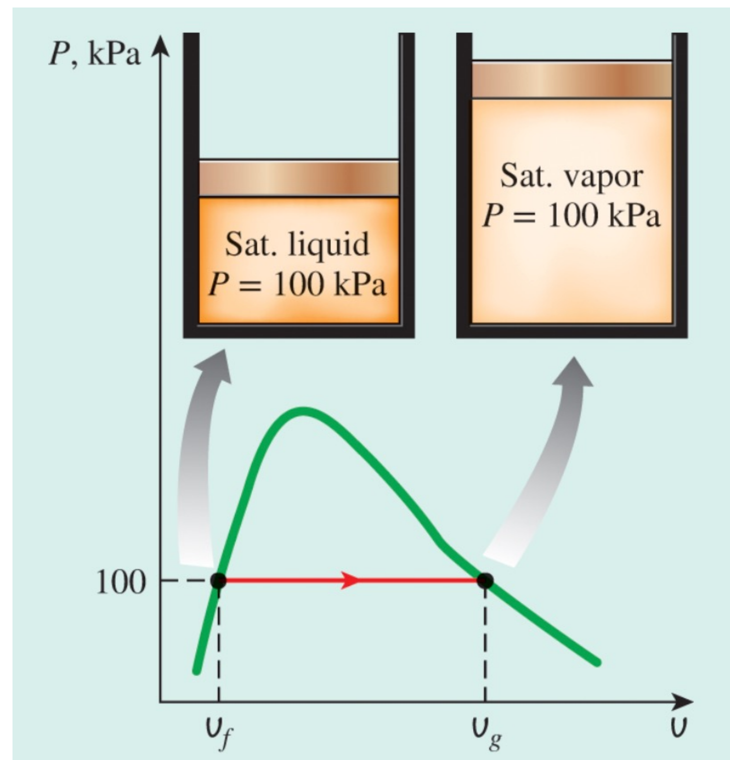
Class Activity

- Solution:

$$v_{fg} = v_g - v_f = 1.6941 - 0.001043 = 1.6931\, m^3/kg$$

$$\Delta V = mv_{fg} = (0.2\, kg)\left(1.6931\, \frac{m^3}{kg}\right) = 0.3386\, m^3$$

$$mh_{fg} = (0.2\, kg)\left(22575.5\, \frac{kJ}{kg}\right) = 451.5\, kJ$$



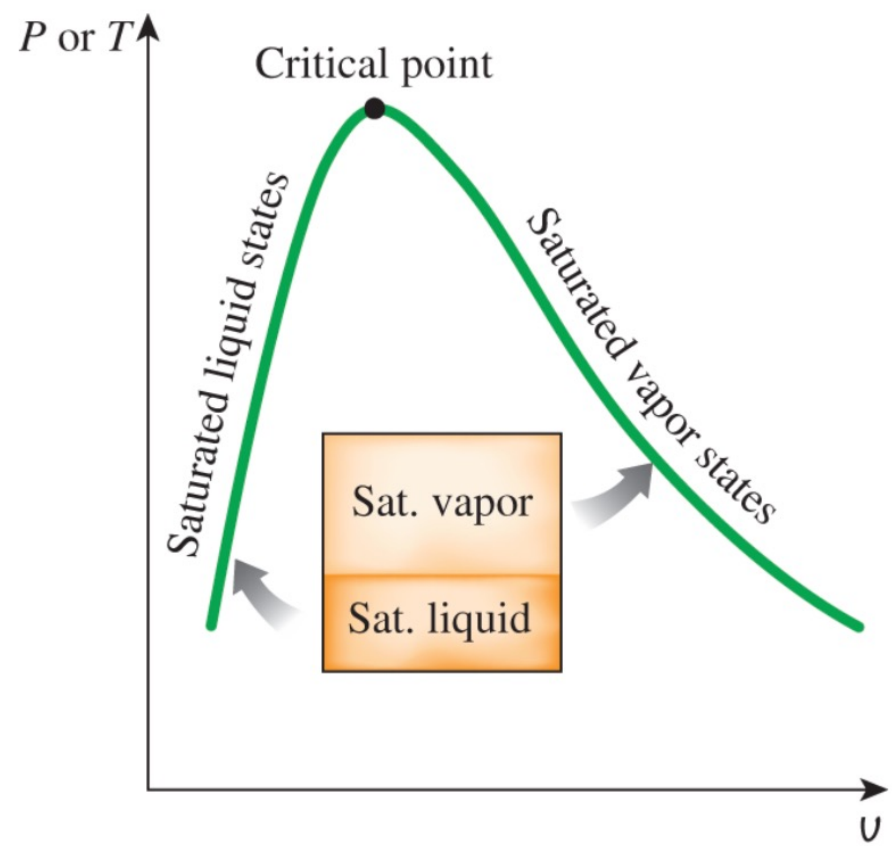
SATURATED LIQUID-VAPOR MIXTURE

Saturated Liquid-Vapor Mixture

- During a vaporization process, a substance exists as part liquid and part vapor

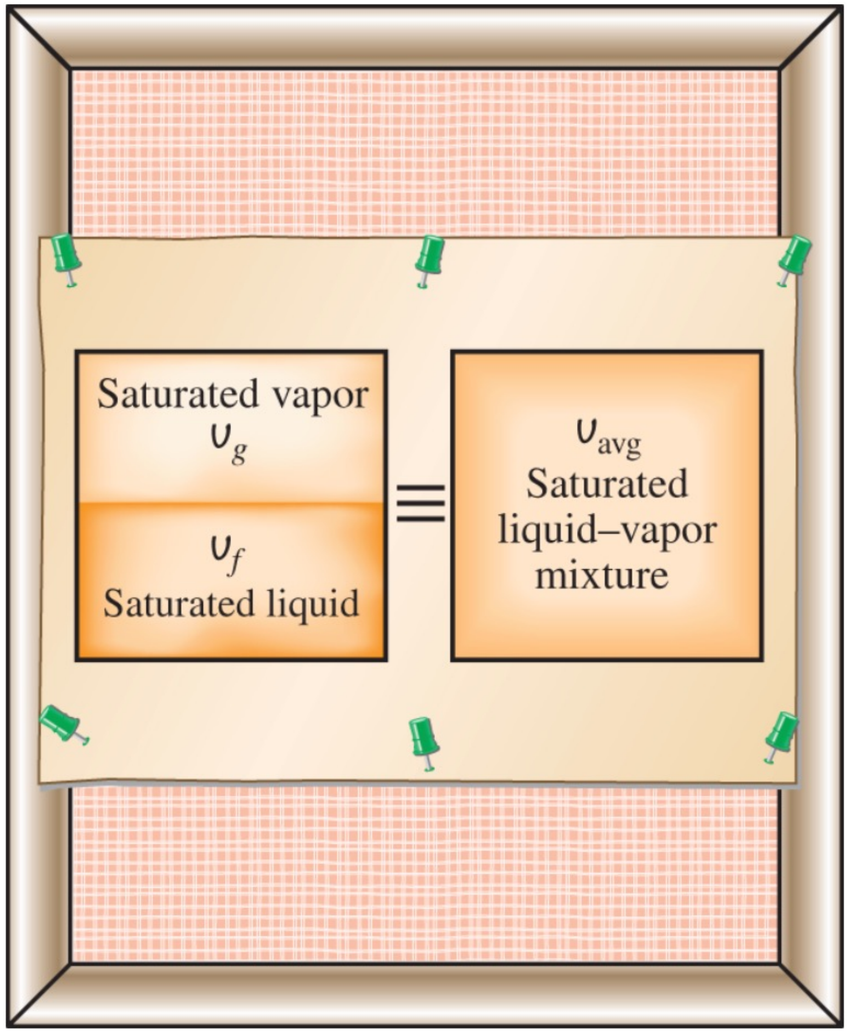
$$x = \frac{m_{vapor}}{m_{total}}$$

$$m_{total} = m_{liquid} + m_{vapor} = m_f + m_g$$



Saturated Liquid-Vapor Mixture

- During a vaporization process, a substance exists as part liquid and part vapor



Saturated Liquid-Vapor Mixture

- Quality is

Saturated Liquid-Vapor Mixture

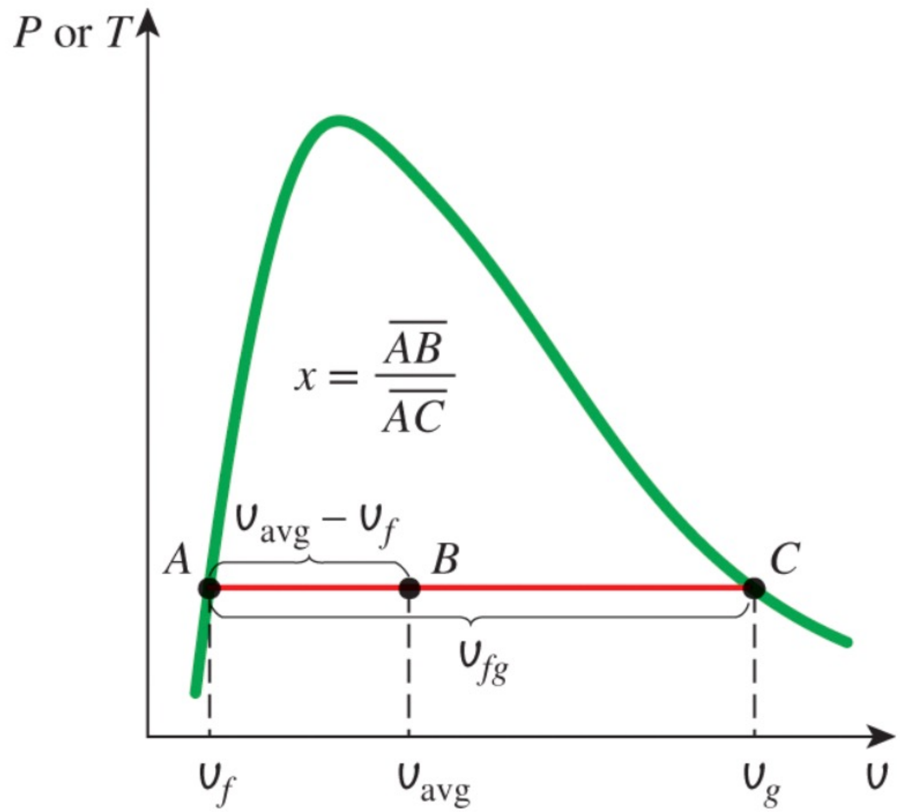
- We can write:

$$V = V_f + V_g$$

$$m_t = m_f + m_g$$

$$v_{avg} = v_f + x v_{fg}$$

$$x = \frac{v_{avg} - v_f}{v_{fg}}$$



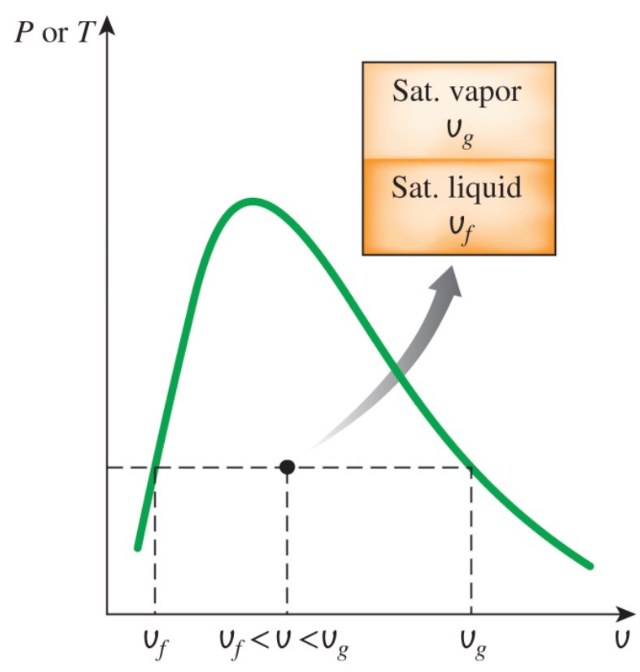
Saturated Liquid-Vapor Mixture

- We can write:

$$v_{avg} = v_f + xv_{fg}$$

$$u_{avg} = u_f + uv_{fg}$$

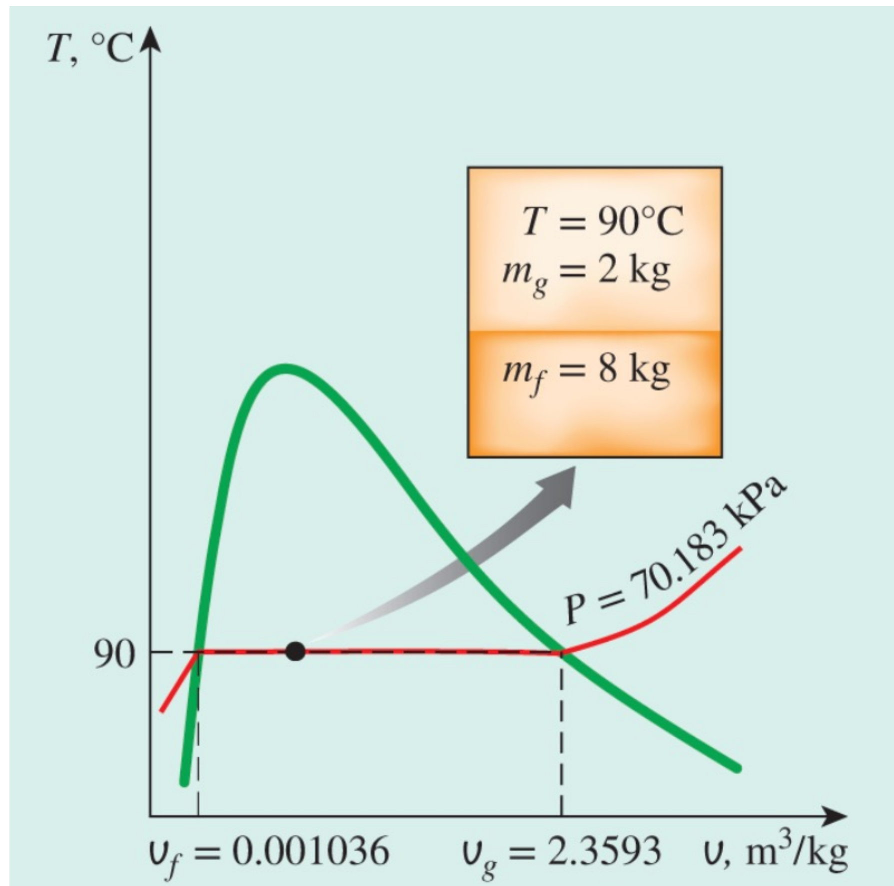
$$h_{avg} = h_f + hv_{fg}$$



CLASS ACTIVITY

Class Activity

- A rigid tank contains 10 kg of water at 90 °C. If 8 kg of the water is in the liquid form and the rest is in the vapor form, determine (a) the pressure in the tank and (b) the volume of the tank



Class Activity

- Solution:

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	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
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

Class Activity

- Part (b) – Solution 1

$$V = V_f + V_g = m_f v_f + m_g v_g$$

$$V = (8\ kg)\left(0.001036\,\frac{m^3}{kg}\right) + (2\ kg)\left(2.3593\,\frac{m^3}{kg}\right) = 4.73\ m^3$$

$$V = 4.73\ m^3$$

Class Activity

- Part (b) – Solution 2:

$$x = \frac{m_g}{m_t} = \frac{2}{2+8} = 0.2$$

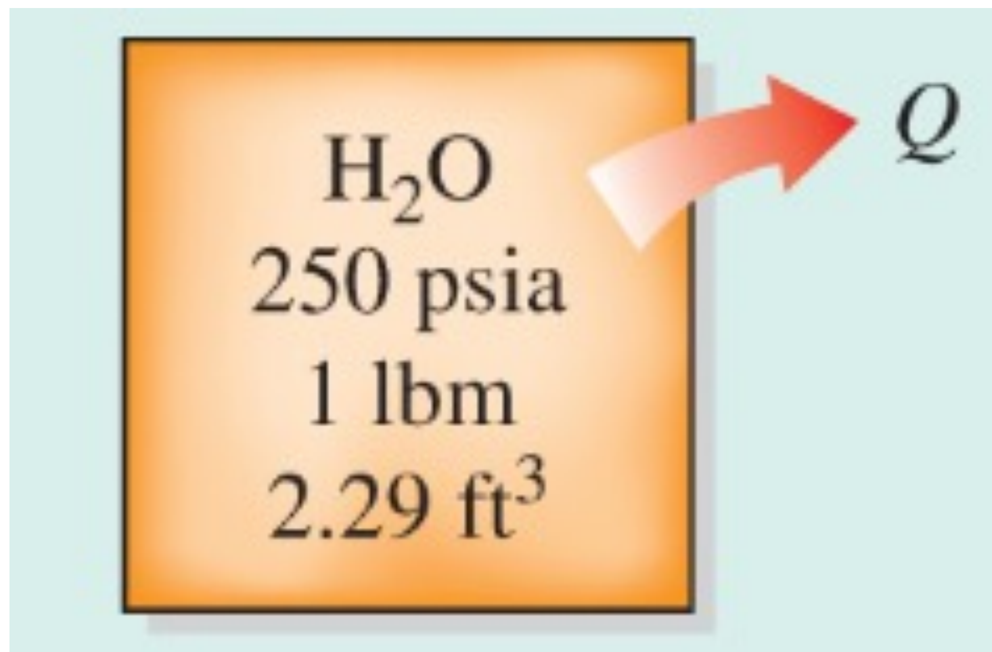
$$v = v_f + xv_{fg} = \left(0.001036\,\frac{m^3}{kg}\right) + (0.2)\left(2.3593 - 0.001036\,\frac{m^3}{kg}\right) = 0.473\,\frac{m^3}{kg}$$

$$V = mv = (10\ kg)\left(0.473\,\frac{m^3}{kg}\right) = 4.73\ m^3$$

CLASS ACTIVITY

Class Activity

- One pound-mass of water fills a 2.29 ft^3 rigid container at an initial pressure of 150 psia. The container is then cooled to 100 °F. Determine the initial temperature and final pressure of the water.



Class Activity

- Solution:

$$v_i = \frac{V}{m} = \frac{2.29\ ft^3}{1\ lbm} = 2.29\ \frac{ft^3}{lbm}$$

TABLE A–5E

Saturated water—Pressure table

Press., P psia	Sat. temp., T_{sat} °F	*Specific volume, ft³/lbm* Sat. liquid, v_f	Sat. vapor, v_g	*Internal energy, Bt* Sat. liquid, u_f	Evap., u_{fg}
1	101.69	0.01614	333.49	69.72	973.99
2	126.02	0.01623	173.71	94.02	957.45
3	141.41	0.01630	118.70	109.39	946.90
4	152.91	0.01636	90.629	120.89	938.97
5	162.18	0.01641	73.525	130.17	932.53
190	377.52	0.01833	2.4040	350.24	763.31
200	381.80	0.01839	2.2882	354.78	759.32
250	400.97	0.01865	1.8440	375.23	741.02
300	417.35	0.01890	1.5435	392.89	724.77
350	431.74	0.01912	1.3263	408.55	709.98

$$v_i > v_g$$

Class Activity

- Solution:

TABLE A–6E

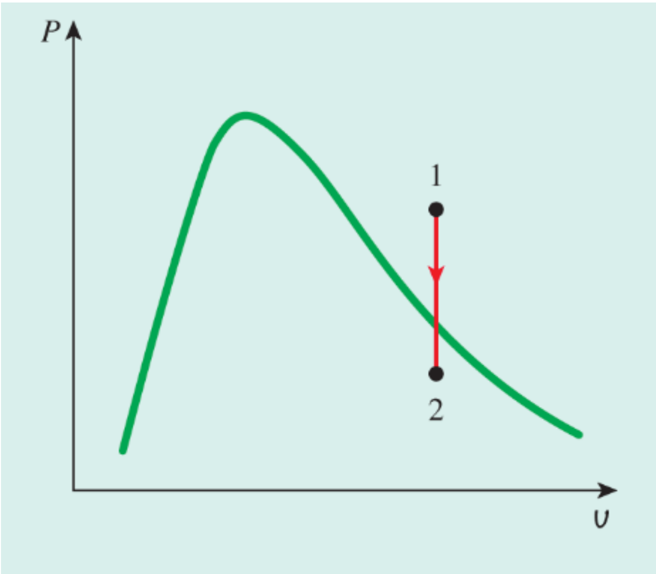
Superheated water

T °F	v ft^3/lbm	u Btu/lbm	h Btu/lbm	s Btu/lbm · R
	P = 250 psia (400.97°F)			
Sat.	1.8440	1116.3	1201.6	1.5270
450	2.0027	1141.3	1234.0	1.5636
500	2.1506	1164.1	1263.6	1.5953
550	2.2910	1185.6	1291.5	1.6237
600	2.4264	1206.3	1318.6	1.6499
650	2.5586	1226.8	1345.1	1.6743

$$\begin{cases} P_1 = 250\ psia \\ v_1 = 2.29\ ft^3/lbm \end{cases}$$

Class Activity

- Solution:



$$T_2 = 100\ °F$$

$$v_2 = v_1 = 2.29\ ft^3/lbm$$

$$P_2 = P_{sat\ @\ 100\ F} = 20.9505\ psia$$